GLMRIS

GREAT LAKES AND MISSISSIPPI RIVER INTERBASIN STUDY

Risk of Adverse Impacts from the Movement through the CAWS and Establishment of Aquatic Nuisance Species in the Great Lakes and Mississippi River Basins

Volume II: Appendix E

Final Report
January 2014

US Army Corps of Engineers®

Product of the GLMRIS Team

The Great Lakes and Mississippi River Interbasin Study (GLMRIS) Team consists of a regional, collaborative effort led by the U.S. Army Corps of Engineers (Corps), including various District and Division offices, as well as Corps Centers of Expertise and Research Laboratories. Products of the GLMRIS Team are also made possible in collaboration with various federal, state, local, and non-governmental stakeholders.

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PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). The species appears to be expanding in the Mid-South region of the United States (McLaurin & Wersal 2011). However, the species has been in the United States for a century and has not moved to the upper Midwest.

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline modifications. However, the Cuban bulrush can be carried by boats for short distances, and this could allow it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Cuban bulrush is native to the New World tropics, from the southern United States through northern South America (NBII & ISSG 2008). The species has been in the southeastern United States for more than a century (Bryson et al. 2008) and is found sporadically throughout Florida, Louisiana, southern Georgia, southern Alabama, Mississippi (Galvao et al. undated), and coastal Texas. Populations have recently been found in Aliceville Lake in Pickens County, Alabama, and in Aberdeen Lake and the Tennessee-Tombigbee Waterway in east-central Mississippi. Cuban bulrush was observed in the Ross Barnett Reservoir, Mississippi, for the first time in 2009 (McLaurin & Wersal 2011).

T_{10}: See T_0. The species may disperse closer to the pathway over time. However, on the basis of the species' native distribution, it may not tolerate extended freezing temperatures.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The species' distance from the Brandon Road Lock and Dam may depend on the range in the region's temperature, which may increase seasonally because of future climate change. Over time, the species may disperse closer to the pathway if the climate becomes more suitable.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size (Bryson et al. 2008). It appears to be more of a tropical or subtropical species based on its native distribution. This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, based on the native species distribution, it may not tolerate extended freezing temperatures.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future changes in temperature and rainfall related to future climate change may affect the suitability of habitat and the northward expansion of this species.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat exists from the current location of this species to the Brandon Road Lock and Dam (section 2f). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat in the MRB is highly fragmented (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. Cuban bulrush has been in the southeastern United States for a century and has not spread beyond the southern states, so it may not be likely to move to the WPS pathway in the near term (section 2e). The cold climate of the Midwest may prevent the spread of this species to the Brandon Road Lock and Dam. Therefore, the probability of arrival is low.
T_{10}: See T_0. If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. However, it is not expected to reach the Brandon Road Lock and Dam during this time step.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: In order to better understand the dispersal of the Cuban bulrush and its potential to invade wetland habitats, additional research is needed on both its reproductive biology, to determine the extent to which it reproduces sexually and spreads from achenes, and its association with other aquatic weeds (Bryson et al. 2008). It is not documented how far north Cuban bulrush will be able to disperse or whether the species will be able to survive the region's conditions. However, it has not spread very far north in decades. It is unlikely at this time step for the Cuban bulrush to travel the far distance to arrive at the pathway; therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be sufficient time for Cuban bulrush to expand to the WPS pathway entrance. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water. Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983).

b. Human-Mediated Transport through Aquatic Pathways
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is no cargo vessel traffic to the WPS (USACE 2011a) from the Brandon Road Lock and Dam. Commercial vessels could transport the Cuban bulrush as far as the Chicago River. There is small boat recreational use in the North Shore Channel.

c. *Existing Physical Human/Natural Barriers*

T_0: The sluice gate at the WPS separates the Chicago Area Waterway System (CAWS) from Lake Michigan. However, flow is occasionally reversed back into Lake Michigan.
T_{10}: See T_0. Future use of the WPS is not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size (Bryson et al. 2008). This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). Much of the CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Overall, there is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). There is some shallow shoreline with and without canopy cover in the Chicago Sanitary and Ship Canal (CSSC) that may be suitable. Cuban bulrush may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). This species is not likely to survive in near-shore nonvegetated areas with manmade structures, like harbors consisting of stone blocks and steel sheet piling. Much of the CSSC is vertical limestone or manmade walls. Virtually all (more than 90%) of the Chicago River and the lower north branch of the Chicago River is vertical wall (LimnoTech 2010). The North Shore Channel contains suitable habitat for the Cuban bulrush. Macrophytes are documented to exist in the North Shore Channel (LimnoTech 2010). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the native species distribution, it may not tolerate extended freezing temperatures.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in most areas of the CAWS channel, suggesting that the CAWS is generally not suitable habitat for aquatic macrophytes like Cuban bulrush (section 3d). The Cuban bulrush spreads by floating and must move upstream to reach the WPS (section 3a). Vessels could potentially transport this species upstream from the Brandon Road Lock and Dam to the Chicago River. However, the vertical walls of the Chicago River would likely keep this species from invading and moving further upstream to

the North Shore Channel and the WPS (section 3d). There is suitable habitat on the banks of the North Shore Channel, and if established near the WPS, Cuban bulrush could spread by achenes (section 3a) into the Great Lakes when the sluice gate is open (section 3c). Overall, this species is unlikely to spread throughout the CAWS during this time step because of habitat limitation and the need for upstream movement through the CAWS channel. Therefore, Cuban bulrush has a low probability of passing through the pathway.
T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in a fashion that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The probability of passage may increase over time and allow the Cuban bulrush to pass through the WPS. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The lack of suitable habitat in the CAWS is documented, although the North Shore Channel may be suitable. The potential for vessels to transport the Cuban bulrush upstream through the CAWS is uncertain. The only chance for the species to move upstream into the Great Lakes Basin (GLB) is to float through the sluice gate when it is open. The uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through the WPS. However, the habitat and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Cuban bulrush is commonly established in fresh water ponds and lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether

this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures. Wilmette Harbor contains no emergent wetland habitat, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap. Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan (unpublished data from USACE). Illinois Beach State Park, located approximately 50 km (31 mi) north of the WPS, contains emergent wetlands near the shoreline of Lake Michigan. There is little emergent wetland habitat between the WPS and the Indiana border (unpublished data from USACE) because of human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the Cuban bulrush to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands. This species could form populations along the shoreline of Lake Michigan in calm areas with an accumulation of organic matter.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The Cuban bulrush invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the Cuban bulrush to reach marsh habitat after exiting Wilmette Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow Cuban bulrush to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of Cuban bulrush passing from the North Shore Channel into the Wilmette Harbor and Lake Michigan could be transported by vessels. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the Cuban bulrush seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but Cuban bulrush could colonize tributaries if transported upriver by flooding or wind-driven currents. However, such tributaries are greater than 96 km (60 mi) from the WPS.

Evidence for Probability Rating

Recreational boat traffic from Wilmette Harbor could potentially assist in the dispersal of Cuban bulrush. However, the Cuban bulrush is not likely to colonize Wilmette Harbor, making vessel transport less likely (section 4b). Cuban bulrush is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of the WPS or on the sandy, higher energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan. However, these areas are primarily found in Indiana and are not located near the WPS (section 4a). In addition, the Cuban bulrush is a warm-climate species, and the GLB may be too cold for this species to establish. Therefore, the probability of this species colonizing in Lake Michigan after exiting the WPS is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach to suitable habitat after exiting the WPS by drift alone. The climatological suitability of the GLB is uncertain. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. **P(spreads): LOW**

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   On the basis of the species' native distribution, it may not tolerate extended freezing temperatures. The Cuban bulrush appears to be more of a tropical or subtropical species.

b. *Type of Mobility/Invasion Speed*
   Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). However, the species has been in the United States for a century and has not moved to the upper Midwest.

c. *Fecundity*
   The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).

d. *History of Invasion Success*
   Cuban bulrush can exist at high density where established. The species has been spreading throughout the southeastern United States for a century (Bryson et al. 2008).

e. *Human-Mediated Transport through Aquatic Pathways*
   Cuban bulrush was likely introduced via ship ballast (Bryson et al. 1996). The WPS is not a port; therefore, there is no commercial vessel traffic to the WPS.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The Cuban bulrush is a wetland obligate. Cuban bulrush is commonly established in fresh water lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). There is marsh habitat throughout the Great Lakes. There are areas of near-shore emergent herbaceous habitat in tributaries and rivers feeding into the Great Lakes that would be suitable for the species (unpublished data from USACE), but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries of the Great Lakes through which the Cuban bulrush could spread (unpublished data from USACE). Based on the species' native distribution, it may not tolerate extended freezing temperatures.

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan (section 5f). It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals. However, suitable wetland habitat is present in marsh and riverine habitats in the GLB, and human and natural mechanisms of spread are possible (sections 5b, 5e, 5f). However, the native range of the Cuban bulrush suggests it is a tropical species, and it has not spread very far north in a century, suggesting climate is unsuitable in the GLB. Therefore, the probability of spreading in the Great Lakes is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat in the GLB, but the climate is potentially unsuitable, although this has not been tested. Therefore, the uncertainty associated with the spread of the Cuban bulrush in the GLB is medium.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). The species appears to be expanding in the Mid-South region of the United States (McLaurin & Wersal 2011). However, the

species has been in the United States for a century and has not moved to the upper Midwest.

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline modifications. However, the Cuban bulrush can be carried by boats for short distances, and this could allow it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Cuban bulrush is native to the New World tropics, from the southern United States through northern South America (NBII & ISSG 2008). The species has been in the southeastern United States for more than a century (Bryson et al. 2008) and is found sporadically throughout Florida, Louisiana, southern Georgia, southern Alabama, Mississippi (Galvao et al. undated), and coastal Texas. Populations have recently been found in Aliceville Lake in Pickens County, Alabama, and in Aberdeen Lake and the Tennessee-Tombigbee Waterway in east-central Mississippi. Cuban bulrush was observed in the Ross Barnett Reservoir, Mississippi, for the first time in 2009 (McLaurin & Wersal 2011).
T_{10}: See T_0. The species may disperse closer to the pathway over time. However, on the basis of the species' native distribution, it may not tolerate extended freezing temperatures.
T_{25}: See T_{10}.
T_{50}: See T_0. The species' distance from the Brandon Road Lock and Dam may depend on the range in the region's temperature, which may increase seasonally because of future climate change. Over time, the species may disperse closer to the pathway if the climate becomes more suitable.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size (Bryson et al. 2008). It appears to be more of a tropical or subtropical species based on its native distribution. This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, on the basis of the species' native distribution, it may not tolerate extended freezing temperatures.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future changes in temperature and rainfall related to future climate change may affect the suitability of habitat and the northward expansion of this species.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat exists from the current location of this species to the Brandon Road Lock and Dam (section 2f). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. Cuban bulrush has been in the southeastern United States for a century and has not spread very far up the Mississippi River beyond the southern states, so it may not be likely to move to the CRCW pathway in the near term (section 2e). The cold climate of the Midwest may prevent the spread of this species to the Brandon Road Lock and Dam. Therefore, the probability of arrival is low.

T_{10}: See T_0. If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. However, it is not expected to reach the Brandon Road Lock and Dam during this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: In order to better understand the dispersal of the Cuban bulrush and its potential to invade wetland habitats, additional research is needed on both its reproductive biology, to determine the extent to which it reproduces sexually and spreads from achenes, and its association with other aquatic weeds (Bryson et al. 2008). It is not documented how far north Cuban bulrush will be able to disperse or whether the species will be able to survive the region's conditions. However, it has not spread very far north in decades. It is unlikely at this time step for the Cuban bulrush to travel the far distance to arrive at the pathway; therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be sufficient time for Cuban bulrush to expand to the CRCW pathway entrance. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is heavy vessel traffic between the Brandon Road Lock and Dam and the CRCW (USACE 2011a).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size (Bryson et al. 2008). This species commonly establishes in fresh water ditches, marshes,

ponds, lakes, rivers, and swamps (Bryson et al. 2008). Much of the CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Overall, there is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. Cuban bulrush may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). This species is not likely to survive in near-shore nonvegetated areas with manmade structures, like harbors consisting of stone blocks and steel sheet piling. Much of the CSSC is vertical limestone or manmade walls. Virtually all (more than 90%) of the Chicago River is vertical wall (LimnoTech 2010). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in most areas of the CAWS channel, suggesting that the CAWS is generally not suitable habitat for aquatic macrophytes like Cuban bulrush (section 3d). The Cuban bulrush spreads by floating and must move upstream to reach the CRCW (section 3a). Vessels could potentially transport this species upstream from the Brandon Road Lock and Dam to the CRCW. However, the vertical walls of the Chicago River would likely keep this species from establishing and naturally moving further upstream (section 3d). If the species becomes established near the CRCW, Cuban bulrush could spread by achenes (section 3a) into the Great Lakes when the locks are open (section 3c). Overall, this species is unlikely to spread throughout the CAWS during this time step because of habitat limitation and the need for upstream movement through the CAWS channel. Therefore, Cuban bulrush has a low probability of passing through the pathway.
T_{10}: See $T_{0.}$ Conditions in the CAWS (e.g., banks) are not likely to change in a fashion that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The probability of passage may increase over time and allow the Cuban bulrush to pass through the CRCW. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The lack of suitable habitat in the CAWS is documented. The potential for vessels to transport the Cuban bulrush upstream through the CAWS is uncertain. The only chance for the species to move upstream into the GLB is to float through the CRCW when it is open. The uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through the CRCW. However, the uncertainties of habitat and upstream transport remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Cuban bulrush is commonly established in fresh water ponds and lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures. There is no marsh habitat or floodplain habitat in the vicinity of the CRCW (unpublished data from USACE), and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap. Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan (unpublished data from USACE). Illinois Beach State Park, located approximately 80 km (50 mi) north of the CRCW, contains emergent wetlands near the shoreline of Lake Michigan. There is little emergent wetland habitat between the CRCW and the Indiana border (unpublished data from USACE) because of human modification of the shoreline. There are some emergent wetlands offshore of downtown Chicago that may provide suitable habitat. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the Cuban bulrush to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent

wetlands. This species could form populations along the shoreline of Lake Michigan in calm areas with an accumulation of organic matter.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The Cuban bulrush invades new locations when flood waters transport seed, roots, and stem fragments. Overall, the ability of the Cuban bulrush to reach marsh habitat after exiting the CRCW is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow Cuban bulrush to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of Cuban bulrush passing from the CRCW into Lake Michigan could be transported by vessels. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the Cuban bulrush seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but Cuban bulrush could colonize tributaries if transported upriver by flooding or wind-driven currents. However, such tributaries are more than 32 km (20 mi) from the CRCW.

Evidence for Probability Rating

Vessel traffic from the CRCW could potentially assist in the dispersal of Cuban bulrush. However, the Cuban bulrush is not likely to colonize near the CRCW, making vessel transport less likely (section 4b). Cuban bulrush is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of the CRCW or the sandy, high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan. However, these areas are primarily found in Indiana and are not located near the CRCW (section 4a). In addition, the Cuban bulrush is a warm-climate species, and the GLB may be too cold for this species to establish. Therefore, the probability of this species colonizing in Lake Michigan after exiting the CRCW is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport seeds or adult fragments is uncertain. It is uncertain whether, after exiting the CRCW, the species will be able to reach suitable habitat by drift alone. The climatological suitability of the GLB is uncertain. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
On the basis of the species' native distribution, it may not tolerate extended freezing temperatures; it appears to be more of a tropical or subtropical species.

b. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). However, the species has been in the United States for a century and has not moved to the upper Midwest.

c. *Fecundity*
The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).

d. *History of Invasion Success*
Cuban bulrush can exist at high density where established. The species has been spreading throughout the southeastern United States for a century (Bryson et al. 2008).

e. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast (Bryson et al. 1996). There is heavy boat traffic between the CRCW and other ports in the Great Lakes. Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water discharged at the ports along Lake Michigan is from ports in all the other Great Lakes (NBIC 2012).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The Cuban bulrush is a wetland obligate. Cuban bulrush is commonly established in fresh water lakes (Bryson et al. 2008). It may be on the water's edge (up to 50m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). There is marsh habitat throughout the Great Lakes. There are areas of near-shore emergent herbaceous habitat in tributaries and rivers feeding into the Great Lakes that would be suitable for the species (unpublished data from USACE). On the basis of the species' native

distribution, it may not tolerate extended freezing temperatures. There are areas of near-shore emergent herbaceous habitat in tributaries and rivers that would be suitable for the species (unpublished data from USACE). There are areas of near-shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries of the Great Lakes through which the Cuban bulrush could spread (unpublished data from USACE).

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan (section 5f). It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals. However, suitable wetland habitat is present in marsh and riverine habitats in the GLB, and human and natural mechanisms of spread are possible (sections 5b, 5e, 5f). However, the native range of the Cuban bulrush suggests it is a tropical species, and it has not spread very far north in a century, suggesting climate is unsuitable in the GLB. Therefore, the probability of spreading in the Great Lakes is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat in the GLB, but the climate is potentially unsuitable, although this has not been tested. Therefore, the uncertainty associated with the spread of the Cuban bulrush in the GLB is medium.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). The species appears to be expanding in the Mid-South region of the United States (McLaurin & Wersal 2011). However, the species has been in the United States for a century and has not moved to the upper Midwest.

b. Human-Mediated Transport through Aquatic Pathways
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. Current Abundance and Reproductive Capacity
T_0: The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline modifications. However, the Cuban bulrush can be carried by boats for short distances, and this could allow it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Cuban bulrush is native to the New World tropics, from the southern United States through northern South America (NBII & ISSG 2008). The species has been in the southeastern United States for more than a century (Bryson et al. 2008) and is found sporadically throughout Florida, Louisiana, southern Georgia, southern Alabama, Mississippi (Galvao et al. undated) and coastal Texas. Populations have recently been found in Aliceville Lake in Pickens County, Alabama, and in Aberdeen Lake and the Tennessee-Tombigbee Waterway in east-central Mississippi. Cuban bulrush was observed in the Ross Barnett Reservoir, Mississippi, for the first time in 2009 (McLaurin & Wersal 2011).
T_{10}: See T_0. The species may disperse closer to the pathway over time. However, on the basis of the native species distribution, it may not tolerate extended freezing temperatures.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The species' distance from the Brandon Road Lock and Dam may depend on the range in the region's temperature, which may increase seasonally due to future climate change. Over time, the species may disperse closer to the pathway if the climate becomes more suitable.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size (Bryson et al. 2008). It appears to be more of a tropical or subtropical species based on its native distribution. This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, on the basis of the native species distribution, it may not tolerate extended freezing temperatures.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future changes in temperature and rainfall related to future climate change may affect the suitability of habitat and the northward expansion of this species.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat exists from the current location of this species to the Brandon Road Lock and Dam (section 2f). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. Cuban bulrush has been in the southeastern United States for a century and has not spread very far up the Mississippi River beyond the southern states. The cold climate of the Midwest may limit the spread of this species to the Brandon Road Lock and Dam, so it may not be likely to move to the Calumet Harbor pathway in the near term (section 2e). Therefore, the probability of arrival is low.
T_{10}: See T_0. If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. However, it is not expected to reach the Brandon Road Lock and Dam during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: In order to better understand the dispersal of the Cuban bulrush and its potential to invade wetland habitats, additional research is needed on both its reproductive biology, to determine the extent to which it reproduces sexually and spreads from achenes, and its association with other aquatic weeds (Bryson et al. 2008). It is not documented how far north Cuban bulrush will be able to disperse or whether the species will be able to survive the region's conditions. However, it has not spread very far north in decades. It is unlikely at this time step for the Cuban bulrush to travel the far distance to arrive at the pathway; therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be sufficient time for Cuban bulrush to expand to the Calumet Harbor pathway entrance. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). Although there is little commercial river traffic to Calumet Harbor, there is heavy commercial vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size (Bryson et al. 2008). This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). Much of the CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Overall, there is low macrophyte cover in all areas of the CAWS channel. There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. Much of the CSSC is vertical limestone or manmade walls (LimnoTech 2010). The banks of the Calumet Sag Channel are primarily vertical walls, riprap, and natural soft sediment and cobble with overhanging vegetation (LimnoTech 2010). There are ditches and tributaries along the Calumet Sag Channel that may be suitable habitat for Cuban bulrush. Calumet Harbor is lined by vertical walls. Cuban bulrush may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). This species is not likely to survive in near-shore nonvegetated areas with manmade structures, like harbors consisting of stone blocks and steel sheet piling. It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of

dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the native species distribution, it may not tolerate extended freezing temperatures.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in most areas of the CAWS channel, suggesting that the CAWS is generally not suitable habitat for aquatic macrophytes like Cuban bulrush (section 3d). The Cuban bulrush spreads by floating and must move upstream to reach the Calumet Harbor (section 3a). Vessels could potentially transport this species upstream from the Brandon Road Lock and Dam to the T.J. O'Brien Lock and Dam. There is some suitable habitat, primarily in the Calumet Sag Channel, but this species is unlikely to spread throughout the CAWS during this time step because of habitat limitation and the need for upstream movement through the CAWS channel. The banks of the Calumet Harbor are primarily vertical wall (section 3d). This species is not likely to survive in near-shore nonvegetated areas or on potentially manmade structures, like harbors consisting of stone blocks and steel sheet piling (section 3d). Therefore, Cuban bulrush is not likely to form populations in Calumet Harbor and has a low probability of passage.
T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in a fashion that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The probability of passage may increase over time and allow the Cuban bulrush to pass through the Calumet Harbor. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The lack of suitable habitat in the CAWS is documented. The potential for vessels to transport the Cuban bulrush upstream through the CAWS is uncertain. The only chance for the species to move upstream into the GLB is to float through the Calumet Harbor. The uncertainty of this species passing through this pathway is considered to be low.

T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species, therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through the Calumet Harbor. However, the habitat and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Cuban bulrush is commonly established in fresh water ponds and lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the native species distribution, it may not tolerate extended freezing temperatures. Calumet Harbor is lined by vertical walls, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap. There is little emergent wetland habitat near the shoreline of Lake Michigan between Calumet Harbor and the Indiana border (unpublished data from USACE) because of human modification of the shoreline. This species could form populations along the shoreline of Lake Michigan in calm areas with an accumulation of organic matter. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the Cuban bulrush to colonize. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The Cuban bulrush invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the Cuban bulrush to reach marsh habitat after exiting Calumet Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow Cuban bulrush to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of Cuban bulrush passing from the Calumet Harbor into Lake Michigan could be transported by vessels. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001). The counterclockwise flow could carry the Cuban bulrush seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not

hydrologically connected to Lake Michigan, but Cuban bulrush could colonize tributaries if transported up river by flooding or wind-driven currents.

Evidence for Probability Rating

Boat traffic from Calumet Harbor could potentially assist in the dispersal of Cuban bulrush. However, the Cuban bulrush is not likely to colonize in Calumet Harbor, making vessel transport less likely (section 4b). Cuban bulrush is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of the Calumet Harbor or the sandy, high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan, the closest of which are found in Indiana (section 4a). In addition, the Cuban bulrush is a warm-climate species, and the GLB may be too cold for this species to establish. Therefore, the probability of this species colonizing in Lake Michigan after exiting the Calumet Harbor is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach to suitable habitat after exiting the Calumet Harbor by drift alone. The climatological suitability of the GLB is uncertain. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
On the basis of the species' native distribution, it may not tolerate extended freezing temperatures; the species appears to be more of a tropical or subtropical species.

b. Type of Mobility/Invasion Speed
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). However, the species has been in the United States for a century and has not moved to the upper Midwest.

c. *Fecundity*
   The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).

d. *History of Invasion Success*
   Cuban bulrush can exist at high density where established. The species has been spreading throughout the southeastern United States for a century (Bryson et al. 2008).

e. *Human-Mediated Transport through Aquatic Pathways*
   Cuban bulrush was likely introduced via ship ballast (Bryson et al. 1996). There is heavy boat traffic between the Calumet Harbor and other ports in the Great Lakes. Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water discharged at the ports along Lake Michigan is from ports in all the other Great Lakes (NBIC 2012).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The Cuban bulrush is a wetland obligate. Cuban bulrush is commonly established in fresh water lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). There are areas of near-shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected to Lake Michigan. However, there is floodplain habitat associated with tributaries of the Great Lakes through which the Cuban bulrush could spread (unpublished data from USACE). Although suitable physical habitat is present, on the basis of the species' native distribution, the Cuban bulrush may not the tolerate extended freezing temperatures characteristic of the GLB.

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan (section 5f). The Cuban bulrush is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals. However, suitable wetland habitat is present in marsh and riverine habitats in the GLB, and human and natural mechanisms of spread are possible (sections 5b, 5e, 5f). However, the native range of the Cuban bulrush suggests it is a tropical species, and it has not spread very far north in a century, suggesting climate is unsuitable in the GLB. Therefore, the probability of spreading in the Great Lakes is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB, but the climate is potentially unsuitable, although this has not been tested. Therefore, the uncertainty associated with the spread of the Cuban bulrush in the GLB is medium.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of

Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). The species appears to be expanding in the Mid-South region of the United States (McLaurin & Wersal 2011). However, the species has been in the United States for a century and has not moved to the upper Midwest.

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline modifications. However, the Cuban bulrush can be carried by boats for short distances, which could allow it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Cuban bulrush is native to the New World tropics, from the southern United States through northern South America (NBII & ISSG 2008). The species has been in the southeastern United States for more than a century (Bryson et al. 2008) and is found sporadically throughout Florida, Louisiana, southern Georgia, southern Alabama, Mississippi (Galvao et al. undated), and coastal Texas. Populations have recently been found in Aliceville Lake in Pickens County, Alabama, and in Aberdeen Lake and the Tennessee-Tombigbee Waterway in east-central Mississippi. Cuban bulrush was observed in the Ross Barnett Reservoir, Mississippi, for the first time in 2009 (McLaurin & Wersal 2011).
T_{10}: See T_0. The species may disperse closer to the pathway over time. However, on the basis of the species' native distribution, it may not tolerate extended freezing temperatures.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The species' distance from the Brandon Road Lock and Dam may depend on the range in the region's temperature, which may increase seasonally due to future

climate change. Over time, the species may disperse closer to the pathway if the climate becomes more suitable.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size. It appears to be more of a tropical or subtropical species based on its native distribution. This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, on the basis of the native species distribution, it may not tolerate extended freezing temperatures.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future changes in temperature and rainfall related to future climate change may affect the suitability of habitat and the northward expansion of this species.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat exists from the current location of this species to the Brandon Road Lock and Dam (section 2f). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. Cuban bulrush has been in the southeastern United States for a century and has not spread up the Mississippi River beyond the southern states, so it may not be likely to move to the Indiana Harbor pathway in the near term (section 2e). The cold climate of the upper Midwest may limit the spread of this species to the Brandon Road Lock and Dam. Therefore, the probability of arrival is low.
T_{10}: See T_0. If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. However, it is not expected to reach the Brandon Road Lock and Dam during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: In order to better understand the dispersal of Cuban bulrush and its potential to invade wetland habitats, additional research is needed on both its reproductive biology, to determine the extent to it reproduces sexually and spreads from achenes, and its association with other aquatic weeds (Bryson et al. 2008). It is not documented how far north Cuban bulrush will be able to disperse or whether the species will be able to survive the region's conditions. However, it has not spread very far north in decades. It is unlikely at this time step for the Cuban bulrush to travel the far distance to arrive at the pathway; therefore, the uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be sufficient time for Cuban bulrush to expand to the Indiana Harbor pathway entrance. The impacts of future climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is no cargo vessel traffic to Indiana Harbor originating within the MRB. Vessels could transport the Cuban bulrush north as far as the T.J. O'Brien Lock and Dam located on the Grand Calumet River (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size (Bryson et al. 2008). This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). Much of the CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas**.** Overall, there is low macrophyte cover in all areas of the CAWS channel. Much of the CSSC is vertical limestone or manmade walls (LimnoTech 2010). There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. The banks of the Calumet Sag Channel are primarily vertical walls, riprap, and natural soft sediment and cobble with overhanging vegetation (LimnoTech 2010). There are ditches and tributaries along the Calumet Sag Channel that may be suitable habitat for Cuban bulrush. In the east branch of the Grand Calumet River, suitable marsh habitat is common, but biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments consist of primarily cobble, bedrock or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water can flow east or west depending on the water level in Lake Michigan. Conditions at the Indiana Harbor are highly industrialized. Cuban bulrush may be on the water’s edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). This species is not likely to survive in near-shore nonvegetated areas with manmade structures, like harbors consisting of stone blocks and steel sheet piling. It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the native species distribution, it may not tolerate extended freezing temperatures.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in most areas of the CAWS channel, suggesting that the CAWS is generally not suitable habitat for aquatic macrophytes like Cuban bulrush (section 3d). The Cuban bulrush spreads by floating and must move upstream to reach Indiana Harbor (section 3a). Vessels could potentially transport this species upstream from the Brandon Road Lock and Dam to the T.J. O’Brien Lock and Dam. There is some suitable habitat, primarily in the Grand Calumet River, but this species is unlikely to spread throughout the CAWS during this time step because of habitat limitation and the need for upstream movement through the CAWS channel. The banks of the Indiana Harbor are primarily vertical wall (section 3d). This species is not likely to survive in near-shore

nonvegetated areas or on potentially manmade structures, like harbors consisting of stone blocks and steel sheet piling (section 3d). Therefore, Cuban bulrush is not likely to form populations in the Indiana Harbor and has a low probability of passage.
T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in a fashion that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The probability of passage may increase over time and allow the Cuban bulrush to pass through Indiana Harbor. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The potential for vessels to transport the Cuban bulrush upstream through the CAWS is uncertain. Another uncertainty is that the Grand Calumet can flow east or west, and this could increase or decrease the rate of spread to Indiana Harbor. The lack of suitable habitat in the CAWS is documented. Therefore, uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through Indiana Harbor. However, the habitat and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Cuban bulrush is commonly established in fresh water ponds and lakes (Bryson 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures. There are no emergent wetlands in Indiana Harbor, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap (unpublished data from USACE). East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the Cuban bulrush to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands. This species could form populations along the shoreline of Lake Michigan in calm areas with an accumulation of organic matter.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The Cuban bulrush invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the Cuban bulrush to reach marsh habitat after exiting Indiana Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow Cuban bulrush to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of Cuban bulrush passing from Indiana Harbor into Lake Michigan could be transported by vessels. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001). The counterclockwise flow could carry the Cuban bulrush seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but Cuban bulrush could colonize tributaries if transported up river by flooding or wind-driven currents.

Evidence for Probability Rating

Vessel traffic from Indiana Harbor could potentially assist in the dispersal of Cuban bulrush. However, the Cuban bulrush is not likely to colonize in Indiana Harbor, making vessel transport less likely (section 4b). Cuban bulrush is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of Indiana Harbor or the sandy, high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan, the closest of which are found in Indiana (section 4a). In addition, the Cuban bulrush is a warm-climate species, and the GLB may be too cold for this species to establish. Therefore, the probability of this species colonizing in Lake Michigan after exiting Indiana Harbor is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach suitable habitat after exiting Indiana Harbor by drift alone. The climatological suitability of the GLB is uncertain. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
On the basis of the species' native distribution, it may not tolerate extended freezing temperatures; the species appears to be more of a tropical or subtropical species.

b. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water. Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). However, the species has been in the United States for a century and has not moved to the upper Midwest.

c. *Fecundity*
The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).

d. *History of Invasion Success*
Cuban bulrush can exist at high density where established. The species has been spreading throughout the southeastern United States for a century (Bryson et al. 2008).

e. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast (Bryson et al. 1996). There is heavy boat traffic between Indiana Harbor and other ports in the Great Lakes. Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water discharged at the ports along Lake Michigan is from ports in all the other Great Lakes (NBIC 2012).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The Cuban bulrush is a wetland obligate. Cuban bulrush is commonly established in fresh water lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). There is marsh habitat throughout the Great Lakes. There are areas of near-shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries of the Great Lakes

through which the Cuban bulrush could spread (unpublished data from USACE). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures.

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan (section 5f). It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals. However, suitable wetland habitat is present in marsh and riverine habitats in the GLB, and human and natural mechanisms of spread are possible (sections 5b, 5e, 5f). However, the native range of the Cuban bulrush suggests it is a tropical species, and it has not spread very far north in a century, suggesting climate is unsuitable in the GLB. Therefore, the probability of spreading in the Great Lakes is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB, but the climate is potentially unsuitable, although this has not been tested. Therefore, the uncertainty associated with the spread of the Cuban bulrush in the GLB is medium.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). The species appears to be expanding in the Mid-South region of the United States (McLaurin & Wersal 2011). However, the species has been in the United States for a century and has not moved to the upper Midwest.

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline modifications. However, the Cuban bulrush can be carried by boats for short distances, which could allow it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Cuban bulrush is native to the New World tropics, from the southern United States through northern South America (NBII & ISSG 2008). The species has been in the

southeastern United States for more than a century (Bryson et al. 2008) and is found sporadically throughout Florida, Louisiana, southern Georgia, southern Alabama, Mississippi (Galvao et al. undated), and coastal Texas. Populations have recently been found in Aliceville Lake in Pickens County, Alabama, and in Aberdeen Lake and the Tennessee-Tombigbee Waterway in east-central Mississippi. Cuban bulrush was observed in the Ross Barnett Reservoir, Mississippi, for the first time in 2009 (McLaurin & Wersal 2011).

T_{10}: See T_0. The species may disperse closer to the pathway over time. However, on the basis of the native species distribution, it may not tolerate extended freezing temperatures.

T_{25}: See T_{10}.

T_{50}: See T_0. The species' distance from the Brandon Road Lock and Dam may depend on the range in the region's temperature, which may increase seasonally because of future climate change. Over time, the species may disperse closer to the pathway if the climate becomes more suitable.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size. It appears to be more of a tropical or subtropical species based on its native distribution. This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, on the basis of the species' native distribution, it may not tolerate extended freezing temperatures.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future changes in temperature and rainfall related to future climate change may affect the suitability of habitat and the northward expansion of this species.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat exists from the current location of this species to the Brandon Road Lock and Dam (section 2f). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. Cuban bulrush has been

in the southeastern United States for a century and has not spread up the Mississippi River beyond the southern states, so it may not be likely to move to the BSBH pathway in the near term (section 2e). The cold climate of the upper Midwest may limit the spread of this species to the Brandon Road Lock and Dam. Therefore, the probability of arrival is low.
T_{10}: See T_0. If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. However, it is not expected to reach the Brandon Road Lock and Dam during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: In order to better understand the dispersal of Cuban bulrush and the potential for it to invade wetland habitats, additional research is needed on both its reproductive biology, to determine the extent to which it reproduces sexually and spreads from achenes, and its association with other aquatic weeds (Bryson et al. 2008). It is not documented how far north Cuban bulrush will be able to disperse or whether the species will be able to survive the region's conditions. However, it has not spread very far north in decades. It is unlikely at this time step for the Cuban bulrush to travel the far distance to arrive at the pathway; therefore, uncertainty for arrival is low.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be sufficient time for Cuban bulrush to expand to the BSBH pathway entrance. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Cuban bulrush was likely introduced via ship ballast from the West Indies or South America (Bryson et al. 1996). There is no cargo vessel traffic to the BSBH originating within the MRB. Vessels could transport the Cuban bulrush as far as the Little Calumet River. Therefore, natural dispersal by floating upstream through the south branch of the Little Calumet River and Burns Ditch, approximately 64 km (40 mi), would be required to arrive at the BSBH. There is some small boat recreational use in the Little Calumet River.

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Cuban bulrush is a perennial, rhizomatous, emergent sedge of littoral regions (NBII & ISSG 2008). It is found in free-floating mats and rafts that vary greatly in size. This species commonly establishes in fresh water ditches, marshes, ponds, lakes, rivers, and swamps (Bryson et al. 2008). Much of the CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. The habitat in the CAWS consists of mostly (about 75%) manmade waterways designed to be straight and deep (LimnoTech 2010). Overall, there is low macrophyte cover in all areas of the CAWS channel. There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. Much of the CSSC is vertical limestone or manmade walls (LimnoTech 2010). The banks of the Calumet Sag Channel are primarily vertical walls, riprap, and natural soft sediment and cobble with overhanging vegetation (LimnoTech 2010). There are ditches and tributaries along the Calumet Sag Channel that may be suitable habitat for Cuban bulrush. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). The BSBH is lined by vertical walls and sandy vegetated banks with riprap. Cuban bulrush may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). This species is not likely to survive in near-shore nonvegetated areas with manmade structures, like harbors consisting of stone blocks and steel sheet piling. It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in most areas of the CAWS channel, suggesting that the CAWS is generally not suitable habitat for aquatic macrophytes like Cuban bulrush (section 3d). The Cuban bulrush spreads by floating and must move upstream to reach the BSBH (section 3a). There is some suitable habitat, primarily in the Calumet Sag Channel and south branch of the Little Calumet River, but this species is unlikely to spread throughout the CAWS during this time step because of habitat limitation and the need for upstream movement through the CAWS channel. The banks of the BSBH are primarily vertical wall, sand, and riprap (section 3d). This species is not likely to survive in near-shore nonvegetated areas or on potentially manmade structures, like harbors consisting of stone blocks and steel sheet piling (section 3d). Therefore, Cuban bulrush is not likely to form populations in the BSBH and has a low probability of passage.

T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in a fashion that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.

T_{25}: See T_{10}.

T_{50}: See T_{10}. The probability of passage may increase over time and allow the Cuban bulrush to pass through the BSBH. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The lack of suitable habitat in the CAWS is documented. The potential for vessels to transport the Cuban bulrush upstream through the CAWS is uncertain. Another uncertainty is that the south branch of the Little Calumet can flow east or west, and this could increase or decrease the rate of spread to the BSBH. The uncertainty of this species passing through this pathway is considered to be low.

T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through the BSBH. However, the habitat and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Cuban bulrush is commonly established in fresh water ponds and lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures. There are emergent wetlands south of the BSBH, but it is not known whether they are hydrologically connected to the CAWS. The BSBH itself contains no emergent wetland habitat, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap (unpublished data from USACE). Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan. There are scattered emergent wetlands near Lake Michigan north of the BSBH, but they are likely to be too far inland from Lake Michigan for the Cuban bulrush to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands. This species could form populations along the shoreline of Lake Michigan in calm areas with an accumulation of organic matter.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The Cuban bulrush invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the Cuban bulrush to reach marsh habitat after exiting the BSBH is severely restricted by the lack of marsh and natural floodplain along the shoreline of Lake Michigan. However, there may be suitable habitat within the BSBH. Potential dispersal mechanisms via aquatic pathways that would allow Cuban bulrush to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of Cuban bulrush passing from the BSBH into Lake Michigan could be transported by vessels. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001). The counterclockwise flow could carry the Cuban bulrush seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but Cuban bulrush could colonize tributaries if transported up river by flooding or wind driven currents.

Evidence for Probability Rating

Recreational boat traffic from the BSBH could potentially assist in the dispersal of Cuban bulrush. However, the Cuban bulrush is not likely to colonize in the BSBH, making vessel transport less likely (section 4b). Cuban bulrush is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of the BSBH or on the sandy, high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan (section 4a). However, these areas are not located near the BSBH (section 4a). In addition, the Cuban bulrush is a warm-climate species, and the GLB may be too cold for this species to establish. Therefore, the probability of this species colonizing in Lake Michigan after exiting the BSBH is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach suitable habitat after exiting the BSBH by drift alone. The climatological suitability of the GLB is uncertain. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
On the basis of the species' native distribution, it may not tolerate extended freezing temperatures; the species appears to be more of a tropical or subtropical species.

b. Type of Mobility/Invasion Speed
Cuban bulrush is a floating, epiphytic perennial herb. It is thought to be extremely invasive in appropriate conditions (Bryson et al. 2008). The corky, buoyant achenes of Cuban bulrush are adapted to dispersal by moving water (Bryson et al. 2008). Its mat-forming, floating habit facilitates asexual reproduction and transport of vegetative fragments by moving water (Haines & Lye 1983). However, the species has been in the United States for a century and has not moved to the upper Midwest.

c. Fecundity
The Cuban bulrush reproduces by rhizomes/stolons and by the production of achenes (seeds) (NBII & ISSG 2008). Asexual reproduction by fragmentation occurs (Bryson et al. 2008).

d. *History of Invasion Success*
   Cuban bulrush can exist at high density where established. The species has been spreading throughout the southeastern United States for a century (Bryson et al. 2008).

e. *Human-Mediated Transport through Aquatic Pathways*
   Cuban bulrush was likely introduced via ship ballast (Bryson et al. 1996). There is recreational but not commercial vessel traffic to the BSBH from Lake Michigan. However, there is heavy boat traffic between the nearby Burns Harbor and other ports in the Great Lakes (USACE 2011a,b). Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water discharged at the ports along Lake Michigan is from other ports in all the other Great Lakes (NBIC 2012).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The Cuban bulrush is a wetland obligate. Cuban bulrush is commonly established in fresh water lakes (Bryson et al. 2008). It may be on the water's edge (up to 50 m [164 ft] from the coast) or may detach from the land and float freely (NBII & ISSG 2008). It is unclear whether this species requires other vegetation for establishment and mat formation, but it appears that the epiphytic form of Cuban bulrush prefers areas of dense floating aquatic vegetation (McLaurin & Wersal 2011). There is marsh habitat throughout the Great Lakes. There are areas of near-shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries of the Great Lakes through which the Cuban bulrush could spread (unpublished data from USACE). On the basis of the species' native distribution, it may not tolerate extended freezing temperatures.

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan (section 5f). It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals. However, suitable wetland habitat is present in marsh and riverine habitats in the GLB, and human and natural mechanisms of spread are possible (sections 5b, 5e, 5f). However, the native range of the Cuban bulrush suggests it is a tropical species, and it has not spread very far north in a century, suggesting climate is unsuitable in the GLB. Therefore, the probability of spreading in the Great Lakes is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB, but the climate is potentially unsuitable, although this has not been tested. Therefore, the uncertainty associated with the spread of the Cuban bulrush in the GLB is medium.

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E.1.1.2 Dotted Duckweed - *Landoltia punctate*

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] “-“ Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002). It has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002). The species was first recorded in Illinois in 1962 (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
This species can potentially be spread by recreational or cargo vessel traffic. Duckweed can be spread by sticking to the sides of boats (Lembi 2009). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: Dotted duckweed has a high rate of vegetative propagation (Jacono 2002). Propagation occurs mainly via vegetative budding of daughter fronds from two pouches at the base of the frond (Jacono 2002); occasionally the plant reproduces sexually by seed (Jacono 2002). This species is not widespread in Illinois (Jacono 2002).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as barriers because of the associated shoreline modifications. However, the dotted duckweed can attach to boats, allowing it to transfer through the locks.
T_{10}: See T_0. No changes in lock operations are anticipated.
T_{25}: See T_{10}.
T_{50}: See T_{10}. .

e. *Distance from Pathway*
T_0: Dotted duckweed was first documented in Missouri in 1934 and is now well naturalized in the southeastern United States (Jacono 2002). Dotted duckweed has been established in Senachwine Lake in Bureau County, Illinois, since 1986, a distance of less than 161 km (100 mi) from the Brandon Road Lock and Dam (Jacono 2002). Senachwine Lake is connected to the Illinois River. Populations of the species are overlooked because of its superficial resemblance to native duckweeds (Jacono 2002).
T_{10}: See T_0. If current trends continue, dotted duckweed may disperse closer to pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The distance of the species from the Brandon Road Lock and Dam may depend on the range in the region's temperature (Jacono 2002), which may increase seasonally because of climate change. Dotted duckweed may disperse closer to the pathway over time if the climate becomes more suitable.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Dotted duckweed is native to Australia and Southeast Asia (Jacono 2002). Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). It is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, Jacono (2002) states, "Many duckweeds, including our native Spirodela polyrrhiza, survive climate in

cold regions by forming an abundant supply of turions (rootless fronds rich in starch) that sink to the warm bottom to overwinter. The inability of Landoltia punctata to form turions accounts for its absence in the northern and Midwestern United States. Its fronds are sensitive to severe frosts and plants are reportedly limited by absolute minimum temperatures ≤20°C (–4°F).” Jacono (2002) also states that, “The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival.”

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future changes in temperature and rainfall related to climate change may affect the suitability of habitat and the northward expansion of this species. If temperatures warm, dotted duckweed may expand north. However, if winters become more severe, habitat suitability may decrease.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dotted duckweed has been established less than 161 km (100 mi) from the Brandon Road Lock and Dam for 25 years and has not spread north; therefore, the plant is unlikely to move to the pathway entrance in the near term (section 2e). The species is a free-floating plant that must move upstream by natural dispersal or vessel transport to reach the WPS pathway entrance (section 2a). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. The cold winters of the Chicago area may be too cold for the dotted duckweed to survive (section 2f). For these reasons, the probability of dotted duckweed reaching the Brandon Road Lock and Dam is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Dotted duckweed has spread across the Southeast over several decades (sections 2a, 2e). If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. Future climate change may promote or inhibit the spread of this species to the Brandon Road Lock and Dam. Therefore, 50 years may be sufficient time to expand to the pathway, raising the probability of arrival to medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for dotted duckweed to travel the distance to arrive at the pathway, and the cold temperature of the region may limit survival. Therefore, uncertainty of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Dotted duckweed has been recorded less than 161 km (100 mi) from the Brandon Road Lock and Dam. Populations of this species are often overlooked because of its superficial resemblance to native duckweeds (Jacono 2002); therefore, it may be closer than currently known. If it is closer than currently described, 25 years may be enough time to reach the Brandon Road Lock and Dam. Therefore, uncertainty of arrival is medium for this time step.
T_{50}: See T_0. Fifty years may be sufficient time to expand to the pathway. However, the future impacts of climate change on the distribution of this species and its ability to adapt to climate change are not documented. This raises the uncertainty of arrival to high.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

b. Human-Mediated Transport through Aquatic Pathways
There is potential for spread by recreational vessel traffic. Duckweed can stick to the sides of boats (Lembi 2009), but it can dry out within a few hours (Landolt 1986). There is no cargo vessel traffic north through the CAWS to the WPS (USACE 2011a). Vessels could transport dotted duckweed as far as the Chicago River. There is small-boat recreational use only in the North Shore Channel. However, the sluice gate at the WPS prevents any vessel traffic between the North Shore Channel and Lake Michigan.

c. Existing Physical Human/Natural Barriers
T_0: The sluice gate at the WPS separates the CAWS from Lake Michigan. However, occasionally flow is reversed back into Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the WPS is a slow-moving eutrophic river with a flow of

0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Dotted duckweed is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). The plant is associated with trees, suggesting leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). Sediments in the CAWS can range from bedrock to soft sediment but are typically inorganic silt (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways designed to be straight and deep. Much of the CSSC is vertical limestone or manmade walls, which may limit the establishment of this species. Virtually all (>90%) of the Chicago River and the lower north branch of the Chicago River is vertical wall with sediments of concrete, silt, or sludge. Toxic organic and inorganic pollutants are also present in the Chicago River (LimnoTech 2010; Gallagher et al. 2009). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. In the North Shore Channel and the upper north branch of the Chicago River, in-stream there are partly shaded banks with submerged aquatic plants, tree roots, and brush debris jams, and sediments are silt and sand (LimnoTech 2010). Although submerged aquatic plants are not common in the CAWS, they have been documented to exist in the CSSC and the North Shore Channel (LimnoTech 2010). Dotted duckweed is typically found in waters less than 2 m (6.6 ft) in depth; the maximum depth in the CAWS is about 10 m (32.8 ft); and depth is typically about 5 m (16.4 ft) (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. The dotted duckweed thrives in high-nutrient water (section 3d). Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012), reducing not only pollutants but also nutrient levels, and this could in turn affect habitat suitability of the CAWS for the dotted duckweed.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Much of the CAWS is lined with concrete and steel banks, and the sediment is not nutrient rich with organic matter (section 3d). Although submerged aquatic vegetation is very limited in the CAWS, it is present in the CSSC, and there is vessel traffic in the CSSC, which could potentially transport dotted duckweed to the Chicago River (sections 3b, 3d). If the species establishes near the WPS, it could float (section 3a) into the Great Lakes when the sluice gate is open (section 3c). However, the lack of suitable habitat in the Chicago River and the need for upstream dispersal are likely to slow spread to the North Shore Channel. Short-distance vessel transport is likely to be the primary mechanism for

upstream passage to the WPS. For these reasons, the dotted duckweed has a low probability of passing through the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0. Future water quality improvements may reduce the suitability of the CAWS for the dotted duckweed (section 3d). However, the lack of suitable habitat and limited upstream dispersal mechanisms will continue to hinder movement to the WPS. Therefore, the future probability of passage remains low.
T_{50}: See T_{25}. Fifty years may be sufficient time for the species to pass through the pathway, raising the probability of passage to medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: It is uncertain whether an adequate upstream transport mechanism exists. The winter months in the CAWS are likely too cold for the dotted duckweed to survive and establish. The CAWS may be unsuitable due to its poor sediment quality. The lack of suitable habitat in the CAWS is documented. Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. The future water quality of the CAWS and its effects on dotted duckweed passage are uncertain. The potential rate of upstream spread within the CAWS is uncertain for this species, but over 25 years this species may be able to spread upstream through the CAWS. Therefore, uncertainty associated with passage during this time step is medium.
T_{50}: See T_{25}.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments, such as ponds that receive drainage from farm fields. Wilmette Harbor, which is on the lake side of the WPS, contains no emergent wetland habitat, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap.

Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan (unpublished data from USACE). Illinois Beach State Park, located approximately 50 km (31 mi) north of the WPS, contains emergent wetlands near the shoreline of Lake Michigan. There is little emergent wetland habitat between the WPS and the Indiana border (unpublished data from USACE) because of human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the dotted duckweed to colonize. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Dotted duckweed invades new locations via floodwater transport. Overall, the ability of the dotted duckweed to reach marsh habitat after exiting Wilmette Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow dotted duckweed to colonize suitable habitat include transport by boats and drift along the Lake Michigan Shoreline. Dotted duckweed passing from the North Shore Channel into the Wilmette Harbor and Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the dotted duckweed seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but dotted duckweed could colonize tributaries if transported upriver by wind-driven currents. However, such tributaries are more than 96.6 km (60 mi) from the WPS.

Evidence for Probability Rating

Recreational boat traffic from Wilmette Harbor could potentially assist in the dispersal of dotted duckweed. However, the species is not likely to colonize Wilmette Harbor, making vessel transport less likely (section 4b). Dotted duckweed is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of the WPS or the sandy high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan. However, these areas are primarily found in Indiana and are not located near the WPS (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting the WPS is considered to be low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport dotted duckweed is uncertain. It is uncertain whether the species will be able by drift alone to reach suitable habitat after exiting the WPS. Therefore, the uncertainty associated with this species colonizing in the GLB from the WPS is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Cold temperature may limit the species' establishment in the upper Midwest. The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks) (Landolt 1986). Therefore, the species cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Jacono 2002).

b. Type of Mobility/Invasion Speed
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

c. Fecundity
This species exhibits a high rate of vegetative propagation. Propagation can occur via vegetative budding of daughter fronds from two pouches at base of the frond or occasionally through sexual reproduction by seed (Jacono 2002).

d. History of Invasion Success
Its irregularity in distribution in the United States suggests multiple introduction sites. Dotted duckweed has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002).

e. Human-Mediated Transport through Aquatic Pathways
The species can potentially be spread by recreational or cargo vessel traffic. Dotted duckweed can be spread by sticking to the sides of boats (Lembi 2009).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Dotted duckweed is a wetland obligate species. Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so it is typically found in nutrient-rich environments, such as ponds that receive drainage from farm fields. Its association with trees suggests that leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can

be a major source of nutrients (Lembi 2009). The littoral wetlands along Lake Michigan are primarily sandy beaches. This species is known not to tolerate cold temperatures (absolute minimum air temperatures of ≤20°C [−4°F] for extended periods) (Jacono 2002). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Landolt 1986).

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan. It is not likely to grow near shore on nonvegetated areas, like a harbor or rocky shoals (section 5f). Human-mediated dispersal may assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. Overall, however, the winter months have been identified in the literature as too cold for dotted duckweed to establish in portions of the GLB (section 5f). Therefore, the probability of spread throughout the Great Lakes from the WPS is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat in the GLB in the form of emergent wetland and littoral habitat. However, it is uncertain whether the climate of the GLB is too cold for this species. Therefore, there is a medium level of uncertainty associated with the probability of spread of dotted duckweed through the Great Lakes.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Dotted duckweed is a tiny, free-floating plant that disperses readily (Jacono 2002). It has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002). The species was first recorded in Illinois in 1962 (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
This species can potentially be spread by recreational or cargo vessel traffic. Duckweed can be spread by sticking to the sides of boats (Lembi 2009). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: Dotted duckweed has a high rate of vegetative propagation (Jacono 2002). Propagation mainly occurs via vegetative budding of daughter fronds from two pouches at the base of the frond; occasionally the plant reproduces sexually by seed (Jacono 2002). This species is not widespread in Illinois (Jacono 2002).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline

modifications. However, the dotted duckweed can attach to boats, allowing it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Dotted duckweed was first documented in Missouri in 1934 and is now well naturalized in the southeastern United States (Jacono 2002). Dotted duckweed has been established in Senachwine Lake in Bureau County, Illinois, since 1986, a distance of less than 161 km (100 mi) from the Brandon Road Lock and Dam (Jacono 2002). Senachwine Lake is connected to the Illinois River. Populations of the species are overlooked because of its superficial resemblance to native duckweeds (Jacono 2002).
T_{10}: See T_0. If current trends continue, dotted duckweed may disperse closer to pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The distance of the species from the Brandon Road Lock and Dam may depend on the range in the region's temperature (Jacono 2002), which may increase seasonally because of future climate change. Dotted duckweed may disperse closer to the pathway over time if the climate becomes more suitable.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Dotted duckweed is native to Australia and Southeast Asia (Jacono 2002). Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). It is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, Jacono (2002) states, "Many duckweeds, including our native Spirodela polyrrhiza, survive climate in cold regions by forming an abundant supply of turions (rootless fronds rich in starch) that sink to the warm bottom to overwinter. The inability of Landoltia punctata to form turions accounts for its absence in the northern and Midwestern United States. Its fronds are sensitive to severe frosts and plants are reportedly limited by absolute minimum temperatures ≤20°C (−4°F)". Jacono (2002) also states that, "The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival."
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future changes in temperature and rainfall related to climate change may affect the suitability of habitat and the northward expansion of this species. If temperatures warm, dotted duckweed may expand north. However, if winters become more severe, habitat suitability may decrease.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dotted duckweed has been established less than 161 km (100 mi) from the Brandon Road Lock and Dam for 25 years and has not spread north; therefore, the plant is unlikely to move to the pathway entrance in the near term (section 2e). The dotted duckweed is a free-floating plant that must move upstream by natural dispersal or vessel transport to reach the CRCW pathway entrance (section 2a). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 4f), so upstream movement toward the Brandon Road Lock and Dam may be slow. The winters of the Chicago area may be too cold for the dotted duckweed to survive (section 2f). For these reasons, the probability of dotted duckweed reaching the Brandon Road Lock and Dam is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Dotted duckweed has spread across the Southeast over several decades (sections 2a, 2e). If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. Future climate change may promote or inhibit the spread of this species to the Brandon Road Lock and Dam. Therefore, 50 years may be sufficient time to expand to the pathway, raising the probability of arrival to medium.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the dotted duckweed to travel the distance to arrive at the pathway, and the cold temperature of the region may limit survival. Therefore, uncertainty of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Dotted duckweed has been recorded less than 161 km (100 mi) from the Brandon Road Lock and Dam. Populations of this species are overlooked because of its superficial resemblance to native duckweeds (Jacono 2002); therefore, it may be closer than currently known. If it is closer than currently described, 25 years may be enough time to reach the Brandon Road Lock and Dam. Therefore, uncertainty of arrival is medium for this time step.
T_{50}: See T_{25}. Fifty years may be sufficient time to expand to the pathway. However, the future impacts of climate change on the distribution of this species and the species' ability to adapt to climate change are not documented. This raises the uncertainty of arrival to high.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by vessel traffic. Duckweed can stick to the sides of boats (Lembi 2009), but it can dry out within a few hours (Landolt 1986). There is heavy vessel traffic between the Brandon Road Lock and Dam and the CRCW (USACE 2011a).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the CRCW is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Dotted duckweed is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). The plant is associated with trees, suggesting leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). Sediments in the CAWS can range from bedrock to soft sediment but are typically inorganic silt (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways designed to be straight and deep. Much of the CSSC is vertical limestone or manmade walls, which may limit the establishment of this species. Virtually all (>90%) of the Chicago River is vertical wall with sediments of concrete, silt, or sludge. Toxic organic and inorganic pollutants are also present in the Chicago River (LimnoTech 2010; Gallagher et al. 2009). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS (LimnoTech 2010). Although submerged aquatic plants are not common in the CAWS, they have been documented to exist in the CSSC (LimnoTech 2010). Dotted duckweed is typically found in waters less than 2 m (6.6 ft) in depth; the maximum depth in the CAWS is about 10 m (32.8 ft); and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Therefore, water depth in the CAWS may be suitable only on a shallow channel shoreline.
T_{10}: See T_0.

T_{25}: See T_0. The dotted duckweed thrives in high-nutrient water (section 3d). Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012), reducing not only pollutants but also nutrient levels, which could in turn affect habitat suitability of the CAWS for the dotted duckweed.
T_{50}: See T_{25}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Much of the CAWS is lined with concrete and steel banks, and the sediment is not nutrient rich with organic matter (section 3d). Although submerged aquatic vegetation is very limited in the CAWS, it is present in the CSSC, and there is vessel traffic in the CSSC, which could potentially transport dotted duckweed to the Chicago River (sections 3b, 3d). If the species establishes near the CRCW, it could float (section 3a) into the Great Lakes when the CRCW is open (section 3c). However, the lack of suitable habitat in the Chicago River and the need for upstream dispersal are likely to slow spread. For these reasons, the dotted duckweed has a low probability of passing through the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0. Future water quality improvements may reduce the suitability of the CAWS for the dotted duckweed (section 3d). However, the lack of suitable habitat and limited upstream dispersal mechanisms will continue to hinder movement to the CRCW. Therefore, the future probability of passage remains low.
T_{50}: See T_{25}. Fifty years may be sufficient time to pass through the pathway, raising the probability of passage to medium.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: It is uncertain whether an adequate upstream transport mechanism exists. The winter months in the CAWS are likely too cold for the dotted duckweed to survive and establish. The CAWS may be unsuitable due to its poor sediment quality. The lack of suitable habitat in the CAWS is documented. Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. The future water quality of the CAWS and its effects on dotted duckweed passage are uncertain. The potential rate of upstream spread within the CAWS is uncertain

for this species, but over 25 years this species may be able to spread upstream through the CAWS. Therefore, uncertainty associated with passage during this time step is medium.
T_{50}: See T_{25}.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments such as ponds that receive drainage from farm fields. There is no marsh habitat or floodplain habitat in the vicinity of the CRCW (unpublished data from USACE), and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap. Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan (unpublished data from USACE). Illinois Beach State Park, located approximately 80.5 km (50 mi) north of the CRCW, contains emergent wetlands near the shoreline of Lake Michigan. There is little emergent wetland habitat between the CRCW and the Indiana border (unpublished data from USACE) because of human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the dotted duckweed to colonize. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The dotted duckweed invades new locations via floodwaters transport. Overall, the ability of the dotted duckweed to reach marsh habitat after exiting the CRCW is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow dotted duckweed to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Dotted duckweed passing from the CRCW into Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the dotted duckweed seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but dotted

duckweed could colonize tributaries if transported upriver by wind-driven currents. However, such tributaries are more than 32 km (20 mi) from the CRCW.

Evidence for Probability Rating

Vessel traffic from the CRCW could potentially assist in the dispersal of dotted duckweed. However, the dotted duckweed is not likely to colonize near the CRCW, making vessel transport less likely (section 4b). Dotted duckweed is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of the CRCW or the sandy high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan. However, these areas are primarily found in Indiana and are not located near the CRCW (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting the CRCW is considered to be low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport dotted duckweed is uncertain. It is uncertain whether the species will be able to reach suitable habitat after exiting the CRCW by drift alone. Therefore, the uncertainty associated with this species colonizing in the GLB from the CRCW is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Cold temperature may limit the species' establishment in the upper Midwest. The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks) (Landolt 1986). Therefore, the species cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Jacono 2002).

b. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

c. *Fecundity*
Dotted duckweed has a high rate of vegetative propagation. Propagation can occur via vegetative budding of daughter fronds from two pouches at the base of the frond (Jacono 2002); occasionally the plant reproduces sexually by seed (Jacono 2002).

d. *History of Invasion Success*
   Its irregularity in distribution in the United States suggests multiple introduction sites. Dotted duckweed has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002).

e. *Human-Mediated Transport through Aquatic Pathways*
   This species can potentially be spread by recreational or cargo vessel traffic. Dotted duckweed can be spread by sticking to the sides of boats (Lembi 2009).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Dotted duckweed is a wetland obligate. Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments, such as ponds that receive drainage from farm fields. Its association with trees suggests that leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). The littoral wetlands along Lake Michigan are primarily sandy beaches. This species is known not to tolerate cold temperatures (absolute minimum air temperatures of ≤20°C [−4°F] for extended periods) (Jacono 2002). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Landolt 1986). Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012). There are areas of near-shore emergent herbaceous habitat in tributaries and rivers that would be suitable for the species (unpublished data from USACE).

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable for the dotted duckweed due to the high-energy shoreline of Lake Michigan. It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals (section 5f). Human-mediated dispersal may assist the species in spreading further from the pathway entrance (section 5f) to suitable habitat throughout the GLB. Overall, however, the winter months have been identified in the literature as too cold for the dotted duckweed to establish in portions of the GLB (section 5f). Therefore, the probability of spreading throughout the Great Lakes from the CRCW is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat in the GLB in the form of emergent wetland and littoral habitat. However, it is uncertain whether the climate of the GLB is too cold for this species. Therefore, there is a medium level of uncertainty associated with the species' ability to spread throughout the Great Lakes.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Dotted duckweed is a tiny, free-floating plant that disperses readily (Jacono 2002). It has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002). The species was first recorded in Illinois in 1962 (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
This species has the potential to be spread by recreational or cargo vessel traffic. Duckweed can be spread by sticking to the sides of boats (Lembi 2009). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: Dotted duckweed has a high rate of vegetative propagation (Jacono 2002). Propagation mainly occurs via vegetative budding of daughter fronds from two pouches at the base of the frond; occasionally the plant reproduces sexually by seed (Jacono 2002). Dotted duckweed is not widespread in Illinois (Jacono 2002).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline modifications. However, the dotted duckweed can attach to boats, which could allow it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Dotted duckweed was first documented in Missouri in 1934 and is now well naturalized in the southeastern United States (Jacono 2002). Dotted duckweed has been established in Senachwine Lake in Bureau County, Illinois, since 1986, a distance of less than 161 km (100 mi) from the Brandon Road Lock and Dam. Senachwine Lake is connected to the Illinois River. Populations of this species are overlooked because of its superficial resemblance to native duckweeds (Jacono 2002).
T_{10}: See T_0. If current trends continue, dotted duckweed may disperse closer to pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The distance of the species from the Brandon Road Lock and Dam may depend on the range in the region's temperature (Jacono 2002), which may increase seasonally because of future climate change. Dotted duckweed may disperse closer to the pathway over time if the climate becomes more suitable.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Dotted duckweed is native to Australia and Southeast Asia (Jacono 2002). Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, Jacono (2002) states, "Many duckweeds, including our native Spirodela polyrrhiza, survive climate in cold regions by forming an abundant supply of turions (rootless fronds rich in starch) that sink to the warm bottom to overwinter. The inability of Landoltia punctata to form turions accounts for its absence in the northern and Midwestern United States. Its fronds are sensitive to severe frosts and plants are reportedly limited by absolute minimum temperatures ≤20°C (−4°F)." Jacono (2002) also states that, "The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival."

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future changes in temperature and rainfall related to climate change may affect the suitability of habitat and the northward expansion of this species. If temperatures warm, dotted duckweed may expand north. However, if winters become more severe, habitat suitability may decrease.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dotted duckweed has been established less than 161 km (100 mi) from the Brandon Road Lock and Dam for 25 years and has not spread north; therefore, the plant is unlikely to move to the pathway entrance in the near term (section 2e). The dotted duckweed is a free-floating plant that must move upstream by natural dispersal or vessel transport to reach the Calumet Harbor pathway entrance (section 2a). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. The winters of the Chicago area may be too cold for the dotted duckweed to survive (section 2f). For these reasons, the probability of dotted duckweed reaching the Brandon Road Lock and Dam is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Dotted duckweed has spread across the Southeast over several decades (sections 2a, 2e). If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. Therefore, 50 years may be sufficient time to expand to the pathway, raising the probability of arrival to medium. Future climate change may promote or inhibit the spread of this species to the Brandon Road Lock and Dam.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the dotted duckweed to travel the distance to arrive at the pathway, and the cold temperature of the region may limit survival. Therefore, uncertainty of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Dotted duckweed has been recorded less than 161 km (100 mi) from the Brandon Road Lock and Dam. Populations of the species are often overlooked because of its superficial resemblance to native duckweeds (Jacono 2002); therefore, it may be closer than currently known. If it is closer than currently described, 25 years may be enough time to reach the Brandon Road Lock and Dam. Therefore, uncertainty of arrival is medium for this time step.
T_{50}: See T_0. Fifty years may be sufficient time to expand to the pathway. However, the future impacts of climate change on the distribution of this species and its ability to adapt to climate change are not documented. This raises the uncertainty of arrival to high.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by vessel traffic. Duckweed can stick to the sides of boats (Lembi 2009), but it can dry out within a few hours (Landolt 1986). Although there is little commercial river traffic to Calumet Harbor, there is heavy commercial vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the Calumet Harbor is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Dotted duckweed is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). The plant is associated with trees, suggesting leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). Sediments in the CAWS can range from bedrock to soft sediment but are typically inorganic silt (LimnoTech 2010). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present. Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present. The habitat in the CAWS consists of mostly (about 75%) manmade waterways designed to be straight and deep. The Calumet Sag Channel and the CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River with silt, sand, cobble or bedrock substrate, little canopy cover, and no natural floodplain. Calumet Harbor is lined by vertical walls of steel and concrete. Although submerged aquatic plants are not common in the CAWS, they have been documented to exist in the CSSC (LimnoTech 2010). Dotted duckweed is typically found in waters less than 2 m (6.6 ft) in depth; the maximum depth in the CAWS is about 10 m (32.8 ft); and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Therefore, water depth in the CAWS may be suitable only on a shallow channel shoreline.

T_{10}: See T_0.

T_{25}: See T_0. The dotted duckweed thrives in high-nutrient water (section 3d). Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012), reducing not only pollutants but also nutrient levels, and this could in turn affect habitat suitability of the CAWS for the dotted duckweed.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Much of the CAWS is lined with concrete and steel banks, and the sediment is not nutrient rich with organic matter (section 2d). There is some suitable habitat, primarily in the Calumet Sag Channel. If the species establishes near the Calumet Harbor, it could float (section 2a) into the Great Lakes when the T.J. O'Brien Lock and Dam is open (section 2c). However, the limited suitable habitat in the CSSC and Calumet Sag Channel, the absence of habitat in Calumet Harbor, and the need for upstream dispersal are likely to slow spread. Short-distance vessel transport is likely to be the primary mechanism for upstream passage

to Calumet Harbor. For these reasons, the dotted duckweed has a low probability of passing through the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0. Future water quality improvements may affect the suitability of the CAWS for the dotted duckweed (section 2d). However, the lack of suitable habitat and limited upstream dispersal mechanisms will continue to hinder movement to the Calumet Harbor. Therefore, the future probability of passage remains low.
T_{50}: See T_{25}. Fifty years may be sufficient time to pass through the pathway, raising the probability of passage to medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: It is uncertain whether an adequate upstream transport mechanism exists. The winter months in the CAWS are likely too cold for the dotted duckweed to survive and establish. The CAWS may be unsuitable due to its poor sediment quality. The lack of suitable habitat in the CAWS is documented. Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. The future water quality of the CAWS and its effects on dotted duckweed passage are uncertain. The potential rate of upstream spread within the CAWS is uncertain for this species, but over 25 years, this species may be able to spread upstream through the CAWS. Therefore, uncertainty associated with passage during this time step is medium.
T_{50}: See T_{25}.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments, such as ponds that receive drainage from farm fields.

Calumet Harbor is lined by vertical walls, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap. There is little emergent wetland habitat near the shoreline of Lake Michigan between Calumet Harbor and the Indiana border (unpublished data from USACE) because of human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the dotted duckweed to colonize. There are small tributaries and large rivers in Indiana that have emergent wetlands. Illinois Beach State Park, located approximately 96 km (60 mi) north of Calumet Harbor, contains emergent wetlands near the shoreline of Lake Michigan.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal* The dotted duckweed invades new locations via floodwaters transport. Overall, the ability of the dotted duckweed to reach marsh habitat after exiting the Calumet Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow dotted duckweed to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Dotted duckweed passing from the Calumet Harbor into Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the dotted duckweed seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but dotted duckweed could colonize tributaries if transported upriver by wind-driven currents.

Evidence for Probability Rating

Vessel traffic from the Calumet Harbor could potentially assist in the dispersal of dotted duckweed. However, the dotted duckweed is not likely to colonize in Calumet Harbor, making vessel transport less likely (section 4b). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan, the closest of which are found in Indiana (section 4a). Dotted duckweed is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of Calumet Harbor or the sandy, high-energy shoreline of Lake Michigan (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting Calumet Harbor is considered to be low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport dotted duckweed is uncertain. It is uncertain whether the species will be able by drift alone to reach suitable habitat after exiting Calumet Harbor. Therefore, the uncertainty associated with this species colonizing in the GLB from the Calumet Harbor is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Cold temperature may limit establishment of the species in the upper Midwest. The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks) (Landolt 1986). Therefore, the species cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Jacono 2002).

b. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

c. *Fecundity*
Dotted duckweed has a high rate of vegetative propagation. Propagation mainly occurs via vegetative budding of daughter fronds from two pouches at the base of the frond; occasionally the plant reproduces sexually by seed (Jacono 2002).

d. *History of Invasion Success*
Its irregularity in distribution in the United States suggests multiple introduction sites. Dotted duckweed has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002).

e. *Human-Mediated Transport through Aquatic Pathways*
Dotted duckweed can potentially be spread by recreational or cargo vessel traffic. The species can be spread by sticking to the sides of boats (Lembi 2009).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Dotted duckweed is a wetland obligate. Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). It is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments, such as ponds that receive drainage from farm fields. Its association with trees suggests that leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can

be a major source of nutrients (Lembi 2009). The littoral wetlands along Lake Michigan are primarily sandy beaches. This species is known not to tolerate cold temperatures (absolute minimum air temperatures of ≤20°C [−4°F] for extended periods) (Jacono 2002). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Landolt 1986).

Except for large bays, macrophytes are typically not found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012). There are areas of near-shore emergent herbaceous habitat in tributaries and rivers that would be suitable for the species (unpublished data from USACE).

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable for the dotted duckweed due to the high-energy shoreline of Lake Michigan. It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals (section 5f). Human-mediated dispersal may assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. Overall, however, the winter months have been identified in the literature as too cold for the dotted duckweed to establish in portions of the GLB (section 5f). Therefore, the probability of spreading throughout the Great Lakes from Calumet Harbor is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat in the GLB in the form of emergent wetland and littoral habitat. However, it is uncertain whether the climate of the GLB is too cold for this species.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way tocharacterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002). It has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002). The species was first recorded in Illinois in 1962 (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
The species can potentially be spread by recreational or cargo vessel traffic. Duckweed can be spread by sticking to the sides of boats (Lembi 2009). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: Dotted duckweed has a high rate of vegetative propagation (Jacono 2002). Propagation mainly occurs via vegetative budding of daughter fronds from two pouches at the base of the frond (Jacono 2002); occasionally the plant reproduces sexually by seed (Jacono 2002). This species is not widespread in Illinois (Jacono 2002).
T_{10}: See T_0. There are no predicted changes to reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline

modifications. However, the dotted duckweed can attach to boats, allowing it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Dotted duckweed was first documented in Missouri in 1934 and is now well naturalized in the southeastern United States (Jacono 2002). Dotted duckweed has been established less than 161 km (100 mi) from the Brandon Road Lock and Dam in Senachwine Lake in Bureau County, Illinois, since 1986. Senachwine Lake is connected to the Illinois River. Populations of this species are overlooked because of its superficial resemblance to native duckweeds (Jacono 2002).
T_{10}: See T_0. If current trends continue, dotted duckweed may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The distance of the species from the Brandon Road Lock and Dam may depend on the range in the region's temperature (Jacono 2002), which may increase seasonally because of future climate change. Dotted duckweed may disperse closer to the pathway over time if the climate becomes more suitable.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Dotted duckweed is native to Australia and Southeast Asia (Jacono 2002). Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, Jacono (2002) states, "Many duckweeds, including our native Spirodela polyrrhiza, survive climate in cold regions by forming an abundant supply of turions (rootless fronds rich in starch) that sink to the warm bottom to overwinter. The inability of Landoltia punctata to form turions accounts for its absence in the northern and Midwestern United States. Its fronds are sensitive to severe frosts and plants are reportedly limited by absolute minimum temperatures ≤20°C (−4°F)." Jacono (2002) also states that, "The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival."
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future changes in temperature and rainfall related to climate change may affect the suitability of habitat and the northward expansion of this species. If temperatures warm, dotted duckweed may expand north. However, if winters become more severe, habitat suitability may decrease.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dotted duckweed has been established less than 161 km (100 mi) from the Brandon Road Lock and Dam for 25 years and has not spread north; therefore, the plant is unlikely to move to the pathway entrance in the near term (section 2e). The dotted duckweed is a free-floating plant that must move upstream by natural dispersal or vessel transport to reach the Indiana Harbor pathway entrance (section 2a). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. The winters of the Chicago area may be too cold for the dotted duckweed to survive (section 2f). For these reasons, the probability of dotted duckweed reaching the Brandon Road Lock and Dam is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Dotted duckweed has spread across the Southeast over several decades (sections 2a, 2e). If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. Therefore, 50 years may be sufficient time to expand to the pathway, raising the probability of arrival to medium. Future climate change may promote or inhibit the spread of this species to the Brandon Road Lock and Dam.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the dotted duckweed to travel the distance to arrive at the pathway, and the cold temperature of the region may limit survival. Therefore, uncertainty of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Dotted duckweed has been recorded less than 161 km (100 mi) from the Brandon Road Lock and Dam. Populations of the species are overlooked because of its superficial resemblance to native duckweeds (Jacono 2002); therefore, it may be closer than currently known. If it is closer than currently described, 25 years may be enough time to reach the Brandon Road Lock and Dam. Therefore, uncertainty of arrival is medium for this time step.
T_{50}: See T_0. Fifty years may be sufficient time to expand to the pathway. However, the future impacts of climate change on the distribution of this species and its ability to adapt to climate change are not documented. This raises the uncertainty of arrival to high.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by vessel traffic. Duckweed can stick to the sides of boats (Lembi 2009), but it can dry out within a few hours (Landolt 1986). There is no cargo vessel traffic to Indiana Harbor originating within the MRB. Vessels could transport the dotted duckweed as far as the Grand Calumet River (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical and Climatological)*
T_0: Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at Indiana Harbor is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Dotted duckweed is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). The plant is associated with trees, suggesting leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). Sediments in the CAWS can range from bedrock to soft sediment but are typically inorganic silt (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways designed to be straight and deep. The Calumet Sag Channel and the CSSC have banks of bedrock and steel sheet piling with inorganic silt, sand, cobble or bedrock substrate, little canopy cover, and no natural floodplain. Although submerged aquatic plants are not common in the CAWS, they have been documented to exist in the CSSC (LimnoTech 2010). The Grand Calumet River can be shallow, less than 0.3 m (1 ft) in depth, in areas of the west branch near the state line (LimnoTech 2010). Conditions at the Indiana Harbor are highly industrialized; concrete and steel vertical walls line the harbor. The east branch of the Grand Calumet River has heavily vegetated banks and associated emergent marsh habitat that may be suitable, but biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments consist of primarily cobble, bedrock or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water in the east branch of the Grand

Calumet River can flow east or west depending on the water level in Lake Michigan. Dotted duckweed is typically found in waters less than 2 m (6.6 ft) in depth; the maximum depth in the CAWS is about 10 m (32.8 ft); and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Therefore, water depth in the CAWS may be suitable only on a shallow channel shoreline.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Short-distance vessel transport is likely to be the primary mechanism for upstream passage through portions of the CAWS with vessel traffic (section 3b). There may be some suitable habitat, primarily in the east branch of the Grand Calumet River and the Calumet Sag Channel, but this species is unlikely to spread throughout the CAWS because of habitat limitation and the need for upstream movement through the CAWS channel. The banks of Indiana Harbor are primarily vertical wall (section 3d). This species is not likely to survive in near-shore nonvegetated areas or near potentially manmade structures, like harbors consisting of stone blocks and steel sheet piling (section 3d). Therefore, dotted duckweed is not likely to establish in Indiana Harbor and has a low probability of passage.
T_{10}: See T_0.
T_{25}: See T_0. Future water quality improvements may affect the suitability of the CAWS for the dotted duckweed (section 3d). However, the lack of suitable habitat and limited upstream dispersal mechanisms will continue to hinder movement to Indiana Harbor. Therefore, the future probability of passage remains low.
T_{50}: See T_{25}. Fifty years may be sufficient time to pass through the pathway, raising the probability of passage to medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: It is uncertain whether an adequate upstream transport mechanism exists. The winter months in the CAWS are likely too cold for the dotted duckweed to survive and establish. The CAWS may be unsuitable due to its poor sediment quality. Another uncertainty is that the Grand Calumet River can flow east or west, increasing or decreasing the rate of spread through the pathway. The lack of suitable habitat in the CAWS is documented. Therefore, there is a low level of uncertainty regarding this species passing through this pathway.

T_{10}: See T_0.
T_{25}: See T_0. The future water quality of the CAWS and its effects on dotted duckweed passage are uncertain. The potential rate of upstream spread within the CAWS is uncertain for this species, but over 25 years this species may be able to spread upstream through the CAWS. Therefore, uncertainty associated with passage during this time step is medium.
T_{50}: See T_{25}.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). It is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments, such as ponds that receive drainage from farm fields.

There are no emergent wetlands in Indiana Harbor, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap (unpublished data from USACE). East of Indiana harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the dotted duckweed to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The dotted duckweed invades new locations via floodwaters transport. Overall, the ability of the dotted duckweed to reach marsh habitat after exiting Indiana Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow dotted duckweed to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Dotted duckweed passing from Indiana Harbor into Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the dotted duckweed seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake

Michigan, but dotted duckweed could colonize tributaries if transported upriver by wind-driven currents.

Evidence for Probability Rating

Vessel traffic from Indiana Harbor could potentially assist in the dispersal of dotted duckweed. However, the dotted duckweed is not likely to colonize in Indiana Harbor, making vessel transport less likely (section 4b). Dotted duckweed is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of Indiana Harbor or the sandy, high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan, the closest of which are found in Indiana (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting Indiana Harbor is considered to be low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport dotted duckweed is uncertain. It is uncertain whether the species will be able by drift alone to reach suitable habitat after exiting Indiana Harbor. Therefore, the uncertainty associated with this species colonizing in the GLB from Indiana Harbor is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Cold temperature may limit the establishment of dotted duckweed in the upper Midwest. The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks) (Landolt 1986). Therefore, the species cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Jacono 2002).

b. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

c. *Fecundity*
The species has a high rate of vegetative propagation. Propagation mainly occurs via the vegetative budding of daughter fronds from two pouches at the base of the frond (Jacono 2002); occasionally the species reproduces sexually by seed (Jacono 2002).

d. *History of Invasion Success*
Its irregularity in distribution in the United States suggests multiple introduction sites. Dotted duckweed has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002).

e. *Human-Mediated Transport through Aquatic Pathways*
The species can potentially be spread by recreational or cargo vessel traffic. Dotted duckweed can be spread by sticking to the sides of boats (Lembi 2009).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Dotted duckweed is considered a wetland obligate. Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). It is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments, such as ponds that receive drainage from farm fields. Its association with trees suggests that leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). The littoral wetlands along Lake Michigan are primarily sandy beaches. This species is known not to tolerate cold temperatures (absolute minimum air temperatures of ≤20°C (−4°F) for extended periods) (Jacono 2002). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Landolt 1986).

Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012). There are areas of near-shore emergent herbaceous habitat in tributaries and rivers that would be suitable for the species (unpublished data from USACE).

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan. It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals (section 5f). Human-mediated dispersal may assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. Overall, however, the winter months have been identified in the literature as too cold for the dotted duckweed to establish in portions of the GLB (section 5f). Therefore, the probability of spreading throughout the Great Lakes from Indiana Harbor is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat in the GLB in the form of emergent wetland and littoral habitat. However, it is uncertain whether the climate of the GLB is too cold for this species. For these reasons, there is a medium level of uncertainty associated with the probability of spread by the species.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses readily (Jacono 2002). It has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002). The species was first recorded in Illinois in 1962 (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
Dotted duckweed can potentially be spread by recreational or cargo vessel traffic. Duckweed can be spread by sticking to the sides of boats (Lembi 2009). There is heavy vessel traffic between the lower MRB and the Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: The species has a high rate of vegetative propagation. Propagation of this species mainly occurs via vegetative budding of daughter fronds from two pouches at the base of the frond (Jacono 2002); occasionally dotted duckweed reproduces sexually by seed (Jacono 2002). The species is not widespread in Illinois (Jacono 2002).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The three Illinois River locks located south of the Brandon Road Lock and Dam have the potential to act as temporary barriers because of the associated shoreline modifications. However, the dotted duckweed can attach to boats, allowing it to transfer through the locks.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Dotted duckweed was first documented in Missouri in 1934 and is now well naturalized in the southeastern United States (Jacono 2002). Dotted duckweed has been established less than 161 km (100 mi) from the Brandon Road Lock and Dam in Senachwine Lake in Bureau County, Illinois, since 1986. Senachwine Lake is connected to the Illinois River. Populations of this species are often overlooked because of its superficial resemblance to native duckweeds (Jacono 2002).
T_{10}: See T_0. If current trends continue, dotted duckweed may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The distance of the species from the Brandon Road Lock and Dam may depend on the range in the region’s temperature (Jacono 2002), which may increase seasonally because of future climate change. Dotted duckweed may disperse closer to the pathway over time if the climate becomes more suitable.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Dotted duckweed is native to Australia and Southeast Asia (Jacono 2002). Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). This species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Suitable emergent wetland habitat is present in the vicinity of the Brandon Road Lock and Dam. However, Jacono (2002) states, "Many duckweeds, including our native Spirodela polyrrhiza, survive climate in cold regions by forming an abundant supply of turions (rootless fronds rich in starch) that sink to the warm bottom to overwinter. The inability of Landoltia punctata to form turions accounts for its absence in the northern and Midwestern United States. Its fronds are sensitive to severe frosts and plants are reportedly limited by absolute minimum temperatures ≤20°C (−4°F)." Jacono (2002) also states that, "The seeds of dotted duckweed are known not to tolerate cold temperatures (~ 0°C [32°F] for several weeks). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival."

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future changes in temperature and rainfall related to climate change may affect the suitability of habitat and the northward expansion of this species. If temperatures warm, dotted duckweed may expand north. However, if winters become more severe, habitat suitability may decrease.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dotted duckweed has been established less than 161 km (100 mi) from the Brandon Road Lock and Dam for 25 years and has not spread north; therefore, the plant is unlikely to move to the pathway entrance in the near term (section 2e). The dotted duckweed is a free-floating plant that must move upstream by natural dispersal or vessel transport to reach the BSBH pathway entrance (section 2a). The Mississippi River is poorly connected to the floodplain in many areas, and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward the Brandon Road Lock and Dam may be slow. In addition, the winters of the Chicago area may be too cold for the dotted duckweed to survive (section 2f). For these reasons, the probability of dotted duckweed reaching the Brandon Road Lock and Dam is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See $T_{0.}$ Dotted duckweed has spread across the Southeast over several decades (sections 2a, 2e). If current trends continue, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway. Future climate change may promote or inhibit the spread of this species to the Brandon Road Lock and Dam. Therefore, 50 years may be sufficient time for the species to expand to the pathway, raising the probability of arrival to medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the dotted duckweed to travel the distance to arrive at the pathway, and the cold temperature of the region may limit survival. Therefore, uncertainty of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Dotted duckweed has been recorded less than 161 km (100 mi) from the Brandon Road Lock and Dam. Populations of this species are overlooked because of its superficial resemblance to native duckweeds (Jacono 2002); therefore, it may be closer than currently known. If it is closer than currently described, 25 years may be enough time for the species to reach the Brandon Road Lock and Dam. Therefore, uncertainty of arrival is medium for this time step.
T_{50}: See T_0. Fifty years may be sufficient time for the species to expand to the pathway. However, the future impacts of climate change on the distribution of this species and its ability to adapt to climate change are not documented. This raises the uncertainty of arrival to high.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that disperses easily (Jacono 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by vessel traffic. Duckweed can stick to the sides of boats (Lembi 2009), but it can dry out within a few hours (Landolt 1986). There is no cargo vessel traffic to the BSBH (USACE 2011a). Vessels could transport the dotted duckweed as far as the Little Calumet River. Therefore, natural dispersal by floating upstream through the south branch of the Little Calumet River and Burns Ditch, approximately 64 km (40 mi), would be required to arrive at the BSBH. There is some small-boat recreational use in the Little Calumet River.

c. *Existing Physical Human/Natural Barriers*

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the BSBH is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Dotted duckweed is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). The plant is associated with trees, suggesting leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). Sediments in the CAWS can range from bedrock to soft sediment but are typically inorganic silt (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways designed to be straight and deep. The Calumet Sag Channel and the CSSC have banks of bedrock and steel sheet piling with inorganic silt, sand, cobble or bedrock substrate, little canopy cover, and no natural floodplain. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). The Little Calumet River can flow east or west, depending on water levels in Lake Michigan and the CAWS. The BSBH is lined by vertical walls and sandy vegetated banks with riprap. Although submerged aquatic plants are not common in the CAWS, they have been documented to exist in the CSSC (LimnoTech 2010). Dotted duckweed is typically found in waters less than 2 m (6.6 ft) in depth. The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically about 5 m (16.4 ft). Therefore, water depth in the CAWS may be suitable only on a shallow channel shoreline.

T_{10}: See T_0.

T_{25}: See T_0. The dotted duckweed thrives in high-nutrient water (section 3d). Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012), reducing not only pollutants but also nutrient levels, and this could in turn affect habitat suitability of the CAWS for the dotted duckweed.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Short-distance vessel transport is likely to be the primary mechanism for upstream passage through portions of the CAWS with vessel traffic. The cold winter temperature of the CAWS may be unsuitable for the dotted duckweed to survive (section 3d). The Lockport Lock and Dam and the Brandon Road Lock and Dam may slow the northward movement of dotted duckweed through the CAWS (section 3c). There is some suitable habitat, primarily in the Calumet Sag Channel, but this species is unlikely to spread throughout the CAWS because of habitat limitation and the need for upstream movement through the CAWS channel. The banks of the BSBH are primarily vertical wall (section 3e). This species is not likely to survive in near-shore nonvegetated areas or near potentially manmade structures, like harbors consisting of stone blocks and steel sheet piling (section 3e). Therefore, dotted duckweed is not likely to establish in the BSBH and has a low probability of passage.
T_{10}: See T_0.
T_{25}: See T_0. Future water quality improvements may affect the suitability of the CAWS for the dotted duckweed (section 3d). However, the lack of suitable habitat and limited upstream dispersal mechanisms will continue to hinder movement to the BSBH. Therefore, the future probability of passage remains low.
T_{50}: See T_{25}. Fifty years may be sufficient time to pass through the pathway, raising the probability of passage to medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: It is uncertain whether an adequate upstream transport mechanism exists. The winter months in the CAWS are likely too cold for the dotted duckweed to survive and establish. The CAWS may be unsuitable due to its poor sediment quality. Another uncertainty is that the south branch of the Little Calumet River can flow east or west, increasing or decreasing the rate of spread through the pathway. The lack of suitable habitat in the CAWS is documented. Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. The future water quality of the CAWS and its effects on dotted duckweed passage are uncertain. The potential rate of upstream spread within the CAWS is uncertain for this species, but over 25 years this species may be able to spread upstream through the CAWS. Therefore, the uncertainty associated with passage during this time step is medium.
T_{50}: See T_{25}.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 2002). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so it is typically found in nutrient-rich environments, such as ponds that receive drainage from farm fields.

   There are emergent wetlands south of the BSBH, but it is not known whether they are hydrologically connected to the CAWS. The BSBH itself contains no emergent wetland habitat, and the adjacent near-shore areas of Lake Michigan are sandy beach and riprap (unpublished data from USACE). Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan. There are scattered emergent wetlands near Lake Michigan north of the BSBH (unpublished data from USACE), but they are likely to be too far inland from Lake Michigan for the dotted duckweed to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The dotted duckweed invades new locations via floodwaters. Overall, the ability of the dotted duckweed to reach marsh habitat after exiting the BSBH is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline of Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow dotted duckweed to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Dotted duckweed passing from the BSBH into Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the dotted duckweed seeds or fragments to Indiana, where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but dotted duckweed could colonize tributaries if transported upriver by wind-driven currents. The closest large tributary is the St. Joseph River located more than 80.5 km (50 mi) from the BSBH. There are smaller tributaries that are closer and that may be suitable.

Evidence for Probability Rating

Recreational boat traffic from the BSBH could potentially assist in the dispersal of dotted duckweed. However, dotted duckweed is not likely to colonize in the BSBH, making vessel transport less likely (section 4b). Dotted duckweed is also not likely to grow on the nonvegetated shoreline or rocky shoals that are in the vicinity of the BSBH or the sandy, high-energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan (section 4a). However, these areas are not located near the BSBH (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting the BSBH is considered to be low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The distance that boats could transport dotted duckweed is uncertain. It is uncertain whether the species will be able by drift alone to reach suitable habitat after exiting the BSBH. Therefore, the uncertainty associated with this species colonizing in the GLB is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Cold temperatures may limit the establishment of dotted duckweed in the upper Midwest. The seeds of dotted duckweed are known not to tolerate cold temperatures (~0°C [32°F] for several weeks) (Landolt 1986). Therefore, the species cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Jacono 2002).

b. *Type of Mobility/Invasion Speed*
The dotted duckweed is a tiny, free-floating plant that is disperses easily (Jacono 2002).

c. *Fecundity*
This species has a high rate of vegetative propagation. Propagation mainly occurs via the vegetative budding of daughter fronds from two pouches at the base of the frond (Jacono 2002); occasionally dotted duckweed reproduces sexually by seed (Jacono 2002).

d. *History of Invasion Success*
Its irregularity in distribution in the United States suggests multiple introduction sites. Dotted duckweed has spread through much of the United States since first being recorded in Missouri in the 1930s (Jacono 2002).

e. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread of dotted duckweed via recreational or cargo vessel traffic. Dotted duckweed can be spread by sticking to the sides of boats (Lembi 2009).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

It is a wetland obligate. Dotted duckweed thrives in nutrient-rich waters and prefers slow-moving or stagnant ponds (Jacono 20*02*). The species is frequently found in stagnant small ponds or ditches rich in organic matter or near sewer outlets (Hillman 1961). Duckweed is more common in ponds located in or at the edge of woods than in ponds in open areas. The plant requires a lot of nutrients (nitrogen and phosphorus) to grow, so typically it is found in nutrient-rich environments, such as ponds that receive drainage from farm fields. Its association with trees suggests that leaf litter may play an important role in providing nutrients. The bottom sediments of infested ponds are often very black and mucky. This organically rich material also can be a major source of nutrients (Lembi 2009). The littoral wetlands along Lake Michigan are primarily sandy beaches. This species is known not to tolerate cold temperatures (absolute minimum air temperatures of ≤20°C [−4° F] for extended periods) (Jacono 2011). Therefore, dotted duckweed cannot be expected to overwinter by seed in regions of the United States that are too cold for vegetative survival (Landolt 1986). Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012). There are areas of near-shore emergent herbaceous habitat in tributaries and rivers that would be suitable for the species (unpublished data from USACE).

Evidence for Probability Rating

The abundant beach habitat in the GLB is likely unsuitable due to the high-energy shoreline of Lake Michigan. It is not likely to grow near shore on nonvegetated areas like a harbor or rocky shoals (section 5f). Human-mediated dispersal may assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. Overall, however, the winter months have been identified in the literature as too cold for dotted duckweed to establish in portions of the GLB (section 5f). Therefore, the probability of spreading throughout the Great Lakes from the BSBH is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat in the GLB in the form of emergent wetland and littoral habitat. However, it is uncertain whether the climate of the GLB is too cold for this species. Therefore, there is a medium degree of uncertainty regarding the spread of the species in the GLB.

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E.1.1.3 Marsh Dewflower - *Murdannia keisak*

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. Seeds are dispersed by wildlife. This species can also spread by root fragments during flood events (Swearingen et al. 2010). Expansion in the southeastern United States has occurred slowly over many decades (Dunn & Sharitz 1990b).

b. *Human-Mediated Transport through Aquatic Pathways*
This species was introduced by accident in agriculture (Dunn & Sharitz 1990b). There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spread. There is heavy vessel traffic between the lower MRB and Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: Marsh dewflower typically produces 9000–70,000 seeds per m^2, can also reproduce vegetatively (Swearingen et al. 2010), and is autogamous (Dunn & Sharitz 1991).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The species is currently located over 805 km (500 mi) from the Brandon Road Lock and Dam. Habitat maps show the species in Tennessee in 1993, likely coming from the east, and an isolated established population in Arkansas in 1978 (Howard 2011).
T_{10}: See T_0. The species may expand its range closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) along with its U.S. distribution (southeastern United States and Pacific Northwest) suggest a wide climatological tolerance. Habitats of this species include forested emergent and shrub scrub wetlands (Bason 2004). Marsh dewflower is found along ditches, pond and stream edges, freshwater marshes, freshwater tidal marshes, large river deltas, and lakes (Dunn & Sharitz 1990b; NatureServe 2010). Stream order and gradient in the MRB may be suitable in shallow, slower areas. Marsh dewflower has been known to move up rivers (Dunn & Sharitz 1990b). Marsh habitat is highly fragmented in the MRB, and many rivers have been channelized and are not well connected to their floodplain.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Marsh dewflower was reported in Louisiana in the 1920s and has not spread very far up the Mississippi River in the approximately 90 years since that time (Dunn & Sharitz 1990b), so it may not be likely to move to the GLB in the near term (section 2e). Flood-mediated transport would likely act to transport plant fragments downstream and away from the CAWS. Suitable climatological conditions and habitat exists from the current location of this species to Brandon Road Lock and Dam (section 2f). The Mississippi River is poorly connected to the floodplain in many areas and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward Brandon Road Lock and Dam may be slow. Overall, the probability of arrival is low for this time step.
T_{10}: See T_0. If the historic rate of spread continues, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway, but would likely still be well distant of the dam and locks.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Marsh dewflower requires upstream movement by vessels to reach the pathway. It has not spread to the Illinois River in the several decades that it has been present in the lower MRB (sections 2a, 2e). Therefore, 50 years may not be sufficient time to expand to the pathway. Thus, the probability of arrival remains low.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the marsh dewflower to travel the far distance (>805 km; 500 mi) required to arrive at the pathway; therefore, the uncertainty for arrival is low. The temperature range for the species to survive is not documented. The potential for human-mediated transport is not well characterized.
T_{10}: See T_0. It is not documented how far north the species will be able to disperse or if the species will be able to survive the region's conditions. However, it has not spread very far north in decades.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be sufficient time for the species to expand to the pathway. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species is described as having vigorous growth and high seed number. Its vigorous growth enables it to out-compete native plants by forming dense mats. It can spread by root fragments during flood events (Swearingen et al. 2010). Expansion in the Southeast has occurred over many decades (Dunn & Sharitz 1990b).

b. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spread. There is no cargo vessel traffic to the WPS (USACE 2011a) from Brandon Road Lock and Dam. Vessels could transport the marsh dewflower as far as the Chicago River. There is small boat recreational use in the North Shore Channel.

c. *Existing Physical Human/Natural Barriers*
T_0: The sluice gate at the WPS separates the CAWS from Lake Michigan. However, occasionally the sluice gates are opened and flow into Lake Michigan occurs.
T_{10}: See T_0. No change in sluice gate operations at the WPS is expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Marsh dewflower prefers littoral, herbaceous marsh, saturated conditions. Open water is not likely suitable habitat (Dunn & Sharitz 1991). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas, and there is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). The marsh dewflower is found in water depths less than 1.5 m (4.9 ft) (Jacono 2011). There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. This species is not likely to survive in nearshore non-vegetated areas with manmade structures, such as harbors, consisting of stone blocks and steel sheet piling. Much of the CSSC has vertical limestone or manmade walls. Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River have vertical walls (LimnoTech 2010). The North Shore Channel contains suitable habitat for the marsh dewflower (unpublished data from USACE). Macrophytes are documented to exist in the North Shore Channel (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in all areas of the CAWS channel, suggesting that the CAWS has relatively little suitable habitat for aquatic macrophytes such as the marsh dewflower (section 3d). Marsh dewflower spreads by root fragments during flood events (Swearingen et al. 2010). However, this is not possible in much of the CAWS because there is no floodplain (section 3d). Vessels could potentially transport this species upstream from Brandon Road Lock and Dam to the Chicago River. However, the vertical walls of the Chicago River would likely keep this species from establishing and moving further upstream to the North Shore Channel and the WPS (section 3d). There is suitable habitat on the banks of the North Shore Channel, and if established near the WPS, marsh dewflower could spread (section 3a) into the Great Lakes when the sluice gate is open (section 3c). Overall, however, this species is unlikely to spread throughout the CAWS due to habitat limitation and the lack of a mechanism for upstream movement through the CAWS channel. Therefore, the marsh dewflower has a low probability of passing through the pathway during this time step.
T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over time, the probability of passage may increase, assuming the marsh dewflower establishes populations in the limited suitable habitat within the CAWS, and then reaches and passes through the WPS. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The species is not likely to survive in open water or on manmade structures. The lack of suitable habitat in the CAWS is documented, although the North Shore Channel may be suitable. The only chance for the species to move upstream into the GLB is to float through the sluice gate when it is open. The uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0.
T_{25}: See T_{10}. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.

T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through the WPS. However, habitat availability and upstream transport uncertainties remain. Therefore the uncertainty associated with passage at this time step is medium.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b). The species prefers littoral, nearshore emergent herbaceous habitats with saturated conditions (Bason 2004; Dunn & Sharitz 1991). There are no emergent wetlands near the WPS (unpublished data from USACE). Wilmette Harbor contains no emergent wetland habitat, and the adjacent nearshore areas of Lake Michigan are sandy beach and riprap. Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan (unpublished data from USACE). Illinois Beach State Park, located approximately 50 km (31 mi) north of WPS, contains emergent wetlands near the shoreline of Lake Michigan. There is little emergent wetland habitat between the WPS and the Indiana border (unpublished data from USACE) due to human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the marsh dewflower to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands. It could form populations in sheltered areas where organic matter has accumulated.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The marsh dewflower invades new locations when floodwaters transport seed, roots and stem fragments. Overall, the ability of the marsh dewflower to reach marsh habitat after exiting Wilmette Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural shoreline along Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow marsh dewflower to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of marsh dewflower passing from the North Shore Channel into the Wilmette Harbor and Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001) so drift to the emergent wetlands in Illinois Beach State Park is unlikely. The counterclockwise flow could carry the marsh dewflower seeds or fragments to Indiana where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but marsh

dewflower could colonize tributaries if transported up-river by flooding or wind-driven currents. However, such tributaries are greater than 96.5 km (60 mi) from the WPS.

Evidence for Probability Rating

Recreational boat traffic from Wilmette Harbor could potentially assist in the dispersal of marsh dewflower. However, the marsh dewflower is not likely to colonize Wilmette Harbor, making vessel transport less likely (section 4b). Marsh dewflower is also not likely to grow on the non-vegetated shoreline or rocky shoals that are in the vicinity of the WPS, or the sandy, higher energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan. However, these areas are primarily found in Indiana and are not located near the WPS (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting the WPS is considered to be low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The ability of boats to transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach suitable habitat after exiting the WPS by drift alone. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. **P(spreads): MEDIUM**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The native distribution of this species (China, Japan, Korea, Tibet [Howard 2011]) suggests a wide climatological tolerance. However, it is unknown whether the plant can survive the low temperatures in the GLB.

b. Type of Mobility/Invasion Speed
Marsh dewflower has been described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). The species has spread over the southeastern U.S. over many decades (NatureServe 2010). Spread occurs during flooding (Swearingen et al. 2010).

c. Fecundity
This species typically produces 9000–70,000 seeds per m^2 (Dunn & Sharitz 1990a), and can reproduce vegetatively (Dunn & Sharitz 1990b).

d. *History of Invasion Success*
   Marsh dewflower can exist at high density where established. The species was reported in Louisiana in the 1920s (Dunn & Sharitz 1990b), but has not spread very far north since that time (about 90 years).

e. *Human-Mediated Transport through Aquatic Pathways*
   Spread can potentially occur by recreational vessel traffic, although this is not cited in the literature as a means of spread.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The marsh dewflower is a wetland obligate. The marsh dewflower prefers slow-moving water in marshy areas. The abundant beach habitat of Lake Michigan is likely unsuitable due to the sandy sediments and wave action. Except for large bays, there are few aquatic macrophytes on the shore of Lake Michigan (MTRI 2012), so it is probably not a suitable habitat. The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b) and saturated littoral, emergent, and shrub scrub wetlands (Bason 2004; Dunn & Sharitz 1991). There are suitable emergent marsh and littoral habitats in the GLB in floodplain areas (unpublished data from USACE).

Evidence for Probability Rating

The marsh dewflower has a high seed production (section 5c), but a historically low dispersal rate in the lower MRB, according to literature (section 5d). The abundant beach habitat in the GLB is likely unsuitable, as are the high-energy shoreline areas of Lake Michigan. It is not likely to grow near shore on non-vegetated areas such as a harbor or rocky shoals. Once it colonizes in the GLB, this species could spread because suitable wetland habitat is present inland of the Lake Michigan shoreline and in tributaries and rivers (section 5f). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland and littoral habitat. However, there is uncertainty associated with the probability of spread mechanisms via aquatic pathways. Assuming initial colonization occurs, the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species is described as having vigorous growth and high seed number (Swearingen et al. 2010; Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. Seeds are dispersed by wildlife. This species can also spread by root fragments during flood events (Swearingen et al. 2010). Expansion in the southeastern United States has occurred slowly over many decades (Dunn & Sharitz 1990b).

b. *Human-Mediated Transport through Aquatic Pathways*
The species was introduced by accident in agriculture (Dunn & Sharitz 1990b). There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spread. There is heavy-vessel traffic between the lower MRB and Brandon Road Lock and Dam.

c. *Current Abundance and Reproductive Capacity*
T_0: Marsh dewflower typically produces 9000–70,000 seeds per m^2, can reproduce vegetatively (Dunn & Sharitz 1990b), and is also autogamous (Dunn & Sharitz 1991).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The marsh dewflower is currently located over 805 km (500 mi) from the Brandon Road Lock and Dam. Habitat maps show the species in Tennessee in 1993, likely dispersing from the east, and an isolated established population in Arkansas in 1978 (Howard 2011).
T_{10}: See T_0. The species may expand its range closer to the pathway over time.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) along with its U.S. distribution (southeastern United States and Pacific Northwest [NatureServe 2010]) suggests a wide climatological tolerance. The habitat for this species includes forested, emergent, and shrub scrub wetlands (Bason 2004); marsh dewflower is also found along pond and stream edges, freshwater marshes, freshwater tidal marshes, large river deltas, and lakes (Dunn & Sharitz 1990b; NatureServe 2010). Stream order and gradient in the MRB may be suitable in shallow, slower areas. Marsh dewflower has been known to move up rivers (Dunn & Sharitz 1990b). Marsh habitat is highly fragmented in the MRB, and many rivers have been channelized and are not well connected to their floodplain.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Marsh dewflower was reported in Louisiana in the 1920s and has not spread very far up the Mississippi River in the approximately 90 years since that time (Dunn & Sharitz 1990b), so the species may not be likely to move to the GLB in the near term (section 2e). Suitable climatological conditions and habitat exist from the current location of this species to Brandon Road Lock and Dam (section 2f). The species produces a high number of seeds (section 2c) and has a vigorous growth rate when introduced to new areas (section 2a). The Mississippi River is poorly connected to the floodplain in many areas and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward Brandon Road Lock and Dam may be slow. In addition, flood-mediated transport would likely act to transport plant fragments downstream and away from the CAWS. Overall, there is a low probability the species will arrive at the pathway during this time step.
T_{10}: See T_0. If the historic rate of spread continues, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway, but would likely still be well distant of the dam and locks.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Marsh dewflower requires upstream movement by vessels to reach the pathway. It has not spread to the Illinois River in the several decades that it has been present in the lower MRB (sections 2a, 2e). Thus, 50 years may not be sufficient time to expand to the pathway. Therefore, the probability of arrival remains low.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the marsh dewflower to travel the far distance (>805 km; 500 mi) required to arrive at the pathway; therefore, the uncertainty for arrival is low. The temperature range for the species to survive is not known. The potential for human-mediated transport is not well characterized.
T_{10}: See T_0. It is not documented how far north the species will be able to disperse or if the species will be able to survive the region's conditions. However, it has not spread very far north in decades.
T_{25}: See T_{10}.
T_{50}: See $T_{10.}$ Fifty years may be sufficient time for the species to expand to the pathway. The impacts of future climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species is described as having vigorous growth and high seed number (Swearingen et al. 2010; Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. It can spread by root fragments during flood events (Swearingen et al. 2010). The species' expansion in the Southeast has occurred over many decades (Dunn & Sharitz 1990b).

b. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spread. There is direct vessel traffic between Brandon Road Lock and Dam and the CRCW (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Marsh dewflower prefers littoral, herbaceous marsh, saturated conditions. Open water is not likely suitable habitat (Dunn & Sharitz 1991). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas, and there is very low aquatic macrophyte cover in all sections of the CAWS (LimnoTech 2010). The marsh dewflower is found in water depths less than 1.5 m (4.9 ft) (Jacono 2011). There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. This species is not likely to survive in areas of nearshore non-vegetated potentially manmade structures, such as harbors, consisting of stone blocks and steel sheet piling. Much of the CSSC consists of vertical limestone or manmade walls. Greater than 90% of the Chicago River and the Lower North Branch of the Chicago River is vertical wall (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in all areas of the CAWS channel, suggesting the CAWS has relatively little suitable habitat for aquatic macrophytes such as the marsh dewflower (section 3d). Marsh dewflower spreads by root fragments during flood events. However, this is not possible in much of the CAWS because there is no floodplain (section 3d). The marsh dewflower is not likely to survive in open water, nearshore non-vegetated areas, or areas with manmade structures such as harbors consisting of stone blocks and steel sheet piling. Therefore, suitable habitat is not present in the Chicago River or the CRCW area (section 3d). Thus, marsh dewflower is not likely to form populations in the CRCW area. Vessel transport was not documented to be an important transport mechanism. Overall, marsh dewflower is unlikely to spread throughout the CAWS due to habitat limitation and the lack of a mechanism for upstream movement through the CAWS channel, and therefore the probability of passage is low for this time step.

T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Over time, the probability of passage may increase, assuming the marsh dewflower forms populations in the limited suitable habitat within the CAWS and reaches and passes through the CRCW. It is not known whether sufficient habitat occurs within the CAWS to support this species reaching the CRCW. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The Chicago River and the CRCW area are confirmed to not contain habitat suitable for the marsh dewflower. It is unlikely for the species' roots to be present in this pathway and more unlikely that it would move upstream through the locks when open. The potential for vessels to transport this species is not documented. The uncertainty of this species passing through this pathway is considered to be low.

T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through the CRCW. However, the habitat availability and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b), preferring slow water. The species prefers littoral, nearshore emergent herbaceous habitats with saturated conditions (Bason 2004; Dunn & Sharitz 1991). There is no marsh habitat or floodplain habitat in the vicinity of the CRCW (unpublished data from USACE), and the adjacent nearshore areas of Lake Michigan are sandy beach and riprap. Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan (unpublished data from USACE. However, there is little emergent wetland habitat between the CRCW and the Indiana border (unpublished data from USACE) due to human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the marsh dewflower to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands. The marsh dewflower could form populations in sheltered areas where organic matter has accumulated.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The marsh dewflower invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the marsh dewflower to reach marsh habitat after exiting CRCW is severely restricted by urbanization, harbors, and the lack of marsh and natural shoreline along Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow marsh dewflower to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of marsh dewflower passing from the CRCW into Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so flow could carry the marsh dewflower seeds or fragments to Indiana where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but marsh dewflower could colonize tributaries if transported upriver by flooding or wind-driven currents. However, such tributaries are greater than 80.5 km (50 mi) from the CRCW.

Evidence for Probability Rating

Recreational boat traffic from the CRCW could potentially assist in the dispersal of marsh dewflower. However, the marsh dewflower is not likely to colonize the vicinity of the CRCW, making vessel transport less likely (section 4b). Marsh dewflower is also not likely to grow on the non-vegetated shoreline or rocky shoals that are in the vicinity of the CRCW, or the sandy, higher energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan. However, these areas are primarily found in Indiana and are not located near the CRCW (section a). Therefore, the probability of this species colonizing in Lake Michigan after exiting the CRCW is considered to be low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The ability of boats to transport seeds or adult fragments is uncertain. It is uncertain if the species will be able to reach to suitable habitat after exiting the CRCW by drift alone. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) suggests a wide climatological tolerance. However, it is unknown if the plant can survive the low temperatures in the upper GLB.

b. *Type of Mobility/Invasion Speed*
Marsh dewflower is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). The expansion of the species' range in the southeastern United States has occurred over many decades (Dunn & Sharitz 1990b).

c. *Fecundity*
The species typically produces 9000–70,000 seeds per m^2 (Dunn & Sharitz 1990a) and can reproduce vegetatively (Dunn & Sharitz 1990b).

d. *History of Invasion Success*
Marsh dewflower can exist at high density where established. This species was reported in Louisiana in the 1920s (Dunn & Sharitz 1990b), but it has not spread very far north since that time (about 90 years).

e. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spread.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The marsh dewflower is a wetland obligate. The marsh dewflower prefers slow-moving water in marshy areas. The abundant beach habitat of Lake Michigan is likely unsuitable, due to the sandy sediments and wave action. Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan (MTRI 2012), so it is probably not a suitable habitat. The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b) and saturated littoral, emergent, and shrub scrub wetlands (Bason 2004; Dunn & Sharitz 1991). There are areas of nearshore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the marsh dewflower could spread (unpublished data from USACE).

Evidence for Probability Rating

The marsh dewflower has a high seed production (section 5c) but a historically low dispersal rate in the lower MRB according to literature (section 5d). The abundant beach habitat in the GLB is likely unsuitable, as are the high-energy shoreline areas of Lake Michigan. It is not likely to grow near shore on non-vegetated areas such as a harbor or rocky shoals. Once it colonizes in the GLB, suitable wetland habitat is present inland of the Lake Michigan shoreline and in tributaries and rivers through which this species could spread (section 5f). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland and littoral habitat. However, there is uncertainty associated with the probability of spread mechanisms via aquatic pathways. Assuming initial colonization occurs, the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. Seeds are dispersed by wildlife. This species can spread by root fragments during flood events (Swearingen et al. 2010). The species' expansion in the southeastern United States has occurred slowly over many decades (Dunn & Sharitz 1990b).

b. *Human-Mediated Transport through Aquatic Pathways*
Marsh dewflower was introduced by accident in agriculture through rice fields (Dunn & Sharitz 1990b). There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spread. There is vessel traffic between Brandon Road Lock and Dam and the lower MRB.

c. *Current Abundance and Reproductive Capacity*
T_0: Marsh dewflower typically produces 9000–70,000 seeds per m^2, can reproduce vegetatively (Dunn & Sharitz 1990b), and is autogamous (Dunn & Sharitz 1991).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Currently, this species is located over 805 km (500 mi) from the Brandon Road Lock and Dam. Habitat maps show the species in Tennessee in 1993, likely dispersing from the east, and an isolated established population in Arkansas in 1978 (Howard 2011).
T_{10}: See T_0. The species may expand its range closer to the pathway over time.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) along with its U.S. distribution (southeastern United States and Pacific Northwest) suggest a wide climatological tolerance. The habitat for this species includes forested, emergent and shrub scrub wetlands (Bason 2004); marsh dewflower is also found along pond and stream edges, freshwater marshes, freshwater tidal marshes, large river deltas, and lakes (Dunn & Sharitz 1990b; NatureServe 2010). Stream order and gradient in the MRB may be suitable in shallow, slower areas. Marsh dewflower has been known to move up rivers (Dunn & Sharitz 1990b). Marsh habitat is highly fragmented in the MRB, and many rivers have been channelized and are not well connected to their floodplains.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species was reported in Louisiana in the 1920s and has not spread very far up the Mississippi River in the approximately 90 years since that time (Dunn & Sharitz 1990b), so it may not be likely to move to the Great Lakes in the near term (section 2e). Flood-mediated transport would likely act to transport plant fragments downstream and away from the CAWS. Suitable climatological conditions and habitat exists from the current location of this species to Brandon Road Lock and Dam (section 2f). The species produces a high number of seeds (section 2c) and has a vigorous growth rate when introduced to new areas (section 2a). The Mississippi River is poorly connected to the floodplain in many areas and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward Brandon Road Lock and Dam may be slow. Overall, the probability of arrival is low for this time step.

T_{10}: See T_0. If the historic rate of spread continues, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway, but would likely still be well distant of the dam and locks.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Marsh dewflower requires upstream movement by vessels to reach the pathway. It has not spread to the Illinois River in the several decades that it has been present in the lower MRB (sections 2a, 2e). Thus, 50 years may not be sufficient time to expand to the pathway. Therefore, the probability of arrival remains low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the marsh dewflower to travel the far distance (>805 km; 500 mi) required to arrive at the pathway; therefore, the uncertainty for arrival is low. The temperature range for the species to survive is not known. The potential for human-mediated transport is not well characterized.
T_{10}: See T_0. It is not documented how far north the species will be able to disperse or if the species will be able to survive the region's conditions. However, it has not spread very far north in decades.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be sufficient time for the species to expand to the pathway. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The species is described as having vigorous growth and high seed number (Swearingen et al. 2010; Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. It can spread by root fragments during flood events (Swearingen et al. 2010). Expansion in the Southeast has occurred over many decades (Dunn & Sharitz 1990b).

b. Human-Mediated Transport through Aquatic Pathways

There is potential for spread by vessel traffic, although this is not cited in the literature as a means of spread. There is direct vessel traffic between Brandon Road Lock and

Dam and the T.J. O'Brien Lock and Dam (USACE 2011a,b), which is located 8 km (5 mi) south of Calumet Harbor.

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Marsh dewflower prefers littoral, herbaceous marsh, saturated conditions. Open water is not likely suitable habitat (Dunn & Sharitz 1991). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas, and there is very low aquatic macrophyte cover in all sections of the CAWS (LimnoTech 2010). The marsh dewflower is found in water depths less than 1.5 m (4.9 ft) (Jacono 2011). There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. This species is not likely to survive in nearshore non-vegetated areas with manmade structures, such as harbors, consisting of stone blocks and steel sheet piling. Much of the CSSC consists of vertical limestone or manmade walls. The banks of the Calumet Sag Channel are primarily vertical walls, riprap, and natural soft sediment and cobble with overhanging vegetation (LimnoTech 2010). There are ditches and tributaries along the Calumet Sag Channel that may be suitable habitat for marsh dewflower.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in all areas of the CAWS channel, suggesting the CAWS has relatively little suitable habitat for aquatic macrophytes such as the marsh dewflower (section 3d). Marsh dewflower spreads by root fragments during flood events. However, this is not possible in much of the CAWS because there is no floodplain (section 3d). There is some suitable habitat, primarily in the Calumet Sag Channel, but this species is unlikely to spread throughout the CAWS due to habitat limitation and the lack of a mechanism for upstream movement through the CAWS channel. The Calumet Harbor consists primarily vertical walls (section 3d). This species is not likely to survive in nearshore non-vegetated areas or on potentially manmade structures, such as harbors, consisting of stone blocks and steel sheet piling (section 3d). Therefore, marsh dewflower is not likely to form populations in Calumet Harbor and has a low probability of passage.

T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over time, the probability of passage may increase, assuming the marsh dewflower forms populations in the limited suitable habitat within the CAWS and reaches and passes through Calumet Harbor. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The species is not likely to survive in open water or on manmade structures. The lack of suitable habitat in the CAWS is well documented. The uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through Calumet Harbor. However, habitat availability and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b). The species prefers littoral, nearshore emergent herbaceous habitats with saturated conditions (Bason 2004; Dunn & Sharitz 1991). Calumet Harbor is lined by vertical walls, and the adjacent nearshore areas of Lake Michigan are sandy beach and riprap. There is little emergent wetland habitat near the shoreline of Lake Michigan between Calumet Harbor and the Indiana border (unpublished data from USACE) due to human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the marsh dewflower to colonize. There are small tributaries and large rivers in Indiana that have emergent wetlands. It could form populations in sheltered areas where organic matter has accumulated.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The marsh dewflower invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the marsh dewflower to reach marsh habitat after exiting Calumet Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural shoreline along Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow marsh dewflower to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of marsh dewflower passing from Calumet Harbor into Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so flow could carry the marsh dewflower seeds or fragments to Indiana where there are emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but marsh dewflower could colonize tributary and riverine floodplains if transported up upstream by wind driven currents.

Evidence for Probability Rating

Boat traffic from Calumet Harbor could potentially assist in the dispersal of marsh dewflower. However, the marsh dewflower is not likely to colonize in Calumet Harbor, making vessel transport less likely (section 4b). Marsh dewflower is also not likely to grow on the non-vegetated shoreline or rocky shoals that are in the vicinity of Calumet Harbor, or the sandy, higher energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan, the closest of which are found in Indiana (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting Calumet Harbor is considered to be low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The temperature range for the species to survive is not documented. There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The ability of boats to transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach suitable habitat after Calumet Harbor by drift alone. Therefore, the uncertainty of this species colonizing in Lake Michigan is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The native distribution of this species (China, Japan, Korea, Tibet [Howard 2011]) suggests a wide climatological tolerance. However, it is unknown whether the plant can survive the low temperatures in the upper GLB.

b. *Type of Mobility/Invasion Speed*
Marsh dewflower is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). The expansion of the species' range in the southeastern United States has occurred over many decades (Dunn & Sharitz 1990b).

c. *Fecundity*
This species typically produces 9000–70,000 seeds per m^2 (Dunn & Sharitz 1990a) and can reproduce vegetatively (Dunn & Sharitz 1990b).

d. *History of Invasion Success*
Marsh dewflower can exist at high density where established. The species was reported in Louisiana in the 1920s (Dunn & Sharitz 1990b), but has not spread very far north since that time (about 90 years).

e. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spread. There is vessel traffic between Calumet Harbor and the other Great Lakes.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The marsh dewflower is a wetland obligate. The marsh dewflower prefers slow-moving water in marshy areas. The abundant beach habitat of Lake Michigan is likely unsuitable due to the sandy sediments and wave action. Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan (MTRI 2012), so it is probably not a suitable habitat. The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b) and saturated littoral, emergent, and shrub scrub wetlands (Bason 2004; Dunn & Sharitz 1991). There are also smaller tributaries closer to Calumet Harbor. There are areas of nearshore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the marsh dewflower could spread (unpublished data from USACE). The St. Joseph's River is the closest large river system and is located more than 112 km (70 mi) from Calumet Harbor.

Evidence for Probability Rating

The marsh dewflower has a high seed production (section 5c) but a historically low dispersal rate in the lower MRB according to literature (section 5d). The abundant beach habitat in the GLB is likely unsuitable, as are the high-energy shoreline areas of Lake Michigan. It is not likely to grow near shore on non-vegetated areas such as a harbor or rocky shoals. Once it colonizes in the GLB, suitable wetland habitat is present inland of the Lake Michigan shoreline and in tributaries and rivers through which this species could spread (section 5f). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland and littoral habitat. However, there is uncertainty associated with the probability of spread mechanisms via aquatic pathways. Assuming initial colonization occurs, the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The species is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. Seeds are dispersed by wildlife, and it can spread by means of root fragments during flood events (Swearingen et al. 2010). The species' expansion in the southeastern United States has occurred slowly over many decades (Dunn & Sharitz 1990b).

b. Human-Mediated Transport through Aquatic Pathways

Marsh dewflower was introduced by accident in agriculture through rice fields (Dunn & Sharitz 1990b). There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spreading. There is commercial and recreational vessel traffic between the lower Mississippi River Basin and Brandon Road Lock and Dam.

c. Current Abundance and Reproductive Capacity

T_0: Marsh dewflower typically produces 9000–70,000 seeds per m^2 (Dunn & Sharitz 1990a), can reproduce vegetatively (Dunn & Sharitz, 1990b), and is autogamous (Dunn & Sharitz 1991).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers

T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: Currently, this species is located more than 805 km (500 mi) from the Brandon Road Lock and Dam. Habitat maps show the species in Tennessee in 1993, likely coming from the east, and an isolated established population in Arkansas in 1978 (Howard 2011).
T_{10}: See T_0. The species may expand its range closer to the pathway over time.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) along with its U.S. distribution (southeastern United States and Pacific Northwest [NatureServe 2010]) suggests a wide climatological tolerance. The habitat for this species includes forested, emergent, and shrub scrub wetlands (Bason 2004); marsh dewflower is also found along pond and stream edges, freshwater marshes, freshwater tidal marshes, large river deltas, and lakes (Dunn & Sharitz 1990b; NatureServe 2010). Stream order and gradient in the MRB may be suitable in shallow, slower areas. Marsh dewflower has been known to move up rivers (Dunn & Sharitz 1990b). Marsh habitat is highly fragmented in the MRB, and many rivers have been channelized and are not well connected to their floodplains.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: It was reported in Louisiana in the 1920s and has not spread very far up the Mississippi in the approximately 90 years since that time (Dunn & Sharitz 1990b), so it may not be likely to move to the GLB in the near term (section 2e). Flood-mediated transport would likely act to transport plant fragments downstream and away from the CAWS. Suitable climatological conditions and habitat exist from the current location of this species to Brandon Road Lock and Dam (section 2f). The species produces a high number of seeds (section 2c) and has a vigorous growth rate when introduced to new areas (section 2a). The Mississippi River is poorly connected to the floodplain in many areas and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward Brandon Road Lock and Dam may be slow. Overall, the probability of arrival is low for this time step.
T_{10}: See T_0. If the historic rate of spread continues, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway, but would likely still be well distant of the dam and locks.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Marsh dewflower requires upstream movement by vessels to reach the pathway. It has not spread to the Illinois River in the several decades that it has been present in the lower MRB (sections 2a, 2e). Thus, 50 years may not be sufficient time to expand to the pathway. Therefore, the probability of arrival remains low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the marsh dewflower to travel the far distance (>805 km; 500 mi) required to arrive at the pathway; therefore, the uncertainty for arrival is low. The temperature range for the species to survive is not documented. The potential for human-mediated transport is not well characterized.
T_{10}: See T_0.It is not documented how far north the species will be able to disperse or whether the species will be able to survive the regional conditions. However, it has not spread very far north in decades.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be sufficient time to expand to the pathway. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The species is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. It can spread by means of root fragments during flood events (Swearingen et al. 2010). Expansion in the Southeast has occurred over many decades (Dunn & Sharitz 1990b).

b. Human-Mediated Transport through Aquatic Pathways
There is potential for spread by vessel traffic, although this is not cited in the literature as a means of spreading. There is no cargo vessel traffic to Indiana Harbor originating within the MRB. Vessels could transport the marsh dewflower as far as the Calumet River (USACE 2011a,b).

c. Existing Physical Human/Natural Barriers
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrological, Hydraulic, Chemical, and Climatological)
T_0: Marsh dewflower prefers littoral, herbaceous marsh, saturated conditions (Dunn & Sharitz 1991). Open water is not likely suitable habitat (Dunn & Sharitz 1991). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas, and there is very low aquatic macrophyte cover in all sections of the CAWS

(LimnoTech, 2010). The marsh dewflower is found in water depths less than 1.5 m (4.9 ft) (Jacono 2011). Much of the CSSC consists of vertical limestone or manmade walls. There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. The banks of the Calumet Sag Channel are primarily vertical walls, riprap, and natural soft sediment and cobble with overhanging vegetation (LimnoTech 2010). There are ditches and tributaries along the Calumet Sag Channel that may be suitable habitat for marsh dewflower. Portions of the Grand Calumet River are marshy and are likely to be suitable. Water in the Grand Calumet can flow east or west depending on the water level in Lake Michigan. This species is not likely to survive in nearshore non-vegetated areas with manmade structures, such as harbors, consisting of stone blocks and steel sheet piling. Indiana Harbor is heavily industrialized, and its banks are primarily vertical walls.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in all areas of the CAWS channel, suggesting the CAWS has relatively little suitable habitat for aquatic macrophytes such as the marsh dewflower (section 3d). Marsh dewflower spreads by root fragments during flood events. However, this is not possible in much of the CAWS because there is no floodplain (section 3e). There is some suitable habitat, primarily in the Calumet Sag Channel and the Grand Calumet River, but this species is unlikely to spread throughout the CAWS due to habitat limitation and the lack of a mechanism for upstream movement through the CAWS (section 3b). The banks of Indiana Harbor are primarily vertical walls (section 3e). This species is not likely to survive in nearshore non-vegetated areas or near potentially manmade structures, such as harbors, consisting of stone blocks and steel sheet piling (section 3e). Therefore, marsh dewflower is not likely to inhabit in Indiana Harbor. Overall, the marsh dewflower and has a low probability of passage for this time step.
T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over time, the probability of passage may increase, assuming the marsh dewflower forms populations in the limited suitable habitat within the CAWS and reaches and passes through Indiana Harbor. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The species is not likely to survive in open water or on manmade structures. The lack of suitable habitat in the CAWS is documented, although portions of the Grand Calumet River may be suitable. Water in the Grand Calumet can flow east or west depending on the water level in Lake Michigan. Therefore, spread to Indiana Harbor could be promoted or impeded depending on flow direction. The uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0.
T_{25}: See T_{10}. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{50}: See T_{25}. Fifty years may allow enough time for this species to pass through Indiana Harbor. However, habitat availability and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b). The species prefers littoral, nearshore emergent herbaceous habitats with saturated conditions (Bason 2004; Dunn & Sharitz 1991). There are no emergent wetlands in Indiana Harbor, and the adjacent nearshore areas of Lake Michigan are sandy beach and riprap (unpublished data from USACE). East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands, but they are likely to be too far inland from Lake Michigan for the marsh dewflower to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands. The marsh dewflower could form populations in sheltered areas where organic matter has accumulated.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The marsh dewflower invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the marsh dewflower to reach marsh habitat after exiting Indiana Harbor is severely restricted by urbanization, harbors, and the lack of marsh and natural floodplain along the shoreline along Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow marsh dewflower to

colonize suitable habitat include transport by boats and drifting along the Lake Michigan shoreline. Seeds or fragments of marsh dewflower passing from Indiana Harbor to Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001) so flow could carry the marsh dewflower seeds or fragments to emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but marsh dewflower could colonize tributaries if transported upriver by flooding or wind-driven currents. The closest large tributary is the St. Josephs River located more than 112 km (70 mi) from Indiana Harbor. There are smaller tributaries that are closer and that may be suitable.

Evidence for Probability Rating

Recreational boat traffic from Indiana Harbor could potentially assist in the dispersal of marsh dewflower. However, the marsh dewflower is not likely to colonize Indiana Harbor, making vessel transport less likely (section 4b). Marsh dewflower is also not likely to grow on the non-vegetated shoreline or rocky shoals that are in the vicinity of Indiana Harbor, or the sandy, higher energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan (section 4a). Overall, the probability of this species colonizing in Lake Michigan after exiting Indiana Harbor is considered to be low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The ability of boats to transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach suitable habitat after exiting Indiana Harbor by drift alone. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) suggests a wide climatological tolerance. However, it is unknown whether the plant can survive the low temperatures in the GLB.

b. *Type of Mobility/Invasion Speed*
This species has been described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). The species' spread over the southeastern U.S. has occurred over many decades.

c. *Fecundity*
Marsh dewflower typically produces 9000–70,000 seeds per m^2 (Dunn & Sharitz 1990a) and can reproduce vegetatively (NatureServe 2010).

d. *History of Invasion Success*
The marsh dewflower can exist at high density where established. The species was reported in Louisiana in the 1920s (Dunn & Sharitz 1990b), but has not spread very far north since that time (about 90 years).

e. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spreading. There is vessel traffic from Indiana Harbor to other Great Lakes.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The marsh dewflower is a wetland obligate. The marsh dewflower prefers slow-moving water in marshy areas. The abundant beach habitat of Lake Michigan is likely unsuitable due to the sandy sediments and wave action. Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan (MTRI 2012), so it is probably not a suitable habitat. The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b) and saturated littoral, emergent, and shrub scrub wetlands (Bason 2004; Dunn & Sharitz 1991). There are areas of nearshore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the marsh dewflower could spread (unpublished data from USACE).

Evidence for Probability Rating

The species has a high seed production (section 5c), but a historically low dispersal rate in the lower MRB, according to literature (section 5d). Suitable wetland habitat is present in the GLB in tributaries and rivers (section 5f). The abundant beach habitat in the GLB is likely unsuitable, as are the high-energy shoreline areas of Lake Michigan. If the marsh dewflower colonizes in the GLB, suitable wetland habitat is present inland of the Lake Michigan shoreline and in tributaries and rivers through which this species could spread (section 5f). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland and littoral habitat. However, there is uncertainty associated with the probability of spread mechanisms via aquatic pathways. Assuming initial colonization occurs, the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
The marsh dewflower is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). Its vigorous growth enables it to outcompete native plants by forming dense mats. Seeds are dispersed by wildlife. This species can also spread by root fragments during flood events (Swearingen et al. 2010). Expansion in the southeastern United States has occurred slowly over many decades (Dunn & Sharitz 1990b).

b. Human-Mediated Transport through Aquatic Pathways
Marsh dewflower was introduced by accident in agriculture (Dunn & Sharitz 1990b). There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spreading. There is recreational and commercial vessel traffic to Brandon Road Lock and Dam from the lower Mississippi River Basin.

c. Current Abundance and Reproductive Capacity
T_0: Marsh dewflower typically produces 9000–70,000 seeds per m^2 (Dunn & Sharitz 1990a), can reproduce vegetatively (Dunn & Sharitz 1990b), and is autogamous (Dunn & Sharitz 1991).
T_{10}: See T_0. There are no predicted changes to reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway
T_0. Currently, this species is located more than 805 km (500 mi) from the Brandon Road Lock and Dam. Habitat maps show the species in Tennessee in 1993, likely dispersing from the east, and an isolated established population in Arkansas in 1978 (Howard 2011).
T_{10}: See T_0. The species may expand its range closer to the pathway over time.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) along with its U.S. distribution [southeastern United States and Pacific Northwest (NatureServe 2010)] suggest a wide climatological tolerance. The habitat for this species includes forested, emergent, and shrub scrub wetlands (Bason 2004); marsh dewflower is also found along pond and stream edges, freshwater marshes, freshwater

tidal marshes, large river deltas, and lakes (Dunn & Sharitz 1990b; NatureServe 2010). Stream order and gradient in the MRB may be suitable in shallow, slower areas. Marsh dewflower has been known to move up rivers (Dunn & Sharitz 1990b). Marsh habitat is highly fragmented in the MRB and many rivers have been channelized and are not well connected to their floodplain.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: It was reported in Louisiana in the 1920s, and it has not spread very far up the Mississippi River in the approximately 90 years since that time (Dunn & Sharitz 1990b), so it may not likely move to the Great Lakes in the near term (section 2e). Flood-mediated transport would likely act to transport plant fragments downstream and away from the CAWS. Suitable climatological conditions and habitat exist from the current location of this species to Brandon Road Lock and Dam (section 2f). The species produces a high number of seeds (section 2c) and has a vigorous growth rate when introduced to new areas (section 2a). The Mississippi River is poorly connected to the floodplain in many areas and marsh habitat is highly fragmented in the MRB (section 2f), so upstream movement toward Brandon Road Lock and Dam may be slow. Overall, the probability of arrival is low for this time step.
T_{10}: See T_0. If the historic rate of spread continues, the species may slowly disperse north closer to the Brandon Road Lock and Dam pathway, but would likely still be well distant of the dam and locks.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Marsh dewflower requires upstream movement by vessels to reach the pathway. It has not spread to the Illinois River in the several decades that it has been present in the lower MRB (sections 2a, 2e). Thus, 50 years may not be sufficient time to expand to the pathway. Therefore, the probability of arrival remains low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: It is unlikely at this time step for the marsh dewflower to travel the far distance (>805 km; 500 mi) required to arrive at the pathway; therefore, the uncertainty for arrival is

low. The temperature range for the species to survive is not documented. The potential for human-mediated transport is not well characterized.
T_{10}: See T_0. It is not documented how far north the species will be able to disperse or whether the species will be able to survive the region's conditions. However, it has not spread very far north in decades.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be sufficient time to expand to the pathway. The future impacts of climate change on the distribution of this species are not documented. This raises the uncertainty of arrival to medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species is described as having vigorous growth and high seed number (Swearingen et al. 2010; Dunn & Sharitz 1990b). Its vigorous growth enables it to out-compete native plants by forming dense mats. It can spread by means of root fragments during flood events (Swearingen et al. 2010). Expansion in the Southeast has occurred over many decades (Dunn & Sharitz 1990b).

b. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spreading. There is no cargo vessel traffic to BSBH (USACE 2011a). Vessels could transport the marsh dewflower as far as the Little Calumet River. There is some small boat recreational use in the Little Calumet River that could aid upstream dispersal.

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Marsh dewflower prefers littoral, herbaceous marsh, saturated conditions. Open water is not likely suitable habitat (Dunn & Sharitz 1991). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas, and there is low aquatic macrophyte cover in all sections of the CAWS (LimnoTech 2010). The marsh dewflower is found in water depths less than 1.5 m (4.9 ft) (Jacono 2011). There is some shallow shoreline with and without canopy cover in the CSSC that may be suitable. This species is not likely to survive in nearshore non-vegetated areas with manmade

structures, such as harbors, consisting of stone blocks and steel sheet piling. Much of the CSSC is lined with vertical limestone or manmade walls. The banks of the Calumet Sag Channel are primarily vertical walls, riprap, and natural soft sediment and cobble with overhanging vegetation (LimnoTech 2010). There are ditches and tributaries along the Calumet Sag Channel that may be suitable habitat for marsh dewflower. Portions of the South Branch of the Little Calumet River are shallow and may be suitable. Flow direction in the South Branch of the Little Calumet River is variable depending on the water level in Lake Michigan. The banks of BSBH are riprap and vertical walls.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is low macrophyte cover in all areas of the CAWS channel, suggesting the CAWS has relatively little suitable habitat for aquatic macrophytes such as the marsh dewflower (section 3d). Marsh dewflower spreads by root fragments during flood events. However, this is not possible in much of the CAWS because there is no floodplain (section 3d). There is some suitable habitat, primarily in the Calumet Sag Channel and Little Calumet River. Vessels could transport marsh dewflower to the Little Calumet River. However, due to the low vessel traffic, dispersal by floating upstream through the South Branch of the Little Calumet River to Burns Ditch, approximately 64 km (40 mi), would likely be required to arrive at BSBH. The banks of the BSBH are primarily vertical wall and riprap (section 3d). This species is not likely to survive in areas of nearshore rock and vertical steel or concrete walls (section 3d). Overall, marsh dewflower is unlikely to spread throughout the CAWS due to habitat limitation and the lack of a mechanism for upstream movement through the CAWS channel. Therefore, marsh dewflower is not likely to establish in the BSBH and has a low probability of passage.
T_{10}: See T_0. Conditions in the CAWS (e.g., banks) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over time, the probability of passage may increase, assuming the marsh dewflower establishes populations in the limited suitable habitat within the CAWS and reaches and passes through the BSBH. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The species is not likely to survive in open water or on manmade structures. The lack of suitable habitat in the CAWS is documented, although portions of the South Branch of the Little Calumet River may be suitable. Flow direction in the South Branch of the Little Calumet River is variable and may promote or inhibit the spread of the marsh dewflower to BSBH. The uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may allow enough time for this species to pass through the BSBH. However, the habitat availability and upstream transport uncertainties remain. Therefore, the uncertainty associated with passage at this time step is medium.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b). The species prefers littoral, nearshore emergent herbaceous habitats with saturated conditions (Bason 2004; Dunn & Sharitz 1991). There are emergent wetlands south of BSBH, but they may not be hydrologically connected to the CAWS. BSBH itself contains no emergent wetland habitat, and the adjacent nearshore areas of Lake Michigan are sandy beach and riprap (unpublished data from USACE). Emergent wetlands can be found scattered inland of the Lake Michigan shoreline and associated with tributaries to Lake Michigan. There are scattered emergent wetlands near Lake Michigan north of BSBH (unpublished data from USACE), but they are likely to be too far inland from Lake Michigan for the marsh dewflower to colonize from Lake Michigan. There are small tributaries and large rivers in Indiana that have emergent wetlands. The marsh dewflower could form populations in sheltered areas where organic matter has accumulated.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The marsh dewflower invades new locations when floodwaters transport seed, roots, and stem fragments. Overall, the ability of the marsh dewflower to reach marsh habitat after exiting BSBH is severely restricted by urbanization, harbors, and the lack of marsh and natural shoreline along Lake Michigan. Potential dispersal mechanisms via aquatic pathways that would allow marsh dewflower to colonize suitable habitat include transport by boats and drift along the Lake Michigan shoreline. Seeds or fragments of marsh dewflower passing from the BSBH to Lake Michigan could be transported by vessels, although evidence for boats as a long-distance dispersal mechanism was not

found in the literature. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001), so flow could carry the marsh dewflower seeds or fragments to emergent wetlands scattered inland of the shoreline of Lake Michigan and associated with rivers and tributaries (unpublished data from USACE). Most emergent wetlands are not hydrologically connected to Lake Michigan, but marsh dewflower could colonize tributaries, if transported upriver by flooding or wind-driven currents. The closest large tributary is the St. Josephs River located more than 80.5 km (50 mi from BSBH). There are smaller tributaries that are closer and that may be suitable.

Evidence for Probability Rating

Recreational boat traffic from BSBH could potentially assist in the dispersal of marsh dewflower. However, the marsh dewflower is not likely to colonize BSBH, making vessel transport less likely (section 4b). Marsh dewflower is also not likely to grow on the non-vegetated shoreline or rocky shoals that are in the vicinity of BSBH, or the sandy, higher energy shoreline of Lake Michigan (section 4a). Suitable habitat is present in emergent wetlands associated with tributaries to Lake Michigan. However, these areas are not located near BSBH (section 4a). Therefore, the probability of this species colonizing in Lake Michigan after exiting BSBH is considered to be low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

There is a documented lack of suitable habitat along much of the shoreline of southern Lake Michigan. The ability of boats to transport seeds or adult fragments is uncertain. It is uncertain whether the species will be able to reach suitable habitat after exiting the BSBH by drift alone. Therefore, the uncertainty of this species colonizing in the GLB is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The native distribution of this species (China, Japan, Korea, and Tibet [Howard 2011]) suggests a wide climatological tolerance. However, it is unknown if the plant can survive the low temperatures in the GLB.

b. *Type of Mobility/Invasion Speed*
The species is described as having vigorous growth (Swearingen et al. 2010) and high seed number (Dunn & Sharitz 1990b). Its spread over the southeastern United States has occurred over many decades (Dunn & Sharitz 1990b).

c. *Fecundity*
Marsh dewflower typically produces 9000–70,000 seeds per m^2 (Dunn & Sharitz 1990a) and can reproduce vegetatively (Dunn & Sharitz 1990b).

d. *History of Invasion Success*
Marsh dewflower can exist at high density where established. The species was reported in Louisiana in the 1920s (Dunn & Sharitz 1990b), but has not spread very far north since that time (about 90 years).

e. *Human-Mediated Transport through Aquatic Pathways*
There is potential for spread by recreational vessel traffic, although this is not cited in the literature as a means of spreading.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The marsh dewflower is a wetland obligate. The marsh dewflower prefers slow-moving water in marshy areas. The abundant beach habitat of Lake Michigan is likely unsuitable due to the sandy sediments and wave action. Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan (MTRI 2012), so it is probably not a suitable habitat. The marsh dewflower can be found along large lakes (Dunn & Sharitz 1990b) and saturated littoral, emergent, and shrub scrub wetlands (Bason 2004; Dunn & Sharitz 1991). There are areas of nearshore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the marsh dewflower could spread (unpublished data from USACE).

Evidence for Probability Rating

The marsh dewflower has a high seed production (section 5c), but a historically low dispersal rate in the lower MRB according to literature (section 5d). The abundant beach habitat in the GLB is likely unsuitable, as are the high-energy shoreline areas of Lake Michigan. It is not likely to grow near shore on non-vegetated areas such as a harbor or rocky shoals. Once it colonizes in the GLB, suitable wetland habitat is present inland of the Lake Michigan shoreline and in tributaries and rivers through which this species could spread (section 5f). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland and littoral habitat. However, there is uncertainty associated with the probability of spread mechanisms via aquatic pathways. Assuming initial colonization occurs, the uncertainty of this species spreading in the Great Lakes is medium.

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E.1.2 Crustaceans

E.1.2.1 Scud - *Apocorophium lacustre*

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO THE WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The species is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles; therefore, there is

no planktonic stage. *A. lacustre* was first reported from fresh water in North America in 1987–1988 from the lower Mississippi River between 820 and 829 km (510 and 515 river miles [rm]) (Grigorovich et al. 2008). In 1989, it was detected downriver at 719 km (447 rm). In 1996, it was first found in the Ohio River and subsequently moved 1149 km (714 mi) up the Ohio River within a year (Grigorovich et al. 2008). Based on these movement data, this species exhibits a very rapid invasion speed. By 2003, *A. lacustre* invaded the Illinois River and expanded into the upper Mississippi River in 2005 (USGS 2011). "*A. lacustre* rapidly expanded its range into the upper reaches of the Ohio and Illinois Rivers. These discontinuous rapid expansions within the upper Mississippi River waterway are attributed to shipping transport, most likely via hull-fouling" (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*

The species may be transported by attaching to boat hulls or ballast water, and vessel traffic is the fastest means of upstream spread (Grigorovich et al. 2008; Johnson et al. 2007). There is also heavy commercial and recreational traffic through the Brandon Road Lock and Dam from the lower MRB (USACE 2011b), suggesting a high probability of human-mediated transport.

c. *Current Abundance and Reproductive Capacity*

T_0: The species does not densely populate the MRB but can be locally abundant. "A kick sample from the upper Mississippi River in 2006 yielded 196 *A. lacustre* (density = 457 individuals/m^{-2}), but most samples had far fewer specimens. Population density of *A. lacustre* in the Ohio River increased from 6.7 (±6.3; standard deviation)/m^{-2} in 2004 to 15.7 (±31.1)/m^{-2} in 2006, and density in the upper Mississippi River increased from 65.6 (±87.3)/m^{-2} in 2005 to 87.3 (±182.1) individuals/m^{-2} in 2006; these differences, however, were not statistically significant" (Grigorovich et al. 2008).
T_{10}: See T_0**.** Abundance is expected to increase beyond T_0 levels.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers. This species is at or close to the pathway and moved through several locks as it moved northward from the lower MRB.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: In 2005 *A. lacustre* was found in the Illinois River just above the Dresden Lock and Dam, less than 32.2 km (20 mi) from the Brandon Road Lock and Dam in the Illinois River (USGS 2011).
T_{10}: See T_0. The species may be closer to the pathway or at the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitat for this species includes the benthos of estuaries, rivers, and lakes and intertidal zones in native estuarine habitat; *A. lacustre* has been collected on snags and in the benthos in the Ohio and upper Mississippi Rivers (Angradi et al. 2009). In the upper Mississippi River, this species is associated with rocks and snags (Angradi 2009); in the Ohio River where cobble and boulder habitats are less common, it is primarily associated with sand and snags (Grigorovich et al. 2008). The species tolerates a wide range of temperatures based on existing distribution. *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000) and is not found in fast-flowing or turbid water (Grigorovich et al. 2008).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species does not densely populate the MRB but can be locally abundant (section 2d). *A. lacustre* is located less than 32.2 km (20 mi) from the Brandon Road Lock and Dam (section 2e) and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (sections 2a, 2b). There is heavy upbound boat traffic through the CAWS (section 2b), suggesting a high potential for human transport to the Brandon Road Lock and Dam. *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000), and there is suitable habitat present in the vicinity of the Brandon Road Lock and Dam (section 2f) where populations could establish. Therefore, the probability of this species arriving at the Brandon Road Lock and Dam is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been empirically verified to spread rapidly and over large distances via boat traffic (sections 2a, 2b). Ballast water intake in inland Illinois is unlikely. Hull-fouling and natural species dispersal may occur. The last survey for this species was Grigorovich et al. (2008), so its current distribution is unknown, but it may currently be even

closer than 32 km (20 mi) from the Brandon Road Lock and Dam. Therefore, the uncertainty of the arrival of this species is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species

a. Type of Mobility/Invasion Speed
A. lacustre is a tube-dwelling, benthic filter-feeding amphipods (Grigorovich et al. 2008). The scud is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. Human-Mediated Transport through Aquatic Pathways
In 2008, about 15.9 million tons of commodity traffic moved on the CAWS, accounting for about 43% of traffic on the entire Illinois Waterway (USACE 2011a). About 71% of this traffic moved through the Lockport Lock and Dam facility (USACE 2011a). *A. lacustre* may be transported via ballast water and hull-fouling (Grigorovich et al. 2008; Johnson et al. 2007). Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan. The WPS regulates the amount of Lake Michigan flow allowed down the North Shore Channel; the sluice gate is a means by which excess stormwater is reversed back into the lake (USACE 2011b). The species typically moves downstream, not upstream (Grigorovich et al. 2008), so it may require human-mediated transport to move through the Brandon Road Lock and Dam area and up the North Shore Channel to the WPS.

c. Existing Physical Human/Natural Barriers
T_0: The sluice gate at the WPS is a barrier that could retard dispersion by boat transport. The scud moved through several locks as it moved northward from the lower MRB, suggesting locks are not a barrier.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: *A. lacustre* is not found in fast-flowing or turbid water (Grigorovich et al. 2008). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at WPS is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The low flow of the North Shore Channel may allow the species to naturally move upstream without assistance. *A. lacustre* has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Suitable habitat includes rocky and/or sandy shoals (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are suitable habitat for the species. The banks of the CSSC are vertical walls, rock, and some vegetative debris. Sediments in the CSSC can be rock to soft sediment and sand. The Chicago River is more than 90% vertical wall and has a sludge or silt bottom. The upper north branch of the Chicago River and the North Shore channel are more natural habitats with cobble banks and woody debris (LimnoTech 2010). This species tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution. The scud typically moves downstream, not upstream (Grigorovich et al. 2008).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has moved hundreds of miles in a single year via vessel-mediated transport (section 3a). According to literature, *A. lacustre* requires human-mediated transport to travel far distances upstream (sections 3b, 3d), and there is vessel traffic from the Brandon Road Lock and Dam to the WPS. The upper north branch of the Chicago River and the North Shore Channel are suitable for this species. The North Shore Channel has a low flow (section 3e), which may allow *A. lacustre* to naturally disperse upstream. Vessel traffic does not pass through the WPS; however, the flow of water may be reversed back into Lake Michigan through the sluice gate (section 3c), allowing the species to pass into the Great Lakes. Overall, the probability of passage for this species is high.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *A. lacustre* is a rapid invader and is documented to have moved hundreds of miles in a single year by vessel-mediated transport (section 3a). There is documented vessel traffic in the CAWS that could potentially transport this species upstream to the WPS. Overall, the uncertainty of passage for this species is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
This species is common in ports on the Atlantic coast (Power et al. 2006). Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species. The species inhabits relict oyster reefs (USGS 2011), so zebra mussel beds in Lake Michigan may be suitable. The river and tributaries of the Great Lakes are also suitable habitat. This species tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution. It is not found in fast-flowing or turbid water; therefore, the near-shore high current of Lake Michigan may not be suitable for the species. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
A harbor is considered suitable habitat for the species. The species is a sideswimmer (NEANS 2003) and may be able to swim or drift to reach the sandy shoal adjacent to the pathway entrance.

Evidence for Probability Rating

Because appropriate habitat conditions are present (section 4a) and near the pathway entrance (section 4b), this element is rated a high probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

The near-shore high current of Lake Michigan may not be suitable for the species. However, the abundance of rocky shoals may provide protection. Therefore, the uncertainty of colonization for this species is low.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Based on existing distribution, the species tolerates a wide range of temperatures. It is native to the United States coast of the Atlantic Ocean (USGS 2011).

b. Type of Mobility/Invasion Speed
A. lacustre is a tube-dwelling, benthic filter-feeding amphipods (Grigorovich et al. 2008). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles. This species exhibits a very rapid invasion speed (Grigorovich et al. 2008).

c. Fecundity
No fecundity data are available. Females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973).

d. History of Invasion Success
A. lacustre was reported in 1987–1988 from the lower Mississippi River (Grigorovich et al. 2008). In 1996, it was found in the Ohio River and moved 1149 km (714 mi) up the Ohio River within a year. By 2003, *A. lacustre* had invaded the Illinois River, and in 2005, it expanded to the upper Mississippi River (USGS 2011).

e. Human-Mediated Transport through Aquatic Pathways
According to literature, to travel long distances upstream the species must be moved via ballast water or hull-fouling (Grigorovich et al. 2008). There is recreational but no commercial vessel traffic between the Great Lakes and the WPS Harbor.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
This is a generalist species; the species tolerates a wide range of temperatures and habitat types. Benthos of rivers and tributaries of the Great Lakes would be suitable. Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including

manmade structures like a harbor, are considered suitable habitat for the species. This species tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution. It is not found in fast-flowing or turbid water (Grigorovich et al. 2008). *A. lacustre* does well in relict oyster reefs (USGS 2011), so zebra mussel beds in the Great Lakes may be suitable.

Evidence for Probability Rating

Suitable climatological conditions and suitable habitat are present and accessible for a species that has a high invasion speed (sections 5a, 5b, 5d, 5f). Human-mediated dispersal will assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. The WPS is not a port and will not have vessels taking in ballast water. However, recreational vessels may promote spread via hull-fouling from Wilmette Harbor. Therefore, the probability of spread for this species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is good evidence available. Data gaps that do exist in fecundity, hull-fouling, and near-shore current effects are not significant and would not alter the probability rating. Therefore, the uncertainty of spread is low.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008**).** The species is a side swimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles; therefore, there is no planktonic stage (Bousfield 1973). *A. lacustre* was first reported from fresh water in North America in 1987–1988 from the lower Mississippi River between 820 and 829 km (510 and 515 river miles [rm]) (Grigorovich et al. 2008). In 1989, it was detected downriver at 719 km (447 rm). The species was first found in the Ohio River in 1996 and subsequently moved 1,149 km (714 mi) up the Ohio River within a year (Grigorovich et al. 2008). Based on these movement data, this species exhibits a very rapid invasion speed. By 2003, *A. lacustre* had invaded the Illinois River; it expanded to the upper Mississippi River in 2005 (USGS 2011). "*A. lacustre* rapidly expanded its range into the upper reaches of the Ohio and Illinois Rivers. These discontinuous rapid expansions within the upper Mississippi River waterway are attributed to shipping transport, most likely via hull-fouling" (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
The species may be transported by attaching to boat hulls or through ballast water, and vessel traffic is the fastest means of upstream spread (Grigorovich et al. 2008; Johnson et al. 2007). However, there is little ballast water discharge at ports near the Brandon Road Lock and Dam (NBIC 2012). Hull-fouling could be an important vector for the secondary spread of established freshwater aquatic nonindigenous species within the Great Lakes (Reid & Ruiz 2007). In 2008, about 15.9 million tons of commodity

traffic moved on the CAWS, accounting for about 43% of traffic on the entire Illinois Waterway. About 71% of this traffic moved through the Lockport Lock and Dam facility (USACE 2011a). There is also heavy commercial and recreational traffic through the Brandon Road Lock and Dam from the lower MRB (USACE 2011b), suggesting a high probability of human-mediated transport.

c. *Current Abundance and Reproductive Capacity*
T_0: The species does not densely populate the MRB but can be locally abundant. “A kick sample from the upper Mississippi River in 2006 yielded 196 *A. lacustre* (density = 457 individuals/m^{-2}), but most samples had far fewer specimens. Population density of *A. lacustre* in the Ohio River increased from 6.7 (±6.3; standard deviation)/m^{-2} in 2004 to 15.7 (±31.1)/m^{-2} in 2006, and density in the upper Mississippi River increased from 65.6 (±87.3)/m^{-2} in 2005 to 87.3 (±182.1) individuals/m^{-2} in 2006; these differences, however, were not statistically significant” (Grigorovich et al. 2008).
T_{10}: Abundance is expected to increase beyond T_0 levels.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers. This species is at or close to the pathway and moved through several locks as it moved northward from the lower MRB.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In 2005 *A. lacustre* was found in the Illinois River just above the Dresden Lock and Dam, less than 32 km (20 mi) from the Brandon Road Lock and Dam in the Illinois River (USGS 2011).
T_{10}: See T_0. The species may be closer to the pathway or at the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitat includes the benthos of estuaries, rivers, and lakes and intertidal zones in native estuarine habitat (Angradi et al. 2009); in addition, the species has been collected on snags and in the benthos in the Ohio and upper Mississippi Rivers (Angradi et al. 2009). In the upper Mississippi River, it is associated with rocks and snags (Angradi et al. 2009); in the Ohio River where cobble and boulder habitats are less common, habitat is primarily sand and snags (Grigorovich et al. 2008). On the basis of existing distribution, the species tolerates a wide range of temperatures. *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000) and is not found in fast-flowing or turbid water (Grigorovich et al. 2008).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species does not densely populate the MRB but can be locally abundant (section 2d). *A. lacustre* is located less than 32 km (20 mi) from the Brandon Road Lock and Dam (section 2e) and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (sections 2a, 2b). There is heavy upbound boat traffic through the CAWS (section 2b), suggesting there is high potential for human transport to the Brandon Road Lock and Dam. *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000), and there is suitable habitat present in the vicinity of the Brandon Road Lock and Dam (section 2f) where populations could establish. Therefore, the probability of arrival at the Brandon Road Lock and Dam for this species is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been empirically verified to spread rapidly and over large distances via boat traffic. There is documented vessel traffic between the lower MRB and the Brandon Road Lock and Dam. The last survey for this species was Grigorovich et al. (2008), so its current distribution is not documented, but it may currently be even closer than 32 km (20 mi) from the Brandon Road Lock and Dam. Therefore, the uncertainty of arrival for *A. lacustre* is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species

a. *Type of Mobility/Invasion Speed*
   A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The scud is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
   In 2008, about 15.9 million tons of commodity traffic moved on the CAWS, accounting for about 43% of traffic on the entire Illinois Waterway (USACE 2011a). About 71% of this traffic moved through the Lockport Lock and Dam facility (USACE 2011a). *A. lacustre* may be transported via ballast water and hull-fouling (Grigorovich et al. 2008; Johnson et al. 2007). There is vessel traffic between the Brandon Road Lock and Dam and the CRCW (USACE 2011a). At the CRCW there is an average of 711,902 commercial one-way trips and 41,071 non-cargo-vessel one-way trips a year (USACE 2011b).

c. *Existing Physical Human/Natural Barriers*
   T_0: *A. lacustre* moved through several locks as it moved northward from the lower MRB, suggesting locks are not a barrier.
   T_{10}: See T_0.
   T_{25}: See T_0.
   T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   T_0: *A. lacustre* is not found in fast-flowing or turbid water (Grigorovich et al. 2008). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan is a slow-moving eutrophic river. The south branch of the Chicago River has a flow of 0.05–0.25 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The low flow of the CAWS may allow the species to naturally move upstream without assistance. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Suitable habitat includes rocky and/or sandy shoals (Angradi et al. 2009; Grigorovich et al. 2008). Vegetative and woody debris is very limited in the CAWS (LimnoTech 2010). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are suitable habitat for the species (Power et al. 2006). The banks of the CSSC are vertical walls, rock, and some vegetative debris. Substrates in the CSSC are typically rock, cobble, or silt. The Chicago River is less than 90% vertical wall and has a sludge or silt bottom. *A. lacustre* tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution.
   T_{10}: See T_0.
   T_{25}: See T_0.
   T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present in portions of the CAWS for the species (section 3e). This species has moved hundreds of miles in a single year via vessel-mediated transport (section 3a). According to literature, *A. lacustre* requires human-mediated transport to travel far distances upstream, and the vessel traffic between the Brandon Road Lock and Dam and the CRCW provides opportunity (sections 3b, 3d). In addition, the low flow of the CAWS may allow *A. lacustre* to naturally disperse upstream through the south branch of the Chicago River and through the CRCW. Therefore, the probability of passage for this species is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *A. lacustre* is a rapid invader and is documented to have moved hundreds of miles in a single year by vessel-mediated transport (section 3a). Passage will likely occur via human-mediated transport, which has been rapid in the MRB. There is documented vessel traffic in the CAWS that could potentially transport this species upstream to the CRCW. However, the rate of vessel transport in the CAWS is uncertain. The potential rate of upstream movement by natural dispersion is not known, although the slow flow of the river may allow *A. lacustre* to spread upstream. Overall, the uncertainty of passage for this species at this time step is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

The probability of colonization is the same for all time steps. In determining the probability of spread, the species is assumed to have passed through the pathway.

Factors That Influence Colonization of Species

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   This species is common in ports on the Atlantic coast (Power et al. 2006). Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species (Power et al.2006). The species inhabits relict oyster reefs (USGS 2011), so zebra mussel beds in Lake Michigan may be suitable. The river and tributaries of the Great Lakes are also suitable habitat. *A. lacustre* tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution. It is not found in fast-flowing or turbid water; therefore, the near-shore high current of Lake Michigan may not be suitable for the species. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The Chicago harbor area is considered suitable habitat for *A. lacustre*. The species is a sideswimmer (NEANS 2003) and may be able to swim, drift, or use human-mediated transport to reach the sandy shoal adjacent to the pathway entrance.

Evidence for Probability Rating

Because appropriate habitat conditions are present (section 4a) and near the pathway entrance (section 4b), this element is rated a high probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

The nearshore high current of Lake Michigan may not be suitable for the species. However, the abundance of rocky shoals may provide protection. Therefore, the uncertainty of colonization of this species is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   The species tolerates a wide range of temperatures based on its existing distribution. It is native to the United States coast of the Atlantic Ocean (USGS 2011).

b. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed (Grigorovich et al. 2008).

c. *Fecundity*
No fecundity data are available. Females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973).

d. *History of Invasion Success*
A. lacustre was reported in 1987–1988 from the lower Mississippi River (Grigorovich et al. 2008). It was found in the Ohio River in 1996 and moved 1149 km (714 mi) up the Ohio River within a year (Grigorovich et al. 2008). By 2003, *A. lacustre* had invaded the Illinois River and in 2005 expanded to the upper Mississippi River (USGS 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
According to literature, to travel long distances upstream the species must be moved via ballast water or hull-fouling (Grigorovich et al. 2008). There is heavy boat traffic between the CRCW and other ports in the Great Lakes. Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water discharged at the ports along Lake Michigan is from other ports in all the other Great Lakes (NBIC 2012).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This is a generalist species; the species tolerates a wide range of temperatures and habitat types. Benthos of rivers and tributaries of the Great Lakes would be suitable (Angradi et al. 2009). Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species. The species tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on its existing distribution. It is not found in fast-flowing or turbid water (Grigorovich et al. 2008). *A. lacustre* does well in relict oyster reefs (USGS 2011), so zebra mussel beds in the Great Lakes may be suitable.

Evidence for Probability Rating

Suitable climatological conditions and suitable habitat are present and accessible for a species that has a high invasion speed (sections 5a, 5b, 5d, 5f). Human-mediated dispersal will assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. Therefore, the probability of spread for this species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is good evidence available. Data gaps that do exist in fecundity, hull-fouling, and near-shore current effects are not significant and would not alter the probability rating. Therefore, the uncertainty of spread is low.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The species is a side swimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles; therefore, there is no planktonic stage (Bousfield 1973). *A. lacustre* was first reported from fresh water in North America in 1987–1988 from the lower Mississippi River between 820 and 829 km (510 and 515 river miles [rm]) (Grigorovich et al. 2008). In 1989, it was detected downriver at 719 km (447 rm) (Grigorovich et al. 2008). It was first found in the Ohio River in 1996 and subsequently moved 1,149 km (714 mi) up the Ohio River within a year (Grigorovich et al. 2008). Based on these movement data, this species exhibits a very rapid invasion speed. By 2003, *A. lacustre* had invaded the Illinois River; in 2005, it expanded into the upper Mississippi River (USGS 2011). "*A. lacustre* rapidly expanded its range into the upper reaches of the Ohio and Illinois Rivers. These discontinuous rapid expansions within the upper Mississippi River waterway are attributed to shipping transport, most likely via hull-fouling" (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
The species may be transported by attaching to boat hulls or through ballast water, and vessel traffic is the fastest means of upstream spread (Grigorovich et al. 2008; Johnson et al. 2007). However, there is little ballast water discharge at ports near the Brandon Road Lock and Dam (NBIC 2012). Hull-fouling could be an important vector for the secondary spread of established freshwater aquatic nonindigenous species within the Great Lakes (Reid & Ruiz 2007). There is also heavy commercial and recreational traffic through the Brandon Road Lock and Dam (USACE 2011b), suggesting a high probability of human-mediated transport. At the T.J. O'Brien Lock and Dam, there is an average of 179 commercial passenger one-way trips and 19,274 non-cargo-vessel one-way trips a year (USACE 2011b) that connect the CAWS to Lake Michigan via Calumet Harbor.

c. *Current Abundance and Reproductive Capacity*
The species does not densely populate the MRB but can be locally abundant. "A kick sample from the upper Mississippi River in 2006 yielded 196 *A. lacustre* (density = 457 individuals/m^{-2}), but most samples had far fewer specimens. Population density of *A. lacustre* in the Ohio River increased from 6.7 (± 6.3; standard deviation)/m^{-2} in 2004 to 15.7 (±31.1)/m^{-2} in 2006, and density in the upper Mississippi River increased from 65.6 (±87.3)/m^{-2} in 2005 to 87.3 (±182.1) individuals/m^{-2} in 2006; these differences, however, were not statistically significant" (Grigorovich et al. 2008).
T_{10}: Abundance is expected to increase beyond T_0 levels.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers

T_0: The T.J. O'Brien Lock and Dam is between the current location of *A. lacustre* and the Calumet Harbor. However, this species is at or close to the pathway and moved through several locks as it moved northward from the lower MRB.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: In 2005 *A. lacustre* was found in the Illinois River just above the Dresden Lock and Dam, less than 32 km (20 mi) from the Brandon Road Lock and Dam in the Illinois River (USGS 2011).
T_{10}: See T_0. The species may be closer to the pathway or at the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical and Climatological)

T_0: Suitable habitat for *A. lacustre* includes the benthos of estuaries, rivers, and lakes and intertidal zones in native estuarine habitat (Angradi et al. 2009); the species has been collected on snags and in the benthos in the Ohio and upper Mississippi Rivers (Angradi et al. 2009). In the upper Mississippi River, it is associated with rocks and snags (Angradi et al. 2009); in the Ohio River, where cobble and boulder habitats are less common, the species is primarily associated with sand and snags (Grigorovich et al. 2008). On the basis of existing distribution, the species tolerates a wide range of temperatures. *A. lacustre* is a pollution-tolerant species (Ysebaert 2000) and is not found in fast-flowing or turbid water (Grigorovich et al. 2008).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species does not densely populate the MRB but can be locally abundant (section 2d). *A. lacustre* is located less than 32 km (20 mi) from the Brandon Road Lock and Dam (section 2e) and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (sections 2a,2b). There is heavy upbound boat traffic through the CAWS (section 2b), suggesting there is high potential for human transport to the Brandon Road Lock and Dam. *A. lacustre* is a pollution-tolerant species (Ysebaert 2000), and there is suitable habitat present in the vicinity of the Brandon Road Lock and Dam (section 2f) where populations could establish. Therefore, the probability of the species arriving at the Brandon Road Lock and Dam is high.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been empirically verified to spread rapidly and over large distances via boat traffic. Although ballast water intake in inland Illinois is unlikely, hull-fouling and natural species dispersal may occur. The last survey for this species was Grigorovich et al. (2008), so its current distribution is uncertain, but it may currently be even closer than 32 km (20 mi) from the Brandon Road Lock and Dam. Therefore, the uncertainty of arrival for *A. lacustre* is low.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species

a. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The scud is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
Transport may occur through ballast water and hull-fouling (Grigorovich et al. 2008; Johnson et al. 2007). Hull-fouling could be an important vector for the secondary spread of established freshwater aquatic nonindigenous species within the Great Lakes (Reid & Ruiz 2007). Most commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam located 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*

T_0: Existing potential barriers include the three lock and dam structures along the pathway. *A. lacustre* moved through several locks as it moved northward from the lower MRB, suggesting locks are not a barrier.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: *A. lacustre* is not found in fast-flowing or turbid water and typically moves downstream, not upstream (Grigorovich et al. 2008). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at Calumet Harbor is a slow-moving eutrophic river averaging 0.13 m/s (0.43 ft/s) (LimnoTech 2010). The low flow of the Calumet Sag Channel may allow the species to naturally move upstream without assistance. *A. lacustre* has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Suitable habitat includes rocky and/or sandy shoals (Angradi et al. 2009; Grigorovich et al. 2008). Vegetation and woody debris is very limited in the CAWS (LimnoTech 2010). The banks of the CSSC are vertical walls, rock, and some vegetative debris. Sediments in the CSSC can be rock to soft sediment and sand. Near-shore nonvegetated areas, including potentially manmade structures like a harbor, are suitable habitat for the species. The banks of the Calumet Sag Channel are vertical walls, rock, and some vegetative debris. Sediments can be gravel to soft sediment. This species tolerates pollution (Ysebaert 2000) and a wide range of temperatures based on existing distribution.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present in portions of the CAWS for the species (section 3e). This species has moved hundreds of miles in a single year via vessel-mediated transport (section 2a). According to literature, *A. lacustre* requires human-mediated transport to travel far distances upstream, and the vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, as well as the heavy vessel use of Calumet Harbor, provides opportunity for the species to be transported (sections 3b, 3d). The low flow of the CAWS may allow *A. lacustre* to naturally disperse upstream through the Calumet River and through Calumet Harbor. Overall, the probability of passage for this time step is high.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *A. lacustre* is a rapid invader and is documented to have moved hundreds of miles in a single year by vessel-mediated transport (section 3a). There is documented vessel traffic in the CAWS that could potentially transport this species upstream to Calumet Harbor. Passage will likely occur via human-mediated transport, although the slow flow of the river may allow the species to spread upstream without it. However, the potential rate of upstream movement by natural dispersion is not known. Overall, the uncertainty of passage for this species is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The species is common in ports on the Atlantic coast (Power et al. 2006). Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, including potentially manmade structures like a harbor, are considered suitable habitat for the species. *A. lacustre* inhabits relict oyster reefs (USGS 2011), so zebra mussel beds in Lake Michigan may be suitable. The rivers and tributaries of the Great Lakes are suitable habitat for the species. This species tolerates pollution (Ysebaert 2000) and a wide range of temperatures based on existing distribution. *A. lacustre* is not found in fast-flowing or turbid water; therefore, the near-shore high current of Lake Michigan may not be suitable for the species. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
A harbor is considered suitable habitat for *A. lacustre*. The species is a side swimmer (NEANS) and may be able to swim, drift, or use human-mediated transport to reach the rocky shoals adjacent to the pathway entrance.

Evidence for Probability Rating

Because appropriate habitat conditions are present (section 4a) and near the pathway entrance (section 4b), this element is rated a high probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

The near-shore high current of Lake Michigan may not be suitable for the species. However, the abundance of rocky shoals may provide protection. Therefore, the uncertainty of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Based on existing distribution, the species can tolerate a wide range of temperatures. It is native to the United States coast of the Atlantic Ocean (USGS 2011).

b. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). *A. lacustre* exhibits a very rapid invasion speed (Grigorovich et al. 2008).

c. *Fecundity*
No fecundity data are available. Females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973).

d. *History of Invasion Success*
A. lacustre was reported in 1987–1988 from the lower Mississippi River (USGS 2011). In 1996, the species was found in the Ohio River and moved 1149 km (714 mi) up the Ohio River within a year (USGS 2011). By 2003, *A. lacustre* had invaded the Illinois River; by 2005 it had expanded to the upper Mississippi River (USGS 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
According to literature, to travel long distances upstream the species must be moved via ballast water or hull-fouling (Grigorovich et al. 2008). There is heavy boat traffic between Calumet Harbor and other ports in the Great Lakes. Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water

discharged at the ports along Lake Michigan is from other ports in all the other Great Lakes (NBIC 2012).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This is a generalist species; it tolerates a wide range of temperatures and habitat types. Benthos of rivers and tributaries of the Great Lakes would be suitable. Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species. The species tolerates pollution (Ysebaert 2000) and a wide range of temperatures based on existing distribution. The species is not found in fast-flowing or turbid water (Grigorovich et al. 2008). *A. lacustre* does well in relict oyster reefs (USGS 2011), so zebra mussel beds in the Great Lakes may be suitable.

Evidence for Probability Rating

Suitable climatological conditions and suitable habitat are present and accessible for a species that has a high invasion speed (sections 5a, 5b, 5d, 5f). Human-mediated dispersal will assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. Therefore, the probability of spread for this species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is good evidence available. Data gaps that do exist in fecundity, hull-fouling, and near-shore current effects are not significant and would not alter the probability rating. Therefore, the uncertainty of spread for this species is low.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Medium	Medium	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Medium	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The species is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles; therefore, there is no planktonic stage (Bousfield 1973). *A. lacustre* was first reported from fresh water in North America in 1987–1988 from the lower Mississippi River between 820 and 829 km (510 and 515 river miles [rm]) (Grigorovich et al. 2008). In 1989, it was detected downriver at 719 km (447 rm). It was first found in the Ohio River in 1996 and subsequently moved 1,149 km (714 mi) up the Ohio River within a year (Grigorovich et al. 2008). Based on these movement data, this species exhibits a very rapid invasion speed. By 2003, *A. lacustre* invaded the Illinois River and expanded into the upper Mississippi River in 2005 (USGS 2011). *"A. lacustre* rapidly expanded its range into the upper reaches of the Ohio and Illinois Rivers. These discontinuous rapid expansions within the upper Mississippi River waterway are attributed to shipping transport, most likely via hull fouling" (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
The species may be transported by attaching to boat hulls or ballast water, and vessel traffic is the fastest means of upstream spread (Grigorovich et al. 2008; Johnson et al. 2007). However, there is little ballast water discharge at ports near the Brandon Road Lock and Dam (NBIC 2012). Hull-fouling could be an important vector for the secondary spread of established freshwater aquatic nonindigenous species within the Great Lakes (Reid & Ruiz 2007). There is heavy commercial and recreational traffic

through the Brandon Road Lock and Dam from the lower MRB (USACE 2011b), suggesting a high probability of human-mediated transport.

c. *Current Abundance and Reproductive Capacity*
T_0: The species does not densely populate the MRB but can be locally abundant. “A kick sample from the upper Mississippi River in 2006 yielded 196 *A. lacustre* (density = 457 individuals/m^{-2}), but most samples had far fewer specimens. Population density of *A. lacustre* in the Ohio River increased from 6.7 (±6.3; standard deviation)/m^{-2} in 2004 to 15.7 (±31.1)/m^{-2} in 2006, and density in the upper Mississippi River increased from 65.6 (±87.3)/m^{-2} in 2005 to 87.3 (±182.1) individuals/m^{-2} in 2006; these differences, however, were not statistically significant” (Grigorovich et al. 2008).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers. This species is at or close to the pathway and moved through several locks as it moved northward from the lower MRB.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In 2005, *A. lacustre* was found in the Illinois River just above the Dresden Lock and Dam, less than 32.2 km (20 mi) from the Brandon Road Lock and Dam in the Illinois River (USGS 2011).
T_{10}: See T_0. The species may be closer to the pathway or at the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitat includes the benthos of estuaries, rivers, and lakes and intertidal zones in native estuarine habitat; in addition, the species has been collected on snags and in the benthos in the Ohio and upper Mississippi Rivers (Angradi et al. 2009). In the upper Mississippi River, it is associated with rocks and snags (Angradi et al. 2009); in the Ohio River where cobble and boulder habitats are less common, habitat is primarily sand and snags (Grigorovich et al. 2008). Based on existing distribution, the species tolerates a wide range of temperatures. *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000) and is not found in fast-flowing or turbid water (Grigorovich et al. 2008).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species does not densely populate the MRB but can be locally abundant (section 2d). *A. lacustre* is located less than 32.2 km (20 mi) from the Brandon Road Lock and Dam (section 2e) and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (sections 2a, 2b). There is heavy upbound boat traffic through the CAWS (section 2b), suggesting there is high potential for human-mediated transport to the Brandon Road Lock and Dam. *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000), and there is suitable habitat present in the vicinity of the Brandon Road Lock and Dam (section 2f) where populations could establish. Therefore, the probability of the species arriving at the Brandon Road Lock and Dam during this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been empirically verified to spread rapidly and over large distances via boat traffic. The last survey for this species was Grigorovich et al. 2008, so its current distribution is unclear, but it may currently be even closer than 32.2 km (20 mi) from the Brandon Road Lock and Dam. Therefore, the uncertainty of arrival for this species during this time step is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The scud is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
A. lacustre may be transported via ballast water and hull-fouling (Grigorovich et al. 2008; Johnson et al. 2007). There is cargo traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam (USACE 2011a; NBIC 2012), but vessel traffic to Indiana Harbor is lake-wide. Therefore, natural dispersal upstream through the Grand Calumet River may be required for *A. lacustre* to move through the Grand Calumet River to Indiana Harbor.

c. *Existing Physical Human/Natural Barriers*
T_0: The scud moved through several locks as it moved northward from the lower MRB, suggesting locks are not a barrier. The Grand Calumet River is shallow and turbid. The channel depth is 0.3 m (1 ft) or less in portions of the West Branch near the state line (LimnoTech 2010). There is no documentation of the species being collected at less than 2.5 m (8.2 ft) in depth (Grigorovich et al. 2008). There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a temporary barrier, especially under low flows.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *A. lacustre* is not found in fast-flowing or turbid water (Grigorovich et al. 2008). The pathway from the Brandon Road Lock and Dam and the mouth of Lake Michigan at Indiana Harbor is a slow-moving, turbid, eutrophic river averaging 0.13 m/s (0.43 ft/s) (LimnoTech 2010). The low flow of the Calumet Sag Channel may allow the species to naturally move upstream without assistance. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Suitable habitat includes rocky and/or sandy shoals (Angradi et al. 2009; Grigorovich et al. 2008). Vegetative and woody debris is very limited in the CAWS (LimnoTech 2010). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are suitable habitat for the species. The banks of the CSSC are vertical walls, rock, and some vegetative debris. Substrates in the CSSC are typically rock, cobble, or silt. The banks of the Calumet Sag Channel and the Grand Calumet River are vertical walls, rock, and some vegetative debris. Sediments can be

gravel to soft sediment. The species tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution. Water flows out of Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern-most sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, *A. lacustre* would be able to flow with the current out into Lake Michigan once it reached the eastern section of the Grand Calumet.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has moved hundreds of miles in a single year via vessel-mediated transport (section 3a). According to literature, *A. lacustre* requires human-mediated transport to travel far distances upstream (sections 3b, 3d), and there is vessel traffic from the Brandon Road Lock and Dam to the T. J. O'Brien Lock and Dam but not to Indiana Harbor. The low flow of water in the CAWS may allow the species to swim upstream (section 3d). Suitable habitat is present in portions of the CAWS (section 3e). The Grand Calumet River is turbid and shallow and may not be suitable for this species (section 3e). However, portions flow towards Lake Michigan and will allow the species to flow with current. Overall, the probability of passage during this time step is low.
T_{10}. See T_0. Given time to naturally spread upstream, the species may be able to move through the passage during this time step. The probability of passage increases to medium for this time step.
T_{25}: See T_{10}. *A. lacustre* is capable of spreading rapidly, and the probability of this species reaching Indiana Harbor increases over time. Therefore, the probability of passage increases to high for this time step.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: *A. lacustre* is a rapid invader and is documented to have moved hundreds of miles in a single year by vessel-mediated transport (section 3a). There is documented vessel traffic in the CAWS that could potentially transport this species upstream to the Chicago River, but upstream movement to Indiana Harbor may require natural dispersal. It is uncertain

whether the species will move through the shallow, turbid water of the Grand Calumet River. Overall, the uncertainty of passage for the species at this time step is medium.
T_{10}: See T_0.
T_{25}: See T_0. Over time it is more certain that this species will spread to Indiana Harbor. Therefore, uncertainty decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The species is common in ports on the Atlantic coast (Power et al. 2006). Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species. The species inhabits relict oyster reefs (USGS 2011), so zebra mussel beds in Lake Michigan may be suitable. The river and tributaries of the Great Lakes are also suitable habitat. *A. lacustre* tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution. It is not found in fast-flowing or turbid water; therefore, the near-shore high current of Lake Michigan may not be suitable for the species. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The harbor is considered suitable habitat for the species. The species is a sideswimmer (NEANS 2003) and may be able to swim, drift, or use human-mediated transport to reach suitable habitat adjacent to the pathway entrance.

Evidence for Probability Rating

Because appropriate habitat conditions are present (section 4a) and near the pathway entrance (section 4b), this element is rated a high probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

The near-shore high current of Lake Michigan may not be suitable for the species. However, the abundance of rocky shoals may provide protection. Therefore, the uncertainty of colonization for this species is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Based on existing distribution, the species tolerates a wide range of temperatures. It is native to the United States coast of the Atlantic Ocean (USGS 2011).

b. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed (Grigorovich et al. 2008).

c. *Fecundity*
No fecundity data are available. Females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973).

d. *History of Invasion Success*
A. lacustre was reported in 1987–1988 from the lower Mississippi River (Grigorovich et al. 2008). It was found in the Ohio River in 1996 and moved 1149 km (714 mi) up the Ohio within a year. By 2003, *A. lacustre* had invaded the Illinois River and in 2004 expanded to the upper Mississippi River (USGS 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
According to literature, to travel long distances upstream the species must be moved via ballast water or hull-fouling (Grigorovich et al. 2008). A large majority (884,618 tons) of lake-wide shipments originated in the state of Indiana, specifically Indiana Harbor (71%), providing numerous vessels to transport the species. Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water discharged at the ports along Lake Michigan is from other ports in all the other Great Lakes (NBIC 2012).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This is a generalist species; it tolerates a wide range of temperatures and habitat types. Benthos of rivers and tributaries of the Great Lakes would be suitable. Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species. Species tolerates pollution (Ysebaert 2000) and a wide range of temperatures based on existing distribution. It is not found in fast-flowing or turbid water (Grigorovich et al. 2008). *A. lacustre* does well

in relict oyster reefs (USGS 2011), so zebra mussel beds in the Great Lakes may be suitable.

Evidence for Probability Rating

Suitable climatological conditions and suitable habitat are present and accessible for a species that has a high invasion speed (sections 5a, 5b, 5d, 5f). Human-mediated dispersal will assist the species in spreading further from the pathway entrance (section 5e) to suitable habitat throughout the GLB. Therefore, the probability of spread for this species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is good evidence available. Data gaps that do exist in fecundity, hull-fouling, and near-shore current effects are not significant and would not alter the probability rating. Therefore, the uncertainty of spread for *A. lacustre* is low.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO THE BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Medium	Medium	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Medium	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The species is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles; therefore, there is no planktonic stage (Bousfield 1973). *A. lacustre* was first reported from fresh water in North America in 1987–1988 from the Lower Mississippi River between 820 and 829 km (510 and 515 river miles [rm]) from the mouth (Grigorovich et al. 2008). In 1989, it was detected downriver at 719 km (447 rm) (Grigorovich et al. 2008). It was first found in the Ohio River in 1996 and subsequently moved 1149 km (714 mi) up the Ohio River within a year (Grigorovich et al. 2008). Based on these movement data, this species exhibits a very rapid invasion speed. By 2003, *A. lacustre* had invaded the Illinois River; in 2005, its range had expanded to the upper Mississippi (USGS 2011). *"A. lacustre* rapidly expanded its range into the upper reaches of the Ohio and Illinois Rivers. These discontinuous, rapid expansions within the Upper Mississippi River waterway are attributed to shipping transport, most likely via hull-fouling" (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
This species is documented to be transported by attaching to boat hulls or ballast water, and vessel traffic is the fastest means of upstream spread (Grigorovich et al. 2008; Johnson et al. 2007). However, there is little ballast water discharge at ports near the Brandon Road Lock and Dam (NBIC 2012). Hull-fouling could be an important vector for the secondary spread of established freshwater aquatic nonindigenous aquatic species (NAS) (Reid & Ruiz 2007). There is also heavy commercial and recreational traffic through the Brandon Road Lock and Dam from the lower MRB (USACE 2011b), suggesting a high probability of human-mediated transport.

c. *Current Abundance and Reproductive Capacity*
T_0: The species does not densely populate the MRB but can be locally abundant. "A kick sample from the Upper Mississippi River in 2006 yielded 196 *A. lacustre* (density = 457 individuals/m^{-2}), but most samples had far fewer specimens. Population density of *A. lacustre* in the Ohio River increased from 6.7 (±6.3; standard deviation)/m^{-2} in 2004 to 15.7 (±31.1)/m^{-2} in 2006, and density in the upper Mississippi River increased from

65.6 (±87.3)/m^{-2} in 2005 to 87.3 (±182.1) individuals/m^{-2} in 2006; these differences, however, were not statistically significant" (Grigorovich et al. 2008).
T_{10}: See T_0. Abundance is expected to increase beyond T_0 levels.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers. This species is at or close to the pathway and moved through several locks as it moved northward from the lower MRB.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In 2005, *A. lacustre* was found in the Illinois River just above the Dresden Lock and Dam, less than 32 km (20 mi) from the Brandon Road Lock and Dam in the Illinois River (USGS 2011).
T_{10}: See T_0. The species may be closer to the pathway or at the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitat for *A. lacustre* includes the benthos of estuaries, rivers and lakes and intertidal zones in native estuarine habitat (Angradi et al. 2009); the species has been collected on snags and in the benthos in the Ohio and upper Mississippi Rivers (Angradi et al. 2009). In the upper Mississippi River, it is associated with rocks and snags (Angradi et al. 2009); in the Ohio River, where cobble and boulder habitats were less common, *A. lacustre* is primarily associated with sand and snags (Grigorovich et al. 2008). The species tolerates a wide range of temperatures based on existing distribution. *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000) and is not found in fast-flowing or turbid water (Grigorovich et al. 2008).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species does not densely populate the MRB but can be locally abundant (section 2d). *A. lacustre* is a pollution-tolerant species (Ysebaert et al. 2000), and there is suitable habitat present in the vicinity of the Brandon Road Lock and Dam (section 2f), where populations

could establish. *A. lacustre* is located less than 32 km (20 mi) from Brandon Road Lock and Dam (section 2e) and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (sections 2a, 2b). There is heavy upbound boat traffic through the CAWS from the lower MRB (section 2b), suggesting there is high potential for human transport to the Brandon Road Lock and Dam. Therefore, the probability of arrival during this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been empirically verified to spread rapidly and over large distances via boat traffic. Hull-fouling and natural species dispersal may occur. The last survey for this species was Grigorovich et al. (2008), so its current distribution is unknown, but it may currently be even closer than 32 km (20 mi) from the Brandon Road Lock and Dam. Therefore, the uncertainty of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). The scud is a sideswimmer (NEANS 2003). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed and is capable of increasing its range by hundreds of miles in a single year via vessel-mediated transport (Grigorovich et al. 2008). *A. lacustre* typically moves downstream, not upstream (Grigorovich et al. 2008).

b. Human-Mediated Transport through Aquatic Pathways
Transport may occur through ballast water and hull-fouling (Grigorovich et al. 2008). Most commercial traffic through the Illinois River moves to the T.J. O'Brien Lock and Dam (USACE 2011a; NBIC 2012). There is no cargo vessel traffic to the BSBH (USACE 2011a). Vessels could transport *A. lacustre* as far as the Little Calumet River.

Therefore, natural dispersal upstream through the south branch of the Little Calumet River and Burns Ditch, approximately 64 km (40 mi), would be required to move to the BSBH. There is small, nonmotorized, recreational boat use in the Little Calumet River that may assist in transporting the species.

c. *Existing Physical Human/Natural Barriers*
T_0: *A. lacustre* moved through several locks as it moved northward from the lower MRB, suggesting locks are not a barrier. A natural barrier is depth; both the Little Calumet and Burns Ditch are shallow. There is no documentation of the species being collected in depths less than 2.5 m (8.2 ft) (Grigorovich et al.2008).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *A. lacustre* is not found in fast-flowing or turbid water (Grigorovich et al. 2008). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the BSBH is a slow-moving, turbid, eutrophic river with a flow of 0.13 m/s (0.43 ft/s) (LimnoTech 2010). The low flow of the CAWS may allow the species to naturally move upstream without assistance. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Suitable habitat includes rocky and/or sandy shoals (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are suitable habitat for the species. Vegetative and woody debris is very limited in the CAWS (LimnoTech 2010). The banks of the CSSC are vertical walls, rock, and some vegetative debris. Substrate in the CSSC is typically rock, silt, or cobble (LimnoTech 2012). The Little Calumet River and Burns Ditch are both shallow water. The banks of the Calumet Sag Channel and the Little Calumet River are vertical walls, rock, and some vegetative debris. Sediments can be gravel to soft sediment (LimnoTech 2010). Species tolerates pollution (Ysebaert et al. 2000) and a wide range of temperatures based on existing distribution. Water flows out of BSBH into Lake Michigan. The eastern segment of the south branch of the Little Calumet River also generally flows toward Lake Michigan (GSWMD 2008). Thus, *A. lacustre* would be able to flow with the current out into Lake Michigan once it reached the eastern branch of the Little Calumet River.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has moved hundreds of miles in a single year via vessel-mediated transport (section 3a). According to literature, *A. lacustre* requires human-mediated transport to travel far distances upstream (sections 3b, 3d), and there is vessel traffic from the Brandon Road Lock and Dam to the T. J. O'Brien Lock and Dam but not to Indiana Harbor. The low flow of water in the CAWS may allow the species to swim upstream (section 3d). Suitable habitat is present in portions of the CAWS for the species (section 3e). The Calumet Sag Channel and the Little Calumet River are shallow and have a low flow. There is no documentation that the species survives at depths less than 2.5 m (8.2 ft) (section 3e). The portions of the Little Calumet River that flow toward Lake Michigan will allow the species to drift with current through the BSBH. Overall, the probability of passage for the species at this time step is low.
T_{10}: See T_0. Given time to naturally spread upstream, the species may be able to pass through the passage during this time step. The probability of passage increases to medium for this time step.
T_{25}: See T_{10}. *A. lacustre* is capable of spreading rapidly. Given time to establish in the CAWS, the species is likely to spread closer to the BSBH over time. Therefore, the probability of passage increases to high for this time step.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: *A. lacustre* is a rapid invader and is documented to have moved hundreds of miles in a single year by vessel-mediated transport (section 3a). There is documented vessel traffic in the CAWS that could potentially transport this species upstream to the Little Calumet River. Movement to the BSBH may require natural dispersal through the south branch of the Little Calumet River, and it is uncertain whether habitat is suitable in this waterway. Overall, the uncertainty of passage for *A. lacustre* at this time step is medium.
T_{10}: See T_0.
T_{25}: See T_0. Over time, it is more certain that this species will spread to Indiana Harbor. Therefore, uncertainty decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This species is common in ports on the Atlantic coast (Power et al. 2006). Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species. The species inhabits relict oyster reefs (USGS 2011), so zebra mussel beds in Lake Michigan may be suitable. The river and tributaries of the Great Lakes are suitable habitat for the species. The species tolerates pollution (Ysebaert 2000) and a wide range of temperatures based on existing distribution. It is not found in fast-flowing or turbid water; therefore, the high near-shore current of Lake Michigan may not be suitable for the species. The species has been collected from shallow 2.5- to 4-m (8.2- to 13.1-ft) depths (Grigorovich et al. 2008).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
A harbor is considered suitable habitat for the species. The species is a sideswimmer (NEANS 2003) and may be able to swim, drift, or use human-mediated transport to reach the sandy or rocky shoals adjacent to the pathway entrance.

Evidence for Probability Rating

Because appropriate habitat conditions are present (section 4a) and near the pathway entrance (section 4b), this element is rated a high probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

The high near-shore current of Lake Michigan may not be suitable for the species. However, the abundance of rocky shoals may provide protection. Therefore, the uncertainty of colonization for this species is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
This species tolerates a wide range of temperatures based on existing distribution. It is native to the United States coast of the Atlantic Ocean (USGS 2011).

b. *Type of Mobility/Invasion Speed*
A. lacustre is a tube-dwelling, benthic filter-feeding amphipod (Grigorovich et al. 2008). During reproduction, females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973). This species exhibits a very rapid invasion speed (Grigorovich et al. 2008).

c. *Fecundity*
No fecundity data are available. Females brood embryos on their underside, which hatch out as crawling juveniles (Bousfield 1973).

d. *History of Invasion Success*
The species was first reported in 1987–1988 from the lower Mississippi River (Grigorovich et al. 2008). It was found in the Ohio River in 1996 and moved 1149 km (714 mi) up the Ohio within a year (Grigorovich et al. 2008). By 2003, *A. lacustre* had invaded the Illinois River (USGS 2011); it expanded to the Upper Mississippi in 2005 (USGS 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
According to literature, to travel long distances upstream the species must be moved via ballast water or hull-fouling (Grigorovich et al. 2008). Ballast water is discharged and taken in at the CAWS ports along Lake Michigan. The majority of ballast water discharged at the ports along Lake Michigan is from other ports in all the other Great Lakes (NBIC 2012). A large majority (884,618 tons) of lake-wide shipments originate in the state of Indiana, specifically nearby Burns Harbor (12%), providing numerous vessels to transport the species (USACE 2011a).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This is a generalist species; the species tolerates a wide range of temperatures and habitat types. Benthos of rivers and tributaries of the Great Lakes would be suitable. Rocky and sandy shoals are suitable habitat for *A. lacustre* (Angradi et al. 2009; Grigorovich et al. 2008). Near-shore nonvegetated areas, potentially including manmade structures like a harbor, are considered suitable habitat for the species. The species tolerates pollution (Ysebaert et al.2000) and a wide range of temperatures based on existing distribution. It is not found in fast-flowing or turbid water (Grigorovich et al. 2008). *A. lacustre* does well in relict oyster reefs (USGS 2011), so zebra mussel beds in the Great Lakes may be suitable.

Evidence for Probability Rating

Suitable climatological conditions and suitable habitat are present and accessible for a species that has a high invasion speed (sections 4a, 4b, 4d, 4f). Human-mediated dispersal will assist the species in spreading further from the pathway entrance (section 4e) to suitable habitat throughout the GLB. It is for these reasons that *A. lacustre*is expected to have a high probability of spread.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is good evidence available. Data gaps that do exist in fecundity, hull-fouling, and near-shore current effects are not significant and would not alter the probability rating. Therefore, the uncertainty of spread for the species is low.

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E.1.3 Fish

E.1.3.1 Inland Silverside - *Menidia beryllina*

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	Medium	High	Medium	High	Medium	High	High
P(passage)	Low	Low	Medium	High	High	Medium	High	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. **P(pathway) T_0-T_{50}: HIGH**

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. **P(arrival) T_0-T_{50}: MEDIUM-HIGH**

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The inland silverside moves in large schools that can number in the tens of thousands (NatureServe 2010). They can travel far up streams and rivers, especially in the southern part of their range (NatureServe 2010). The species' natural spread rate through the MRB is not known because it has been actively stocked in lakes.

b. *Human-Mediated Transport through Aquatic Pathways*
There is no evidence that this species is transported by vessel traffic.

c. *Current Abundance and Reproductive Capacity*
T_0: The inland silverside is capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982). Most individuals spawn and die during their second summer (NatureServe 2010). Eggs hatch in 4–30 days at temperatures of 13–34°C (55.4–93.2°F) (Weinstein 1986); hatching is delayed at water temperatures below 19°C (66.2°F), which may cause embryos to exhaust nutrient supplies and starve to death prior to hatching (Hubbs et al. 1971). Females may produce eggs throughout the breeding season. The average lifespan of the inland silverside is about 16 months; few individuals survive their second winter (NatureServe 2010). Near the northern limit of its geographical range, the inland silverside has a unimodal reproductive season, whereas at southern latitudes the season can be unimodal or bimodal (Weinstein 1986). No data on current abundance in Illinois were found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In 1996, the inland silverside was recorded within 120 km (75 mi) of the pathway, in the Kankakee River in Will County, Illinois (Fuller & Nico 2012b). The species has also been collected in Illinois from Lake Baldwin, Lake of Egypt, Rend Lake, and the Cache, Wabash, Mississippi, Ohio, and Kankakee Rivers (Laird & Page 1996). The presence of the species in the Mississippi River in southern Illinois and in the lower Ohio River in Illinois and Kentucky is believed to be a result of natural dispersal (Fuller & Nico 2012a).
T_{10}: See T_0. Given time to naturally disperse, the species may move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The inland silverside's native range is confined to latitudes south of Illinois (Gilbert & Lee 1980). The species' native range is eastern North America, including the Atlantic and Gulf Slopes (mostly near the coast) from Massachusetts to the Rio Grande drainage, Texas, and southeastern New Mexico; and north from the Mississippi River and major tributaries (mainly Arkansas and Red Rivers) to southern Illinois and eastern Oklahoma

(Page & Burr 1991). The inland silverside is a marine species that ascends rivers (Fishbase 2010). It prefers estuaries, lagoons, brackish seas, rivers, streams (Fishbase 2010), lakes, coastal and freshwater habitats (NatureServe 2010), and reservoirs (Chizinski et al. 2007). The species is most abundant in the littoral zone (Lienesch & Gophen 2001) and prefers moderate to highly alkaline and euryhaline waters (NatureServe 2010). Huge aggregations of silversides have been reported over inundated vegetation and structures, such as docks (Wurtsbaugh & Li 1985). Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). The species migrates offshore both at dawn and in the afternoon to feed on zooplankton (Lienesch & Gophen 2001); the principal feeding period is in the morning (Weinstein 1986).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation, where the eggs attach to vegetation (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes.

The inland silverside is categorized as a subtropical species (Fishbase 2010). An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside survived several winters in southern Illinois; however, during severe winters complete winterkill also occurred. The brook silverside *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Changes in temperature related to future climate change may affect the expansion of this species; warmer temperatures may promote its northward expansion.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species may be within 120 km (75 mi) of Brandon Road Lock and Dam (section 2e) and can swim upstream to the pathway entrance (section 2a). Suitable habitat is present near Brandon Road Lock and Dam; however, it is unlikely that the inland silverside will be

able to consistently survive winter temperatures below Brandon Road Lock and Dam (section 2f). The inland silverside could be present at Brandon Road Lock and Dam during the warmer months. However, although it has been has been present in Illinois since at least 1996, it has not been recorded at Brandon Road Lock and Dam or the CAWS (Wasik & Minarik 2008). Based on its apparent lack of spread to northern Illinois and potentially prohibitive climate tolerances, this species has a medium probability of arriving at Brandon Road Lock and Dam during this time step.
T_{10}: See T_0. The inland silverside has been found in the Kankakee River and 10 years may be a sufficient length of time for the species to expand to the pathway. The inland silverside could be present at Brandon Road Lock and Dam during the warmer months and could potentially survive mild winters, raising the probability of arrival to high.
T_{25}: See T_0.
T_{50}: See T_0. The distribution of inland silverside appears to be determined by temperature, and increased temperatures may permit the northward expansion of this species.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The inland silverside has been collected in southern Illinois over 120 km (75 mi) from the pathway entrance. However, the uncertainty of arrival for the inland silverside is medium because the species' location in the Kankakee River is uncertain and no recent records for this species were found. The natural rate of spread for the inland silverside is uncertain. The literature suggests the climate in the vicinity of Brandon Road Lock and Dam will not be consistently suitable over time, although it would be suitable during the warmer months. Therefore, the uncertainty associated with the arrival of this species is medium for this time step.
T_{10}: See T_0. The climatological suitability of the Brandon Road Lock and Dam area remains uncertain. However, given time to disperse the species may naturally arrive at the pathway entrance. Therefore uncertainty for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be a sufficient length of time for the inland silverside to expand to the WPS pathway entrance. The future impacts of climate change on the distribution of this species are not documented. Therefore, uncertainty is high.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The inland silverside moves far up streams and rivers, especially in the southern part of its range (NatureServe 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic between Brandon Road Lock and Dam and the Chicago River, but this traffic does not go to WPS (USACE 2011a,b). Inland silverside actively swims and does not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. As part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), and there are ongoing studies on the efficacy of Barrier II with regard to small fish. Inland silverside typically do not grow to more than 10.2 cm (4 in.) (Weinstein 1986), which suggests the possibility that small inland silverside may be able to safely pass through the Electric Dispersal Barrier System at the water's surface where the current is weakest. Operation of the Electric Dispersal Barrier System may change over this time step to become more effective at deterring small fish. There are other potential mechanisms of Electric Dispersal Barrier System failure. For example, temporary power failures have occurred at the Electric Barrier Dispersal System. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additional potential barrier bypass vectors are currently under investigation and include reverse flow events in the canal (wind or current driven), electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge-induced water currents across the Electric Dispersal Barrier System. The sluice gate at the WPS also separates the CAWS from Lake Michigan. However, flow is occasionally reversed back into Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Huge aggregations of silversides have been documented over inundated areas with vegetation and structures such as docks (Wurtsbaugh & Li 1985). The inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-

Williams & Bonner 2007). Sand and gravel bottoms and manmade structures like docks are found through much of the CAWS (LimnoTech 2010).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation. The eggs attach to vegetation, and the young develop in lower-salinity areas of estuaries (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. There is low submerged aquatic macrophyte cover in all areas of the CAWS channel. Much of the CSSC has vertical limestone or manmade walls. Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River has vertical walls (LimnoTech 2010). Although living submerged aquatic vegetation is not common in the CAWS, it can be found at low densities in the CSSC and the North Shore Channel (LimnoTech 2010). Although it is not a dominant substrate component, plant debris is present in the CAWS (LimnoTech 2010).

Inland silverside is most abundant over firm substrates with high sand content and low percentages of organics. Population densities are low in areas where soft silts and reducing substrates (and consequently low dissolved oxygen) predominate (Weinstein 1986). Sediment texture does not influence habitat quality for inland silversides directly; however, grain size is a good indicator. Water movements fast enough to scour fine particles are most suitable; therefore, suitability decreases as the percentage of fine particles increases (Weinstein 1986). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010).

Inland silverside larvae avoid waters with dissolved oxygen (DO) below 3.8 mg/L (Weltzien et al. 1999). Adults have been found in a bay with DO ranging from 3.0 to 10.8 mg/L (Weltzien et al. 1999; Middaugh & Hemmer 1992). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L, but seasonal hypoxia may occur in portions of the CAWS (MWRD 2010).

An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the inland silverside is a function of its inability to consistently tolerate winter temperatures north of its native range. The species was able to overwinter in ponds in southern Illinois for several years, but the population did not survive a harsh winter. Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971). Effluent discharges increase water temperature in the CAWS year-round and may allow this species to survive there during the winter.

T_{10}: See T_0.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The passage through the WPS into the Great Lakes is blocked by the sluice gate (section 3c), which may temporarily slow the passage of this species through the WPS. There is no documentation that suggests the inland silverside may be transported by vessels, but this species is an active swimmer capable of long-distance migrations (section 3b). Physical habitat in the CAWS is suitable for adults, but spawning habitat may not be ideal (section 3d). Temperatures in the CAWS may be warm enough to support the inland silverside throughout the year. Overall, the probability of passage is low for this time step.
T_{10}: See T_0. The inland silverside is an active swimmer, and over 10 years the inland silverside may have adequate time to travel the 104.6 km (65 mi) from Brandon Road Lock and Dam to the WPS. The electric dispersal barrier system is not likely to control passage of this species due to its small size and surface swimming behavior. Inland silverside live only 2 years, so repeated introductions may be needed if the population does not survive winter. The probability of this species passing through this pathway is medium for this time step.
T_{25}: See T_{10}. Over time, the probability of passage increases, raising the probability to high.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The suitability of temperature and spawning habitat in the CAWS is not known; however, spawning is not required for passage and temperatures would be suitable for adults for much of the year (section 3d). The potential rate of movement of the inland silverside through the CAWS is uncertain. The literature suggests that multiple structures could act as barriers to the inland silverside (section 3c). Therefore, the uncertainty of this species passing through this pathway is low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species. The degree to which the electric dispersal barrier system would slow the upstream movement of this species is uncertain. The potential rate of movement of the inland silverside through the CAWS is uncertain. Whether 10 years is enough time for the species to pass through the barriers is uncertain. Therefore, uncertainty associated with passage is high for this time step.
T_{25}: See T_{10}. Inland silverside is an active swimmer. Therefore, over time it is more certain that the inland silverside will move upstream of the dams and pass through the CAWS. Therefore uncertainty is medium for this time step.

T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation (NatureServe 2010; Weinstein 1986). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shores of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012), in which the inland silverside can spawn (Weinstein 1986).

An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are lower than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986). Summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal

There is suitable physical habitat in Lake Michigan and its tributaries, and the inland silverside has the ability to swim to suitable habitat.

Evidence for Probability Rating

There is suitable adult and reproductive habitat in Lake Michigan (section 4a). However, the low winter temperature of southern Lake Michigan may deplete the species during a harsh winter (section 4a). Therefore, the probability of this species colonizing Lake Michigan is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether the species will be able to overwinter in southern Lake Michigan. The species may be able to survive in small numbers after a harsh winter; however, the population may not persist indefinitely. Therefore, the uncertainty of the species colonizing is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986); summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. Type of Mobility/Invasion Speed
Inland silversides are small, short-lived, highly fecund fish (NOAA 2006) that travel in large schools (NatureServe 2010).

c. Fecundity
Females of this species are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982).

d. History of Invasion Success
The species was intentionally stocked as forage for sport fish in most locations (Fuller & Nico 2012a). Two years after these fish were unintentionally introduced into Clear Lake, California, this species became the most abundant fish in the littoral zone (Moyle 1976). In Clear Lake, inland silversides were reported as having displaced native fishes,

including the hitch, *Lavinia exilicauda*; the Sacramento blackfish, *Orthodon microlepidotus*; and the now-extinct Clear Lake splittail, *Pogonichthys ciscoides*, apparently through competition for food (Cook & Moore 1970).

e. Human-Mediated Transport through Aquatic Pathways
The inland silverside is an active swimmer and does not require human-mediated transport to spread.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation. Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shore of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012), in which the inland silverside can spawn (Weinstein 1986). Areas of near-shore emergent herbaceous habitat in tributaries and rivers along the Great Lakes would provide suitable spawning habitat (unpublished data from USACE).

Evidence for Probability Rating

Although suitable habitat is available, low overwinter temperatures may keep the species from spreading throughout the Great Lakes (sections 5a, 5f). It is thought that the species' southern distribution is due to the cold winter climate of the upper Midwest (section 5a). Therefore, persistent populations are unlikely to develop, especially in more northern latitudes, thus reducing the probability of spread. Overall, the probability of this species spreading through the Great Lakes Basin is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is potential for this species to establish in the Great Lakes, but the existing literature suggests that a harsh winter could wipe out the species in the region or leave a small remnant population. Therefore, the uncertainty associated with this species spreading in the Great Lakes is medium.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	Medium	High	Medium	High	Medium	High	High
P(passage)	Low	Low	Medium	High	High	Medium	High	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
The inland silverside moves in large schools that can number in the tens of thousands (NatureServe 2010). They can travel far up streams and rivers, especially in the southern part of their range (NatureServe 2010). The species' natural spread rate through the MRB is not known because they have been actively stocked in lakes.

b. Human-Mediated Transport through Aquatic Pathways
There is no evidence that this species is transported by vessel traffic.

c. *Current Abundance and Reproductive Capacity*

T_0: The inland silverside is capable of producing 30,000 eggs a month (Stoeckel 1984). Female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982). Eggs hatch in 4–30 days at 13–34°C (55.4–93.2°F) (Weinstein 1986); hatching is delayed at water temperatures below 19°C (66.2°F), which may cause embryos to exhaust nutrient supplies and starve to death prior to hatching (Hubbs et al. 1971). Females may produce eggs throughout their breeding season. Most individuals spawn and die in their second summer (NatureServe 2010). Their average lifespan is about 16 months; few individuals survive their second winter (NatureServe 2010; Weinstein 1986). Near the northern limit of its geographical range, the inland silverside has a unimodal reproductive season, whereas at southern latitudes the season can be unimodal or bimodal (Weinstein 1986). No data on its current abundance in Illinois were found.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: In 1996, the inland silverside was recorded within 120 km (75 mi) of the pathway in the Kankakee River in Will County, Illinois (Fuller & Nico 2012b). The species has also been collected in Illinois from Lake Baldwin, Lake of Egypt, Rend Lake, and the Cache, Wabash, Mississippi, Ohio, and Kankakee Rivers (Laird & Page 1996). The presence of the species in the Mississippi River in southern Illinois and in the lower Ohio River in Illinois and Kentucky is believed to be a result of natural dispersal (Fuller & Nico 2012a).

T_{10}: See T_0. Given time to naturally disperse, the species may move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The inland silverside's native range is confined to latitudes south of Illinois (Gilbert & Lee 1980). The species' native range is eastern North America, including the Atlantic and Gulf Slopes (mostly near the coast) from Massachusetts to the Rio Grande drainage, Texas, and southeastern New Mexico; and north from the Mississippi River and major tributaries (mainly Arkansas and Red Rivers) to southern Illinois and eastern Oklahoma (Page & Burr 1991). The inland silverside is a marine species that ascends rivers (Fishbase 2010). It prefers estuaries, lagoons, brackish seas, rivers, streams (Fishbase 2010), lakes, coastal and freshwater habitats (NatureServe 2010), and reservoirs (Chizinski et al. 2007). The species is most abundant in the littoral zone

(Lienesch & Gophen 2001) and prefers moderate to highly alkaline and euryhaline waters (NatureServe 2010). Huge aggregations of silversides have been reported over inundated vegetation and structures, such as docks (Wurtsbaugh & Li 1985). Such habitat is present at the CRCW. Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). The species migrates offshore both at dawn and in the afternoon to feed on zooplankton (Lienesch & Gophen 2001); the principal feeding period is in the morning (Weinstein 1986).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation, where the eggs attach to vegetation (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes.

The inland silverside is categorized as a subtropical species (Fishbase 2010). An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside survived several winters in southern Illinois; however, during severe winters complete winterkill also occurred. The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future changes in temperature related to climate change may affect the expansion of this species; warmer temperatures may promote its northward expansion.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species may be within 120 km (75 mi) of Brandon Road Lock and Dam (section 2e) and can swim upstream to the pathway entrance (section 2a). Suitable habitat is present near Brandon Road Lock and Dam; however, it is unlikely that the inland silverside will be able to consistently survive winter temperatures below Brandon Road Lock and Dam (section 2f). The inland silverside could be present at Brandon Road Lock and Dam during the warmer months. However, although it has been has been present in Illinois since at least 1996, it has not been recorded at Brandon Road Lock and Dam or the CAWS (Wasik &

Minarik 2008). Based on its apparent lack of spread to northern Illinois and potentially prohibitive climate tolerances, this species has a medium probability of arriving at Brandon Road Lock and Dam during this time step.
T_{10}: See T_0. The inland silverside has been found in the Kankakee River, and 10 years may be a sufficient length of time for the species to expand to the pathway. The inland silverside could be present at Brandon Road Lock and Dam during the warmer months and could potentially survive mild winters, raising the probability of arrival to high.
T_{25}: See T_0.
T_{50}: See T_0. The distribution of inland silverside appears to be determined by temperature, and increased temperatures may permit the northward expansion of this species.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The inland silverside has been collected in southern Illinois, over 120 km (75 mi) from the pathway entrance. However, the uncertainty of arrival for the inland silverside is medium because the species' location in the Kankakee River is uncertain and no recent records for this species were found. The natural rate of spread for the inland silverside is uncertain. The literature suggests climate in the vicinity of Brandon Road Lock and Dam will not be consistently suitable over time, although it would be suitable during the warmer months. Therefore, the uncertainty associated with the arrival of this species is medium for this time step.
T_{10}: See T_0. The climatological suitability of the Brandon Road Lock and Dam area remains uncertain. However, given time to disperse, the species may naturally arrive at the pathway entrance. Therefore, uncertainty for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be a sufficient length of time for the inland silverside to expand to the CRCW pathway entrance. The future impacts of climate change on the distribution of this species are not documented. Therefore, uncertainty is high.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The inland silverside swims far up streams and rivers, especially in the southern part of its range (NatureServe 2010). The distance from the Brandon Road Lock and Dam to the CRCW is greater than 56 km (35 mi). The rate of natural dispersion of the inland silverside is not well known.

b. *Human-Mediated Transport through Aquatic Pathways*
There is some commercial and recreational vessel traffic between Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b). Inland silverside actively swims and does not require humans for dispersal. Natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. As part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), and there are ongoing studies on the efficacy of Barrier II with regard to small fish. Inland silverside typically do not grow to more than 10.2 cm (4 in.) (Weinstein 1986), which suggests the possibility that small inland silverside may be able to safely pass through the Electric Dispersal Barrier System at the water's surface where the current is weakest. Operation of the Electric Dispersal Barrier System may change over this time step to become more effective at deterring small fish. There are other potential mechanisms of Electric Dispersal Barrier System failure. For example, temporary power failures have occurred at the Electric Barrier Dispersal System. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additional potential barrier bypass vectors are currently under investigation and include reverse flow events in the canal (wind or current driven), electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge-induced water currents across the Electric Dispersal Barrier System.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Huge aggregations of silversides have been reported over inundated vegetation and structures such as docks (Wurtsbaugh & Li 1985). Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). Sand and gravel bottoms and manmade structures such as docks are found through much of the CAWS (LimnoTech 2010).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation. The eggs attach to vegetation, and the young develop in lower-salinity areas of estuaries (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. There is low submerged aquatic macrophyte cover in all areas of the CAWS channel. Much of the CSSC has vertical limestone or manmade walls, and virtually all (>90%) of the Chicago River has vertical walls (LimnoTech 2010). Although living submerged aquatic vegetation is not common in the CAWS, it can be found in the CSSC in low densities (LimnoTech 2010). Although it is not a dominant substrate component, plant debris is present in the CAWS (LimnoTech 2010).

Inland silverside is most abundant over firm substrates with high sand content and low percentages of organics. Population densities are low in areas where soft silts and reducing substrates (and consequently low dissolved oxygen) predominate (Weinstein 1986). Sediment texture does not influence habitat quality for inland silversides directly; however, grain size is a good indicator. Water movements fast enough to scour fine particles are most suitable; therefore, suitability decreases as the percentage of fine particles increases (Weinstein 1986). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010).

Inland silverside larvae avoid waters with DO below 3.8 mg/L (Weltzien et al. 1999). Adults have been found in a bay with a DO range from 3.0 to 10.8 mg/L (Weltzien et al. 1999; Middaugh & Hemmer 1992). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L, but seasonal hypoxia may occur in portions of the CAWS (MWRD 2010).

An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. It was able to overwinter in ponds in southern Illinois for several years, but the population did not survive a harsh winter. Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971). Effluent discharge in the CAWS increases water temperature in the CAWS year-round and may allow this species to survive there during the winter.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is no documentation that suggests the species may be transported by vessels, but the inland silverside is an active swimmer capable of long distance migrations (section 3b). Physical habitat in the CAWS is suitable for adults, but spawning habitat may not be ideal

(section 3d). Temperatures in the CAWS may be warm enough to support the inland silverside throughout the year. Overall, the probability of passage is low for this time step.
T_{10}: See T_0. The inland silverside is an active swimmer, and over 10 years the inland silverside may have adequate time to travel from Brandon Road Lock and Dam to the CRCW. Inland silversides live only 2 years, so repeated introductions may be needed if the population does not survive winter. The probability of this species passing through this pathway is medium for this time step.
T_{10}: See T_0. Conditions in the CAWS (e.g., dam controls and vegetation cover) are not likely to change in ways that would facilitate the active unaided dispersal of this species. The inland silverside is an active swimmer, and over 10 years it may have adequate time to travel from Brandon Road Lock and Dam to the CRCW. The Electric Dispersal Barrier System is not likely to control passage of this species, due to its small size and surface swimming behavior. Inland silversides live only 2 years, so repeated introductions may be necessary if the population does not survive the winter. The probability of this species passing through this pathway is medium for this time step.
T_{25}: See T_{10}. Over time, the probability of passage increases, raising the probability to high.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The suitability of temperature and spawning habitat in the CAWS is not known; however, spawning is not required for passage and temperatures would be suitable for adults for much of the year (section 3d). The potential rate of movement of the inland silverside through the CAWS is uncertain. The literature suggests that multiple structures could act as barriers to the inland silverside (section 3c). Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species. The degree to which the Electric Dispersal Barrier System would slow the upstream movement of this species is uncertain. The potential rate of movement of the inland silverside through the CAWS is uncertain. Whether 10 years is enough time for the species to pass through the barriers is uncertain. Therefore, uncertainty associated with passage is high for this time step.
T_{25}: See T_{10}. Inland silverside is an active swimmer. Therefore, over time it is more certain that the inland silverside will move upstream of the dams and pass through the CAWS. Therefore, uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation (NatureServe 2010; Weinstein 1986). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shore of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012), in which the inland silverside can spawn (Weinstein 1986).

   An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986); summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   There is suitable physical habitat in Lake Michigan and its tributaries, and the inland silverside has the ability to swim to suitable habitat.

Evidence for Probability Rating

There is suitable adult and reproductive habitat in Lake Michigan (section 4a). However, the low winter temperature of southern Lake Michigan may deplete the species during a harsh winter (section 4a). Therefore, the probability of this species colonizing in Lake Michigan is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether the species will be able to overwinter in southern Lake Michigan. The species may be able to survive in small numbers after a harsh winter; however, the

populations may not persist indefinitely. Therefore, the uncertainty of the species colonizing is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986). Summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. *Type of Mobility/Invasion Speed*
Inland silversides are small, short-lived, highly fecund fish (NOAA 2006) that travel in large schools (NatureServe 2010).

c. *Fecundity*
Females of this species are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982).

d. *History of Invasion Success*
The species was intentionally stocked as forage for sport fish in most locations (Fuller & Nico 2012a). Two years after these fish were unintentionally introduced into Clear Lake, California, this species became the most abundant fish in the littoral zone (Moyle 1976). In Clear Lake, inland silversides were reported as having displaced native fishes, including the hitch, *Lavinia exilicauda*; the Sacramento blackfish, *Orthodon microlepidotus*; and the now-extinct Clear Lake splittail, *Pogonichthys ciscoides*, apparently through competition for food (Cook & Moore 1970).

d. *Human-Mediated Transport through Aquatic Pathways*
The inland silverside is an active swimmer and does not require human-mediated transport to spread.

e. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation. Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shore of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012), in which the inland silverside can spawn (Weinstein 1986). Areas of near-shore emergent herbaceous habitat in tributaries and rivers along the Great Lakes would provide suitable spawning habitat (unpublished data from USACE).

Evidence for Probability Rating

Although suitable habitat is available, the low overwinter temperature may keep the species from spreading throughout the Great Lakes (sections 5a, 5f). It is thought that the species' southern distribution is due to the cold winter climate of the upper Midwest (section 5a). Therefore, persistent populations are unlikely to develop, especially in more northern latitudes, which would reduce the probability of spread. Overall, the probability of this species spreading through the Great Lakes Basin is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is potential for this species to establish in the Great Lakes, but the existing literature suggests that a harsh winter could wipe out the species in the region or leave a small population. Therefore, the uncertainty associated with this species spreading in the Great Lakes is medium.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	Medium	High	Medium	High	Medium	High	High
P(passage)	Low	Low	Medium	High	High	Medium	High	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The inland silverside moves in large schools that can number in the tens of thousands (NatureServe 2010). They can travel far up streams and rivers, especially in the southern part of their range (NatureServe 2010). The species' natural spread rate through the MRB is not known because it has been actively stocked in lakes.

b. *Human-Mediated Transport through Aquatic Pathways*
There is no evidence that this species is transported by vessel traffic.

c. *Current Abundance and Reproductive Capacity*

T_0: Female inland silversides are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982). Eggs hatch in 4–30 days at 13–34°C (55.4–93.2°F) (Weinstein 1986); hatching is delayed at water temperatures below 19°C (66.2°F), which may cause embryos to exhaust nutrient supplies and starve to death prior to hatching (Hubbs et al. 1971). Females may produce eggs throughout breeding the season. Most individuals spawn and die their second summer of life (NatureServe 2010). The average lifespan of inland silversides is about 16 months; few individuals survive their second winter (NatureServe 2010). Near the northern limit of their geographical range, inland silversides have a unimodal reproductive season, but at southern latitudes the season can be unimodal or bimodal (Weinstein 1986). No data on current abundance in Illinois were found.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: In 1996, the inland silverside was recorded within 120 km (75 mi) of the pathway in the Kankakee River in Will County, Illinois (Fuller & Nico 2012b). The species has also been collected in Illinois from Lake Baldwin, Lake of Egypt, Rend Lake, and the Cache, Wabash, Mississippi, Ohio, and Kankakee Rivers (Laird & Page 1996). The presence of the species in the Mississippi River in southern Illinois and in the lower Ohio River in Illinois and Kentucky is believed to be a result of natural dispersal (Fuller & Nico 2012a).

T_{10}: See T_0. Given time to naturally disperse, the species may move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The inland silverside's native range is confined to latitudes south of Illinois (Gilbert & Lee 1980). Its native range is eastern North America, including the Atlantic and Gulf Slopes (mostly near the coast) from Massachusetts to the Rio Grande drainage, Texas, and southeastern New Mexico; and north from the Mississippi River and major tributaries (mainly Arkansas and Red Rivers) to southern Illinois and eastern Oklahoma (Page & Burr 1991). The inland silverside is a marine species that ascends rivers (Fishbase 2010). It prefers estuaries, lagoons, brackish seas, rivers, streams (Fishbase 2010), lakes, coastal and freshwater habitats (NatureServe 2010), and reservoirs (Chizinski et al. 2007). The species is most abundant in the littoral zone

(Lienesch & Gophen 2001) and prefers moderate to highly alkaline and euryhaline waters (NatureServe 2010). Huge aggregations of silversides have been reported over inundated vegetation and structures such as docks (Wurtsbaugh & Li 1985); therefore, Calumet Harbor would likely be suitable. Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). The species migrates offshore both at dawn and in the afternoon to feed on zooplankton (Lienesch & Gophen 2001); the principal feeding period is in the morning (Weinstein 1986).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922). They spawn over beds of aquatic vegetation or among emergent vegetation, where the eggs attach to vegetation (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes.

The inland silverside is categorized as a subtropical species (Fishbase 2010). An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implied that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside survived several winters in southern Illinois; however, during severe winters complete winterkill also occurred. The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel and Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future changes in temperature related to climate change may affect the expansion of this species; warmer temperatures may promote its northward expansion.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species may be present within 120 km (75 mi) of Brandon Road Lock and Dam (section 2e) and can swim upstream to the pathway entrance (section 2a). Suitable habitat is present near Brandon Road Lock and Dam; however, it is unlikely that the inland silverside will be able to consistently survive winter temperatures below Brandon Road Lock and Dam (section 2f). The inland silverside could be present at Brandon Road Lock and Dam during the warmer months. However, although it has been has been present in Illinois since

at least 1996, it has not been recorded at Brandon Road Lock and Dam or the CAWS (Wasik & Minarik 2008). Based on its apparent lack of spread to northern Illinois and potentially prohibitive climate tolerances, this species has a medium probability of arriving at Brandon Road Lock and Dam during this time step.
T_{10}: See T_0. The inland silverside has been found in the Kankakee River, and 10 years may be a sufficient length of time for it to expand to the pathway. The inland silverside could be present at Brandon Road Lock and Dam during the warmer months and could potentially survive mild winters, raising the probability of arrival to high.
T_{25}: See T_0.
T_{50}: See T_0. The distribution of inland silverside appears to be determined by temperature, and increased temperatures may permit the northward expansion of this species.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The inland silverside has been collected in southern Illinois over 120 km (75 mi) from the pathway entrance. However, the uncertainty of arrival for the inland silverside is medium because the species' location in the Kankakee River is uncertain and no recent records for this species were found. The natural rate of spread for the inland silverside is uncertain. The literature suggests climate in the vicinity of Brandon Road Lock and Dam will not be consistently suitable over time, although it would be suitable during the warmer months. Therefore, the uncertainty associated with the arrival of this species is medium for this time step.
T_{10}: See T_0. The climatological suitability of the Brandon Road Lock and Dam area remains uncertain. However, given time to disperse, the species may naturally arrive at the pathway entrance. Therefore, uncertainty for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be a sufficient length of time for the inland silverside to expand to the Calumet Harbor pathway entrance. The future impacts of climate change on the distribution of this species are not documented. Therefore, uncertainty is high.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The inland silverside swims far up streams and rivers, especially in the southern part of its range (NatureServe 2010). The distance from the Calumet Harbor to Brandon Road

Lock and Dam is greater than 56 km (35 mi). The rate of natural dispersion of the inland silverside is not well known.

b. *Human-Mediated Transport through Aquatic Pathways*
Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Inland silverside actively swims and does not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, as part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), and there are ongoing studies on the efficacy of Barrier II with regard to small fish. Inland silverside typically do not grow to more than 10.2 cm (4 in.) (Weinstein 1986), which suggests the possibility that small inland silverside may be able to safely pass through the Electric Dispersal Barrier System at the water's surface where the current is weakest. Operation of the Electric Dispersal Barrier System may change over this time step to become more effective at deterring small fish. There are other potential mechanisms of Electric Dispersal Barrier System failure. For example, temporary power failures have occurred at the Electric Barrier Dispersal System. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additional potential barrier bypass vectors are currently under investigation and include reverse flow events in the canal (wind or current driven), electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge-induced water currents across the Electric Dispersal Barrier System. The T.J. O'Brien Lock and Dam on the Calumet River blocks the passage from the river into Lake Michigan through Calumet Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Huge aggregations of silversides have been reported over inundated vegetation and structures such as docks (Wurtsbaugh & Li 1985). Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). Sand and gravel bottoms and manmade structures such as docks are found through much of the CAWS (LimnoTech 2010).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation. The eggs attach to vegetation, and the young develop in lower-salinity areas of estuaries (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. There is low submerged aquatic macrophyte cover in all areas of the CAWS channel. Much of the CSSC and the Calumet Sag Channel have vertical limestone or manmade walls (LimnoTech 2010). Although living submerged aquatic vegetation is not common in the CAWS, it can be found in the CSSC at low densities (LimnoTech 2010). Plant debris is present in the CAWS, but it is not a dominant substrate component (LimnoTech 2010).

Inland silverside is most abundant over firm substrates with high sand content and low percentages of organics. Population densities are low where soft silts and reducing substrates (and consequently low dissolved oxygen) predominate (Weinstein 1986). Sediment texture does not influence habitat quality for inland silversides directly; however, grain size is a good indicator. Water movements fast enough to scour fine particles are most suitable; therefore, suitability decreases as the percentage of fine particles increases (Weinstein 1986). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010).

Inland silverside larvae avoid waters with DO below 3.8 mg/L (Weltzien et al. 1999). Adults have been found in a bay with a DO range from 3.0 to 10.8 mg/L (Weltzien et al. 1999; Middaugh & Hemmer 1992). Although seasonal hypoxia may occur in portions of the CAWS, annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L (MWRD 2010).

An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. It was able to overwinter in ponds in southern Illinois for several years, but populations did not survive a harsh winter. Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971). Effluent discharge in the CAWS increases water temperature in the CAWS year-round and may allow this species to survive there during the winter.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is no documentation that suggests the species may be transported by vessels, but this species is an active swimmer capable of long-distance migrations (section 3b). Physical habitat in the CAWS is suitable for adults, but spawning habitat may not be ideal (section 3d). Temperatures in the CAWS may be warm enough to support the inland silverside throughout the year. Overall, the probability of passage is low for this time step.
T_{10}: See T_0. The inland silverside is an active swimmer, and over 10 years the species may have adequate time to travel from Brandon Road Lock and Dam to the Calumet Harbor. The Electric Dispersal Barrier System is not likely to control passage of this species due to its small size and surface swimming behavior. Inland silversides live only 2 years, so repeated introductions may be needed if the population does not survive winter. The probability of this species passing through this pathway is medium for this time step.
T_{25}: See T_{10}. Over time the probability of passage increases, raising the probability to high.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The suitability of temperature and spawning habitat in the CAWS is not known; however, spawning is not required for passage and temperatures would be suitable for adults for much of the year (section 3d). The potential rate of movement of the inland silverside through the CAWS is uncertain. The literature suggests that there are multiple structures that could act as barriers to the inland silverside (section 3c). Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species. The degree to which the Electric Dispersal Barrier System would slow the upstream movement of this species is uncertain. The potential rate of movement of the inland silverside through the CAWS is uncertain. Whether 10 years is enough time for the species to pass through the barriers is uncertain. Therefore, uncertainty associated with passage is high for this time step.
T_{25}: See T_{10}. Inland silverside is an active swimmer. Therefore, over time it is more certain that the inland silverside will move upstream of the dams and pass through the CAWS. Therefore, uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation (NatureServe 2010; Weinstein 1986). Weinstein (1986) states that the preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shore of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012), in which the inland silverside can spawn (Weinstein 1986).

   An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986). Summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   There is suitable physical habitat in Lake Michigan and its tributaries, and the inland silverside has the ability to swim to suitable habitat.

Evidence for Probability Rating

There is suitable adult and reproductive habitat in Lake Michigan (section 4a). However, the low winter temperature of southern Lake Michigan could deplete the species during a harsh winter (section 4a). Therefore, the probability of this species colonizing in Lake Michigan is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether the species will be able to over winter in southern Lake Michigan. The species may be able to survive in small numbers after a harsh winter; however, the

populations may not persist indefinitely. Therefore, the uncertainty of the species colonizing is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986). Summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. *Type of Mobility/Invasion Speed*
Inland silversides are small, short-lived, highly fecund fish (NOAA 2006) that travel in large schools (NatureServe 2010).

c. *Fecundity*
Females of this species are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982).

d. *History of Invasion Success*
The species was intentionally stocked as forage for sport fish in most locations (Fuller & Nico 2012a). Two years after these fish were unintentionally introduced into Clear Lake, California, this species became the most abundant fish in the littoral zone (Moyle 1976). In Clear Lake, inland silversides were reported as having displaced native fishes, including the hitch, *Lavinia exilicauda*; the Sacramento blackfish, *Orthodon microlepidotus*; and the now-extinct Clear Lake splittail, *Pogonichthys ciscoides*, apparently through competition for food (Cook & Moore 1970).

e. *Human-Mediated Transport through Aquatic Pathways*
   The inland silverside is an active swimmer and does not require human-mediated transport to spread.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation. Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shore of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012) in which the inland silverside can spawn (Weinstein 1986). Areas of near-shore emergent herbaceous habitat in tributaries and rivers along the Great Lakes would provide suitable spawning habitat (unpublished data from USACE).

Evidence for Probability Rating

Although suitable habitat is available, low overwintering temperatures may keep the species from spreading throughout the Great Lakes (sections 5a, 5f). It is thought that the species' southern distribution is due to the cold winter climate of the upper Midwest (section 5a). Therefore, persistent populations are unlikely to develop, especially in more northern latitudes, which reduces the probability of spread. Overall, the probability of this species spreading through the GLB is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is potential for this species to establish in the Great Lakes, but the existing literature suggests that a harsh winter could wipe out the species in the region or leave a small remnant population. Therefore, the uncertainty associated with this species spreading in the Great Lakes is medium.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	Medium	High	Medium	High	Medium	High	High
P(passage)	Low	Low	Medium	High	High	Medium	High	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The inland silverside moves in large schools that can number in the tens of thousands (NatureServe 2010). They can travel far up streams and rivers, especially in the southern part of their range (NatureServe 2010). The species' natural spread rate through the MRB is not known because it has been actively stocked in lakes.

b. *Human-Mediated Transport through Aquatic Pathways*
There is no evidence that this species is transported by vessel traffic.

c. *Current Abundance and Reproductive Capacity*

T_0: Females of the species are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982). Females may produce eggs throughout the breeding season. Eggs hatch in 4–30 days at 13–34°C (55.4–93.2°F) (Weinstein 1986); hatching is delayed at water temperatures below 19°C (66.2°F), which may cause embryos to exhaust nutrient supplies and starve to death prior to hatching (Hubbs et al. 1971). Most individuals spawn and die in their second summer (NatureServe 2010). Adult inland silversides live to about 16 months; few individuals survive their second winter (NatureServe 2010). Near the northern limit of their geographical range, inland silversides have a unimodal reproductive season, but at southern latitudes the season is unimodal or bimodal (Weinstein 1986). No data on the species' current abundance in Illinois were found.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: In 1996, the inland silverside was recorded within 120 km (75 mi) of the pathway in the Kankakee River in Will County, Illinois (Fuller & Nico 2012b). The species has also been collected in **Illinois** from Lake Baldwin, Lake of Egypt, Rend Lake, and the Cache, Wabash, Mississippi, Ohio, and Kankakee Rivers (Laird & Page 1996). It is believed that the presence of the species in the Mississippi River in southern Illinois and in the lower Ohio River in Illinois and Kentucky are a result of natural dispersal (Fuller & Nico 2012a).

T_{10}: See T_0. Given time to naturally disperse, the species may move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical and Climatological)*

T_0: The inland silverside's native range is confined to latitudes south of Illinois (Gilbert & Lee 1980). The species native range is eastern North America, including the Atlantic and Gulf Slopes (mostly near the coast) from Massachusetts to the Rio Grande drainage, Texas, and southeastern New Mexico; and north from the Mississippi River and major tributaries (mainly Arkansas and Red Rivers) to southern Illinois and eastern Oklahoma (Page & Burr 1991). The inland silverside is a marine species that ascends rivers (Fishbase 2010). It prefers estuaries, lagoons, brackish seas, rivers, streams (Fishbase 2010), lakes, coastal and freshwater habitats (NatureServe 2010), and reservoirs (Chizinski et al. 2007). The species is most abundant in the littoral zone

(Lienesch & Gophen 2001) and prefers moderate to highly alkaline and euryhaline waters (NatureServe 2010). Huge aggregations of silversides have been reported over inundated vegetation and structures such as docks (Wurtsbaugh & Li 1985). Thus, Indiana Harbor would likely be suitable. Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). The species migrates offshore both at dawn and in the afternoon to feed on zooplankton (Lienesch & Gophen 2001); the principal feeding period is in the morning (Weinstein 1986).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922). They spawn over beds of aquatic vegetation or among emergent vegetation, where the eggs attach to vegetation (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes.

The inland silverside is categorized as a subtropical species (Fishbase 2010). An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside survived several winters in southern Illinois; however, during severe winters complete winterkill also occurred. The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel and Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Changes in temperature related to future climate change may affect the expansion of this species; warmer temperatures may promote its northward expansion.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species may be within 120 km (75 mi) of Brandon Road Lock and Dam (section 2e) and can swim upstream to the pathway entrance (section 2a). Suitable habitat is present near Brandon Road Lock and Dam; however, it is unlikely that the inland silverside will be able to consistently survive winter temperatures below Brandon Road Lock and Dam (section 2f). The inland silverside could be present at Brandon Road Lock and Dam during the warmer months. However, although it has been has been present in Illinois since at

least 1996, it has not been recorded at Brandon Road Lock and Dam or the CAWS (Wasik & Minarik 2008). Based on its apparent lack of spread to northern Illinois and its potentially prohibitive climate tolerances, this species has a medium probability of arriving at Brandon Road Lock and Dam during this time step.
T_{10}: See T_0. The inland silverside has been found in the Kankakee River, and 10 years may be a sufficient length of time for it to expand to the pathway. The inland silverside could be present at Brandon Road Lock and Dam during the warmer months and could potentially survive mild winters, raising the probability of arrival to high.
T_{25}: See T_0.
T_{50}: See T_0. The distribution of inland silverside appears to be determined by temperature, and increased temperatures may permit the northward expansion of this species.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The inland silverside has been collected in southern Illinois, over 120 km (75 mi) from the pathway entrance. However, the uncertainty of arrival for the inland silverside is medium since the species' location in the Kankakee River is uncertain and no recent records for this species were found. The natural rate of spread for the inland silverside is also uncertain. The literature suggests climate in the vicinity of Brandon Road Lock and Dam will not be consistently suitable over time, although it would be suitable during the warmer months. Therefore, the uncertainty associated with the arrival of this species is medium for this time step.
T_{10}: See T_0. The climatological suitability of the Brandon Road Lock and Dam area remains uncertain. However, given time to disperse the species may naturally arrive at the pathway entrance. Therefore uncertainty for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be a sufficient length of time for the inland silverside to expand to the Indiana Harbor pathway entrance. The future impacts of climate change on the distribution of this species are not documented. Therefore, uncertainty is high.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The inland silverside swims far up streams and rivers, especially in the southern part of its range (NatureServe 2010). The distance from the Brandon Road Lock and Dam to

Indiana Harbor is greater than 56 km (35 mi). The rate of natural dispersion of the inland silverside is not well known.

b. *Human-Mediated Transport through Aquatic Pathways*

Most commercial vessel traffic to Indiana Harbor is lake-wise, and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (USACE 2011a; NBIC 2012). There is little, if any, vessel traffic in the Grand Calumet River due to its shallow depth, and inland silverside actively swims and does not require humans for dispersal; therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, as part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), and there are ongoing studies on the efficacy of Barrier II with regard to small fish. Inland silverside typically do not grow to more than 10.2 cm (4 in.) (Weinstein 1986), which suggests the possibility that small inland silverside may be able to safely pass through the Electric Dispersal Barrier System at the water's surface where the current is weakest. Operation of the Electric Dispersal Barrier System may change over this time step to become more effective at deterring small fish. There are other potential mechanisms of Electric Dispersal Barrier System failure. For example, temporary power failures have occurred at the Electric Barrier Dispersal System. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additional potential barrier bypass vectors are currently under investigation and include reverse flow events in the canal (wind or current driven), electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge-induced water currents across the Electric Dispersal Barrier System. These mechanisms may allow inland silverside to move upstream of the Electric Barrier Dispersal System.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical and Climatological)*

T_0: Huge aggregations of silversides have been reported over inundated vegetation and structures such as docks (Wurtsbaugh & Li 1985). Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, but then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). Sand and gravel bottoms and manmade structures such as docks are found through much of the CAWS (LimnoTech 2010).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation. The eggs attach to vegetation, and the young develop in lower-salinity areas of estuaries (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. There is low submerged aquatic macrophyte cover in all areas of the CAWS channel. Much of the CSSC and the Calumet Sag Channel have vertical limestone or manmade walls (LimnoTech 2010). Although living submerged aquatic vegetation is not common in the CAWS, it can be found in the CSSC at low densities. The Grand Calumet River can be less than 0.3 m (1 ft) in depth in areas of the West Branch near the state line (LimnoTech 2010). The Grand Calumet has a vegetated shoreline and areas of emergent marsh. Although it is not a dominant substrate component, plant debris is present in the CAWS (LimnoTech 2010).

Inland silverside is most abundant over firm substrates with high sand content and low percentages of organics. Population densities are low where soft silts and reducing substrates (and consequently low dissolved oxygen) predominate (Weinstein 1986). Sediment texture does not influence habitat quality for inland silversides directly; however, grain size is a good indicator. Water movements fast enough to scour fine particles are most suitable; therefore, suitability decreases as the percentage of fine particles increases (Weinstein 1986). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010).

The inland silverside larvae avoid waters with DO below 3.8 mg/L (Weltzien et al. 1999). Adults have been found in a bay with a DO range from 3.0 to 10.8 mg/L (Weltzien et al. 1999; Middaugh & Hemmer 1992). Although seasonal hypoxia may occur in portions of the CAWS, annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L (MWRD 2010).

An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. It was able to overwinter in ponds in southern Illinois for several years, but the population did not survive a harsh winter (Stoeckel & Heidinger 1998). Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F) (Hubbs et al. 1971). Optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971). Effluent discharge in the CAWS increases water temperature in the CAWS year-round and may allow this species to survive there during the winter.
T_{10}: See T_0.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0 There is no documentation that suggests inland silverside may be transported by vessels, but this species is an active swimmer capable of long-distance migrations (section 3b). Physical habitat in the CAWS is suitable for adults, but spawning habitat may not be ideal (section 3d). Temperatures in the CAWS may be warm enough to support the inland silverside throughout the year. Overall, the probability of passage is low for this time step.
T_{10}: See T_0. The inland silverside is an active swimmer, and over 10 years the inland silverside may have adequate time to travel from Brandon Road Lock and Dam to Indiana Harbor. The Electric Dispersal Barrier System is not likely to control passage of this species due to its small size and surface swimming behavior. Inland silversides live only 2 years, so repeated introductions may be needed if the population does not survive winter. The probability of this species passing through this pathway is medium for this time step.
T_{25}: See T_{10}. Over time the probability of passage increases, raising the probability to high.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The suitability of temperature and spawning habitat in the CAWS is not known; however, spawning is not required for passage and temperatures would be suitable for adults for much of the year (section 3d). The potential rate of movement of the inland silverside through the CAWS is uncertain. The literature suggests that there are multiple structures that could act as barriers to the inland silverside (section 3c). Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species. The degree to which the Electric Dispersal Barrier System would slow the upstream movement of this species is uncertain. The potential rate of movement of the inland silverside through the CAWS is uncertain. It is uncertain whether 10 years is enough time for the species to pass through the barriers. Therefore, uncertainty associated with passage is high for this time step.
T_{25}: See T_{10}. Inland silverside is an active swimmer. Therefore, over time it is more certain that the inland silverside will move upstream of the dams and pass through the CAWS. Therefore, uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation (NatureServe 2010; Weinstein 1986). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shores of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012) in which the inland silverside can spawn (Weinstein 1986).

An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986). Summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal

There is suitable physical habitat in Lake Michigan and its tributaries, and the inland silverside has the ability to swim to suitable habitat.

Evidence for Probability Rating

There is suitable adult and reproductive habitat in Lake Michigan (section 4a). However, the low winter temperatures of southern Lake Michigan may deplete the species during a harsh winter (section 4a). Therefore, the probability of this species colonizing Lake Michigan is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether the inland silverside will be able to overwinter in southern Lake Michigan. The species may be able to survive in small numbers after a harsh winter; however, the populations may not persist indefinitely. Therefore, the uncertainty of the species colonizing is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. Following the severe 1983–1984 winter, no inland silversides were collected from unheated bodies of water (Stoeckel & Heidinger 1998). The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986); summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. *Type of Mobility/Invasion Speed*
Inland silversides are small, short-lived, highly fecund fish (NOAA 2006) that travel in large schools (NatureServe 2010).

c. *Fecundity*
Females of the species are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982).

d. *History of Invasion Success*
The species was intentionally stocked as forage for sport fish in most locations (Fuller & Nico 2012a). Two years after these fish were unintentionally introduced into Clear Lake, California, this species became the most abundant fish in the littoral zone (Moyle 1976). In Clear Lake, inland silversides were reported as having displaced native fishes,

including the hitch, *Lavinia exilicauda*; the Sacramento blackfish, *Orthodon microlepidotus*; and the now-extinct Clear Lake splittail, *Pogonichthys ciscoides*, apparently through competition for food (Cook & Moore 1970).

e. Human-Mediated Transport through Aquatic Pathways
The inland silverside is an active swimmer and does not require human-mediated transport to spread.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation. Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shore of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012), in which the inland silverside can spawn (Weinstein 1986). Areas of near-shore emergent herbaceous habitat in tributaries and rivers along the Great Lakes would provide suitable spawning habitat (unpublished data from USACE).

Evidence for Probability Rating

Although suitable habitat is available, low overwinter temperatures may keep the inland silverside from spreading throughout the Great Lakes (sections 5a, 5f). It is thought that the species' southern distribution is due to the cold winter climate of the upper Midwest (section 5a). Therefore, persistent populations are unlikely to develop, especially in more northern latitudes, which would reduce the probability of spread. Overall, the probability of this species spreading through the GLB is low.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is potential for the inland silverside to establish in the Great Lakes, but the existing literature suggests that a harsh winter could wipe out the species in the region or leave a small remnant population. Therefore, the uncertainty associated with this species spreading in the Great Lakes is medium.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	Medium	High	Medium	High	Medium	High	High
P(passage)	Low	Low	Medium	High	High	Medium	High	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The inland silverside moves in large schools that can number in the tens of thousands (NatureServe 2010). They can travel far up streams and rivers, especially in the southern part of their range (NatureServe 2010). The species' natural spread rate through the MRB is not known because they have been actively stocked in lakes.

b. *Human-Mediated Transport through Aquatic Pathways*
There is no evidence that this species is transported by vessel traffic.

c. Current Abundance and Reproductive Capacity

T_0: Females of the species are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982). Eggs hatch in 4–30 days at 13–34°C (55.4–93.2°F) (Weinstein 1986); hatching is delayed at water temperatures below 19°C (66.2°F), which may cause embryos to exhaust nutrient supplies and starve to death prior to hatching (Hubbs et al. 1971). Females may produce eggs throughout the breeding season. Most individuals spawn and die in their second summer of life (NatureServe 2010). The average lifespan for the species is about 16 months, and few individuals survive their second winter (NatureServe 2010). Near the northern limit of the geographical range, the inland silverside has a unimodal reproductive season, but at southern latitudes the season can be unimodal or bimodal (Weinstein 1986). No data on the inland silverside's current abundance in Illinois were found.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. Distance from Pathway

T_0: In 1996, the inland silverside was recorded within 120 km (75 mi) of the pathway in the Kankakee River in Will County, Illinois (Fuller & Nico 2012b). The species has also been collected in Illinois from Lake Baldwin, Lake of Egypt, Rend Lake, and the Cache, Wabash, Mississippi, Ohio, and Kankakee Rivers (Laird & Page 1996). It is believed that the presence of the species in the Mississippi River in southern Illinois and in the lower Ohio River in Illinois and Kentucky is a result of natural dispersal (Fuller & Nico 2012a).

T_{10}: See T_0. Given time to naturally disperse, the species may move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The inland silverside's native range is confined to latitudes south of Illinois (Gilbert & Lee 1980). The species' native range is eastern North America including the Atlantic and Gulf Slopes (mostly near the coast) from Massachusetts to the Rio Grande drainage, Texas, and southeastern New Mexico; and north from the Mississippi River and major tributaries (mainly Arkansas and Red Rivers) to southern Illinois and eastern Oklahoma (Page & Burr 1991). The inland silverside is a marine species that ascends rivers (Fishbase 2010). It prefers estuaries, lagoons, brackish seas, rivers, streams (Fishbase 2010), lakes, coastal and freshwater habitats (NatureServe 2010), and reservoirs (Chizinski et al. 2007). The species is most abundant in the littoral zone (Lienesch & Gophen 2001) and prefers moderate to highly alkaline and euryhaline waters (NatureServe 2010). Huge aggregations of silversides have been reported over inundated vegetation and structures such as docks (Wurtsbaugh & Li 1985); therefore, Calumet Harbor would likely be suitable. Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, and then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). The species migrates offshore both at dawn and in the afternoon to feed on zooplankton (Lienesch & Gophen 2001), but the principal feeding period in the morning (Weinstein 1986).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation, where the eggs attach to the vegetation (NOAA 2006). Weinstein (1986) also states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes.

The inland silverside is categorized as a subtropical species (Fishbase 2010). An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside survived several winters in southern Illinois; however, during severe winters complete winterkill also occurred (NatureServe 2010). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F); optimal development occurred over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future changes in temperature related to climate change may affect the expansion of this species; warmer temperatures may promote its northward expansion.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species may be within 120 km (75 mi) of Brandon Road Lock and Dam (section 2e) and can swim upstream to the pathway entrance (section 2a). Suitable habitat is present near Brandon Road Lock and Dam; however, it is unlikely that the inland silverside will be able to consistently survive winter temperatures below Brandon Road Lock and Dam (section 2f). The inland silverside could be present at Brandon Road Lock and Dam during

the warmer months. However, although it has been has been present in Illinois since at least 1996, it has not been recorded at Brandon Road Lock and Dam or the CAWS (Wasik et al. 2008). Based on the apparent lack of spread to northern Illinois and its potentially prohibitive climate, this species has a medium probability of arriving at Brandon Road Lock and Dam during this time step.
T_{10}: See T_0. The inland silverside has been found in the Kankakee River, and 10 years may be sufficient time for the species to expand to the pathway. The inland silverside could be present at Brandon Road Lock and Dam during the warmer months and could potentially survive mild winters, raising the probability of arrival to high.
T_{25}: See T_0.
T_{50}: See T_0. The distribution of inland silverside appears to be determined by temperature, and increased temperatures may permit the northward expansion of this species.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The inland silverside has been collected in southern Illinois over 120 km (75 mi) from the pathway entrance. However, the uncertainty of arrival is medium because the species' location in the Kankakee River is uncertain and no recent records for this species were found. The natural rate of spread for the inland silverside is uncertain. The literature suggests the climate in the vicinity of Brandon Road Lock and Dam will not be consistently suitable over time, although it would be suitable during the warmer months. Therefore, the uncertainty associated with the arrival of this species is medium for this time step.
T_{10}: See T_0. The climatological suitability of the Brandon Road Lock and Dam area remains uncertain. However, given time to disperse the species may naturally arrive at the pathway entrance. Therefore, uncertainty for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years may be a sufficient length of time for the inland silverside to expand to the BSBH pathway entrance. The future impacts of climate change on the distribution of this species are not documented. Therefore, uncertainty is high.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The inland silverside swims far up streams and rivers, especially in the southern part of its range (NatureServe 2010). The distance from the Brandon Road Lock and Dam to the

BSBH is greater than 64 km (40 mi). The rate of natural dispersion of the inland silverside is not well known.

b. *Human-Mediated Transport through Aquatic Pathways*
Most commercial vessel traffic to BSBH is lake-wise, and there is no commercial vessel traffic to inland ports in the CAWS to or from BSBH (USACE 2011a; NBIC 2012). Inland silverside actively swims and does not require humans for dispersal, so natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, as part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), and there are ongoing studies on the efficacy of Barrier II with regard to small fish. Inland silverside typically do not grow to more than 10.2 cm (4 in.) (Weinstein 1986), which suggests the possibility that small inland silverside may be able to safely pass through the Electric Dispersal Barrier System at the water's surface where the current is weakest. Operation of the Electric Dispersal Barrier System may change over this time step to become more effective at deterring small fish. There are other potential mechanisms of Electric Dispersal Barrier System failure. For example, temporary power failures have occurred at the Electric Barrier Dispersal System. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additional potential barrier bypass vectors are currently under investigation and include reverse flow events in the canal (wind or current driven), electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge-induced water currents across the Electric Dispersal Barrier System. These mechanisms may allow inland silverside to move upstream of the Electric Barrier Dispersal System.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Huge aggregations of silversides have been reported over inundated vegetation and structures such as docks (Wurtsbaugh & Li 1985). Inland silversides congregate in the shallows, generally over sand or gravel bottoms with overhead cover if possible, and then move out to open water in search of additional food (Hassan-Williams & Bonner 2007). Sand and gravel bottoms and manmade structures such as docks are found through much of the CAWS (LimnoTech 2010).

Spawning occurs in shallow water in areas with abundant vegetation (Hildebrand 1922), over beds of aquatic vegetation or among emergent vegetation. The eggs attach to the vegetation, and the young develop in lower-salinity areas of estuaries (NOAA 2006). Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. There is low submerged aquatic macrophyte cover in all areas of the CAWS channel. Much of the CSSC and the Calumet Sag Channel have vertical limestone or manmade walls (LimnoTech 2010). Although living submerged aquatic vegetation is not common in the CAWS, it can be found in the CSSC at low densities (LimnoTech 2010). Plant debris is present in the CAWS, but it is not a dominant substrate component (LimnoTech 2010). The south branch of the Little Calumet River has vegetated banks and some associated emergent marsh.

Inland silverside is most abundant over firm substrates with high sand content and low percentages of organics. Population densities are low where soft silts and reducing substrates (and consequently low dissolved oxygen) predominate (Weinstein 1986). Sediment texture does not influence habitat quality for inland silversides directly; however, grain size is a good indicator. Water movements fast enough to scour fine particles are most suitable; therefore, suitability decreases as the percentage of fine particles increases (Weinstein 1986). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010).

Inland silverside larvae avoid waters with DO below 3.8 mg/L (Weltzien et al. 1999). Adults have been found in a bay with a DO range from 3.0–10.8 mg/L (Weltzien et al. 1999; Middaugh & Hemmer 1992). Although seasonal hypoxia may occur in portions of the CAWS, annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L (MWRD 2010).

An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The species was able to overwinter in ponds in southern Illinois for several years, but did not survive a harsh winter (Stoeckel & Heidinger 1998). Egg survival was highest between 17 and 33.5°C (62.6 and 92.3°F), with optimal development occurring over the range from 20 to 25°C (68 to 77°F) (Hubbs et al. 1971). Effluent discharge in the CAWS increases water temperature in the CAWS year-round and may allow this species to survive there during the winter.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is no documentation that suggests the species may be transported by vessels, but this species is an active swimmer capable of long distance migrations (section 3b). Physical habitat in the CAWS is suitable for adults, but spawning habitat may not be ideal (section 3d). Temperatures in the CAWS may be warm enough to support the inland silverside throughout the year. Overall, the probability of passage is low for this time step.
T_{10}: See T_0. The inland silverside is an active swimmer, and over 10 years the inland silverside may have adequate time to travel from Brandon Road Lock and Dam to the BSBH. The Electric Dispersal Barrier System is not likely to control passage of this species due to its small size and surface swimming behavior. Inland silversides live only 2 years, so repeated introductions may be needed if the population does not survive winter. The probability of this species passing through this pathway is medium for this time step.
T_{25}: See T_{10}. Over time the probability of passage increases, raising the probability to high.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The suitability of temperature and spawning habitat in the CAWS is not known; however, spawning is not required for passage and temperatures would be suitable for adults for much of the year (section 3d). The potential rate of movement of the inland silverside through the CAWS is uncertain. The literature suggests that there are multiple structures that could act as barriers to the inland silverside (section 3c). Therefore, the uncertainty of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species. The degree to which the Electric Dispersal Barrier System would slow the upstream movement of this species is uncertain. The potential rate of movement of the inland silverside through the CAWS is uncertain. It is uncertain whether 10 years is enough time for the species to pass through the barriers. Therefore, uncertainty associated with passage is high for this time step.
T_{25}: See T_{10}. Inland silverside is an active swimmer. Therefore, over time it is more certain that the inland silverside will move upstream of the dams and pass through the CAWS. Therefore, uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller & Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation. Weinstein (1986) states that the preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shore of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012) in which the inland silverside can spawn (Weinstein 1986).

   An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are less than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13 °C (55.4°F) (Weinstein 1986); summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   There is suitable physical habitat in Lake Michigan and its tributaries, and the inland silverside has the ability to swim to suitable habitat.

Evidence for Probability Rating

There is suitable adult and reproductive habitat in Lake Michigan (section 4a). However, the low winter temperature of southern Lake Michigan may deplete the species during a harsh winter (section 4a). Therefore, the probability of this species colonizing in Lake Michigan is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether the species will be able to overwinter in southern Lake Michigan. The species may be able to survive in small numbers after a harsh winter; however, the

populations may not persist indefinitely. Therefore, the uncertainty of the species colonizing is high.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
An outdoor overwintering study of the inland silverside in southern Illinois performed by Stoeckel and Heidinger (1998) implies that the southern distribution of the species is a function of its inability to consistently tolerate winter temperatures north of its native range. The inland silverside can survive relatively mild winters; however, there are winters in which a complete winterkill occurs (Stoeckel & Heidinger 1998). The brook silverside, *Labidesthes sicculus*, which is native to Illinois, did not exhibit marked declines over winter months (Stoeckel & Heidinger 1998). However, overwintering mortality in the 80–90% range has been reported for the inland silverside in Rhode Island waters (Bengtson 1982). A decrease in feeding was observed at temperatures less than 15°C (59°F) (Stoeckel & Heidinger 1998), and winter temperatures in Lake Michigan are lower than this for extended periods of time (Beletsky & Schwab 2001). The literature indicates that inland silverside spawn from spring to summer in warmer areas and at temperatures as low as 13°C (55.4°F) (Weinstein 1986); summer temperatures in Lake Michigan would be suitable for spawning (Beletsky & Schwab 2001).

b. *Type of Mobility/Invasion Speed*
Inland silversides are small, short-lived, highly fecund fish (NOAA 2006) that travel in large schools (NatureServe 2010).

c. *Fecundity*
Female inland silversides are capable of producing 30,000 eggs a month (Stoeckel 1984); female clutches (which can be laid daily) varied between 384 and 1699, with large females producing more eggs than small females (Hubbs 1982).

d. *History of Invasion Success*
The species was intentionally stocked as forage for sport fish in most locations (Fuller & Nico 2012a). Two years after these fish were unintentionally introduced into Clear Lake, California, this species became the most abundant fish in the littoral zone (Moyle 1976). In Clear Lake, inland silversides were reported as having displaced native fishes, including the hitch, *Lavinia exilicauda*; the Sacramento blackfish, *Orthodon microlepidotus*; and the now-extinct Clear Lake splittail, *Pogonichthys ciscoides*, apparently through competition for food (Cook & Moore 1970).

e. *Human-Mediated Transport through Aquatic Pathways*
The inland silverside is an active swimmer and does not require human-mediated transport to spread.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Inland silversides are found in lakes, rivers, and estuaries (Wurtsbaugh & Li 1985; Fuller and Nico 2012a). They spawn over beds of aquatic vegetation or among emergent vegetation. Weinstein (1986) states that preferred spawning habitat includes all forms of plants, such as dead leaves, tree roots, algal mats, or rooted aquatic plants in marshes. Except in large bays, submerged aquatic macrophytes are not typically found on the shores of Lake Michigan (MTRI 2012). However, there are extensive submerged *Cladophora* beds in Lake Michigan (MTRI 2012), in which the inland silverside can spawn (Weinstein 1986). Areas of near-shore emergent herbaceous habitat in tributaries and rivers along the Great Lakes would be suitable spawning habitat for the species (unpublished data from USACE).

Evidence for Probability Rating

Although suitable habitat is available, the low overwinter temperatures may keep the species from spreading throughout the Great Lakes (sections 5a, 5f). It is thought that the species' southern distribution is due to the cold winter climate of the upper Midwest (section 5a). Therefore, persistent populations are unlikely to develop, especially in more northern latitudes, which would reduce the probability of spread. Overall, the probability of this species spreading through the Great Lakes Basin is low.
Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is potential for inland silverside to establish in the Great Lakes, but the existing literature suggests that a harsh winter could wipe out the species in the region or leave a small population. Therefore, the uncertainty associated with this species spreading in the Great Lakes is medium.

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E.1.3.2 Black Carp - *Mylopharyngodon piceus*

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	High	Medium	High	Low
P(passage)	Low	Medium	Low	High	Low	High	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	High	Medium	High	Medium	High	Medium	High	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). Nico et al. (2005) states that there is a high probability of the black carp spreading in the MRB. Since the 1990s, the black carp has

spread from the lower MRB to southern Illinois. It was recorded in the Mississippi River in southern Illinois in 2004, but has not yet been found in the Illinois River (Nico 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Swimming would likely be the primary mechanism of upstream movement. Although, vessel-mediated transport has not been described in the literature for this species, there is extensive commercial and recreational vessel traffic in the Illinois River, and black carp eggs and larvae have the potential to be spread by ballast water if water quality is suitable. It is uncertain whether reproductive populations of this species are present in the U.S.; therefore, the viability of this transport mechanism is uncertain. In addition, Heilprin et al. (2013) concluded that Asian carp eggs and larvae were able to survive the poor water quality conditions within most ballast water but risk of passage was low due to very high mortality rates associated with bilge pump passage.

c. *Current Abundance and Reproductive Capacity*
T_0: Current abundance is unknown throughout the black carp's range. The fact that black carp, including diploid adults, have been in the wild in the lower Mississippi basin for well over a decade is evidence that the species may already be established or on the verge of establishment in the United States (Nico 2011). Collections of black carp in Illinois appear to be infrequent, suggesting they are not abundant. Reproductively competent diploid black carp have been collected in Louisiana waters (Nico et al. 2005). Black carp collected in Illinois can be triploid (not capable of reproduction) or diploid (Conover 2012; Nico 2011). To date, there have been no confirmed collections of larval or small juvenile black carp in the wild. Maturity is reached at 6 to 11 years of age in the species' native habitat (Williams et al. 2007). Individuals can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and survival rates are generally extremely low. Adult mortality is low due to the black carp's large size.
T_{10}: See T_0. A portion of black carp in the MRB are triploid and are not capable of reproduction. Consequently, populations could increase or decrease depending on the future reproductive capacity of populations of black carp in the MRB.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The black carp has been documented above multiple lock and dam structures on the Mississippi River (Nico 2011). Therefore, the Marseilles Lock and Dam and Dresden Lock and Dam are not expected to be significant barriers to upstream movement.
T_{10}: See T_0. The lock operations are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Black carp are most abundant in the lower MRB. However, at least ten specimens have been documented from Illinois. The first was captured in 2003 from Horseshoe

Lake, in Alexander County (Chick et al. 2003). A second was found in 2004 in the Mississippi River, just above Lock and Dam No. 24, near Clarksville, Missouri (Nico et al. 2005). A third was found in 2010 in Pool 25 of the Mississippi River, near Hamburg, Illinois (Nico 2011). Assuming this species is present at the confluence of the Mississippi and Illinois Rivers, current distribution puts it about 458 km (285 mi) from the entrance to Brandon Road Lock and Dam. Because black carp superficially resemble grass carp, it is conceivable that some captures have gone unreported. In addition, because black carp is a bottom-dwelling and deepwater species, it is less likely to be observed or captured than other Asian carp species (Nico et al. 2005).
T_{10}: See T_0. The species may, over time, move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. The species is a bottom-dwelling, freshwater fish that inhabits lakes and big rivers and backwaters (Nico et al. 2005). It prefers fast-moving rivers (Williams et al. 2007). Black carp commonly feed on mollusks, using their pharyngeal teeth to crush the mollusks' shells, then consuming soft tissue. Four-year-old juveniles are capable of consuming around 1–2 kg (2.2–4.4 lb) of mollusks per day (Linder et al. 2005). When small, they feed on zooplankton and fingerlings (Williams et al. 2007). Habitat and food resources are available between their current location in the Mississippi River and Brandon Road Lock and Dam.

Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In general, black carp successfully spawn only in riverine environments (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels; Williams et al. 2007). Black carp are known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat could be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Asian carp are classified as "pelagophils," which are defined as non-guarding, open-substratum spawning fish that release and scatter non-adhesive eggs in open waters in areas where the direction of the current favors distribution and survival (Nico et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is potential for the black carp to be a rapid invader similar to the grass carp (section 2a). Suitable habitat and climate are present along the pathway between their current location and the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the black carp (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location (section 2e). The black carp is found in southern Illinois in the Illinois River (at least 415 km [258 mi] from Brandon Road Lock and Dam) (section 2a). Therefore, the probability of the species arriving at the pathway entrance at this time step is low.
T_{10}: See T_0. Black carp are large, actively swimming fish potentially capable of rapid upstream movement. Since the 1990s, they have spread from the lower MRB to southern Illinois. Unless the species is eradicated, over time the potential for the black carp to spread north from its current location in the Mississippi River in southern Illinois toward the pathway entrance (at Brandon Road Lock and Dam) increases. Given time to naturally spread upstream, the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.
T_{25}: See T_{10}. If current dispersal trends continue, the probability of black carp reaching Brandon Road Lock and Dam increases with time. Therefore, the probability of arrival at this time step increases to high.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: The natural rate of spread through the MRB is uncertain. Currently, there has been only one black carp captured in the Illinois River and it is unlikely that the species will naturally disperse and swim from its current location in southern Illinois to the pathway entrance during this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0. Future population trends for the black carp are uncertain because of uncertainty about the reproductive capabilities of wild populations. However, if the documented dispersal trends continue, 10 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{25}: See T_{10}.

T_{50}: See T_{10}. Fifty years should be enough time for the back carp to arrive at the pathway. Therefore, the uncertainty associated with arrival is low.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005).

b. *Human-Mediated Transport through Aquatic Pathways*
Black carp actively swim and do not require humans for dispersal through existing waterways. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is vessel traffic between the Brandon Road Lock and Dam and the CRCW (USACE 2011a), and there is the potential for black carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). However, vessel-mediated transport has not been described in the literature for this species, so the potential for this species to be transported in ballast water is uncertain. Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. It is uncertain whether black carp reproduce in the Illinois River. If reproduction does occur, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin & Ehrler 2012) making ballast water transport unlikely.

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water onboard, if there is an intention to release that water in any form within or on the other side of the safety zone (USCG 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in section 4c: Existing Physical Human/Natural Barriers.

Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan.

c. Existing Physical Human/Natural Barriers

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, black carp are assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier — 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz, and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish that were most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013, and caught gizzard shad (*Dorosoma cepedianum*), threadfin shad (*Dorosoma petenense*), and skipjack herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA, and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind-, vessel-, or current-driven), electric field shielding by steel hulled vessels or side wall crevices, and small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS, has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in-water electrical parameters in this area (USACE 2013).

The USFWS placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time because back carp are not present in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish, or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

Potential barriers to movement above the electric dispersal barrier system include a sluice gate at the WPS that separates the CAWS from Lake Michigan. However, the gates are periodically opened to allow reverse flow back into Lake Michigan, which could allow passage of black carp.

T_{10}: See T_0. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events. A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring, and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort. Black carp are not abundant in the Illinois River, and a portion of these individuals are triploid and are not capable of reproduction. Therefore, even if the black carp reaches the electric barrier, it is unlikely to exist in high abundance, even by T_{25}. Consequently, it is assumed that black carp propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.

T_{50}: See T_{10} and T_{25}

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Black carp are bottom-dwelling, freshwater fish that inhabit large, fast-moving rivers. The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Spawning sites of Asian carps have a water velocity of 1–1.85 m/s (3.28–6.07 ft/s); however, the minimum required velocity may extend to 0.8 or 0.6 m/s (1.97 or 2.62 ft/s), or even less. Turbulence is thought to be important, causing the fertilized egg to become fully water hardened and more buoyant. Sufficient flow is needed to create enough turbulence to keep the eggs in suspension (Nico et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at WPS is a slow-moving, eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat would be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6 °F), water levels are rising, and mollusks are available (Williams et al. 2007). In the CAWS, annual average water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7 °F) (MWRD 2010). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas (LimnoTech 2010). Black carp inhabit water depths ranging from 0 to 10 m (0 to 32.8 ft), allowing for an abundance of mollusks (Nico et al. 2005).

Black carp take refuge in deep water during winter (Nico et al. 2005). The maximum depth in the CAWS is about 10 m (32.8 ft) (LimnoTech 2010).

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the MWRD is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. In addition, in coordination with the USACE, MWRD will increase the capacity of stormwater catchment and retention in adjacent tunnels and reservoirs, leading to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may also change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable adult habitat for black carp is present in the CAWS. Turbulence in the areas of the locks may provide suitable spawning habitat (section 3d). The species has the ability to swim upstream to the WPS. The passage to the WPS includes two lock complexes and the Electric Dispersal Barrier System (section 3c). Black carp would be able to swim through the locks during the open phase of their normal operations. Black carp would be able to swim through the locks during the open phase of their normal operations. However, the Electric Barrier Dispersal System is expected to control their passage during this time step. Consequently, the probability of this species passing successfully through this pathway is rated as low.
T_{10}: See T_0. Black carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Consequently, there will be few fish expected to challenge the barrier, which reduces its probability of the barrier failing to prevent the passage of black carp upstream of the barrier. The Brandon Road and Lockport locks and dams may also slow black carp passage. Therefore, risk of passage at this time step is considered to be low.
T_{25}: See T_{10}. Funding for monitoring and removal programs for Asian carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. However,propagule pressure of this species immediately downstream of the Electric Dispersal Barrier System is expected to remain low at T_{50} because existing populations of black carp in Illinois are small and a portion will not be capable of reproduction. Therefore, the Electric Dispersal Barrier System is expected to remain effective at controlling passage of this species. Therefore, the probability of passage is expected to remain low.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Consequently, probability estimates for each potential barrier failure mechanism have not yet been established. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium.
T_{10}: See $T_{0.}$ Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events. The current and future reproductive status of this species is unknown and therefore future propagule pressure at the electric barrier is also unknown. Therefore, uncertainty increases to high.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
As with other introduced Asian carps, if the black carp becomes established in main-stem rivers it could become common and invade connected lakes and streams (Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); zebra mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, black carp have been reported to spawn in reservoirs in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Fertilization occurs upstream and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). Resulting eggs reportedly drift to the larger part of the reservoir, into areas with little or no current where the eggs sink and die (Nico et al. 2005). In addition, seven tributaries of Lake Michigan, including St. Joseph River in the southeastern part of the lake, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
There is suitable adult habitat in Lake Michigan and its tributaries, and black carp has the ability to swim to suitable spawning habitat.

Evidence for Probability Rating

Suitable habitat is present and abundant for adult black carp. It is thought that spawning requires a flowing riverine environment, which is largely absent in Lake Michigan in the vicinity of WPS. However, black carp spawning habitat does exist in many Lake Michigan tributaries. Therefore, the probability of colonizing is medium for black carp.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Suitable feeding habitat is available in Lake Michigan, and similar species have been documented to establish in the GLB. However, no spawning habitat is available in the vicinity of the WPS, and it is uncertain whether this species would swim to suitable reproductive habitat. Therefore, the uncertainty of colonizing is medium for the black carp.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6 °F) (Williams et al. 2007).

b. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the GLB. Eggs are non-adhesive and are released in the water column, where they are transported downstream (Williams et al. 2007).

c. *Fecundity*
Black carp can produce an average of 1–3 million eggs each year, depending on body size (Nico 2011). However, there is no parental care and generally extremely low survival rates. Adult mortality is low due to the black carp's adult size. Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). However, reproductively viable black carp populations are not certain to exist in the U.S.

d. *History of Invasion Success*
The black carp became established after it was introduced to several localities in Asia (e.g., Japan, possibly northern Vietnam), including at least one canal in the former Soviet Union. Three other Asian carp, all large-river cyprinids with habitat and spawning requirements similar to those of the black carp, now have established, naturally-reproducing populations in open waters of the United States (Nico et al. 2005).

e. *Human-Mediated Transport through Aquatic Pathways*
None described in the literature. Swimming would likely be the primary mechanism of upstream movement.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The black carp is a generalist consumer of mollusks, and is capable of inhabiting a variety of aquatic habitats. Black carp inhabit lakes and lower reaches of large, fast-moving rivers (Williams et al. 2007; Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); dreissenid mussels are abundant in Lake Michigan. Black

carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, the black carp has been reported to spawn in reservoirs' river tributaries in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent. Fertilization occurs upstream and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). In addition, 22 tributaries of the Great Lakes have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

Evidence for Probability Rating

Black carp have a high fecundity (section 5c) and are potentially rapid invaders (section 5d). Suitable habitat is present for adult black carp, which could swim (section 5b) to suitable spawning habitats in the GLB (section 5f). Therefore, the probability of spread for the black carp is high.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Climate and habitat in the GLB are suitable for adult black carp. There are many tributaries and rivers that the black carp could potentially use to spawn, although suitability of these spawning habitats is speculative. Overall, the uncertainty of spread is medium for black carp.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	High	Medium	High	Low
P(passage)	Low	Medium	Low	High	Low	High	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	High	Medium	High	Medium	High	Medium	High	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). Nico et al. (2005) states that the probability of the black carp spreading in the MRB is high. Since the 1990s, the black carp has spread from the lower MRB to southern Illinois. It was recorded in the Mississippi River in southern Illinois in 2004, but has not yet been found in the Illinois River (Nico 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Swimming would likely be the primary mechanism of upstream movement. Although, vessel-mediated transport has not been described in the literature for this species, there is extensive commercial and recreational vessel traffic in the Illinois River, and black carp eggs and larvae have the potential to be spread by ballast water if water quality is suitable. However, it is uncertain whether reproductive populations of this species are present in the United States; therefore, the viability of this transport mechanism is uncertain. In addition, Heilprin et al. (2013) concluded that Asian carp eggs and larvae were able to survive the poor water quality conditions within most ballast water, but the risk of passage was low due to very high mortality rates associated with bilge pump passage.

c. *Current Abundance and Reproductive Capacity*
T_0: Current abundance is unknown throughout the black carp's range. The fact that black carp, including diploid adults, have been in the wild for well over a decade in the

lower Mississippi basin is evidence that the species may already be established or on the verge of establishment in the United States (Nico 2011). Collections of black carp in Illinois appear to be infrequent, suggesting they are not abundant. Reproductively competent diploid black carp have been collected in Louisiana waters (Nico et al. 2005). Black carp collected in Illinois can be triploid (not capable of reproduction) or diploid (Conover 2012; Nico 2011). To date, there have been no confirmed collections of larval or small juvenile black carp in the wild. Maturity is reached at 6 to 11 years of age in the species' native habitat (Williams et al. 2007). Individuals can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and survival rates are generally extremely low. Adult mortality is low due to the black carp's large size.
T_{10}: See T_0. A portion of black carp in the MRB are triploid and are not capable of reproduction. Consequently, populations could increase or decrease depending on the future reproductive capacity of populations of black carp in the MRB.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The black carp has been documented above multiple lock and dam structures on the Mississippi River (Nico 2011). Therefore, the Marseilles Lock and Dam and Dresden Lock and Dam are not expected to be significant barriers to upstream movement.
T_{10}: See T_0. The lock operations are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Black carp are most abundant in the lower MRB. However, at least ten specimens have been documented in Illinois. The first was captured in 2003 from Horseshoe Lake, in Alexander County (Chick et al. 2003). A second was found in 2004 in the Mississippi River, just above Lock and Dam No. 24, near Clarksville, Missouri (Nico et al. 2005). A third was found in 2010 in Pool 25 of the Mississippi River, near Hamburg, Illinois (Nico 2011). Assuming this species is present at the confluence of the Mississippi and Illinois Rivers, current distribution puts it about 458 km (285 mi) from the entrance to Brandon Road Lock and Dam. Because black carp superficially resemble grass carp, it is conceivable that some captures have gone unreported. In addition, because black carp is a bottom-dwelling and deepwater species, it is less likely to be observed or captured than other Asian carp species (Nico et al. 2005).
T_{10}: See T_0. The species may, over time, move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states

could be suitable for the black carp. The species is a bottom-dwelling, freshwater fish that inhabits lakes and big rivers and backwaters (Nico et al. 2005). It prefers fast-moving rivers. Black carp commonly feed on mollusks, using their pharyngeal teeth to crush the mollusks' shells, then consuming soft tissue. Four-year-old juveniles are capable of consuming around 1–2 kg (2.2–4.4 lb) of mollusks per day (Linder et al. 2005). When small, they feed on zooplankton and fingerlings (Williams et al. 2007). Habitat and food resources are available between their current location in the Mississippi River and Brandon Road Lock and Dam.

Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising and mollusks are available (Williams et al. 2007). In general, black carp successfully spawn only in riverine environments (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). Black carp are known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat could be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Asian carp are classified as "pelagophils," which are defined as non-guarding, open-substratum spawning fish that release and scatter non-adhesive eggs in open waters in areas where the direction of the current favors distribution and survival (Nico et al. 2005).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is potential for the black carp to be a rapid invader similar to the grass carp (section 2a). Suitable habitat and climate are present along the pathway between their current location and the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the black carp (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location (section 2e). The black carp is found in southern Illinois in the Illinois River (at least 415 km [258 mi] from Brandon Road Lock and Dam) (section 2a). Therefore, the probability of the species arriving at the pathway entrance at this time step is low.

T_{10}: See T_0. Black carp are large, actively swimming fish potentially capable of rapid upstream movement. Since the 1990s, they have spread from the lower MRB to southern Illinois. Unless the species is eradicated, over time the potential for the black carp to spread north from its current location in the Mississippi River in southern Illinois toward the

pathway entrance (at Brandon Road Lock and Dam) increases. Given time to naturally spread upstream, the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.
T_{25}: See T_{10}. If current dispersal trends continue, the probability of black carp reaching Brandon Road Lock and Dam increases with time. Therefore, the probability of arrival at this time step increases to high.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: The natural rate of spread through the MRB is uncertain. Currently, there has been only one black carp captured in the Illinois River and it is unlikely that the species will naturally disperse and swim from its current location in southern Illinois to the pathway entrance during this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0. Future population trends for the black carp are uncertain because of uncertainty about the reproductive capabilities of wild populations. However, if the documented dispersal trends continue, 10 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years should be enough time for the back carp to arrive at the pathway. Therefore, the uncertainty associated with arrival is low.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005).

b. *Human-Mediated Transport through Aquatic Pathways*
Black carp actively swims and do not require humans for dispersal through existing waterways. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. there is vessel traffic between the Brandon Road Lock and Dam and the CRCW

(USACE 2011a) and there is the potential for black carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). However, vessel-mediated transport has not been described in the literature for this species, so the potential for this species to be transported in ballast water is uncertain. Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. It is uncertain whether black carp reproduce in the Illinois River. If reproduction does occur, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin & Ehrler 2012) making ballast water transport unlikely.

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if there is an intention to release that water in any form within, or on the other side of the safety zone (USCG 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. Existing Physical Human/Natural Barriers.

Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, black carp are assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp

were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish that we most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught gizzard shad (*Dorosoma cepedianum*), threadfin shad (*Dorosoma petenense*), and skipjack herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002. Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels (USACE 2013). Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 20130).

The USFWS placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers. Further research is being conducted to mitigate this bypass (USACE 2013). While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time because back carp are not present in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

Potential barriers to movement above the electric dispersal barrier system include a sluice gate at the WPS that separates the CAWS from Lake Michigan. However, the gates are periodically opened to allow reverse flow back into Lake Michigan, which could allow passage of black carp.

T_{10}: See T_0. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events. A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort. Black carp are not abundant in the Illinois River, and a portion of these individuals are triploid and are not capable of reproduction. Therefore, even if the black carp reaches the electric barrier, it is unlikely to exist in high abundance, even by T_{25}. Consequently, it is assumed that black carp propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.

T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Black carp are bottom-dwelling, freshwater fish that inhabit large, fast-moving rivers. The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Spawning sites of Asian carps have a water velocity of 1–1.85 m/s (3.28–6.07 ft/s); however, the minimum required velocity may extend to 0.8 or 0.6 m/s (1.97 or 2.62 ft/s) or even less. Turbulence is thought to be important, causing the fertilized egg to become fully water hardened and more buoyant. Sufficient flow is needed to create enough turbulence to keep the eggs in suspension (Nico et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the CRCW is a slow-moving, eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat would be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In the CAWS, annual average water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas (LimnoTech 2010). Black carp inhabit water depths ranging from 0 to 10 m (0 to 32.8 ft), allowing for an abundance of mollusks (Nico et al. 2005). Black carp take refuge in deep water during winter (Nico et al. 2005). The maximum depth in the CAWS is about 10 m (32.8 ft) (LimnoTech 2010).

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the MWRD is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. In addition, in coordination with the USACE, MWRD will increase the capacity of stormwater catchment and retention in adjacent tunnels and reservoirs, leading to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may also change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable adult habitat for black carp is present in the CAWS. Turbulence in the areas of the locks may provide suitable spawning habitat (section 3d). The species has the ability to swim upstream to the WPS. The passage to the WPS includes two lock complexes and the Electric Dispersal Barrier System (section 3c). Black carp would be able to swim through the locks during the open phase of their normal operations. Black carp would be able to swim through the locks during the open phase of their normal operations. However, the Electric Barrier Dispersal System is expected to control their passage during this timestep. Consequently, the probability of this species passing successfully through this pathway is rated as low.
T_{10}: See T_0. Black carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Consequently, there will be few fish expected to challenge the barrier, which reduces its probability of the barrier failing to prevent the passage of black carp upstream of the barrier. The Brandon Road and Lockport locks and dams may also slow black carp passage. Therefore, risk of passage at this time step is considered to be low.
T_{25}: See T_{10}. Funding for monitoring and removal programs for Asian carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. However,propagule pressure of this species immediately downstream of the Dispersal Barriers is expected to remain low at T_{50} because existing populations of black carp in Illinois are small and a portion will not be capable of reproduction. Therefore, the electric barrier is expected to remain effective at controlling passage of this species. Therefore, the probability of passage is expected to remain low.
T_{50}: See T_{25}

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Consequently, probability estimates for each potential barrier failure mechanism have not yet been established. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium.
T_{10}: See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. The current and future reproductive status of this species is unknown and, therefore, future propagule pressure at the electric barrier is also unknown. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
As with other introduced Asian carps, if the black carp becomes established in main-stem rivers it could become common and invade connected lakes and streams (Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); zebra mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, black carp have been reported to spawn in reservoirs in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Fertilization occurs upstream and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). Resulting eggs reportedly drift to the larger part of the reservoir, into areas with little or no current where the eggs sink and die (Nico et al. 2005). In addition, seven tributaries of Lake Michigan, including St. Joseph River in the southeastern part of the lake, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
There is suitable adult habitat in Lake Michigan and its tributaries, and black carp has the ability to swim to suitable spawning habitat.

Evidence for Probability Rating

Suitable habitat is present and abundant for adult black carp. It is thought that spawning requires a flowing riverine environment, which is largely absent in Lake Michigan in the vicinity of Indiana Harbor. However, black carp spawning habitat does exist in many Lake Michigan tributaries. Therefore, the probability of colonizing is medium for black carp.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Suitable feeding habitat is available in Lake Michigan, and similar species have been documented to establish in the GLB. However, no spawning habitat is available in the vicinity of the CRCW, and it is uncertain whether this species would swim to suitable reproductive habitat. Therefore, the uncertainty of colonizing is medium for the black carp.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F) (Williams et al. 2007).

b. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the GLB. Eggs are non-adhesive and are released in the water column, where they are transported downstream (Williams et al. 2007).

c. *Fecundity*
Black carp can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and generally extremely low survival rates. Adult mortality is low due to the black carp's adult size. Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). However, reproductively viable black carp populations are not certain to exist in the United States.

d. *History of Invasion Success*
   The black carp became established after it was introduced to several localities in Asia (e.g., Japan, possibly northern Vietnam), including at least one canal in the former Soviet Union. Three other Asian carp, all large-river cyprinids with habitat and spawning requirements similar to those of the black carp, now have established, naturally-reproducing populations in open waters of the United States (Nico et al. 2005).

e. *Human-Mediated Transport through Aquatic Pathways*
   None described in the literature. Swimming would likely be the primary mechanism of upstream movement.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The black carp is a generalist consumer of mollusks, and is capable of inhabiting a variety of aquatic habitats. Black carp inhabit lakes and lower reaches of large, fast-moving rivers (Williams et al. 2007; Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); dreissenid mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, the black carp has been reported to spawn in reservoirs' river tributaries in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent. Fertilization occurs upstream and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). In addition, 22 tributaries of the Great Lakes have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

Evidence for Probability Rating

Black carp have a high fecundity (section 5c) and are potentially rapid invaders (section 5d). Suitable habitat is present for adult black carp, which could swim (section 5b) to suitable spawning habitats in the GLB (section 5f). Therefore, the probability of spread for the black carp is high.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Climate and habitat in the GLB is suitable for adult black carp. There are many tributaries and rivers that the black carp could potentially use to spawn, although suitability of these spawning habitats is speculative. Overall, the uncertainty of spread is medium for black carp.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	High	Medium	High	Low
P(passage)	Low	Medium	Low	High	Low	High	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	High	Medium	High	Medium	High	Medium	High	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). Nico et al. (2005) states that the probability of the black carp spreading in the MRB is high. Since the 1990s, the black carp has spread from the lower MRB to southern Illinois. The black carp was recorded in the Mississippi River in southern Illinois in 2004, but has not yet been found in the Illinois River (Nico 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Swimming would likely be the primary mechanism of upstream movement. Although, vessel-mediated transport has not been described in the literature for this species, there is extensive commercial and recreational vessel traffic in the Illinois River, and black carp eggs and larvae have the potential to be spread by ballast water if water quality is suitable. However, it is uncertain whether reproductive populations of this species are present in the United States; therefore, the viability of this transport mechanism is uncertain. In addition, Heilprin et al. (2013) concluded that Asian carp eggs and larvae were able to survive the poor water quality conditions within most ballast water, but risk of passage was low due to very high mortality rates associated with bilge pump passage.

c. *Current Abundance and Reproductive Capacity*
T_0: Current abundance is unknown throughout the black carp's range. The fact that black carp, including diploid adults, have been in the wild for well over a decade in the lower Mississippi basin is evidence that the species may already be established or on the verge of establishment in the United States (Nico 2011). Collections of black carp in Illinois appear to be infrequent, suggesting they are not abundant. Reproductively competent diploid black carp have been collected in Louisiana waters (Nico et al. 2005). Black carp collected in Illinois can be triploid (not capable of reproduction) or diploid (Conover 2012; Nico 2011). To date, there have been no confirmed collections of larval or small juvenile black carp in the wild. Maturity is reached at 6 to 11 years of age in the species' native habitat (Williams et al. 2007). Individuals can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and survival rates are generally extremely low. Adult mortality is low due to the black carp's large size.
T_{10}: See T_0. A portion of black carp in the MRB are triploid and are not capable of reproduction. Consequently, populations could increase or decrease depending on the future reproductive capacity of populations of black carp in the MRB.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The black carp has been documented above multiple lock and dam structures on the Mississippi River (Nico 2011). Therefore, the Marseilles Lock and Dam and Dresden Lock and Dam are not expected to be significant barriers to upstream movement.
T_{10}: See T_0. The lock operations are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Black carp are most abundant in the lower MRB. However, at least ten specimens have been documented from Illinois. The first was captured in 2003 from Horseshoe Lake, in Alexander County (Chick et al. 2003). A second was discovered in 2004 in the Mississippi River, just above Lock and Dam No. 24, near Clarksville, Missouri

(Nico et al. 2005). A third was found in 2010 in Pool 25 of the Mississippi River, near Hamburg, Illinois (Nico 2011). Assuming this species is present at the confluence of the Mississippi and Illinois Rivers, current distribution puts it about 458 km (285 mi) from the entrance to Brandon Road Lock and Dam. Because black carp superficially resemble grass carp, it is conceivable that some captures have gone unreported. In addition, because black carp is a bottom-dwelling and deepwater species, it is less likely to be observed or captured than other Asian carp species (Nico et al. 2005).
T_{10}: See T_0. The species may, over time, move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. The species is a bottom-dwelling, freshwater fish that inhabits lakes and big rivers and backwaters (Nico et al. 2005). The species prefers fast-moving rivers (Williams et al. 2007). Black carp commonly feed on mollusks, using their pharyngeal teeth to crush the mollusks' shells, then consuming soft tissue. Four-year-old juveniles are capable of consuming around 1–2 kg (2.2–4.4 lb) of mollusks per day (Linder et al. 2005). When small, they feed on zooplankton and fingerlings (Williams et al. 2007). Habitat and food resources are available between their current location in the Mississippi River and Brandon Road Lock and Dam.

Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In general, black carp successfully spawn only in riverine environments (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels; Williams et al. 2007). Black carp are known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat could be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Asian carp are classified as "pelagophils," which are defined as non-guarding, open-substratum spawning fish that release and scatter non-adhesive eggs in open waters in areas where the direction of the current favors distribution and survival (Nico et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is potential for the black carp to be a rapid invader similar to the grass carp (section 2a). Suitable habitat and climate are present along the pathway between their current location and the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the black carp (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location (section 2e). The black carp is found in southern Illinois in the Illinois River (at least 415 km [258 mi] from Brandon Road Lock and Dam) (section 2a). Therefore, the probability of the species arriving at the pathway entrance at this time step is low.

T_{10}: See T_0. Black carp are large, actively swimming fish potentially capable of rapid upstream movement. Since the 1990s, they have spread from the lower MRB to southern Illinois. Unless the species is eradicated, over time the potential for black carp to spread north from its current location in the Mississippi River in southern Illinois toward the pathway entrance (at Brandon Road Lock and Dam) increases. Given time to naturally spread upstream, the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.

T_{25}: See T_{10}. If current dispersal trends continue, the probability of the black carp reaching Brandon Road Lock and Dam increases with time. Therefore, the probability of arrival at this time step increases to high.

T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: The natural rate of spread through the MRB is uncertain. Currently, there has been only one black carp captured in the Illinois River and it is unlikely that the species will naturally disperse and swim from its current location in southern Illinois to the pathway entrance during this time step. Therefore, the uncertainty associated with arrival is low.

T_{10}: See T_0. Future population trends for the black carp are uncertain because of uncertainty about the reproductive capabilities of wild populations. However, if the documented dispersal trends continue, 10 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Fifty years should be enough time for the black carp to arrive at the pathway. Therefore, the uncertainty associated with arrival is low.

3. P(passage) T_0-T_{50} : LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005).

b. *Human-Mediated Transport through Aquatic Pathways*
Black carp actively swims and do not require humans for dispersal through existing waterways. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, located south of Calumet Harbor (USACE 2011a,b), and there is the potential for black carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). However, vessel-mediated transport has not been described in the literature for this species, so the potential for this species to be transported in ballast water is uncertain. Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. It is uncertain whether black carp reproduce in the Illinois River. If reproduction does occur, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin & Ehrler 2012), making ballast water transport unlikely. USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. Existing Physical Human/Natural Barriers.

Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan.

c. *Existing Physical Human/Natural Barriers*
T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp.

There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, black carp are assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier — 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish that we most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in

2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002. Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels (USACE 2013). Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 20130).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, their possibility of these bypasses occurring in the field is low at this time because back carp are not present in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

Potential barriers to movement above the electric dispersal barrier system include a sluice gate at the WPS that separates the CAWS from Lake Michigan. However, the gates are periodically opened to allow reverse flow back into Lake Michigan, which could allow passage of black carp.

T_{10}: See T_0. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effortBlack carp are not abundant in the Illinois River, and a portion of these individuals are triploid and are not capable of reproduction. Therefore, even if the black carp reaches the electric barrier, it is unlikely to exist in high abundance, even by T_{25}. Consequently, it is assumed that black carp propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage,. Therefore, the probability of passage remains low.

T_{50}: See T_{10} and T_{25}

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Black carp are bottom-dwelling, freshwater fish that inhabit large, fast-moving rivers. The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Spawning sites of Asian carps have a water velocity of 1–1.85 m/s (3.28–6.07 ft/s); however, the minimum required velocity may extend to 0.8 or 0.6 m/s (1.97 or 2.62 ft/s), or even less. Turbulence is thought to be important, causing the fertilized egg to become fully water hardened and more buoyant. Sufficient flow is needed to create enough turbulence to keep the eggs in suspension (Nico et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at Calumet Harbor is a slow-moving, eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat would be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In the CAWS, annual average water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas (LimnoTech 2010).

Black carp inhabit water depths ranging from 0 to 10 m (0 to 32.8 ft), allowing for an abundance of mollusks (Nico et al. 2005). Black carp take refuge in deep water during winter (Nico et al. 2005). The maximum depth in the CAWS is about 10 m (32.8 ft) (LimnoTech 2010).

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through the pathway. For example, the MWRD is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. In addition, in coordination with the USACE, MWRD will increase the capacity of stormwater catchment and retention in adjacent tunnels and reservoirs, leading to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may also change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity, and to a lesser extent downstream.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable adult habitat for black carp is present in the CAWS. Turbulence in the areas of the locks may provide suitable spawning habitat (section 3d). The species has the ability to swim upstream to the WPS. The passage to the WPS includes two lock complexes and the Electric Dispersal Barrier System (section 3c). Black carp would be able to swim through the locks during the open phase of their normal operations. Black carp would be able to swim through the locks during the open phase of their normal operations. However, the Electric

Barrier Dispersal System is expected to control their passage during this timestep. Consequently, the probability of this species passing successfully through this pathway is rated as low.

T_{10}: See T_0. Black carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Consequently, there will be few fish expected to challenge the barrier, which reduces its probability of the barrier failing to prevent the passage of black carp upstream of the barrier. The Brandon Road and Lockport locks and dams may also slow black carp passage. Therefore, risk of passage at this time step is considered to be low.

T_{25}: See T_{10}. Funding for monitoring and removal programs for Asian carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. However,propagule pressure of this species immediately downstream of the Dispersal Barriers is expected to remain low at T_{50} because existing populations of black carp in Illinois are small and a portion will not be capable of reproduction. Therefore, the electric barrier is expected to remain effective at controlling passage of this species. Therefore, the probability of passage is expected to remain low.

T_{50}: See T_{25}

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Consequently, probability estimates for each potential barrier failure mechanism have not yet been established. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium.

T_{10}: See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. The current and future reproductive status of this species is unknown, and therefore future propagule pressure at the electric barrier is also unknown. Therefore, uncertainty increases to high.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   As with other introduced Asian carps, if the black carp becomes established in main-stem rivers it could become common and invade connected lakes and streams (Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); zebra mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, black carp have been reported to spawn in reservoirs in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). Resulting eggs reportedly drift to the larger part of the reservoir, into areas with little or no current where the eggs sink and die (Nico et al. 2005). In addition, seven tributaries of Lake Michigan, including St. Joseph River in the southeastern part of the lake, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   There is suitable adult habitat in Lake Michigan and its tributaries, and black carp has the ability to swim to suitable spawning habitat.

Evidence for Probability Rating

Suitable habitat is present and abundant for adult black carp. It is thought that spawning requires a flowing riverine environment, which is largely absent in Lake Michigan in the vicinity of Indiana Harbor. However, black carp spawning habitat does exist in many Lake Michigan tributaries. Therefore, the probability of colonizing is medium for black carp.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Suitable feeding habitat is available in Lake Michigan and similar species have been documented to establish in the GLB. However, no spawning habitat is available in the vicinity of Calumet Harbor, and it is uncertain whether this species would swim to suitable reproductive habitat. Therefore, the uncertainty of colonizing is medium for the black carp.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F) (Williams et al. 2007).

b. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the GLB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007).

c. *Fecundity*
Black carp can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and generally extremely low survival rates. Adult mortality is low due to the black carp's adult size. Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). However, reproductively viable black carp populations are not certain to exist in the United States.

d. *History of Invasion Success*
The black carp became established after it was introduced to several localities in Asia (e.g., Japan, possibly northern Vietnam), including at least one canal in the former Soviet Union. Three other Asian carp, all large-river cyprinids with habitat and spawning requirements similar to those of the black carp, now have established, naturally-reproducing populations in open waters of the United States (Nico et al. 2005).

e. *Human-Mediated Transport through Aquatic Pathways*
None described in the literature. Swimming would likely be the primary mechanism of upstream movement.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The black carp is a generalist consumer of mollusks, and is capable of inhabiting a variety of aquatic habitats. Black carp inhabit lakes and lower reaches of large, fast-moving rivers (Williams et al. 2007; Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); dreissenid mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, the black carp has been reported to spawn in reservoirs' river tributaries in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent. Fertilization occurs upstream, and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). In addition, 22 tributaries of the Great Lakes have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

Evidence for Probability Rating

Black carp have a high fecundity (section 5c) and are potentially rapid invaders (section 5d). Suitable habitat is present for adult black carp, which could swim (section 5b) to suitable spawning habitats in the GLB (section 5f). Therefore, the probability of spread for the black carp is high.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Climate and habitat in the GLB is suitable for adult black carp. There are many tributaries and rivers that the black carp could potentially use to spawn, although suitability of these spawning habitats is speculative. Overall, the uncertainty of spread is medium for black carp.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	High	Medium	High	Low
P(passage)	Low	Medium	Low	High	Low	High	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	High	Medium	High	Medium	High	Medium	High	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). Nico et al. (2005) states that the probability of the black carp spreading in the MRB is high. Since the 1990s, the black carp has spread from the lower MRB to southern Illinois. The black carp was recorded in the Mississippi River in southern Illinois in 2004, but has not yet been found in the Illinois River (Nico 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Swimming would likely be the primary mechanism of upstream movement. Although, vessel-mediated transport has not been described in the literature for this species, there is extensive commercial and recreational vessel traffic in the Illinois River, and black carp eggs and larvae have the potential to be spread by ballast water if water quality is suitable. However, it is uncertain whether reproductive populations of this species are present in the United States; therefore, the viability of this transport mechanism is uncertain. In addition, Heilprin et al. (2013) concluded that Asian carp eggs and larvae were able to survive the poor water quality conditions within most ballast water, but risk of passage was low due to very high mortality rates associated with bilge pump passage.

c. *Current Abundance and Reproductive Capacity*
T_0: Current abundance is unknown throughout the black carp's range. The fact that black carp, including diploid adults, have been in the wild for well over a decade in the lower Mississippi basin is evidence that the species may already be established or on the verge of establishment in the United States (Nico 2011). Collections of black carp in Illinois appear to be infrequent, suggesting they are not abundant. Reproductively competent diploid black carp have been collected in Louisiana waters (Nico et al. 2005). Black carp collected in Illinois can be triploid (not capable of reproduction) or diploid (Conover 2012; Nico 2011). To date, there have been no confirmed collections of larval or small juvenile black carp in the wild. Maturity is reached at 6 to 11 years of age in the species' native habitat (Williams et al. 2007). Individuals can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and survival rates are generally extremely low. Adult mortality is low due to the black carp's large size.
T_{10}: See T_0. A portion of black carp in the MRB are triploid and are not capable of reproduction. Consequently, populations could increase or decrease depending on the future reproductive capacity of populations of black carp in the MRB.
T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. The black carp has been documented above multiple lock and dam structures on the Mississippi River (Nico 2011). Therefore, the Marseilles Lock and Dam and Dresden Lock and Dam are not expected to be significant barriers to upstream movement.

T_{10}: See T_0. The lock operations are not expected to change.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: Black carp are most abundant in the lower MRB. However, at least ten specimens have been documented from Illinois. The first was captured in 2003 from Horseshoe Lake, in Alexander County (Chick et al. 2003). A second was found in 2004 in the Mississippi River, just above Lock and Dam No. 24, near Clarksville, Missouri (Nico et al. 2005). A third was found in 2010 in Pool 25 of the Mississippi River, near Hamburg, Illinois (Nico 2011). Assuming this species is present at the confluence of the Mississippi and Illinois Rivers, current distribution puts it about 458 km (285 mi) from the entrance to Brandon Road Lock and Dam. Because black carp superficially resemble grass carp, it is conceivable that some captures have gone unreported. In addition, because black carp is a bottom-dwelling and deepwater species, it is less likely to be observed or captured than other Asian carp species (Nico et al. 2005).

T_{10}: See T_0. The species may, over time, move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. The species is a bottom-dwelling, freshwater fish that inhabits lakes and big rivers and backwaters (Nico et al. 2005). The species prefers fast-moving rivers (Williams et al. 2007). Black carp commonly feed on mollusks, using their pharyngeal teeth to crush the mollusks' shells, then consuming soft tissue. Four-year-old juveniles are capable of consuming around 1–2 kg (2.2–4.4 lb) of mollusks per day (Linder et al. 2005). When small, they feed on zooplankton and fingerlings (Williams et al. 2007). Habitat and food resources are available between their current location in the Mississippi River and Brandon Road Lock and Dam.

Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In general, black carp successfully spawn only in riverine environments (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels; Williams et al. 2007). Black carp are known to spawn in riverine environments that are

highly turbulent (Nico et al. 2005). Lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat could be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Asian carp are classified as “pelagophils,” which are defined as non-guarding, open-substratum spawning fish that release and scatter non-adhesive eggs in open waters in areas where the direction of the current favors distribution and survival (Nico et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is potential for the black carp to be a rapid invader similar to the grass carp (section 2a). Suitable habitat and climate are present along the pathway between their current location and the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the black carp (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location (section 2e). The black carp is found in southern Illinois in the Illinois River (at least 415 km [258 mi] from Brandon Road Lock and Dam) (section 2a). Therefore, the probability of the species arriving at the pathway entrance at this time step is low.
T_{10}: See T_0. Black carp are large, actively swimming fish potentially capable of rapid upstream movement. Since the 1990s, they have spread from the lower MRB to southern Illinois. Unless the species is eradicated, over time the potential for black carp to spread north from its current location in the Mississippi River in southern Illinois toward the pathway entrance (at Brandon Road Lock and Dam) increases. Given time to naturally spread upstream, the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.
T_{25}: See T_{10}. If current dispersal trends continue, the probability of the black carp reaching Brandon Road Lock and Dam increases with time. Therefore, the probability of arrival at this time step increases to high.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: The natural rate of spread through the MRB is uncertain. Currently, there has only been one black carp captured in the Illinois River and it is unlikely that the species will naturally disperse and swim to the pathway entrance from its current location in southern Illinois during this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0. Future population trends for the black carp are uncertain because of uncertainty about the reproductive capabilities of wild populations. However, if the documented dispersal trends continue, 10 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years should be enough time for the back carp to arrive at the pathway. Therefore, the uncertainty associated with arrival is low.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive and released in the water column where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005).

b. *Human-Mediated Transport through Aquatic Pathways*
Black carp actively swims and do not require humans for dispersal through existing waterways. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam (USACE 2011a,b) and there is the potential for black carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). However, vessel-mediated transport has not been described in the literature for this species, so the potential for this species to be transported in ballast water is uncertain. Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. It is uncertain whether black carp reproduce in the Illinois River. If reproduction does occur, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin & Ehrler 2012), making ballast water transport unlikely USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water onboard, if there is an intention to release that water in any form within, or on the other side of the safety zone (USCG 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. Existing Physical Human/Natural Barriers.

Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, black carp are assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish that we most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002. Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 20130).

The USFWS placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers. Further research is being conducted to mitigate this bypass (USACE 2013). While preliminary results from these investigations have shown these bypasses to be viable, their possibility of these bypasses occuring in the field is low at this time because back carp are not present in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

Potential barriers to movement above the electric dispersal barrier system include a sluice gate at the WPS that separates the CAWS from Lake Michigan. However, the gates are periodically opened to allow reverse flow back into Lake Michigan, which could allow passage of black carp.

T_{10}: See T_0. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort. Black carp are not abundant in the Illinois River, and a portion of these individuals are triploid and are not capable of reproduction. Therefore, even if the black carp reaches the electric barrier, it is unlikely

to exist in high abundance, even by T_{25}. Consequently, it is assumed that black carp propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.
T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Black carp are bottom-dwelling, freshwater fish that inhabit large, fast-moving rivers. The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Spawning sites of Asian carps have a water velocity of 1–1.85 m/s (3.28–6.07 ft/s); however, the minimum required velocity may extend to 0.8 or 0.6 m/s (1.97 or 2.62 ft/s), or even less. Turbulence is thought to be important, causing the fertilized egg to become fully water hardened and more buoyant. Sufficient flow is needed to create enough turbulence to keep the eggs in suspension (Nico et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at Indiana Harbor is a slow-moving, eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat would be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In the CAWS, annual average water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas (LimnoTech 2010). Black carp inhabit water depths ranging from 0 to 10 m (0 to 32.8 ft), allowing for an abundance of mollusks (Nico et al. 2005). Black carp take refuge in deep water during winter (Nico et al. 2005). The maximum depth in the CAWS is about 10 m (32.8 ft) (LimnoTech 2010).
T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through the pathway. For example, the MWRD is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. In addition, in coordination with the USACE, MWRD will increase the capacity of stormwater catchment and retention in adjacent tunnels and reservoirs, leading to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may also change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable adult habitat for black carp is present in the CAWS. Turbulence in the areas of the locks may provide suitable spawning habitat (section 3d). The species has the ability to swim upstream to the WPS. The passage to the WPS includes two lock complexes and the Electric Dispersal Barrier System (section 3c). Black carp would be able to swim through the locks during the open phase of their normal operations. Black carp would be able to swim through the locks during the open phase of their normal operations. However, the Electric Barrier Dispersal System is expected to control their passage during this timestep. Consequently, the probability of this species passing successfully through this pathway is rated as low.

T_{10}: See T_0. Black carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Consequently, there will be few fish expected to challenge the barrier, which reduces its probability of the barrier failing to prevent the passage of black carp upstream of the barrier. The Brandon Road and Lockport locks and dams may also slow black carp passage. Therefore, risk of passage at this time step is considered to be low.

T_{25}: See T_{10}. Funding for monitoring and removal programs for Asian carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. However,propagule pressure of this species immediately downstream of the Electric Dispersal Barrier System is expected to remain low at T_{50} because existing populations of black carp in Illinois are small and a portion will not be capable of reproduction. Therefore, the Electric Dispersal Barrier System is expected to remain effective at controlling passage of this species. Therefore, the probability of passage is expected to remain low.

T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Consequently, probability estimates for each potential barrier failure mechanism have not yet been established. It is also unclear if additional mechanisms could still be discovered. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium.

T_{10}: See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. The current and future reproductive status of this species is unknown, and, therefore, future propagule pressure at the electric barrier is also unknown. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
As with other introduced Asian carps, if the black carp becomes established in main-stem rivers it could become common and invade connected lakes and streams (Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); zebra mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, black carp have been reported to spawn in reservoirs in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). Resulting eggs reportedly drift to the larger part of the reservoir, into areas with little or no current where the eggs sink and die (Nico et al. 2005). In addition, seven tributaries of Lake Michigan, including St. Joseph River in the southeastern part of the lake, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
There is suitable adult habitat in Lake Michigan and its tributaries, and black carp has the ability to swim to suitable spawning habitat.

Evidence for Probability Rating

Suitable habitat is present and abundant for adult black carp. It is thought that spawning requires a flowing riverine environment, which is largely absent in Lake Michigan in the vicinity of Indiana Harbor. However, black carp spawning habitat does exist in many Lake Michigan tributaries. Therefore, the probability of colonizing is medium for black carp.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Suitable feeding habitat is available in Lake Michigan, and similar species have been documented to establish in the GLB. However, no spawning habitat is available in the vicinity of Indiana Harbor, and it is uncertain whether this species would swim to suitable reproductive habitat. Therefore, the uncertainty of colonizing is medium for the black carp.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F) (Williams et al. 2007).

b. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the GLB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007).

c. *Fecundity*
Black carp can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and generally extremely low survival rates. Adult mortality is low due to the black carp's adult size. Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). However, reproductively viable black carp populations are not certain to exist in the United States.

d. *History of Invasion Success*
The black carp became established after it was introduced to several localities in Asia (e.g., Japan, possibly northern Vietnam), including at least one canal in the former Soviet Union. Three other Asian carp, all large-river cyprinids with habitat and spawning requirements similar to those of the black carp, now have established, naturally-reproducing populations in open waters of the United States (Nico et al. 2005).

e. *Human-Mediated Transport through Aquatic Pathways*
None described in the literature. Swimming would likely be the primary mechanism of upstream movement.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The black carp is a generalist consumer of mollusks, and is capable of inhabiting a variety of aquatic habitats. Black carp inhabit lakes and lower reaches of large, fast-moving rivers (Williams et al. 2007; Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); dreissenid mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, the black carp has been reported to spawn in reservoirs' river tributaries in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent. Fertilization occurs upstream, and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). In addition, 22 tributaries of the Great Lakes have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

Evidence for Probability Rating

Black carp have a high fecundity (section 5c) and are potentially rapid invaders (section 5d). Suitable habitat is present for adult black carp, which could swim (section 5b) to suitable spawning habitats in the GLB (section 5f). Therefore, the probability of spread for the black carp is high.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Climate and habitat in the GLB is suitable for adult black carp. There are many tributaries and rivers that the black carp could potentially use to spawn, although suitability of these spawning habitats is speculative. Overall, the uncertainty of spread is medium for black carp.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	High	Medium	High	Low
P(passage)	Low	Medium	Low	High	Low	High	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	High	Medium	High	Medium	High	Medium	High	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). Nico et al. (2005) states that the probability of the black carp spreading in the MRB is high. Since the 1990s, the black carp has spread from the lower MRB to southern Illinois. The black carp was recorded in southern Illinois in the Mississippi River in 2004, but has not yet been found in the Illinois River (Nico 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Swimming would likely be the primary mechanism of upstream movement. Although, vessel-mediated transport has not been described in the literature for this species, there is extensive commercial and recreational vessel traffic in the Illinois River, and black carp eggs and larvae have the potential to be spread by ballast water if water quality is suitable. However, it is uncertain whether reproductive populations of this species are present in the United States; therefore, the viability of this transport mechanism is uncertain. In addition, Heilprin et al. (2013) concluded that Asian carp eggs and larvae were able to survive the poor water quality conditions within most ballast water, but risk of passage was low due to very high mortality rates associated with bilge pump passage.

c. *Current Abundance and Reproductive Capacity*
T_0: Current abundance is unknown throughout the black carp's range. The fact that black carp, including diploid adults, have been in the wild for well over a decade in the lower Mississippi basin is evidence that the species may already be established or on the verge of establishment in the United States (Nico 2011). Collections of black carp in Illinois appear to be infrequent, suggesting they are not abundant. Reproductively competent diploid black carp have been collected in Louisiana waters (Nico et al. 2005). Black carp collected in Illinois can be triploid (not capable of reproduction) or diploid (Conover 2012; Nico 2011). To date, there have been no confirmed collections of larval or small juvenile black carp in the wild. Maturity is reached at 6 to 11 years of age in the species' native habitat (Williams et al. 2007). Individuals can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and survival rates are generally extremely low. Adult mortality is low due to the black carp's large size.
T_{10}: See T_0. A portion of black carp in the MRB are triploid and are not capable of reproduction. Consequently, populations could increase or decrease depending on the future reproductive capacity of populations of black carp in the MRB.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The black carp has been documented above multiple lock and dam structures on the Mississippi River (Nico 2011). Therefore, the Marseilles Lock and Dam and Dresden Lock and Dam are not expected to be significant barriers to upstream movement.
T_{10}: See T_0. The lock operations are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Black carp are most abundant in the lower MRB. However, at least ten specimens have been documented from Illinois. The first was captured in 2003 from Horseshoe Lake, in Alexander County (Chick et al. 2003). A second was found in 2004 in the Mississippi River, just above Lock and Dam No. 24, near Clarksville, Missouri

(Nico et al. 2005). A third was found in 2010 in Pool 25 of the Mississippi River, near Hamburg, Illinois (Nico 2011). Assuming this species is present at the confluence of the Mississippi and Illinois Rivers, current distribution puts it about 548 km (285 mi) from the entrance to Brandon Road Lock and Dam. Because black carp superficially resemble grass carp, it is conceivable that some captures have gone unreported. In addition, because black carp is a bottom-dwelling and deepwater species, it is less likely to be observed or captured than other Asian carp species (Nico et al. 2005).
T_{10}: See T_0. The species may, over time, move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. The species is a bottom-dwelling, freshwater fish that inhabits lakes and big rivers and backwaters (Nico et al. 2005). The species prefers fast-moving rivers (Williams et al. 2007). Black carp commonly feed on mollusks, using their pharyngeal teeth to crush the mollusks' shells, then consuming soft tissue. Four-year-old juveniles are capable of consuming around 1–2 kg of mollusks per day (Linder et al. 2005). When small, they feed on zooplankton and fingerlings (Williams et al. 2007). Habitat and food resources are available between their current location in the Mississippi River and Brandon Road Lock and Dam.

Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In general, black carp successfully spawn only in riverine environments (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels; Williams et al. 2007). Black carp are known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat could be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Asian carp are classified as "pelagophils," which are defined as non-guarding, open-substratum spawning fish that release and scatter non-adhesive eggs in open waters in areas where the direction of the current favors distribution and survival (Nico et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is potential for the black carp to be a rapid invader similar to the grass carp (section 2a). Suitable habitat and climate are present between their current location and the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the black carp (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location (section 2e). The black carp is found in southern Illinois in the Illinois River (at least 415 km [258 mi] from Brandon Road Lock and Dam) (section 2a). Therefore, the probability of the species arriving at the pathway entrance at this time step is low.
T_{10}: See T_0. Black carp are large, actively swimming fish potentially capable of rapid upstream movement. Since the 1990s, they have spread from the lower MRB to southern Illinois. Unless the species is eradicated, over time the potential for black carp to spread north towards the pathway entrance (at Brandon Road Lock and Dam) from its current location in the Mississippi River in southern Illinois increases. Given time to naturally spread upstream, the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.
T_{25}: See T_{10}. If current dispersal trends continue, the probability of the black carp reaching Brandon Road Lock and Dam increases with time. Therefore, the probability of arrival at this time step increases to high.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: The natural rate of spread through the MRB is uncertain. Currently, there has been only one black carp captured in the Illinois River and it is unlikely that the species will naturally disperse and swim from its current location in southern Illinois to the pathway entrance during this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0. Future population trends for the black carp are uncertain, because of uncertainty about the reproductive capabilities of wild populations. However, if the documented dispersal trends continue, 10 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Fifty years should be enough time for the back carp to arrive at the pathway. Therefore, the uncertainty associated with arrival is low.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Swimming would be the primary mode of spread in the MRB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007). Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005).

b. Human-Mediated Transport through Aquatic Pathways

Black carp actively swims and do not require humans for dispersal through existing waterways. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam (USACE 2011a,b), and there is the potential for black carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). However, vessel-mediated transport has not been described in the literature for this species, so the potential for this species to be transported in ballast water is uncertain. Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. It is uncertain whether black carp reproduce to sustain juvenile and adult Asian carp. It is uncertain whether black carp reproduce in the Illinois River. If reproduction does occur, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin & Ehrler 2012), making ballast water transport unlikely. USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water onboard if there is an intention to release that water in any form within, or on the other side of the safety zone (USCG 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. Existing Physical Human/Natural Barriers.

Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan.

c. Existing Physical Human/Natural Barriers

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, black carp are assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish that we most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002. Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels (USACE 2013). Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 20130).

The USFWS placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic will lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers. Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, their probability of occurring in the field is low at this time because back carp are not present in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

Potential barriers to movement above the electric dispersal barrier system include a sluice gate at the WPS that separates the CAWS from Lake Michigan. However, the gates are periodically opened to allow reverse flow back into Lake Michigan, which could allow passage of black carp.

T_{10}: See T_0. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort. With a decrease in removal efforts at the upstream edge of the invasion front, the risk for propagule pressure at the Dispersal Barrier System could increase, thus increasing the potential for an individual to move past the barrier. However, black carp are not abundant in the Illinois River, and a portion of these individuals are triploid and are not capable of reproduction. Therefore, even if the black carp reaches the electric barrier, it is unlikely to exist in high abundance, even by T_{25}. Consequently, it is assumed that black carp propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage, even if monitoring and removal efforts for Asian carp were ended. Therefore, the probability of passage remains low.

T_{50}: See T_{10} and T25.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Black carp are bottom-dwelling, freshwater fish that inhabit large, fast-moving rivers. The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Spawning sites of Asian carps have a water velocity of 1–1.85 m/s (3.28–6.07 ft/s); however, the minimum required velocity may extend to 0.8 or 0.6 m/s (1.97 or 2.62 ft/s), or even less. Turbulence is thought to be important, causing the fertilized egg to become fully water hardened and more buoyant. Sufficient flow is needed to create enough turbulence to keep the eggs in suspension (Nico et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at BSBH is a slow-moving, eutrophic river with a flow of 0.13 m/s (0.43 ft/s) (LimnoTech 2010). The lock chambers allow for frequent passage of boats and fishes in both directions. Spawning habitat would be created by turbulent flows below the structures, as a result of water rushing through gates (Nico et al. 2005). Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F), water levels are rising, and mollusks are available (Williams et al. 2007). In the CAWS, annual average water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). Fertilization occurs upstream, and eggs drift downstream with the current until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas (LimnoTech 2010). Black carp inhabit water depths ranging from 0 to 10 m (0 to 32.8 ft), allowing for an abundance of mollusks (Nico et al. 2005). Black carp take refuge in deep water during winter (Nico et al. 2005). The maximum depth in the CAWS is about 10 m (32.8 ft) (LimnoTech 2010). The south branch of the Little Calumet River is small and shallow (Gallagher et al. 2011), and may not be preferred habitat for the black carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the MWRD is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. In addition, in coordination with the USACE, MWRD will increase the capacity of stormwater catchment and retention in adjacent tunnels and reservoirs, leading to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may also change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable adult habitat for black carp is present in the CAWS. Turbulence in the areas of the locks may provide suitable spawning habitat (section 3d). The species has the ability to swim upstream to the WPS. The passage to the WPS includes two lock complexes and the Electric Dispersal Barrier System (section 3c). Black carp would be able to swim through the locks during the open phase of their normal operations. Black carp would be able to swim through the locks during the open phase of their normal operations. However, the Electric Barrier Dispersal System is expected to preven passage during this timestep. Consequently, the probability of this species passing successfully through this pathway is rated as low.

T_{10}: See T_0. Black carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Consequently, there will be few fish expected to challenge

the barrier, which reduces its probability of the barrier failing to prevent the passage of black carp upstream of the barrier. The Brandon Road and Lockport locks and dams may also slow black carp passage. Therefore, risk of passage at this time step is considered to be low.
T_{25}: See T_{10}. Funding for monitoring and removal programs for Asian carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. However,propagule pressure of this species immediately downstream of the Dispersal Barriers is expected to remain low at T_{50} because existing populations of black carp in Illinois are small and a portion will not be capable of reproduction. Therefore, even if monitoring and removal efforts for Asian carp are suspended, the electric barrier is expected to remain effective at controlling passage of this species. Therefore, the probability of passage is expected to remain low.
T_{50}: See T_{25}

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Consequently, probability estimates for each potential barrier failure mechanism have not yet been established. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium.
T_{10}: See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. The current and future reproductive status of this species is unknown and, therefore, future propagule pressure at the electric barrier is also unknown. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   As with other introduced Asian carps, if the black carp becomes established in main-stem rivers it could become common and invade connected lakes and streams (Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); dreissenid mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, black carp have been reported to spawn in reservoirs in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent (Nico et al. 2005). Fertilization occurs upstream, and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). Resulting eggs reportedly drift to the larger part of the reservoir, into areas with little or no current where the eggs sink and die (Nico et al. 2005). In addition, seven tributaries of Lake Michigan, including St. Joseph River in the southeastern part of the lake (less than 97 km [60 mi] from BSBH), have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   There is suitable adult habitat in Lake Michigan and its tributaries, and black carp has the ability to swim to suitable spawning habitat.

Evidence for Probability Rating

Suitable habitat is present and abundant for adult black carp. It is thought that spawning requires a flowing riverine environment, which is largely absent in Lake Michigan in the vicinity of Indiana Harbor. However, black carp spawning habitat does exist in many Lake Michigan tributaries. Therefore, the probability of colonizing is medium for black carp.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Suitable feeding habitat is available in Lake Michigan and spawning habitat does exist in many Lake Michigan tributaries. However, no spawning habitat is available in the vicinity of BSBH, and it is uncertain whether this species would swim to suitable reproductive habitat. Therefore, the uncertainty of colonizing is medium for the black carp.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin

The black carp's native distribution is primarily subtropical, lying between 53°N and 15°N (Linder et al. 2005). Nico et al. (2005) states that climate in the lower 48 states could be suitable for the black carp. Spawning occurs annually when water temperatures are 17–27°C (62.6–80.6°F) (Williams et al. 2007).

b. Type of Mobility/Invasion Speed

Swimming would be the primary mode of spread in the GLB. Eggs are non-adhesive. They are released in the water column, where they are transported downstream (Williams et al. 2007).

c. Fecundity

Black carp can produce an average of 1–3 million eggs each year depending on body size (Nico 2011). However, there is no parental care and survival rates are generally extremely low. Adult mortality is low due to the black carp's adult size. Population doubling times are relatively low, and range between 4.5 and 14 years (Linder et al. 2005). However, reproductively viable black carp populations are not certain to exist in the United States.

d. History of Invasion Success

The black carp became established after it was introduced to several localities in Asia (e.g., Japan, possibly northern Vietnam), including at least one canal in the former Soviet Union. Three other Asian carp, all large-river cyprinids with habitat and spawning requirements similar to those of the black carp, now have established, naturally reproducing populations in open waters of the United States (Nico et al. 2005).

e. Human-Mediated Transport through Aquatic Pathways

None described in the literature. Swimming would likely be the primary mechanism of upstream movement.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The black carp is a generalist consumer of mollusks, and is capable of inhabiting a variety of aquatic habitats. Black carp inhabit lakes and lower reaches of large, fast-moving rivers (Williams et al. 2007; Nico et al. 2005). Black carp commonly feed on mollusks (Linder et al. 2005); dreissenid mussels are abundant in Lake Michigan. Black carp are known to survive and grow in lakes, but there is little evidence indicating that the species is able to successfully reproduce in lentic environments. However, the black carp has been reported to spawn in reservoirs' river tributaries in China (Nico et al. 2005). The species is known to spawn in riverine environments that are highly turbulent. Fertilization occurs upstream, and eggs drift downstream with the current (Williams et al. 2007) until they reach areas with little current (e.g., floodplain lakes, smaller streams, and water channels) (Nico et al. 2005). In addition, 22 tributaries of the Great Lakes have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005).

Evidence for Probability Rating

Black carp have a high fecundity (section 5c) and are potentially rapid invaders (section 5d). Suitable habitat is present for adult black carp, which could swim (section 5b) to suitable spawning habitats in the GLB (section 5f). Therefore, the probability of spread for the black carp is high.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Climate and habitat in the GLB is suitable for adult black carp. There are many tributaries and rivers that the black carp could potentially use to spawn, although suitability of these spawning habitats is speculative. Overall, the uncertainty of spread is medium for black carp.

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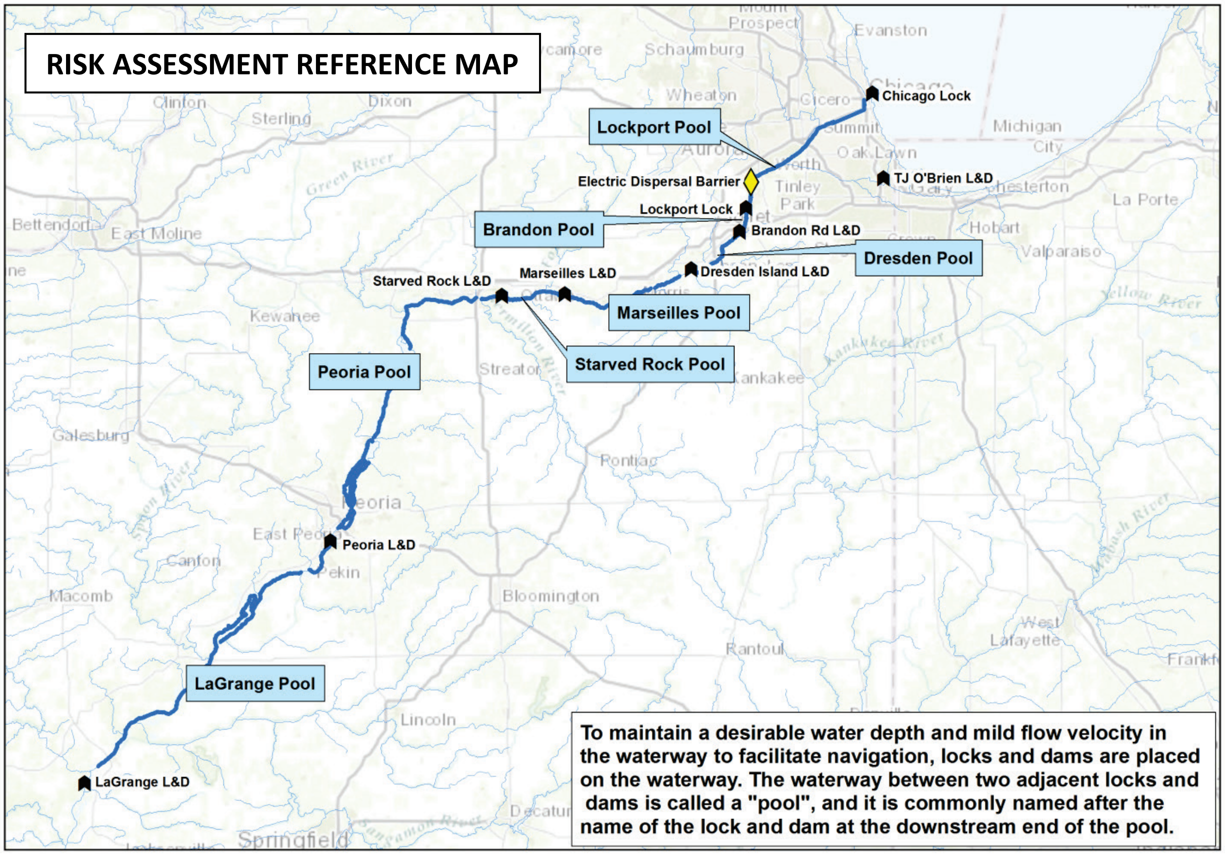
E.1.3.3 Bighead Carp - *Hypophthalmichthys nobilis*


RISK ASSESSMENT REFERENCE MAP

To maintain a desirable water depth and mild flow velocity in the waterway to facilitate navigation, locks and dams are placed on the waterway. The waterway between two adjacent locks and dams is called a "pool", and it is commonly named after the name of the lock and dam at the downstream end of the pool.

◊ The Electric Dispersal Barrier System located approximately 5 miles upstream of the Lockport Lock and Dam is assumed to continue operation through T_{50}.

Pools of the Upper Illinois River and CAWS			Lock and Dams of the Upper Illinois and CAWS	
Pool	River Miles	Approximate Length (mi.)	Lock and Dams	Approximate Distance from Electric Barrier System (mi.)
Lockport Pool*			Chicago Lock	31
Electric Barrier System	296	--	T.J O'Brien Lock and Dam*	30.5
To Chicago Lock	291-327	36	Lockport Lock and Dam	5
To T.J. O'Brien	291-326.5	35.5	Brandon Road Lock and Dam	10
Brandon Road Pool	286-291	5	Dresden Island Lock and Dam	24.5
Dresden Island Pool	271.5-286	14.5	Marseilles Lock and Dam	49
Marseilles Pool	247-271.5	24.5	Starved Rock Lock and Dam	65
Starved Rock Pool	231-247	16	Peoria Lock and Dam	138.4
Peoria Pool	157.6-231	73.4	LaGrange Lock and Dam	215.8
LaGrange Pool	80.2-157.6	77.4		

*Lockport Pool encompasses river miles both below and above the Electric Dispersal Barrier System. Upstream of the Electric Dispersal Barrier System, the Chicago Sanitary and Ship Canal (CSSC) continues north to the Chicago Lock at Lake Michigan. The Cal-Sag Channel connects with the CSSC at approximately river mile 303, and proceeds eastward toward the T.J. O'Brien Lock and Dam. Lake Michigan is approximately six miles north of the T.J. O'Brien Lock and Dam.

Note: River Miles were determined from the U.S. Army Corps of Engineers, Illinois Waterway Navigation Charts from Mississippi River at Grafton, Illinois to Lake Michigan at Chicago and Calumet Harbors, 1998.

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and WPS over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Bighead carp are active swimmers. Total maximum distance traveled upstream by an individual was 163 km (101 mi) over 35 days (Peters et al. 2006), with an average of 4.5 km (2.8 mi) traveled per day. Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010) and they were able to move from Arkansas into Mississippi, Missouri, Ohio, and Illinois rivers. Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River; 1991) to the La Grange reach (IL

River; 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of bighead carp and the Brandon Road Lock and Dam. Bighead carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current and Potential Abundance and Reproductive Capacity*
T_0: Adult bighead carp are abundant in the Illinois Waterway from Starved Rock Lock & Dam (RM231) to the confluence with Mississippi River (Chick and Pegg 2001; Irons et al. 2009; ACRCC 2012; Garvey, et al. 2013; Wyffels et al. 2013). Bighead carp were reported to have high abundances within the La Grange pool of the Illinois River from sampling conducted from 2000 to 2006 (Irons et al. 2011). Bighead carp reached peak abundance levels in 2000 and have declined between 2004 and 2006, however these declines may be due to capture gear inefficiencies (Irons et al. 2011). Sampling efforts for Asian carp conducted in the upper pools of the Illinois River (Marseilles-Lockport) from 2010 through 2012 indicated a decreasing population from downstream to upstream (Ruebush et al. 2013).

A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

In 2013, a significant number of bighead carp were captured in the Rock Run Rookery Preserve Lake, a backwater in the Dresden Island pool, 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Above Dresden Island Pool, one bighead was collected in 2009 within Lockport Pool downstream of the Electric Dispersal Barrier System during a rotenone application

(ACRCC 2009). In 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012).

Bighead carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Females with as many as 1.1 million eggs have been found in the Yangtze River, China (Kolar et al. 2005). In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank and Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 180,000 per female (DeGrandchamp et al. 2007). Kolar et al. (2007) reported that their analysis suggested that populations appear to be growing exponentially at the time of the report. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: Based on the above information, bighead carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is anticipated to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood, Hoopes, and Marchetti 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movement of bighead carp from their current position to Brandon Road Lock and Dam.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: There have been two recorded captures of bighead carp above the Brandon Road Pool. The first was collected in 2009 within the Lockport Pool, downstream of the Electric Dispersal Barrier System, during a rotenone application (ACRCC 2009). The second capture occurred during routine monitoring in Lake Calumet. Lake Calumet is directly connected to the Little Calumet River, only 6 miles from Lake Michigan (ACRCC 2012). Multiple bighead carp have been captured in landlocked Chicago-area urban fishing ponds above the barrier. It is likely that these fish were accidentally introduced during stocking for the Illinois Department of Natural Resources urban fishing program of catchable sized channel catfish in the 2002-2003 timeframe (ILDNR 2011; ACRCC 2013). In addition, there have been multiple positive eDNA detections upstream of electric barriers for bighead carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, bighead carp have been detected in the Dresden Island pool. A significant number of adult bighead carp were captured approximately 4 miles downstream of the Brandon Road Lock and Dam in the Rock Run Rookery Preserve Lake in 2013 (ACCRC 2013c). The USACE telemetry program has also recorded one individual bighead carp that approached the Brandon Road Lock and Dam in 2012 before returning downstream to the mouth of the Kankakee River (Shanks and Barkowski 2013). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the bighead carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Bighead carp prefer eutrophic conditions but can survive with low growth rates under low plankton concentrations (Kolar et al. 2007). There was no difference in catch rate regarding location within the water column as measured within the backwaters of the Illinois River (Schultz et al. 2007). DeGrandchamp et al. (2008) suggest that bighead carp rarely occupy depths greater than 4 m (13 ft) regardless of abiotic factors. Other studies indicate that 3 m (9.8 ft) deep or more provides suitable conditions for bighead carp (Kolar et al. 2005). Bighead carp can be found in low velocity and off-channel habitats in the Mississippi, Missouri, Wabash and lower Ohio Rivers and all sizes collected in the Upper Mississippi River Basin were strongly associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005). During low flow, bighead carp avoid channels & backwaters (DeGrandchamp et al. 2008), but will use spur dikes (Kolar et al. 2007; Cooke et al. 2009). These varied habitats are found throughout the Dresden Island Pool, including the Rock Run Rookery Preserve Lake and in the Kankakee River. This species is found in Swan Lake, which is connected to the Illinois River (DeGrandchamp et al. 2007). Heilprin (2013) found that larvae of bighead carp can survive under low DO conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate adults (0.5 mg/L; Oregon Sea Grant 2011), juveniles (0.33 mg/L) and young (0.4 mg/L; Jennings 1988) can survive low DO conditions. Critical spawning temperature for bighead carp is reported as 18°C (64.4°F) (Irons et al. 2009). However, typically successful fertilization occurs between 21° and 26°C (69.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake

Michigan near Chicago ranges between 20 and 23°C (64.4°F). Adult bighead carp can withstand water temperatures up to 38.8 °C (101.8°F) (Bettoli et al. 1985).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp have been documented at the Brandon Road Lock and Dam and Lockport Pool upstream of Brandon Road Lock and Dam. Therefore, the probability of bighead carp having arrived at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: A bighead carp was captured in the Lockport pool, upstream of the Brandon Road Lock and Dam; telemetric tracking of tagged individual bighead carp has provided evidence of at least one individual approaching the Brandon Road Lock and Dam in 2012; and in the spring of 2013, the capture of significant numbers of bighead carp at Rock Run Rookery Forest Preserve Lake, which is approximately 4 miles from the Brandon Road Lock and Dam. Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. Bighead carp populations in the Dresden Island Pool are expected to increase to existing levels or higher. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_{25}.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Bighead carp is an active swimmer that can swim against the slow current of the CAWS. An individual can travel as far as 4.5 km (2.8 mi) per day (Peters et al. 2006). Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River 1991) to the La Grange Pool (IL River 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013). Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for bighead and silver carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward Asian carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

As noted above, in 2007, bighead carp were first captured in Dresden Island Pool. In 2009, one bighead carp was found in the Lockport Pool during a rotenone event (ACRCC 2009), and in 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences.

Within the Marseilles and Dresden Island Pools, reproductively mature bighead carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool . The nearest population of juvenile sized individuals is in the Peoria Pool, 5 locks downstream from the Electric Barrier System. The nearest collection of Asian carp eggs was found near Henry, Illinois within the Peoria Pool. Larval Asian carp were only collected in the LaGrange Pool. (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Bighead carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b) and there is the potential for bighead carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, bighead carp are expected to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 5 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier

System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The USFWS placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of bighead carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

In addition, there are water control structures separating WPS from Lake Michigan, which are periodically opened and closed (LimnoTech 2010). When these structures are opened, bighead carp would be able to swim into Lake Michigan.

T_{10}: Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

Future operations of WPS sluice gate are not predicted to change.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for bighead carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005, Cooke et al. 2009). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for bighead carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (ACRCC 2013a, Butler et al. 2013). Bighead carp utilize all parts of the water column in rivers (Schultz et al. 2007; DeGrandchamp et al. 2008; Kolar et al. 2005). They can be found in low velocity and off-channel habitats associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005), but are capable of swimming in very-high-velocity habitats, with a maximum measured swimming speed of approximately 7.5 m/s (24.6 ft/s) (Konagaya and Cai 1987). During normal conditions, the CAWS has a slow-moving current (LimnoTech 2010). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Heilprin et al. (2013a) found that larvae of bighead carp can survive under low dissolved oxygen conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate the species can survive low dissolved oxygen conditions: adults (0.5 mg/L) (Oregon Sea Grant 2011), juveniles (0.33 mg/L), and young (0.4 mg/L) (Jennings 1988). Adult bighead carp can withstand water temperatures up to 38.8 ^{o}C (101.8^{o}F) (Bettoli et al. 1985). Overall, the conditions of the CAWS are not expected to impede movement of bighead carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species bighead carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs. This will lead to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. This is not expected to significantly affect the ability of bighead carp to pass through this pathway.

T_{25}: See T_{10}

T_{50}: See T_{10}

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of bighead carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of bighead carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of bighead carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier

System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming bighead carp is in Dresden Island Pool and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the bighead carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See $T_{0.}$ Bighead carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow bighead carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990’s (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would informed by this analysis.

The probability of passage for the bighead carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for bighead carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases from low to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.
T_{10}: See $T_{0.}$ Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See $T_{10.}$

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005). Bighead carp are generalist planktivores (Laird and Page 1996), primarily zooplankton, with the ability to feed on phytoplankton (Kolar et al. 2005). They filter prey out of the water column as they swim through the water, taking advantage of various sizes of food items (Kolar et al. 2005). Bighead carp has recently been shown to consume *Cladophora*, this algae is abundant in Lake Michigan (Rasmussen et al. 2011). Spawning occurs during the growing season as early as May through August (Coulter and Goforth 2011; Papoulias et al. 2006). Spawning is triggered by changes in water temperature and may also be triggered by changes in water levels (e.g., spring floods) and velocity (Iron et al. 2011; Stainbrook et al. 2007).

Critical spawning temperature for bigheaded carp is reported as 18°C (64.4°F) (Irons et al. 2011). However, typical successful fertilization occurs between 21 and 26°C (6.9.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Reports have indicated a positive relationship between Asian carp spawning and increasing river flow (Jennings 1988, DeGrandchamp et al. 2007, Kolar et al. 2007, Lohmeyer & Garvey 2009, and Irons et al. 2011). However, DeGrandchamp et al. (2007) indicate that high river flow does not appear to be critical for successful spawning but may aid in egg and larval survival. A specific substrate is not necessary for spawning to occur. However, the eggs may not survive if covered by sediment, hence the need for a shifter current during fertilization and egg development (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013 the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen 2011). The Great Lakes likely have the habitat required for all life stages of Asian carp (The Asian Carp Regional Coordinating Committee 2012; Canadian Science Advisory Report 2012).

b. *Ability of the species to reach suitable habitat by natural or human-mediated dispersal*
Bighead carp is an active swimmer and could find more optimal habitat in the 22 rivers that flow into the Great Lakes. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2009; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers and reproductive habitat can be found in Lake Michigan and in rivers that flow into Lake Michigan that bighead carp could disperse to after exiting the WPS. Therefore, there is a High probability of bighead carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known if the fertilized eggs of bighead carp could successfully hatch and if larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear if optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, bighead carp would have to swim or be carried into one of the large or medium rivers that flow into Lake Michigan. The nearest suitable river is the St. Joseph, the mouth is located at Benton Harbor, MI. Benton Harbor is approximately 113 km (70 mi) from WPS. It is not certain that bighead carp would be able to successfully navigate from WPS to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spreading, the species is assumed to have colonized near the pathway. The probability of spreading is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin

Bighead carp is found in the Upper Mississippi River Basin, Wisconsin and Minnesota. The Upper Mississippi River Basin and the Great Lakes Basin share similar climatic conditions.

b. Type of Mobility/Invasion Speed

Bighead carp is an active swimmer and has an average expansion rate of 8.99 river miles per year (Jerde et al. 2010). Hybridization between bighead carp and silver carp reduces jumping behavior in post F_1 hybrids, which may decrease invasion success as introgression continues (Lamer et al. 2010).

c. Fecundity

In the Missouri River, the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank & Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 1.8×10^5 per female (DeGrandchamp et al. 2007). Kolar et al. (2005) reported that their analysis suggested that populations appear to be growing exponentially. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp.

d. History of Invasion Success

Moved from Arkansas into Mississippi, Missouri, Ohio and Illinois rivers. Bighead carp are very abundant in the Illinois River from Starved Rock Lock and Dam (RM231) to the confluence with Mississippi River. Five Bighead carp have been individually collected between 1995 and 2003 in western Lake Erie. Since 2004, the U.S. Fish and Wildlife Service have monitored western Lake Erie in Sandusky and Toledo, Ohio and sampling has not resulted in any additional collections of bighead. Monitoring efforts suggest a reproducing population does not exist in Lake Erie (http://www.asiancarp.us/faq.htm#Q10). Bighead carp have been thought to outcompete gizzard shad, bigmouth buffalo and paddlefish (Kolar et al. 2005), and by age 3, bighead carp have outsized any natural predator (Wanner and Klumb 2009). These ecological traits increase the probability of successful invasion of the GLB.

e. Human-Mediated Transport through Aquatic Pathways

There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological))*

   Bighead carp are generalists, considered opportunistic feeders of plankton & detritus (Kolar et al. 2005). Bighead carp are pump filter feeders that produce mucous allowing them to take advantage of various sizes of food items (Kolar et al. 2005). Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005).

   Early studies have reported eggs and larvae to passively flow into flood plains or tributary mouths (Kolar et al. 2005). Larvae will disperse to nursery areas and move up and/or down a river channel (Kolar et al. 2005). Juveniles are recorded from low velocity and off-channel habitats in rivers and lakes. During low flow adults have been recorded as avoiding river channels and use slower backwaters (DeGrandchamp et al. 2008) and along spur dikes (Kolar et al. 2005). There are 22 tributaries located on the United States side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water.

Evidence for Probability Rating

Bighead carp are active swimmers with a history of successful invasion of new riverine environments and can survive in lake conditions as well. The GLB will provide suitable habitat. Therefore, there is a high probability bighead carp will spread throughout the GLB if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well bighead carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if bighead carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the GLB have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and CRCW over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Bighead carp are active swimmers. Total maximum distance traveled upstream by an individual was 163 km (101 mi) over 35 days (Peters et al. 2006), with an average of 4.5 km (2.8 mi) traveled per day. Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010) and they were able to move from Arkansas into Mississippi, Missouri, Ohio, and Illinois rivers. Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and

Illinois Rivers. First detections at Pool 26 (MS River; 1991) to the La Grange reach (IL River; 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of bighead carp and the Brandon Road Lock and Dam. Bighead carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current and Potential Abundance and Reproductive Capacity*
T_0: Adult bighead carp are abundant in the Illinois Waterway from Starved Rock Lock & Dam (RM231) to the confluence with Mississippi River (Chick and Pegg 2001; Irons et al. 2009; ACRCC 2012; Garvey, et al. 2013; Wyffels et al. 2013). Bighead carp were reported to have high abundances within the La Grange pool of the Illinois River from sampling conducted from 2000 to 2006 (Irons et al. 2011). Bighead carp reached peak abundance levels in 2000 and have declined between 2004 and 2006, however these declines may be due to capture gear inefficiencies (Irons et al. 2011). Sampling efforts for Asian carp conducted in the upper pools of the Illinois River (Marseilles-Lockport) from 2010 through 2012 indicated a decreasing population from downstream to upstream (Ruebush et al. 2013).

A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

In 2013, a significant number of bighead carp were captured in the Rock Run Rookery Preserve Lake, a backwater in the Dresden Island pool, 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Above Dresden Island Pool, one bighead was collected in 2009 within Lockport Pool downstream of the Electric Dispersal Barrier System during a rotenone application

(ACRCC 2009). In 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012).

Bighead carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Females with as many as 1.1 million eggs have been found in the Yangtze River, China (Kolar et al. 2005). In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank and Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 180,000 per female (DeGrandchamp et al. 2007). Kolar et al. (2007) reported that their analysis suggested that populations appear to be growing exponentially at the time of the report. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: Based on the above information, bighead carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is anticipated to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood, Hoopes, and Marchetti 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movement of bighead carp from their current position to Brandon Road Lock and Dam.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: There have been two recorded captures of bighead carp above the Brandon Road Pool. The first was collected in 2009 within the Lockport Pool, downstream of the Electric Dispersal Barrier System, during a rotenone application (ACRCC 2009). The second capture occurred during routine monitoring in Lake Calumet. Lake Calumet is directly connected to the Little Calumet River, only 6 miles from Lake Michigan (ACRCC 2012). Multiple bighead carp have been captured in landlocked Chicago-area urban fishing ponds above the barrier. It is likely that these fish were accidentally introduced during stocking for the Illinois Department of Natural Resources urban fishing program of catchable sized channel catfish in the 2002-2003 timeframe (ILDNR 2011; ACRCC 2013). In addition, there have been multiple positive eDNA detections upstream of electric barriers for bighead carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, bighead carp have been detected in the Dresden Island pool. A significant number of adult bighead carp were captured approximately 4 miles downstream of the Brandon Road Lock and Dam in the Rock Run Rookery Preserve Lake in 2013 (ACCRC 2013c). The USACE telemetry program has also recorded one individual bighead carp that approached the Brandon Road Lock and Dam in 2012 before returning downstream to the mouth of the Kankakee River (Shanks and Barkowski 2013). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the bighead carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Bighead carp prefer eutrophic conditions but can survive with low growth rates under low plankton concentrations (Kolar et al. 2007). There was no difference in catch rate regarding location within the water column as measured within the backwaters of the Illinois River (Schultz et al. 2007). DeGrandchamp et al. (2008) suggest that bighead carp rarely occupy depths greater than 4 m (13 ft) regardless of abiotic factors. Other studies indicate that 3 m (9.8 ft) deep or more provides suitable conditions for bighead carp (Kolar et al. 2005). Bighead carp can be found in low velocity and off-channel habitats in the Mississippi, Missouri, Wabash and lower Ohio Rivers and all sizes collected in the Upper Mississippi River Basin were strongly associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005). During low flow, bighead carp avoid channels & backwaters (DeGrandchamp et al. 2008), but will use spur dikes (Kolar et al. 2007; Cooke et al. 2009). These varied habitats are found throughout the Dresden Island Pool, including the Rock Run Rookery Preserve Lake and in the Kankakee River. This species is found in Swan Lake, which is connected to the Illinois River (DeGrandchamp et al. 2007). Heilprin (2013) found that larvae of bighead carp can survive under low DO conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate adults (0.5 mg/L; Oregon Sea Grant 2011), juveniles (0.33 mg/L) and young (0.4 mg/L; Jennings 1988) can survive low DO conditions. Critical spawning temperature for bighead carp is reported as 18°C (64.4°F) (Irons et al. 2009). However, typically successful fertilization occurs between 21° and 26°C (69.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake

Michigan near Chicago ranges between 20 and 23°C (64.4°F). Adult bighead carp can withstand water temperatures up to 38.8 °C (101.8°F) (Bettoli et al. 1985).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp have been documented at the Brandon Road Lock and Dam and Lockport Pool upstream of Brandon Road Lock and Dam. Therefore, the probability of bighead carp having arrived at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: A bighead carp was captured in the Lockport pool, upstream of the Brandon Road Lock and Dam; telemetric tracking of tagged individual bighead carp has provided evidence of at least one individual approaching the Brandon Road Lock and Dam in 2012; and in the spring of 2013, the capture of significant numbers of bighead carp at Rock Run Rookery Forest Preserve Lake, which is approximately 4 miles from the Brandon Road Lock and Dam. Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. Bighead carp populations in the Dresden Island Pool are expected to increase to existing levels or higher. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_{25}.

4. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*

Bighead carp is an active swimmer that can swim against the slow current of the CAWS. An individual can travel as far as 4.5 km (2.8 mi) per day (Peters et al. 2006). Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River 1991) to the La Grange Pool (IL River 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013). Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for bighead and silver carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward Asian carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

As noted above, in 2007, bighead carp were first captured in Dresden Island Pool. In 2009, one bighead carp was found in the Lockport Pool during a rotenone event (ACRCC 2009), and in 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences.

Within the Marseilles and Dresden Island Pools, reproductively mature bighead carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. The nearest population of juvenile sized individuals is in the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. The nearest collection of Asian carp eggs was found near

Henry, Illinois within the Peoria Pool. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Bighead carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b) and there is the potential for bighead carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, bighead carp are expected to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 5 miles upstream of Lockport Lock and Dam and approximately31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested

Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The USFWS placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of bighead carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for bighead carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005, Cooke et al. 2009). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for bighead carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (ACRCC 2013a, Butler et al. 2013). Bighead carp utilize all parts of the water column in rivers (Schultz et al. 2007; DeGrandchamp et al. 2008; Kolar et al. 2005). They can be found in low velocity and off-channel habitats associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005), but are capable of swimming in very-high-velocity habitats, with a maximum measured swimming speed of approximately 7.5 m/s (24.6 ft/s) (Konagaya and Cai 1987). During normal conditions, the CAWS has a slow-moving current (LimnoTech 2010). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Heilprin et al. (2013a) found that larvae of bighead carp can survive under low dissolved oxygen conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate the species can survive low dissolved oxygen conditions: adults (0.5 mg/L) (Oregon Sea Grant 2011), juveniles (0.33 mg/L), and young (0.4 mg/L) (Jennings 1988). Adult bighead carp can withstand water temperatures up to 38.8 °C (101.8°F) (Bettoli et al. 1985). Overall, the conditions of the CAWS are not expected to impede movement of bighead carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species bighead carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs. This will lead to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. This is not expected to significantly affect the ability of bighead carp to pass through this pathway.

T_{25}: See T_{10}

T_{50}: See T_{10}

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of bighead carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of bighead carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a). Adult populations of bighead carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming bighead carp is in Dresden Island Pool. and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the bighead carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric

Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Bighead carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow bighead carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990's (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would informed by this analysis.

The probability of passage for the bighead carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for bighead carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases from low to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.
T_{10}: See $T_{0.}$ Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See $T_{10.}$

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005). Bighead carp are generalist planktivores (Laird and Page 1996), primarily zooplankton, with the ability to feed on phytoplankton (Kolar et al. 2005). They filter prey out of the water column as they swim through the water, taking advantage of various sizes of food items (Kolar et al. 2005). Bighead carp has recently shown to consume *Cladophora*, this algae is abundant in Lake Michigan (Rasmussen et al. 2011). Spawning occurs during the growing season as early as May through August (Coulter & Goforth 2011; Papoulias et al. 2006). Spawning is triggered by changes in water temperature and may also be triggered by changes water levels (e.g., spring floods) and velocity (Iron et al. 2011 and Stainbrook et al. 2007). Critical spawning temperature for bigheaded carp is reported as 18°C (64.4°F) Irons et al. 2011). However, typical successful fertilization occurs between 21 and 26°C (6.9.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Reports have indicated a positive relationship between Asian carp spawning and increasing river flow (Jennings 1988, DeGrandchamp et al. 2007, Kolar et al. 2007, Lohmeyer & Garvey 2009, and Irons et al. 2011). However,

DeGrandchamp et al. (2007) indicate that high river flow does not appear to be critical for successful spawning but may aid in egg and larval survival. A specific substrate is not necessary for spawning to occur. However, the eggs may not survive if covered by sediment, hence the need for a shifter current during fertilization and egg development (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013, the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen 2011). The Great Lakes likely has the habitat required for all life stages of Asian carp (The Asian Carp Regional Coordinating Committee 2012; Canadian Science Advisory Report 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Bighead carp is an active swimmer and could find more optimal habitat in the 22 rivers that flow into the Great Lakes. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2009; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers and reproductive habitat can be found in Lake Michigan and in rivers that flow into Lake Michigan that bighead carp could disperse to after exiting the CRCW. Therefore, there is a high probability of bighead carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known if the fertilized eggs of bighead carp could successfully hatch and if larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear if optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, bighead carp would have to swim or be carried into one of the large or medium rivers that flow into Lake Michigan. The nearest suitable river is St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that bighead carp would be able to successfully navigate from the CRCW to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spreading, the species is assumed to have colonized near the pathway. The probability of spreading is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Bighead carp is found in the Upper Mississippi River Basin, Wisconsin and Minnesota. The Upper Mississippi River Basin and the Great Lakes Basin share similar climatic conditions.

b. *Type of Mobility/Invasion Speed*
Bighead carp is an active swimmer and has an average expansion rate of 8.99 river miles per year (Jerde et al. 2010). Hybridization between *H. nobilis* and *H. molitrix* (silver carp) reduces jumping behavior, fitness, and condition in post F_1 hybrids, which may decrease invasion success as introgression continues (Lamer et al. 2010).

c. *Fecundity*
In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank & Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 1.8×10^5 per female (DeGrandchamp et al. 2007). Kolar et al. (2005) reported that their analysis suggested that populations appear to be growing exponentially. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp.

d. *History of Invasion Success*
Moved from Arkansas into Mississippi, Missouri, Ohio and Illinois rivers. Bighead carp are very abundant in the Illinois River from Starved Rock Lock and Dam (RM231) to the confluence with Mississippi River. Five Bighead carp have been individually collected between 1995 and 2003 in western Lake Erie. Since 2004, the U.S. Fish and Wildlife Service have monitored western Lake Erie in Sandusky and Toledo, Ohio and sampling has not resulted in any additional collections of bighead. Monitoring efforts suggest a reproducing population does not exist in Lake Erie (http://www.asiancarp.us/faq.htm#Q10). Bighead carp have been thought to outcompete gizzard shad, bigmouth buffalo and paddlefish (Kolar et al. 2005), and by age 3, have outsized any natural predator (Wanner & Klumb 2009). These ecological traits increase the probability of successful invasion of the GLB.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Bighead carp are generalists, considered opportunistic feeders of plankton & detritus (Kolar et al. 2005). Bighead carp are pump filter feeders that produce mucous allowing them to take advantage of various sizes of food items (Kolar et al. 2005). Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005).

Early studies have reported eggs and larvae to passively flow into flood plains or tributary mouths (Kolar et al. 2005). Larvae will disperse to nursery areas and move up and/or down a river channel (Kolar et al. 2005). Juveniles are recorded from low velocity and off-channel habitats in rivers and lakes. During low flow adults have been recorded as avoiding river channels and use slower backwaters (DeGrandchamp et al. 2008) and along spur dikes (Kolar et al. 2005). There are 22 tributaries located on the U.S. side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water.

Evidence for Probability Rating

Bighead carp are active swimmers with a history of successful invasion of new riverine environments and can survive in lake conditions as well. The GLB will provide suitable habitat. Therefore, there is a high probability bighead carp will spread throughout the GLB if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well bighead carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if bighead carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the GLB have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and Calumet Harbor over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Bighead carp are active swimmers. Total maximum distance traveled upstream by an individual was 163 km (101 mi) over 35 days (Peters et al. 2006), with an average of 4.5 km (2.8 mi) traveled per day. Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010) and they were able to move from Arkansas into Mississippi, Missouri, Ohio, and Illinois rivers. Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River; 1991) to the La Grange reach (IL River; 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of bighead carp and the Brandon Road Lock and Dam. Bighead carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current and Potential Abundance and Reproductive Capacity*
T_0: Adult bighead carp are abundant in the Illinois Waterway from Starved Rock Lock & Dam (RM231) to the confluence with Mississippi River (Chick and Pegg 2001; Irons et al. 2009; ACRCC 2012; Garvey, et al. 2013; Wyffels et al. 2013). Bighead carp were

reported to have high abundances within the La Grange pool of the Illinois River from sampling conducted from 2000 to 2006 (Irons et al. 2011). Bighead carp reached peak abundance levels in 2000 and have declined between 2004 and 2006, however these declines may be due to capture gear inefficiencies (Irons et al. 2011). Sampling efforts for Asian carp conducted in the upper pools of the Illinois River (Marseilles-Lockport) from 2010 through 2012 indicated a decreasing population from downstream to upstream (Ruebush et al. 2013).

A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in 283,290 the capture of specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

In 2013, a significant number of bighead carp were captured in the Rock Run Rookery Preserve Lake, a backwater in the Dresden Island pool, 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Above Dresden Island Pool, one bighead was collected in 2009 within Lockport Pool downstream of the Electric Dispersal Barrier System during a rotenone application (ACRCC 2009). In 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012).

Bighead carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Females with as many as 1.1 million eggs have been found in the Yangtze River, China (Kolar et al. 2005). In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank and Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 180,000 per female (DeGrandchamp et al. 2007). Kolar et al. (2007) reported that their analysis suggested that populations appear to be growing exponentially at the time of the report. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool.

Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: Based on the above information, bighead carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is anticipated to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood, Hoopes, and Marchetti 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movement of bighead carp from their current position to Brandon Road Lock and Dam.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: There have been two recorded captures of bighead carp above the Brandon Road Pool. The first was collected in 2009 within the Lockport Pool, downstream of the Electric Dispersal Barrier System, during a rotenone application (ACRCC 2009). The second capture occurred during routine monitoring in Lake Calumet. Lake Calumet is directly connected to the Little Calumet River, only 6 miles from Lake Michigan (ACRCC 2012). Multiple bighead carp have been captured in landlocked Chicago-area urban fishing ponds above the barrier. It is likely that these fish were accidentally introduced during stocking for the Illinois Department of Natural Resources urban fishing program of catchable sized channel catfish in the 2002-2003 timeframe (ILDNR 2011; ACRCC 2013). In addition, there have been multiple positive eDNA detections upstream of electric barriers for bighead carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, bighead carp have been detected in the Dresden Island pool. A significant number of adult bighead carp were captured approximately 4 miles downstream of the Brandon Road Lock and Dam in the Rock Run Rookery Preserve Lake in 2013 (ACCRC 2013c). The USACE telemetry program has also recorded one individual bighead carp that approached the Brandon Road Lock and Dam in 2012 before returning downstream to the mouth of the Kankakee River (Shanks and

Barkowski 2013). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the bighead carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Bighead carp prefer eutrophic conditions but can survive with low growth rates under low plankton concentrations (Kolar et al. 2007). There was no difference in catch rate regarding location within the water column as measured within the backwaters of the Illinois River (Schultz et al. 2007). DeGrandchamp et al. (2008) suggest that bighead carp rarely occupy depths greater than 4 m (13 ft) regardless of abiotic factors. Other studies indicate that 3 m (9.8 ft) deep or more provides suitable conditions for bighead carp (Kolar et al. 2005). Bighead carp can be found in low velocity and off-channel habitats in the Mississippi, Missouri, Wabash and lower Ohio Rivers and all sizes collected in the Upper Mississippi River Basin were strongly associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005). During low flow, bighead carp avoid channels & backwaters (DeGrandchamp et al. 2008), but will use spur dikes (Kolar et al. 2007; Cooke et al. 2009). These varied habitats are found throughout the Dresden Island Pool, including the Rock Run Rookery Preserve Lake and in the Kankakee River. This species is found in Swan Lake, which is connected to the Illinois River (DeGrandchamp et al. 2007). Heilprin (2013) found that larvae of bighead carp can survive under low DO conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate adults (0.5 mg/L; Oregon Sea Grant 2011), juveniles (0.33 mg/L) and young (0.4 mg/L; Jennings 1988) can survive low DO conditions. Critical spawning temperature for bighead carp is reported as 18°C (64.4°F) (Irons et al. 2009). However, typically successful fertilization occurs between 21° and 26°C (69.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Adult bighead carp can withstand water temperatures up to 38.8 ^{o}C (101.8^{o}F) (Bettoli et al. 1985).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp have been documented at the Brandon Road Lock and Dam and Lockport Pool upstream of Brandon Road Lock and Dam. Therefore, the probability of bighead carp having arrived at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: A bighead carp was captured in the Lockport pool, upstream of the Brandon Road Lock and Dam; telemetric tracking of tagged individual bighead carp has provided evidence of at least one individual approaching the Brandon Road Lock and Dam in 2012; and in the spring of 2013, the capture of significant numbers of bighead carp at Rock Run Rookery Forest Preserve Lake, which is approximately 4 miles from the Brandon Road Lock and Dam. Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. Bighead carp populations in the Dresden Island Pool are expected to increase to existing levels or higher. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_{25}.

4. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Bighead carp is an active swimmer that can swim against the slow current of the CAWS. An individual can travel as far as 4.5 km (2.8 mi) per day (Peters et al. 2006). Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River 1991) to the La

Grange Pool (IL River 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013). Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for bighead and silver carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward Asian carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

As noted above, in 2007, bighead carp were first captured in Dresden Island Pool. In 2009, one bighead carp was found in the Lockport Pool during a rotenone event (ACRCC 2009), and in 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences.

Within the Marseilles and Dresden Island Pools, reproductively mature bighead carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. The nearest population of juvenile sized individuals is in the Peoria Pool below Starved Rock Lock and Dam, 5 locks downstream of the Electric Dispersal Barrier System. The nearest collection of Asian carp eggs was found near Henry, Illinois within the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Bighead carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b) and there is the potential for bighead carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, bighead carp are expected to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 5 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The USFWS placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of bighead carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events. A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for bighead carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005, Cooke et al. 2009). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for bighead carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (ACRCC 2013a, Butler et al. 2013). Bighead carp utilize all parts of the water column in rivers (Schultz et al. 2007; DeGrandchamp et al. 2008; Kolar et al. 2005). They can be found in low velocity and off-channel habitats associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005), but are capable of swimming in very-high-velocity habitats, with a maximum measured swimming speed of approximately 7.5 m/s (24.6 ft/s) (Konagaya and Cai 1987). During normal conditions, the CAWS has a slow-moving current (LimnoTech 2010). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Heilprin et al. (2013a) found that larvae of bighead carp can survive under low dissolved oxygen conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate the species can survive low dissolved oxygen conditions: adults (0.5 mg/L) (Oregon Sea Grant 2011), juveniles (0.33 mg/L), and young (0.4 mg/L) (Jennings 1988). Adult bighead carp can withstand water temperatures up to 38.8 °C (101.8°F) (Bettoli et al. 1985). Overall, the conditions of the CAWS are not expected to impede movement of bighead carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species bighead carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs. This will lead to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. This is not expected to significantly affect the ability of bighead carp to pass through this pathway.

T_{25}: See T_{10}

T_{50}: See T_{10}

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of bighead carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of bighead carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of bighead carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming bighead carp is in Dresden Island Pool. and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the bighead carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Bighead carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow bighead carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990's (Conover et al. 2007;

Irons et al. 2009; ACRCC 2013a). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would informed by this analysis.

The probability of passage for the bighead carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for bighead carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases from low to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.

T_{10}: See $T_{0.}$ Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.

T_{25}: See T_{10}.

T_{50}: *See T_{10}.*

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005). Bighead carp are generalist planktivores (Laird and Page 1996), primarily zooplankton, with the ability to feed on phytoplankton (Kolar et al. 2005). They filter prey out of the water column as they swim through the water, taking advantage of various sizes of food items (Kolar et al. 2005). Bighead carp has recently been shown to consume *Cladophora*, this algae is abundant in Lake Michigan (Rasmussen et al. 2011). Spawning occurs during the growing season as early as May through August (Coulter & Goforth 2011; Papoulias et al. 2006). Spawning is triggered by changes in water temperature and may also be triggered by changes water levels (e.g., spring floods) and velocity (Iron et al. 2011 and Stainbrook et al. 2007). Critical spawning temperature for bigheaded carp is reported as 18°C (64.4°F) Irons et al. 2011). However, typical successful fertilization occurs between 21 and 26°C (6.9.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Reports have indicated a positive relationship between Asian carp spawning and increasing river flow (Jennings 1988, DeGrandchamp et al. 2007, Kolar et al. 2007, Lohmeyer & Garvey 2009, and Irons et al. 2011). However, DeGrandchamp et al. (2007) indicate that high river flow does not appear to be critical for successful spawning but may aid in egg and larval survival. A specific substrate is not necessary for spawning to occur. However, the eggs may not survive if covered by sediment, hence the need for a shifter current during fertilization and egg development (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013, the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013). Food resources and potential spawning areas are available in the GLB (Rasmussen 2011). The Great Lakes likely has the habitat required for all life stages of Asian carp (The Asian Carp Regional Coordinating Committee 2012; Canadian Science Advisory Report 2012).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal

Bighead carp is an active swimmer and could find more optimal habitat in the 22 rivers that flow into the Great Lakes. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2009; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers and reproductive habitat can be found in Lake Michigan and in rivers that flow into Lake Michigan that bighead carp could disperse to after exiting Calumet Harbor. Therefore, there is a high probability of bighead carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known if the fertilized eggs of bighead carp could successfully hatch and if larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear if optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, bighead carp would have to swim or be carried into one of the large or medium rivers that flow into Lake Michigan. The nearest suitable river is St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that bighead carp would be able to successfully navigate from Calumet Harbor to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spreading, the species is assumed to have colonized near the pathway. The probability of spreading is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Bighead carp is found in the Upper Mississippi River Basin, Wisconsin and Minnesota. The Upper Mississippi River Basin and the Great Lakes Basin share similar climatic conditions.

b. *Type of Mobility/Invasion Speed*
Bighead carp is an active swimmer and has an average expansion rate of 8.99 river miles per year (Jerde et al. 2010). Hybridization between *H. nobilis* and *H. molitrix* (silver carp) reduces jumping behavior, fitness, and condition in post F_1 hybrids, which may decrease invasion success as introgression continues (Lamer et al. 2010).

c. *Fecundity*
In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank & Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 1.8×10^5 per female (DeGrandchamp et al. 2007). Kolar et al. (2005) reported that their analysis suggested that populations appear to be

growing exponentially. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp.

d. *History of Invasion Success*
Moved from Arkansas into Mississippi, Missouri, Ohio and Illinois rivers. Bighead carp are very abundant in the Illinois River from Starved Rock Lock and Dam (RM231) to the confluence with Mississippi River. Five bighead carp have been individually collected between 1995 and 2003 in western Lake Erie. Since 2004, the U.S. Fish and Wildlife Service have monitored western Lake Erie in Sandusky and Toledo, Ohio and sampling has not resulted in any additional collections of bighead. Monitoring efforts suggest a reproducing population does not exist in Lake Erie (http://www.asiancarp.us/faq.htm#Q10). Bighead carp have been thought to outcompete gizzard shad, bigmouth buffalo and paddlefish (Kolar et al. 2005), and by age 3, bighead carp have outsized any natural predator (Wanner & Klumb 2009). These ecological traits increase the probability of successful invasion of the GLB.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Bighead carp are generalists, considered an opportunistic feeder of plankton & detritus (Kolar et al. 2005). Bighead carp are a pump filter feeder that produce mucous allowing them to take advantage of various sizes of food items (Kolar et al. 2005). Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005).
Early studies have reported eggs and larvae to passively flow into flood plains or tributary mouths (Kolar et al. 2005). Larvae will disperse to nursery areas and move up and/or down a river channel (Kolar et al. 2005). Juveniles are recorded from low velocity and off-channel habitats in rivers and lakes. During low flow adults have been recorded as avoiding river channels and use slower backwaters (DeGrandchamp et al. 2008) and along spur dikes (Kolar et al. 2005). There are 22 tributaries located on the U.S. side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water.

Evidence for Probability Rating

Bighead carp are active swimmers with a history of successful invasion of new riverine environments and can survive in lake conditions as well. The Great Lakes Basin will provide suitable habitat. Therefore, there is a high probability bighead carp will spread throughout the Great Lakes Basin if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well bighead carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if bighead carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the GLB have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and Indiana Harbor over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Bighead carp are active swimmers. Total maximum distance traveled upstream by an individual was 163 km (101 mi) over 35 days (Peters et al. 2006), with an average of 4.5 km (2.8 mi) traveled per day. Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010) and they were able to move from Arkansas into Mississippi, Missouri, Ohio, and Illinois rivers. Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River; 1991) to the La Grange reach (IL River; 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of bighead carp and the Brandon Road Lock and Dam. Bighead carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current and Potential Abundance and Reproductive Capacity*
T_0: Adult bighead carp are abundant in the Illinois Waterway from Starved Rock Lock & Dam (RM231) to the confluence with Mississippi River (Chick and Pegg 2001; Irons et al. 2009; ACRCC 2012; Garvey, et al. 2013; Wyffels et al. 2013). Bighead carp were reported to have high abundances within the La Grange pool of the Illinois River from sampling conducted from 2000 to 2006 (Irons et al. 2011). Bighead carp reached peak abundance levels in 2000 and have declined between 2004 and 2006, however these declines may be due to capture gear inefficiencies (Irons et al. 2011). Sampling efforts for Asian carp conducted in the upper pools of the Illinois River (Marseilles-Lockport) from 2010 through 2012 indicated a decreasing population from downstream to upstream (Ruebush et al. 2013).

A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

In 2013, a significant number of bighead carp were captured in the Rock Run Rookery Preserve Lake, a backwater in the Dresden Island pool, 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Above Dresden Island Pool, one bighead was collected in 2009 within Lockport Pool downstream of the Electric Dispersal Barrier System during a rotenone application (ACRCC 2009). In 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012).

Bighead carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Females with as many as 1.1 million eggs have been found in the Yangtze River, China (Kolar et al. 2005). In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank and Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 180,000 per female (DeGrandchamp et al. 2007). Kolar et al. (2007) reported that their analysis suggested that populations appear to be growing exponentially at the time of the report. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: Based on the above information, bighead carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is anticipated to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood, Hoopes, and Marchetti 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. Existing Physical Human/Natural Barriers

T_0: None. There are no barriers to movement of bighead carp from their current position to Brandon Road Lock and Dam.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: There have been two recorded captures of bighead carp above the Brandon Road Pool. The first was collected in 2009 within the Lockport Pool, downstream of the Electric Dispersal Barrier System, during a rotenone application (ACRCC 2009). The second capture occurred during routine monitoring in Lake Calumet. Lake Calumet is directly connected to the Little Calumet River, only 6 miles from Lake Michigan (ACRCC 2012). Multiple bighead carp have been captured in landlocked Chicago-area urban fishing ponds above the barrier. It is likely that these fish were accidentally introduced during stocking for the Illinois Department of Natural Resources urban fishing program of catchable sized channel catfish in the 2002-2003 timeframe (ILDNR 2011; ACRCC 2013). In addition, there have been multiple positive eDNA detections upstream of electric barriers for bighead carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, bighead carp have been detected in the Dresden Island pool. A significant number of adult bighead carp were captured approximately 4 miles downstream of the Brandon Road Lock and Dam in the Rock Run Rookery Preserve Lake in 2013 (ACCRC 2013c). The USACE telemetry program has also recorded one individual bighead carp that approached the Brandon Road Lock and Dam in 2012 before returning downstream to the mouth of the Kankakee River (Shanks and Barkowski 2013). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the bighead carp has arrived at the pathway (Brandon Road Lock and Dam).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Bighead carp prefer eutrophic conditions but can survive with low growth rates under low plankton concentrations (Kolar et al. 2007). There was no difference in catch rate regarding location within the water column as measured within the backwaters of the Illinois River (Schultz et al. 2007). DeGrandchamp et al. (2008) suggest that bighead carp rarely occupy depths greater than 4 m (13 ft) regardless of abiotic factors. Other studies indicate that 3 m (9.8 ft) deep or more provides suitable conditions for bighead

carp (Kolar et al. 2005). Bighead carp can be found in low velocity and off-channel habitats in the Mississippi, Missouri, Wabash and lower Ohio Rivers and all sizes collected in the Upper Mississippi River Basin were strongly associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005). During low flow, bighead carp avoid channels & backwaters (DeGrandchamp et al. 2008), but will use spur dikes (Kolar et al. 2007; Cooke et al. 2009). These varied habitats are found throughout the Dresden Island Pool, including the Rock Run Rookery Preserve Lake and in the Kankakee River. This species is found in Swan Lake, which is connected to the Illinois River (DeGrandchamp et al. 2007). Heilprin (2013) found that larvae of bighead carp can survive under low DO conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate adults (0.5 mg/L; Oregon Sea Grant 2011), juveniles (0.33 mg/L) and young (0.4 mg/L; Jennings 1988) can survive low DO conditions. Critical spawning temperature for bighead carp is reported as 18°C (64.4°F) (Irons et al. 2009). However, typically successful fertilization occurs between 21° and 26°C (69.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Adult bighead carp can withstand water temperatures up to 38.8 ^{o}C (101.8^{o}F) (Bettoli et al. 1985).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp have been documented at the Brandon Road Lock and Dam and Lockport Pool upstream of Brandon Road Lock and Dam. Therefore, the probability of bighead carp having arrived at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: A bighead carp was captured in the Lockport pool, upstream of the Brandon Road Lock and Dam; telemetric tracking of tagged individual bighead carp has provided evidence of at least one individual approaching the Brandon Road Lock and Dam in 2012; and in the spring of 2013, the capture of significant numbers of bighead carp at Rock Run Rookery Forest

Preserve Lake, which is approximately 4 miles from the Brandon Road Lock and Dam. Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. Bighead carp populations in the Dresden Island Pool are expected to increase to existing levels or higher. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_{25}.

4. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*

Bighead carp is an active swimmer that can swim against the slow current of the CAWS. An individual can travel as far as 4.5 km (2.8 mi) per day (Peters et al. 2006). Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River 1991) to the La Grange Pool (IL River 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013). Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for bighead and silver carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward Asian carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

As noted above, in 2007, bighead carp were first captured in Dresden Island Pool. In 2009, one bighead carp was found in the Lockport Pool during a rotenone event (ACRCC

2009), and in 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences.

Within the Marseilles and Dresden Island Pools, reproductively mature bighead carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. The nearest population of juvenile sized individuals is in the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. The nearest collection of Asian carp eggs was found near Henry, Illinois within the Peoria Pool. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Bighead carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b) and there is the potential for bighead carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, bighead carp are expected to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 5 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were

installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of bighead carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for bighead carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005, Cooke et al. 2009). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for bighead carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (ACRCC 2013a, Butler et al. 2013). Bighead carp utilize all parts of the water column in rivers (Schultz et al. 2007; DeGrandchamp et al. 2008; Kolar et al. 2005). They can be found in low velocity and off-channel habitats associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005), but are capable of swimming in very-high-velocity habitats, with a maximum measured swimming speed of approximately 7.5 m/s (24.6 ft/s) (Konagaya and Cai 1987). During normal conditions, the CAWS has a slow-moving current (LimnoTech 2010). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Heilprin et al. (2013a) found that larvae of bighead carp can survive under low dissolved oxygen conditions

(0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate the species can survive low dissolved oxygen conditions: adults (0.5 mg/L) (Oregon Sea Grant 2011), juveniles (0.33 mg/L), and young (0.4 mg/L) (Jennings 1988). Adult bighead carp can withstand water temperatures up to 38.8 °C (101.8°F) (Bettoli et al. 1985). Overall, the conditions of the CAWS are not expected to impede movement of bighead carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species bighead carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs. This will lead to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. This is not expected to significantly affect the ability of bighead carp to pass through this pathway.

T_{25}: See T_{10}

T_{50}: See T_{10}

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of bighead carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of bighead carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of bighead carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming bighead carp is in Dresden Island Pool. and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the bighead carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Bighead carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow bighead carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990's (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would informed by this analysis.

The probability of passage for the bighead carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a

low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.
T_{25}: See T_{10}. Funding for monitoring and removal programs for bighead carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases from low to medium.
T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.
T_{10}: See $T_{0.}$ Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See $T_{10.}$

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005). Bighead carp are generalist planktivores (Laird & Page 1996), primarily zooplankton, with the ability to feed on phytoplankton (Kolar et al. 2005). They filter prey out of the water column as they swim through the water, taking advantage of various sizes of food items (Kolar et al. 2005). Bighead carp has recently been shown to consume *Cladophora*, this algae is abundant in Lake Michigan (Rasmussen et al. 2011). Spawning occurs during the growing season as early as May through August (Coulter & Goforth 2011; Papoulias et al. 2006). Spawning is triggered by changes in water temperature and may also be triggered by changes water levels (e.g., spring floods) and velocity (Iron et al. 2011 and Stainbrook et al. 2007). Critical spawning temperature for bigheaded carp is reported as 18°C (64.4°F) Irons et al. 2011). However, successful fertilization typically occurs between 21 and 26°C (6.9.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Reports have indicated a positive relationship between Asian carp spawning and increasing river flow (Jennings 1988, DeGrandchamp et al. 2007, Kolar et al. 2007, Lohmeyer & Garvey 2009, and Irons et al. 2011). However, DeGrandchamp et al. (2007) indicate that high river flow does not appear to be critical for successful spawning but may aid in egg and larval survival. A specific substrate is not necessary for spawning to occur. However, the eggs may not survive if covered by sediment, hence the need for a shifter current during fertilization and egg development (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013, the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013). Food resources and potential spawning areas are available in the Great Lakes Basin (Rasmussen 2011). The Great Lakes likely has the habitat required for all life stages of Asian carp (The Asian Carp Regional Coordinating Committee 2012; Canadian Science Advisory Report 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Bighead carp is an active swimmer and could find more optimal habitat in the 22 rivers that flow into the Great Lakes. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2009; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers and reproductive habitat can be found in Lake Michigan and in rivers that flow into Lake Michigan that bighead carp could disperse to after exiting Indiana Harbor. Therefore, there is a High probability of bighead carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known if the fertilized eggs of bighead carp could successfully hatch and if larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear if optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, bighead carp would have to swim or be carried into one of the large or medium rivers that flow into Lake Michigan. The nearest suitable river is St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that bighead carp would be able to successfully navigate from Indiana Harbor to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spreading, the species is assumed to have colonized near the pathway. The probability of spreading is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
Bighead carp is found in the Upper Mississippi River Basin, Wisconsin and Minnesota. The Upper Mississippi River Basin and the Great Lakes Basin share similar climatic conditions.

b. Type of Mobility/Invasion Speed
Bighead carp is an active swimmer and has an average expansion rate of 8.99 river miles per year (Jerde et al. 2010). Hybridization between *H. nobilis* and *H. molitrix* (silver carp) reduces jumping behavior, fitness, and condition in post F_1 hybrids, which may decrease invasion success as introgression continues (Lamer et al. 2010).

c. Fecundity
In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank & Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 1.8×10^5 per female (DeGrandchamp et al. 2007). Kolar et al. (2005) reported that their analysis suggested that populations appear to be growing exponentially. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp.

d. History of Invasion Success
Moved from Arkansas into Mississippi, Missouri, Ohio and Illinois rivers. Bighead carp are very abundant in the Illinois River from Starved Rock Lock and Dam (RM231) to the confluence with Mississippi River. Five bighead carp have been individually collected between 1995 and 2003 in western Lake Erie. Since 2004, the U.S. Fish and Wildlife Service have monitored western Lake Erie in Sandusky and Toledo, Ohio and sampling has not resulted in any additional collections of bighead. Monitoring efforts suggest a

reproducing population does not exist in Lake Erie (http://www.asiancarp.us/faq.htm#Q10). Bighead carp have been thought to outcompete gizzard shad, bigmouth buffalo and paddlefish (Kolar et al. 2005), and by age 3, bighead carp have outsized any natural predator (Wanner & Klumb 2009). These ecological traits increase the probability of successful invasion of the GLB.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Bighead carp are generalists, considered an opportunistic feeder of plankton & detritus (Kolar et al. 2005). Bighead carp are pump filter feeders that produce mucous allowing them to take advantage of various sizes of food items (Kolar et al. 2005). Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005).

Early studies have reported eggs and larvae to passively flow into flood plains or tributary mouths (Kolar et al. 2005). Larvae will disperse to nursery areas and move up and/or down a river channel (Kolar et al. 2005). Juveniles are recorded from low velocity and off-channel habitats in rivers and lakes. During low flow adults have been recorded as avoiding river channels and use slower backwaters (DeGrandchamp et al. 2008) and along spur dikes (Kolar et al. 2005). There are 22 tributaries located on the U.S. side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water.

Evidence for Probability Rating

Bighead carp are active swimmers with a history of successful invasion of new riverine environments and can survive in lake conditions as well. The Great Lakes Basin will provide suitable habitat. Therefore, there is a high probability bighead carp will spread throughout the Great Lakes Basins if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well bighead carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if bighead carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the GLB have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH]

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and BSBH over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
Bighead carp are active swimmers. Total maximum distance traveled upstream by an individual was 163 km (101 mi) over 35 days (Peters et al. 2006), with an average of 4.5 km (2.8 mi) traveled per day. Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010) and they were able to move from Arkansas

into Mississippi, Missouri, Ohio, and Illinois rivers. Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River; 1991) to the La Grange reach (IL River; 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of bighead carp and the Brandon Road Lock and Dam. Bighead carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current and Potential Abundance and Reproductive Capacity*
T_0: Adult bighead carp are abundant in the Illinois Waterway from Starved Rock Lock & Dam (RM231) to the confluence with Mississippi River (Chick and Pegg 2001; Irons et al. 2009; ACRCC 2012; Garvey, et al. 2013; Wyffels et al. 2013). Bighead carp were reported to have high abundances within the La Grange pool of the Illinois River from sampling conducted from 2000 to 2006 (Irons et al. 2011). Bighead carp reached peak abundance levels in 2000 and have declined between 2004 and 2006, however these declines may be due to capture gear inefficiencies (Irons et al. 2011). Sampling efforts for Asian carp conducted in the upper pools of the Illinois River (Marseilles-Lockport) from 2010 through 2012 indicated a decreasing population from downstream to upstream (Ruebush et al. 2013).

A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

In 2013, a significant number of bighead carp were captured in the Rock Run Rookery Preserve Lake, a backwater in the Dresden Island pool, 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Above Dresden Island Pool, one bighead was collected in 2009 within Lockport Pool downstream of the Electric Dispersal Barrier System during a rotenone application (ACRCC 2009). In 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012).

Bighead carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Females with as many as 1.1 million eggs have been found in the Yangtze River, China (Kolar et al. 2005). In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank and Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 180,000 per female (DeGrandchamp et al. 2007). Kolar et al. (2007) reported that their analysis suggested that populations appear to be growing exponentially at the time of the report. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: Based on the above information, bighead carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is anticipated to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood, Hoopes, and Marchetti 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movement of bighead carp from their current position to Brandon Road Lock and Dam.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: There have been two recorded captures of bighead carp above the Brandon Road Pool. The first was collected in 2009 within the Lockport Pool, downstream of the Electric Dispersal Barrier System, during a rotenone application (ACRCC 2009). The second capture occurred during routine monitoring in Lake Calumet. Lake Calumet is directly connected to the Little Calumet River, only 6 miles from Lake Michigan (ACRCC

2012). Multiple bighead carp have been captured in landlocked Chicago-area urban fishing ponds above the barrier. It is likely that these fish were accidentally introduced during stocking for the Illinois Department of Natural Resources urban fishing program of catchable sized channel catfish in the 2002-2003 timeframe (ILDNR 2011; ACRCC 2013). In addition, there have been multiple positive eDNA detections upstream of electric barriers for bighead carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, bighead carp have been detected in the Dresden Island pool. A significant number of adult bighead carp were captured approximately 4 miles downstream of the Brandon Road Lock and Dam in the Rock Run Rookery Preserve Lake in 2013 (ACCRC 2013c). The USACE telemetry program has also recorded one individual bighead carp that approached the Brandon Road Lock and Dam in 2012 before returning downstream to the mouth of the Kankakee River (Shanks and Barkowski 2013). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the bighead carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Bighead carp prefer eutrophic conditions but can survive with low growth rates under low plankton concentrations (Kolar et al. 2007). There was no difference in catch rate regarding location within the water column as measured within the backwaters of the Illinois River (Schultz et al. 2007). DeGrandchamp et al. (2008) suggest that bighead carp rarely occupy depths greater than 4 m (13 ft) regardless of abiotic factors. Other studies indicate that 3 m (9.8 ft) deep or more provides suitable conditions for bighead carp (Kolar et al. 2005). Bighead carp can be found in low velocity and off-channel habitats in the Mississippi, Missouri, Wabash and lower Ohio Rivers and all sizes collected in the Upper Mississippi River Basin were strongly associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005). During low flow, bighead carp avoid channels & backwaters (DeGrandchamp et al. 2008), but will use spur dikes (Kolar et al. 2007; Cooke et al. 2009). These varied habitats are found throughout the Dresden Island Pool, including the Rock Run Rookery Preserve Lake and in the Kankakee River. This species is found in Swan Lake, which is connected to the Illinois River (DeGrandchamp et al. 2007). Heilprin (2013) found that larvae of bighead carp can survive under low DO conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate adults (0.5 mg/L; Oregon Sea Grant 2011), juveniles (0.33 mg/L) and young (0.4 mg/L; Jennings 1988) can survive low DO conditions. Critical spawning temperature for bighead carp is reported as 18°C (64.4°F) (Irons et al. 2009). However, typically successful fertilization occurs between 21° and

26°C (69.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Adult bighead carp can withstand water temperatures up to 38.8 ^{o}C (101.8^{o}F) (Bettoli et al. 1985).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp have been documented at the Brandon Road Lock and Dam and Lockport Pool upstream of Brandon Road Lock and Dam. Therefore, the probability of bighead carp having arrived at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: A bighead carp was captured in the Lockport pool, upstream of the Brandon Road Lock and Dam; telemetric tracking of tagged individual bighead carp has provided evidence of at least one individual approaching the Brandon Road Lock and Dam in 2012; and in the spring of 2013, the capture of significant numbers of bighead carp at Rock Run Rookery Forest Preserve Lake, which is approximately 4 miles from the Brandon Road Lock and Dam. Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) can reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. Bighead carp populations in the Dresden Island Pool are expected to increase to existing levels or higher. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_{25}.

4. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*

Bighead carp is an active swimmer that can swim against the slow current of the CAWS. An individual can travel as far as 4.5 km (2.8 mi) per day (Peters et al. 2006). Bighead carp expansion rates were also tracked via the Long Term Resource Monitoring Program in the Mississippi and Illinois Rivers. First detections at Pool 26 (MS River 1991) to the La Grange Pool (IL River 1995) indicated the detectable population moved over 98 river miles in just four years (Irons et al. 2009) and continued upstream progression in the Illinois River to the Dresden Island Pool by 2007 (USGS 2013). Average expansion rates for bighead carp are recorded at 9 river miles per year (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for bighead and silver carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward Asian carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

As noted above, in 2007, bighead carp were first captured in Dresden Island Pool. In 2009, one bighead carp was found in the Lockport Pool during a rotenone event (ACRCC 2009), and in 2010, a bighead was captured in Lake Calumet during routine monitoring upstream of the Electric Dispersal Barrier System (ACRCC 2012). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences.

Within the Marseilles and Dresden Island Pools, reproductively mature bighead carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. The nearest population of juvenile sized individuals is in the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. The nearest collection of Asian carp eggs was found near

Henry, Illinois within the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Bighead carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel traffic between Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b) and there is the potential for bighead carp eggs and larvae to be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2011) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, bighead carp are expected to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 5 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp

were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional study is underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with every different configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of bighead carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for bighead carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005, Cooke et al. 2009). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for bighead carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (ACRCC 2013a, Butler et al. 2013). Bighead carp utilize all parts of the water column in rivers (Schultz et al. 2007; DeGrandchamp et al. 2008; Kolar et al. 2005). They can be found in low velocity and off-channel habitats associated with slow-moving water (<0.3 m/s [1.0 ft/s]) (Kolar et al. 2005), but are capable of swimming in very-high-velocity habitats, with a maximum measured swimming speed of approximately 7.5 m/s (24.6 ft/s) (Konagaya and Cai 1987). During normal conditions, the CAWS has a slow-moving current (LimnoTech 2010). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Heilprin et al. (2013a) found that larvae of bighead carp can survive under low dissolved oxygen conditions (0.86 mg/L) inside a barge ballast tank. This supports the findings of other studies that indicate the species can survive low dissolved oxygen conditions: adults (0.5 mg/L) (Oregon Sea Grant 2011), juveniles (0.33 mg/L), and young (0.4 mg/L) (Jennings 1988). Adult bighead carp can withstand water temperatures up to 38.8 ^{o}C (101.8^{o}F) (Bettoli et al. 1985). Overall, the conditions of the CAWS are not expected to impede movement of bighead carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway. For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species bighead carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs.

This will lead to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. This is not expected to significantly affect the ability of bighead carp to pass through this pathway.

T_{25}: See T_{10}

T_{50}: See T_{10}

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Bighead carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of bighead carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of bighead carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring data, it appears that few bighead carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of bighead carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming bighead carp is in Dresden Island Pool. and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the bighead carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Bighead carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow bighead carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990's (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, bighead carp were captured in Dresden Island Pool; however, based on this monitoring, it appears that few bighead carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is anticipated that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would informed by this analysis.

The probability of passage for the bighead carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for bighead carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases from low to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.
T_{10}: See $T_{0.}$ Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See $T_{10.}$

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Bighead carp prefer eutrophic conditions but survive with low growth rates under low plankton concentrations (Kolar et al. 2005). Bighead carp are generalist planktivores (Laird and Page 1996), primarily zooplankton, with the ability to feed on phytoplankton (Kolar et al. 2005). They filter prey out of the water column as they swim through the water, taking advantage of various sizes of food items (Kolar et al. 2005). Bighead carp has recently been shown to consume *Cladophora*, this algae is abundant in Lake Michigan (Rasmussen et al. 2011). Spawning occurs during the growing season as early as May through August (Coulter & Goforth 2011; Papoulias et al. 2006). Spawning is triggered by changes in water temperature and may also be triggered by changes water levels (e.g., spring floods) and velocity (Iron et al. 2011 and Stainbrook et al. 2007). Critical spawning temperature for bigheaded carp is reported as 18°C (64.4°F) Irons et al. 2011). However, typical successful fertilization occurs between 21 and 26°C (6.9.8 and 78.8°F) (Kolar et al. 2005). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (64.4°F). Reports have indicated a positive relationship between Asian carp spawning and increasing river flow (Jennings 1988; DeGrandchamp et al. 2007; Kolar et al. 2007; Lohmeyer & Garvey 2009; Irons

et al. 2011). However, DeGrandchamp et al. (2007) indicate that high river flow does not appear to be critical for successful spawning but may aid in egg and larval survival. A specific substrate is not necessary for spawning to occur. However, the eggs may not survive if covered by sediment, hence the need for a shifter current during fertilization and egg development (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013, the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen 2011). The Great Lakes likely have the habitat required for all life stages of Asian carp (The Asian Carp Regional Coordinating Committee 2012; Canadian Science Advisory Report 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Bighead carp is an active swimmer and could find more optimal habitat in the 22 rivers that flow into the Great Lakes. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2009; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers and reproductive habitat can be found in Lake Michigan and in rivers that flow into Lake Michigan that bighead carp could disperse to after exiting BSBH. Therefore, there is a high probability of bighead carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known if the fertilized eggs of bighead carp could successfully hatch and if larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear if optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, bighead carp would have to swim or be carried into one of the large or medium rivers that flow into Lake Michigan. The nearest suitable river is St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that bighead carp would be able to successfully navigate from BSBH to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spreading, the species is assumed to have colonized near the pathway. The probability of spreading is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Bighead carp is found in the Upper Mississippi River Basin, Wisconsin, and Minnesota. The Upper Mississippi River Basin and the Great Lakes Basin share similar climatic conditions.

b. *Type of Mobility/Invasion Speed*
Bighead carp is an active swimmer and has an average expansion rate of 14.5 km (8.99 river miles) per year (Jerde et al. 2010). Hybridization between *H. nobilis* and *H. molitrix* (silver carp) reduces jumping behavior, fitness, and condition in post F_1 hybrids, which may decrease invasion success as introgression continues (Lamer et al. 2010).

c. *Fecundity*
In the Missouri River the mean fecundity was measured as the average adult female producing 226,213 eggs (Shrank & Guy 2002). In 2004, in the Illinois River, mean egg production was measured as 1.8×10^5 per female (DeGrandchamp et al. 2007). Kolar et al. (2005) reported that their analysis suggested that populations appear to be growing exponentially. Garvey et al. (2006) points out that bighead carp have a slower population level somatic growth rate, higher survival, lower fecundity, later maturity and longer lives relative to silver carp.

d. *History of Invasion Success*
Moved from Arkansas into Mississippi, Missouri, Ohio and Illinois rivers. Bighead carp are very abundant in the Illinois River from Starved Rock Lock and Dam (RM231) to the confluence with Mississippi River. Five Bighead carp have been individually collected between 1995 and 2003 in western Lake Erie. Since 2004, the USFWS have monitored western Lake Erie in Sandusky and Toledo, Ohio and sampling has not resulted in any additional collections of bighead. Monitoring efforts suggest a reproducing population does not exist in Lake Erie (http://www.asiancarp.us/faq.htm#Q10). Bighead carp have been thought to outcompete gizzard shad, bigmouth buffalo and paddlefish (Kolar et al. 2005), and by age 3, bighead carp have outsized any natural predator (Wanner & Klumb 2009). These ecological traits increase the probability of successful invasion of the GLB.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Bighead carp are a generalist, considered an opportunistic feeder of plankton & detritus (Kolar et al. 2005). Bighead carp are a pump filter feeder that produces mucous allowing them to take advantage of various sizes of food items (Kolar et al. 2005).

Bighead carp prefer eutrophic conditions but survive with low growth rates with low plankton concentrations (Kolar et al. 2005).

Early studies have reported eggs and larvae to passively flow into flood plains or tributary mouths (Kolar et al. 2005) Larvae will disperse to nursery areas and move up and/or down a river channel (Kolar et al. 2005). Juveniles are recorded from low velocity and off-channel habitats in rivers and lakes. During low flow adults have been recorded as avoiding river channels and use slower backwaters (DeGrandchamp et al. 2008) and along spur dikes (Kolar et al. 2005). There are 22 tributaries located on the U.S. side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water.

Evidence for Probability Rating

Bighead carp are active swimmers with a history of successful invasion of new riverine environments and can survive in lake conditions as well. The Great Lakes Basin will provide suitable habitat. Therefore, there is a high probability bighead carp will spread throughout the Great Lakes Basin if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well bighead carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if bighead carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the GLB have been identified as suitable for reproduction. Therefore, uncertainty is low.

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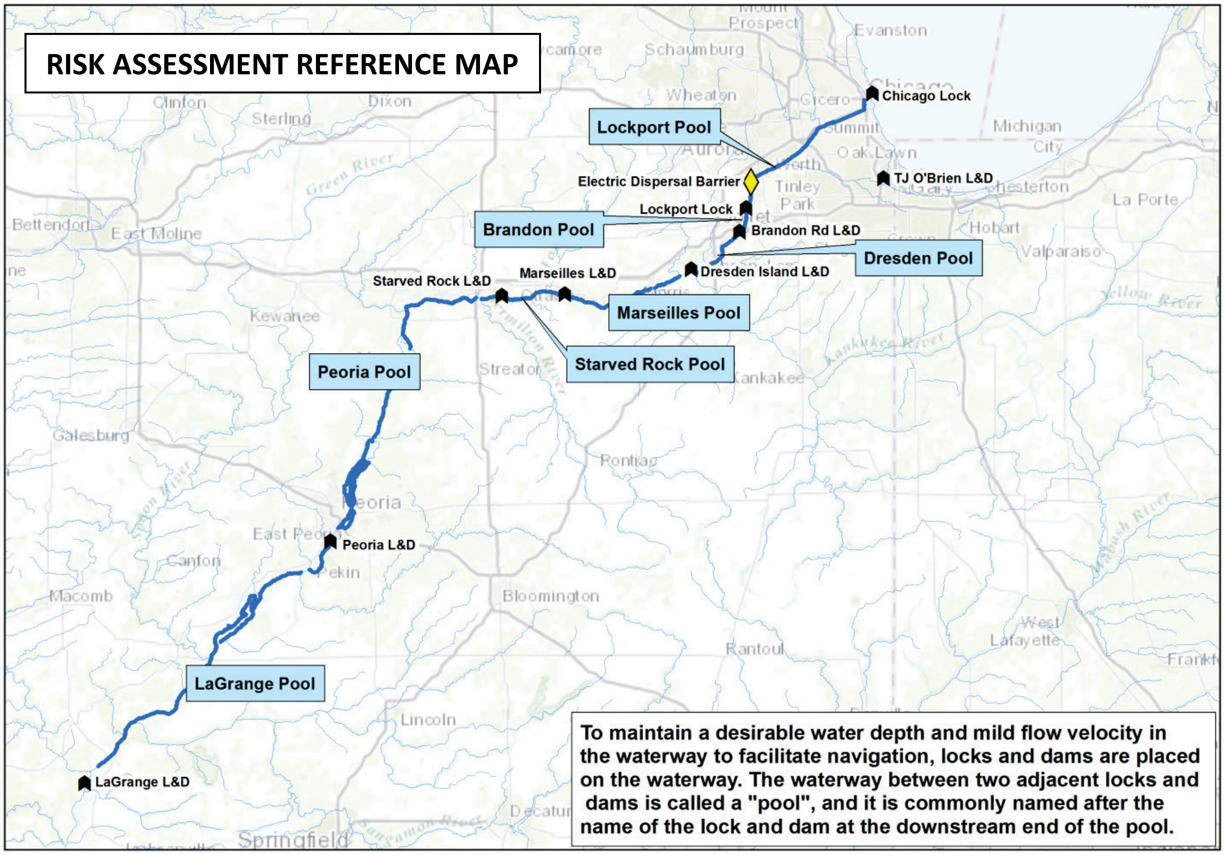
E.1.3.4 Silver Carp - *Hypophthalmichthys molitrix*



To maintain a desirable water depth and mild flow velocity in the waterway to facilitate navigation, locks and dams are placed on the waterway. The waterway between two adjacent locks and dams is called a "pool", and it is commonly named after the name of the lock and dam at the downstream end of the pool.

◆ The Electric Dispersal Barrier System located approximately 5 miles upstream of the Lockport Lock and Dam is assumed to continue operation through T_{50}.

Pools of the Upper Illinois River and CAWS			Lock and Dams of the Upper Illinois and CAWS	
Pool	River Miles	Approximate Length (mi.)	Lock and Dams	Approximate Distance from Electric Barrier System (mi.)
Lockport Pool*			Chicago Lock	31
Electric Barrier System	296	--	T.J O'Brien Lock and Dam*	30.5
To Chicago Lock	291-327	36	Lockport Lock and Dam	5
To T.J. O'Brien	291-326.5	35.5	Brandon Road Lock and Dam	10
Brandon Road Pool	286-291	5	Dresden Island Lock and Dam	24.5
Dresden Island Pool	271.5-286	14.5	Marseilles Lock and Dam	49
Marseilles Pool	247-271.5	24.5	Starved Rock Lock and Dam	65
Starved Rock Pool	231-247	16	Peoria Lock and Dam	138.4
Peoria Pool	157.6-231	73.4	LaGrange Lock and Dam	215.8
LaGrange Pool	80.2-157.6	77.4		

*Lockport Pool encompasses river miles both below and above the Electric Dispersal Barrier System. Upstream of the Electric Dispersal Barrier System, the Chicago Sanitary and Ship Canal (CSSC) continues north to the Chicago Lock at Lake Michigan. The Cal-Sag Channel connects with the CSSC at approximately river mile 303, and proceeds eastward toward the T.J. O'Brien Lock and Dam. Lake Michigan is approximately six miles north of the T.J. O'Brien Lock and Dam.

Note: River Miles were determined from the U.S. Army Corps of Engineers, Illinois Waterway Navigation Charts from Mississippi River at Grafton, Illinois to Lake Michigan at Chicago and Calumet Harbors, 1998.

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are expected to reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and the WPS over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers. The expansion rate of the silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) and abundance peaks quickly following establishment. Silver carp range expansion surpasses that of bighead, because silver can more readily bypass locks (Jerde et al. 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of silver carp and the Brandon Road Lock and Dam. Silver carp eggs, larvae and fry have the

potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current Abundance and Reproductive Capacity*

T_0: A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

Based on catch data reported through November 2013, approximately 80 silver carp have been caught in Rock Run Rookery, a backwater in the Dresden Island pool, approximately 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Silver carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Eggs are released in the water column and float downstream where they develop in slow-moving waters. Reproduction has not been documented in waters upstream of Marseilles Lock and Dam, which is less than 64 km (40 mi) from the Brandon Road Lock and Dam. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: See T_0**.** Based on the above information, silver carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is expected to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996;

Nico and Fuller 1999; Lockwood et al. 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.
T_{25}: See T_{10}. It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.
T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*
T_0: None. There are no barriers to movement of the silver carp from their current position to Brandon Road Lock and Dam. The silver carp has arrived at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The silver carp is established throughout the Illinois River (Nico 2012). Silver carp have been detected as far upstream as Dresden Island Pool. In 2009, one silver carp was observed at the confluence of the Des Plaines River and Chicago Sanitary Ship Canal during routine Asian carp monitoring (ACRCC 2013).

In addition, there have been multiple positive eDNA detections upstream of electric barriers for silver carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, silver carp have been detected in the Dresden Island pool. Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam (ACCRC 2013c). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the silver carp has arrived at the pathway (Brandon Road Lock and Dam).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. The species is native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. This species is native from about 54 °N southward to 21 °N (Xie and Chen 2001; Froese & Pauly 2004). Most of North America falls within these latitudes. Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005).

Silver carp are a pelagic, schooling species (Mukhamedova 1977). Silver carp swim just beneath the water surface (Man and Hodgkiss 1981) where it filter-feeds on phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The water temperature range at which larval silver carp can exist is broad: 16–40°C (60.8–104°F) with optimum temperatures reported as 26–30°C (78.8–86°F). Lethal temperature of larval silver carp was 43.5–46.5°C (110.3–115.7°F). Silver carp are quite tolerant to low water temperatures. In Alberta, Canada, silver carp successfully overwinter in ponds that are near 0°C (32°F) from the beginning of November through the end of April (Kolar et al. 2005).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp have been detected as far upstream as Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam. Therefore, the probability of silver carp arriving at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lockd and Dam (ACCRC 2013c). Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0.. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) may reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be

replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. The silver carp population in the Dresden Island Pool is expected, at a minimum, to remain at existing levels; however an increase in population is more likely through time. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Silver carp are active swimmers and can spread upstream naturally. The expansion rate of the silver carp is 33.62 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for Asian carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward silver carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

In 2009, a confirmed sighting of a silver carp during Asian carp routine monitoring efforts at the confluence of the CSSC and Des Plaines River was reported (ACRCC 2013a); however, the silver carp population in Dresden Island Pool has not progressed upstream. Proposed reasons for this halted progression include limited food resources in the CAWS, hydraulic and hydrologic differences, water quality differences, and a habitat shift from natural to man-made. While these assumptions are still under investigation, the exact cause of the delayed expansion is still unknown but can be compared to other species' invasion histories. Numerous invasive species have long documented cases of extended lag periods in range expansion before an unknown cue (environmental or genetic) sparks another boom in population abundance and/or expanded geographical range (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller

1999; Lockwood et al. 2007). Cudmore et al. (2012) rated the probability of the silver carp entering Lake Michigan as very likely.

Within the Marseilles and Dresden Island Pools, reproductively mature silver carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. The nearest collection of Asian carp eggs was found near Henry, Illinois within the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Silver carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel and recreational vessel traffic between the Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b). Silver carp eggs and larvae could also be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2013) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin et al. 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

Commercial traffic through the Brandon Road Lock and Dam moves to the T.J. O'Brien Lock and Dam or the Chicago River Controlling Works (CRCW); it does not go to the WPS. Recreational boat fishing occurs on the North Shore Channel leading to the WPS, but boats cannot move from the North Shore Channel into Lake Michigan.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway. The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, silver carp is assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional studies are underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were

installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with each configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of silver carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

In addition, there are water control structures separating WPS from Lake Michigan, which are periodically opened and closed (LimnoTech 2010). When these structures are opened, silver carp would be able to swim into Lake Michigan.

T_{10}: See T_0. Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events. A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

Future operations of WPS sluice gate are not predicted to change.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. It is a pelagic, schooling species (Mukhamedova 1977). Silver carp is a filter feeder capable of taking large amounts of phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for silver carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (MRRP 2012).

Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005). They can tolerate long winters under ice cover as well as temperatures higher than 40°C (104° F) (Opuszynski et al. 1989). In the CAWS, mean annual water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). Fry and fingerlings can survive in waters with a pH of 5.0 to 9.0, dissolved oxygen 1–28 mg/L, and total alkalinity 88–620 mg/L (Singh et al. 1967). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Reported current velocities required for successful spawning range from 0.3 to 3.0 m/s (0.98 to 9.8 ft/s) (Kolar et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the WPS is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas (LimnoTech 2010). Overall, the conditions of the CAWS are not expected to impede movement of silver carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway**.** For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species silver carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase the capacity of stormwater catchment and retention in adjacent tunnels and reservoirs, leading to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. These actions are not expected to significantly affect the silver carp's ability to pass through this pathway.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of silver carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of silver carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013);

however, based on this monitoring data, it appears that few silver carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of silver carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming silver carp is in Dresden Island Pooland the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the silver carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Silver carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow silver carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990's (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on current monitoring data, it appears that few silver carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would be informed by this analysis.

The probability of passage for the silver carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for silver carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.

5**T_{10}:** See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. Additionally, funding for management actions that keep the population of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

3. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Silver carp are native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. This species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese & Pauly 2004). The Great Lakes, including Lake Superior, fall within these latitudes (Rasmussen et al. 2011). Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp are a pelagic, schooling species (Mukhamedova 1977) that swim just beneath the water surface (Man & Hodgkiss 1981). Silver carp can tolerate a wide array of environmental variables(Kolar et al. 2005). They are filter-feeders capable of consuming large amounts of phytoplankton. Their diet also includes zooplankton, bacteria, and detritus (Leventer 1987).

Silver carp often spawn after a sharp rise in water level associated with spring floods (Verigin 1979) and a temperature greater than 17°C (62.6°F). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (68 and 73.4°F). It is thought that silver carp require rivers for spawning (Kolar et al. 2005). A minimum length of spawning river is about 100 km (62.1 mi) with a velocity of 0.7–1.4 m/s (2.3–4.6 ft/s) (Kolar et al. 2005). Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). Seven tributaries of Lake Michigan, including the St. Joseph River in southeastern Lake Michigan, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013 the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013).

Silver carp prefer eutrophic water with high plankton concentrations but survive with low growth rates at lower plankton concentrations (Kolar et al. 2005; Calkins 2010). Open areas of most Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Lake Michigan, such as Green Bay, and silver carp have been shown to consume *Cladophora* (Rasmussen et al. 2011), which is abundant in Lake Michigan (MTRI 2012). Seven tributaries to Lake Michigan have velocities potentially high enough to allow successful spawning by Asian carp (Kolar et al. 2005). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes likely have the habitat required for all life stages of Asian carp (ACRCC 2012). Cudmore et al. (2012) rated the probability of the silver carp surviving in Lake Michigan as very likely.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The silver carp is an active swimmer and could find optimal habitat in the 22 rivers that flow into the GLB. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2010; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers, and reproductive habitat can be found in Lake Michigan and in the rivers flowing into Lake Michigan that silver carp could disperse to after exiting the WPS. Therefore, there is a high probability of silver carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known whether the fertilized eggs of silver carp could successfully hatch and whether larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear whether optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, silver carp would have to swim or may be carried by currents to one of the large or medium rivers that flow into Lake Michigan. The nearest potentially suitable river is the St. Joseph, the mouth is located at Benton Harbor, MI. Benton Harbor is approximately 113 km (70 mi) from the WPS. It is not certain that silver carp would be able to successfully navigate from WPS to Benton Harbor within a lake environment.

4. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp can tolerate long winters under ice cover as well as temperatures higher than 40^{o}C (104°F) (Opuszynski et al. 1989).

b. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers and can spread upstream naturally. Expansion rate of silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

c. *Fecundity*

Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) with peaks in abundance occurring quickly following establishment.

d. *History of Invasion Success*

The silver carp has been widely introduced throughout the world. The species has been imported into or has spread by way of connected waterways to at least 88 countries and territories. Yang (1996) reported that silver carp was introduced to Yunnan Province, China, between 1958 and 1965 and that the species is now present in most lakes and rivers of that province.

e. *Human-Mediated Transport through Aquatic Pathways*

There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

Silver carp are considered opportunistic for plankton and detritus. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

Open areas of most of the Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Great Lakes, such as Green Bay, Saginaw Bay, Lake St. Clair, Western Basin Lake Erie, as well as major tributary rivers (Rasmussen et al. 2011), and silver carp have recently been shown to consume *Cladophora*, which is abundant in Lake Michigan (Rasmussen et al. 2011). There are 22 tributaries located on the United States side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water. Cudmore et al. (2012) rated the probability of spread through the Great Lakes as very likely.

Evidence for Probability Rating

Silver carp are active swimmers with a history of successful invasions of riverine and lake environments (sections 5b, 5d). There appears to be suitable climate, adult habitat, reproductive habitat, and food resources in the GLB (section 5f). Therefore, there is a high probability silver carp will spread through the Great Lakes Basin if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well silver carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if silver carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the Great Lakes Basin have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO THE CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are expected to reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and the CRCW over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
Silver carp are active swimmers. The expansion rate of the silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) and abundance peaks quickly following establishment. Silver carp range expansion surpasses that of bighead, because silver can more readily bypass locks (Jerde et al. 2010).

b. Human-Mediated Transport through Aquatic Pathways
There is commercial vessel and recreational boat traffic between the current location of silver carp and the Brandon Road Lock and Dam. Silver carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. Current Abundance and Reproductive Capacity
A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

Based on catch data reported through November 2013, approximately 80 silver carp have been caught in Rock Run Rookery, a backwater in the Dresden Island pool, approximately 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the

Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Silver carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Eggs are released in the water column and float downstream where they develop in slow-moving waters. Reproduction has not been documented in waters upstream of Marseilles Lock and Dam, which is less than 64 km (40 mi) from the Brandon Road Lock and Dam. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: See T_0**.** Based on the above information, silver carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is expected to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood et al. 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: See T_{10}. It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movement of the silver carp from their current position to Brandon Road Lock and Dam. The silver carp has arrived at the pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The silver carp is established throughout the Illinois River (Nico 2012). Silver carp have been detected as far upstream as Dresden Island Pool. In 2009, one silver carp was observed at the confluence of the Des Plaines River and Chicago Sanitary Ship Canal during routine Asian carp monitoring (ACRCC 2013).

In addition, there have been multiple positive eDNA detections upstream of electric barriers for silver carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration

Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, silver carp have been detected in the Dresden Island pool. Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam (ACCRC 2013c). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the silver carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. The species is native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. Native from about 54°N southward to 21°N (Xie & Chen 2001; Froese & Pauly 2004). Most of North America falls within these latitudes. Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005).

Silver carp are a pelagic, schooling species (Mukhamedova 1977). Silver carp swims just beneath the water surface (Man & Hodgkiss 1981), where it filter-feeds on phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The water temperature range at which larval silver carp can exist is broad: 16–40°C (60.8–104°F) with optimum temperatures reported as 26–30°C (78.8–86°F). Lethal temperature of larval silver carp was 43.5–46.5°C (110.3–115.7°F). Silver carp is quite tolerant to low water temperatures. In Alberta, Canada, silver carp successfully overwinter in ponds that are near 0°C (32°F) from the beginning of November through the end of April (Kolar et al. 2005).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp have been detected as far upstream as Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam. Therefore, the probability of silver carp arriving at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lockd and Dam (ACCRC 2013c). Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0.. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) may reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. The silver carp population in the Dresden Island Pool is expected, at a minimum, to remain at existing levels; however an increase in population is more likely through time. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Silver carp are active swimmers and can spread upstream naturally. The expansion rate of the silver carp is 33.62 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for Asian carp was originally incidental to standard routine sampling by the

Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward silver carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

In 2009, a confirmed sighting of a silver carp during Asian carp routine monitoring efforts at the confluence of the CSSC and Des Plaines River was reported (ACRCC 2013a); however, the silver carp population in Dresden Island Pool has not progressed upstream. Proposed reasons for this halted progression include limited food resources in the CAWS, hydraulic and hydrologic differences, water quality differences, and a habitat shift from natural to man-made. While these assumptions are still under investigation, the exact cause of the delayed expansion is still unknown but can be compared to other species' invasion histories. Numerous invasive species have long documented cases of extended lag periods in range expansion before an unknown cue (environmental or genetic) sparks another boom in population abundance and/or expanded geographical range (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood et al. 2007). Cudmore et al. (2012) rated the probability of the silver carp entering Lake Michigan as very likely.

Within the Marseilles and Dresden Island Pools, reproductively mature silver carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. The nearest collection of Asian carp eggs was found near Henry, Illinois within the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Silver carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel and recreational vessel traffic between the Brandon Road Lock and Dam and the CRCW (USACE 2011a,b) and silver carp eggs and larvae could also be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2013) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin et al. 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway.

The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, silver carp is assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional studies are underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with each configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of silver carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. It is a pelagic, schooling species (Mukhamedova 1977). Silver carp is a filter-feeder capable of taking large amounts of phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for silver carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (MRRP 2012).

Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005). They can tolerate long winters under ice cover as well as temperatures higher than 40°C (104°F) (Opuszynski et al. 1989). In the CAWS, mean annual water temperature ranges from 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). Fry and fingerlings can survive in waters with a pH of 5.0 to 9.0, dissolved oxygen 1–28 mg/L, and total alkalinity 88–620 mg/L (Singh et al. 1967; Tripathu 1989). Sections of the CAWS also experiences seasonally low dissolved oxygen (LimnoTech 2010).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Reported current velocities required for successful spawning range from 0.3 to 3.0 m/s (0.98 to 9.8 ft/s) (Kolar et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the CRCW is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas (LimnoTech 2010). Overall, the conditions of the CAWS are not expected to impede movement of silver carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway**.** For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species silver carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs. This will lead to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. These actions are not expected to significantly affect the silver carp's ability to pass through this pathway.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of silver carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of silver carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on this monitoring data, it appears that few silver carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of silver carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming silver carp is in Dresden Island Pool and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the silver carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Silver carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow silver carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990's (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on current monitoring data, it appears that few silver carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would be informed by this analysis.

The probability of passage for the silver carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for silver carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.

T_{10}: See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. Additionally, funding for management actions that keep the population of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Silver carp are native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. This species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese & Pauly 2004). The Great Lakes, including Lake Superior, fall within these latitudes (Rasmussen et al. 2011). Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp are a pelagic, schooling species (Mukhamedova 1977) that swims just beneath the water surface (Man & Hodgkiss 1981). Silver carp can tolerate a wide array of environmental variables (Kolar et al. 2005). They are filter-feeders capable of consuming large amounts of phytoplankton. Their diet also includes zooplankton, bacteria, and detritus (Leventer 1987).

Silver carp often spawn after a sharp rise in water level associated with spring floods (Verigin 1979) and a temperature greater than 17°C (62.6°F). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (68 and 73.4°F). It is thought that silver carp requires rivers for spawning (Kolar et al. 2005). A minimum length of spawning river is about 100 km (62.1 mi) with a velocity of 0.7–1.4 m/s (2.3–4.6 ft/s) (Kolar et al. 2005). Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). Seven tributaries of Lake Michigan, including the St. Joseph River in southeastern Lake Michigan, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013 the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013).

Silver carp prefer eutrophic water with high plankton concentrations but survives with low growth rates at lower plankton concentrations (Kolar et al. 2005; Calkins 2010). Open areas of most of the Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of Lake Michigan, such as Green Bay, and silver carp have been shown to consume *Cladophora* (Rasmussen et al. 2011), which is abundant in Lake Michigan (MTRI 2012). Seven tributaries to Lake Michigan have velocities potentially high enough to allow successful spawning by Asian carp (Kolar et al. 2005). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes likely have the habitat required for all life stages of Asian carp (ACRCC 2012). Cudmore et al. (2012) rated the probability of the silver carp surviving in Lake Michigan as very likely.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The silver carp is an active swimmer and could find optimal habitat in the 22 rivers that flow into the GLB. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2010; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers, and reproductive habitat can be found in Lake Michigan and in the rivers flowing into Lake Michigan that silver carp could disperse to after exiting the CRCW. Therefore, there is a high probability of silver carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known whether the fertilized eggs of silver carp could successfully hatch and whether larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear whether optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, silver carp would have to swim or may be carried by currents to one of the large or medium rivers that flow into Lake Michigan. The nearest potentially suitable river is the St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that silver carp would be able to successfully navigate from CRCW to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp can tolerate long winters under ice cover as well as temperatures higher than 40^{o}C (104°F) (Opuszynski et al. 1989).

b. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers and can spread upstream naturally. Expansion rate of silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

c. *Fecundity*
Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) with peaks in abundance occurring quickly following establishment.

d. *History of Invasion Success*
The silver carp has been widely introduced throughout the world. The species has been imported into or has spread by way of connected waterways to at least 88 countries and territories. Yang (1996) reported that silver carp was introduced to Yunnan Province, China, between 1958 and 1965 and that the carp is now present in most lakes and rivers of that province.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Silver carp are considered opportunistic for plankton and detritus. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

Open areas of most of the Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Great Lakes, such as Green Bay, Saginaw Bay, Lake St. Clair, and Western Basin Lake Erie, as well as major tributary rivers (Rasmussen et al. 2011), and silver carp have recently been shown to consume *Cladophora*, which is abundant in Lake Michigan (Rasmussen et al. 2011). There are 22 tributaries located on the United States side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water. Cudmore et al. (2012) rated the probability of spread through the Great Lakes as very likely.

Evidence for Probability Rating

Silver carp are active swimmers with a history of successful invasions of riverine and lake environments (sections 5b, 5d). There appears to be suitable climate, adult habitat, reproductive habitat, and food resources in the GLB (section 5f). Therefore, there is a high probability silver carp will spread through the Great Lakes Basin if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well silver carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if silver carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the Great Lakes Basin have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO THE CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are expected to reduce or eliminate the hydrologic connection between Brandon Road Lock and Dam and Calumet Harbor over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers. The expansion rate of the silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) and abundance peaks quickly following establishment. Silver carp range expansion surpasses that of bighead, because silver can more readily bypass locks (Jerde et al. 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of silver carp and the Brandon Road Lock and Dam. Silver carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current Abundance and Reproductive Capacity*
T_0: A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

Based on catch data reported through November 2013, approximately 80 silver carp have been caught in Rock Run Rookery, a backwater in the Dresden Island pool, approximately 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Silver carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Eggs are released in the water column and float downstream where they develop in slow-moving waters. Reproduction has not been documented in waters upstream of Marseilles Lock and Dam. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: See T_0. Based on the above information, silver carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is expected to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood et al. 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: See T_{10}. It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movements of the silver carp from their current position to Brandon Road Lock and Dam. The silver carp has arrived at the pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The silver carp is established throughout the Illinois River (USGS 2012). Silver carp have been detected as far upstream as Dresden Island Pool. In 2009, observed one silver carp at the confluence of the Des Plaines River and Chicago Sanitary Ship Canal during routine Asian carp monitoring (ACRCC 2013).

In addition, there have been multiple positive eDNA detections upstream of electric barriers for silver carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, silver carp have been detected in the Dresden Island pool. Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam (ACCRC 2013c). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the silver carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. The species is native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. The species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese &

Pauly 2004). Most of North America falls within these latitudes. Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005).

Silver carp are pelagic, schooling species (Mukhamedova 1977). Silver carp swim just beneath the water surface (Man & Hodgkiss 1981), where it filter-feeds on phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The water temperature range at which larval silver carp can exist is broad: 16–40°C (60.8–104°F), with optimum temperatures reported as 26–30°C (87.8–86°F). Lethal temperature of larval silver carp was 43.5–46.5°C (110.3–115.7°F). Silver carp is quite tolerant to low water temperatures. In Alberta, Canada, silver carp successfully overwinter in ponds that are near 0°C (32°F) from the beginning of November through the end of April (Kolar et al. 2005).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp have been detected as far upstream as Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam. Therefore, the probability of silver carp arriving at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lockd and Dam (ACCRC 2013c). Therefore, there is no uncertainty whether this species has arrived at the pathway.

T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) may reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.

T_{25}: See T_0. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. The silver carp population in the Dresden Island Pool is expected, at a minimum, to remain at existing levels; however an increase in population is more likely through time. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Silver carp are active swimmers and can spread upstream naturally. The expansion rate of the silver carp is 33.62 km/yr (20.62 river miles/yr) (Jerde et al. 2010).
Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for Asian carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward silver carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

In 2009, a confirmed sighting of a silver carp during Asian carp routine monitoring efforts at the confluence of the CSSC and Des Plaines River was reported (ACRCC 2013a); however, the silver carp population in Dresden Island Pool has not progressed upstream. Proposed reasons for this halted progression include limited food resources in the CAWS, hydraulic and hydrologic differences, water quality differences, and a habitat shift from natural to man-made. While these assumptions are still under investigation, the exact cause of the delayed expansion is still unknown but can be compared to other species' invasion histories. Numerous invasive species have long documented cases of extended lag periods in range expansion before an unknown cue (environmental or genetic) sparks another boom in population abundance and/or expanded geographical range (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood et al. 2007). Cudmore et al. (2012) rated the probability of the silver carp entering Lake Michigan as very likely.

Within the Marseilles and Dresden Island Pools, reproductively mature silver carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a). The nearest collection of Asian carp eggs were found near Henry, Illinois within the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Silver carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel and recreational vessel traffic between the Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b). Silver carp eggs and larvae could also be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2013) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin et al. 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway.

The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, silver carp is assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional studies are underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were

installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with each configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of silver carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.

T_{50}: See T_{10} and T_{25}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. It is a pelagic, schooling species (Mukhamedova 1977). Silver carp is a filter feeder capable of taking large amounts of phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for silver carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (MRRP 2012).

Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005). They can tolerate long winters under ice cover as well as temperatures higher than 40°C (104°F) (Opuszynski et al. 1989). In the CAWS, mean annual water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). Fry and fingerlings can survive in waters with a pH of 5.0 to 9.0, dissolved oxygen 1–28 mg/L, and total alkalinity 88–620 mg/L (Singh et al. 1967). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Reported current velocities required for successful spawning range from 0.3 to 3.0 m/s (0.98 to 9.8 ft/s) (Kolar et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at Calumet Harbor is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas (LimnoTech 2010). Overall, the conditions of the CAWS are not expected to impede movement of silver carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change, but not in a way that would affect the likelihood of this species passing through this pathway**.** For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species silver carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs; this will lead to a lower hydrologic peak during storm events. The environmental conditions with the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. These actions are not expected to significantly affect the silver carp's ability to pass through this pathway.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of silver carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of silver carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on this monitoring data, it appears that few silver carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of silver carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming silver carp is in Dresden Island Pool and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the silver carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Silver carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow silver carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990’s (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on current monitoring data, it appears that few silver carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would be informed by this analysis.

The probability of passage for the silver carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for silver carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases to medium. **T_{50}:** See T_{10} and T_{25}.

Uncertainty of Passages

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.

T_{10}: See T_0. See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified beyond 2016. The factors contributing to the historic absence of range

expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Silver carp are native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. This species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese & Pauly 2004). The Great Lakes, including Lake Superior, fall within these latitudes (Rasmussen et al. 2011). Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp are a pelagic, schooling species (Mukhamedova 1977) that swim just beneath the water surface (Man & Hodgkiss 1981). Silver carp can tolerate a wide array of environmental variables(Kolar et al. 2005). They are filter-feeders capable of consuming large amounts of phytoplankton. Their diet also includes zooplankton, bacteria, and detritus (Leventer 1987).

Silver carp often spawn after a sharp rise in water level associated with spring floods (Verigin 1979) and a temperature greater than 17°C (62.6°F). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (68 and 73.4°F). It is thought that silver carp require rivers for spawning (Kolar et al. 2005). A minimum length of spawning river is about 100 km (62.1 mi) with a velocity of 0.7–1.4 m/s (2.3–4.6 ft/s) (Kolar et al. 2005). Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). Seven tributaries of Lake Michigan, including the St. Joseph River in southeastern Lake Michigan, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013 the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013).

Silver carp prefer eutrophic water with high plankton concentrations but survive with low growth rates at lower plankton concentrations (Kolar et al. 2005; Calkins 2010). Open areas of most Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Lake Michigan, such as Green Bay, and silver carp have been shown to consume *Cladophora* (Rasmussen et al. 2011), which is abundant in Lake Michigan (MTRI 2012). Seven tributaries to Lake Michigan have velocities potentially high enough to allow successful spawning by Asian carp (Kolar et al. 2005). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes likely have the habitat required for all life stages of Asian carp (ACRCC 2012). Cudmore et al. (2012) rated the probability of the silver carp surviving in Lake Michigan as very likely.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Silver carp is an active swimmer and could find optimal habitat in the 22 rivers that flow into the GLB. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2010; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers, and reproductive habitat can be found in Lake Michigan and in the rivers flowing into Lake Michigan that silver carp could disperse to after exiting the Calumet Harbor. Therefore, there is a high probability of silver carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known whether the fertilized eggs of silver carp could successfully hatch and whether larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear whether optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, silver carp would have to swim or may be carried by currents to one of the large or medium rivers that flow into Lake Michigan. The nearest potentially suitable river is the St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that silver carp would be able to successfully navigate from Calumet Harbor to Benton Harbor within a lake environment.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   Silver carp can tolerate long winters under ice cover as well as temperatures higher than 40^{o}C (104°F) (Opuszynski et al. 1989).

b. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers and can spread upstream naturally. Expansion rate of silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

c. *Fecundity*
Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) with peaks in abundance occurring quickly following establishment.

d. *History of Invasion Success*
The silver carp has been widely introduced throughout the world. The species has been imported into or has spread by way of connected waterways to at least 88 countries and territories. Yang (1996) reported that silver carp was introduced to Yunnan Province, China, between 1958 and 1965 and that the carp is now present in most lakes and rivers of that province.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Silver carp are considered opportunistic for plankton and detritus. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

Open areas of most of the Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Great Lakes, such as Green Bay, Saginaw Bay, Lake St. Clair, and Western Basin Lake Erie, as well as major tributary rivers (Rasmussen et al. 2011), and silver carp have recently been shown to consume *Cladophora*, which is abundant in Lake Michigan (Rasmussen et al. 2011).

There are 22 tributaries located on the United States side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water. Cudmore et al. (2012) rated the probability of spread through the Great Lakes as very likely.

Evidence for Probability Rating

Silver carp are active swimmers with a history of successful invasions of riverine and lake environments (sections 5b, 5d). There appears to be suitable climate, adult habitat, reproductive habitat, and food resources in the GLB (section 5f). Therefore, there is a high probability silver carp will spread through the Great Lakes Basin if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well silver carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if silver carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the Great Lakes Basin have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO THE INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

Silver carp are active swimmers. The expansion rate of the silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) and abundance peaks quickly following establishment. Silver carp range expansion surpasses that of bighead, because silver can more readily bypass locks (Jerde et al. 2010).

b. Human-Mediated Transport through Aquatic Pathways

There is commercial vessel and recreational boat traffic between the current location of silver carp and the Brandon Road Lock and Dam. Silver carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. Current Abundance and Reproductive Capacity

T_0: A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

Based on catch data reported through November 2013, approximately 80 silver carp have been caught in Rock Run Rookery, a backwater in the Dresden Island pool, approximately 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c).

There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Silver carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Eggs are released in the water column and float downstream where they develop in slow-moving waters. Reproduction has not been documented in waters upstream of Marseilles Lock and Dam, which is less than 64 km (40 mi) from the Brandon Road Lock and Dam. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: See T_0. Based on the above information, silver carp seem to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is expected to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood et al. 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: See T_{10}. It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movements of the silver carp from their current position to Brandon Road Lock and Dam. The silver carp has arrived at the pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The silver carp is established throughout the Illinois River (USGS 2012). Silver carp have been detected as far upstream as Dresden Island Pool. In 2009, observed one silver carp at the confluence of the Des Plaines River and Chicago Sanitary Ship Canal during routine Asian carp monitoring (ACRCC 2013).

In addition, there have been multiple positive eDNA detections upstream of electric barriers for silver carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration

Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, silver carp have been detected in the Dresden Island pool. Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam (ACCRC 2013c). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the silver carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. The species is native to several major Pacific drainages in eastern Asia, from the Amur River in far eastern Russia south through much of the eastern half of China to the Pearl River. The species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese & Pauly 2004). Most of North America falls within these latitudes. Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005).

Silver carp are pelagic, schooling species (Mukhamedova 1977). Silver carp swims just beneath the water surface (Man & Hodgkiss 1981), where it filter-feeds on phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The water temperature range at which larval silver carp can exist is broad: 16–40°C (60.8–104°F) with optimum temperatures reported as 26–30°C (78.8–86°F). Lethal temperature of larval silver carp was 43.5–46.5°C (110.3–115.7°F) (Kolar et al. 2005). Silver carp is quite tolerant to low water temperatures. In Alberta, Canada, silver carp successfully overwinter in ponds that are near 0°C (32°F) from the beginning of November through the end of April (Kolar et al. 2005).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp have been detected as far upstream as Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam. Therefore, the probability of silver carp arriving at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lockd and Dam (ACCRC 2013c). Therefore, there is no uncertainty whether this species has arrived at the pathway.
T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) may reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.

T_{25}: See T_{10}. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. The silver carp population in the Dresden Island Pool is expected, at a minimum, to remain at existing levels; however an increase in population is more likely through time. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_{25}.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Silver carp are active swimmers and can spread upstream naturally. The expansion rate of the silver carp is 33.62 km/yr (20.62 river miles/yr) (Jerde et al. 2010). Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for Asian carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward silver carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

In 2009, a confirmed sighting of a silver carp during Asian carp routine monitoring efforts at the confluence of the CSSC and Des Plaines River was reported (ACRCC 2013a); however, the silver carp population in Dresden Island Pool has not progressed upstream. Proposed reasons for this halted progression include limited food resources in the CAWS, hydraulic and hydrologic differences, water quality differences, and a habitat shift from natural to man-made. While these assumptions are still under investigation, the exact cause of the delayed expansion is still unknown but can be compared to other species' invasion histories. Numerous invasive species have long documented cases of extended lag periods in range expansion before an unknown cue (environmental or genetic) sparks another boom in population abundance and/or expanded geographical range (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood et al. 2007). Cudmore et al. (2012) rated the probability of the silver carp entering Lake Michigan as very likely.

Within the Marseilles and Dresden Island Pools, reproductively mature silver carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a). The nearest collection of Asian carp eggs were found near Henry, Illinois within the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Vessel traffic to Indiana Harbor is lake-wide (USACE 2011a,b). Silver carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel and recreational vessel traffic between the Brandon Road Lock and Dam and the Little Calumet River, but this traffic does not go to Indiana Harbor(USACE 2011a,b). Silver carp eggs and larvae could also be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2013) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin et al. 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0: There are two lock complexes (Brandon Road Lock and Dam and Lockport Lock and Dam) within the pathway.

The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, silver carp is assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp

were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional studies are underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with each configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of silver carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: See T_0. Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.
T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.
T_{50}: See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Silver carp inhabits freshwater riverine systems and confluent lakes. It is a pelagic, schooling species (Mukhamedova 1977). Silver carp is a filter-feeder capable of taking large amounts of phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The CAWS is the recipient of treated wastewater from numerous facilities that produces eutrophic conditions suitable for silver carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (MRRP 2012).

Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005). They can tolerate long winters under ice cover as well as temperatures higher than 40°C (104°F) (Opuszynski et al. 1989). In the CAWS, the mean annual water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). Fry and fingerlings can survive in waters with a pH of 5.0 to 9.0, dissolved oxygen 1–28 mg/L, and total alkalinity 88–620 mg/L (Singh et al. 1967). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Reported current velocities required for successful spawning range from 0.3 to 3.0 m/s (0.98 to 9.8 ft/s) (Kolar et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at Indiana Harbor is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas (LimnoTech 2010). Overall, the conditions of the CAWS are not expected to impede movement of silver carp.
T_{10}: See T_0. Conditions of the CAWS are predicted to change but not in a way that would affect the likelihood of this species passing through this pathway**.** For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of

organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species silver carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs; this will lead to a lower hydrologic peak during storm events. The environmental conditions within the CAWS may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. These actions are not expected to significantly affect the silver carp's ability to pass through this pathway.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of silver carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of silver carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on this monitoring data, it appears that few silver carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange poo. Adult populations of silver carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming silver carp is in Dresden Island Pool and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the silver carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0.
Silver carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow silver carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990's (Conover et al. 2007; Irons et al. 2009; ACRCC 2013a). Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on current monitoring data, it appears that few silver carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would be informed by this analysis.

The probability of passage for the silver carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for silver carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.

T_{10}: See $T_{0.}$ Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.

T_{25}: See T_0.

T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

Silver carp are native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. This species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese & Pauly 2004). The Great Lakes, including Lake Superior, fall within these latitudes (Rasmussen et al. 2011). Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp are a pelagic, schooling species (Mukhamedova 1977) that swim just beneath the water surface (Man & Hodgkiss 1981). Silver carp can tolerate a wide array of environmental variables(Kolar et al. 2005). They are filter-feeders capable of consuming large amounts of phytoplankton. Their diet also includes zooplankton, bacteria, and detritus (Leventer 1987).

Silver carp often spawn after a sharp rise in water level associated with spring floods (Verigin 1979) and a temperature greater than 17°C (62.6°F). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (68 and 73.4°F). It is thought that silver carp require rivers for spawning (Kolar et al. 2005). A minimum length of spawning river is about 100 km (62.1 mi) with a velocity of 0.7–1.4 m/s (2.3–4.6 ft/s) (Kolar et al. 2005). Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). Seven tributaries of Lake Michigan, including the St. Joseph River in southeastern Lake Michigan, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013 the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013).

Silver carp prefer eutrophic water with high plankton concentrations but survive with low growth rates at lower plankton concentrations (Kolar et al. 2005; Calkins 2010). Open areas of most Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Lake Michigan, such as Green Bay, and silver carp have been shown to consume *Cladophora* (Rasmussen et al. 2011), which is abundant in Lake Michigan (MTRI 2012). Seven tributaries to Lake Michigan have velocities potentially high enough to allow successful spawning by Asian carp (Kolar et al. 2005). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes likely have the habitat required for all life stages of Asian carp (ACRCC 2012). Cudmore et al. (2012) rated the probability of the silver carp surviving in Lake Michigan as very likely.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Silver carp is an active swimmer and could find optimal habitat in the 22 rivers that flow into the GLB. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2010; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers, and reproductive habitat can be found in Lake Michigan and in the rivers flowing into Lake Michigan that silver carp could disperse to after exiting the Indiana Harbor. Therefore, there is a high probability of silver carp colonizing.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known whether the fertilized eggs of silver carp could successfully hatch and whether larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear whether optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, silver carp would have to swim or may be carried by currents to one of the large or medium rivers that flow into Lake Michigan. The nearest potentially suitable river is the St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that silver carp would be able to successfully navigate from Indiana Harbor to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp can tolerate long winters under ice cover as well as temperatures higher than 40°C (104°F) (Opuszynski et al. 1989).

b. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers and can spread upstream naturally. Expansion rate of silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

c. *Fecundity*
Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) with peaks in abundance occurring quickly following establishment.

d. *History of Invasion Success*
The silver carp has been widely introduced throughout the world. The species has been imported into or has spread by way of connected waterways to at least 88 countries and territories. Yang (1996) reported that silver carp was introduced to Yunnan Province, China, between 1958 and 1965 and that the carp is now present in most lakes and rivers of that province.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Silver carp are considered opportunistic for plankton and detritus. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

Open areas of most of the Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Great Lakes, such as Green Bay, Saginaw Bay, Lake St. Clair, Western Basin Lake Erie, as well as major tributary rivers (Rasmussen et al. 2011), and silver carp have recently been shown to consume *Cladophora*, which is abundant in Lake Michigan (Rasmussen et al. 2011). There are 22 tributaries located on the United States side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water. Cudmore et al. (2012) rated the probability of spread through the Great Lakes as very likely.

Evidence for Probability Rating

Silver carp are active swimmers with a history of successful invasions of riverine and lake environments (sections 5b, 5d). There appears to be suitable climate, adult habitat, reproductive habitat, and food resources in the GLB (section 5f). Therefore, there is a high probability silver carp will spread through the Great Lakes Basin if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well silver carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if silver carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the Great Lakes Basin have been identified as suitable for reproduction. Therefore, uncertainty is low.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO THE BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	High	Medium	High	Medium	High	Medium	High	Medium
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist. Arrival of an individual specimen is examined here and drives the risk rating.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers. The expansion rate of the silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) and abundance peaks quickly following establishment. Silver carp range expansion surpasses that of bighead, because silver can more readily bypass locks (Jerde et al. 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial vessel and recreational boat traffic between the current location of silver carp and the Brandon Road Lock and Dam. Silver carp eggs, larvae and fry have the potential to be spread by ballast water if water quality is suitable, although the viability of this ballast water transport is considered to be low (Heilprin et al. 2013).

c. *Current Abundance and Reproductive Capacity*
T_0: A Monitoring and Response Work Group (MRWG) composed of academic, local, state and federal agencies was established in 2010 by the Asian Carp Coordinating Committee (ACRCC). The ACRCC's mission statement is to create a sustainable Asian carp control program for protecting the integrity and safety of the Great Lakes ecosystem by preventing introduction of a sustainable Asian carp population into the Great Lakes via all viable pathways (ACRCC 2013d). The MRWG has projects focusing on waterway monitoring, removal efforts, Electric Dispersal Barrier System efficacy, gear catch efficacy and alternative pathway monitoring. Regular electrofishing and netting efforts have consisted of 16,497 person-hours of sampling from the Starved Rock Pool to Lake Michigan resulting in the capture of 283,290 specimens from 2010 to 2012. Removal efforts below the barrier system include contracted commercial fishermen setting over 643.3 miles of nets through 2012 to remove 698.72 tons of bighead, silver and grass carp. Additional workgroup projects include juvenile, larval and egg sampling, ichthyoplankton surveys, telemetry studies, hydro-acoustic surveys, and alternative gear development all of which provide up-to-date information on the status of Asian carp populations and range expansion (ACRCC 2013a).

Based on catch data reported through November 2013, approximately 80 silver carp have been caught in Rock Run Rookery, a backwater in the Dresden Island pool, approximately 4 miles downstream of the Brandon Road Lock and Dam (ACCRC 2013c). There are no physical barriers between Rock Run Rookery Preserve Lake and the Brandon Road Lock and Dam. It is unknown whether this represents a population increase in this pool since the rookery was not previously sampled.

Silver carp are broadcast spawners that spawn in large aggregates (Kolar et al. 2005). Female egg production is correlated with increased body mass and age. Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Eggs are released in the water column and float downstream where they develop in slow-moving waters. Reproduction has not been documented in waters upstream of Marseilles Lock and Dam. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a).

T_{10}: See T_0. Based on the above information, silver carp seems to have a high reproductive capacity in terms of producing new young per year. Therefore, current populations are expected to increase in abundance. Additionally, future environmental conditions or population genetics have the potential to shift in such a way that would allow a rapid growth and expansion of downstream populations that could lead to increased immigration into the pathway (Kolar et al. 2007); therefore, abundance is expected to increase below the Brandon Road Lock and Dam. This assessment is based on past invasion histories for multiple species (Crooks and Soulé 1996; Williamson, 1996; Nico and Fuller 1999; Lockwood et al. 2007); also, see the above section *Type of Mobility/Invasion Speed* for more information.

T_{25}: See T_{10}. It is expected that, in areas with established populations, natural constraints on population growth would begin to reach a plateau. Thus, reproductive capacity would remain the same, but would no longer result in an exponentially increasing population.

T_{50}: See T_{25}.

d. *Existing Physical Human/Natural Barriers*

T_0: None. There are no barriers to movements of the silver carp from their current position to Brandon Road Lock and Dam. The silver carp has arrived at the pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The silver carp is established throughout the Illinois River (Nico 2012). Silver carp have been detected as far upstream as Dresden Island Pool. In 2009, observed one silver carp at the confluence of the Des Plaines River and Chicago Sanitary Ship Canal during routine Asian carp monitoring (ACRCC 2013).

In addition, there have been multiple positive eDNA detections upstream of electric barriers for silver carp (Jerde et al. 2011). However, there is no evidence to correlate the eDNA detections to an established Asian carp population above the Electric Dispersal Barrier System within the CAWS (ACRCC 2012; Environmental DNA Calibration Study 2013). Calibration studies are underway to better understand the relationship between positive eDNA and Asian carp populations (ACRCC 2013b).

Below the Brandon Road Pool, silver carp have been detected in the Dresden Island pool. Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam (ACCRC 2013c). Based on the persistent populations in Marseilles Pool, and the 2013 captures in Rock Run Rookery Preserve Lake approximately four miles from Brandon Road Lock and Dam, the silver carp has arrived at the pathway (Brandon Road Lock and Dam).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. The species is native to several major Pacific drainages in eastern Asia, from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. This species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese &

Pauly 2004). Most of North America falls within these latitudes. Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005).

Silver carp are pelagic, schooling species (Mukhamedova 1977). Silver carp swim just beneath the water surface (Man & Hodgkiss 1981), where it filter-feeds on phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The water temperature range at which larval silver carp can exist is broad, 16–40°C (60.8–104°F), with optimum temperatures reported as 26–30°C (87.8–86°F). Lethal temperature of larval silver carp was 43.5–46.5°C (110.3–115.7°F) (Kolar et al. 2005). Silver carp is quite tolerant to low water temperatures. In Alberta, Canada, silver carp successfully overwinters in ponds that are near 0°C (32°F) from the beginning of November through the end of April (Kolar et al. 2005).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp have been detected as far upstream as Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lock and Dam. Therefore, the probability of silver carp arriving at the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Based on 2013 catch data reported through November, approximately 80 silver carp have been caught in Rock Run Rookery, approximately 4 miles downstream of Brandon Road Lockd and Dam (ACCRC 2013c). Therefore, there is no uncertainty whether this species has arrived at the pathway.

T_{10}: See T_0. Existing data indicate that harvesting in the upper pools (above Starved Rock Lock and Dam) may reduce Asian carp populations. However, the removal efforts are unlikely to amount to a total extirpation from a single pool because removed fish could be replenished by reproducing populations (Tsehaye et al. 2013) and immigration from the lower pools (ACRCC 2013a).
Therefore, the uncertainty of the probability of arrival remains none.
T_{25}: See T_{10}. It is uncertain whether Asian carp monitoring and harvesting activities in Dresden Island Pool will continue during this time step. The silver carp population in the Dresden Island Pool is expected, at a minimum, to remain at existing levels; however an increase in population is more likely through time. Therefore, the uncertainty of the probability of arrival remains none.
T_{50}: See T_{25}.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers and can spread upstream naturally. The expansion rate of the silver carp is 33.62 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

Asian carp were first sampled from the Illinois River during the 1990's and populations have since progressed upstream (Conover et al. 2007; Irons et al. 2009). Monitoring for Asian carp was originally incidental to standard routine sampling by the Illinois Department of Natural Resources (IDNR) and the Illinois Natural History Survey (INHS). Sampling directed toward silver carp in the upper Illinois Waterway began with the US Fish and Wildlife Service's (USFWS) annual Carp Corral & Round Goby Roundup. Subsequently, the US Army Corps of Engineers (USACE) adopted a plan specifically to monitor Asian carp downstream of the electric barrier system located near Romeoville, Illinois (ACRCC 2013a). By 2010, the ACRCC was formed to coordinate this intensive monitoring effort which was expanded to include techniques including but not limited to eDNA, electrofishing, netting, sonar, and telemetry above and below the barrier generally between Lake Michigan and the Peoria Lock and Dam (ACRCC 2010).

In 2009, a confirmed sighting of a silver carp during Asian carp routine monitoring efforts at the confluence of the CSSC and Des Plaines River was reported (ACRCC 2013a); however, the silver carp population in Dresden Island Pool has not progressed upstream. Proposed reasons for this halted progression include limited food resources in the CAWS, hydraulic and hydrologic differences, water quality differences, and a habitat shift from natural to man-made. While these assumptions are still under investigation, the exact cause of the delayed expansion is still unknown but can be compared to other species' invasion histories. Numerous invasive species have long documented cases of extended lag periods in range expansion before an unknown cue (environmental or genetic) sparks another boom in population abundance and/or expanded geographical range (Crooks and Soulé 1996; Williamson 1996; Nico and Fuller 1999; Lockwood et al. 2007). Cudmore et al. (2012) rated the probability of the silver carp entering Lake Michigan as very likely.

Within the Marseilles and Dresden Island Pools, reproductively mature silver carp have been captured but no fertilized eggs or larvae have been found. In 2012, age-1 Asian carp were relatively abundant in the LaGrange and Peoria pools, but only one was caught in the Starved Rock pool and none in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool (ACRCC 2013a). The nearest collection of Asian carp eggs were found near Henry, Illinois within the Peoria Pool, 5 locks downstream of the Electric Dispersal Barrier System. Larval Asian carp were only collected in LaGrange Pool (ACRCC 2013a).

b. *Human-Mediated Transport through Aquatic Pathways*

Silver carp actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from the Brandon Road Lock and Dam. There is heavy commercial vessel and recreational vessel traffic between the Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b). Silver carp eggs and larvae could also be transported upstream of the Electric Dispersal Barrier System by passive entrainment in a ballast tank (no pumping). Heilprin et al. (2013) found water sampled from barge ballast through a single summer to be within published water quality parameters to sustain juvenile and adult Asian carp. Additionally, survivability of larvae and eggs within ballast water was found to be high for periods up to 144 hours, but a very low percentage of larvae survived pump passage when expelling the ballast water (Heilprin et al. 2013).

USCG has established a regulated navigation area around the Electric Dispersal Barrier System which prohibits vessels from transiting the safety zone with any non-potable water on board if they intend to release that water in any form within, or on the other side of the safety zone (USCG, 2011).

Other vessel-related transport mechanisms that may reduce the effectiveness of the Electric Dispersal Barrier System are discussed in Section 4c. *Existing Physical Human/Natural Barriers*.

c. *Existing Physical Human/Natural Barriers*

T_0:

The Brandon Road and Lockport locks and dams are expected to control the upstream movement of fish except during lockages. The complexity of navigating through the lock may slow the upstream passage of Asian carp. There is some leakage around and through the gates (Ackerson 2012) that small larvae could move through, but the larvae would not be able to swim against the current created by the leakage. It is unlikely larvae or other bigger individuals could move through closed lock gates. However, during normal operations, silver carp is assumed to be able to swim through open gates.

In addition, there is an electrical barrier complex referred to as the Electric Dispersal Barrier System. The Electric Dispersal Barrier System, located approximately 4 miles upstream of Lockport Lock and Dam and approximately 31 miles downstream of Lake Michigan, consists of three electrical barriers: Demonstration Barrier, Barrier IIA, and Barrier IIB (USACE 2011c). The barriers consist of steel electrodes mounted across the bed of the Chicago Sanitary and Ship Canal (CSSC) that pulse direct current into the water at a strength, pulse duration, and frequency that repels and stuns fish.

The Demonstration Barrier has been operational since 2002 and was rehabilitated in 2008, but it was designed and built with materials that were not intended for long-term use because of its demonstration status. Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier – 1 volt per inch, 5 Hertz, and 4 milliseconds. These settings were increased in August 2009 to 2 volts per inch, 15 Hertz, and 6.5 milliseconds in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed. Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. In October 2011, Barrier II's operational settings were changed to 2.3 volts per inch, 30 Hertz and 2.5 milliseconds, based on laboratory research suggesting these settings would be more effective in deterring very small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish.

USFWS is evaluating feral fish populations and their behavior within the electric dispersal barrier using a dual-frequency identification SONAR (DIDSON; Sound Metrics Corp., Bellevue, WA) unit to evaluate fish populations throughout the entire barrier system (Parker 2013). Results of sampling across the entire barrier system during the summer of 2013, using DIDSON equipment, revealed a large accumulation of fish below the active barrier. Some of the fish that were immediately below the active barrier (either Barrier IIA or IIB) were observed persistently probing and challenging the barrier. DIDSON results showed schools of small fish breaching the barrier. Typically, as the schools of fish penetrated deeper into the zone of ultimate field strength, the size of the school contracted into a tight sphere shape and after they breached, the group expanded again. The sizes of the fish that breached the barrier are estimated to range from approximately two to four inches in length. To help determine the species of fish most likely observed breaching the barrier, the USFWS performed a limited amount of fish sampling within the narrow array on September 27, 2013 and caught Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense*), and Skipjack Herring (*Alosa chrysochloris*) (USACE 2013). Additional studies are underway to further evaluate operational protocols of the barriers and to identify any potential actions that may be employed to address the findings discussed in this paper.

There are several other mechanisms identified for potential barrier bypass. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in

2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Work is underway on a redundant power supply for Barrier IIA and similar work is planned for Barrier IIB. In addition, automatic transfer mechanisms were installed on both Barriers IIA and IIB to maintain power in the water in the event of a power loss. Permanent Barrier I, the upgrade for the Demonstration Barrier, will provide yet another redundant electric field of the Dispersal Barrier System during power outages at Barrier IIA or IIB. Secondly, the Electric Dispersal Barrier System would be intentionally shut down completely in emergency situations under a man-overboard scenario; however, there have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2002.

Additional potential barrier aquatic bypass vectors are currently under investigation and include reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Preliminary research at the USACE Engineer Research and Development Center in Vicksburg, MS has shown model fish (soft plastic fish lures) to become entrained at numerous surface junctions, to varying degrees, between inter-barge and tow-barge connections on model tow-barge vessels. Additionally, electrical readings taken within the void created between a raked (sloped) bow and a boxed (flat) stern junction show that steel hulled barges reduce the in water electrical parameters in this area (USACE 2013).

The US Fish and Wildlife Service placed live surrogate species of fish in cages alongside and between junctions of barges in the CSSC to evaluate fish-barge interactions and assess the possibility of the fish becoming incapacitated as they traversed the electrical barrier. Fish were incapacitated as they encountered the electrical field at all barge locations, except the void space in the rake to box junction. Several feral fish were observed being entrained in two locations around the barges during trial runs indicating that wild fish do interact with barge traffic near the barriers. In order to determine if wild fish would stay in this void without a cage, a follow-up study was conducted with externally tagged fish (tethered to a float). Tethered fish placed in barge junctions breached the barrier to some degree in all but one barge configuration tested. When tethered fish were placed below the barriers as barges approached, some degree of fish breaching the barrier occurred with each configuration tested (USACE 2013). Results from these ongoing studies are preliminary. This combination of increased possibility of entrainment and reduced electrical parameters due to barge traffic is expected to lead to an increased possibility of fish being transported over the barrier system. Vessel speed and tow/barge configuration are considered to be primary factors that affect the possible entrainment and transport of fish through the electric barriers (USACE 2013). Further research is being conducted to mitigate this bypass. While preliminary results from these investigations have shown these bypasses to be viable, the possibility of these bypasses occurring in the field is low at this time due to the low or non-existent population of silver carp in the Lockport Pool.

In 2010, lateral barricades were constructed between the CSSC, the Des Plaines River, and the Illinois and Michigan Canal to control upstream bypass of the Electrical Dispersal Barrier System during flooding between these adjacent waterways. The Des Plaines

River Barricade extends approximately 13 miles and consists of concrete barriers and specially fabricated ¼ inch wire mesh that allows water to flow through the fence but controls the passage juvenile and adult fish, and the Illinois and Michigan Canal is walled-off using a stone berm. Small sections of the Des Plaines barricade fence failed during flooding in 2013; however, monitoring crews immediately responded and monitored for the presence of fish along breaches. Though these efforts indicated that fish (common carp) had moved through the breaches, no Asian carp were caught (Barkowski 2013), and prior monitoring efforts in the Des Plaines River had not captured or observed Asian carp, larval fish or eggs (ACRCC 2013b).

Under current operational protocols, monitoring for Asian carp occurs downstream and upstream of the Electric Dispersal Barrier System. In the event an individual is found upstream of the Lockport Lock and Dam, protocol dictates the use of intensive electrofishing and netting to find and remove individuals or the use of rotenone to immobilize and kill all fish within the reach of concern (ACRCC 2011). It is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp are above the Brandon Road Lock and Dam.

T_{10}: See T_0.
Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam locks are not expected to change as of the time of this assessment. The Electric Dispersal Barrier System is expected to have additional redundancies in power supply, thereby reducing potential power outage events**.** A new barrier is currently under construction that will upgrade the Demo Barrier to permanent status (Barrier I). Barrier I will be capable of producing higher electrical outputs than those of Barrier II and will add an additional narrow array on the downstream boundary. Barrier I is expected to become operational by 2016. Further study of the current Electric Dispersal Barrier System to address electric field shielding by steel-hulled vessels, fish entrainment within barge-induced water currents and very small fish would continue and would inform future operations.

T_{25}: See T_{10}. Funding for research, monitoring and removal programs for Asian carp at this time step is highly uncertain. Currently, no funding source has been identified for any one agency to maintain the present level of effort.**T_{50}:** See T_{10} and T_{25}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Silver carp inhabit freshwater riverine systems and confluent lakes. It is a pelagic, schooling species (Mukhamedova 1977). Silver carp is a filter-feeder capable of taking large amounts of phytoplankton. Its diet also includes zooplankton, bacteria, and detritus (Leventer 1987). The CAWS is the recipient of treated wastewater from numerous facilities that produce eutrophic conditions suitable for silver carp. Additionally, recent plankton surveys within the CAWS suggest there are relatively high concentrations of zooplankton available as a food resource (MRRP 2012).

Silver carp are tolerant to a wide array of environmental variables (Kolar et al. 2005). They can tolerate long winters under ice cover as well as temperatures higher than 40°C (104°F) (Opuszynski et al. 1989). In the CAWS, the mean annual water temperature ranges from 11.3 to 19.3°C (52.3 to 66.7° F) (MWRD 2010). Fry and fingerlings can survive in waters with a pH of 5.0 to 9.0, dissolved oxygen 1–28 mg/L, and total alkalinity 88–620 mg/L (Singh et al. 1967). Sections of the CAWS also experience seasonally low DO (LimnoTech 2010).

Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Reported current velocities required for successful spawning range from 0.3 to 3.0 m/s (0.98 to 9.8 ft/s) (Kolar et al. 2005). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at the BSBH is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas (LimnoTech 2010). The south branch of the Little Calumet River is small and shallow (Gallagher et al. 2011) and may not be preferred habitat for the silver carp. Overall, the conditions of the CAWS are not expected to impede movement of silver carp.

T_{10}: See T_0. Conditions of the CAWS are predicted to change but not in a way that would affect the likelihood of this species passing through this pathway**.** For example, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is in the process of evaluating ways to improve the water quality of the CAWS by decreasing the amount of organic materials released into the CAWS. This could potentially decrease the amount of plankton and other food species silver carp would need to survive within the CAWS. In addition, in coordination with the USACE, MWRD will increase capacity of stormwater catchment and retention in adjacent tunnels and reservoirs. This increased capacity will lead to a lower hydrologic peak during storm events. The environmental conditions within the pools may change slightly with the closing of two coal-fired power plants (Midwest Generation's Fisk and Crawford Plants) in August 2012. These plants used canal water in their cooling process and returned heated water back to the canal. As a result, temperature profiles may be reduced significantly in the near vicinity and to a lesser extent downstream. These actions are not expected to significantly affect the silver carp's ability to pass through this pathway.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Silver carp would need to pass through the Brandon Road and Lockport locks and dams, the Electric Dispersal Barrier System and an intermittent sluice gate opening to pass through this pathway. Adults and all life sizes of silver carp would be able to swim through the locks when the lock is in operation; however, the locks may slow passage of silver carp through the pathway.

Based on the sampling and monitoring data, the abundance of individuals within the Lockport Pool below the dispersal barriers is expected to be low to non-existent at this timestep. Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on this monitoring data, it appears that few silver carp have expanded past the Brandon Road Lock and Dam. As discussed in P(arrival), *Current and Potential Abundance and Reproductive Capacity*, in 2012, small Asian carp were relatively abundant in the LaGrange Lock and Dam and Peoria Lock and Dam. Only one was caught in the Starved Rock pool. No small age-1 Asian carp were found in the Marseilles pool. Only one age-0 Asian carp was captured at Peoria Lock and Dam, LaGrange pool. Adult populations of silver carp are in the Dresden Island Pool (ACRCC 2013a). In an effort to control the Asian carp population downstream of the barrier, fisherman have been contracted to remove these fish from the waterway.

Monitoring and research have found several potential bypass mechanisms for the Electric Barrier System: man overboard scenario when power to the barrier is intentionally turned off, power outages, bypass during flood events, stunned fish floating through the barrier during reverse flow events in the canal (wind, vessel, or current driven), electric field shielding by steel hulled vessels or side wall crevices, small fish passage and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. Bypass due to these various mechanisms is not likely, because the nearest detectable population of swimming silver carp is in Dresden Island Pool and the nearest detected eggs, larvae and fry are farther downstream (ACRCC 2013a). Additionally, research on these bypasses continues and will inform future operations.

In summary, current propagule pressure of this species immediately downstream of the Dispersal Barriers is considered low or non-existent as measured by monitoring efforts of local, state and federal agencies. The probability of passage for the silver carp is low for T_0 because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier, then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

The low passage rating is in conflict with the Canadian Science Advisory Report (2012) that rates passage through the CAWS as highly likely. However, the Canadian report explicitly did not evaluate the effectiveness of the Electric Dispersal Barrier System.

T_{10}: See T_0. Silver carp are expected to remain in low populations immediately below the Electric Dispersal Barrier System. Contracted fishermen are expected to continue to improve their fishing techniques to increase their catch rates. The Brandon Road and Lockport locks and dams may also slow silver carp passage.

Federal and state natural resource agencies have monitored the upstream progress of Asian carp populations since their arrival in the IWW in the 1990’s (Conover et al. 2007;

Irons et al. 2009; ACRCC 2013a). Since 2007, silver carp were captured in Dresden Island Pool (USGS 2013); however, based on current monitoring data, it appears that few silver carp have moved from Dresden Island Pool to reaches above the Brandon Road Lock and Dam. The factors driving this apparent stalled range expansion are not understood but may include food and habitat availability, channel morphology and hydrology, and lock specific differences. Also, it is expected that the ACRCC Monitoring and Response Group would evaluate and respond to any evidence of Asian carp above the Brandon Road Lock and Dam.

Further refinement of the Electric Dispersal Barrier System operations and redundant power sources are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and future operations would be informed by this analysis.

The probability of passage for the silver carp is low for T_{10} because, 1) small Asian carp are not expected to be present at the Electric Dispersal Barrier System, 2) the abundance of adults is expected to be absent or low near the Electric Dispersal Barrier System, and 3) if a low population of adults approaches the barrier then it is expected, based on current research, that the barrier would be effective at controlling passage of these fish.

T_{25}: See T_{10}. Funding for monitoring and removal programs for silver carp at this time step is uncertain because there is not a funding source identified to maintain the present level of management. With the continued expected immigration from the lower pools (Tsehaye et al. 2013), the propagule pressure at the Dispersal Barrier System is expected to increase, and thus increase the potential for an individual to move past the Barriers. The probability of passage increases to medium.

T_{50}: See T_{10} and T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. Each risk assessment was conducted qualitatively under the assumption that bypass is possible but did not address the frequency that it might occur under a set of quantitative conditions. It is also uncertain whether additional bypass mechanisms could still be discovered. Though comprehensive monitoring upstream and downstream of the barrier for Asian carp is ongoing, uncertainty still exists concerning whether monitoring has identified the true abundance of bighead carp within upper Illinois River and the CAWS. Therefore, uncertainty of the passage probability is medium.

T_{10}: See T_0. Although empirical tests are underway to see if the potential transport mechanisms across the barriers are viable, at this time uncertainty increases with time because of unknown events and a general lack of published literature discussing future bypass mechanisms. Additionally, funding for management actions that keep the populations of Asian carp in check immediately downstream of the Dispersal Barriers are not specified. The factors contributing to the historic absence of range expansion beyond the Brandon Road Lock and Dam are uncertain and may change. Therefore, uncertainty increases to high.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Silver carp are native to several major Pacific drainages in eastern Asia from the Amur River of far eastern Russia south through much of the eastern half of China to the Pearl River. This species is native from about 54°N southward to 21°N (Xie & Chen 2001; Froese & Pauly 2004). The Great Lakes, including Lake Superior, fall within these latitudes (Rasmussen et al. 2011). Cudmore et al. (2012) rated the climate of the GLB as suitable for silver carp. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp are a pelagic, schooling species (Mukhamedova 1977) that swim just beneath the water surface (Man & Hodgkiss 1981). Silver carp can tolerate a wide array of environmental variables(Kolar et al. 2005). They are filter-feeders capable of consuming large amounts of phytoplankton. Their diet also includes zooplankton, bacteria, and detritus (Leventer 1987).

Silver carp often spawn after a sharp rise in water level associated with spring floods (Verigin 1979) and a temperature greater than 17°C (62.6°F). The mean summer temperature of Lake Michigan near Chicago ranges between 20 and 23°C (68 and 73.4°F). It is thought that silver carp require rivers for spawning (Kolar et al. 2005). A minimum length of spawning river is about 100 km (62.1 mi) with a velocity of 0.7–1.4 m/s (2.3–4.6 ft/s) (Kolar et al. 2005). Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963). Seven tributaries of Lake Michigan, including the St. Joseph River in southeastern Lake Michigan, have been identified as potentially suitable for spawning by Asian carp (Kolar et al. 2005). The river length requirements for Asian carp recruitment may be lower than previously thought. In 2013 the USGS provided evidence that grass carp have spawned and successfully recruited in the Sandusky River, a tributary to Lake Erie (Chapman et al. 2013).

Silver carp prefer eutrophic water with high plankton concentrations but survive with low growth rates at lower plankton concentrations (Kolar et al. 2005; Calkins 2010).

Open areas of most Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Lake Michigan, such as Green Bay, and silver carp have been shown to consume *Cladophora* (Rasmussen et al. 2011), which is abundant in Lake Michigan (MTRI 2012). Seven tributaries to Lake Michigan have velocities potentially high enough to allow successful spawning by Asian carp (Kolar et al. 2005). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes likely have the habitat required for all life stages of Asian carp (ACRCC 2012). Cudmore et al. (2012) rated the probability of the silver carp surviving in Lake Michigan as very likely.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Silver carp is an active swimmer and could find optimal habitat in the 22 rivers that flow into the GLB. Rivers are more likely to provide suitable habitat if suitable habitat is not found within Lake Michigan (Rasmussen et al. 2011; Chapman 2010; Canadian Science Advisory Report 2012).

Evidence for Probability Rating

Suitable food resources, spawning triggers, and reproductive habitat can be found in Lake Michigan and in the rivers flowing into Lake Michigan that silver carp could disperse to after exiting the BSBH. Therefore, there is a high probability of silver carp being able to form a persistent population after entering Lake Michigan.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is not known whether the fertilized eggs of silver carp could successfully hatch and whether larvae could survive in Lake Michigan. Successful reproduction is correlated to seasonal high water levels and velocities. It is not clear whether optimal reproductive habitat is available in Lake Michigan. If suitable habitat is not available in Lake Michigan, silver carp would have to swim or may be carried by currents to one of the large or medium rivers that flow into Lake Michigan. The nearest potentially suitable river is the St. Joseph, the mouth is located at Benton Harbor, MI. It is not certain that silver carp would be able to successfully navigate from BSBH to Benton Harbor within a lake environment.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Silver carp can tolerate long winters under ice cover as well as temperatures higher than 40 C (104° F) (Opuszynski et al. 1989).

b. *Type of Mobility/Invasion Speed*
Silver carp are active swimmers and can spread upstream naturally. Expansion rate of silver carp is 33.18 km/yr (20.62 river miles/yr) (Jerde et al. 2010).

c. *Fecundity*
Total fecundity of silver carp from the middle of the Mississippi River in 2003 ranged from 57,283 to 328,538 eggs (Kolar et al. 2005). In 2004 and 2005, fecundity of silver carp ranged from 26,650–598,767 and 274,917 to 3,683,150, respectively (Garvey et al. 2006). Populations of silver carp appear to be growing exponentially (Kolar et al. 2005) with peaks in abundance occurring quickly following establishment.

d. *History of Invasion Success*
The silver carp has been widely introduced throughout the world. The species has been imported into or has spread by way of connected waterways to at least 88 countries and territories. Yang (1996) reported that silver carp was introduced to Yunnan Province, China, between 1958 and 1965 and that the carp is now present in most lakes and rivers of that province.

e. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic throughout the Great Lakes Basin, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Silver carp are considered opportunistic for plankton and detritus. Silver carp inhabit freshwater riverine systems and confluent lakes. Silver carp eggs are semi-buoyant; spawning typically occurs in water of sufficient flow to keep the eggs from sinking to the bottom and dying (Laird & Page 1996). Large lakes connected to rivers often serve as nursery areas for silver carp (Wang et al. 2003). Currents bring larvae to slow-flowing backwaters, creeks, reservoirs, or other flooded areas that become nursery areas (Nikolsky 1963).

Open areas of most of the Great Lakes, excluding Lake Erie in the spring, would not likely meet metabolic requirements of Asian carp (Hill & Pegg 2008; Cooke & Hill 2010). However, food resources are available in productive embayments of the Great Lakes, such as Green Bay, Saginaw Bay, Lake St. Clair, Western Basin Lake Erie, as well as major tributary rivers (Rasmussen et al. 2011), and silver carp have recently been shown to consume *Cladophora*, which is abundant in Lake Michigan (Rasmussen et al. 2011). There are 22 tributaries located on the United States side that flow into the Great Lakes, forming the Great Lakes watershed, that have velocities high enough to allow for Asian carp eggs to hatch (Kolar et al. 2007; Rasmussen et al. 2011). Food resources and potential spawning areas are available in the Great Lakes (Rasmussen et al. 2011). The Great Lakes Basin likely has the habitat required for all life stages of Asian carp (ACRCC 2012; Canadian Science Advisory Report 2012). Suitable habitat may be present within the Great Lakes and optimal habitat is likely to occur within the 22 tributaries flowing in from the U.S. side all connected by year-round surface water. Cudmore et al. (2012) rated the probability of spread through the Great Lakes as very likely.

Evidence for Probability Rating

Silver carp are active swimmers with a history of successful invasions of riverine and lake environments (sections 5b, 5d). There appears to be suitable climate, adult habitat, reproductive habitat, and food resources in the GLB (section 5f). Therefore, there is a high probability silver carp will spread through the Great Lakes Basin if a persistent colony develops.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain how well silver carp will navigate Lake Michigan or navigate from one tributary to the next. It is not known if silver carp could be transported from one tributary to another by way of commercial or recreational vessel traffic. However, several tributaries in the Great Lakes Basin have been identified as suitable for reproduction. Therefore, uncertainty is low.

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E.1.3.5 Northern Snakehead - *Channa argus*

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The northern snakehead swims and spreads naturally through watercourses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). The snakehead may move in stream and river networks, reproducing and spreading to adjacent watersheds. The species can be a rapid invader. Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland, on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

b. *Human-Mediated Transport through Aquatic Pathways*

None described in the literature. This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water.

c. *Current Abundance and Reproductive Capacity*

T_0: Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008). Adults care for their young, which feed on plankton until they are about four weeks old (NBII & ISSG 2008). Sexual maturity is reached at the age of two to three years and a length of about 30 cm (11.8 in.) (NBII & ISSG 2008). They are long-lived, with one specimen recorded at eight years old and 760 mm (30 in.) long (Courtenay & Williams 2004; FishBase 2010; Galveston Bay undated). There is an established population in Piney Creek, Arkansas, which is the closest population to Brandon Road Lock and Dam that is located in the MRB (Sattelberg et al. 2008). The population has been greatly suppressed by eradication efforts. However, the northern snakehead is still considered established in Piney Creek.

T_{10}: See T_0. Management efforts may continue to suppress or even eliminate the Piney Creek population using Rotenone and/or Antimycin A within the Piney Creek drainage (Sattelberg et al. 2008). Alternatively, management efforts could fail and the species could increase in abundance in the MRB.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*

T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). The Marseilles Lock and Dam and Dresden Lock and Dam are potential barriers to passage as the dams may create hydrological and shoreline modifications that may not be favorable to the northern snakehead. While this species is capable of overland movements that may aid it in bypassing any barriers, the overland distance necessary to bypass the locks and dams may limit this mode of transit along the river.

T_{10}: See T_0. The lock operations are not expected to change.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: The closest established population of the northern snakehead to the pathway is in Piney Creek, a Mississippi River tributary in Arkansas (Sattelberg et al. 2008) which is hundreds of miles from the Brandon Road Lock and Dam. The northern snakehead was being cultured on three fish farms in Arkansas until importation, culture, sale, and possession of snakeheads was prohibited by the Arkansas Fish and Game Commission in August 2002 (Courtenay & Williams 2004). There are efforts underway to control its downstream spread, which have so far been successful (Sattelberg et al. 2008). A specimen was collected in Lake Michigan at the Burnham Harbor in downtown Chicago, Illinois, in 2004 (Fuller et al. 2012). This species is considered to be failed/eradicated in Lake Michigan (Fuller et al. 2012).

T_{10}: See T_0. If management efforts fail, the species may, over time, spread beyond Piney Creek, and move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The northern snakehead has a native range of China, Russia, and Korea (Fuller et al. 2012). It appears to occupy waters, usually with vegetation, close to shore, and also feeds in schools (Courtenay & Williams 2004). The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate (Fuller et al. 2012). It can tolerate temperatures ranging from 0 to more than 30°C (32–86°F) (Fuller et al. 2012). The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams, 2004).

This species builds a mostly circular nest of pieces of aquatic plants, about 1 m (3.28 ft) in diameter, in shallow aquatic vegetation (Courtenay & Williams 2004). The water surface above the nest is cleaned by the parents, and spawning occurs at dawn or in early morning (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Eggs hatch in 28 hours at 31°C (87.8°F), 45 hours at 25°C (77°C), and 120 hours at 18°C (64.4°C) (Courtenay & Williams 2004). Wee (1982) cited Parameswaran and Murugesan (1976) as having documented several snakehead species that are also capable of reproducing in waters lacking vegetation. The same may be true for the northern snakehead, which colonized reservoirs on the Talas River of Kazakhstan that did not contain vegetation (Courtenay & Williams 2004).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Young of this species may be able to move over land for short distances using wiggling motions to travel to new bodies of water (Courtenay &

Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: The northern snakehead is a potentially rapid invader and highly fecund species (sections 2a, 2c). Suitable habitat is present between the current location and Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the northern snakehead (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location in Arkansas (section 2e). The Piney Creek population is monitored and there is a management plan in place to eradicate and prevent the spread of this species. There is no evidence that the species has spread from Piney Creek (section 2c). The locks and dams along the pathway to Brandon Road Lock and Dam may act as a temporary barrier to the species (section 2d). Overall, the probability of the species arriving at the pathway entrance at this time step is low.

T_{10}: See T_0. Thus far, management efforts to prevent the spread of northern snakehead from Piney Creek have been successful. Therefore the probability of arrival remains low for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Unless the spread of this species is controlled, over time, the potential for the northern snakehead to spread to the Mississippi River from Piney Creek increases. Given time to naturally disperse upstream, the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: Currently, the northern snakehead is located in Arkansas and is subject to management efforts to eradicate the population (section 2c) and prevent its spread to the Mississippi River (section 2e). In addition, it is unlikely that the northern snakehead would naturally disperse and swim to the pathway entrance from its current location in Arkansas at this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. The future success of management efforts to prevent this species from moving to the Mississippi River from Piney Creek is uncertain. The natural rate of spread through the MRB is uncertain. It is uncertain if or how long it will take the northern snakehead to pass the locks and dams along the pathway. However, there is no documentation that a dam would act as a barrier for the northern snakehead. Overall, the uncertainty associated with arrival is medium for this time step.
T_{50}: See T_{25}. Fifty years may be enough time for the species to spread to the pathway entrance. However, uncertainty associated with existing containment programs and the spread to the pathway increases over time. Overall, the uncertainty associated with arrival is high for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic between Brandon Road Lock and Dam and the Chicago River, but this traffic does not go to WPS (USACE 2011a,b). This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water. The northern snakehead actively swims and does not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). Brandon Road Lock and Dam and the Lockport Lock and Dam could act as temporary barriers to passage through the CAWS, by altering the natural hydrogeomorphology of the river. However, no literature was found on the effect of dams on the movement of

this species. The Electric Dispersal Barrier System located north of Lockport Lock and Dam is expected to be a significant barrier to upstream passage. This species prefers shallow bottom waters, where the electric field is strongest. As part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), and there are ongoing studies on the efficacy of Barrier II with regard to small fish. The U.S. Army Corps of Engineers continues to study the optimal operating parameters to deter very small fish. However, northern snakehead are not known to be reproduce in the Illinois waterway, therefore, small individual are not expected to be present at the barrier at this time step. However, there are several potential mechanisms identified for barrier failure for larger fish. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the dispersal barrier systems are shut down completely in emergency situations under a man-overboard scenario. There have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demonstration Barrier in 2009. Additional potential barrier bypass vectors are currently under investigation and include wind or current driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is very low at this time due to the non-existent population of northern snakehead at the site. This research is ongoing and future mitigation actions will be taken under advisement. Potential barriers to movement above the electric dispersal barrier system include a sluice gate at the WPS that separates the CAWS from Lake Michigan. However, the gates are periodically opened to allow reverse flow back into Lake Michigan, which could allow passage of the northern snakehead.

T_{10}: See T_0. Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to change. Future operations of the Electric Dispersal Barrier System are expected to be based on a more sustainable and predictable power supply; as a result, fewer potential power outage events are expected. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.

T_{25}: See T_{10}.

T_{50}: See T_0. Future operations at the barrier system may also change to increase the efficacy as research continues to discover potential weaknesses within the system. However, it is unlikely that the Dispersal Barrier System will ever become 100% effective at deterring fish passage due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the risk of Dispersal Barrier passage could increase as propagule pressure of northern snakehead immediately downstream increases. However, northern snakehead numbers are expected to remain low or non-existent below the Dispersal Barriers during this time step. The reason for low numbers may be related to a failure to spread from its current location in Arkansas or future local, state, and federal monitoring and removal efforts. Future operations of the WPS sluice gate are not predicted to change. Even if the northern snakehead reaches the electric barrier, it is unlikely to exist in high abundance, even by T_{50}. Consequently, it is assumed that propagule pressure would remain low, and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to over 30°C (32 to 86°F) (Fuller et al. 2012). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at WPS is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) and a water temperature of 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). The maximum depth in the CAWS is about 10 m (32.8 ft) deep (LimnoTech 2010). Northern snakeheads are typically collected in less than 2 m (6.6 ft) and often in water less than 1 m (3.3 ft) in depth. The CSSC and the Chicago River are 3–9.1 m (10–30 ft) deep. Northern snakeheads were associated with *Hydrilla* or Eurasian watermilfoil near a channel or shoreline edge and floating or emergent plants (Odenkirk & Owens 2005). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Submerged aquatic macrophytes are uncommon in the CAWS. Much of the CSSC is vertical limestone or manmade walls. Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River is vertical wall (LimnoTech 2010). Sediments in the CSSC can be rock to soft sediment and sand. The Upper North Branch of the Chicago River and the North Shore channel are more natural habitat with cobble banks and woody debris. The Chicago River has a sludge or silt bottom (LimnoTech 2010).

This species builds a mostly circular nest of pieces of aquatic plants in shallow aquatic vegetation (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC and the North Shore Channel in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2010). Young of this species may be able to move over land for short distances

using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the northern snakehead in the CAWS, although the CSSC and the Chicago River are not typical of the preferred habitat for this species due to their depth and vertical banks (section 3d). The species is a potentially rapid invader with the ability to swim upstream through the CAWS to the WPS. The passage into the CAWS is blocked by the Brandon Road Lock and Dam and the Lockport Lock and Dam (section 3c) both of which may act as a temporary barrier as this species prefers shallow water. Although potential mechanisms exist for this species to move beyond the Electric Dispersal Barrier System (section 3c), the Electric Barrier is expected to be a significant barrier to the upstream movement of this species. The northern snakehead would be able to pass into the GLB at the WPS through the sluice gate when the flow is reversed back into the lake (section 3c). Overall the probability of the northern snakehead passing through the passage at this time step is low.
T_{10}: See T_0. Improvements in the Electric Dispersal Barrier operations will decrease the number and length of potential power outages. Potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce passage. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Propagule pressure of this species immediately downstream of the Dispersal Barriers is expected to remain low at T_{50} because populations in Illinois are expected to be small or non-existent at T_{50}, resulting in low propagule pressure. Therefore, the Electric Barrier is expected to remain effective at controlling passage of this species, and the probability of passage is expected to remain low.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The ability of the northern snakehead to pass through the locks and the electric barrier during this time step is uncertain. Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier, thereby reducing uncertainty. However, the uncertainty associated with the propagule pressure of this species at the Electric Barrier and the efficacy of the barrier at controlling passage of this species also increases with time. Therefore, the uncertainty associated with its passage during this time step is high.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The presence of juveniles in a pond in Crofton, Maryland demonstrates the significant potential that the northern snakehead would invade ponds, lakes and rivers in Maryland (Fuller et al. 2012). The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

There are no emergent wetlands near the WPS (unpublished data from USACE). Wilmette Harbor contains no emergent wetland habitat and the adjacent near shore areas of Lake Michigan are sandy beach and riprap. This species prefers still, shallow water with submerged macrophytes. Most submerged aquatic vegetation in southern Lake Michigan is in the form of *Cladophora* beds, which may be suitable. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. Emergent wetlands that may be suitable for the northern snakehead are found scattered inland of the Lake Michigan shoreline and are associated with tributaries to Lake Michigan (unpublished data from USACE). Illinois Beach State Park, located approximately 50 km

(31 mi) north of WPS contains emergent wetlands near the shoreline of Lake Michigan. There is little emergent wetland habitat between the WPS and the Indiana border (unpublished data from USACE) due to human modification of the shoreline. East of Indiana Harbor where the shoreline is more natural, there are scattered emergent wetlands. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal* The northern snakehead could potentially swim to suitable habitat such as sheltered waters and tributaries with emergent wetlands. Tributaries to Lake Michigan contain suitable habitat, although large tributaries are more than 97 km (60 mi) from the WPS. The nearest being located 50 km (31 mi) north at Illinois Beach State Park. The northern snakehead could potentially swim to these tributaries. In southern Lake Michigan, most emergent wetlands inshore of Lake Michigan are not hydrologically connected to the lake. The ability of the northern snakehead to move on land (Courtenay & Williams 2004) may allow the species to reach ponds and emergent wetlands near the shoreline of Lake Michigan.

Evidence for Probability Rating

The northern snakehead is unlikely to colonize Wilmette Harbor. The species prefers shallow, vegetated habitat with a mud substrate, the nearest being 50 km (31 mi) away. The high-energy shoreline of Lake Michigan is likely to be unsuitable for this species and may limit access to habitats at the park. While suitable habitat is present in shallow, sheltered waters along the shoreline of Lake Michigan and in emergent wetlands associated with tributaries to the lake, these areas are primarily found in Indiana and near the Wisconsin/Illinois border and are not located near the WPS (section 4a). The northern snakehead may be capable of swimming or moving across land to emergent wetlands inland of Lake Michigan. Overall, the probability of this species colonizing in the GLB after exiting the WPS is considered to be medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is uncertain if *Cladophora* beds would be suitable for this species. It is uncertain if the species will be able to reach suitable habitat after exiting the WPS by natural dispersal alone given the high-energy shoreline typical of Lake Michigan. Therefore, the uncertainty of this species colonizing in the GLB is medium.

5. **P(spreads): MEDIUM**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004). The northern snakehead can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

b. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

c. *Fecundity*
Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008).

d. *History of Invasion Success*
Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). In 2002, a self-sustaining population was discovered and later eradicated in a small pond in Maryland (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

e. *Human-Mediated Transport through Aquatic Pathways*
None.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The northern snakehead is an obligate air breather that occupies shallow water. The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate (Fuller et al. 2012). Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan although extensive *Cladophora* beds are present (MTRI 2012) which may be suitable for this species. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable

for this species. Harbors or sheltered areas within Lake Michigan may be suitable. In Lake Michigan, the bowfin (*Amia calva*), which has similar habitat and life history requirements to the snakehead, is found in sheltered waters (e.g., Green Bay) and at river mouths (Goodyear et al. 1982). There are suitable emergent marsh, swamps, and littoral habitats in the GLB in floodplain areas (unpublished data from USACE). There are areas of near shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the northern snakehead could spread (unpublished data from USACE).

Evidence for Probability Rating

The northern snakehead is a highly fecund species (section 5c) with a potentially rapid invasion rate (section 5d). Low-energy, vegetated, shallow waters of the Great Lakes may be suitable as well as tributaries to the Great Lakes and their floodplains. There is near shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected to Lake Michigan (section 5f). The northern snakehead could potentially move across the landscape to suitable habitat (section 5b). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland, swamps, and littoral habitat, although these are located distant from the CAWS and it is unknown how effectively the northern snakehead could traverse intervening areas to reach these suitable habitats. Assuming initial colonization occurs the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). The snakehead may move in stream and river networks, reproducing and spreading to adjacent watersheds. The species can be a rapid invader. Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland, on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
None described in the literature. This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water.

c. *Current Abundance and Reproductive Capacity*

T_0: Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008). Adults care for their young, which feed on plankton until they are about four weeks old (NBII & ISSG 2008). Sexual maturity is reached at the age of two to three years and a length of about 30 cm (11.8 in.) (NBII & ISSG 2008). They are long-lived, with one specimen recorded at eight years old and 760 mm (30 in.) long (Courtenay & Williams 2004; FishBase 2010; Galveston Bay undated). There is an established population in Piney Creek, Arkansas which is the closest population to Brandon Road Lock and Dam that is located in the MRB (Sattelberg et al. 2008). The population has been greatly suppressed by eradication efforts. However, the northern snakehead is still considered established in Piney Creek.

T_{10}: See T_0. Management efforts may continue to suppress or even eliminate the Piney Creek population using Rotenone and/or Antimycin A within the Piney Creek drainage (Sattelberg et al. 2008). Alternatively, management efforts could fail and the species could increase in abundance in the MRB.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*

T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). The Marseilles Lock and Dam and Dresden Lock and Dam are potential barriers to passage as the dams may create hydrological and shoreline modifications that may not be favorable to the northern snakehead. While this species is capable of overland movements which may aid it in bypassing any barriers, the overland distance necessary to bypass the locks and dams may limit the mode of transit along the river.

T_{10}: See T_0. The lock operations are not expected to change.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: The closest established population of the northern snakehead to the pathway is in Piney Creek, a Mississippi River tributary in Arkansas (Sattelberg et al. 2008) which is hundreds of miles from the Brandon Road Lock and Dam. The northern snakehead was being cultured on three fish farms in Arkansas until importation, culture, sale, and possession of snakeheads was prohibited by the Arkansas Fish and Game Commission in August 2002 (Courtenay & Williams 2004) and there are efforts underway to control its downstream spread, which has so far been successful (Sattelberg et al. 2008). A specimen was collected in Lake Michigan at the Burnham Harbor in downtown Chicago, Illinois, in 2004 (Fuller et al. 2012). This species is considered to be failed/eradicated in Lake Michigan (Fuller et al. 2012).

T_{10}: See T_0. If management efforts fail, the species may, over time, spread beyond Piney Creek, and move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The northern snakehead has a native range of China, Russia and Korea (Fuller et al. 2012). It appears to occupy waters, usually with vegetation, close to shore, and also feeds in schools (Courtenay & Williams 2004). The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate. It can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012). The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004).

This species builds a mostly circular nest of pieces of aquatic plants, about 1 m (3.28 ft) in diameter, in shallow aquatic vegetation. The water surface above the nest is cleaned by the parents, and spawning occurs at dawn or in early morning. The female rises near the surface and releases eggs, which are then fertilized by the male. Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Eggs hatch in 28 hours at 31°C (87.8°F), 45 hours at 25°C (77°F), and 120 hours at 18°C (64.4°F) (Courtenay & Williams 2004). Wee (1982) cited Parameswaran and Murugesan (1976) as having documented several snakehead species that are also capable of reproducing in waters lacking vegetation. The same may be true for the northern snakehead, which colonized reservoirs on the Talas River of Kazakhstan that did not contain vegetation (Courtenay & Williams 2004).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Young of this species may be able to move over land for short distances using wiggling motions to travel to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The northern snakehead is a potentially rapid invader and highly fecund species (sections 2a, 2c). Suitable habitat is present between the current location and the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the northern snakehead (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location in Arkansas (section 2e). The Piney Creek population is monitored and there is a management plan in place to eradicate and prevent the spread of this species. There is no evidence that the species has spread from Piney Creek (section 2c). The locks and dams along the pathway to Brandon Road Lock and Dam may act as a temporary barrier to the species (section 2d). Overall, the probability of the species arriving at the pathway entrance at this time step is low.
T_{10}: See T_0. Thus far management efforts to control the spread of northern snakehead from Piney Creek have been successful. Therefore the probability of arrival remains low for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Unless the spread of this species is controlled, over time, the potential for the northern snakehead to spread to the Mississippi River from Piney Creek increases. Given time to naturally disperse upstream the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: Currently, the northern snakehead is located in Arkansas and is subject to management efforts to eradicate the population (section 2c) and prevent its spread to the Mississippi River (section 2e). In addition, it is unlikely for the northern snakehead to naturally disperse and swim to the pathway entrance from its current location in Arkansas at this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. The future success of management efforts to prevent this species from moving to the Mississippi River from Piney Creek is uncertain. The natural rate of spread through the MRB is uncertain. It is uncertain if the northern snakehead will pass the locks and dams along the pathway or how long this would take. However, there is no documentation that a dam would act as a barrier for the northern snakehead, and 25 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{50}: See T_{25}. Fifty years may be enough time for the species to spread to the pathway entrance. However, uncertainty associated with existing containment programs and the spread to the pathway increases over time. Overall, the uncertainty associated with arrival is high for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic between Brandon Road Lock and Dam and the Chicago River (USACE 2011a,b). This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water. The northern snakehead actively swims and does not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). Brandon Road Lock and Dam and the Lockport Lock and Dam could act as temporary barriers to passage through the CAWS, by altering the natural hydrogeomorphology of the river. However, no literature was found on the effect of dams on the movement of this species. The Electric Dispersal Barrier System located north of Lockport Lock and Dam is expected to be a significant barrier to upstream passage. This species prefers shallow bottom waters, where the electric field is strongest. As part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011). The U.S. Army Corps of Engineers continues to study the optimal operating parameters for Barrier II to deter very small fish. However, northern snakehead are not known to reproduce in the Illinois waterway; therefore, small fish are not expected to be present at the barrier at this time step. However, there are several potential mechanisms identified for barrier failure for larger fish. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the Dispersal Barrier Systems are shut down completely in emergency situations under a man-overboard scenario. There have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demonstration Barrier in 2009. Additional potential barrier bypass vectors are currently under investigation and include wind or current-driven reverse flow events in the canal,

electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is very low at this time due to the non-existent population of northern snakehead at the site. This research is ongoing, and future mitigation actions will be taken under advisement.

T_{10}: See T_0. Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to change. Future operations of the Electric Dispersal Barrier System are expected to be based on a more sustainable and predictable power supply; as a result, fewer potential power outage events are expected. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.

T_{25}: See T_{10}.

T_{50}: See T_0. Future operations at the barrier system may also change to increase its efficacy as research continues to discover potential weaknesses within the system. However, it is unlikely that the Electric Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the risk of Dispersal Barrier passage could increase as propagule pressure of northern snakehead immediately downstream increases. However, northern snakehead numbers are expected to remain low or non-existent below the Dispersal Barriers during this time step. The reason for low numbers may be related to a failure to spread from its current location in Arkansas or future local, state, and federal monitoring and removal efforts. Even if the northern snakehead reaches the Electric Barrier, it is unlikely to exist in high abundance, even by T_{50}. Consequently, it is assumed that propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to over 30°C (32 to 86°F) (Fuller et al. 2012). The pathway from the Brandon Road Lock and Dam to the mouth of Lake Michigan at CRCW is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) and a water temperature of 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). The maximum depth in the CAWS is about 10 m (32.8 ft) deep (LimnoTech 2010). Northern snakeheads are typically collected in less than 2 m (6.6 ft) and often in water less than 1 m (3.3 ft) in depth. The CSSC and the Chicago River are 3–9.1 m (10–30 ft) deep. Water depth in the CAWS can be shallow along the channel edge and should be suitable. Northern snakeheads were associated with *Hydrilla* or Eurasian watermilfoil near a channel or shoreline edge and floating or emergent plants (Odenkirk & Owens 2005). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Submerged aquatic macrophytes are uncommon in the CAWS. Much of the CSSC is vertical limestone or manmade walls. Virtually all (>90%) of the Chicago River is vertical wall (LimnoTech 2010). Sediments in the CSSC can be rock to soft sediment and sand. The Chicago River has a sludge or silt bottom (LimnoTech 2010). The North Branch Chicago River is more natural habitat with cobble banks and woody d. builds a mostly circular nest of pieces of aquatic plants in shallow aquatic vegetation (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2010). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the northern snakehead in the CAWS, although portions of the CSSC, the Chicago River and CRCW are not typical of the preferred habitat for this species due to their depth and vertical banks (section 3d). The species is a potentially rapid invader with the ability to swim upstream through the CAWS to the CRCW. The passage into the CAWS is blocked by the Brandon Road Lock and Dam and the Lockport Lock and Dam (section 3c) both of which may act as a temporary barrier as this species prefers shallow water. Although potential mechanisms exist for this species to move beyond the Electric Dispersal Barrier System (section 3c), the Electric Barrier is expected to be a significant barrier to the upstream movement of this species, although potential mechanisms exist for this species to move beyond the electric barrier (section 3c). Overall the probability of the northern snakehead passing through the passage at this time step is low.

T_{10}: See T_0. Improvements in the Electric Dispersal Barrier operations will decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass. Therefore, the probability of passage remains low.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Propagule pressure of this species immediately downstream of the Dispersal Barriers is expected to remain low at T_{50} because populations in Illinois are expected to be small or non-existent at T_{50}, resulting in low propagule pressure. Therefore, the Electric Barrier is expected to remain effective at controlling passage of this species, and the probability of passage is expected to remain low.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The ability of the northern snakehead to pass through the locks and the electric barrier during this time step is uncertain. Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. It is also unclear if additional mechanisms could still be discovered. The potential speed of natural dispersion through the CAWS is uncertain. The Chicago River and CRCW do not appear to be suitable habitat for this species and it is uncertain if it will move through these waterways. For these reasons, there is a medium degree of uncertainty associated with the probability of its passage.

T_{10}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System thereby reducing uncertainty. However, the uncertainty associated with the electric barrier effectively controlling passage of this species also increases with time. Therefore, the uncertainty associated with its passage is high during this time step.

T_{25}: See T_0.

T_{50}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System, thereby reducing uncertainty. However, the uncertainty associated with the propagule pressure of this species at the Electric Barrier and the efficacy of the barrier at controlling passage of this species also increases with time. Therefore, the uncertainty associated with its passage during this time step is high.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The presence of juveniles in a pond in Crofton, Maryland, demonstrates the significant potential that the northern snakehead could invade ponds, lakes, and rivers in Maryland (Fuller et al. 2012). The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

   There are no emergent wetlands near the CRCW (unpublished data from USACE). CRCW contains no emergent wetland habitat and the adjacent near shore areas of Lake Michigan are sandy beach and riprap. This species prefers still, shallow water with submerged macrophytes. Most submerged aquatic vegetation in southern Lake Michigan is in the form of *Cladophora* beds, which may be suitable. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. Emergent wetlands that may be suitable for the northern snakehead are found scattered inland of the Lake Michigan shoreline and are associated with tributaries to Lake Michigan (unpublished data from USACE). Illinois Beach State Park, located north of CRCW contains emergent wetlands near the shoreline of Lake Michigan. There is little emergent wetland habitat between the CRCW and the Indiana border (unpublished data from USACE) due to human modification of the shoreline. East of Indiana Harbor, where the shoreline is more natural, there are scattered emergent wetlands. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The northern snakehead could potentially swim to suitable habitat such as sheltered waters and tributaries with emergent wetlands. Tributaries to Lake Michigan contain suitable habitat, although large tributaries are greater than 96 km (60 mi) from the CRCW. The northern snakehead could potentially swim to these tributaries. In southern Lake Michigan, most emergent wetlands inshore of Lake Michigan are not hydrologically connected to the lake. The ability of the northern snakehead to move on land (Courtenay & Williams 2004) may allow the species to reach ponds and emergent wetlands near the shoreline of Lake Michigan.

Evidence for Probability Rating

The northern snakehead is unlikely to colonize near the CRCW. The species prefers shallow, vegetated habitat with a mud substrate. The high-energy shoreline of Lake Michigan is likely to be unsuitable for this species. Suitable habitat is present in shallow, sheltered waters along the shoreline of Lake Michigan and in emergent wetlands associated with tributaries to the lake. These areas are primarily found in Indiana and near the Wisconsin/Illinois border and are not located near the CRCW (section 4a). The northern snakehead may be capable of swimming or moving across land to emergent wetlands inland of Lake Michigan. Overall, the probability of this species colonizing in the GLB after exiting the CRCW is considered to be medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is uncertain if *Cladophora* beds would be suitable for this species. It is uncertain if the species will be able to reach to suitable habitat after exiting the CRCW by natural dispersal alone given the high-energy shoreline typical of Lake Michigan. Therefore, the uncertainty of this species colonizing in the GLB is medium.

5. **P(spreads): MEDIUM**

Factors That Influence Spread of Species

a. Suitable Climate in New Basin

The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004). The northern snakehead can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

b. Type of Mobility/Invasion Speed

The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

c. Fecundity

Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008).

d. History of Invasion Success

Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited. In 2002, a self-sustaining population was discovered and later eradicated in a small pond in Maryland (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac

River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

e. Human-Mediated Transport through Aquatic Pathways
None.

f. Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The northern snakehead is an obligate air breather that occupies shallow water. The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate (Fuller et al. 2012). Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan although extensive *Cladophora* beds are present (MTRI 2012), which may be suitable for this species. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. In Lake Michigan, the bowfin (*Amia calva*), which has similar habitat and life history requirements to the snakehead, is found in sheltered waters (e.g., Green Bay) and at river mouths (Goodyear et al. 1982). There are suitable emergent marsh, swamps, and littoral habitats in the GLB in floodplain areas (unpublished data from USACE). There are areas of near shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the northern snakehead could spread (unpublished data from USACE).

Evidence for Probability Rating

The northern snakehead is a highly fecund species (section 4c) with a rapid invasion rate (section 4d). Low-energy, vegetated, shallow waters of the Great Lakes may be suitable as well as tributaries to the Great Lakes and their floodplains. There is near-shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected to Lake Michigan (section 4f). The northern snakehead could potentially move across the landscape to suitable habitat (section 4b). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland, swamps, and littoral habitat, although these are located distant from the CAWS and it is unknown how effectively the northern snakehead could traverse intervening areas to reach these suitable habitats. Assuming initial colonization occurs the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). The snakehead may move in stream and river networks, reproducing and spreading to adjacent watersheds. The species can be a rapid invader. Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland on April 27, 2004 (Northern Snakehead Working

Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
None described in the literature. This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water.

c. *Current Abundance and Reproductive Capacity*
T_0: Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008). Adults care for their young, which feed on plankton until they are about four weeks old (NBII & ISSG 2008). Sexual maturity is reached at the age of two to three years and a length of about 30 cm (11.8 in.) (NBII & ISSG 2008). They are long lived, with one specimen recorded at eight years old and 760 mm (30 in.) long (Courtenay & Williams 2004; FishBase 2010; Galveston Bay undated). There is an established population in Piney Creek, Arkansas, which is the closest population to Brandon Road Lock and Dam that is located in the MRB (Sattelberg et al. 2008). The population has been greatly suppressed by eradication efforts. However, the northern snakehead is still considered established in Piney Creek.
T_{10}: See T_0. Management efforts may continue to suppress or even eliminate the Piney Creek population using Rotenone and/or Antimycin A within the Piney Creek drainage (Sattelberg et al. 2008). Alternatively, management efforts could fail and the species could increase in abundance in the MRB.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). The Marseilles Lock and Dam and Dresden Lock and Dam are potential barriers to passage as the dams may create hydrological and shoreline modifications that may not be favorable to the northern snakehead. While this species is capable of overland movements that may aid it in bypassing any barriers, the overland distance necessary to bypass the locks and dams may limit this mode of transit along the river.
T_{10}: See T_0. The lock operations are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: The closest established population of the northern snakehead to the pathway is in Piney Creek, a Mississippi River tributary in Arkansas (Sattelberg et al. 2008), which is

hundreds of miles from the Brandon Road Lock and Dam. The northern snakehead was being cultured on three fish farms in Arkansas until importation, culture, sale, and possession of snakeheads was prohibited by the Arkansas Fish and Game Commission in August 2002 (Courtenay & Williams 2004) and there are efforts underway to stop its downstream spread, which has so far been successful (Sattelberg et al. 2008). A specimen was collected in Lake Michigan at the Burnham Harbor in downtown Chicago, Illinois, in 2004 (Fuller et al. 2012). This species is considered to be failed/eradicated in Lake Michigan (Fuller et al. 2012).
T_{10}: See T_0. If management efforts fail, the species may, over time, spread beyond Piney Creek, and move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The northern snakehead has a native range of China, Russia, and Korea (Fuller et al. 2012). It appears to occupy waters, usually with vegetation, close to shore, and also feeds in schools (Courtenay & Williams 2004). The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate. It can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012). The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004).

This species builds a mostly circular nest of pieces of aquatic plants, about 1 m (3.28 ft) in diameter, in shallow aquatic vegetation (Courtenay & Williams 2004). The water surface above the nest is cleaned by the parents, and spawning occurs at dawn or in early morning (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Eggs hatch in 28 hours at 31°C (87.8°F), 45 hours at 25°C (77°F), and 120 hours at 18°C (64.4°F) (Courtenay & Williams 2004). Wee (1982) cited Parameswaran and Murugesan (1976) as having documented several snakehead species that are also capable of reproducing in waters lacking vegetation. The same may be true for the northern snakehead, which colonized reservoirs on the Talas River of Kazakhstan that did not contain vegetation (Courtenay & Williams 2004).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Young of this species may be able to move over land for short distances using wiggling motions to travel to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly

on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The northern snakehead is a potentially rapid invader and highly fecund species (sections 2a, 2c). Suitable habitat is present between the current location and in the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the northern snakehead (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location in Arkansas (section 2e). The Piney Creek population is monitored and there is a management plan in place to eradicate and prevent the spread of this species. There is no evidence that the species has spread from Piney Creek (section 2c). The locks and dams along the pathway to Brandon Road Lock and Dam may act as a temporary barrier to the species (section 2d). Overall, the probability of the species arriving at the pathway entrance at this time step is low.
T_{10}: See T_0. Thus far, management efforts to prevent the spread of northern snakehead from Piney Creek have been successful. Therefore, the probability of arrival remains low for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Unless the spread of this species is controlled, over time, the potential for the northern snakehead to spread to the Mississippi River from Piney Creek increases. Given time to naturally disperse upstream the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: Currently, the northern snakehead is located in Arkansas and is subject to management efforts to eradicate the population (section 2c) and prevent its spread to the Mississippi River (section 2e). In addition, it is unlikely for the northern snakehead to naturally disperse

and swim to the pathway entrance from its current location in Arkansas at this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. The future success of management efforts to prevent this species from moving to the Mississippi River from Piney Creek is uncertain. The natural rate of spread through the MRB is uncertain. It is uncertain if the northern snakehead will pass the locks and dams along the pathway or how long this would take. However, there is no documentation that a dam would act as a barrier for the northern snakehead, and 25 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{50}: See T_{25}. Fifty years may be enough time for the species to spread to the pathway entrance. However, uncertainty associated with existing containment programs and the spread to the pathway increases over time. Overall, the uncertainty associated with arrival is high for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic in the CAWS between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam (USACE 2011a,b). This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water. The northern snakehead actively swims and does not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). Brandon Road Lock and Dam and the Lockport Lock and Dam could act as temporary barriers to passage through the CAWS, by altering the natural hydrogeomorphology of the river. However, no literature was found on the effect of dams on the movement of this species. The Electric Dispersal Barrier System located north of Lockport Lock and Dam is expected to be a significant barrier to upstream passage. This species prefers shallow bottom waters, where the electric field is strongest. As part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that

small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011). The U.S. Army Corps of Engineers continues to study the optimal operating parameters for Barrier II to deter very small fish. However, northern snakehead are not known to reproduce in the Illinois waterway; therefore, small fish are not expected to be present at the barrier at this time step. However, there are several potential mechanisms identified for barrier failure for larger fish. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the Electric Dispersal Barrier Systems are shut down completely in emergency situations under a man-overboard scenario. There have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demonstration Barrier in 2009. Additional potential barrier bypass vectors are currently under investigation and include wind or current-driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is very low at this time due to the non-existent population of northern snakehead at the site. This research is ongoing, and future mitigation actions will be taken under advisement.

T_{10}: See T_0. Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to change. Future operations of the Electric Dispersal Barrier System are expected to be based on a more sustainable and predictable power supply; as a result, fewer potential power outage events are expected. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.

T_{25}: See T_{10}.

T_{50}: See T_0. Future operations at the barrier system may change to increase the efficacy as research continues to discover potential weaknesses within the system. However, it is unlikely that the Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the risk of Dispersal Barrier passage could increase as propagule pressure of northern snakehead immediately downstream increases. However, northern snakehead numbers are expected to remain low or non-existent below the Dispersal Barriers during this time step. The reason for low numbers may be related to a failure to spread from its current location in Arkansas or future local, state, and federal monitoring and removal efforts. Even if the northern snakehead reaches the electric barrier, it is unlikely to exist in high abundance, even by T_{50}. Consequently, it is assumed that propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012). The pathway from the Brandon Road Lock and Dam to the Calumet Harbor is a slow-moving eutrophic river with a flow of approximately 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010); and a mean annual water temperature of 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). The maximum depth in the CAWS is about 10 m (32.8 ft) deep (LimnoTech 2010), but it is typically much shallower. Northern snakeheads are typically collected in less than 2 m (6.6 ft) and often in water less than 1 m (3.28 ft) in depth. The CSSC is 3 to approximately 9.1 m (10 to 30 ft) deep. Water depth is 3 m (10 ft) or less in the Calumet Sag Channel. Water depth in the CAWS can be shallow along the channel edge and should be suitable. Northern snakeheads were associated with *Hydrilla* or Eurasian watermilfoil near a channel or shoreline edge and floating or emergent plants (Odenkirk & Owens 2005). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Submerged aquatic macrophytes are uncommon in the CAWS. Much of the CSSC is vertical limestone or manmade walls. Sediments in the CSSC can be rock to soft sediment and sand. The banks of the Calumet Sag Channel are vertical walls, rock, and some vegetative debris. Sediments can be gravel to soft sediment (LimnoTech 2010). In the Little Calumet River and Calumet River there is in-stream habitat for aquatic life in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches (LimnoTech 2010). However, Calumet Harbor itself is deep with vertical walls.

This species builds a mostly circular nest of pieces of aquatic plants in shallow aquatic vegetation (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2010). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does

not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the northern snakehead in the CAWS within the Calumet Sag Channel, the Little Calumet River and the portions of the Calumet River (section 3d). Much of the CSSC are not typical of the preferred habitat for this species due to its depth and vertical banks (section 3d). The species is a potentially rapid invader with the ability to swim upstream through the CAWS to the Calumet Harbor. The passage into the CAWS is blocked by the Brandon Road Lock and Dam and the Lockport Lock and Dam (section 3c) both of which may act as a temporary barrier as this species prefers shallow water. Although potential mechanisms exist for this species to move beyond the Electric Dispersal Barrier System (section 3c), the Electric Barrier is expected to be a significant barrier to the upstream movement of this species. Overall the probability of the northern snakehead passing through the passage at this time step is low.
T_{10}: See T_0. Improvements in the Electric Dispersal Barrier operations will decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Propagule pressure of this species immediately downstream of the Electric Dispersal Barriers is expected to remain low at T_{50} because populations in Illinois are expected to be small or non-existent at T_{50}, resulting in low propagule pressure. Therefore, the Electric Barrier is expected to remain effective at controlling passage of this species, and the probability of passage is expected to remain low.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The ability of the northern snakehead to pass through the locks and the electric barrier during this time step is uncertain. Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium. The potential speed of natural dispersion through the CAWS is uncertain. For these reasons, there is a medium degree of uncertainty associated with the probability of its passage.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System, thereby reducing uncertainty. However, the uncertainty associated with the propagule pressure of this species at the Electric Barrier and the efficacy of the barrier at controlling passage of this species also increase with time. Therefore, the uncertainty associated with its passage during this time step is high.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The presence of juveniles in a pond in Crofton, Maryland, demonstrates the significant potential that the northern snakehead could invade ponds, lakes and rivers in Maryland (Fuller et al. 2012). The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

The nearshore areas of Lake Michigan adjacent to Calumet Harbor are sandy beach and riprap. This species prefers still, shallow water with submerged macrophytes. Most submerged aquatic vegetation in southern Lake Michigan is in the form of *Cladophora* beds, which may be suitable. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. Emergent wetlands that may be suitable for the northern snakehead are found scattered inland of the Lake Michigan shoreline and are associated with tributaries to Lake Michigan (unpublished data from USACE). East of Indiana Harbor, where the shoreline is more natural, there are scattered emergent wetlands. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal

The northern snakehead could potentially swim to suitable habitat such as sheltered waters and tributaries with emergent wetlands. Tributaries to Lake Michigan contain suitable habitat. In southern Lake Michigan, most emergent wetlands inshore of Lake Michigan are not hydrologically connected to the lake. The ability of the northern snakehead to move on land (Courtenay & Williams 2004) may allow the species to reach ponds and emergent wetlands near the shoreline of Lake Michigan.

Evidence for Probability Rating

The northern snakehead is unlikely to colonize near the Calumet Harbor. The species prefers shallow, vegetated habitat with a mud substrate. The sandy, high-energy shoreline of Lake Michigan is likely to be unsuitable for this species and may limit access to habitats. While suitable habitat is present in shallow, sheltered waters along the shoreline of Lake Michigan and in emergent wetlands associated with tributaries to the lake. The northern snakehead may be capable of swimming or moving across land to suitable habitat along Lake Michigan. Overall, the probability of this species colonizing in the GLB after exiting the Calumet Harbor is considered to be medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is uncertain if *Cladophora* beds would be suitable for this species. It is uncertain if the species will be able to reach to suitable habitat after exiting the Calumet Harbor by natural dispersal alone given the high-energy shoreline typical of Lake Michigan. Therefore, the uncertainty of this species colonizing in the GLB is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004). The northern snakehead can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

b. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

c. *Fecundity*
Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008).

d. *History of Invasion Success*
Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). In 2002, a self-sustaining population was discovered and later eradicated in a small pond in Maryland (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland, on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

e. *Human-Mediated Transport through Aquatic Pathways*
None.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The northern snakehead is an obligate air breather that occupies shallow water. The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate (Fuller et al. 2012). Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan although extensive *Cladophora* beds are present (MTRI 2012), which may be suitable for this species. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. In Lake Michigan, the bowfin (*Amia calva*), which has similar habitat and life history requirements to the snakehead, is found in sheltered waters (e.g., Green Bay) and at river mouths (Goodyear et al. 1982). There are suitable emergent marsh, swamps, and littoral habitats in the GLB in floodplain areas (unpublished data from USACE). There are areas of nearshore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the northern snakehead could spread (unpublished data from USACE).

Evidence for Probability Rating

The northern snakehead is a highly fecund species (section 5c) with a potentially rapid invasion rate (section 5d). Low-energy, vegetated, shallow waters of the Great Lakes may be suitable as well as tributaries to the Great Lakes and their floodplains. There is nearshore emergent herbaceous habitat inland of Lake Michigan, but it may not be hydrologically connected to Lake Michigan (section 5f). The northern snakehead could potentially move across the landscape to suitable habitat (section 5b). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland, swamps, and littoral habitat, although these are located distant from the CAWS and it is unknown how effectively the northern snakehead could traverse intervening areas to reach these suitable habitats. Assuming initial colonization occurs the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). The snakehead may move in stream and river networks, reproducing and spreading to adjacent watersheds.

The species can be to be a rapid invader. Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland, on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
None described in the literature. This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water.

c. *Current Abundance and Reproductive Capacity*
T_0: Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008). Adults care for their young, which feed on plankton until they are about four weeks old (NBII & ISSG 2008). Sexual maturity is reached at the age of two to three years and a length of about 30 cm (11.8 in.) (NBII & ISSG 2008). They are long-lived, with one specimen recorded at eight years old and 760 mm (30 in.) long (Courtenay & Williams 2004; FishBase 2010; Galveston Bay undated). There is an established population in Piney Creek, Arkansas, which is the closest population to Brandon Road Lock and Dam that is located in the MRB (Sattelberg et al. 2008). The population has been greatly suppressed by eradication efforts. However, the northern snakehead is still considered established in Piney Creek.
T_{10}: See T_0. Management efforts may continue to suppress or even eliminate the Piney Creek population using Rotenone and/or Antimycin A within the Piney Creek drainage (Sattelberg et al. 2008). Alternatively, management efforts could fail and the species could increase in abundance in the MRB.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*

T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). The Marseilles Lock and Dam and Dresden Lock and Dam are potential barriers to passage as the dams may create hydrological and shoreline modifications that may not be favorable to the northern snakehead. While this species is capable of overland movements that may aid it in bypassing any barriers, the overland distance necessary to bypass the locks and dams may limit this mode of transit along the river.

T_{10}: See T_0. The lock operations are not expected to change.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: The closest established population of the northern snakehead to the pathway is in Piney Creek, a Mississippi River tributary in Arkansas (Sattelberg et al. 2008), which is hundreds of miles from the Brandon Road Lock and Dam. The northern snakehead was being cultured on three fish farms in Arkansas until importation, culture, sale, and possession of snakeheads was prohibited by the Arkansas Fish and Game Commission in August 2002 (Courtenay & Williams 2004). There are efforts underway to prevent its downstream spread, which have so far been successful (Sattelberg et al. 2008). A specimen was collected in Lake Michigan at the Burnham Harbor in downtown Chicago, Illinois, in 2004. This species is considered to be failed/eradicated in Lake Michigan (Fuller et al. 2012).

T_{10}: See T_0. If management efforts fail, the species may, over time, spread beyond Piney Creek, and move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The northern snakehead has a native range of China, Russia, and Korea (Fuller et al. 2012). It appears to occupy waters, usually with vegetation, close to shore, and also feeds in schools (Courtenay & Williams 2004). The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate (Fuller et al. 2012). It can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012). The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004).

This species builds a mostly circular nest of pieces of aquatic plants, about 1 m (3.28 ft) in diameter, in shallow aquatic vegetation (Courtenay & Williams 2004). The water surface above the nest is cleaned by the parents, and spawning occurs at dawn or in early morning (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Eggs hatch in 28 hours at 31°C (87.8°F), 45 hours at 25°C (77°F), and 120 hours at 18°C (64.4°F) (Courtenay & Williams 2004). Wee (1982) cited Parameswaran and Murugesan (1976) as having documented several snakehead species that are also capable of reproducing in waters lacking vegetation. The same may be true for the northern snakehead, which colonized reservoirs on the Talas River of Kazakhstan that did not contain vegetation (Courtenay & Williams 2004).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Young of this species may be able to move over land for short distances using wiggling motions to travel to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The northern snakehead is a potentially rapid invader and highly fecund species (sections 2a, 2c). Suitable habitat is present between the current location and Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the northern snakehead (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location in Arkansas (section 2e). The Piney Creek population is monitored and there is a management plan in place to eradicate and prevent the spread of this species. There is no evidence that the species has spread from Piney Creek (section 2c). The locks and dams along the pathway to Brandon Road Lock and Dam may act as a temporary barrier to the species (section 2d). Overall, the probability of the species arriving at the pathway entrance at this time step is low.

T_{10}: See T_0. Thus far, management efforts to prevent the spread of northern snakehead from Piney Creek have been successful. Therefore the probability of arrival remains low for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Unless the spread of this species is controlled, over time, the potential for the northern snakehead to spread to the Mississippi River from Piney Creek increases. Given time to naturally disperse upstream the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	

Evidence for Uncertainty Rating

T_0: Currently, the northern snakehead is located in Arkansas and is subject to management efforts to eradicate the population (section 2c) and prevent its spread to the Mississippi River (section 2e). In addition, it is unlikely for the northern snakehead to naturally disperse and swim to the pathway entrance from its current location in Arkansas at this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. The future success of management efforts to prevent this species from moving to the Mississippi River from Piney Creek is uncertain. The natural rate of spread through the MRB is uncertain. It is uncertain if the northern snakehead will pass the locks and dams along the pathway or how long this would take. However, there is no documentation that a dam would act as a barrier for the northern snakehead, and 25 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{50}: See T_{25}. Fifty years may be enough time for the species to spread to the pathway entrance. However, uncertainty associated with existing containment programs and the spread to the pathway increases over time. Overall, the uncertainty associated with arrival is high for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

b. Human-Mediated Transport through Aquatic Pathways

There is no cargo vessel traffic to Indiana Harbor originating within the MRB. River vessels travel from Brandon Road Lock and Dam as far as the Grand Calumet River (USACE 2011a,b). This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water. The northern snakehead actively swims and does not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). Brandon Road Lock and Dam and the Lockport Lock and Dam could act as temporary barriers to passage through the CAWS, by altering the natural hydrogeomorphology of the river. However, no literature was found on the effect of dams on the movement of this species. The Electric Dispersal Barrier System located north of Lockport Lock and Dam is expected to be a significant barrier to upstream passage. This species prefers shallow bottom waters, where the electric field is strongest. As part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011). The U.S. Army Corps of Engineers continues to study the optimal operating parameters for Barrier II to deter very small fish. However, northern snakehead are not known to reproduce in the Illinois waterway, therefore small individuals smaller are not expected to be present at the barrier at this time step. However, there are several potential mechanisms identified for barrier failure for larger fish. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the Dispersal Barrier Systems are shut down completely in emergency situations under a man-overboard scenario. There have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demo Barrier in 2009. Additional potential barrier bypass vectors are currently under investigation and include wind or current-driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is very low at this time due to the non-existent population of northern snakehead at the site. This research is ongoing, and future mitigation actions will be taken under advisement. There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a barrier, especially under low flows.

T_{10}: See T_0. Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to change. Future operations of the Electric Dispersal Barrier System are expected to be based on a more sustainable and predictable power supply; as a result, fewer potential power outage events are expected. A permanent Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.

T_{25}: See T_{10}.

T_{50}: See T_0. Future operations at the Barrier System may also change to increase the efficacy as research continues to discover potential weaknesses within the system. However, it is unlikely that the Electric Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the risk of Dispersal Barrier passage could increase as propagule pressure of northern snakehead immediately downstream increases. However, northern snakehead numbers are expected to remain low or non-existent below the Dispersal Barriers during this time step. The reason for low numbers may be related to a failure to spread from its current location in Arkansas or future local, state, and federal monitoring and removal efforts. Even if the northern snakehead reaches the Electric Barrier, it is unlikely to exist in high abundance, even by T_{50}. Consequently, it is assumed that propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012). The pathway from the Brandon Road Lock and Dam to the Indiana Harbor is a slow-moving eutrophic river with a flow of approximately 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) and a mean annual water temperature of 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). The maximum depth in the CAWS is about 10 m (32.8 ft) deep (LimnoTech 2010), but it is typically much shallower. Northern snakeheads are typically collected in waters less than 2 m (6.6 ft) deep and often in waters less than 1 m (3.3 ft) in depth. The Chicago Sanitary and Ship Canal is 3 to approximately 9.1 m deep (10–30 ft), but is 3 m (10 ft) or less in the Calumet Sag Channel and the Grand Calumet River. Water depth in the CAWS can be shallow along the channel edge and should be suitable. Northern snakeheads were associated with *Hydrilla* or Eurasian watermilfoil near a channel or shoreline edge and floating or emergent plants (Odenkirk & Owens 2005). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Submerged aquatic macrophytes are uncommon in the CAWS. Much of the CSSC is vertical limestone or manmade walls. Sediments in the CSSC can be rock to soft sediment and sand. The banks of the Calumet Sag Channel are vertical walls, rock, and some vegetative debris. Sediments can be gravel to soft sediment (LimnoTech 2010). In the Little Calumet River there is in-stream habitat for aquatic life in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches (LimnoTech 2010). Sediments in the Grand Calumet consist of primarily cobble, bedrock or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water depth is as shallow as a few feet, which is the preferred habitat of this species (Gallagher et al. 2011). However, Indiana Harbor itself is deep with vertical walls.

This species builds a mostly circular nest of pieces of aquatic plants in shallow aquatic vegetation (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen, and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2010). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the northern snakehead in the CAWS within the Calumet Sag Channel, the Little Calumet River and the portions of the Calumet River (section 3d). Much of the Chicago Sanitary and Ship Canal are not typical of the preferred habitat for the species due to its depth and vertical banks (section 3d). The species is a potentially rapid invader with the ability to swim upstream through the CAWS to the Indiana Harbor. The passage through the CAWS may be interrupted by the Brandon Road Lock and Dam and the Lockport Lock and Dam (section 3c), both of which may act as a temporary barrier as this species prefers shallow water. Although potential mechanisms exist for this species to move beyond the Electric Dispersal Barrier System (section 3c), the Electric Barrier is expected to be a significant barrier to the upstream movement of this species. In addition, the sheet pile across the Grand Calumet River could act as a barrier, especially under low flows. Overall the probability of the northern snakehead passing through the passage at this time step is low.
T_{10}: See T_0. Further refinement of the Electric Dispersal Barrier System operations will decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating

parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Propagule pressure of this species immediately downstream of the Dispersal Barriers is expected to remain low at T_{50} because populations in Illinois are expected to be small or non-existent at T_{50}, resulting in low propagule pressure. Therefore, the Electric Barrier is expected to remain effective at controlling passage of this species, and the probability of passage is expected to remain low.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The ability of the northern snakehead to pass through the locks and the electric barrier during this time step is uncertain. Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. It is also unclear if additional mechanisms could still be discovered. The potential speed of natural dispersion through the CAWS is uncertain. For these reasons, there is a medium degree of uncertainty associated with the probability of its passage.
T_{10}: See T_0. **T_{25}:** See T_0.
T_{50}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier, thereby reducing uncertainty. However, the uncertainty associated with the propagule pressure of this species at the Electric Barrier and the efficacy of the barrier at controlling passage of this species also increase with time. Therefore, the uncertainty associated with its passage during this time step is high.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The presence of juveniles in a pond in Crofton, Maryland, demonstrates the significant potential that the northern snakehead could invade ponds, lakes and rivers in Maryland (Fuller et al. 2012). The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32–86°F) (Fuller et al. 2012).

The nearshore areas of Lake Michigan adjacent to Indiana Harbor are sandy beach and riprap. This species prefers still, shallow water with submerged macrophytes. Most submerged aquatic vegetation in southern Lake Michigan is in the form of *Cladophora* beds, which may be suitable. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. Emergent wetlands that may be suitable for the northern snakehead are found scattered inland of the Lake Michigan shoreline and are associated with tributaries to Lake Michigan (unpublished data from USACE). East of Indiana Harbor, where the shoreline is more natural, there are scattered emergent wetlands. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The northern snakehead could potentially swim to suitable habitat such as sheltered waters and tributaries with emergent wetlands. Tributaries to Lake Michigan contain suitable habitat. In southern Lake Michigan, most emergent wetlands inshore of Lake Michigan are not hydrologically connected to the lake. The ability of the northern snakehead to move on land (Courtenay & Williams 2004) may allow the species to reach pond and emergent wetlands near the shoreline of Lake Michigan.

Evidence for Probability Rating

The northern snakehead is unlikely to colonize near the Indiana Harbor. The species prefers shallow, vegetated habitat with a mud substrate. The sandy, high-energy shoreline of Lake Michigan is likely to be unsuitable for this species and may limit access to habitats. Suitable habitat is present in shallow, sheltered waters along the shoreline of Lake Michigan and in emergent wetlands associated with tributaries to the lake. The northern snakehead may be capable of swimming or moving across land to suitable habitat along Lake Michigan. Overall, the probability of this species colonizing in the GLB after exiting the Indiana Harbor is considered to be medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is uncertain if *Cladophora* beds would be suitable for this species. It is uncertain if the species will be able to reach suitable habitat after exiting the Indiana Harbor by natural dispersal alone given the high-energy shoreline typical of Lake Michigan. Therefore, the uncertainty of this species colonizing in the GLB is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004). The northern snakehead can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

b. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

c. *Fecundity*
Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008).

d. *History of Invasion Success*
Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). In 2002, a self-sustaining population was discovered and later eradicated in a small pond in Maryland (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

e. *Human-Mediated Transport through Aquatic Pathways*
None.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The northern snakehead is an obligate air breather that occupies shallow water. The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate (Fuller et al. 2012). Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan, although extensive *Cladophora* beds are present (MTRI 2012) that may be suitable for this species. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable

for this species. Harbors or sheltered areas within Lake Michigan may be suitable. In Lake Michigan, the bowfin (*Amia calva*), which has similar habitat and life history requirements to the snakehead, is found in sheltered waters (e.g., Green Bay) and at river mouths (Goodyear et al. 1982). There are suitable emergent marsh, swamps, and littoral habitats in the GLB in floodplain areas (unpublished data from USACE). There are areas of nearshore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers, through which the northern snakehead could spread (unpublished data from USACE).

Evidence for Probability Rating

The northern snakehead is a highly fecund species (section 5c) with a rapid invasion rate (section 5d). Low-energy, vegetated, shallow waters of the Great Lakes may be suitable as well as tributaries to the Great Lakes and their floodplains. There is nearshore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected to Lake Michigan (section 5f). The northern snakehead could potentially move across the landscape to suitable habitat (section 5b). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland, swamps, and littoral habitat, although these are located distant from the CAWS and it is unknown how effectively the northern snakehead could traverse intervening areas to reach these suitable habitats. Assuming initial colonization occurs the uncertainty of this species spreading in the Great Lakes is medium.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Medium	Medium	High
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). The snakehead may move in stream and river networks, reproducing and spreading to adjacent watersheds. The species can be a rapid invader. Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland, on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
None described in the literature. This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water.

c. *Current Abundance and Reproductive Capacity*

T_0: Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008). Adults care for their young, which feed on plankton until they are about four weeks old (NBII & ISSG 2008). Sexual maturity is reached at the age of two to three years and a length of about 30 cm (11.8 in.) (NBII & ISSG 2008). They are long-lived, with one specimen recorded at 8 years old and 760 mm (30 in.) long (Courtenay & Williams 2004; FishBase 2010; Galveston Bay undated). There is an established population in Piney Creek, Arkansas, which is the closest population to Brandon Road Lock and Dam that is located in the MRB (Sattelberg et al. 2008). The population has been greatly suppressed by eradication efforts. However, the northern snakehead is still considered established in Piney Creek.

T_{10}: See T_0. Management efforts may continue to suppress or even eliminate the Piney Creek population using Rotenone and/or Antimycin A within the Piney Creek drainage (Sattelberg et al. 2008). Alternatively, management efforts could fail and the species could increase in abundance in the MRB.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*

T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). The Marseilles Lock and Dam and Dresden Lock and Dam are potential barriers to passage as the dams may create hydrological and shoreline modifications that may not be favorable to the northern snakehead. While this species is capable of overland movements that may aid it in bypassing any barriers, the overland distance necessary to bypass the locks and dams may limit this mode of transit along the river.

T_{10}: See T_0. The lock operations are not expected to change.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: The closest established population of the northern snakehead to the pathway is in Piney Creek, a Mississippi River tributary in Arkansas (Sattelberg et al. 2008) which is hundreds of miles from the Brandon Road Lock and Dam. The northern snakehead was being cultured on three fish farms in Arkansas until importation, culture, sale, and possession of snakeheads was prohibited by the Arkansas Fish and Game Commission in August 2002 (Courtenay & Williams 2004) and there are efforts underway to stop its downstream spread, which has so far been successful (Sattelberg et al. 2008). A specimen was collected in Lake Michigan at the Burnham Harbor in downtown Chicago, Illinois in 2004. This species is considered to be failed/eradicated in Lake Michigan (Fuller et al. 2012).

T_{10}: See T_0. If management efforts fail, the species may, over time, spread beyond Piney Creek, and move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The northern snakehead has a native range of China, Russia, and Korea (Fuller et al. 2012). It appears to occupy waters, usually with vegetation, close to shore, and also feeds in schools (Courtenay & Williams 2004). The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate. It can tolerate temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012). The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004).

This species builds a mostly circular nest of pieces of aquatic plants, about 1 m (3.28 ft) in diameter, in shallow aquatic vegetation. The water surface above the nest is cleaned by the parents, and spawning occurs at dawn or in early morning. The female rises near the surface and releases eggs, which are then fertilized by the male. Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents. Eggs hatch in 28 hours at 31°C (87.8°F), 45 hours at 25°C (77°F), and 120 hours at 18°C (64.4°F) (Courtenay & Williams 2004). Wee (1982) cited Parameswaran and Murugesan (1976) as having documented several snakehead species that are also capable of reproducing in waters lacking vegetation. The same may be true for the northern snakehead, which colonized reservoirs on the Talas River of Kazakhstan that did not contain vegetation (Courtenay & Williams 2004).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Young of this species may be able to move over land for short distances using wiggling motions to travel to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter, but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The northern snakehead is a potentially rapid invader and highly fecund species (sections 2a, 2c). Suitable habitat is present between the current location and the vicinity of Brandon Road Lock and Dam (section 2f). There is no documented human-mediated aquatic transport for the northern snakehead (section 2b); therefore, the species would have to naturally disperse and swim upstream to the pathway entrance from its current location in Arkansas (section 2e). The Piney Creek population is monitored and there is a management plan in place to eradicate and prevent the spread of this species. There is no evidence that the species has spread from Piney Creek (section 2c). The locks and dams along the pathway to Brandon Road Lock and Dam may act as a temporary barrier to the species (section 2d). Overall, the probability of the species arriving at the pathway entrance at this time step is low.
T_{10}: See T_0. Thus far management efforts to prevent the spread of northern snakehead from Piney Creek have been successful. Therefore, the probability of arrival remains low for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Unless the spread of this species is controlled, over time, the potential for the northern snakehead to spread to the Mississippi River from Piney Creek increases. Given time to naturally disperse upstream the species may arrive at the pathway entrance at this time step. Therefore, the probability of arrival at this time step increases to medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Uncertainty Rating

T_0: Currently, the northern snakehead is located in Arkansas and is subject to management efforts to eradicate the population (section 2c) and prevent its spread to the Mississippi River (section 2e). In addition, it is unlikely for the northern snakehead to naturally disperse and swim to the pathway entrance from its current location in Arkansas at this time step. Therefore, the uncertainty associated with arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. The future success of management efforts to prevent this species from moving to the Mississippi River from Piney Creek is uncertain. The natural rate of spread through the MRB is uncertain. It is uncertain if the northern snakehead will pass the locks and dams along the pathway or how long this would take. However, there is no documentation that a dam would act as a barrier for the northern snakehead, and 25 years may be enough time for the species to spread to the pathway entrance. Overall, the uncertainty associated with arrival is medium for this time step.
T_{50}: See T_{25}. Fifty years may be enough time for the species to spread to the pathway entrance. However, uncertainty associated with existing containment programs and the spread to the pathway increases over time. Overall, the uncertainty associated with arrival is high for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

b. *Human-Mediated Transport through Aquatic Pathways*
There is no cargo vessel traffic to BSBH Harbor originating within the MRB. River vessels travel from Brandon Road Lock and Dam as far as the Grand Calumet River (USACE 2011a,b). This species lays eggs in a nest and, therefore, eggs and larvae are unlikely to be taken up in ballast water. The northern snakehead actively swims and does not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS from Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The northern snakehead prefers shallow, slow-moving water (Fuller et al. 2012). Brandon Road Lock and Dam and the Lockport Lock and Dam could act as temporary barriers to passage through the CAWS, by altering the natural hydrogeomorphology of the river. However, no literature was found on the effect of dams on the movement of this species. The Electric Dispersal Barrier System located north of Lockport Lock and Dam is expected to be a significant barrier to upstream passage. This species prefers shallow bottom waters, where the electric field is strongest. As part of the U.S. Army Corps of Engineers' efficacy testing of the Demonstration Barrier, it was discovered that small fish are capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011). The U.S. Army Corps of Engineers continues to study the optimal operating parameters for Barrier II to deter very small fish. However, northern snakehead are not known to reproduce in the Illinois waterway; therefore small individuals are not expected to be present at the barrier at this time step. However, there are several potential mechanisms identified for barrier failure for larger fish. First, fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the Electric Dispersal Barrier Systems are shut down completely in emergency situations under a man-overboard scenario. There have been no man-overboard scenarios near the Dispersal Barriers as far back as the initialization of the Demonstration Barrier in 2009. Additional potential

barrier bypass vectors are currently under investigation and include wind or current-driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is very low at this time due to the non-existent population of northern snakehead at the site. This research is ongoing, and future mitigation actions will be taken under advisement.

T_{10}: See T_0. Future operations of the Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to change. Future operations of the Electric Dispersal Barrier System are expected to be based on a more sustainable and predictable power supply; as a result, fewer potential power outage events are expected. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.

T_{25}: See T_{10}.

T_{50}: See T_0. Future operations at the barrier system may also change to increase the efficacy as research continues to discover potential weaknesses within the system. However, it is unlikely that the Electric Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the risk of Dispersal Barrier passage could increase as propagule pressure of northern snakehead immediately downstream increases. However, northern snakehead numbers are expected to remain low or non-existent below the Dispersal Barriers during this time step. The reason for low numbers may be related to a failure to spread from its current location in Arkansas or future local, state, and federal monitoring and removal efforts. Even if the northern snakehead reaches the Electric Barrier, it is unlikely to exist in high abundance, even by T_{50}. Consequently, it is assumed that propagule pressure would remain low and, therefore, the barrier would be effective at controlling passage. Therefore, the probability of passage remains low.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32–86°F) (Fuller et al. 2012). The pathway from the Brandon Road Lock and Dam to the BSBH is a slow-moving eutrophic river with a flow of approximately 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) and a mean annual water temperature of 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and (LimnoTech 2010), but it is typically much shallower. Northern snakeheads are typically collected in waters less than 2 m (6.6 ft) deep and often in waters less than 1 m (3.28 ft) in depth. The CSSC is 3 to approximately 9.1 m (10 to 30 ft) deep. Water depth in the CAWS can be shallow along the channel edge and should be suitable. Water depth is 3 m (10 ft) or less in the Calumet Sag Channel and the south branch of the Little Calumet River. Northern snakeheads were associated with *Hydrilla* or Eurasian watermilfoil near a channel or shoreline edge and floating or emergent plants (Odenkirk & Owens 2005). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Submerged aquatic macrophytes are uncommon in the CAWS. Much of the CSSC is vertical limestone or manmade walls. Sediments in the CSSC can be rock to soft sediment and sand. The banks of the Calumet Sag Channel are vertical walls, rock, and some vegetative debris. Sediments can be gravel to soft sediment (LimnoTech 2010). The banks of the south branch of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Water depth is as shallow as a few feet, which is the preferred habitat of this species (Gallagher et al. 2011).

This species builds a mostly circular nest of pieces of aquatic plants in shallow aquatic vegetation (Courtenay & Williams 2004). The female rises near the surface and releases eggs, which are then fertilized by the male (Courtenay & Williams 2004). Eggs are buoyant, due to a large oil droplet in the yolk mass, and rise to the surface where they are vigorously guarded by one or both parents (Courtenay & Williams 2004). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010).

The northern snakehead is an obligate air-breather; it can survive out of water for up to 4 days by breathing oxygen and is capable of surviving in water with very little oxygen content (NBII & ISSG 2008). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2010). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). All snakehead species are carnivorous thrust predators as adults, and are mainly piscivorous (Cudmore & Mandrak 2006). Juveniles eat zooplankton, insect larvae, small crustaceans, and the fry of other fish (Fuller et al. 2012); adults feed mostly on other fishes, with the remainder of their diet comprised of crustaceans, frogs, small reptiles, and sometimes small birds and mammals (Fuller et al. 2012). The species does not feed during winter but hibernates by burrowing into mud/substrate (Courtenay & Williams 2004).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Much of the CSSC are not typical of the preferred habitat for this species due to its depth and vertical banks (section 3d). However, suitable habitat is present for the northern snakehead in the CAWS within the Calumet Sag Channel and the Little Calumet River

(section 3d). The species is a rapid invader with the ability to swim upstream through the CAWS to BSBH. The passage into the CAWS is blocked by the Brandon Road Lock and Dam and the Lockport Lock and Dam (section 3c), both of which may act as a temporary barrier as this species prefers shallow water. Although potential mechanisms exist for this species to move beyond the Electric Dispersal Barrier System (section 3c), the Electric Barrier is expected to be a significant barrier to the upstream movement of this species. Overall, the probability of the northern snakehead passing through the passage at this time step is low.
T_{10}: See T_0. Further refinement of the Electric Dispersal Barrier System operations will decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Propagule pressure of this species immediately downstream of the Dispersal Barriers is expected to remain low at T_{50} because populations in Illinois are expected to be small or non-existent at T_{50}, resulting in low propagule pressure. Therefore, the Electric Barrier is expected to remain effective at controlling passage of this species, and the probability of passage is expected to remain low.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The ability of the northern snakehead to pass through the locks and the electric barrier during this time step is uncertain. Although there has been an extraordinary effort from multiple agencies to research potential barrier bypass mechanisms, much of that research is currently underway and only preliminary results have been reported. It is also unclear if additional mechanisms could still be discovered. Therefore, uncertainty of the passage probability is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System, thereby reducing uncertainty. However, the uncertainty associated with the propagule pressure of this species at the Electric Barrier and the efficacy of the barrier at preventing the passage of this species also increase with time. Therefore, the uncertainty associated with its passage during this time step is high.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The presence of juveniles in a pond in Crofton, Maryland, demonstrates the significant potential that the northern snakehead could invade ponds, lakes, and rivers in Maryland (Fuller et al. 2012). The northern snakehead prefers stagnant shallow ponds, swamps, and slow streams with mud or vegetated substrate, with temperatures ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

   The nearshore areas of Lake Michigan adjacent to BSBH are sandy beach and riprap. This species prefers still, shallow water with submerged macrophytes. Most submerged aquatic vegetation in southern Lake Michigan is in the form of *Cladophora* beds, which may be suitable. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. Emergent wetlands that may be suitable for the northern snakehead are found scattered inland of the Lake Michigan shoreline and are associated with tributaries to Lake Michigan (unpublished data from USACE). East of BSBH, where the shoreline is more natural, there are scattered emergent wetlands. There are small tributaries and large rivers in Indiana that have emergent wetlands.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The northern snakehead could potentially swim to suitable habitat such as sheltered waters and tributaries with emergent wetlands. Tributaries to Lake Michigan contain suitable habitat. In southern Lake Michigan, most emergent wetlands inshore of Lake Michigan are not hydrologically connected to the lake. The ability of the northern snakehead to move on land (Courtenay & Williams 2004) may allow the species to reach pond and emergent wetlands near the shoreline of Lake Michigan.

Evidence for Probability Rating

The northern snakehead is unlikely to colonize near the BSBH. The species prefers shallow, vegetated habitat with a mud substrate. The sandy, high-energy shoreline of Lake Michigan is likely to be unsuitable for this species and may limit access to habitats. Suitable habitat is present in shallow, sheltered waters along the shoreline of Lake Michigan and in emergent wetlands associated with tributaries to the lake. The northern snakehead may be capable of swimming or moving across land to suitable habitat along Lake Michigan. Overall, the probability of this species colonizing in the GLB after exiting the BSBH is considered to be medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

It is uncertain if *Cladophora* beds would be suitable for this species. It is uncertain if the species will be able to reach suitable habitat after exiting the BSBH by natural dispersal alone, given the high-energy shoreline typical of Lake Michigan. Therefore, the uncertainty of this species colonizing in the GLB is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay & Williams 2004). The northern snakehead can tolerate temperature ranging from 0 to more than 30°C (32 to 86°F) (Fuller et al. 2012).

b. *Type of Mobility/Invasion Speed*
The northern snakehead swims and spreads naturally through water courses (Courtenay & Williams 2004). Young of this species may be able to move over land for short distances using wiggling motions to travel over land to new bodies of water (Courtenay & Williams 2004). It appears that the species is a potentially rapid invader based on its distribution in Maryland.

c. *Fecundity*
Females produce eggs one to five times per year and release 22,000 to 51,000 eggs per spawn (NBII & ISSG 2008). Females can lay as many as 100,000 eggs a year (NBII & ISSG 2008).

d. *History of Invasion Success*
Prior to 2002, the occurrence of northern snakeheads in the United States was fairly limited (Northern Snakehead Working Group 2006). In 2002, a self-sustaining population was discovered and later eradicated in a small pond in Maryland (Northern Snakehead Working Group 2006). A single specimen was identified from Pine Lake, Wheaton, Maryland, on April 27, 2004 (Northern Snakehead Working Group 2006). Twenty northern snakeheads were captured within a 23-km (14.3-mi) reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland in May 2004 and over 300 individuals were captured in 2005 (Northern Snakehead Working Group 2006). Occurrence in Maryland's Potomac River tributaries appeared to be on the rise during the spring of 2006 (Northern Snakehead Working Group 2006). These fish are successfully foraging, using available habitat, and reproducing, and are now apparently self-sustaining in the Potomac River (Northern Snakehead Working Group 2006).

e. *Human-Mediated Transport through Aquatic Pathways*
None.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The northern snakehead is an obligate air breather that occupies shallow water. The northern snakehead prefers stagnant shallow ponds, swamps and slow streams with mud or vegetated substrate (Fuller et al. 2012). Except for large bays, there are few submerged aquatic macrophytes on the shore of Lake Michigan although extensive *Cladophora* beds are present (MTRI 2012) that may be suitable for this species. The shallow shoreline of Lake Michigan can have high wave energy that may not be suitable for this species. Harbors or sheltered areas within Lake Michigan may be suitable. In Lake Michigan, the bowfin (*Amia calva*), which has similar habitat and life history requirements to the snakehead, is found in sheltered waters (e.g., Green Bay) and at river mouths (Goodyear et al. 1982). There are suitable emergent marsh, swamps, and littoral habitats in the GLB in floodplain areas (unpublished data from USACE). There are areas of near shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected. However, there is floodplain habitat associated with tributaries and rivers through which the northern snakehead could spread (unpublished data from USACE).

Evidence for Probability Rating

The northern snakehead is a highly fecund species (section 5c) with a rapid invasion rate (section 5d). Low-energy, vegetated, shallow waters of the Great Lakes may be suitable as well as tributaries to the Great Lakes and their floodplains. There is near shore emergent herbaceous habitat inland of Lake Michigan, but they may not be hydrologically connected to Lake Michigan (section 5f). The northern snakehead could potentially move across the landscape to suitable habitat (section 5b). Therefore, the probability of spreading in the Great Lakes is medium.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is suitable habitat found in the GLB in the form of emergent wetland, swamps, and littoral habitat, although these are located distant from the CAWS and it is unknown how effectively the northern snakehead could traverse intervening areas to reach these suitable habitats. Assuming initial colonization occurs, the uncertainty of this species spreading in the Great Lakes is medium.

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E.1.3.6 Skipjack Herring - *Alosa chrysochloris*

PATHWAY: 1 (BRANDON ROAD LOCK AND DAM TO WILMETTE PUMPING STATION [WPS])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Skipjack Herring are active swimmers that migrate upstream for spawning.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

c. *Current Abundance and Reproductive Capacity*

T_0: In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975). Females produce between 100,000 and 300,000 eggs annually. The native range of the skipjack herring is the Red River drainage (Hudson Bay basin) and Mississippi River Basin (MRB) from central Minnesota south to the Gulf of Mexico; from southwestern Pennsylvania west to eastern South Dakota, Nebraska, Kansas, Oklahoma, and Texas; and the Gulf Slope drainages from the Apalachicola River, Florida, to the Colorado River, Texas (Fuller 2011). The skipjack herring was virtually extirpated from the upper Mississippi River system because construction of lock and dam facilities on the Mississippi River blocked their migration route to the upper sectors of the river (Cross & Huggins 1975). This species has been collected in Lake Michigan in Wisconsin, but it is not considered to be established there (Fuller 2011). The first collection was a single fish taken in Green Bay north of Dyckesville, in Kewaunee County in 1989. A second fish was caught in Lake Michigan just east of Kenosha, in Kenosha County in 1991. A third was caught east of Bailey’s Harbor near the outlet of Moonlight Bay in 1992 (Fuller 2011). They may have entered Lake Michigan via the CAWS (Fuller 2011). This species is listed as endangered in Wisconsin (WDNR 2009).

T_{10}: See T_0. The skipjack herring is listed as a species of special concern in Wisconsin due to its rarity. Temporary stocking and the addition of ladders or lifts on Mississippi River lock and dams will be required If the skipjack herring is to be reestablished in Minnesota (MDNR 2012). Whether these recovery measures will be implemented is unknown. Therefore, abundance may decrease over time if the overall population decreases in the upper Midwest.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*

T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. Therefore, the lock and dams below Brandon Road Lock and Dam may act as barriers to arrival for individuals moving upstream through the Illinois River. However, skipjack herring have been collected in the Lockport pool above Brandon Road Lock and Dam (Shanks 2012a), suggesting the locks are only a temporary barrier.

T_{10}: See T_0. Lock and dam operations are not expected to change over time.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: Skipjack herring have been collected at the junction of the Kankakee and Des Plaines rivers (Illinois Natural History Survey undated). They have also been collected above and below the Brandon Road Lock and Dam and are considered established in Dresden Pool (Shanks 2012a). They are also found in the Illinois River and the upper Mississippi River in Wisconsin (Fuller 2011). There are three records of this species being collected in Lake Michigan. However, the population is not considered to be established. Skipjack herring may have entered Lake Michigan via the CAWS (Fuller 2011).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The skipjack herring is historically distributed in the MRB; therefore climate is suitable in the region of the Brandon Road Lock and Dam. By preventing the skipjack herring from reaching its spawning grounds, dams have extirpated this species over much of its native range in the upper MRB. However, the skipjack herring is common in the lower MRB. The species is found below Brandon Road Lock and Dam, suggesting habitat there is suitable (Shanks 2012a).
T_{10}: See T_0. Habitat is expected to remain suitable below Brandon Road Lock and Dam.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an actively swimming, migratory fish (section 2a). It is present in the Illinois River below and above Brandon Road Lock and Dam (sections 2c, 2e) and in the upper MRB. Although dams below Brandon Road Lock and Dam may slow arrival, there are three records of this species being found in the CAWS and Lake Michigan, suggesting the locks are not a significant barrier (sections 2c 2e). Therefore, the probability of arrival is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The skipjack herring is documented to be established in Dresden Pool below Brandon Road Lock and Dam and in Lake Michigan (sections 2c 2e). Therefore, there is no uncertainty associated with arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Skipjack herring are active, migratory swimmers that move upstream to spawn.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

c. *Existing Physical Human/Natural Barriers*
T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. However, skipjack herring have been found above Brandon Road Lock and Dam, suggesting the dams are only a temporary barrier to passage into Lake Michigan. The Electric Dispersal Barrier System should act as a barrier to upstream dispersal. In the past, this species is thought to have entered Lake Michigan via the CAWS (Fuller 2011). However, the specimens were found in Lake Michigan in the 1990s (Fago 1993) before the implementation of the electric barriers. The electric barrier was observed to inhibit the upstream movement of gizzard shad (Veraldi 2012). However, there are several potential mechanisms for barrier failure. First, small fish may be capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011) and Barrier II, or fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the dispersal barrier systems are shut down completely in emergency situations under a man-overboard scenario. Additional potential barrier bypass vectors are currently under investigation and include wind driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is low at this time due to the low abundance of skipjack herring at the site and the assumed effectiveness of the Electric Barrier Dispersal System. There is a sluice gate separating WPS from Lake Michigan that may act as another barrier. However, the sluice gate is periodically opened, which would allow passage.
T_{10}: See T_0. Lock and dam operations are not expected to change over time, and the Electric Dispersal Barrier System is expected to remain in place. Future operations of the Electric Dispersal Barrier System are expected to change based on a more sustainable and predictable power supply, thereby reducing potential power outage events. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical

outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The skipjack herring migrates upstream through rivers and streams. The skipjack herring spawns in deep water of main channels over bars of coarse sand or gravel (NatureServe 2010). Gravel and sandy substrate is present in the CAWS (LimnoTech 2010). However, the skipjack herring prefers fast flowing waters, particularly when spawning (NatureServe 2010), and these are not present in the CAWS. Skipjack herring have recently been documented in the CAWS as far upstream as the Lockport pool (Shanks 2012a), suggesting that there are no unsuitable habitat conditions known in the CAWS that could limit/prevent passage.
T_{10}: See T_0. No changes in the habitat of the CAWS are anticipated that would affect the probability of passage.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an active, migratory swimmer (section 3a). This species has been found in the CAWS (section 3d), and the literature suggests it has transited the CAWS and accessed Lake Michigan in the past (section 3c). Habitat is suitable in the CAWS and Lake Michigan, although the CAWS does not have the fast flowing water this species prefers (section 3d). There are multiple barriers to passage, including two lock and dam structures and the Electric Dispersal Barrier System, that would slow or prohibit the upstream movement of this species (section 3c). However, the skipjack herring has transited the locks in the past and several low potential bypass mechanisms have been identified by which fish may move upstream of the Electric Dispersal Barrier System (section 3c). Although preliminary results reveal a low probability of occurrence for these mechanisms, further study will inform USACE managers of the best mitigation actions to reduce or eliminate the likelihood of passage. Overall, the probability of this species passing successfully through this pathway is rated as low.
T_{10}: See T_0. Improvements in the Electric Dispersal Barrier System operations are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the likelihood of passage. Therefore, the probability of passage remains low.

T_{25}: See T_{10}. It is unlikely that the Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the probability of the skipjack herring moving upstream of the Dispersal Barrier is expected to increase over time. Consequently, the probability of passage at this time step is medium.
T_{50}: See T_{10} and T_{25}. Although the Electric Dispersal Barrier System will remain in place, each contributing factor identified above that would increase the risk of individual passage is expected to continue. Therefore, the risk of passage remains medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: This species is thought to have possibly passed through the CAWS into Lake Michigan in the recent past, but passage through the CAWS has not been confirmed. The ability of the skipjack herring to pass through the Electric Dispersal Barrier System during this time step is uncertain but evidence suggests it has a low probability of occurring. Empirical tests (but none using skipjack herring) are underway to determine the probability of several potential barrier failure mechanisms. For now, uncertainty associated with passage during this time step is medium.
T_{10}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System. However, the effectiveness of these measures are uncertain. In addition, population trends in the skipjack herring and the subsequent changes in propagule pressure at the Electric Barrier are uncertain. Therefore uncertainty increases to high for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The skipjack herring is known to occupy large lakes (Fuller 2011). Therefore, physical habitat in Lake Michigan is expected to be suitable. Although the skipjack herring was not historically present in the Great Lakes, three specimens were collected in Lake Michigan between 1989 and 1992 (Fago 1993). However, the species is not considered to be established (Fuller 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The skipjack herring is an active swimmer and would be able to reach suitable habitat, if it is available.

Evidence for Probability Rating

Suitable habitat for the skipjack herring appears to be present in Lake Michigan. Records of the skipjack herring exist for Lake Michigan, but the species is not considered established; the most recent record is from 1992 (section 4a). Therefore, probability of colonizing and persisting for the long term is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The skipjack herring was historically present in the Mississippi River Basin, and has been collected in Lake Michigan. It did not appear to establish, and the cause for failure is unknown. Therefore, the uncertainty of this species colonizing Lake Michigan is high.

5. **P(spreads): MEDIUM**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Although the skipjack herring was not historically present in the Great Lakes, three specimens have been collected in Lake Michigan since 1989 (Fago 1993). However, this species is not considered to be established (Fuller 2011).

b. *Type of Mobility/Invasion Speed*
Skipjack herring are active swimmers that migrate upstream for spawning.

c. *Fecundity*
In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975).

d. *History of Invasion Success*
This species is not widely invasive (Fuller 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The skipjack herring requires rivers to spawn. The species can be found in open waters of lakes, medium and large rivers, and large reservoirs (NatureServe 2010). Such habitat is abundant throughout the GLB.

Evidence for Probability Rating

The skipjack herring has not historically been found in the GLB (section 5a), although habitat appears to be suitable. Records of the skipjack herring exist for Lake Michigan, but the species is not considered established and the most recent record is from 1992 (section 5a). Therefore, probability of spreading is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although the skipjack herring has not historically been found in the Great Lakes (section 5a), records of the skipjack herring exist for Lake Michigan (section 5a). Why this species has not established in the Great Lakes is uncertain. Therefore, uncertainty associated with the probability of spreading is high.

PATHWAY: 2 (BRANDON ROAD LOCK AND DAM TO THE CHICAGO RIVER CONTROLLING WORKS [CRCW])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Skipjack herring are active swimmers that migrate upstream for spawning.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: The native range of the skipjack herring is the Red River drainage (Hudson Bay basin) and the MRB from central Minnesota south to the Gulf of Mexico; from southwestern Pennsylvania west to eastern South Dakota, Nebraska, Kansas, Oklahoma, and Texas; and the Gulf Slope drainages from the Apalachicola River, Florida, to the Colorado River, Texas (Fuller 2011). The skipjack herring was virtually extirpated from the upper Mississippi River system because the construction of lock and dam facilities on the Mississippi River blocked their migration route to the upper sectors of the river (Cross & Huggins 1975). The species has been collected in Lake Michigan in Wisconsin, but it is not considered to be established there (Fuller 2011). The first collection was a single fish taken in Green Bay north of Dyckesville, in Kewaunee County in 1989. A second fish was caught in Lake Michigan just east of Kenosha, in Kenosha County in 1991. A third was caught east of Bailey's Harbor near the outlet of Moonlight Bay in 1992 (Fuller 2011). They may have entered Lake Michigan via the CAWS (Fuller 2011). This species is listed as endangered in Wisconsin and vulnerable in Illinois (WDNR 2009). In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975). Females produce between 100,000 and 300,000 eggs annually.

T_{10}: See T_0. The skipjack herring is listed as special concern in Wisconsin due to its rarity. Temporary stocking and the addition of ladders or lifts on Mississippi River lock and dams will be required If the skipjack herring is to be reestablished in Minnesota (MDNR 2012). Whether these recovery measures will be implemented is unknown. Therefore, abundance may decrease over time if the overall population decreases in the upper Midwest.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: Lock and dam structures hinder the upstream migration of skipjacks during early spring. Therefore, the lock and dams below Brandon Road Lock and Dam may act as a barrier to arrival for individuals moving upstream through the Illinois River. However, skipjack herring have been collected in the Lockport pool above Brandon Road Lock and Dam (Shanks 2012a), suggesting the locks are only a temporary barrier.
T_{10}: See T_0. Lock and dam operations are not expected to change over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Skipjack herring have been collected at the junction of the Kankakee and Des Plaines rivers (Illinois Natural History Survey undated). They have also been collected above and below the Brandon Road Lock and Dam and are considered established in Dresden Pool (Shanks 2012a). They are also found in the Illinois River and the upper Mississippi River in Wisconsin (Fuller 2011). There are three records of skipjack herring being collected in Lake Michigan. However, the population is not considered to be established; they may have entered Lake Michigan via the CAWS (Fuller 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The skipjack herring was historically distributed in the MRB; therefore climate is suitable in the region of the Brandon Road Lock and Dam. By preventing the skipjack herring from reaching its spawning grounds, dams have extirpated this species over much of its native range in the upper MRB. However, the skipjack herring is common in the lower MRB. The species is found below Brandon Road Lock and Dam, suggesting habitat there is suitable (Shanks 2012a).
T_{10}: See T_0. Habitat is expected to remain suitable below Brandon Road Lock and Dam.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an actively swimming, migratory fish (section 2a). It is present in the Illinois River below Brandon Road Lock and Dam (sections 2c, 2e) and in the upper MRB. Although dams below Brandon Road Lock and Dam may slow or prevent arrival, there are three records of this species in the CAWS and from Lake Michigan, suggesting the locks are not a significant barrier (sections 2c, 2e). Therefore, the probability of arrival is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The skipjack herring is documented to be established in Dresden Pool below Brandon Road Lock and Dam and in Lake Michigan (sections 2c, 2e). Therefore, there is no uncertainty associated with arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Skipjack Herring are active, migratory swimmers that move upstream to spawn.

b. Human-Mediated Transport through Aquatic Pathways
Vessel traffic is not documented as a significant spread mechanism.

c. *Existing Physical Human/Natural Barriers*

T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. However, skipjack herring have been found above Brandon Road Lock and Dam, suggesting the dams are only a temporary barrier to passage into Lake Michigan. The Electric Dispersal Barrier System should act as a barrier to upstream dispersal. This species is thought to have entered Lake Michigan via the CAWS in the past (Fuller 2011). However, the specimens were found in Lake Michigan in the 1990s before the implementation of the electric barriers. However, there are several potential mechanisms for barrier failure. First, small fish may be capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011) and Barrier II, or fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the dispersal barrier systems are shut down completely in emergency situations under a man-overboard scenario. Additional potential barrier bypass vectors are currently under investigation and include wind driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is low at this time due to the low abundance of skipjack herring at the site and the assumed effectiveness of the Electric Barrier Dispersal System.

T_{10}: See T_0. Lock and dam operations are not expected to change over time, and the Electric Dispersal Barrier System is expected to remain in place. Future operations of the Electric Dispersal Barrier System are expected to change based on a more sustainable and predictable power supply, thereby reducing potential power outage events. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The skipjack herring migrates upstream through rivers and streams; therefore, the CAWS should provide suitable habitat for passage. The skipjack herring spawns in deep water of main channels over bars of coarse sand or gravel (NatureServe 2010). Gravel and sandy substrate is present in the CAWS (LimnoTech 2010). However, the skipjack herring prefers fast-flowing waters, particularly when spawning (NatureServe 2010), and these are not present in the CAWS. Skipjack herring have recently been documented in the CAWS as far upstream as the Lockport pool (Shanks 2012a), suggesting that there are no unsuitable habitat conditions known in the CAWS that could limit passage.

T_{10}: See T_0. No changes in the habitat of the CAWS are anticipated that would reduce the probability of passage.

T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an active, migratory swimmer (section 3a). This species has been found in the CAWS (section 3d) and the literature suggests this species has transited the CAWS and accessed Lake Michigan in the past (section 3c). Habitat is suitable in the CAWS and Lake Michigan, although the CAWS does not have the fast-flowing water this species prefers (section 3d). There are multiple barriers to passage, including two lock and dam structures and the Electric Dispersal Barrier System that would slow or prohibit the upstream movement of this species (section 3c). However, the skipjack herring has transited the locks in the past and several low potential bypass mechanisms have been identified by which fish may move upstream of the Electric Dispersal Barrier System (section 3c). Although preliminary results reveal a low probability of occurrence for these mechanisms, further study will inform USACE managers of the best mitigation actions to reduce or eliminate the associated risk. Overall, the probability of this species passing successfully through this pathway is rated as low.
T_{10}: See T_0. Improvements in the Electric Dispersal Barrier System operations are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass. Therefore, the probability of passage remains low
T_{25}: See T_{10}. It is unlikely that the Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the probability of skipjack herring moving upstream of the Dispersal Barrier is expected to increase over time. Consequently, the probability of passage at this time step is medium.
T_{50}: See T_{10} and T_{25}. Although the Electric Dispersal Barrier System will remain in place, each contributing factor identified above that would increase the risk of individual passage is expected to continue. Therefore, the risk of passage remains medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: This species is thought to have possibly passed through the CAWS into Lake Michigan in the recent past, but passage through the CAWS has not been confirmed. The ability of the skipjack herring to pass through the Electric Dispersal Barrier System during this time step is uncertain. Empirical tests (but none using skipjack herring) are underway to determine the probability of several potential barrier failure mechanisms. For now, uncertainty associated with passage during this time step is medium.
T_{10}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System. However, the effectiveness of these measures is uncertain. In addition, population trends in the skipjack herring and the subsequent changes in propagule pressure at the electric barrier are uncertain. Therefore, uncertainty increases to high for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The skipjack herring is known to occupy large lakes (Fuller 2011). Therefore, physical habitat in Lake Michigan is expected to be suitable. Although the skipjack herring is not historically present in the Great Lakes, three specimens were collected in Lake Michigan between 1989 and 1992 (Fago 1993). However, the species is not considered to be established (Fuller 2011).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The skipjack herring is an active swimmer and would be able to reach suitable habitat, if available.

Evidence for Probability Rating

Suitable habitat for the skipjack herring appears to be present in Lake Michigan. Records of the skipjack herring exist for Lake Michigan, but the species is not considered to be established: the most recent record is from 1992 (section 4a). Therefore, probability of colonizing and persisting for the long term is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The skipjack herring was historically present in the Mississippi River Basin, and has been collected in Lake Michigan. It did not appear to establish, and the cause for this failure is unknown. Therefore, the uncertainty of this species colonizing Lake Michigan is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Although the skipjack herring was not historically present in the Great Lakes, three specimens have been collected in Lake Michigan since 1989 (Fago 1993). However, this species is not considered to be established (Fuller 2011).

b. *Type of Mobility/Invasion Speed*
Skipjack herring are active swimmers that migrate upstream for spawning.

c. *Fecundity*
In the Missouri River, the minimum population doubling time was 1.4—4.4 years (Cross & Huggins 1975).

d. *History of Invasion Success*
The species is not widely invasive (Fuller 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The skipjack herring requires rivers to spawn. It can be found in open waters of lakes, medium and large rivers, and large reservoirs (NatureServe 2010). Such habitat is abundant throughout the GLB. Skipjack herring requires rivers to spawn. This species prefers river habitat and is likely to primarily occupy tributaries of the Great Lakes rather than the lakes themselves.

Evidence for Probability Rating

The skipjack herring was not historically found in the GLB (section 5a), although habitat appears to be suitable. Records of skipjack herring exist for Lake Michigan, but the species is not considered established and the most recent record is from 1992 (section 5a). Therefore, the probability of spreading is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although the skipjack herring is not historically found in the Great Lakes (section 5a), records of skipjack herring exist for Lake Michigan (section 5a). Why this species has not established in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of spreading is high.

PATHWAY: 3 (BRANDON ROAD LOCK AND DAM TO THE CALUMET HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	High	Medium	High	Medium	High
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Brandon Road Lock and Dam and Calumet Harbor over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Skipjack herring are active swimmers that migrate upstream for spawning.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: The native range of the skipjack herring is the Red River drainage (Hudson Bay basin) and the MRB from central Minnesota south to the Gulf of Mexico; from southwestern Pennsylvania west to eastern South Dakota, Nebraska, Kansas, Oklahoma, and Texas; and Gulf Slope drainages from the Apalachicola River, Florida, to the Colorado River, Texas (Fuller 2011). The skipjack herring was virtually extirpated from the upper Mississippi River system because construction of lock and dam facilities on the Mississippi River blocked their migration route to the upper sectors of the river (Cross & Huggins 1975). This species has been collected in Lake Michigan in Wisconsin, but it is not considered to be established there (Fuller 2011). The first collection was a single fish taken in Green Bay north of Dyckesville, in Kewaunee County in 1989. A second fish was caught in Lake Michigan just east of Kenosha, in Kenosha County in 1991. A third was caught east of Bailey’s Harbor near the outlet of Moonlight Bay in 1992 (Fuller 2011). They may have entered Lake Michigan via the CAWS (Fuller 2011). This species is listed as endangered in Wisconsin (WDNR 2009). In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975). Females produce between 100,000 and 300,000 eggs annually.
T_{10}: See T_0. The skipjack herring is listed as a species of special concern in Wisconsin because of its rarity. Temporary stocking and the addition of ladders or lifts on Mississippi River lock and dams will be required If the skipjack herring is to be reestablished in Minnesota (MDNR 2012). Whether these recovery measures will be implemented is unknown. Therefore, abundance may decrease over time if the overall population decreases in the upper Midwest.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. Therefore, the lock and dams below Brandon Road Lock and Dam may act as a barrier to arrival for individuals moving upstream through the Illinois River. However, skipjack herring have been collected in the Lockport pool above Brandon Road Lock and Dam (Shanks 2012a), suggesting the locks are only a temporary barrier.
T_{10}: See T_0. Lock and dam operations are not expected to change over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: Skipjack herring have been collected at the junction of the Kankakee and Des Plaines rivers (Illinois Natural History Survey undated). They have also been collected above and below the Brandon Road Lock and Dam and are considered established in Dresden Pool (Shanks 2012a). They are also found in the Illinois River and the upper Mississippi River in Wisconsin (Fuller 2011). There are three records of this species being collected in Lake Michigan. However, the population is not considered to be established. They may have entered Lake Michigan via the CAWS (Fuller 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The skipjack herring is historically distributed in the MRB; therefore, climate is suitable in the region of the Brandon Road Lock and Dam. By preventing the skipjack herring from reaching its spawning grounds, dams have extirpated this species over much of its native range in the upper MRB. However, the skipjack herring is common in the lower MRB. The species is found below Brandon Road Lock and Dam, suggesting habitat there is suitable (Shanks 2012a).
T_{10}: See T_0. Habitat is expected to remain suitable below Brandon Road Lock and Dam.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an actively swimming, migratory fish (section 2a). It is present in the Illinois River below and above Brandon Road Lock and Dam (sections 2c, 2e) and in the upper MRB. Although dams below Brandon Road Lock and Dam may slow arrival, there are three records of this species in the CAWS and from Lake Michigan, suggesting the locks are not a significant barrier (sections 2c, 2e). Therefore, the probability of arrival is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The skipjack herring is documented to be established in Dresden Pool below Brandon Road Lock and Dam and in Lake Michigan (sections 2c, 2e). Therefore, there is no uncertainty associated with arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Skipjack herring are active, migratory swimmers that move upstream to spawn.

b. Human-Mediated Transport through Aquatic Pathways
Vessel traffic is not documented as a significant spread mechanism.

c. Existing Physical Human/Natural Barriers
T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. However, skipjack herring have been found above Brandon Road Lock and Dam, suggesting the dams are only a temporary barrier to passage into Lake Michigan. The Electric Dispersal Barrier System should act as a barrier to upstream dispersal. This species is thought to have entered Lake Michigan via the CAWS in the past (Fuller 2011). However, the specimens were found in Lake Michigan in the 1990s (Fago 1993) before the implementation of the electric barriers. The electric barrier was observed to inhibit the upstream movement of gizzard shad (Veraldi 2012). However, there are several potential mechanisms for barrier failure. First, small fish may be capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), or fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the dispersal barrier systems are shut down completely in emergency situations under a man-overboard scenario. Additional potential barrier bypass vectors are currently under investigation and include wind driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is low at this time due to the low abundance of skipjack herring at the site and the assumed effectiveness of the Electric Barrier Dispersal System.

T_{10}: See T_0. Lock and dam operations are not expected to change over time, and the Electric Dispersal Barrier System is expected to remain in place. Future operations of the Electric Dispersal Barrier System are expected to change based on a more sustainable and predictable power supply, thereby reducing potential power outage events. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The skipjack herring migrates upstream through rivers and streams. It spawns in deep water of main channels over bars of coarse sand or gravel (NatureServe 2010). Gravel and sandy substrate are present in the CAWS (LimnoTech 2010). However, the skipjack herring prefers fast-flowing waters, particularly when spawning (NatureServe 2010), and these are not present in the CAWS. Skipjack herring have recently been documented in the CAWS as far upstream as the Lockport pool (Shanks 2012a), suggesting that there are no unsuitable habitat conditions known in the CAWS that could limit/prevent passage.
T_{10}: See T_0. No changes in the habitat of the CAWS are anticipated that would reduce the probability of passage.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an active, migratory swimmer (section 3a). This species has been found in the CAWS (section 3d), and the literature suggests this species has transited the CAWS and accessed Lake Michigan in the past (section 3c). Habitat is suitable in the CAWS and Lake Michigan, although the CAWS does not have the fast-flowing water this species prefers (section 3d). There are multiple barriers to passage, including two lock and dam structures and the Electric Dispersal Barrier System, that would slow or prohibit the upstream movement of this species (section 3c). However, the skipjack herring has transited the locks in the past and several low potential bypass mechanisms have been identified by which fish may move upstream of the Electric Dispersal Barrier System (section 3c). Although preliminary results reveal a low probability of occurrence for these mechanisms, further study will inform USACE managers of the best mitigation actions to reduce or eliminate the associated risk. Overall, the probability of this species passing successfully through this pathway is rated as low.

T_{10}: See T_0. Improvements in Electric Dispersal Barrier System operations are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass. Therefore, the probability of passage remains low.
T_{25}: See T_{10}. It is unlikely that the Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the probability of the skipjack herring moving upstream of the Dispersal Barrier is expected to increase over time. Consequently, the probability of passage at this time step is medium.
T_{50}: See T_{10} and T_{25}. Although the Electric Dispersal Barrier System will remain in place, each contributing factor identified above that would increase the risk of individual passage is expected to continue. Therefore, the risk of passage remains medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	High	High	High

Evidence for Uncertainty Rating

T_0: This species is thought to have possibly passed through the CAWS into Lake Michigan in the recent past, but passage through the CAWS has not been confirmed. The ability of the skipjack herring to pass through the Electric Dispersal Barrier System during this time step is uncertain. Empirical tests (but none using skipjack herring) are underway to determine the probability of several potential barrier failure mechanisms. For now, uncertainty associated with passage during this time step is medium.
T_{10}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System. However, the effectiveness of these measures are is uncertain. In addition, population trends in the skipjack herring and the subsequent changes in propagule pressure at the electric barrier are uncertain. Therefore, uncertainty increases to high for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The skipjack herring is known to occupy large lakes (Fuller 2011). Therefore, physical habitat in Lake Michigan is expected to be suitable. Although the skipjack herring was not historically present in the Great Lakes, three specimens were collected in Lake Michigan between 1989 and 1992 (Fago 1993). However, the species is not considered to be established (Fuller 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The skipjack herring is an active swimmer and would be able to reach suitable habitat if available.

Evidence for Probability Rating

Suitable habitat for the skipjack herring appears to be present in Lake Michigan. Records of the skipjack herring exist for Lake Michigan, but the species is not considered to be established: the most recent record is from 1992 (section 4a). Therefore, the probability of colonizing and persisting for the long term is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The skipjack herring was historically present in the Mississippi River Basin, and it has been collected in Lake Michigan. It did not appear to establish, and the cause for this failure is unknown. Therefore, the uncertainty of this species colonizing Lake Michigan is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Although the skipjack herring was not historically present in the Great Lakes, three specimens have been collected in Lake Michigan since 1989 (Fago 1993). However, this species is not considered to be established (Fuller 2011).

b. *Type of Mobility/Invasion Speed*
Skipjack herring are active swimmers that migrate upstream for spawning.

c. *Fecundity*
In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975).

d. *History of Invasion Success*
The species is not widely invasive (Fuller 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The skipjack herring requires rivers to spawn. It can be found in open waters of lakes, medium and large rivers, and large reservoirs (NatureServe 2010). Such habitat is abundant throughout the GLB. This species prefers river habitat and is likely to primarily occupy tributaries of the Great Lakes rather than the lakes themselves.

Evidence for Probability Rating

The skipjack herring is not historically found in the GLB (section 5a), although habitat appears to be suitable. Records of the skipjack herring exist for Lake Michigan, but the species is not considered to be established; the most recent record is from 1992 (section 5a). Therefore, the probability of spreading is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although the skipjack herring was not historically found in the Great Lakes (section 5a), records of the skipjack herring exist for Lake Michigan (section 5a). Why this species has not established in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of spreading is high.

PATHWAY: 4 (BRANDON ROAD LOCK AND DAM TO INDIANA HARBOR)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Brandon Road Lock and Dam and Indiana Harbor over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
   Skipjack herring are active swimmers that migrate upstream for spawning.

b. *Human-Mediated Transport through Aquatic Pathways*
   Vessel traffic is not documented as a significant spread mechanism.

c. *Current Abundance and Reproductive Capacity*
   T_0: The native range of the skipjack herring is the Red River drainage (Hudson Bay basin) and MRB from central Minnesota south to the Gulf of Mexico; from southwestern Pennsylvania west to eastern South Dakota, Nebraska, Kansas, Oklahoma, and Texas; and the Gulf Slope drainages from the Apalachicola River, Florida, to the Colorado River, Texas (Fuller 2011). The skipjack herring was virtually extirpated from the upper Mississippi River system because the construction of lock and dam facilities on the Mississippi River blocked their migration route to the upper sectors of the river (Cross & Huggins 1975). The species has been collected in Lake Michigan in Wisconsin, but it is not considered to be established there (Fuller 2011). The first collection was a single fish taken in Green Bay north of Dyckesville, in Kewaunee County in 1989. A second fish was caught in Lake Michigan just east of Kenosha, in Kenosha County in 1991. A third was caught east of Bailey's Harbor near the outlet of Moonlight Bay in 1992 (Fuller 2011). They may have entered Lake Michigan via the CAWS (Fuller 2011). Skipjack herring is listed as endangered in Wisconsin and vulnerable in Illinois (WDNR 2009). In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975). Females produce between 100,000 and 300,000 eggs annually.

T_{10}: See T_0. The skipjack herring is listed as a species of special concern in Wisconsin because of its rarity. Temporary stocking and the addition of ladders or lifts on Mississippi River lock and dams will be required If the skipjack herring is to be reestablished in Minnesota (MDNR 2012). Whether these recovery measures will be implemented is unknown. Therefore, abundance may decrease over time if the overall population decreases in the upper Midwest.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. Therefore, the lock and dams below Brandon Road Lock and Dam may act as a barrier to arrival for individuals moving upstream through the Illinois River. However, skipjack herring have been collected in the Lockport pool above Brandon Road Lock and Dam (Shanks 2012a), suggesting the locks are only a temporary barrier.
T_{10}: See T_0. Lock and dam operations are not expected to change over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Skipjack herring have been collected at the junction of the Kankakee and Des Plaines rivers (Illinois Natural History Survey undated). They have also been collected above and below the Brandon Road Lock and Dam and are considered to be established in Dresden Pool (Shanks 2012a). They are also found in the Illinois River and the upper Mississippi River in Wisconsin (Fuller 2011). There are three records of this species being collected in Lake Michigan. However, the population is not considered to be established. They may have entered Lake Michigan via the CAWS (Fuller 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The skipjack herring was historically distributed in the MRB; therefore, climate is suitable in the region of the Brandon Road Lock and Dam. By preventing the skipjack herring from reaching its spawning grounds, dams have extirpated this species over much of its native range in the upper MRB. However, the skipjack herring is common in the lower MRB. The species is found below Brandon Road Lock and Dam, suggesting habitat there is suitable (Shanks 2012a).
T_{10}: See T_0. Habitat is expected to remain suitable below Brandon Road Lock and Dam.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an actively swimming, migratory fish (section 2a). It is present in the Illinois River below and above Brandon Road Lock and Dam (sections 2c, 2e) and in the upper MRB. Although dams below Brandon Road Lock and Dam may slow its arrival, there are three records of this species in the CAWS and from Lake Michigan, suggesting the locks are not a significant barrier (sections 2c, 2e). Therefore, the probability of arrival is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The skipjack herring is documented to be established in Dresden Pool below Brandon Road Lock and Dam and in Lake Michigan (sections 2c, 2e). Therefore, there is no uncertainty associated with arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Skipjack herring are active, migratory swimmers that move upstream to spawn.

b. Human-Mediated Transport through Aquatic Pathways
Vessel traffic is not documented as a significant spread mechanism.

c. *Existing Physical Human/Natural Barriers*

T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. However, skipjack herring have been found above Brandon Road Lock and Dam, suggesting the dams are only a temporary barrier to passage into Lake Michigan. The Electric Dispersal Barrier System should act as a barrier to upstream dispersal. This species is thought to have entered Lake Michigan via the CAWS in the past (Fuller 2011). However, the specimens were found in Lake Michigan in the 1990s (Fago 1993) before the implementation of the electric barriers. The electric barrier was observed to inhibit the upstream movement of gizzard shad (Veraldi 2012). However, there are several potential mechanisms for barrier failure. First, small fish may be capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), or fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the dispersal barrier systems are shut down completely in emergency situations under a man-overboard scenario. Additional potential barrier bypass vectors are currently under investigation and include wind driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is low at this time due to the low abundance of skipjack herring at the site and the assumed effectiveness of the Electric Barrier Dispersal System. There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a barrier, especially under low flows. Flow and depth of the Grand Calumet River varies with effluent discharge volumes and water levels in Lake Michigan. The Grand Calumet is shallow and water can be less than 1 ft deep in portions of the West Branch near the Illinois/Indiana border (Simon and Moy 2000). Such shallow depths could act as a barrier to passage from the Calumet Sag Channel to the Indiana Harbor. In addition, water quality in the Grand Calumet River is poor and low dissolved oxygen levels could prohibit the passage of this species.

T_{10}: See T_0. Lock and dam operations are not expected to change over time, and the Electric Dispersal Barrier System is expected to remain in place. Future operations of the Electric Dispersal Barrier System are expected to change based on a more sustainable and predictable power supply, thereby reducing potential power outage events. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The skipjack herring migrates upstream through rivers and streams; therefore, the CAWS should provide suitable habitat for passage. The skipjack herring spawns in the deep water of main channels over bars of coarse sand or gravel (NatureServe 2010). Gravel and sandy substrate is present in the CAWS (LimnoTech 2010). However, the skipjack herring prefers fast-flowing waters, particularly when spawning (NatureServe 2010), and these are not present in the CAWS. Sediments in the Grand Calumet consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water depth is as shallow as a few feet, and can flow east or west (Gallagher et al. 2011). Skipjack herring have recently been documented in the CAWS as far upstream as the Lockport pool (Shanks 2012a), suggesting that portions of the CAWS provide suitable habitat.

T_{10}: See T_0. No changes in the habitat of the CAWS are anticipated that would reduce the probability of passage.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an active, migratory swimmer (section 3a). This species has been found in the CAWS (section 3d), and the literature suggests it has transited the CAWS and accessed Lake Michigan in the past (section 3c). Habitat is suitable in the CAWS and Lake Michigan, although the CAWS does not have the fast-flowing water this species prefers (section 3d). There are multiple barriers to passage, including two lock and dam structures and the Electric Dispersal Barrier System that would slow or prohibit the upstream movement of this species (section 3c). However, the skipjack herring has transited the locks in the past and several low potential bypass mechanisms have been identified by which fish may move upstream of the Electric Dispersal Barrier System (section 3c). Although preliminary results reveal a low probability of occurrence for these mechanisms, further study will inform USACE managers of the best mitigation actions to reduce or eliminate the associated risk. Another barrier is the sheet pile across the Grand Calumet River (section 3c). In addition, during low flows, the Grand Calumet River may not be suitable habitat for the skipjack herring, due to its shallow depth. Therefore, the probability of passage is low for this time step.

T_{10}: See T_0. Improvements in Electric Dispersal Barrier System operations are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass.

The water quality and depth of the Grand Calumet River is expected to remain unsuitable for this species. Overall, the probability of passage remains low.

T_{25}: See T_{10}. It is unlikely that the Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the probability of skipjack herring moving upstream of the Dispersal Barrier is expected to increase over time. Consequently, the probability of passage at this time step is medium.

T_{50}: See T_{10} and T_{25}. Although the Electric Dispersal Barrier System will remain in place, each contributing factor identified above that would increase the risk of individual passage is expected to continue. Therefore, the risk of passage remains medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: This species is thought to have possibly passed through the CAWS into Lake Michigan in the recent past, but passage through the CAWS has not been confirmed. The speed and ability of skipjack herring to pass through Brandon Road Lock and Dam and Lockport Lock and Dam is uncertain. The ability of the skipjack herring to pass through the Electric Dispersal Barrier System during this time step is also uncertain. Empirical tests (but none using skipjack herring) are underway to determine the probability of several potential barrier failure mechanisms. The depth of the Grand Calumet River is likely too shallow for this species to transit. However, this has not been confirmed. Overall, uncertainty associated with passage is medium for this time step.

T_{10}: See T_0. Over time, it is more certain that the skipjack herring will be able to pass through the Brandon Road Lock and Dam and Lockport Lock and Dam systems. However, the shallow depth of the Grand Calumet River will likely remain unsuitable for this species. The south branch of the Little Calumet River is also expected to remain unsuitable. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System. However, the effectiveness of these measures is uncertain. In addition, population trends in the skipjack herring and the subsequent changes in propagule pressure at the electric barrier are uncertain. Therefore, the uncertainty remains medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The skipjack herring is known to occupy large lakes (Fuller 2011). Therefore, physical habitat in Lake Michigan is expected to be suitable. Although the skipjack herring was not historically present in the Great Lakes, three specimens were collected in Lake Michigan between 1989 and 1992 (Fago 1993). However, the species is not considered to be established (Fuller 2011).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The skipjack herring is an active swimmer and would be able to reach suitable habitat, if available.

Evidence for Probability Rating

Suitable habitat for the skipjack herring appears to be present in Lake Michigan. Records of the skipjack herring exist for Lake Michigan, but the species is not considered to be established: the most recent record is from 1992 (section 4a). Therefore, the probability of colonizing and persisting for the long term is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The skipjack herring was historically present in the Mississippi River Basin, and it has been collected in Lake Michigan. It did not appear to establish, and the cause for this failure is unknown. Therefore, the uncertainty of this species colonizing Lake Michigan is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
Although the skipjack herring was not historically present in the Great Lakes, three specimens have been collected in Lake Michigan since 1989 (Fago 1993). However, this species is not considered to be established (Fuller 2011).

b. Type of Mobility/Invasion Speed
Skipjack herring are active swimmers that migrate upstream for spawning.

c. Fecundity
In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975).

d. History of Invasion Success
The species is not widely invasive (Fuller 2011).

e. Human-Mediated Transport through Aquatic Pathways
Vessel traffic is not documented as a significant spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The skipjack herring requires rivers to spawn. The species can be found in open waters of lakes, medium and large rivers, and large reservoirs (NatureServe 2010). Such habitat is abundant throughout the GLB. This species prefers river habitat and is likely to primarily occupy tributaries of the Great Lakes rather than the lakes themselves.

Evidence for Probability Rating

The skipjack herring was not historically found in the GLB (section 5a), although habitat appears to be suitable. Records of the skipjack herring exist for Lake Michigan, but the species is not considered to be established and the most recent record is from 1992 (section 5a). Therefore, the probability of spreading is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although the skipjack herring was not historically found in the Great Lakes (section 5a), records of the skipjack herring exist for Lake Michigan (section 5a). Why this species has not established in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of spreading is high.

PATHWAY: 5 (BRANDON ROAD LOCK AND DAM TO BURNS SMALL BOAT HARBOR [BSBH])

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Brandon Road Lock and Dam and BSBH over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Skipjack herring are active swimmers that migrate upstream for spawning.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: The native range of the skipjack herring is the Red River drainage (Hudson Bay basin) and MRB from central Minnesota south to the Gulf of Mexico; from southwestern Pennsylvania west to eastern South Dakota, Nebraska, Kansas, Oklahoma, and Texas; and the Gulf Slope drainages from the Apalachicola River, Florida, to the Colorado River, Texas (Fuller 2011). The skipjack herring was virtually extirpated from the upper Mississippi River system because the construction of lock and dam facilities on the Mississippi River blocked their migration route to the upper sectors of the river (Cross & Huggins 1975). This species has been collected in Lake Michigan in Wisconsin, but it is not considered to be established there (Fuller 2011). The first collection was a single fish taken in Green Bay north of Dyckesville, in Kewaunee County in 1989. A second fish was caught in Lake Michigan just east of Kenosha, in Kenosha County in 1991. A third was caught east of Bailey's Harbor near the outlet of Moonlight Bay in 1992 (Fuller 2011). They may have entered Lake Michigan via the CAWS (Fuller 2011). This species is listed as endangered in Wisconsin (WDNR 2009). In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975). Females produce between 100,000 and 300,000 eggs annually.
T_{10}: See T_0. The skipjack herring is listed as a species of special concern in Wisconsin because of its rarity. Temporary stocking and the addition of ladders or lifts on Mississippi River lock and dams will be required If the skipjack herring is to be reestablished in Minnesota (MDNR 2012). Whether these recovery measures will be implemented is unknown. Therefore, abundance may decrease over time if the overall population decreases in the upper Midwest.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. Therefore, the lock and dams below Brandon Road Lock and Dam may act as a barrier to arrival for individuals moving upstream through the Illinois River. However, skipjack herring have been collected in the Lockport pool above Brandon Road Lock and Dam (Shanks 2012a), suggesting the locks are only a temporary barrier.
T_{10}: See T_0. Lock and dam operations are not expected to change over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Skipjack herring have been collected at the junction of the Kankakee and Des Plaines rivers (Illinois Natural History Survey undated). They have also been collected above and below the Brandon Road Lock and Dam and are considered to be established in Dresden Pool (Shanks 2012a). They are also found in the Illinois River and the upper Mississippi River in Wisconsin (Fuller 2011). There are three records of this species

being collected in Lake Michigan. However, the population is not considered to be established. They may have entered Lake Michigan via the CAWS (Fuller 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: The skipjack herring is historically distributed in the MRB; therefore, climate is suitable in the region of the Brandon Road Lock and Dam. By preventing the skipjack herring from reaching its spawning grounds, dams have extirpated this species over much of its native range in the upper MRB. However, the skipjack herring is common in the lower MRB. The species is found below Brandon Road Lock and Dam, suggesting habitat there is suitable (Shanks 2012a).
T_{10}: See T_0. Habitat is expected to remain suitable below Brandon Road Lock and Dam.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an actively swimming, migratory fish (section 2a). It is present in the Illinois River below and above Brandon Road Lock and Dam (sections 2c, 2e) and in the upper MRB. Although dams below Brandon Road Lock and Dam may slow its arrival, there are three records of this species in the CAWS and from Lake Michigan, suggesting the locks are not a significant barrier (sections 2c, 2e). Therefore, the probability of arrival is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The skipjack herring is documented to be established in Dresden Pool below Brandon Road Lock and Dam and in Lake Michigan (sections 2c, 2e). Therefore, there is no uncertainty associated with arrival.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Skipjack herring are active, migratory swimmers that move upstream to spawn.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

c. *Existing Physical Human/Natural Barriers*
T_0: Lock and dam structures hinder upstream migration of skipjacks during early spring. However, skipjack herring have been found above Brandon Road Lock and Dam, suggesting the dams are only a temporary barrier to passage into Lake Michigan. The Electric Dispersal Barrier System should act as a barrier to upstream dispersal. This species is thought to have entered Lake Michigan via the CAWS in the past (Fuller 2011). However, the specimens were found in Lake Michigan in the 1990s (Fago 1993) before the implementation of the electric barriers. The electric barrier was observed to inhibit the upstream movement of gizzard shad (Veraldi 2012). However, there are several potential mechanisms for barrier failure. First, small fish may be capable of swimming though an electrical field of similar strength to the Demonstration Barrier (Holliman 2011), or fish could swim through the Dispersal Barrier during times of power outage. According to records through March 2013, the Electric Dispersal Barrier System experienced a loss of power to the water for a total of 4 minutes prior to 2011, and a total of 13 minutes in 2012 (USACE unpublished data, Electric Dispersal Barrier System Power Outage Records, April 1, 2013). Additionally, the dispersal barrier systems are shut down completely in emergency situations under a man-overboard scenario. Additional potential barrier bypass vectors are currently under investigation and include wind driven reverse flow events in the canal, electric field shielding by steel hulled vessels or side wall crevices, and fish entrainment within barge induced water currents across the Electric Dispersal Barrier System. While preliminary results from these investigations have shown these pathways to be viable, their probability of occurring in the field is low at this time due to the low abundance of skipjack herring at the site and the assumed effectiveness of the Electric Barrier Dispersal System. Portions of the south branch of the Little Calumet River can be shallow (<3 ft; Gallagher et al. 2011) and may not be passable by the skipjack herring during periods of low flow.
T_{10}: See T_0. Lock and dam operations are not expected to change over time, and the Electric Dispersal Barrier System is expected to remain in place. Future operations of the Electric Dispersal Barrier System are expected to change based on a more sustainable and predictable power supply, thereby reducing potential power outage

events. A permanent Barrier I is currently under design that will replace the Demonstration Barrier. The new Barrier I will be capable of producing higher electrical outputs similar to those of Barrier II and will add an additional wide array on the upstream boundary. The new Barrier I is expected to become operational by 2016. **T_{25}:** See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The skipjack herring migrates upstream through rivers and streams; therefore, the CAWS should provide suitable habitat for passage. The skipjack herring spawns in the deep water of main channels over bars of coarse sand or gravel (NatureServe 2010). Gravel and sandy substrate is present in the CAWS (LimnoTech 2010). However, the skipjack herring prefers fast-flowing waters, particularly when spawning (NatureServe 2010), and these are not present in the CAWS. Skipjack herring have recently been documented in the CAWS as far upstream as the Lockport pool (Shanks 2012a), suggesting that portions of the CAWS provide suitable habitat. However, the south branch of the Little Calumet River is small and shallow (Gallagher et al. 2011) and may not be preferred habitat for the skipjack herring.
T_{10}: See T_0. No changes in the habitat of the CAWS are anticipated that would affect the probability of passage.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The skipjack herring is an active, migratory swimmer (section 3a). This species has been found in the CAWS (section 3d), and the literature suggests it has transited the CAWS and accessed Lake Michigan in the past (section 3c). Habitat is suitable in the CAWS and Lake Michigan, although the CAWS does not have the fast-flowing water this species prefers (section 3d). There are multiple barriers to passage, including two lock and dam structures and the Electric Dispersal Barrier System, that would slow or prohibit the upstream movement of this species (section 3c). However, the skipjack herring has transited the locks in the past and several low potential bypass mechanisms have been identified by which fish may move upstream of the Electric Dispersal Barrier System (section 3c). Although preliminary results reveal a low probability of occurrence for these mechanisms, further study will inform USACE managers of the best mitigation actions to reduce or eliminate the associated risk. Overall, the probability of this species passing successfully through this pathway is rated as low. Portions of the south branch of the Little Calumet River may be too shallow for this species to swim through (sections 3c, 3d). Therefore, the probability of passage is low for this time step.

T_{10}: See T_0. Improvements in Electric Dispersal Barrier System operations are expected to decrease the number and length of potential power outages. Additionally, potential transport vectors across the barriers (e.g., vessel entrainment, insufficient operating parameters for small fish, reverse flow events, crevice shielding of electric field, etc.) will continue to be analyzed and mitigated where possible to further reduce the risk of bypass. The Little Calumet River is expected to remain unsuitable for this species to transit. Overall, the probability of passage remains low.
T_{25}: See T_{10}. It is unlikely that the Dispersal Barrier System will ever become 100% effective at deterring fish passage, due to individual anomalies and slight risks associated with those failure mechanisms discussed in T_0. Therefore, the probability of the skipjack herring moving upstream of the Dispersal Barrier is expected to increase over time. Consequently, the probability of passage at this time step is medium.
T_{50}: See T_{10} and T_{25}. Although the Electric Dispersal Barrier System will remain in place, each contributing factor identified above that would increase the risk of individual passage is expected to continue. Therefore, the risk of passage remains medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: This species is thought to have possibly passed through the CAWS into Lake Michigan in the recent past, but passage through the CAWS has not been confirmed. The ability of the skipjack herring to pass through the Electric Dispersal Barrier System during this time step is uncertain. Empirical tests (but none using skipjack herring) are underway to determine the probability of several potential barrier failure mechanisms. Portions of the south branch of the Little Calumet River may be too shallow for this species to transit. However, this has not been confirmed. Habitat in the Little Calumet is not considered suitable. For now, uncertainty associated with passage during this time step is medium.
T_{10}: See T_0. Measures can be taken in the future to increase the efficacy of the Electric Dispersal Barrier System. However, the effectiveness of these measures is uncertain. In addition, population trends in the skipjack herring and the subsequent changes in propagule pressure at the electric barrier are uncertain. The south branch of the Little Calumet River is also expected to remain unsuitable. Therefore, uncertainty remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The skipjack herring is known to occupy large lakes (Fuller 2011). Therefore, physical habitat in Lake Michigan is expected to be suitable. Although the skipjack herring was not historically present in the Great Lakes, three specimens were collected in Lake Michigan between 1989 and 1992 (Fago 1993). However, the species is not considered to be established (Fuller 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The skipjack herring is an active swimmer and would be able to reach suitable habitat, if available.

Evidence for Probability Rating

Suitable habitat for the skipjack herring appears to be present in Lake Michigan. Records of the skipjack herring exist for Lake Michigan, but the species is not considered established: the most recent record is from 1992 (section 4a). Therefore, the probability of colonizing and persisting for the long term is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The skipjack herring was historically present in the Mississippi River Basin, and has been collected in Lake Michigan. It did not appear to establish, and the cause for this failure is unknown. Therefore, the uncertainty of this species colonizing Lake Michigan is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Although the skipjack herring was not historically present in the Great Lakes, three specimens have been collected in Lake Michigan since 1989 (Fago 1993). However, this species is not considered to be established there (Fuller 2011).

b. *Type of Mobility/Invasion Speed*
Skipjack herring are active swimmers that migrate upstream for spawning.

c. *Fecundity*
In the Missouri River, the minimum population doubling time was 1.4–4.4 years (Cross & Huggins 1975).

d. *History of Invasion Success*
The species is not widely invasive (Fuller 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic is not documented as a significant spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The skipjack herring can be found in open waters of lakes, medium and large rivers, and large reservoirs (NatureServe 2010). Such habitat is abundant throughout the GLB. The species requires rivers to spawn, prefers river habitat, and is likely to primarily occupy tributaries of the Great Lakes rather than the lakes themselves.

Evidence for Probability Rating

The skipjack herring was not historically found in the GLB (section 5a), although habitat appears to be suitable. Records of the skipjack herring exist for Lake Michigan, but the species is not considered to be established there and the most recent record is from 1992 (section 5a). Therefore, the probability of spreading is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although the skipjack herring was not historically found in the Great Lakes (section 5a), records of the skipjack herring exist for Lake Michigan (section 5a). Why this species has not established in the Great Lakes is uncertain. Therefore, uncertainty associated with the probability of spreading is high.

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E.2 ANS POTENTIALLY INVADING THE MISSISSIPPI RIVER BASIN

E.2.1 Protozoa

E.2.1.1 Testate Amoeba - *Psammonobiotus communis*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. **P(pathway) T_0-T_{50}: HIGH**

   Evidence for Probability Rating

   Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

   Uncertainty: NONE

   Evidence for Uncertainty Rating

   The existence of the pathway has been confirmed with certainty.

2. **P(arrival) T_0-T_{50}: HIGH**

   In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
   Psammonobiotus communis is a benthic amoeba that actively moves between sand grains. It can be moved passively by benthic disturbance. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus communis* are found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).
b. *Human-Mediated Transport through Aquatic Pathways*
   Psammonobiotus communis may be spread by ballast water (Nicholls & MacIsaac 2004). There is no commercial vessel traffic to WPS from the Great Lakes, but there is recreational boat traffic.

c. *Current Abundance and Reproductive Capacity*
   T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but the species is found in scattered locations along beaches in all the other Great Lakes, and at the time of survey, it was the most common *Psammonobiotus* species in the Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
   T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
   T_{25}: See T_{10}.
   T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
   T_0: None.
   T_{10}: See T_0.
   T_{25}: See T_0.
   T_{50}: See T_0.

e. *Distance from Pathway*
   T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current (2012) location of the species is not known, but the closest known location is in adjacent lakes.
   T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to the WPS is not practical at this time.
   T_{25}: See T_{10}.
   T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   T_0: *Psammonobiotus communis* can tolerate salinities of 0–37% depending on the species (Kipp 2011). *Psammonobiotus communis* is thought to be native to and is found in the Black Sea, Caspian Sea, and Aral Sea basins, but is found in oceans worldwide including the Antarctic (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a

marine and brackish species with wide climatological tolerances. In addition, *Psammonobiotus communis* was recorded at sand depths ranging from 10 to 105 cm (3.9–41 in.) (Kipp 2011) and can form round cysts during periods when the habitat dries up (Golemansky 2008). *Psammonobiotus communis* are found in littoral and supralittoral sandy beach sediments and at distances of 0–35 m (0–115 ft) from the shoreline (Nicholls & MacIsaac 2004; Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are a typical component of the shoreline of Lake Michigan.

T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* have been found in four of the Great Lakes and are the most common *Psammonobiotus* species in the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic, and therefore is likely to be present in Lake Michigan, although presently undocumented. Natural and human-mediated transport will continue to spread this species**.** Therefore, the probability of this species arriving at the WPS is considered to be high.

T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species**.**

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus communis* is not present in Lake Michigan beaches, considering it is found in the other four Great Lakes. Therefore, the uncertainty of this species arriving at the WPS is medium.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for *Psammonobiotus communis* in the Great Lakes has likely been ballast water (Kipp 2011). There is no commercial vessel traffic from WPS, so some natural spread (e.g., active movement along substrate or resuspension and drift) would likely be required to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: There is a sluice gate separating WPS from Lake Michigan which is periodically opened and closed (LimnoTech 2010). Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010), which could transport this species into the North Shore Channel if it was suspended in the water column by boat traffic or storms.
T_{10}: See T_0. Future operations of sluice gate are not predicted to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus communis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS also experience seasonally low DO (LimnoTech 2010). Anoxic sand sediments and underground water lack interstitial testate amoebae (Golemansky 2008). It is found in water with DO ranging from 1.3 to 10.2 mg/L (Todorov & Golemansky 2007). Low DO may limit the spread of this species in certain sections of the CAWS. Grain size large enough for interstitial water movement is required by *Psammonobiotus communis*, and clays can inhibit their establishment. In the Chicago River, there is little suitable instream habitat and the banks are typically concrete and steel vertical walls. Instream habitat is predominantly concrete, fine silt, or organic sludge (LimnoTech 2010). Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). Toxic pollutants in the sediments may have a negative impact on this species because of its method of nutrient uptake, which consumes decaying material off of substrate particles. However, there is no documented evidence of pollution inhibiting this species. Most sediments in the Chicago Sanitary and Ship Canal are silty or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Water currents in the CAWS are typically slow (LimnoTech 2010). Slow water movement also will slow any movement by passive floating in the water column. Overall, low-silt, sandy sediments with interstitial water

movement are likely to be rare in the CAWS, which will likely impede their movement through the pathway.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is no commercial vessel traffic from WPS, so reaching Brandon Road Lock and Dam would require active dispersal through bottom substrate (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement through the CAWS via this pathway is not likely to occur. The probability of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Conditions in the CAWS (e.g., sediment and hydrology) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus communis* is well documented as a nearshore sandy sediment species, and the CAWS is documented to not have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach and establish is uncertain. The uncertainty of this species' probability of passing through this pathway is considered to be low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus communis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus communis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Psammonobiotus communis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus communis* is documented in the literature in large inland seas and coastal habitat (section 4a).

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus communis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a).

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   Psammonobiotus communis are native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), and have been found in every ocean basin in the world. In addition, they are found in water with temperatures ranging from 4.2 to 29.5°C (39.5 to 85.1°F), suggesting they have a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows through passive floating in the water column.

c. *Fecundity*
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus communis has spread to scattered locations through the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus communis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus communis occupies only specific sediment types (oxic, low silt, sand). It is found in the littoral and supralittoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus communis* are associated with littoral sandy beach sediments, although they can be found near river mouths. Oxic, low-silt, sandy sediments are suitable for this species. *P. communis* was recorded at 0–35 m (0–114 ft) from the shoreline. Such habitats may be present in the MRB in reaches with higher flow that move finer silts downstream.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus communis* (section 5f). *Psammonobiotus communis* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher-flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus communis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. Therefore, the probability of this species spreading is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. Therefore, the uncertainty of this species spreading throughout the MRB is high.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
Psammonobiotus communis is a benthic amoeba that lives between sand grains. It can be moved passively by benthic disturbance. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus communis* are found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus communis may be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial and recreational vessel traffic to the CRCW from the Great Lakes (USACE 2011a,b), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in all the other Great Lakes, and were the most common *Psammonobiotus* species in the Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current (2012) location of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known and predicting future locations in relation to the CRCW is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus communis* can tolerate salinities of 0–37%, depending on the species (Kipp 2011). *Psammonobiotus communis* is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins, but is found in oceans worldwide including the Antarctic (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments and at distances of 0–35 m (0–115 ft) from the shoreline (Nicholls & MacIsaac 2004; Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* has been found in in four of the Great Lakes and is the most common *Psammonobiotus* species in the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic and therefore is likely to be present in Lake Michigan, although presently undocumented. The heavy ballast water discharge at the CRCW increases the probability of *Psammonobiotus communis* introduction. As a result, there is a high probability of the species arriving at the pathway during this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus communis* is not present in Lake Michigan beaches, considering that they are found in the other four Great Lakes and they are the most common *Psammonobiotus* species in the Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus communis*. Overall, there is a medium level of uncertainty associated with the probability of arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism in the Great Lakes has likely been ballast water (Kipp 2011). There is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for transport on boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2–9.1m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus communis*, based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0. Future operations of sluice gate are not predicted to change.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus communis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus communis*, and clays can inhibit their establishment. In the Chicago River, there is little instream habitat, and the banks are typically concrete and steel vertical walls, with sediments of concrete, silt, or sludge (LimnoTech 2010). Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). Most sediment in the Chicago Sanitary and Ship Canal are silty or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* can be transported in ballast water, and there is a potential for vessel-mediated transport, given vessel traffic between CRCW and Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d), therefore movement into the CAWS is not likely to occur by

natural dispersal. Therefore, the probability of passage by the species is considered to be low at this time step.
T_{10}: See T_0. Conditions in the CAWS (e.g., sediment and hydrology) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus communis* is well documented as a nearshore sandy sediment species, and the CAWS is documented not to have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach and establish is uncertain. The potential for, and speed of, vessel-mediated transport from CRCW to Brandon Road Lock and Dam is not documented. Overall, there is a low degree of uncertainty associated with the probability of passage by the species.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus communis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus communis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Psammonobiotus communis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus communis* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, the probability of colonization by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus communis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). As a result, there is a high level of uncertainty associated with the probability of colonization by the species.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Psammonobiotus communis are native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
Natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. Fecundity
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. History of Invasion Success
Psammonobiotus communis has spread to scattered locations through the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for spread in rivers was not found.

e. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus communis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus communis occupies only specific sediment types (oxic, low-silt, sand). It is found in the littoral and supralittoral zones of lakes and inland seas (Kipp 2011). *Psammonobiotus communis* are associated with littoral sandy beach sediments, although they can be found near river mouths. Oxic, low-silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus communis* (section 5f). *Psammonobiotus communis* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus communis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase its chance of spreading to suitable habitat. As a result, the probability of spread by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. Therefore, there is a high level of uncertainty associated with the probability of spread by the species.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus communis is a benthic amoeba that lives between sand grains. It can be moved passively by benthic disturbance. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus communis* are found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus communis may be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial vessel traffic to the Calumet Harbor from the Great Lakes (USACE 2011a), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in all the other Great Lakes, and were the most common *Psammonobiotus* species in the Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current (2012) location of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to Calumet Harbor is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus communis* can tolerate salinities of 0–37% depending on species (Kipp 2011). *Psammonobiotus communis* are native or found in the Black Sea, Caspian Sea, and Aral Sea basins but are found in oceans worldwide including the Antarctic (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments and at distances of 0–35 m (0–115 ft) from the shoreline (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* has been found in in four of the Great Lakes and is the most common *Psammonobiotus* species in the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic, and therefore is likely to be present in Lake Michigan although presently undocumented. The heavy ballast water discharge at the Calumet Harbor increases the probability of

Psammonobiotus communis introduction. As a result, the probability of arrival is high at this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus communis* is not present in Lake Michigan beaches, considering that it is found in the other four Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus communis*. Overall, there is a medium level of uncertainty regarding the arrival of the species at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for *Psammonobiotus communis* in the Great Lakes has likely been ballast water (Kipp 2011). Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Although *Psammonobiotus* spp. can be transported in ballast, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for transport on boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2–9.1 m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus communis*, based on its depth distribution in the Great Lakes (Kipp 2011).

T_{10}: See T_0. Future operations of sluice gate are not predicted to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus communis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus communis*, and clays can inhibit their establishment. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Cal-Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediments in the Chicago Sanitary and Ship Canal are silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* can be transported in ballast water, and there is a potential for vessel-mediated transport, given vessel traffic between Calumet Harbor and Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. As a result, there is a low probability that the species will pass through the pathway at this time step.
T_{10}: See T_0. Conditions in the CAWS (e.g., sediment and hydrology) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus communis* is well documented as a nearshore sandy sediment species, and the CAWS is documented to have unsuitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach and establish is uncertain. The potential for, and speed of, vessel-mediated transport from Calumet Harbor to Brandon Road Lock and Dam are not documented. Overall, there is a low degree of uncertainty associated with the probability of passage by the species.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus communis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus communis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Psammonobiotus communis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus communis* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, the probability of colonization by this species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus communis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species has a high level of uncertainty (section 4a).

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Psammonobiotus communis is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
Natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. *Fecundity*
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus communis has spread to scattered locations through the Great Lakes, but it is not found at high densities (Nicholls & MacIsaac 2004). Data for spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus communis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus communis occupies only specific sediment types (oxic, low-silt, sand). It is found in the littoral and supralittoral zones of lakes and inland seas (Kipp 2011). *Psammonobiotus communis* are associated with littoral sandy beach sediments, although they can be found near river mouths. Oxic, low-silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus communis* (section 5f). *Psammonobiotus communis* requires high-energy water, and the species is typically found in the swash zones of beaches (section 5f). However, sandy, higher flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus communis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. Therefore, there is a medium probability for spread of the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat has a high level of uncertainty.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus communis is a benthic amoeba that lives between sand grains. It can be moved passively by sediment resuspension. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus communis* are found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus communis may be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial vessel traffic to the Indiana Harbor from the Great Lakes (USACE 2011a), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in all the other Great Lakes, and were the most common *Psammonobiotus* species in the Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current (2012) location of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to the Indiana Harbor is not practical at this time.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *Psammonobiotus communis* can tolerate salinities of 0–37% depending on the species (Kipp 2011). *Psammonobiotus communis* is native or found in the Baltic Sea, Caspian Sea, and Aral Sea basins, but is also found in oceans worldwide including the Antarctic (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments and at distances of 0–35 m (0–115 ft) from the shoreline (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* has been found in four of the Great Lakes and is the most common *Psammonobiotus* species in the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic, and therefore is likely to be present in Lake Michigan, although it is not presently documented. The heavy ballast water discharge at the Indiana Harbor increases the probability of *Psammonobiotus communis* introduction. Natural and human-mediated transport will continue to spread this species**.** Therefore, the probability of this species arriving at Indiana Harbor is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus communis* is not present in Lake Michigan beaches, considering that it is found in the other four Great Lakes. Therefore, the uncertainty of this species arriving at Indiana Harbor is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for *Psammonobiotus communis* in the Great Lakes has likely been ballast water (Kipp 2011). Most commercial vessel traffic to Indiana Harbor is via the lake, and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012), and the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for the transport of the species on boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2–9.1 m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus communis* based on its depth distribution in the Great Lakes (Kipp 2011). Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. However, water flows over the sheet pile.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus communis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus communis* and clays can inhibit their establishment. Conditions at the Indiana Harbor are highly industrialized. In the East Branch of the Grand Calumet

River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments in the Grand Calumet consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Cal-Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediments in the CSSC are silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, sandy sediments with low silt levels and interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* can be transported in ballast water, but there is little potential for vessel-mediated transport to Brandon Road Lock and Dam (section 3b). The appropriate sediment, dissolved oxygen, and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur. The probability of this species passing through this pathway is considered to be low.
T_{10}: See T_0. Conditions in the CAWS (e.g., sediment and hydrology) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus communis* is well documented as a nearshore sandy sediment species, and the CAWS is documented not to have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach them and establish is uncertain. The uncertainty of this species passing through this pathway is considered to be low.

T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus communis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus communis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Psammonobiotus communis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus communis* is documented in the literature in large inland seas and coastal habitat (section 4a).

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus communis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, there is a high degree of uncertainty associated with the probability of colonization by the species.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   Psammonobiotus communis is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
   The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. *Fecundity*
   The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
   Psammonobiotus communis has spread to scattered locations through the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
   Psammonobiotus communis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus communis occupies only specific sediment types (oxic, low-silt, sand). It is found in the littoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus communis* are associated with littoral sandy beach sediments, although they can be found near river mouths. Oxic, low-silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus communis* (section 5f). *Psammonobiotus communis* requires high-energy water, and the species is typically found in the shoreline of beaches. However, sandy, higher flow areas of rivers may provide suitable habitat for this species (section 5f). *Psammonobiotus communis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. Therefore, there is a medium probability of spread by the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. There is a high degree of uncertainty associated with the probability of spread by the species.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
Psammonobiotus communis is a benthic amoeba that lives between sand grains. It can be moved passively by benthic disturbance. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus communis* are found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus communis may be spread by ballast water (Nicholls & MacIsaac 2004). There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic to adjacent Burns Harbor, and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. Current Abundance and Reproductive Capacity
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in all the other Great Lakes, and were the most common *Psammonobiotus* species in the Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers
T_0: None
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway
T_0: No surveys for *Psammonobiotus communis* have been conducted in Lake Michigan (Kipp 2011), but they are found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current (2012) location of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to the BSBH is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *Psammonobiotus communis* can tolerate salinities of 0–37% depending on species (Kipp 2011). *Psammonobiotus communis* is native or found in the Black Sea, Caspian Sea, and Aral Sea basins, but is found in oceans worldwide including the Antarctic (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish

species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments and at distances of 0–35 m (0–115 ft) from the shoreline (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* has been found in in four of the Great Lakes and is the most common *Psammonobiotus* species in the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic, and therefore is likely to be present in Lake Michigan, although it is not presently documented. The heavy ballast water discharge at the Burns Harbor (adjacent to BSBH) increases the probability of *Psammonobiotus communis* introduction. Therefore, there is a high probability of the species arriving at the pathway at this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus communis* is not present in Lake Michigan beaches, considering that it is found in the other four Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus communis*. Overall, the uncertainty of the species arriving at the pathway is considered to be medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the species' rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for *Psammonobiotus communis* in the Great Lakes has likely been ballast water (Kipp 2011). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Vessel traffic to BSBH is via the lake. Although *Psammonobiotus communis* could move to Burns Harbor (which does have commercial vessel traffic), there is no commercial vessel from the Burns Harbor to inland ports in the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2–9.1m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus communis*, based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0. Future operations of sluice gate are not predicted to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus communis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus communis*, and clays can inhibit their establishment. The banks of the BSBH are primarily riprap and vertical walls. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulders (Gallagher et al. 2011). Inorganic silt sediments predominate in the Cal-Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediments in the Chicago Sanitary and Ship Canal are silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus communis* can be transported in ballast water, but there is little potential for vessel-mediated transport to Brandon Road Lock and Dam from BSBH (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. As a result, there is a low probability of the species passing through the pathway at this time step.
T_{10}: See T_0. Conditions in the CAWS (e.g., sediment and hydrology) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus communis* is well documented as a nearshore sandy sediment species, and the CAWS is documented not to have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach them and establish is uncertain.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus communis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus communis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Psammonobiotus communis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus communis* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, there is a medium probability of colonization by the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus communis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, there is a high level of uncertainty associated with the probability of colonization by the species.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   Psammonobiotus communis are native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting they have a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
   The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. *Fecundity*
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus communis has spread to scattered locations throughout the Great Lakes, but is not found at high densities (Nicholls & MacIsaac, 2004). Data for spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus communis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus communis occupies only specific sediment types (oxic, low-silt, sand). It is found in the littoral and supralittoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus communis* are associated with littoral sandy beach sediments, although they can be found near river mouths. Oxic, low-silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus communis* (section 5f). *Psammonobiotus communis* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus communis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. Therefore, the probability of spread by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. As a result, there is a high level of uncertainty associated with the probability of spread by the species.

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E.2.1.2 Testate Amoeba - *Psammonobiotus dziwnowi*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus dziwnowi is a benthic amoeba that moves between sand grains. No data on its historical rate of spread through the Great Lakes were found. *Psammonobiotus dziwnowi* is found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus dziwnowi may be spread by ballast water (Nicholls & MacIsaac 2004). There is no commercial vessel traffic to the WPS from the Great Lakes, but there is recreational traffic.

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it is found in scattered locations along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to those in marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it is found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to the WPS is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus dziwnowi* is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has wide climatological tolerances. *Psammonobiotus dziwnowi* is found in littoral and supralittoral sandy beach sediments (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* has been found in four of the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic and therefore is likely to be present in Lake Michigan, although it is not currently documented. As a result, the probability of the species arriving at the pathway is considered high for this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus dziwnowi* is not present in Lake Michigan beaches, considering it is found in the other four Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus dziwnowi.* Overall, there is a medium degree of uncertainty associated with arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
No data on the species' rate of spread were found.

b. Human-Mediated Transport through Aquatic Pathways
The primary transport mechanism for *Psammonobiotus dziwnowi* in the Great Lakes has likely been ballast water (Kipp 2011). There is no commercial vessel traffic from the

WPS, so some natural spread would likely be required to reach the Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: There is a sluice gate separating the WPS from Lake Michigan, which is periodically opened and closed (LimnoTech 2010). Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010), and this could transport this species into the North Shore Channel if it was suspended in the water column by boat traffic or storms.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus dziwnowi* is found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus dziwnowi*, and clays can inhibit its establishment. Sandy sediments are found in the North Shore Channel. In the Chicago River there is little in-stream habitat, and the banks are typically concrete and steel vertical walls, with sediments of concrete, silt, or sludge (LimnoTech 2010). Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). Most sediments in the CSSC are silty, bedrock, or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is no commercial vessel traffic from the WPS, so reaching the Brandon Road Lock and Dam would require some natural spread (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. As a result, there is a low probability of passage by the species at this time step.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus dziwnowi* is well documented as a near-shore sandy sediment species, and the CAWS is documented not to have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these and establish is uncertain. The potential for, and speed of, vessel-mediated transport from the WPS to the Brandon Road Lock and Dam is not documented. Overall, there is a low degree of uncertainty associated with the species traveling through the pathway at this time step.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus dziwnowi is found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of the Brandon Road Lock and Dam in areas with high flow. However, no information was found documenting *Psammonobiotus dziwnowi* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Psammonobiotus dziwnowi could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in high-flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, in the literature *Psammonobiotus dziwnowi* is documented in large inland seas and coastal habitat (section 4a). Overall, the likelihood of colonization by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus dziwnowi* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of the Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, there is a high degree of uncertainty associated with colonization by the species.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Psammonobiotus dziwnowi is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
The species' natural spread rate is not documented. *Psammonobiotus dziwnowi* could be transported downstream during high flows.

c. Fecundity
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. History of Invasion Success
Psammonobiotus dziwnowi has spread to scattered locations through the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers were not found.

e. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus dziwnowi is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus dziwnowi is found in the littoral and supralittoral zones of lakes and inland seas, although it can be found near river mouths (Kipp 2011). This species requires oxic, low-silt, sandy sediment with interstitial water movement. Such habitats may be present in the MRB in river reaches with high flow and in littoral habitats with sandy beaches.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus dziwnowi* (section 5f). *Psammonobiotus dziwnowi* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, high-flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus dziwnowi* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase the chance of spreading to suitable habitat. Therefore, there is a medium probability of spread by the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. As a result, there is a high degree of uncertainty associated with spread by the species.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS (CRCW) TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. **P(arrival) T_0-T_{50}: HIGH**

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus dziwnowi is a benthic amoeba that moves between sand grains. No data on the historical rate of spread through the Great Lakes were found. *Psammonobiotus dziwnowi* is found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus dziwnowi may be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial and recreational vessel traffic to the CRCW from the Great Lakes (USACE 2011a,b), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it has been found in scattered locations along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). Densities in the beaches of the Great Lakes are low compared to those in marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it has been found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to the CRCW is not practical at this time.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *Psammonobiotus dziwnowi* is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has wide climatological tolerances. *Psammonobiotus dziwnowi* is found in littoral and supralittoral sandy beach sediments (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* has been found in four of the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic and therefore is likely to be present in Lake Michigan, though it is not currently documented. The heavy ballast water discharge at the CRCW increases the probability of *Psammonobiotus dziwnowi* introduction. Therefore, there is considered to be a high probability of the species arriving at the pathway during this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus dziwnowi* is not present in the beaches of Lake Michigan considering it is found in the other four Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus dziwnowi.* Overall, there is a medium level of uncertainty associated with the species' arrival at the pathway.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data on the species' rate of spread were found.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for this species in the Great Lakes has likely been ballast water (Kipp 2011). There is some commercial vessel traffic between the CRCW and the Brandon Road Lock and Dam (USACE 2011a; NBIC 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for the transport of this species on boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus dziwnowi* based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus dziwnowi* is found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus dziwnowi*, and clays can inhibit its establishment. In the Chicago River there is little in-stream habitat, and the banks are typically concrete and steel vertical walls, with sediments of concrete, silt, or sludge (LimnoTech 2010). Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). Most sediment in the CSSC is silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* can be transported in ballast water, and there is a potential for vessel-mediated transport given vessel traffic between the CRCW and the Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus dziwnowi* is well documented as a near-shore sandy sediment species, and the CAWS is documented to have unsuitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach and establish is uncertain. The potential for, and speed of, vessel-mediated transport from the CRCW to the Brandon Road Lock and Dam is not documented.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus dziwnowi is found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of the Brandon Road Lock and Dam in areas with high flow. However, no information was found documenting *Psammonobiotus dziwnowi* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal.*
   Psammonobiotus dziwnowi could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in high-flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus dziwnowi* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, there is a medium probability of the species colonizing in the pathway.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus dziwnowi* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of the Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). As a result, there is a high level of uncertainty associated with colonization by the species.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   Psammonobiotus dziwnowi is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
   The natural spread rate is not documented. *Psammonobiotus dziwnowi* could be transported downstream during high flows.

c. *Fecundity*
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus dziwnowi has spread to scattered locations throughout the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers were not found.

e. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus dziwnowi is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus dziwnowi is found in the littoral and supralittoral zones of lakes and inland seas, although it can be found near river mouths (Kipp 2011). This species requires oxic, low-silt, sandy sediment with interstitial water movement. Such habitats may be present in the MRB in river reaches with high flow and in littoral habitats with sandy beaches.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus dziwnowi* (section 5f). *Psammonobiotus dziwnowi* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, high-flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus dziwnowi* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase its chance of spreading to suitable habitat. Therefore, there is a medium probability of spread by the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. As a result, there is a high degree of uncertainty associated with spread by the species.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus dziwnowi is a benthic amoeba that moves between sand grains. No data on the historical rate of spread through the Great Lakes were found. *Psammonobiotus dziwnowi* is found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus dziwnowi may be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial vessel traffic to the Calumet Harbor from the Great Lakes

(USACE 2011a), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it is found in scattered locations along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to those in marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it has been found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to the Calumet Harbor is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus dziwnowi* is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has wide climatological tolerances. *Psammonobiotus dziwnowi* is found in littoral and supralittoral sandy beach sediments (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* has been found in four of the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic and therefore is likely to be present in Lake Michigan, though not currently documented. The heavy ballast water discharge at the Calumet Harbor increases the probability of *Psammonobiotus dziwnowi* introduction. Therefore, there is a high probability of the species arriving at the pathway during this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c), but there is no reason to assume *Psammonobiotus dziwnowi* is not present in Lake Michigan beaches considering it is found in the other four Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus dziwnowi.* Overall, there is a medium level of uncertainty associated with the species arriving at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data on the species' rate of spread were found.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for *Psammonobiotus dziwnowi* in the Great Lakes has likely been ballast water (Kipp 2011). Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Although *Psammonobiotus dziwnowi* can be transported in ballast, the discharge of ballast water

does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for transport on boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus dziwnowi* based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus dziwnowi* is found in littoral supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus dziwnowi*, and clays can inhibit its establishment. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediment in the CSSC is silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* can be transported in ballast water, and there is a potential for vessel-mediated transport given vessel traffic between Calumet Harbor and the Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus dziwnowi* is well documented as a near-shore sandy sediment species, and the CAWS is documented to have unsuitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these and establish is uncertain. The potential for, and speed of, vessel-mediated transport from Calumet Harbor to the Brandon Road Lock and Dam is not documented.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus dziwnowi is found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of the Brandon Road Lock and Dam in areas with high flow. However, no information was found documenting *Psammonobiotus dziwnowi* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Psammonobiotus dziwnowi could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in high-flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, in the literature *Psammonobiotus dziwnowi* is documented in large inland seas and coastal habitat (section 4a). Overall, the probability of colonization by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus dziwnowi* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of the Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, the uncertainty associated with colonization by the species is considered to be high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Psammonobiotus dziwnowi is native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
The species' natural spread rate is not documented. *Psammonobiotus dziwnowi* could be transported downstream during high flows.

c. Fecundity
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. History of Invasion Success
Psammonobiotus dziwnowi has spread to scattered locations throughout the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers were not found.

e. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus dziwnowi is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus dziwnowi is found in the littoral and supralittoral zones of lakes and inland seas, although it can be found near river mouths (Kipp 2011). This species requires oxic, low-silt, sandy sediment with interstitial water movement. Such habitats may be present in the MRB in river reaches with high flow and in littoral habitats with sandy beaches.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus dziwnowi* (section 5f). *Psammonobiotus dziwnowi* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, high-flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus dziwnowi* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), and this would increase its chance of spreading to suitable habitat. As a result, the probability of spread by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. As a result, there is a high level of uncertainty associated with the spread by the species.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus dziwnowi is a benthic amoeba that moves between sand grains. No data on the historical rate of spread through the Great Lakes were found. *Psammonobiotus dziwnowi* is found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus dziwnowi may be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial vessel traffic to Indiana Harbor from the Great Lakes (USACE 2011a), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it is found in scattered locations along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to those In marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it is found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to Indiana Harbor is not practical at this time.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *Psammonobiotus dziwnowi* is native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has wide climatological tolerances. *Psammonobiotus dziwnowi* is found in littoral and supralittoral sandy beach sediments (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* has been found in four of the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic and therefore is likely to be present in Lake Michigan, although it is not currently documented. The heavy ballast water discharge at Indiana Harbor increases the probability of *Psammonobiotus dziwnowi* introduction. Therefore, there is a high probability that the species will arrive at the pathway at this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 3c), but there is no reason to assume *Psammonobiotus dziwnowi* is not present in Lake Michigan beaches considering it is found in the other four Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus dziwnowi.* Overall, the level of uncertainty associated with the species' arrival at the pathway is considered to be medium.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
No data on the rate of spread were found.

b. Human-Mediated Transport through Aquatic Pathways
The primary transport mechanism for *Psammonobiotus dziwnowi* in the Great Lakes has likely been ballast water (Kipp 2011). Most commercial vessel traffic to Indiana Harbor is lake-wide. There is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012), and the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for the transport of the species on boat hulls was not found in the literature.

c. Existing Physical Human/Natural Barriers
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus dziwnowi* on the basis of its depth distribution in the Great Lakes (Kipp 2011). Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. However, water flows over the sheet pile.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *Psammonobiotus dziwnowi* is found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus dziwnowi*, and clays can inhibit its establishment. Conditions at Indiana Harbor are highly industrialized. In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments in the Grand Calumet consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediment in the CSSC is silt or bedrock or a combination of silt and sand, gravel, or cobble

(LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* can be transported in ballast water, but there is little potential for vessel-mediated transport to the Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. As a result, the probability of passage is considered to be low at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus dziwnowi* is well documented as a near-shore sandy sediment species, and the CAWS is documented to have unsuitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these and establish is uncertain. The potential for, and speed of, vessel-mediated transport from Indiana Harbor to the Brandon Road Lock and Dam is not documented. Overall, the level of uncertainty is considered to be low.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus dziwnowi is found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of the Brandon Road Lock and Dam in high-flow areas. However, no information was found documenting *Psammonobiotus dziwnowi* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal.*
   Psammonobiotus dziwnowi could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in high-flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, in the literature *Psammonobiotus dziwnowi* is documented in large inland seas and coastal habitat (section 4a). Overall, the probability of colonization by the species is considered to be high.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus dziwnowi* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of the Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). As a result, there is a high level of uncertainty associated with colonization by the species.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Psammonobiotus dziwnowi is native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
The species' natural spread rate is not documented. *Psammonobiotus dziwnowi* could be transported downstream during high flows.

c. Fecundity
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. History of Invasion Success
Psammonobiotus dziwnowi has spread to scattered locations throughout the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for the species' spread in rivers were not found.

e. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus dziwnowi is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus dziwnowi is found in the littoral and supralittoral zones of lakes and inland seas, although it can be found near river mouths (Kipp 2011). This species requires oxic, low-silt, sandy sediment with interstitial water movement. Such habitats may be present in the MRB in river reaches with high flow and in littoral habitats with sandy beaches.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus dziwnowi* (section 5f). *Psammonobiotus dziwnowi* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, high-flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus dziwnowi* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), and this would increase its chance of spreading to suitable habitat. Therefore, the probability of spread by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. As a result, there is a high degree of uncertainty associated with the spread of the species.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Medium	High	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus dziwnowi is a benthic amoeba that moves between sand grains. No data on the historical rate of spread through the Great Lakes were found. *Psammonobiotus dziwnowi* is found in the Great Lakes and may have been spread by ballast water (Nicholls & MacIsaac 2004).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus dziwnowi may be spread by ballast water (Nicholls & MacIsaac 2004). There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic to adjacent Burns Harbor, and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it is found in scattered locations along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to those in marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus dziwnowi* in Lake Michigan have been conducted (Kipp 2011), but it has been found along beaches in all the other Great Lakes (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known, and predicting future locations in relation to the BSBH is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus dziwnowi* is native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has wide climatological tolerances. *Psammonobiotus dziwnowi* is found in littoral and supralittoral sandy beach sediments (Golemansky 2008; Kipp 2011) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* has been found in four of the Great Lakes (section 2c). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic and therefore is likely to be present in Lake Michigan although currently undocumented. The heavy ballast water discharge at the Burns Harbor (adjacent to BSBH) increases the probability of *Psammonobiotus dziwnowi* introduction. Therefore, there is a high probability of the species arriving at the pathway during this time step.
T_{10}: See T_0. Natural and human-mediated transport will continue to spread this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 3c), but there is no reason to assume *Psammonobiotus dziwnowi* is not present in Lake Michigan beaches considering it is found in the other four Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus dziwnowi*. Overall, there is a medium degree of uncertainty associated with the species' arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
   No data on the species' rate of spread were found.

b. *Human-Mediated Transport through Aquatic Pathways*
   The primary transport mechanism for *Psammonobiotus dziwnowi* in the Great Lakes has likely been ballast water (Kipp 2011). The discharge of ballast water does not typically

occur at inland ports within the CAWS (NBIC 2012). Vessel traffic to the BSBH is lake-wide. Although *Psammonobiotus dziwnowi* could move to Burns Harbor (which does have commercial vessel traffic), there is no commercial vessel traffic from Burns Harbor to inland ports in the CAWS (NB IC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus dziwnowi* based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0**.**

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus dziwnowi* is found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus dziwnowi*, and clays can inhibit its establishment. The banks of the BSBH are primarily riprap and vertical walls. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediment in the CSSC is silt, bedrock, or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low-silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus dziwnowi* can be transported in ballast water, but there is little potential for vessel-mediated transport to the Brandon Road Lock and Dam from the BSBH (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. As a result, there is a low probability of passage.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus dziwnowi* is well documented as a near-shore sandy sediment species, and the CAWS is documented not to have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these and establish is uncertain. The potential for, and speed of, vessel-mediated transport from BSBH to the Brandon Road Lock and Dam is not documented. Overall, the uncertainty associated with the probability of passage is considered to be low.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus dziwnowi are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments may be present downstream of the Brandon Road Lock and Dam in areas with high flow. However, no information was found documenting *Psammonobiotus dziwnowi* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Psammonobiotus dziwnowi could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible have not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in high-flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus dziwnowi* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, the probability of the species colonizing in the pathway is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus dziwnowi* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of the Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, there is a high degree of uncertainty associated with colonization by the species.

4. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Psammonobiotus dziwnowi is native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
The species' natural spread rate is not documented. *Psammonobiotus dziwnowi* could be transported downstream during high flows.

c. Fecundity
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. History of Invasion Success
Psammonobiotus dziwnowi has spread to scattered locations throughout the Great Lakes but is not found at high densities (Nicholls & MacIsaac, 2004). Data for its spread in rivers were not found.

e. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus dziwnowi is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus dziwnowi is found in the littoral and supralittoral zone of lakes and inland seas, although it can be found near river mouths (Kipp 2011). This species

requires oxic, low-silt, sandy sediment with interstitial water movement. Such habitats may be present in the MRB in river reaches with high flow and in littoral habitats with sandy beaches.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus dziwnowi* (section 5f). *Psammonobiotus dziwnowi* requires high-energy water, and the species is typically found in the shoreline of beaches (section 5f). However, sandy, high-flow areas of rivers may provide suitable habitat for this species. *Psammonobiotus dziwnowi* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), and this would increase its chance of spreading to suitable habitat. As a result, there is a medium probability of spread by the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. Therefore, the degree of uncertainty associated with the species' spread is considered to be high.

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E.2.1.3 Testate Amoeba - *Psammonobiotus linearis*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus linearis is a benthic amoeba that moves between sand grains. It can be moved passively by benthic disturbance. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus linearis* are found in Lake Ontario and Lake Erie and might have been spread by ballast water (Nicholls & MacIsaac 2004). *Psammonobiotus linearis* appears to be a rare species wherever it is recorded (Nicholls & MacIsaac 2004; Todorov & Golemansky 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus linearis might be spread by ballast water (Nicholls & MacIsaac 2004). There is no commercial vessel traffic to WPS from the Great Lakes, but there is recreational traffic (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in Lake Ontario and Lake Erie (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low, compared to marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011) and the closest known records were found along beaches in Lake Erie (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known and predicting future locations in relation to the WPS is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus linearis* can tolerate salinities of 0–31‰ depending on the species (Kipp 2011). *Psammonobiotus linearis* are native to or found in the Baltic Sea, Black Sea, Caspian Sea, Aral Sea basins, and the Bay of Biscay (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* has been found in low numbers in two of the Great Lakes and is typically rare (sections 2c, 2e). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic; and therefore, could be present in Lake Michigan although it is not presently documented. However, there is no long-distance commercial traffic to WPS so ballast water discharge might be limited and some natural spread would likely be required to reach WPS. Therefore, the probability of the species arriving at the pathway at this time step is considered low.
T_{10}: See T_0.
T_{25}: See T_{10}. Natural and human-mediated transport will continue to spread this species, and 25 years might be enough time for *Psammonobiotus linearis* to reach WPS**.** As a result, the probability of arrival rises to medium.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c); *Psammonobiotus linearis* might be present in Lake Michigan beaches considering they are found in two other Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus linearis*. Therefore, there is a medium level of uncertainty associated with the probability of the species' arrival at this time step.
T_{10}: See T_0. No surveys have been conducted in the Great Lakes since 2002; therefore, the present location of this species is unknown and it could be close enough at present to reach the WPS within ten years.
T_{25}: See T_{10}.
T_{50}: See T_{10}. *Psammonobiotus linearis* is more certain to reach the WPS in 50 years. However, this species appears to be rare and it might never become widespread in the Great Lakes.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the species' rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for *Psammonobiotus linearis* in the Great Lakes has likely been ballast water (Kipp 2011). There is no commercial vessel traffic from WPS so some natural spread would likely be required for the species to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: There is a sluice gate separating WPS from Lake Michigan which is periodically opened and closed (LimnoTech 2010). Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010), which could transport this species into the North Shore Channel if it was suspended in the water column by boat traffic or storms.
T_{10}: See T_0. Future operations of the sluice gate are not predicted to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus linearis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS do experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus linearis* and clays can inhibit their establishment. Sandy sediments are found in the North Shore Channel. The Chicago River has little instream habitat and the banks are typically concrete and steel vertical walls, with sediments of concrete, silt, or sludge (LimnoTech 2010). Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). Most sediment in the Chicago Sanitary and Ship Canal is silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is no commercial vessel traffic in the North Shore Channel, so reaching Brandon Road Lock and Dam would require some natural spread (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. As a result, there is a low probability of the species passing through the pathway at this time step.
T_{10}: See T_0. Conditions in the CAWS (e.g., sediment and hydrology) are not likely to change in ways that would facilitate the movement of this species by way of active unaided dispersal. The probability of this species passing through this pathway remains low under future conditions.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus linearis* is well documented as a nearshore sandy sediment species and the CAWS is documented not to have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these areas and establish is uncertain. Overall, there is a low uncertainty associated with the probability of passage.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus linearis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments might be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus linearis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Psammonobiotus linearis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible has not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 3a). However, *Psammonobiotus linearis* is documented in the literature in large inland seas and coastal habitat (section 3a). Overall, there is a medium probability of colonization by the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus linearis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 3b). The overall suitability of riverine habitats for this species is uncertain (section 3a). As a result, there is a high degree of uncertainty associated with the probability of colonization.

4. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Psammonobiotus linearis are native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. *Fecundity*
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus linearis has spread to scattered locations throughout the Great Lakes but it is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers was not found.

e. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus linearis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus linearis occupies only specific sediment types (oxic, low silt, sand). It is found in the littoral and supralittoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus linearis* are associated with littoral sandy beach sediments, although they can be found near the mouths of rivers. Sediment types, specifically oxic, low silt, and sandy sediments are suitable for this species. Such habitats are present in the MRB, in reaches with higher flow.

Evidence for Probability Rating (Considering All Life Stages)

Rivers are not considered typical habitat for *Psammonobiotus linearis* (section 5f). *Psammonobiotus linearis* requires high-energy water and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher flow areas of rivers might provide suitable habitat for this species. *Psammonobiotus linearis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. Therefore, the probability of spread by the species is considered to be high.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. As a result, there is high uncertainty associated with the species' probability of spread.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus linearis is a benthic amoeba that moves between sand grains. It can be moved passively by benthic disturbance. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus linearis* are found in Lake Ontario and Lake Erie and might have been spread by ballast water (Nicholls & MacIsaac 2004). *Psammonobiotus linearis* appears to be a rare species wherever it is recorded (Nicholls & MacIsaac 2004; Todorov & Golemansky 2007).

b. Human-Mediated Transport through Aquatic Pathways
Psammonobiotus linearis might be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial and recreational vessel traffic to the CRCW from the Great Lakes (USACE 2011a,b) and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. Current Abundance and Reproductive Capacity
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in Lake Ontario and Lake Erie (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low compared to marine beaches and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011), and the closest known records were found along beaches in Lake Erie (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known and predicting future locations in relation to the CRCW is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

F. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *Psammonobiotus linearis* can tolerate salinities of 0–31‰ depending on species (Kipp 2011). *Psammonobiotus linearis* are native to or found in the Baltic Sea, Black Sea, Caspian Sea, Aral Sea basins, and the Bay of Biscay (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* has been found in low numbers in two of the Great Lakes and is typically rare (section 2c, 2e). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic and therefore could be present in Lake Michigan, although it is not presently documented. The heavy ballast water discharge at the CRCW increases the probability of *Psammonobiotus linearis* introduction. Overall, however, the probability of the species arriving at the pathway during this time step is considered low.
T_{10}: See T_0. No surveys have been conducted in the Great Lakes since 2002; therefore, the present location of this species is unknown and it could be close enough at present to reach the CRCW within 10 years.
T_{25}: See T_{10}. Natural and human-mediated transport will continue to spread this species, and 25 years might be enough time for *Psammonobiotus linearis* to reach the CRCW**.** Therefore, the probability of arrival rises to medium for this time step.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c); *Psammonobiotus linearis* might be present in Lake Michigan beaches, considering that they are found in two other Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus linearis*. As a result, there is a medium level of uncertainty associated with the probability of the species' arrival.
T_{10}: See T_0. No surveys have been conducted in the Great Lakes since 2002; therefore, the present location of this species is unknown and it could be close enough at present to reach the CRCW within ten years.
T_{25}: See T_{10}.
T_{50}: See T_{10}. *Psammonobiotus linearis* is more certain to reach the CRCW in 50 years. However, this species appears to be rare and it might never become widespread in the Great Lakes.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the species' rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism in the Great Lakes has likely been ballast water (Kipp 2011). There is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for the transport of the species on boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2–9.1 m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus linearis* based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus linearis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus linearis* and clays can inhibit their establishment. The Chicago River has little instream habitat and the banks are typically concrete and steel vertical walls, with sediments of concrete, silt, or sludge (LimnoTech 2010). Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). Most sediment in the Chicago Sanitary and Ship Canal is silt or bedrock; or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* can be transported in ballast water and there is a potential for vessel mediated transport given vessel traffic between CRCW and Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. Consequently, the probability of passage is considered low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus linearis* is well documented as a nearshore sandy sediment species and the CAWS is documented to have unsuitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these areas and establish is uncertain. The potential for, and speed of, vessel mediated transport from CRCW to Brandon Road Lock and Dam is not documented. Overall, the degree of uncertainty associated with passage is considered low.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus linearis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments might be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus linearis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Psammonobiotus linearis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible has not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher-flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus linearis* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, the probability of colonization by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus linearis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). As a result, there is a high degree of uncertainty associated with the species' probability of colonization.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   Psammonobiotus linearis are native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
   The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. *Fecundity*
   The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
   Psammonobiotus linearis has spread to scattered locations throughout the Great Lakes but it is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
   Psammonobiotus linearis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus linearis occupies only specific sediment types (oxic, low silt, sand). It is found in the littoral and supralittoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus linearis* are associated with littoral sandy beach sediments although they can be found near river mouths. Sediment type, specifically oxic, low silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus linearis* (section 5f). *Psammonobiotus linearis* requires high-energy water and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher-flow areas of rivers might provide suitable habitat for this species. *Psammonobiotus linearis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. Therefore, there is a medium probability of spread for the species.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. As a result, the uncertainty associated with the species' probability of spread is considered high.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus linearis is a benthic amoeba that moves between sand grains. It can be moved passively by benthic disturbance. No data was found on its historical rate of spread through the Great Lakes. *Psammonobiotus linearis* are found in Lake Ontario and Lake Erie and might have been spread by ballast water (Nicholls & MacIsaac 2004). *Psammonobiotus linearis* appears to be a rare species wherever it is recorded (Nicholls & MacIsaac 2004; Todorov & Golemansky 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus linearis might be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial vessel traffic to the Calumet Harbor from the Great Lakes (USACE 2011a) and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in Lake Ontario and Lake Erie (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low, compared to marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011), and the closest known records were found along beaches in Lake Erie (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known and predicting future locations in relation to the Calumet Harbor is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus linearis* can tolerate salinities of 0–31‰ depending on the species (Kipp 2011). *Psammonobiotus linearis* are native to or found in the Baltic Sea, Black Sea, Caspian Sea, Aral Sea basins, and the Bay of Biscay (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* has been found in two of the Great Lakes and it is typically rare (sections 2c, 2e). Although no surveys have been conducted in Lake Michigan (section 2c) this species is spread by vessel traffic and; therefore, could be present in Lake Michigan although it is not presently documented. The heavy ballast water discharge at the Calumet Harbor increases the probability of *Psammonobiotus linearis* introduction. Overall, however, the probability of the species arriving at the pathway during this time step is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. Natural and human-mediated transport will continue to spread this species, and 25 years might be enough time for *Psammonobiotus linearis* to reach Calumet Harbor. As a result, the species' probability of arrival is raised to medium for this time step.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c); *Psammonobiotus linearis* might be present in Lake Michigan beaches considering they are found in two other Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus linearis*. Therefore, there is a medium degree of uncertainty associated with the species' probability of arrival.
T_{10}: See T_0. No surveys have been conducted in the Great Lakes since 2002; therefore, the present location of this species is unknown and it could be close enough at present to reach Calumet Harbor within ten years.
T_{25}: See T_{10}.
T_{50}: See T_{10}. *Psammonobiotus linearis* is more certain to reach the WPS in 50 years. However, this species appears to be rare and might never become widespread in the Great Lakes.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

No data was found on the rate of spread.

b. Human-Mediated Transport through Aquatic Pathways

The primary transport mechanism for *Psammonobiotus linearis* in the Great Lakes has likely been ballast water (Kipp 2011). Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Although *Psammonobiotus* spp. can be transported in ballast, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for the transport of the species on boat hulls was not found in the literature.

c. Existing Physical Human/Natural Barriers

T_0: None. The 1.2–9.1 m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus linearis* based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *Psammonobiotus linearis* are found in littoral supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS also experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus linearis* and clays can inhibit their establishment. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediment in the Chicago Sanitary and Ship Canal is silt or bedrock; or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* can be transported in ballast water and there is a potential for vessel mediated transport given the vessel traffic between Calumet Harbor and Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, its movement into the CAWS is not likely to occur by natural dispersal. As a result, its probability of passage is considered low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus linearis* is well documented as a near shore sandy sediment species and the CAWS is documented to have unsuitable habitat (section 3d). The potential for and speed of vessel mediated transport from Calumet Harbor to Brandon Road Lock and Dam is not documented. Overall, the uncertainty associated with the species' passage through the pathway is considered low.
T_{10}: See T_0. Future conditions are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus linearis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments might be present downstream of Brandon Road Lock and Dam in areas with

higher flow. However, no information was found documenting *Psammonobiotus linearis* in riverine habitats.

b. Ability of the species to reach suitable habitat by natural or human-mediated dispersal
Psammonobiotus linearis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible, has not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus linearis* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, the probability of the species colonizing the area is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus linearis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, the uncertainty associated with the probability of colonization is considered high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
Psammonobiotus linearis are native or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. Fecundity
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus linearis has spread to scattered locations throughout the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus linearis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus linearis occupies only specific sediment types (oxic, low silt, sand). It is found in the littoral and supralittoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus linearis* are associated with littoral sandy beach sediments although they can be found near river mouths. Sediment type, specifically oxic, low silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus linearis* (section 5f). *Psammonobiotus linearis* requires high-energy water and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher-flow areas of rivers might provide suitable habitat for this species. *Psammonobiotus linearis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. As a result, there is a medium probability of the species spreading through the MRB.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. Therefore, there is high uncertainty regarding the probability of the species' spread.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus linearis is a benthic amoeba that moves between sand grains. It can be moved passively by benthic disturbance. No data was found on the historical rate of spread through the Great Lakes. *Psammonobiotus linearis* are found in Lake Ontario and Lake Erie and might have been spread by ballast water (Nicholls & MacIsaac 2004). *Psammonobiotus linearis* appears to be a rare species wherever it is recorded (Nicholls & MacIsaac 2004; Todorov & Golemansky 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus linearis might be spread by ballast water (Nicholls & MacIsaac 2004). There is commercial vessel traffic to the Indiana Harbor from the Great Lakes (USACE 2011a) and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in Lake Ontario and Lake Erie (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low, compared with marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See $T_{10.}$
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011) and the closest known records were found along beaches in Lake Erie (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known and predicting future locations in relation to Indiana Harbor is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus linearis* can tolerate salinities of 0–31‰ depending on the species (Kipp 2011). *Psammonobiotus linearis* is native or found in the Baltic Sea, Black Sea, Caspian Sea, Aral Sea basins, and the Bay of Biscay (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* has been found in low numbers in two of the Great Lakes and is typically rare (sections 2c, 2e). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic; and therefore, could be present in Lake Michigan, although it is not presently documented. The heavy ballast water discharge at the Indiana Harbor increases the probability of *Psammonobiotus linearis* introduction. Overall, the species' low numbers keep the probability of its arrival at the pathway low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Natural and human-mediated transport will continue to spread this species, and 25 years might be enough time for *Psammonobiotus linearis* to reach Indiana Harbor. Therefore, the probability of its arrival rises to medium for this time step.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c); *Psammonobiotus linearis* might be present in Lake Michigan beaches considering they are found in two other Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus linearis*. Therefore, there is a medium degree of uncertainty associated with the probability of arrival.
T_{10}: See T_0. No surveys have been conducted in the Great Lakes since 2002; therefore, the present location of this species is unknown, but it could be close enough, at present, to reach Indiana Harbor within ten years.
T_{25}: See T_{10}.
T_{50}: See T_{10}. *Psammonobiotus linearis* is more certain to reach Indiana Harbor in 50 years. However, this species appears to be rare, and it might never become widespread in the Great Lakes.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

No data was found on the species' rate of spread.

b. Human-Mediated Transport through Aquatic Pathways

The primary transport mechanism for *Psammonobiotus linearis* in the Great Lakes has likely been ballast water (Kipp 2011). Most commercial vessel traffic to Indiana Harbor is lakewise and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012) and the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for the species' transport on boat hulls was not found in the literature. There is little, if any, vessel traffic in the Grand Calumet River, due to the shallow depth.

c. Existing Physical Human/Natural Barriers

T_0: None. The 1.2–9.1 m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus linearis* based on its depth distribution in the Great Lakes (Kipp 2011). Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. However, water flows over the sheet pile.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *Psammonobiotus linearis* are found in littoral and supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS do experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus linearis* and clays can inhibit their establishment. Conditions at the Indiana Harbor are highly industrialized. In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments in the Grand Calumet consist of primarily cobble, bedrock, or concrete; but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediment in the Chicago Sanitary and Ship Canal is silt or bedrock; or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* can be transported in ballast water but there is little potential for vessel mediated transport to Brandon Road Lock and Dam (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d); therefore, movement into the CAWS is not likely to occur by natural dispersal. Consequently, there is a low probability of passage for the species at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus linearis* is well documented as a nearshore sandy sediment species and the CAWS is documented not to have suitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these areas and establish is uncertain. The potential for and speed of vessel mediated transport from Indiana Harbor to Brandon Road Lock and Dam is not documented. Overall, the uncertainty associated with the species' passage is considered low.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species; therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Psammonobiotus linearis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments might be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus linearis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Psammonobiotus linearis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible has not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus linearis* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, the probability of the species colonizing the pathway is considered medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus linearis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, there is a high degree of uncertainty associated with the probability of colonization.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Psammonobiotus linearis is native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. *Fecundity*
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus linearis has spread to scattered locations throughout the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus linearis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic through the MRB, so ballast water would be a potential spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Psammonobiotus linearis occupies only specific sediment types (oxic, low silt, sand). It is found in the littoral and supralittoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus linearis* are associated with littoral sandy beach sediments, although they can be found near river mouths. Sediment type, specifically oxic, low silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow.

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus linearis* (section 5f). *Psammonobiotus linearis* requires high-energy water and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher-flow areas of rivers might provide suitable habitat for this species. *Psammonobiotus linearis* could be spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. As a result, the probability of spread by the species is considered medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. Therefore, there is a high level of uncertainty associated with the species' probability of spread.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Low	Medium	Medium	Medium	Medium	Medium
P(passage)	Low	Low	Low	Low	Low	Low	Low	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating:

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Psammonobiotus linearis is a benthic amoeba that moves between sand grains. It can be moved passively by benthic disturbance. No data was found on its historical rate of spread through the Great Lakes. *Psammonobiotus linearis* are found in Lake Ontario and Lake Erie and might have been spread by ballast water (Nicholls & MacIsaac 2004). *Psammonobiotus linearis* appears to be a rare species wherever it is recorded (Nicholls & MacIsaac 2004; Todorov & Golemansky 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus linearis might be spread by ballast water (Nicholls & MacIsaac 2004). There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic to adjacent Burns Harbor and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011), but they are found in scattered locations along beaches in Lake Ontario and Lake Erie (Nicholls & MacIsaac 2004). Densities in the Great Lakes beaches are low, compared with marine beaches, and many samples had few specimens (Nicholls & MacIsaac 2004).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No surveys for *Psammonobiotus linearis* have been conducted in Lake Michigan (Kipp 2011) and the closest known records were found along beaches in Lake Erie (Nicholls & MacIsaac 2004). The current location (2012) of the species is not known, but the closest known location is in adjacent lakes.
T_{10}: See T_0. Speed of movement or dispersal is not known and predicting future locations in relation to the BSBH is not practical at this time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus linearis* can tolerate salinities of 0–31‰ depending on the species (Kipp 2011). *Psammonobiotus linearis* is native to or found in the Baltic Sea, Black Sea, Caspian Sea, Aral Sea basins, and the Bay of Biscay (Nicholls & MacIsaac 2004; Kipp 2011), suggesting it is typically a marine and brackish species with wide climatological tolerances. *Psammonobiotus* spp. are found in littoral and supralittoral sandy beach sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy beach sediments are typical of the shoreline of Lake Michigan.
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* has been found in low numbers in two of the Great Lakes and is typically rare (section 2c and 2e). Although no surveys have been conducted in Lake Michigan (section 2c), this species is spread by vessel traffic; and therefore, it could be present in Lake Michigan, although presently it is undocumented. The heavy ballast water discharge at the Burns Harbor (adjacent to BSBH) increases the probability of *Psammonobiotus linearis* introduction. However, the low numbers of the species keep the probability of its arrival at this time step low.
T_{10}: See T_0.
T_{25}: See T_0. Natural and human-mediated transport will continue to spread this species and 25 years might be enough time for *Psammonobiotus linearis* to reach BSBH. Therefore, the probability of its arrival rises to medium at this time step.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: No surveys have been conducted in Lake Michigan (section 2c); however, *Psammonobiotus linearis* might be present in Lake Michigan beaches considering they are found in two other Great Lakes. However, there is little information about the environmental tolerances of *Psammonobiotus linearis*. Therefore, there is a medium degree of uncertainty associated with the probability of arrival rating.
T_{10}: See T_0. No surveys have been conducted in the Great Lakes since 2002; therefore, the present location of this species is unknown but it could be close enough, at present, to reach the BSBH within 10 years.
T_{25}: See T_{10}.
T_{50}: See T_{10}. *Psammonobiotus linearis* is more certain to reach the BSBH in 50 years. However, this species appears to be rare and it might never become widespread in the Great Lakes.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
No data was found on the species' rate of spread.

b. *Human-Mediated Transport through Aquatic Pathways*
The primary transport mechanism for *Psammonobiotus linearis* in the Great Lakes has likely been ballast water (Kipp 2011). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Vessel traffic to BSBH is lakewise. Although *Psammonobiotus linearis* could move to Burns Harbor (which does have commercial vessel traffic), there is no commercial vessel from the Burns Harbor to inland ports in the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2–9.1 m (4–30 ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Psammonobiotus linearis* based on its depth distribution in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *Psammonobiotus linearis* are found in littoral supralittoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sections of the CAWS do experience seasonally low dissolved oxygen (LimnoTech 2010). Grain size large enough for interstitial water movement is required by *Psammonobiotus linearis* and clays can inhibit their establishment. The banks of the BSBH are primarily riprap and vertical walls. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Inorganic silt sediments predominate in the Calumet Sag channel as well. Bedrock sediments are also present (LimnoTech 2010). Most sediment in the Chicago Sanitary and Ship Canal is silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010). Currents are typically slow in the CAWS (LimnoTech 2010). Overall, low silt, sandy sediments with interstitial water movement are likely to be rare in the CAWS.
T_{10}: See T_0. Conditions of bottom substrate and hydrological flow are not predicted to change in a way that would affect the likelihood of this species passing through this pathway**.**
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Psammonobiotus linearis* can be transported in ballast water but there is little potential for vessel mediated transport to Brandon Road Lock and Dam from BSBH (section 3b). The appropriate sediment and hydrologic conditions are not present in the CAWS (section 3d), therefore movement into the CAWS is not likely to occur by natural dispersal. For these reasons, the species' probability of passage is considered low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *Psammonobiotus linearis* is well documented as a nearshore sandy sediment species and the CAWS is documented to have unsuitable habitat (section 3d). There are sandy areas in the CAWS, but the potential of this species to reach these areas and establish is uncertain. Overall, the uncertainty associated with the species' passage is considered low.
T_{10}: See T_0. Future conditions in the CAWS are not expected to change in any significant way for this species, therefore, uncertainty remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Psammonobiotus linearis are found in littoral sand sediments (Golemansky 2008) where interstitial water movement and oxygen supply are adequate (Kipp 2011). Sandy littoral sediments might be present downstream of Brandon Road Lock and Dam in areas with higher flow. However, no information was found documenting *Psammonobiotus linearis* in riverine habitats.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Psammonobiotus linearis could naturally disperse to suitable habitat. However, the location of suitable habitat and whether it is accessible has not been documented.

Evidence for Probability Rating

Sandy habitat is likely present in higher flow areas downstream of the Brandon Road Lock and Dam (section 4a). However, *Psammonobiotus linearis* is documented in the literature in large inland seas and coastal habitat (section 4a). Overall, the probability of the species colonizing the pathway is considered medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The presence or absence of *Psammonobiotus linearis* depends on grain size. The locations of suitable sandy sediments are not well characterized in the downstream vicinity of Brandon Road Lock and Dam (section 4b). The overall suitability of riverine habitats for this species is uncertain (section 4a). Therefore, there is high uncertainty associated with the colonization of the species.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Psammonobiotus linearis are native to or found in the Baltic Sea, Black Sea, Caspian Sea, and Aral Sea basins (Kipp 2011), suggesting it has a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
The species' natural spread rate is not documented. *Psammonobiotus* spp. could be transported downstream during high flows.

c. *Fecundity*
The reproductive output of the species is driven by asexual reproduction. Its rate of population growth is unknown.

d. *History of Invasion Success*
Psammonobiotus linearis has spread to scattered locations through the Great Lakes but is not found at high densities (Nicholls & MacIsaac 2004). Data for its spread in rivers was not found.

e. *Human-Mediated Transport through Aquatic Pathways*
Psammonobiotus linearis is potentially spread by ballast water (Kipp 2011). There is heavy vessel traffic throughout the MRB, so ballast water would be a potential spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Psammonobiotus linearis occupies only specific sediment types (oxic, low silt, sand). It is found in the littoral and supralittoral zone of lakes and inland seas (Kipp 2011). *Psammonobiotus linearis* are associated with littoral sandy beach sediments although they can be found near river mouths. Sediment type, specifically oxic, low silt, sandy sediments are suitable for this species. Such habitats are present in the MRB in reaches with higher flow

Evidence for Probability Rating

Rivers are not considered typical habitat for *Psammonobiotus linearis* (section 5f). *Psammonobiotus linearis* requires high-energy water and the species is typically found in the shoreline of beaches (section 5f). However, sandy, higher-flow areas of rivers might provide suitable habitat for this species. *Psammonobiotus linearis* could spread through the MRB by natural mechanisms (section 5b) or in ballast water (section 5e), which would increase their chance of spreading to suitable habitat. As a result, there is a medium probability that the species will spread from the pathway.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Surveys of riverine habitat for this species are lacking; therefore, the suitability of sandy riverine habitat is uncertain. This species is typically found along high-energy shorelines. For these reasons, the probability of the species' spread has a high degree of uncertainty.

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E.2.2 Bryozoans

E.2.2.1 Freshwater Bryozoan - *Lophopodella carteri*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Medium	High	Medium	High	Low	High	Low
P(passage)	Low	Medium	Medium	Medium	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Medium	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The freshwater bryozoan *Lophopodella carteri* is an attached, generally colonial invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or surface where they develop into adults (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the sediments, where they eventually germinate into adults under favorable conditions (Rogick 1935; Wood 1993). *L. carteri* is thought to have been introduced via imported aquatic Asian plants in the 1930s and is now found in several states, although human-mediated transport through non-aquatic pathways may have been the primary spread mechanism (Masters 1940). It has been present in Lake Erie since at least the 1930s but has not been recorded in any of the other Great Lakes except Lake Michigan (Lauer et al. 1999). There are no records of *L. carteri* in Lake Michigan before 1999, but the species is inconspicuous and may have been present (Lauer et al. 1999). A colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011).

b. *Human-Mediated Transport through Aquatic Pathways*

No specific documentation for *L. carteri* and vessel transport was found. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also potentially be transported in ballast water or by attaching to a boat. In the Great Lakes, this species is found attached to manmade structures in harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is recreational but no commercial vessel traffic to the WPS, so no ballast water discharge is expected at the WPS (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*

T_0: Lauer et al. (1999) describe *L. carteri* populations in the Great Lakes as scattered and generally uncommon but potentially abundant locally. *L. carteri* is capable of sexual and asexual reproduction (Watermolen 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The closest record of *L. carteri* to the WPS is a 1995 record at the Michigan City Harbor in Indiana, more than 112 shoreline km (70 mi) away from the WPS (Lauer et al. 1999). However, no comprehensive surveys of southern Lake Michigan were found. Therefore, *L. carteri* may be present at the WPS.
T_{10}: See T_0. *L. carteri* may spread to the WPS if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *L. carteri* is found in southern Lake Michigan and lakes in Illinois (Wood & Marsh 1996; Lauer et al. 1999), so climate at the WPS is presumed to be suitable. This species is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi and Lewis 1991). Sandy sediments and hard structures are common near the WPS, including Wilmette Harbor, which is on the lake side of the WPS.

T_{10}: See T_0. Habitat is expected to remain suitable for *L. carteri*.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: When reproducing sexually, *L. carteri* can spread by currents or vessels during its planktonic stage (section 2a, 2b). There is no commercial vessel traffic to the WPS, and this may reduce the potential for transport to the WPS by vessels (section 2b). It has been recorded in southern Lake Michigan (section 2e) and may be present but unrecorded at Wilmette Harbor, which provides suitable habitat (section 2f). Therefore the probability of arrival for this time step is high.

T_{10}: See T_0**.** Based on existing trends, *L. carteri* is expected to continue to spread to the WPS if it is not there already.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: There is no commercial vessel traffic to the WPS (section 2b), and this reduces the chance of introduction by ballast water. This species is established in southern Lake Michigan but has not been recorded at the WPS, although no surveys appear to have been conducted (section 2e). Suitable habitat is present at the WPS (section 2f), and there is recreational vessel traffic at Wilmette Harbor (section 2b). Therefore, the uncertainty associated with arrival is medium for this time step.

T_{10}: See T_0.

T_{25}: Over time this species is expected to continue to spread. Therefore, uncertainty decreases to low for this time step.
T_{50}: See T_{25}.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The freshwater bryozoan *L. carteri* is an attached, generally colonial invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink to the sediment, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).

b. Human-Mediated Transport through Aquatic Pathways
No specific documentation for *L. carteri* and vessel transport was found. It is not possible for any vessel to move from Wilmette Harbor to the North Shore Channel, because the WPS separates Lake Michigan from the North Shore Channel. While the planktonic larvae of the bryozoans could potentially be transported in ballast water, there is no commercial vessel traffic in the North Shore Channel. In addition, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Bryozoans are known to attach to boat hulls (Johnson et al. 2007), so vessel transport is possible through portions of the CAWS with vessel traffic but would not be expected in the North Shore Channel.

c. Existing Physical Human/Natural Barriers
T_0: Water depth in the CAWS is suitable year-round and thus would not be an obstacle to passage. A sluice gate that separates the WPS from Lake Michigan is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010) and could transport this species (especially the planktonic stage) into the North Shore Channel. *L. carteri* attaches to hard surfaces; therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam could provide suitable habitat and are not expected to slow passage.
T_{10}: See T_0. The operation of the sluice gate is not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: This species is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, riprap, and earthen banks with vegetation, all of which would be suitable for this species to colonize. In the North Shore Channel and the upper north branch of the Chicago River, in-stream sediments are silt and sand (LimnoTech 2010). Toward downtown Chicago and in the Chicago River, there is a change to concrete and steel vertical banks, with sediments of concrete, silt, or sludge. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Bryozoans are one of the most common benthic organisms in the CAWS (EA Engineering, Science, and Technology, Inc. 2010), so habitat is likely suitable.

T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is suitable habitat through much of the CAWS (section 3d), and there are no significant barriers to passage (section 3c). Having planktonic larvae could increase the spread rate of *L. carteri* through the CAWS (sections 3a, 3b), because the larvae could be transported by currents or potentially attach to boats. However, there is low potential for vessel-mediated transport in the North Shore Channel, and there is low potential for transport by ballast water in the CAWS. In addition*, L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS or downstream of the Brandon Road Lock and Dam (section 3a). Therefore, the probability of passage is low for this time step.

T_{10}: See T_0. The potential for passage increases with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, the probability of passage increases to medium for this time step.

T_{25}: See T_{10}. The potential for passage increases with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, the probability of passage increases to high for this time step.

T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential natural rate of spread in the CAWS is uncertain, as is potential for spread by vessel transport. Therefore, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. *L. carteri* is more certain to pass through the CAWS with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, uncertainty decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   L. carteri can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). There is suitable habitat downstream of the Brandon Road Lock and Dam in the form of sandy sediments, hard bank structures, and zebra mussel beds.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is connected by flowing water, which could transport planktonic stages. Vessels could also potentially spread *L. carteri* to suitable habitat.

Evidence for Probability Rating

Suitable habitat for *L.* carteri is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *L.* carteri has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
L. carteri is native to Southeast Asia and Northeast Africa and is found in southern Lake Michigan, so it appears to have a wide climatological tolerance. It was recorded in a ditch in Louisville, Kentucky (Rogick 1957), suggesting climate in the MRB is suitable.

b. *Type of Mobility/Invasion Speed*
The freshwater bryozoan *L. carteri* is an attached, generally sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by currents) and then attach to a substrate or hard surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the bottom sediments, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). No information on spread rates through river basins was found.

c. *Fecundity*
L. carteri is capable of sexual and asexual reproduction (Watermolen 2004).

d. *History of Invasion Success*
No information on spread rates through river basins was found.

e. *Human-Mediated Transport through Aquatic Pathways*
No specific documentation for *L. carteri* and vessel transport was found. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also be potentially transported in ballast water or by attaching to a boat. This species is found attached to harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is heavy recreational and commercial vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
L. carteri can occupy a variety of habitat types and thus may be considered a generalist. *L. carteri* can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). Such habitat is abundant in the MRB.

Evidence for Probability Rating

There is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB and connected by flowing water. Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *L.* carteri are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Medium	Medium	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Medium	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The freshwater bryozoan *Lophopodella carteri* is an attached, colonial invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed

by water currents) and then attach to a substrate or surface where they develop into adults (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the sediments, where they eventually germinate into adults under favorable conditions (Rogick 1935; Wood 1993). *L. carteri* is thought to have been introduced via imported aquatic Asian plants in the 1930s and is now found in several states, although human-mediated transport through non-aquatic pathways may have been the primary spread mechanism (Masters 1940). It has been present in Lake Erie since at least the 1930s but has not been recorded in any of the other Great Lakes except Lake Michigan (Lauer et al. 1999). There are no records of *L. carteri* in Lake Michigan before 1999, but the species is inconspicuous and may have been present (Lauer et al. 1999). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011).

b. *Human-Mediated Transport through Aquatic Pathways*

No specific documentation was found for *L. carteri* and vessel transport. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also potentially be transported in ballast water or by attaching to a boat. In the Great Lakes, this species is found attached to manmade structures in harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is recreational and commercial vessel traffic to the CRCW from the Great Lakes, as well as ballast water discharge (USACE 2011a,b; NBIC 2012).

c. *Current Abundance and Reproductive Capacity*

T_0: Lauer et al. (1999) describe *L. carteri* populations in the Great Lakes as scattered and generally uncommon but potentially abundant locally. High densities were found at the Michigan City Harbor (Lauer et al. 1999). *L. carteri* is capable of sexual and asexual reproduction (Watermolen 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The closest record of *L. carteri* to the CRCW is a 1995 record at the Michigan City Harbor in Indiana, more than 80 shoreline km (50 mi) away from the Wilmette Pumping Station (WPS). However, no comprehensive surveys of southern Lake Michigan were found. Therefore, *L. carteri* may be present at the CRCW.
T_{10}: See T_0. *L. carteri* may spread to the CRCW if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *L. carteri* is found in southern Lake Michigan and lakes in Illinois (Wood & Marsh 1996; Lauer et al. 1999), so climate at the CRCW is presumed to be suitable. This species is found on sandy shoals (Smith 1985) and attached to macrophytes and solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). Sandy sediments and hard structures are common near the CRCW, and the CRCW itself contains hard structures suitable for colonization.
T_{10}: See T_0. Habitat is expected to remain suitable for *L. carteri*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: When reproducing sexually, *L. carteri* can spread by currents or vessels during its planktonic stage (sections 2a, 2b). There is commercial vessel traffic to the CRCW, as well as ballast water discharge, which may increase the potential for transport to the CRCW by vessels (section 2b). It has been recorded in southern Lake Michigan (section 2e) and may be present but unrecorded at the CRCW, which provides suitable habitat (section 2f). Therefore the probability of arrival for this time step is high.
T_{10}: See T_0**.** Based on existing trends, *L. carteri* is expected to continue to spread to the CRCW if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species is established in southern Lake Michigan but has not been recorded at the CRCW, although no surveys appear to have been conducted (section 2e). Suitable habitat is present at the CRCW, and potential transport mechanisms are available (section 2f). Overall, the uncertainty associated with arrival is low for this time step.
T_{10}: See T_0. If not already present at the CRCW, over time this species is expected to continue to spread naturally or by the heavy vessel traffic from the Great Lakes to the CRCW. Therefore, uncertainty remains low for this time step.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or hard surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink to the sediment, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
No specific documentation was found for *L. carteri* and vessel transport. The planktonic larvae of the bryozoans could potentially be transported in ballast water. However, ballast water discharge does not typically occur at inland ports within the CAWS (NBIC 2012). Bryozoans are known to attach to boat hulls (Johnson et al. 2007), so vessel transport is possible through portions of the CAWS with vessel traffic. There is commercial and recreational vessel traffic between the CRCW and the Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round and thus would not be an obstacle to passage. The lock at the CRCW is opened on a regular basis, so it should not be a significant barrier to *L. carteri* entering the CAWS from Lake Michigan. *L. carteri* attaches to hard surfaces; therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam could provide suitable habitat and are not expected to slow passage.
T_{10}: See T_0. The operations of the locks in the CAWS are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *L. carteri* is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as to solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, riprap, and earthen banks with vegetation, all of which would be suitable for this

species to colonize. In the Chicago River, there is a change to concrete and steel vertical banks, with sediments of concrete, silt, or sludge. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Bryozoans are one of the most common benthic organisms in the CAWS (EA Engineering, Science, and Technology, Inc. 2010), so habitat is likely suitable.
T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is suitable habitat through much of the CAWS (section 3d) and no significant barriers to passage (section 3c). Having a planktonic larva could increase the spread rate of *L. carteri* through the CAWS (sections 3a, 3b), because the larvae could be transported by currents or potentially attach to boats. *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS or downstream of the Brandon Road Lock and Dam (section 3a). Therefore the probability of passage is low for this time step.
T_{10}: See T_0. The potential for passage increases with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore the probability of passage increases to medium for this time step.
T_{25}: See T_{10}. The potential for passage increases with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). *L. carteri* has larvae with a brief planktonic stage (section 3a) and therefore could move readily downstream. Therefore, the probability of passage increases to high for this time step.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential natural rate of spread in the CAWS is uncertain, as is potential for spread by vessel transport. Therefore, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0**.** *L. carteri* is more certain to pass through the CAWS with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, uncertainty decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
L. carteri can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). There is suitable habitat downstream of the Brandon Road Lock and Dam in the form of sandy sediments, hard bank structures, and zebra mussel beds.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is connected by flowing water, which could transport planktonic stages. Vessels could also potentially spread *L. carteri* to suitable habitat.

Evidence for Probability Rating

Suitable habitat for *L. carteri* is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *L.* carteri has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
L. carteri is native to Southeast Asia and Northeast Africa and is found in southern Lake Michigan, so it appears to have a wide climatological tolerance. It was recorded in a ditch in Louisville, Kentucky (Rogick 1957), suggesting climate is suitable in the MRB.

b. *Type of Mobility/Invasion Speed*
L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage and then attach to a substrate or surface (Wood 1993). They

reproduce asexually by releasing statoblasts, which sink immediately to the bottom sediments, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). No information on spread rates through river basins was found.

c. *Fecundity*
L. carteri is capable of sexual and asexual reproduction (Watermolen 2004).

d. *History of Invasion Success*
No information on spread rates through river basins was found.

e. *Human-Mediated Transport through Aquatic Pathways*
No specific documentation was found for *L. carteri* and vessel transport. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also be potentially transported in ballast water or by attaching to a boat. This species is found attached to harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is heavy recreational and commercial vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
L. carteri can occupy a variety of habitat types and thus may be considered a generalist. *L. carteri* can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). Such habitat is abundant in the MRB.

Evidence for Probability Rating

There is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB and connected by flowing water (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *L. carteri* are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 3 (CALUMET HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Medium	Medium	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Medium	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The freshwater bryozoan *Lophopodella carteri* is an attached, colonial invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or surface where they develop into adults (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the sediments, where they eventually germinate into adults under favorable conditions (Rogick 1935; Wood 1993). *L. carteri* is thought to have been introduced via imported aquatic Asian plants in the 1930s and is now found in several states, although human-mediated transport through non-aquatic pathways may have

been the primary spread mechanism (Masters 1940). It has been present in Lake Erie since at least the 1930s but has not been recorded in any of the other Great Lakes except for Lake Michigan (Lauer et al. 1999). There are no records of *L. carteri* in Lake Michigan before 1999, but the species is inconspicuous and may have been present (Lauer et al. 1999). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011).

b. Human-Mediated Transport through Aquatic Pathways

No specific documentation for *L. carteri* and vessel transport was found. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also potentially be transported in ballast water or by attaching to a boat. In the Great Lakes, this species is found attached to manmade structures in harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is recreational and commercial vessel traffic to Calumet Harbor from the Great Lakes as well as ballast water discharge (USACE 2011a,b; NBIC 2012).

c. Current Abundance and Reproductive Capacity

T_0: Lauer et al. (1999) describes *L. carteri* populations in the Great Lakes as scattered and generally uncommon but potentially abundant locally. High densities were found at Michigan City Harbor in Indiana (Lauer et al. 1999). *L. carteri* is capable of sexual and asexual reproduction (Watermolen 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barrier

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: There is a 1995 record of *L. carteri* at Michigan City Harbor, Indiana, less than 80 km (50 mi) from the Calumet Harbor (Lauer et al. 1999). However, no comprehensive surveys of southern Lake Michigan were found. Therefore, *L. carteri* may be present at Calumet Harbor.
T_{10}: See T_0. *L. carteri* may spread to Calumet Harbor if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *L. carteri* is found in southern Lake Michigan and lakes in Illinois (Wood & Marsh 1996; Lauer et al. 1999), so climate at Calumet Harbor is presumed to be suitable. This species is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected

from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). Sandy sediments and hard structures are common near Calumet Harbor, and Calumet Harbor itself contains hard structure suitable for colonization.
T_{10}: See T_0. Habitat is expected to remain suitable for *L. carteri*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: When reproducing sexually, *L. carteri* can spread by currents or vessels during its planktonic stage (sections 2a, 2b). There is commercial vessel traffic to Calumet Harbor (section 2b), which may increase the potential for transport to Calumet Harbor by vessels (section 2b). *L. carteri* has been recorded in southern Lake Michigan near Calumet Harbor (section 2e) and may be present but unrecorded at Calumet Harbor, which provides suitable habitat (section 2f). Therefore, the probability of arrival for this time step is high.
T_{10}: See T_0**.** Based on existing trends, *L. carteri* is expected to continue to spread to Calumet Harbor if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species is established in southern Lake Michigan less than 80 km (50 mi) from Calumet Harbor. Although it has not been recorded at Calumet Harbor, no surveys appear to have been conducted (section 2e). Suitable habitat is present at Calumet Harbor, and potential transport mechanisms are available (section 2f). Overall, the uncertainty associated with arrival is low for this time step.
T_{10}: See T_0. If not already present at Calumet Harbor, over time this species is expected to continue to spread naturally or by the heavy vessel traffic from the Great Lakes to Calumet Harbor. Therefore, uncertainty is low for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or hard surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink to the sediment, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
No specific documentation was found for *L. carteri* and vessel transport. The planktonic larvae of the bryozoans could potentially be transported in ballast water, but the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Bryozoans are known to attach to boat hulls (Johnson et al. 2007), so vessel transport is possible through portions of the CAWS with vessel traffic. There is heavy vessel traffic between the T.J. O'Brien Lock and the Dam and Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round and thus would not be an obstacle to passage. The lock at the T.J. O'Brien Lock and Dam is opened on a regular basis, so it should not be a significant barrier to *L. carteri* entering the CAWS from Lake Michigan. *L. carteri* attaches to hard surfaces; therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam could provide suitable habitat and are not expected to slow passage.
T_{10}: See T_0. The operations of the locks in the CAWS are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *L. carteri* is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as to solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, riprap, and earthen banks with vegetation, all of which would be suitable for this species to colonize. After entering Calumet Harbor, the *L. carteri* will enter the Calumet River. In the Calumet River there is in-stream habitat for aquatic life in the form of

boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches. Urban industrial and commercial riparian land use is also present. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The Calumet Sag Channel and the CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Bryozoans are one of the most common benthic organisms in the CAWS (EA Engineering, Science, and Technology, Inc. 2010), so habitat is likely suitable.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is suitable habitat through much of the CAWS (section 3d) and no significant barriers to passage (section 3c). Having planktonic larvae could increase the spread rate of *L. carteri* through the CAWS (sections 3a, 3b), because the larvae could be transported by currents or potentially attach to boats. *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS or downstream of the Brandon Road Lock and Dam (section 3a). Therefore, the probability of passage is low for this time step.
T_{10}: See T_0. The potential for passage increases with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, the probability of passage increases to medium for this time step.
T_{25}: See T_{10}. The potential for passage increases with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). *L. carteri* has larvae with a brief planktonic stage (section 3a) and therefore could move readily downstream. Therefore, the probability of passage increases to high for this time step.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential natural rate of spread in the CAWS is uncertain as is potential for spread by vessel transport. Therefore, the uncertainty associated with passage is medium for this time step.

T_{10}: See T_0.
T_{25}: See T_0. *L. carteri* is more certain to pass through the CAWS with time, because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, uncertainty decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
L. carteri can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). There is suitable habitat downstream of the Brandon Road Lock and Dam in the form of sandy sediments, hard bank structures, and zebra mussel beds.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is connected by flowing water. Vessels could also potentially spread *L. carteri* to suitable habitat, which could transport planktonic stages.

Evidence for Probability Rating

Suitable habitat for *L. carteri* is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *L. carteri* has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. (spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB

L. carteri is native to Southeast Asia and Northeast Africa and is found in southern Lake Michigan, so it appears to have a wide climatological tolerance. It was recorded in a ditch in Louisville, Kentucky (Rogick 1957), suggesting climate is suitable in the MRB.

b. Type of Mobility/Invasion Speed

L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage and then attach to a substrate or surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the bottom sediments, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). No information on spread rates through river basins was found.

c. Fecundity

L. carteri is capable of sexual and asexual reproduction (Watermolen 2004).

d. History of Invasion Success

No information on spread rates through river basins was found.

e. Human-Mediated Transport through Aquatic Pathways

No specific documentation was found for *L. carteri* and vessel transport. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also be potentially transported in ballast water or by attaching to a boat. This species is found attached to harbors and marinas (Lauer et al. 1999), which increases the probability of vessel transport. There is heavy recreational and commercial vessel traffic in the MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

L. carteri can occupy a variety of habitat types and thus may be considered a generalist. *L. carteri* can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). Such habitat is abundant in the MRB.

Evidence for Probability Rating

There is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB and connected by flowing water (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *L. carteri* are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 4 (INDIANA HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The freshwater bryozoan *Lophopodella carteri* is an attached, colonial invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or surface where they develop into

adults (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the sediments, where they eventually germinate into adults under favorable conditions (Rogick 1935; Wood 1993). *L. carteri* is thought to have been introduced via imported aquatic Asian plants in the 1930s and is now found in several states, although human-mediated transport through non-aquatic pathways may have been the primary spread mechanism (Masters 1940). It has been present in Lake Erie since at least the 1930s but has not been recorded in any of the other Great Lakes except for Lake Michigan (Lauer et al. 1999). There are no records of *L. carteri* in Lake Michigan before 1999, but the species is inconspicuous and may have been present (Lauer et al. 1999). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011).

b. Human-Mediated Transport through Aquatic Pathways

No specific documentation was found for *L. carteri* and vessel transport. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also potentially be transported in ballast water or by attaching to a boat. In the Great Lakes, this species is found attached to manmade structures in harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is commercial vessel traffic to Indiana Harbor from the Great Lakes as well as ballast water discharge (USACE 2011a,b; NBIC 2012).

c. Current Abundance and Reproductive Capacity

T_0: Lauer et al. (1999) describes *L. carteri* populations in the Great Lakes as scattered and generally uncommon but potentially abundant locally. High densities were found at Michigan City Harbor in Indiana (Lauer et al. 1999). *L. carteri* is capable of sexual and asexual reproduction (Watermolen 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: There is a 1995 record of *L. carteri* at Michigan City Harbor, Indiana, less than 64 km (40 mi) from the Indiana Harbor (Lauer et al. 1999). However, no comprehensive surveys of southern Lake Michigan were found. Therefore, *L. carteri* may be present at Indiana Harbor.
T_{10}: See T_0. *L. carteri* may spread to Indiana Harbor if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *L. carteri* is found in southern Lake Michigan and lakes in Illinois (Wood & Marsh 1996; Lauer et al. 1999), so climate at Indiana Harbor is presumed to be suitable. This species is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). Sandy sediments and hard structures are common near Indiana Harbor, and Indiana Harbor itself contains hard structure suitable for colonization.
T_{10}: See T_0. Habitat is expected to remain suitable for *L. carteri*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: When reproducing sexually, *L. carteri* can spread by currents or vessels during its planktonic stage (sections 2a, 2b). There is commercial vessel traffic to Indiana Harbor, which may increase the potential for transport to Indiana Harbor by vessels (section 2b). It has been recorded in southern Lake Michigan near Indiana Harbor (section 2e) and may be present but unrecorded at Indiana Harbor, which provides suitable habitat (section 2f). Therefore, the probability of arrival for this time step is high.
T_{10}: See T_0. Based on existing trends, *L. carteri* is expected to continue to spread to Indiana Harbor if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species is established in southern Lake Michigan but has not been recorded at Indiana Harbor, although no surveys appear to have been conducted (section 2e). Suitable habitat is present at Indiana Harbor, and potential transport mechanisms are available (section 2f). Overall, the uncertainty associated with arrival is low for this time step.
T_{10}: See T_0. If not already present at Indiana Harbor, over time this species is expected to continue to spread naturally or by the heavy vessel traffic from the Great Lakes to Indiana Harbor. Therefore, uncertainty is low for this time step.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or hard surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink to the sediment, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).

b. Human-Mediated Transport through Aquatic Pathways
No specific documentation for *L. carteri* and vessel transport was found. The planktonic larvae of the bryozoans could potentially be transported in ballast water, but vessel traffic to Indiana Harbor is lake-wide and the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Bryozoans are known to attach to boat hulls (Johnson et al. 2007), so vessel transport is possible through portions of the CAWS with vessel traffic.

c. Existing Physical Human/Natural Barriers
T_0: Water depth in the CAWS is suitable year-round and thus would not be an obstacle to passage. *L. carteri* attaches to hard surfaces; therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam could provide suitable habitat and are not expected to slow passage. There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a temporary barrier, especially under low flows.
T_{10}: See T_0. The operations of the locks in the CAWS are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *L. carteri* is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as to solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, riprap, and earthen banks with vegetation, all of which would be suitable for this

species to colonize. Water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern-most segment of the Grand Calumet River also generally flows toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Sediments in the Grand Calumet consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The Calumet Sag Channel and the CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Bryozoans are one of the most common benthic organisms in the CAWS (EA Engineering, Science, and Technology, Inc. 2010), so habitat is likely suitable.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is suitable habitat through much of the CAWS (section 3d) and no significant barriers to passage (section 3c). Having planktonic larvae could increase the spread rate of *L. carteri* through the CAWS (sections 3a, 3b), because the larvae could be transported by currents or potentially attach to boats. Dispersal by human-mediated transport via ballast water is not possible through the Indiana Harbor because the passage is too shallow for vessels (section 3b). *L. carteri* has larvae with a brief planktonic stage (section 3a) and therefore could move readily downstream, but is not likely to move upstream through Indiana Harbor and the Grand Calumet River. *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS or downstream of the Brandon Road Lock and Dam (section 3a). Therefore, the probability of passage is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The potential for passage increases with time because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, the probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: The potential natural rate of spread in the CAWS is uncertain. Despite inhabiting southern Lake Michigan near Indiana Harbor, *L. carteri* has not been recorded in the CAWS, likely because it is unable to move upstream through the Indiana Harbor. Therefore, the uncertainty associated with passage is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take *L. carteri* to pass upstream through Indiana Harbor and the Grand Calumet River or whether the species is capable of such movement. Therefore, the uncertainty associated with passage during this time step is high.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   L. carteri can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). There is suitable habitat downstream of the Brandon Road Lock and Dam in the form of sandy sediments, hard bank structures, and zebra mussel beds.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is connected by flowing water, which could transport planktonic stages. Vessels could also potentially spread *L. carteri* to suitable habitat.

Evidence for Probability Rating

Suitable habitat for *L. carteri* is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *L. carteri* has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB

L. carteri is native to Southeast Asia and Northeast Africa and is found in southern Lake Michigan, so it appears to have a wide climatological tolerance. It was recorded in a ditch in Louisville, Kentucky (Rogick 1957), suggesting climate is suitable in the MRB.

b. Type of Mobility/Invasion Speed

L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage and then attach to a substrate or surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the bottom sediments, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). No information on spread rates through river basins was found.

c. Fecundity

L. carteri is capable of sexual and asexual reproduction (Watermolen 2004).

d. History of Invasion Success

No information on spread rates through river basins was found.

e. Human-Mediated Transport through Aquatic Pathways

No specific documentation for *L. carteri* and vessel transport was found. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also be potentially transported in ballast water or by attaching to a boat. This species is found attached to harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is heavy recreational and commercial vessel traffic in the MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

L. carteri can occupy a variety of habitat types and thus may be considered a generalist. *L.* carteri can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). Such habitat is abundant in the MRB.

Evidence for Probability Rating

There is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB and connected by flowing water (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *L. carteri* are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*

The freshwater bryozoan *Lophopodella carteri* is an attached, colonial invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or surface where they develop into adults (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the sediments, where they eventually germinate into adults under favorable conditions (Rogick 1935; Wood 1993). *L. carteri* is thought to have been introduced via imported aquatic Asian plants in the 1930s and is now found in several states, although human-mediated transport through non-aquatic pathways may have been the primary spread mechanism (Masters 1940). It has been present in Lake Erie since at least the 1930s but has not been recorded in any of the other Great Lakes except for Lake Michigan (Lauer et al. 1999). There are no records of *L. carteri* in Lake Michigan before 1999, but the species is inconspicuous and may have been present (Lauer et al. 1999). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011).

b. *Human-Mediated Transport through Aquatic Pathways*

No specific documentation for *L. carteri* and vessel transport was found. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also potentially be transported in ballast water or by attaching to a boat. In the Great Lakes, this species is found attached to manmade structures in harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is recreational but no commercial vessel traffic to the BSBH from the Great Lakes (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*

T_0: Lauer et al. (1999) describe *L. carteri* populations in the Great Lakes as scattered and generally uncommon but potentially abundant locally. High densities were found at Michigan City Harbor in Indiana (Lauer et al. 1999). *L. carteri* is capable of sexual and asexual reproduction (Watermolen 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: There is a 1995 record of *L. carteri* at Michigan City Harbor, Indiana, approximately 24 km (15 mi) from the BSBH (Lauer et al. 1999). However, no comprehensive surveys

of southern Lake Michigan were found. Therefore, *L. carteri* may be present at the BSBH.
T_{10}: See T_0. *L. carteri* may spread to BSBH if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *L. carteri* is found in southern Lake Michigan and lakes in Illinois (Wood & Marsh 1996; Lauer et al. 1999) so climate is presumed to be suitable at the BSBH. This species is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as solid substrata like docks and rocks (Lauer et al. 1999). It has also been collected from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). Sandy sediments and hard structure are common near the BSBH, and the BSBH itself contains hard structure suitable for colonization.
T_{10}: See T_0. Habitat is expected to remain suitable for *L. carteri*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: When producing sexually, *L. carteri* can spread by currents or vessels during its planktonic stage (sections 2a, 2b). There is commercial vessel traffic to the BSBH, which may increase the potential for transport to the BSBH by vessels (section 2b). It has been recorded in southern Lake Michigan near the BSBH (section 2e) and may be present but unrecorded at the BSBH, which provides suitable habitat (section 2f). Therefore, the probability of arrival for this time step is high.
T_{10}: See T_0. Based on existing trends, *L. carteri* is expected to continue to spread to the BSBH if it is not there already.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species is established in southern Lake Michigan but has not been recorded at BSBH, although no surveys appear to have been conducted (section 2e). Suitable habitat is

present at the BSBH, and potential transport mechanisms are available (section 2f). Overall, the uncertainty associated with arrival is low for this time step.
T_{10}: See T_0. If not already present at the BSBH, over time this species is expected to continue to spread naturally or by the heavy vessel traffic from the Great Lakes to the BSBH. Therefore, uncertainty is low for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50} : LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage (which may be dispersed by water currents) and then attach to a substrate or hard surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink to the sediment, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
No specific documentation was found for *L. carteri* and vessel transport. The planktonic larvae of the bryozoans could potentially be transported in ballast water, but vessel traffic to the BSBH is lake-wide and the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Bryozoans are known to attach to boat hulls (Johnson et al. 2007), so vessel transport is possible through portions of the CAWS with vessel traffic.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round and thus would not be an obstacle to passage. *L. carteri* attaches to hard surfaces; therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam could provide suitable habitat and are not expected to slow passage.
T_{10}: See T_0. The operations of the locks in the CAWS are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *L. carteri* is found on sandy shoals (Smith 1985) and attached to macrophytes, as well as to solid substrates like docks and rocks (Lauer et al. 1999). It has also been collected

from substrates of gravel and rubble with scattered patches of vegetation (Ricciardi & Lewis 1991). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, riprap, and earthen banks with vegetation, all of which would be suitable for this species to colonize. The BSBH is lined by vertical walls and sandy vegetated banks with riprap. After entering the BSBH and passing through Burns Ditch, *L. carteri* would enter the south branch of the Little Calumet River. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). The water flows out of the BSBH into Lake Michigan. The eastern segment of the south branch of the Little Calumet River also generally flows toward Lake Michigan depending on location and water level in Lake Michigan (GSWMD 2008). Thus, *L. carteri* would have to move upstream to enter the CAWS and move to the Calumet Sag Channel. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The Calumet Sag Channel and the CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Bryozoans are one of the most common benthic organisms in the CAWS (EA Engineering, Science, and Technology, Inc. 2010), so habitat is likely suitable.
T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is suitable habitat through much of the CAWS (section 3d), and there are no significant barriers to passage (section 3c). Having planktonic larvae could increase the spread rate of *L. carteri* through the CAWS (sections 3a, 3b), because the larvae could be transported by currents or potentially could attach to boats. Dispersal by human-mediated transport via ballast water is not possible through the BSBH, because the passage is too shallow for vessels (section 3b). *L. carteri* has larvae with a brief planktonic stage (section 3a) and therefore could move readily downstream, but is not likely to move upstream through the BSBH and the Little Calumet River (section 3d). *L. carteri* has been in southern Lake Michigan since at least 1999 but has not been recorded in the CAWS or downstream of the Brandon Road Lock and Dam (section 3a). Therefore, the probability of passage is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The potential for passage increases with time because there are no known barriers to passage (section 3c) and habitat in the CAWS appears to be suitable (section 3d). Therefore, the probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: The potential natural rate of spread in the CAWS is uncertain. Despite inhabiting southern Lake Michigan near the BSBH, *L. carteri* has not been recorded in the CAWS, likely because it is unable to move upstream through the BSBH. Therefore, the uncertainty associated with passage is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take *L. carteri* to pass upstream through the BSBH and the Little Calumet River or whether the species is capable of such movement. Therefore, uncertainty associated with passage during this time step is high.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
L. carteri can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). There is suitable habitat downstream of the Brandon Road Lock and Dam in the form of sandy sediments, hard bank structures, and zebra mussel beds.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is connected by flowing water, which could transport planktonic stages. Vessels could also potentially spread *L. carteri* to suitable habitat.

Evidence for Probability Rating

Suitable habitat for *L. carteri* is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *L. carteri* has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
L. carteri is native to Southeast Asia and Northeast Africa and is found in southern Lake Michigan, so it appears to have a wide climatological tolerance. It was recorded in a ditch in Louisville, Kentucky (Rogick 1957), suggesting climate is suitable in the MRB.

b. Type of Mobility/Invasion Speed
L. carteri is an attached, sessile invertebrate. If reproducing sexually, the larvae have a brief planktonic stage and then attach to a substrate or surface (Wood 1993). They reproduce asexually by releasing statoblasts, which sink immediately to the bottom sediments, where they eventually germinate under favorable conditions (Rogick 1935; Wood 1993). An adult colony can move up to 12 cm (4.7 in.) per day (Fuller & Maynard 2011). No information on spread rates through river basins was found.

c. Fecundity
L. carteri is capable of sexual and asexual reproduction (Watermolen 2004).

d. History of Invasion Success
No information on spread rates through river basins was found.

e. Human-Mediated Transport through Aquatic Pathways
No specific documentation for *L. carteri* and vessel transport was found. Bryozoans are known to attach to boat hulls (Johnson et al. 2007), and planktonic larvae could also be potentially transported in ballast water or by attaching to a boat. This species is found attached to harbors and marinas (Lauer et al. 1999), and this increases the probability of vessel transport. There is heavy recreational and commercial vessel traffic in the MRB (USACE 2011a,b).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
L. carteri can occupy a variety of habitat types and thus may be considered a generalist. *L. carteri* can live in bivalve shells, attached to algae, concrete walls, vertical surfaces, submerged logs, rocks, and aquatic vegetation (Lauer et al. 1999). Such habitat is abundant in the MRB.

Evidence for Probability Rating

There is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB and connected by flowing water (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *L. carteri* are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

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E.2.3 Algae

E.2.3.1 Cryptic Algae - *Cyclotella cryptica*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
C. cryptica is a planktonic diatom that moves passively by flowing water. *C. cryptica* was first recorded in Lake Michigan in 1964 and was found in the Sandusky River (a major tributary of Lake Erie) in 1976 and now also occurs in Lake Ontario, Lake Erie, and Lake Huron (Kipp 2011), suggesting relatively rapid spread.

b. *Human-Mediated Transport through Aquatic Pathways*
C. cryptica was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is no commercial vessel traffic from the Great Lakes to the WPS, but there is recreational boat traffic (USACE 2011a,b). Like other diatoms, *C. cryptica* could be transported by attaching to recreational boat hulls (GISP 2008), although this was not documented specifically for this species.

c. *Current Abundance and Reproductive Capacity*
T_0: No data is available on the current abundance of *C. cryptica* in the Great Lakes. However, records of *C. cryptica* abundance for Lake Michigan exist as late as the mid-1990s (Kipp 2011). In harbors of the Great Lakes, abundance can be high relative to other diatoms (Kipp 2011). *C. cryptica* is reported to have a generation time ranging from 1.6 to 4 divisions per day depending on environmental conditions (White 1974; Liu & Hellebust 1976; Sriharan et al. 1991). The species has seasonal higher abundances during spring and fall (Scala & Bowler 2001).
T_{10}: See T_0**.** Future abundance cannot be predicted with any accuracy; however, reproductive capacity is predicted to remain the same, which can be very high during certain times of the year.
T_{25}: See T_0 and T_{10}.
T_{50}: See T_{25}. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see Suitable Habitat).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Records of *C. cryptica* exist for Lake Michigan offshore of Evanston, IL, just a few miles south of WPS. No data is available on the current distribution of *C. cryptica* in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *C. cryptica* was found in southern Lake Michigan in the vicinity of the WPS in 1995 (Kipp 2011). In the Great Lakes, *C. cryptica* was significantly correlated with conductivity, nitrate (NO_3), silicon dioxide (SiO_2), and aerobic heterotrophs (Kipp 2011). *C. cryptica* is found in waters where abnormally high chloride concentrations occur such as harbors (Kipp 2011). However, it has also been found in the middle of Lake Michigan. In addition, it is capable of surviving heterotrophically on glucose, so cells found on the

lake bottom may survive an extended period in low light. It is known to grow mesotrophically as well (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. However, diatoms are sensitive to climatological conditions. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *C. cryptica.* Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could increase the productivity of *C. cryptica*. However, climate change could also affect other variables that determine phytoplankton productivity such as nutrients and water circulation.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is considered to be established in Lake Michigan and has been found in Lake Michigan within 16 km (10 mi) of WPS (section 2e). The harbor at the WPS may provide suitable habitat (section 2f). Therefore, the probability of this species arriving at the WPS is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. Therefore, the probability of this species arriving at the WPS remains high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *C. cryptica* is considered to be established in Lake Michigan and was documented near the WPS in 1995 (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}*:* See T_0.
T_{50}: See T_{25}. Diatoms are sensitive to climatological and water quality conditions, which are sources of uncertainty for this species. The effects of future climate change and\or new environmental regulations on *C. cryptica* populations are uncertain (section 2f), but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
C. cryptica is a planktonic diatom that can spread rapidly by natural (current) or human-mediated (ballast water discharge) mechanisms. The species must move from WPS more than 64.4 km (40 mi) downstream to Brandon Road Lock and Dam. *C. cryptica* was first recorded in Lake Michigan in 1964 and, although it was identified offshore of Evanston, IL, it has not been reported to have passed into the CAWS. However, it can appear similar to *C. meneghiniana,* which is a common phytoplankton in the Illinois Waterway (Illinois Natural History Survey 1980).

b. *Human-Mediated Transport through Aquatic Pathways*
C. cryptica can be carried in ballast water (Kipp 2011). There is no commercial vessel traffic and little recreational boat traffic in the North Shore Channel. There is no commercial vessel traffic or recreational boating from Lake Michigan to the North Shore Channel through the WPS. Within the CAWS, there is vessel traffic between the Chicago River and Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Surface water is present all year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010). There is a sluice gate separating the CAWS from Lake Michigan, which is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel. Therefore, *C. cryptica* could be pumped into the North Shore Canal.
T_{10}: See T_0. No changes in human or natural barriers are expected. The sluice gate is expected to continue to operate under current procedures.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: In the Great Lakes*, C. cryptica* is found in waters where abnormally high chloride concentrations occur, such as in harbors (Makarewicz 1987; Kipp 2011). Much of the water in the CAWS is municipal effluent, which could contain the nutrient and conductivity that promote the growth of this species. Multiple violations of chloride concentrations were reported for the CAWS in 2010 (MWRD 2010). In Oswego Harbor, *C. cryptica* was found in waters with chloride concentrations of 40–160 mg/L (Makarewicz 1987); chloride in the CAWS falls within this range (MWRD 2010). Turbidity is high in the CAWS (LimnoTech 2010), which could limit photosynthesis by reducing light levels in the water column. However, *C. cryptica* is capable of temporary heterotrophic growth in dark conditions (White 1974), which may limit any negative

impact from the potential turbidity within the CAWS. The optimal temperature range for the growth of *C. cryptica* is 22.5 to 25.0°C (72.5 to 77°F) (Pahl et al. 2010), which is typical of the seasonal temperature of the CAWS (MWRD 2010). *C. cryptica* is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011). *Cyclotella* was collected from Lake Erie from an area with average depth of 8 m (26 ft) (Verduin 1951). Water depth in the CAWS seems suitable.

T_{10}: See T_0.

T_{25}: See T_0. *C. cryptica* is sensitive to nutrients and conductivity levels. The discharge of common municipal contaminants containing such nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is typically reported as a marine and brackish water species (section 3d). However, it has been reported in rivers with high conductivity, and water quality may be suitable in the CAWS (section 3d). This species could be transported into the WPS as a result of periodic pumping and opening of the sluice gates and subsequently drift downstream to Brandon Road Lock and Dam during this time step. There are no barriers within CAWS that would inhibit the drift of this species. However, although it has been in Lake Michigan for decades, there are no records of *C. cryptica* in the CAWS or downstream of Brandon Road Lock and Dam. The lack of records may be due to misidentification, habitat (specifically water quality) in the CAWS being unsuitable, or a lack of phytoplankton surveys in the Illinois Waterway. Overall, this species is considered to have a high probability of passing through the pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The suitability of hydraulic and light conditions (e.g., turbidity) for *C. cryptica* in CAWS is not clear, although this species has been documented far inland of some rivers of the Great

Lakes. Suitable habitat potentially exists for *C. cryptica*, and there are no barriers to its passage through the pathway. Existing flow within CAWS is sufficient for this species to transit to Brandon Road Lock and Dam during this time step. However, this species has been present in southern Lake Michigan for decades and has not been recorded in the CAWS or the Illinois River. It is uncertain why there are no records of this species in the Illinois Waterway. Therefore, uncertainty of the probability of this species passing through the pathway is high.
T_{10}: See T_0.
T_{25}: Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *C. cryptica*. Because of possible changes to the amounts of limiting nutrients, the future uncertainty of this species passing through the pathway remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
C. cryptica is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011). *C. cryptica* is found in ports and harbors where abnormally high chloride concentrations are found (Makarewicz 1987; Kipp 2011). This suggests that water quality may be suitable downstream of Brandon Road Lock and Dam near urban areas with ports and municipal runoff that could locally elevate conductivity (i.e., road salt). *C. cryptica* is typically reported as a lake species, so reservoirs as well as pools behind mainstem dams may provide suitable habitat.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat such as industrial areas and ports are found in the vicinity of Brandon Road Lock and Dam and are accessible by passive downstream drift.

Evidence for Probability Rating

C. cryptica has been documented in inland rivers (section 4a), and suitable water quality for *C. cryptica* may be present in areas with anthropogenic inputs downstream of Brandon Road Lock and Dam (sections 4a, 4b). However, this species is typically found in lakes and areas with high halogen and nutrient inputs. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions in the Illinois River for this species is not documented. Therefore, there is a high uncertainty associated with this species colonizing after passage through the pathway.

5. P(spreads): MEDIUM

The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
C. cryptica is globally widespread (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
C. cryptica is a phytoplankton that would spread by drifting downstream through the MRB.

c. *Fecundity*
C. cryptica has a high doubling time under the appropriate environmental conditions.

d. *History of Invasion Success*
C. cryptica has become a dominant phytoplankton in specific habitat conditions in the Great Lakes (Kipp 2011). No data was found for rivers.

e. *Human-Mediated Transport through Aquatic Pathways*
C. cryptica can be transported in ballast water and discharged at ports and harbors where habitat is most suitable (Kipp 2011). There is heavy vessel traffic between Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This species specializes in waters with high anthropogenic inputs (Kipp 2011). *C. cryptica* has specific nutrient and halogen requirements because it is typically a marine and brackish water species (Kipp 2011). Suitable habitat may be present in the MRB in waters impacted by anthropogenic inputs that contain elevated conductivity such as ports, harbors, and urban areas (Kipp 2011). *C. cryptica* is not described in the literature as a riverine species. Light levels may not be suitable in river systems, as they are generally turbid.

Evidence for Probability Rating

C. cryptica is globally distributed (section 5a), so climate in the MRB will likely be suitable. *C. cryptica* is found in freshwater under specific water chemistry conditions (section 5f).

Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f) and these areas are hydrologically connected. However, *C. cryptica* is not described in the literature as a riverine species (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the MRB.

Uncertainty: HIGH

Evidence for Uncertainty Rating

C. cryptica is considered a marine and brackish water species (section 5f). The suitability of flow and light conditions, as well as water quality, in the MRB is not clear for this species. Therefore, there is high uncertainty for the probability of this species to spread throughout the MRB.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

C. cryptica is a planktonic diatom that moves passively by flowing water. *C. cryptica* was first recorded in Lake Michigan in 1964 and was found in the Sandusky River (a major tributary of Lake Erie) in 1976, and now also occurs in Lake Ontario and Lake Huron (Kipp 2011), suggesting relatively rapid spread.

b. Human-Mediated Transport through Aquatic Pathways

C. cryptica was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2012). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is commercial and recreational vessel traffic from the Great Lakes to the CRCW (USACE 2011a,b). Like other diatoms, *C. cryptica* could be transported by attaching to recreational boat hulls (GISP 2008), although this was not documented for specifically for this species.

c. Current Abundance and Reproductive Capacity

T_0: No data is available on the current abundance of *C. cryptica* in the Great Lakes. In harbors of the Great Lakes, abundance can be high relative to other diatoms (Kipp 2011). Records for Lake Michigan exist as late as the mid-1990s (Kipp 2011). *C. cryptica* is reported to have a generation time ranging from 1.6 to 4 divisions per day (White 1974; Liu & Hellebust 1976; Sriharan et al. 1991).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see Suitable Habitat).

d. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: Records of *C. cryptica* exist for Evanston, IL, approximately 25.7 km (16 mi) north of the CRCW. No data is available on the current distribution of *C. cryptica* in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: *C. cryptica* was been found in southern Lake Michigan north of the CRCW in 1995 (Kipp 2011). In the Great Lakes, *C. cryptica* were significantly correlated with conductivity, nitrate (NO_3), silicon dioxide (SiO_2), and aerobic heterotrophs. Consequently, in the Great Lakes this species is closely associated with harbors (Kipp 2011). *C. cryptica* is found in waters where abnormally high chloride concentrations occur such as harbors (Kipp 2011). However, it has also been found in the middle of Lake Michigan. In addition, it is capable of surviving heterotrophically on glucose, so cells found on the lake bottom may survive an extended period in low light. It is known to grow mesotrophically as well (Kipp 2011).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_{25}. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. However, diatoms are sensitive to climatological conditions. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *C. cryptica.* Future climate change is projected to increase the water temperature in the Great Lakes (Wuebbles et al. 2010), which could create more optimal conditions for *C. cryptica*. However, climate change could also affect other variables that determine phytoplankton productivity such as nutrients and water circulation.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is considered to be established in Lake Michigan and has been found in Lake Michigan approximately 25.7 km (16 mi) north of the CRCW (section 2e). The harbor at the CRCW would provide suitable habitat (section 2f), and *C. cryptica* may be present though undocumented. Therefore, the probability of this species arriving at the CRCW is considered to be high.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. Therefore, the probability of this species arriving at the CRCW remains high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *C. cryptica* is considered to be established in Lake Michigan and was documented near the CRCW in 1995 (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Diatoms are sensitive to climatological and water quality conditions, which are a source of uncertainty for this species. The effects of future climate change and/or new environmental regulations on *C. cryptica* populations are uncertain (section 2f) but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
C. cryptica is a planktonic diatom that can spread rapidly by natural (current) or human-mediated (ballast water discharge) mechanisms. The species must move from the CRCW more than 32 km (20 mi) downstream to Brandon Road Lock and Dam.
C. cryptica was first recorded in Lake Michigan in 1964, and although it was identified offshore of Evanston, IL, it has not been reported to have passed into the CAWS. However, it can appear similar to *C. meneghiniana,* which is a common phytoplankton in the Illinois Waterway (Illinois Natural History Survey 1980).

b. Human-Mediated Transport through Aquatic Pathways
Within the CAWS, there is vessel traffic between the Chicago River and Brandon Road Lock and Dam. *C. cryptica* can be carried in ballast water (Kipp 2011), and there is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. Existing Physical Human/Natural Barriers
T_0: None. Flowing water is present throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: In the Great Lakes*, C. cryptica* is associated with harbors and waters with anthropogenic inputs (Kipp 2011). Much of the water in the CAWS is municipal effluent, which could contain the nutrient and conductivity that promote the growth of this

species. In Oswego Harbor, *C. cryptica* was found in waters with chloride concentrations 40–160 mg/L (Makarewicz 1987); chloride in the CAWS falls within this range (MWRD 2010). Turbidity is high in the CAWS (LimnoTech 2010), which could limit photosynthesis. *C. cryptica* is capable of temporary heterotrophic growth in dark conditions (White 1974). The optimal temperature range for the growth of *C. cryptica* is 22.5 to 25.0°C (72.5 to 77°F) (Pahl et al. 2010), which is typical of the seasonal temperature of the CAWS (MWRD 2010). *C. cryptica* is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0. *C. cryptica* is sensitive to nutrients and conductivity levels. The discharge of common municipal contaminants containing such nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber, 2012; Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is typically reported as a marine and brackish water species (section 3d). However, it has been reported in rivers with anthropogenic inputs, and water quality may be suitable in the CAWS (section 3d). This species could be transported through the Calumet Harbor and flow downstream to Brandon Road Lock and Dam. There are no barriers within the CAWS that would inhibit the drift of this species. However, although it has been in Lake Michigan for decades, there are no records of *C. cryptica* in the CAWS or downstream of Brandon Road Lock and Dam. The lack of records may be due to habitat (specifically water quality) in the CAWS being unsuitable, or a lack of phytoplankton surveys in the Illinois Waterway. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The suitability for *C. cryptica* of hydraulic and light conditions (e.g., turbidity) in CAWS is not clear, although this species has been documented far inland of some rivers of the Great Lakes. Suitable habitat potentially exists for *C. cryptica*, and there are no barriers to its passage through the pathway. Existing flow within CAWS is sufficient for this species to transit to Brandon Road Lock and Dam during this time step. However, this species has been present in southern Lake Michigan for decades and has not been found in the CAWS or the Illinois River. It is uncertain why there are no records of this species in the Illinois Waterway. Therefore, uncertainty of the probability of this species passing through the pathway is high.
T_{10}: See T_0.
T_{25}: Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *C. cryptica*. Because of possible changes in amount of limiting nutrients, the future uncertainty of this species passing through the pathway remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   C. cryptica is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011). *C. cryptica* is found in ports and harbors where abnormally high chloride concentrations are found (Makarewicz 1987; Kipp 2011). This suggests that water quality may be suitable downstream of Brandon Road Lock and Dam near urban areas with ports and municipal runoff that could locally elevate conductivity (i.e., road salt). *C. cryptica* is typically reported as a lake species, so reservoirs as well as pools behind mainstem dams may provide suitable habitat.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat such as industrial areas and ports are found in the vicinity of Brandon Road Lock and Dam and are accessible by passive downstream drift.

Evidence for Probability Rating

C. cryptica has been documented in inland rivers (section 4a), and suitable water quality for *C. cryptica* may be present in areas with anthropogenic inputs downstream of Brandon Road Lock and Dam (sections 4a, 4b). However, this species is typically found in lakes and areas with high halogen and nutrient inputs. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions in the Illinois River for this species is not documented. Therefore, there is a high uncertainty associated with this species colonizing after passage through the pathway.

5. **P(spreads): MEDIUM**

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
C. cryptica is globally widespread (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. Type of Mobility/Invasion Speed
C. cryptica is a phytoplankton that would spread by drifting downstream.

c. Fecundity
C. cryptica has a high doubling time under the appropriate environmental conditions.

d. History of Invasion Success
C. cryptica has become a dominant phytoplankton in specific habitat conditions in the Great Lakes (Kipp 2011). No data was found for rivers.

e. Human-Mediated Transport through Aquatic Pathways
C. cryptica can be transported in ballast water and discharged at ports and harbors where habitat is most suitable (Kipp 2011). There is heavy vessel traffic between Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
This species specializes in waters with anthropogenic inputs (Kipp 2011). *C. cryptica* has specific nutrient and halogen requirements because it is typically a marine and brackish water species (Kipp 2011). Suitable habitat may be present in the MRB in waters impacted by anthropogenic inputs such as ports, harbors, and urban areas (Kipp 2011). *C. cryptica* is not described in the literature as a riverine species. Light availability may not be suitable in river systems.

Evidence for Probability Rating

C. cryptica is globally distributed (section 5a), so climate in the MRB will likely be suitable. *C. cryptica* is found in freshwater under specific water chemistry conditions (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. However, *C. cryptica* is not described in the literature as a riverine species (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the MRB.

Uncertainty: HIGH

Evidence for Uncertainty Rating

C. cryptica is considered a marine and brackish water species (section 5f). The suitability of flow and light conditions, as well as water quality, in the MRB is not clear for this species. Therefore, there is high uncertainty for the probability of this species to spread throughout the MRB.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
C. cryptica is a planktonic diatom that moves passively by flowing water. *C. cryptica* was first recorded in Lake Michigan in 1964 and was found in the Sandusky River (a major tributary of Lake Erie) in 1976, and now also occurs in Lake Ontario and Lake Huron (Kipp 2011), suggesting relatively rapid spread.

b. Human-Mediated Transport through Aquatic Pathways
C. cryptica was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is commercial vessel traffic from the Great Lakes to the Calumet Harbor (USACE 2011a). Like other diatoms, *C. cryptica* could be transported by attaching to boat hulls (GISP 2008), although this was not documented for specifically for this species.

c. Current Abundance and Reproductive Capacity
T_0: No data is available on the current abundance of *C. cryptica* in the Great Lakes. In harbors of the Great Lakes, abundance can be high relative to other diatoms (Kipp 2011). Records for Lake Michigan exist as late as the mid-1990s (Kipp 2011). *C. cryptica* is reported to have a generation time ranging from 1.6 to 4 divisions per day (White 1974; Liu & Hellebust 1976; Sriharan et al. 1991).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see Suitable Habitat).

d. Existing Physical Human/Natural Barriers
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway
T_0: Records of *C. cryptica* exist off Evanston, IL, in 20 m (65 ft) of water approximately 40 km (25 mi) north of the Calumet Harbor. No data is available on the current distribution of *C. cryptica* in the Great Lakes (Kipp 2011).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *C. cryptica* was been found in southern Lake Michigan north of the Calumet Harbor in 1995 (Kipp 2011). In the Great Lakes, *C. cryptica* was significantly correlated with conductivity, nitrate (NO_3), silicon dioxide (SiO_2), and aerobic heterotrophs (Kipp 2011). Consequently, in the Great Lakes this species is closely associated with harbors (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. However, diatoms are sensitive to climatological conditions. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *C. cryptica.* Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could increase the productivity of *C. cryptica*. However, climate change could also affect other variables that determine phytoplankton productivity such as nutrients and water circulation.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is considered to be established in Lake Michigan and has been found in Lake Michigan approximately 40 km (25 mi) north of the Calumet Harbor (section 2e). Calumet Harbor would provide suitable habitat (section 2f), and *C. cryptica* may currently be present though undocumented.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. Therefore, the probability of this species arriving at the Calumet Harbor remains high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *C. cryptica* is considered to be established in Lake Michigan and was documented in southern Lake Michigan in 1995 (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Diatoms are sensitive to climatological and water quality conditions, which are sources of uncertainty for this species. The effects of future climate change and/or new environmental regulations on *C. cryptica* populations are uncertain (section 2f), but may alter the distribution and annual occurrence. Future uncertainty remains low.

4. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
C. cryptica is a planktonic diatom that can spread rapidly by natural (current) or human-mediated (ballast water discharge) mechanisms. The species must move from Calumet Harbor more than 72 km (45 mi) downstream to Brandon Road Lock and Dam.
C. cryptica was first recorded in Lake Michigan in 1964, and although it was identified offshore of Evanston, IL, it has not been reported to have passed through the CAWS. However, it can appear similar to *C. meneghiniana,* which is a common phytoplankton in the Illinois Waterway (Illinois Natural History Survey 1980).

b. Human-Mediated Transport through Aquatic Pathways
Commercial vessel traffic to Calumet Harbor is typically from the lake (NBIC 2012). There is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). *C. cryptica* can be carried in ballast water (Kipp 2011) although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Like other diatoms, *C. cryptica* could be transported by attaching to boat hulls (GISP 2008), although this was not documented for specifically for this species.

c. Existing Physical Human/Natural Barriers
T_0: None. Flowing water is present throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: In the Great Lakes*, C. cryptica* is associated with harbors and waters with anthropogenic inputs (Kipp 2011). Much of the water in the CAWS is municipal effluent, which could contain the nutrients and conductivity that promote the growth of this species. In Oswego Harbor, *C. cryptica* was found in waters with chloride concentrations 40–160 mg/L (Makarewicz 1987); chloride in the CAWS falls within this range (MWRD 2010). Turbidity is high in the CAWS (LimnoTech 2010), which could limit photosynthesis. *C. cryptica* is capable of temporary heterotrophic growth in dark conditions (White 1974). The optimal temperature range for the growth of *C. cryptica* is 22.5 to 25.0°C (72.5 to 77°F) (Pahl et al. 2010), which is typical of the seasonal temperature of the CAWS (MWRD 2010). *C. cryptica* is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011).

T_{10}: See T_0.

T_{25}: See T_0. *C. cryptica* is sensitive to nutrients and conductivity levels. The discharge of common municipal contaminants containing such nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is typically reported as a marine and brackish water species (section 3d). However, it has been reported in rivers with anthropogenic inputs, and water quality may be suitable in the CAWS (section 3d). This species could be transported through the Calumet Harbor and flow downstream to Brandon Road Lock and Dam. There are no barriers within CAWS that would inhibit the drift of this species. However, although it has been in Lake Michigan for decades, there are no records of *C. cryptica* in the CAWS or downstream of Brandon Road Lock and Dam. The lack of records may be due to misidentification, habitat (specifically water quality) in the CAWS being unsuitable, or a lack of phytoplankton surveys in the Illinois Waterway. Overall, this species is considered to have a high probability of passing through the pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The suitability for *C. cryptica* of hydraulic and light conditions (e.g., turbidity) in CAWS is not clear, although this species has been documented far inland of some rivers of the Great Lakes. Suitable habitat potentially exists for *C. cryptica*, and there are no barriers to its passage through the pathway. Existing flow within the CAWS is sufficient for this species to transit to Brandon Road Lock and Dam during this time step. However, this species has been present in southern Lake Michigan for decades and has not been recorded in the CAWS or the Illinois River. It is uncertain why there are no records of this species in the Illinois Waterway. Therefore, uncertainty of the probability of this species passing through the pathway is high.
T_{10}: See T_0.
T_{25}: Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *C. cryptica*. Because of possible changes in amount of limiting nutrients, the future uncertainty of this species passing through the pathway remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
C. cryptica is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011). *C. cryptica* is found in ports and harbors where abnormally high chloride concentrations are found (Makarewicz 1987; Kipp 2011). This suggests that water quality may be suitable downstream of Brandon Road Lock and Dam near urban areas with ports and municipal runoff that could locally elevate conductivity (i.e., road salt). *C. cryptica* is typically reported as a lake species, so reservoirs as well as pools behind mainstem dams may provide suitable habitat.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat such as industrial areas and ports are found in the vicinity of Brandon Road Lock and Dam and are accessible by passive downstream drift.

Evidence for Probability Rating

C. cryptica has been documented in inland rivers (section 4a), and suitable water quality for *C. cryptica* may be present in areas with anthropogenic inputs downstream of Brandon Road Lock and Dam (sections 4a, 4b). However, this species is typically found in lakes and areas with high halogen and nutrient inputs. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions in the Illinois River for this species is not documented. Therefore, there is a high uncertainty associated with this species colonizing after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
C. cryptica is globally widespread (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
C. cryptica is a phytoplankton that would spread by drifting downstream.

c. *Fecundity*
C. cryptica has a high doubling time under the appropriate environmental conditions.

d. *History of Invasion Success*
C. cryptica has become a dominant phytoplankton in specific habitat conditions in the Great Lakes (Kipp 2011). No data was found for rivers.

e. *Human-Mediated Transport through Aquatic Pathways*
C. cryptica can be transported in ballast water and discharged at ports and harbors where habitat is most suitable (Kipp 2011). There is heavy vessel traffic between Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This species specializes in waters with anthropogenic inputs (Kipp 2011). *C. cryptica* has specific nutrient and halogen requirements because it is typically a marine and brackish

water species (Kipp 2011). Suitable habitat may be present in the MRB in waters impacted by anthropogenic inputs such as ports, harbors, and urban areas (Kipp 2011). *C. cryptica* is not described in the literature as a riverine species. Light availability may not be suitable in river systems.

Evidence for Probability Rating

C. cryptica is globally distributed (section 5a), so climate in the MRB will likely be suitable. *C. cryptica* is found in freshwater under specific water chemistry conditions (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected.

Uncertainty: HIGH

Evidence for Uncertainty Rating

C. cryptica is considered a marine and brackish water species (section 5f). The suitability of flow and light conditions, as well as water quality, in the MRB is not clear for this species. Therefore, there is high uncertainty for the probability of this species to spread throughout the MRB.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
C. cryptica is a planktonic diatom that moves passively by flowing water. *C. cryptica* was first recorded in Lake Michigan in 1964 and was found in the Sandusky River (a major tributary of Lake Erie) in 1976, and now also occurs in Lake Ontario and Lake Huron (Kipp 2011), suggesting relatively rapid spread.

b. *Human-Mediated Transport through Aquatic Pathways*
C. cryptica was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is commercial vessel traffic from the Great Lakes to the Indiana Harbor (USACE 2011a). Like other diatoms, *C. cryptica* could be transported by attaching to boat hulls (GISP 2008), although this was not documented for specifically for this species.

c. *Current Abundance and Reproductive Capacity*
T_0: No data is available on the current abundance of *C. cryptica* in the Great Lakes. In harbors of the Great Lakes, abundance can be high relative to other diatoms (Kipp 2011). Records for *C. cryptica* in Lake Michigan exist as late as the mid-1990s (Kipp 2011). *C. cryptica* is reported to have a generation time ranging from 1.6 to 4 divisions per day (White 1974; Liu & Hellebust 1976; Sriharan et al. 1991).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see Suitable Habitat).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: Records of *C. cryptica* exist off Evanston, IL, in 20 m (65 ft) of water approximately 40 km (25 mi) north of the Indiana Harbor. No data is available on the current distribution of *C. cryptica* in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *C. cryptica* was been found in southern Lake Michigan north of the Indiana Harbor in 1995 (Kipp 2011). In the Great Lakes, *C. cryptica* was significantly correlated with conductivity, nitrate (NO_3), silicon dioxide (SiO_2), and aerobic heterotrophs. Consequently, in the Great Lakes, this species is closely associated with harbors (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. However, diatoms are sensitive to climatological conditions. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *C. cryptica.* Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could increase the productivity of *C. cryptica*. However, climate change could also affect other variables that determine phytoplankton productivity such as nutrients and water circulation.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is considered to be established in Lake Michigan and has been found in Lake Michigan approximately 40 km (25 mi) north of the Indiana Harbor (section 2e). Indiana Harbor would provide suitable habitat (section 2f), and *C. cryptica* may currently be present though undocumented. Therefore, the probability of this species arriving at the Indiana Harbor is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. Therefore, the probability of this species arriving at the WPS remains high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *C. cryptica* is considered to be established in Lake Michigan and was documented in southern Lake Michigan in 1995 (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}. Diatoms are sensitive to climatological and water quality conditions, which are sources of uncertainty for this species. The effects of future climate change and/or new environmental regulations on *C. cryptica* populations are uncertain (section 2f), but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
C. cryptica is a planktonic diatom that can spread rapidly by natural (current) or human-mediated (ballast water discharge) mechanisms. The species must move from Indiana Harbor more than 72 km (45 mi) downstream to Brandon Road Lock and Dam.
C. cryptica was first recorded in Lake Michigan in 1964, and although it was identified offshore of Evanston, Illinois, it has not been reported to have passed through the CAWS. However, it can appear similar to *C. meneghiniana,* which is a common phytoplankton in the Illinois Waterway (Illinois Natural History Survey 1980).

b. Human-Mediated Transport through Aquatic Pathways
Although *C. cryptica* can be transported in ballast water (Kipp et al. 2012) and potentially on boat hulls (GISP 2008), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Most commercial vessel traffic to Indiana Harbor is via the lake, and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is no vessel traffic in the Grand Calumet River east of the Indiana Harbor. Consequently, some natural downstream dispersal would likely be necessary to reach Brandon Road Lock and Dam.

c. Existing Physical Human/Natural Barriers
T_0: None. Flowing water is present throughout the CAWS (LimnoTech 2010). Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile.
T_{10}: See T_0.
T_{25}: See T_{10}. It is assumed that the sheet pile in the Grand Calumet River will be removed by this time step.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: In the Great Lakes*, C. cryptica* is associated with harbors and waters with anthropogenic inputs (Kipp 2011). Much of the water in the CAWS is municipal effluent, which could contain the nutrients and conductivity that promote the growth of this species. In Oswego Harbor, *C. cryptica* was found in waters with chloride concentrations of 40–160 mg/L (Makarewicz 1987); chloride in the CAWS falls within this range (MWRD 2010). Turbidity is high in the CAWS (LimnoTech 2010), which could limit photosynthesis. *C. cryptica* is capable of temporary heterotrophic growth in dark conditions (White 1974). The optimal temperature range for the growth of *C. cryptica* is 22.5 to 25.0°C (72.5 to 77°F) (Pahl et al. 2010), which is typical of the seasonal temperature of the CAWS (MWRD 2010). *C. cryptica* is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011).

Water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the easternmost sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, cryptic algae would have to move upstream to enter the CAWS and move to the Calumet Sag Channel.

T_{10}: See T_0.

T_{25}: See T_0. *C. cryptica* is sensitive to nutrients and conductivity levels. The discharge of common municipal contaminants containing such nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is typically reported as a marine and brackish water species (section 3d). However, it has been reported in rivers with anthropogenic inputs, and water quality may be suitable in the CAWS (section 3d). There is a low potential for vessels to transport this species from Indiana Harbor to inland portions of the CAWS (section3b). Because of the lack of vessel traffic (section3b), natural spread through the Grand Calumet will likely be required for *C. cryptica* to reach the Little Calumet River and the Calumet Sag Channel. Water flow in Indiana Harbor and portions of the Grand Calumet River is toward Lake Michigan. Cryptic algae are phytoplankton and are not likely to move upstream through these waters. Once in the Little Calumet, this species could spread naturally downstream through the CAWS to Brandon Road Lock and Dam. However, although it has been in Lake Michigan for decades, there are no records of *C. cryptica* in the CAWS or downstream of

Brandon Road Lock and Dam. The lack of records may be due to misidentification, habitat (specifically water quality) in the CAWS being unsuitable, or a lack of phytoplankton surveys in the Illinois Waterway. Overall, this species is considered to have a low probability of passing through pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over time, this species may be able to move upstream (by wind or by aquatic life) through Indiana Harbor and the Grand Calumet River to navigable sections of the CAWS that flow toward the MRB. Therefore its probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: The suitability of flow and light conditions in the CAWS for *C. cryptica* is not documented, but this species has been documented far into inland rivers of the Great Lakes. It is uncertain why there are no records of this species in the Illinois Waterway. The lakeward flow of Indiana Harbor and the Grand Calumet River could decrease or inhibit spread through the pathway (section 3d). Although the potential for passage exists, it is uncertain why this species has not been recorded in the Illinois River despite being in southern Lake Michigan for decades. Therefore, the uncertainty associated with passage during this time step is considered to be low.

T_{10}: See T_0.

T_{25}: See T_0. Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *C. cryptica*. Flow conditions in Indiana Harbor and the Grand Calumet River are expected to remain unfavorable to passage. However, this species is more certain to pass through the CAWS in 25 years compared to the previous time step. Overall, the future uncertainty of this species passing through the pathway is medium.

T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   C. cryptica is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011). *C. cryptica* is found in ports and harbors where abnormally high chloride concentrations are found (Makarewicz 1987; Kipp 2011). This suggests that water quality may be suitable downstream of Brandon Road Lock and Dam near urban areas with ports and municipal runoff that could locally elevate conductivity (i.e., road salt). *C. cryptica* is typically reported as a lake species, so reservoirs as well as pools behind mainstem dams may provide suitable habitat.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat such as industrial areas and ports are found in the vicinity of Brandon Road Lock and Dam and are accessible by passive downstream drift.

Evidence for Probability Rating

C. cryptica has been documented in inland rivers (section 4a), and suitable water quality for *C. cryptica* may be present in areas with anthropogenic inputs downstream of Brandon Road Lock and Dam (sections 4a, 4b). However, this species is typically found in lakes and areas with high halogen and nutrient inputs. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions in the Illinois River for this species is not documented. Therefore, there is a high uncertainty associated with this species colonizing after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
   C. cryptica is globally widespread (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
   C. cryptica is a phytoplankton that would spread by drifting downstream.

c. *Fecundity*
   C. cryptica has a high doubling time under the appropriate environmental conditions.

d. *History of Invasion Success*
   C. cryptica has become a dominant phytoplankton in specific habitat conditions in the Great Lakes (Kipp 2011). No data was found for rivers.

e. *Human-Mediated Transport through Aquatic Pathways*
   C. cryptica can be transported in ballast water and discharged at ports and harbors where habitat is most suitable (Kipp 2011). There is heavy vessel traffic between Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The species specializes in waters with anthropogenic inputs (Kipp 2011). *C.* cryptica has specific nutrient and halogen requirements because it is typically a marine and brackish water species (Kipp 2011). Suitable habitat may be present in the MRB in waters impacted by anthropogenic inputs such as ports, harbors, and urban areas (Kipp 2011). *C. cryptica* is not described in the literature as a riverine species. Light availability may not be suitable in river systems.

Evidence for Probability Rating

C. cryptica is globally distributed (section 5a), so climate in the MRB will likely be suitable. *C. cryptica* is found in freshwater under specific water chemistry conditions (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. However, *C. cryptica* is not described in the literature as a riverine species (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the MRB.

Uncertainty: HIGH

Evidence for Uncertainty Rating

C. cryptica is considered a marine and brackish water species (section 5f). The suitability of flow and light conditions, as well as water quality, in the MRB is not clear for this species. Therefore, there is high uncertainty for the probability of this species to spread throughout the MRB.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
C. cryptica is a planktonic diatom that moves passively by flowing water. *C. cryptica* was first recorded in Lake Michigan in 1964 and was found in the Sandusky River (a major tributary of Lake Erie) in 1976, and now also occurs in Lake Ontario and Lake Huron (Kipp 2011), suggesting relatively rapid spread.

b. *Human-Mediated Transport through Aquatic Pathways*
C. cryptica was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances

(Klein et al. 2010). There is recreational but not commercial vessel traffic from the Great Lakes to the BSBH. There is commercial vessel traffic to Burns Harbor, which is adjacent to BSBH (USACE 2011a,b). Like other diatoms, *C. cryptica* could be transported by attaching to recreational boat hulls (GISP 2008), although this was not documented for specifically for this species.

c. *Current Abundance and Reproductive Capacity*
T_0: No data is available on the current abundance of *C. cryptica* in the Great Lakes. In harbors of the Great Lakes, abundance can be high relative to other diatoms (Kipp 2011). Records for *C. cryptica* in Lake Michigan exist as late as the mid-1990s (Kipp 2011). *C. cryptica* is reported to have a generation time ranging from 1.6 to 4 divisions per day (White 1974; Liu & Hellebust 1976; Sriharan et al. 1991).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see Suitable Habitat).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Records of *C. cryptica* exist off Evanston, IL, in 20 m (65 ft) of water approximately 96 km (60 mi) north of the BSBH. No data was found on the current distribution of *C. cryptica* in the Great Lakes (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *C. cryptica* was been found in southern Lake Michigan north of the BSBH in 1995 (Kipp 2011). In the Great Lakes, *C. cryptica* was significantly correlated with conductivity, nitrate (NO_3), silicon dioxide (SiO_2), and aerobic heterotrophs. Consequently, in the Great Lakes this species is closely associated with harbors (Kipp 2011).
T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *C. cryptica* during this time step.
***T_{25}*:** See T_{10}.
T_{50}: See T_{10}. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. However, diatoms are sensitive to climatological conditions. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *C. cryptica.* Future climate change is projected to increase water temperature in the

Great Lakes (Wuebbles et al. 2010), which could increase the productivity of *C. cryptica*. However, climate change could also affect other variables that determine phytoplankton productivity such as nutrients and water circulation, and the effects of these changes on *C. cryptica* are uncertain.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is considered to be established in Lake Michigan and has been found in Lake Michigan approximately 96 km (60 mi) north of the BSBH (section 2e). BSBH would provide suitable habitat (section 2f), and *C. cryptica* may currently be present though undocumented. Therefore, the probability of this species arriving at the BSBH is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Overall, southern Lake Michigan is expected to remain suitable for *C. cryptica*. Therefore, the probability of this species arriving at BSBH remains high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *C. cryptica* is considered to be established in Lake Michigan and was documented in southern Lake Michigan in 1995 (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Diatoms are sensitive to climatological and water quality conditions, which are sources of uncertainty for this species. The effects of future climate change on *C. cryptica* populations are uncertain (section 2f), but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
C. cryptica is a planktonic diatom that can spread rapidly by natural (current) or human-mediated (ballast water discharge) mechanisms. The species must move from BSBH more than 72 km (45 mi) downstream to Brandon Road Lock and Dam. *C. cryptica* was first recorded in Lake Michigan in 1964, and although it was identified offshore of Evanston, IL, it has not been reported to have passed through the CAWS. However, it can appear similar to *C. meneghiniana,* which is a common phytoplankton in the Illinois Waterway (Illinois Natural History Survey 1980).

b. *Human-Mediated Transport through Aquatic Pathways*
Although *C. cryptica* can be transported in ballast water (Kipp 2011), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012), and vessel traffic to Burns Harbor and the adjacent BSBH is via the lake. Consequently, some natural downstream dispersal would likely be necessary to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Flowing water is present throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: In the Great Lakes*, C. cryptica* is associated with harbors and waters with anthropogenic inputs (Kipp 2011). Much of the water in the CAWS is municipal effluent, which could contain the nutrients and conductivity that promote the growth of this species. In Oswego Harbor, *C. cryptica* was found in waters with chloride concentrations of 40–160 mg/L (Makarewicz 1987); chloride in the CAWS falls within this range (MWRD 2010). Turbidity is high in the CAWS (LimnoTech 2010), which could limit photosynthesis. *C. cryptica* is capable of temporary heterotrophic growth in dark conditions (White 1974). The optimal temperature range for the growth of *C. cryptica* is 22.5 to 25.0°C (72.5 to 77°F) (Pahl et al. 2010), which is typical of the seasonal temperature of the CAWS (MWRD 2010). *C. cryptica* is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately (64 km) 40 mi inland (Kipp 2011).

Water flows out of BSBH into Lake Michigan. The eastern segment of the south branch of the Little Calumet River also generally flows toward Lake Michigan, depending on the location and water level in Lake Michigan (GSWMD 2008). To enter and pass through BSBH, this species would have to move upstream through Burns Ditch and portions of the south branch of the Little Calumet River, where the flow direction is toward Lake Michigan.
T_{10}: See T_0.

T_{25}: See T_0. *C. cryptica* is sensitive to nutrients and conductivity levels. The discharge of common municipal contaminants containing such nutrients, metals, total dissolved solids, and sewage may decrease, due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *C. cryptica* is typically reported as a marine and brackish water species (section 3d). However, it has been reported in rivers with anthropogenic inputs and water quality may be suitable in the CAWS (section 3d). Once it reaches the Little Calumet, this species could flow downstream to Brandon Road Lock and Dam. There are no barriers within CAWS that would inhibit the drift of this species. However, although it has been in Lake Michigan for decades, there are no records of *C. cryptica* in the CAWS or downstream of Brandon Road Lock and Dam. The lack of records may be due to misidentification, habitat (specifically water quality) in the CAWS being unsuitable, or a lack of phytoplankton surveys in the Illinois Waterway. Because of the lack of vessel traffic (section 3b), natural spread through the south branch of the Little Calumet River will likely be required for *C. cryptica* to move from Lake Michigan to the Calumet Sag Channel. Water flow in BSBH and portions of the Little Calumet River is toward Lake Michigan. Cryptic algae are phytoplankton and are not likely to move upstream through BSBH and the south branch of the Little Calumet River. Therefore, this species is considered to have a low probability of passing through pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over time, this species may be able to move upstream (by wind or by aquatic life) through BSBH and the Little Calumet River to navigable sections of the CAWS that flow toward the MRB. Therefore its probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: The suitability of flow and light conditions in the CAWS for *C. cryptica* is not documented, but this species has been documented far into inland rivers of the Great Lakes. It is uncertain why there are no records of this species in the Illinois Waterway. Although the potential for passage exists, it is uncertain why this species has not been

recorded in the Illinois River despite being in southern Lake Michigan for decades. The lakeward flow of the BSBH and south branch of the Little Calumet River could decrease or inhibit spread through the pathway (section 3d). Therefore, the uncertainty associated with passage during this time step is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *C. cryptica*. Flow conditions in BSBH and the south branch of the Little Calumet River are expected to remain unfavorable to passage. However, this species is more certain to pass through the CAWS in 25 years compared to the previous time step. Overall, the future uncertainty of this species passing through the pathway is medium.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
C. cryptica is typically reported in marine and brackish systems, but it is established in the Sandusky River approximately 64 km (40 mi) inland (Kipp 2011). It has been reported in rivers with anthropogenic inputs, and water quality may be suitable downstream of Brandon Road Lock and Dam near urban areas with ports and municipal runoff. *C. cryptica* is typically reported as a lake species, so reservoirs as well as pools behind mainstem dams may provide suitable habitat.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat such as industrial areas and ports is found in the vicinity of Brandon Road Lock and Dam and is accessible by passive downstream drift.

Evidence for Probability Rating

C. cryptica has been documented in inland rivers (section 4a), and suitable water quality for *C. cryptica* may be present in areas with anthropogenic inputs downstream of Brandon Road Lock and Dam (sections 4a, 4b). However, this species is typically found in lakes and areas with high halogen and nutrient inputs. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: HIGH

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions in the Illinois River for this species is not documented. Therefore, there is a high uncertainty associated with this species colonizing after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
C. cryptica is globally widespread (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. Type of Mobility/Invasion Speed
C. cryptica is a phytoplankton that would spread by drifting downstream through the MRB.

c. Fecundity
C. cryptica has a high doubling time under the appropriate environmental conditions.

d. History of Invasion Success
C. cryptica has become a dominant phytoplankton in specific habitat conditions in the Great Lakes (Kipp 2011). No data was found for rivers.

e. Human-Mediated Transport through Aquatic Pathways
C. cryptica can be transported in ballast water and discharged at ports and harbors where habitat is most suitable (Kipp 2011). There is heavy vessel traffic between Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The species specializes in waters with anthropogenic inputs (Kipp 2011). *C. cryptica* has specific nutrient and halogen requirements because it is typically a marine and brackish water species (Kipp 2011). Suitable habitat may be present in the MRB in waters impacted by anthropogenic inputs such as ports, harbors, and urban areas (Kipp 2011). *C. cryptica* is not described in the literature as a riverine species. Light availability may not be suitable in river systems.

Evidence for Probability Rating

C. cryptica is globally distributed (section 5a), so climate in the MRB will likely be suitable. *C. cryptica* is found in freshwater under specific water chemistry conditions (section 5f).

Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. However, *C. cryptica* is not described in the literature as a riverine species (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: HIGH

Evidence for Uncertainty Rating

C. cryptica is considered a marine and brackish water species (section 5f). The suitability of flow and light conditions, as well as water quality, in the MRB is not clear for this species. Therefore, there is high uncertainty for the probability of this species to spread throughout the MRB.

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E.2.3.2 Grass Kelp - *Enteromorpha flexuosa*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Medium	High	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
E. flexuosa is a marine attached alga with a worldwide distribution. Its spores are released into the water daily and can float for 8–11 days (Beach et al. 1995). The species is highly invasive, has a rapid growth rate, and can tolerate a wide range of environmental conditions (Lougheed & Stevenson 2004). The ecological success of *E. flexuosa* is attributable in part to the readily available pool of motile unicells that are able to rapidly colonize new areas (Hill 2001). The chance for successful settlement of

these cells is greatly enhanced because gametes and zoospores of this species remain viable for 10 or more days after release due to their ability to photosynthesize (Beach et al. 1995). The adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. Human-Mediated Transport through Aquatic Pathways

E. flexuosa is documented to be transported by boat hulls (Lougheed & Stevenson 2004). WPS is not a port with cargo vessel use; however, there is recreational boat use in the Wilmette Harbor that could potentially transport this species from the Great Lakes to the WPS.

c. Current Abundance and Reproductive Capacity

T_0: *E. flexuosa* is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, with unicells remaining motile for up to 11 days (Hill 2001). A 2003 study indicated *E. flexuosa* was present in Muskegon Lake and in 2 of 11 nearby inland lakes and lagoons that were surveyed (Sturtevant 2011). Overall, the results suggested that, although *E. flexuosa* may not be widespread, local abundance can be high (Lougheed & Stevenson 2004). *E. flexuosa* is an excellent pioneer species, able to colonize newly available strata year-round (Emerson & Zedler 1978). Yet it is not good at competing with other successional species. In an experimental study of the recolonization of intertidal algae following disturbance, Emerson and Zedler (1978) showed that *E. flexuosa* tends to be present at low densities (as measured in percent cover) throughout the year in undisturbed zones. Following disturbance to an area, the density of this species increases dramatically within 2–3 weeks (Emerson & Zedler 1978). However, as other algae become established, the percent cover for this species declines (Emerson & Zedler 1978). This observation suggests that *E. flexuosa* may be unable to maintain dominance in the presence of later successional species such as *Ulva* spp. and other perennial algae that are present in the Great Lakes (Emerson & Zedler 1978).
T_{10}: See T_0. If existing trends continue, *E. flexuosa* may increase in abundance in the Great Lakes.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway

T_0: The closest *E. flexuosa* has been recorded to the WPS was on the beaches of Muskegon Lake in 2003 (Lougheed & Stevenson 2004). Muskegon Lake is a coastal lake on the eastern shore of, and with a hydrologically connected to, Lake Michigan (Lougheed & Stevenson 2004). Muskegon Lake is approximately 290 km (180 mi) from

the pathway entrance. Water circulation in Lake Michigan is typically counterclockwise (Beletsky & Schwab 2001). Therefore, currents would transport the species north, away from the pathway entrance.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The species is widespread around the world in inland and coastal waters (Lougheed & Stevenson 2004). The native range of *E. flexuosa* is unknown, but the species is found worldwide; therefore, the climate in southern Lake Michigan is likely to be suitable. *E. flexuosa* is primarily a marine species, but it is highly tolerant of freshwater conditions. Lougheed and Stevenson (2004) state that industrial activity resulting in increased nutrients and salinity in associated waters may have facilitated the invasion of this marine taxon. It is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). Growth of this species in outdoor ponds in India showed that *E. flexuosa* was able to sustain growth in water temperatures as high as 30°C (86°F) (Mairh et al. 1986; Hill 2001). Favorable growth was maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). Optimal reproduction occurs at temperatures under 30°C (86°F) in waters with a pH of approximately 8.2 (Hill 2001). Historically, urban runoff has allowed the establishment of several eutrophic and/or marine species offshore of the Chicago area, including *Bangia atrpurpurea* and *Cyclotella cryptica*.

E. flexuosa typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). In Muskegon Lake it was primarily found growing on submerged aquatic macrophytes in windswept, littoral areas of eutrophic and mesotrophic lakes (Lougheed & Stevenson 2004). Although submerged macrophytes are not common along the shoreline of southern Lake Michigan, there are scattered macroalgal beds (*Cladophora*) near the WPS (MTRI 2012). Wilmette Harbor, on the lake side of the WPS, has generally sandy beaches and riprap, which are suitable for the species to colonize. There are no emergent wetlands near the WPS (unpublished data from the USACE).

T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *E. flexuosa* during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *E. flexuosa*. In particular, mean water temperature is expected to increase (Wuebbles et al. 2010). However, *E. flexuosa* is found in a wide range of water temperatures and is globally distributed (Hill 2001). Therefore, temperature is expected to remain suitable. However, changes in nutrients and conductivity related to future climate change or new environmental regulations may affect the suitability of southern Lake Michigan for this species.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is a highly invasive, highly fecund species (sections 2a, 2c) that can be transferred by boats (section 2b). The WPS does not receive cargo vessels, but there is recreational boat activity in the area. *E. flexuosa* has been established in Muskegon Lake since 2003, but it has yet to be identified at the WPS (section 2e). The habitat near the WPS is likely suitable for the species to establish due to the higher-energy shoreline of Lake Michigan, which has rocky shoals and hard substrate. The species is opportunistic and may be able to populate disturbed areas that remove competitors such as *Cladophora* (section 2f). Historically, urban runoff has supported marine algal species in the vicinity of the WPS (section 2e). Currently, *E. flexuosa* has only been recorded along the eastern shoreline of central Lake Michigan. Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0. The current of the lake may transport the species away from the pathway entrance; however, transport by boat is possible. This species is expected to spread over time and the probability of arrival remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: *E. flexuosa* is considered to be a rapid invader (section 2a), and the latest record of its presence is from 2003. Therefore, the current location of the species is uncertain (section 2e). In addition, this is a marine species and the suitability of nutrient and conductivity levels in the vicinity of the WPS are uncertain. Overall, the uncertainty of the species arriving at the pathway is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. In addition, the future effects of climate change on *E. flexuosa* and habitat suitability in Lake Michigan are uncertain. Therefore, uncertainty remains medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the CAWS pathway entrance.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
E. flexuosa must move more than 64 km (40 mi) downstream from WPS to reach Brandon Road Lock and Dam. The species is highly invasive, has a rapid growth rate, and can tolerate a wide range of environmental conditions (Lougheed & Stevenson 2004). Its spores are transported by currents, but the adults are attached, unless they become dislodged, in which case it can be transported as floating mats (John et al. 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa is documented to have been transported by boat hulls (Lougheed & Stevenson 2004). There is no cargo traffic and limited recreational vessel traffic in the North Shore Channel (USACE 2011a,b); therefore, natural downstream dispersal through the North Shore Channel will likely be required for *E. flexuosa* to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The sluice gate at the WPS is a barrier that could retard natural dispersion. However, water that could transport the species is pumped from Lake Michigan into the North Shore Channel.
T_{10}: See T_0. Future operations of the sluice gate are not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *E. flexuosa* has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. The species is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010), suggesting that the depth there is suitable. Growth of the species is maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species has been found in turbid water (Sand-Jenson et al. 2008), and turbidity is high in the CAWS (LimnoTech 2010). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Portions of the CAWS flow through limestone bedrock, and there is heavy municipal water discharge into the CAWS; these sources may provide nutrients and carbonates required by *E. flexuosa*.

Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation, and riprap banks are common. In the North Shore Channel and the upper North Branch of the Chicago River there are partly shaded banks with aquatic plants, tree roots, and brush debris jams, and sediments consist of silt and sand. Further downstream in the Chicago River and in the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). Toxic organic and inorganic pollutants are present in the Chicago River (Gallagher et al. 2009). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution, even as the abundance of other genera decreases. In areas affected by polluted discharge, *E. flexuosa* can be a highly successful invader (Lougheed & Stevenson 2004).

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012). These changes may reduce habitat suitability for *E. flexuosa* in the CAWS.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is thought to have a rapid invasion speed (section 3a) and could move from Lake Michigan to the North Shore Channel by water pumping through a sluice gate (section 3c). The planktonic spore stage may facilitate downstream transport to Brandon Road Lock and Dam (section 3a). There is a low potential for human-mediated transport in the North Shore Channel (section 3b), but spores or fragments could float downstream through this portion of the CAWS. Habitat is suitable for *E. flexuosa* throughout much of the CAWS (section 3d), and this species has been found in rivers and tributaries where suitable water quality conditions are present (section 3d). The urban runoff entering the CAWS may provide the high nutrient and conductivity levels that this species prefers. There is low submerged aquatic macrophyte cover in the CAWS, which is a preferred habitat for this species (section 3d). Within the current time step, *E. flexuosa* spores or fragments may drift from WPS to Brandon Road Lock and Dam by natural dispersion or become attached to vessels in portions of the pathway with vessel traffic. The probability of passage is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Although this species is commonly found in waters that are heavily affected by human uses, it is a marine species and the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support *E. flexuosa* is uncertain. *E. flexuosa* is an opportunistic species and will invade areas in the CAWS where a disturbance opens up space for the species. The potential rate of spread of this species through the CAWS is uncertain. Therefore, the uncertainty of the species passing through the pathway is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although the probability of *E. flexuosa* passing through the CAWS increases with time, the future effects of water quality improvements on *E. flexuosa* and habitat suitability in the CAWS are uncertain. Therefore, the uncertainty of the species passing through the pathway at this time step remains medium.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

***Factors That Influence Colonization of Species* (*Considering All Life Stages*)**

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   E. flexuosa has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). The species typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). Physical habitat such as manmade hard substrate is present in the vicinity of Brandon Road Lock and Dam. *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). *Enteromorpha* spp. do well in polluted and eutrophic water (Aguilar-Rosas & Pacheco-Ruiz 1989). Suitable physical habitat is present below Brandon Road Lock and Dam in the form of rocks, manmade hard substrate, and submerged aquatic vegetation. Water quality may be suitable in areas with high urban and agricultural runoff.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse to suitable habitat by spreading downstream as spores or adults, or by vessel transport.

Evidence for Probability Rating

Suitable physical habitat for the *E. flexuosa* is present downstream of Brandon Road Lock and Dam (section 4a). Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present below Brandon Road Lock and Dam (section 4a). Therefore, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The colonization of *E. flexuosa* in freshwater will depend on the presence of suitable water quality below Brandon Road Lock and Dam, likely similar to conditions above the dam. The ability of hydraulic and chemical conditions below Brandon Road Lock and Dam to support *E. flexuosa* is uncertain. Therefore, the uncertainty associated with the species' probability of colonization is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
E. flexuosa is widespread globally and is tolerant of a wide variety of conditions (Hill 2001; Lougheed & Stevenson 2004).

b. *Type of Mobility/Invasion Speed*
E. flexuosa has a worldwide distribution. The species is highly invasive, has a rapid growth rate, and can tolerate a wide range of environmental conditions (Lougheed & Stevenson 2004).

c. *Fecundity*
E. flexuosa is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001).

d. *History of Invasion Success*
E. flexuosa is a highly successful invasive species in marine and estuarine habitats. It has been documented in large rivers with the appropriate water quality conditions (Holmes & Whitton 1977).

e. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa is documented to be transported by boat hulls (Lougheed & Stevenson 2004).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
E. flexuosa is an opportunistic species that specializes in colonizing aquatic macrophytes and disturbed areas. *E. flexuosa* has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). The species typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution. Portions of the MRB with high agricultural and urban runoff may be suitable for this species.

Evidence for Probability Rating

E. flexuosa is globally distributed, so climate in the MRB will likely be suitable (section 5a). The species is found in rivers, reservoirs, and streams under specific water chemistry conditions (section 5f). Within such habitats in the MRB, waters with high anthropogenic nutrient inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present in much of the MRB (section 5f). Overall, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: HIGH

Evidence for Uncertainty Rating

E. flexuosa is considered a marine and brackish water species (section 5f). The suitability of nutrient, conductivity, flow, and light conditions in the MRB for this species is uncertain. Therefore, the uncertainty of spreading is high.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Medium	High	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
E. flexuosa is a marine attached alga with a worldwide distribution. The spores are released into the water daily and can float for 8–11 days (Beach et al. 1995). The species is considered highly invasive, has a rapid growth rate, and can tolerate a wide range of environmental conditions (Lougheed & Stevenson 2004). The ecological success of *E. flexuosa* is, in part, attributable to the readily available pool of motile unicells that are able to rapidly colonize new areas (Hill 2001). The chance for successful settlement of these cells is greatly enhanced because gametes and zoospores of this

species remain viable for 10 or more days after release due to their ability to photosynthesize (Beach et al. 1995). The adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004). There is recreational and commercial boat traffic between the CRCW and multiple ports in Lake Michigan (USACE 2011a,b), including Muskegon, Michigan, where grass kelp can be found (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: *E. flexuosa* is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001). A 2003 study indicated *E. flexuosa* was present in Muskegon Lake and in 2 of 11 nearby inland lakes and lagoons that were surveyed (Sturtevant 2011). Overall, these results suggest that, although *E. flexuosa* may not be widespread, local abundance can be high (Lougheed & Stevenson 2004). *E. flexuosa* is an excellent pioneer species, able to colonize newly available strata year-round (Emerson & Zedler 1978). However, it is not good at competing with other successional species. In an experimental study of recolonization of intertidal algae following disturbance, Emerson and Zedler (1978) showed that *E. flexuosa* tends to be present at low densities (as measured in percent cover) throughout the year in undisturbed zones. Following disturbance to an area, the density of this species increases dramatically within 2–3 weeks (Emerson & Zedler 1978). However, as other algae become established, the percent cover for this species declines (Emerson & Zedler 1978). This observation suggests that *E. flexuosa* may be unable to maintain dominance in the presence of later successional species such as *Ulva* spp. and other perennial algae that are present in the Great Lakes (Emerson & Zedler 1978).
T_{10}: See T_0. If existing trends continue, *E. flexuosa* may increase in abundance in the Great Lakes.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The closest *E. flexuosa* has been recorded to the CRCW was on the beaches of Muskegon Lake in 2003 (Lougheed & Stevenson 2004). Muskegon Lake is a coastal lake on the eastern shore of, and hydrologically connected to, Lake Michigan (Lougheed & Stevenson 2004). Muskegon Lake is approximately 290 km (180 mi) from the pathway entrance. Water circulation in Lake Michigan is typically counterclockwise (Beletsky &

Schwab 2001). Therefore, currents would transport the species north, away from the pathway entrance.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The species is widespread around the world in inland and coastal waters (Lougheed & Stevenson 2004). The native range of *E. flexuosa* is unknown, but the species is found worldwide; therefore the climate in southern Lake Michigan is likely to be suitable. *E. flexuosa* is primarily a marine species, but it is highly tolerant of freshwater conditions. Lougheed and Stevenson (2004) state that industrial activity resulting in increased nutrients and salinity of associated waters may have facilitated the invasion of this marine taxon. It is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). Growth of *E. flexuosa* in outdoor ponds in India showed that this species was able to sustain growth in water temperatures as high as 30°C (86°F) (Mairh et al. 1986). Favorable growth was maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). Optimal reproduction occurs at temperatures under 30°C (86°F), in waters with a pH of approximately 8.2 (Hill 2001). Historically, urban runoff has allowed the establishment of several eutrophic and/or marine species offshore of the Chicago area, including *Bangia atrpurpurea* and *Cyclotella cryptica*.

E. flexuosa typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). In Muskegon Lake it was primarily found growing on submerged aquatic macrophytes in windswept, littoral areas of eutrophic and mesotrophic lakes (Lougheed & Stevenson 2004). Submerged macrophytes are not common along the shoreline of southern Lake Michigan, but there are extensive *Cladophora* beds that may provide suitable habitat (MTRI 2012). CRCW has generally sandy beaches and riprap, which are suitable for the species to colonize.
T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *E. flexuosa* during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *E. flexuosa*. In particular, mean water temperature is expected to increase (Wuebbles et al. 2010). However, *E. flexuosa* can be found in a wide range of water temperatures and is globally distributed (Hill 2001). Therefore, water temperature is expected to remain suitable. However, changes in nutrients and conductivity related to future climate change or new environmental regulations may affect the suitability of southern Lake Michigan for this species.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is a highly invasive, highly fecund species (sections 2a, 2c) that can be transferred by boats (section 2b). The CRCW receives recreational boat activity from Lake Michigan and cargo vessels from many ports in the Great Lakes, including Muskegon, Michigan, where grass kelp can be found. The species has been established in Lake Michigan since 2003, but it has yet to be identified at the CRCW (section 2e). The habitat near the CRCW is likely suitable for *E. flexuosa* due to the higher-energy shoreline of Lake Michigan, which has rocky shoals and hard substrate. The species is opportunistic and may be able to inhabit disturbed areas that remove competitors such as *Cladophora* (section 2f). Historically, urban runoff has supported marine algal species in the vicinity of the CRCW (section 2e). Currently, *E. flexuosa* has only been recorded along the eastern shoreline of central Lake Michigan. Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0. *E. flexuosa* is highly invasive and suitable physical habitat is present in the vicinity of the CRCW. The current of the lake may transport the species away from the pathway entrance; however, transport by boat is also possible. Therefore, this species is expected to spread to the CRCW over time and the probability of arrival increases to medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: *E. flexuosa* is considered to be a rapid invader (section 2a), and the latest record of its presence is from 2003. Therefore, the current location of the species is uncertain (section 2e). In addition, this is a marine species and the suitability of nutrient and conductivity levels in the vicinity of the CRCW are uncertain. Overall, the uncertainty of the species arriving at the pathway is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. In addition, the future effects of climate change on *E. flexuosa* and habitat suitability in Lake Michigan are uncertain. Therefore, uncertainty remains medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the CAWS pathway entrance.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

E. flexuosa must move more than 64 km (40 mi) downstream from CRCW to reach Brandon Road Lock and Dam. The species is highly invasive, has a rapid growth rate, and can tolerate a wide range of environmental conditions (Lougheed & Stevenson 2004). Its spores are transported by currents, but the adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. Human-Mediated Transport through Aquatic Pathways

E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004). There is recreational and commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a,b). The discharge of ballast water originating from the Great Lakes would not likely occur within the CAWS (NBIC 2012), but hull transport to Brandon Road Lock and Dam is possible.

c. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *E. flexuosa* has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. The species is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). The maximum depth in the CAWS is about 10 m (32.8 ft) deep, and depth is typically around 5 m (16.4 ft) (LimnoTech 2010), suggesting that the depth there is suitable. Growth of the species is maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001), and the water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species has been found in turbid water (Sand-Jenson et al. 2008), and turbidity is high in the CAWS (LimnoTech 2010). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Portions of the CAWS flow through limestone bedrock and there is heavy municipal water discharge into the CAWS; these sources may provide the nutrients and carbonates required by *E. flexuosa*.

Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation, and riprap banks are common. In the Chicago River and the CSSC, there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). Toxic organic and inorganic pollutants are present in the Chicago River (Gallagher et al. 2009). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution, even as the abundance of other genera decreases. In areas affected by polluted discharge, *E. flexuosa* can be a highly successful invader (Lougheed & Stevenson 2004).

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012). These changes may reduce habitat suitability for *E. flexuosa* in the CAWS.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is thought to have a rapid invasion speed (section 3a) and can move from Lake Michigan to the Chicago River on boat hulls or by floating through the locks (section 3b). The planktonic spore stage may facilitate downstream transport to Brandon Road Lock and Dam (section 3a). Habitat is suitable for *E. flexuosa* throughout much of the CAWS (section 3d), and the species has been found in rivers and tributaries where suitable water quality conditions are present (section 3d). The urban runoff entering the CAWS may provide the high nutrient and conductivity levels that this species prefers. However, this is an opportunistic species that may require uncolonized habitat. There is low submerged aquatic macrophyte cover in the CAWS, which is a preferred habitat for this species (section 3d). Within the current time step, *E. flexuosa* spores or fragments may drift from CRCW to Brandon Road Lock and Dam as a result of natural dispersion or become attached to vessels. The probability of passage is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Although this species is commonly found in waters that are heavily affected by human uses, it is a marine species, and the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support *E. flexuosa* is uncertain. *E. flexuosa* is an opportunistic species that could grow where a disturbance opens up space. The potential rate of spread of this species through the CAWS is uncertain. Therefore, the uncertainty of the species passing through the pathway is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although the probability of E. flexuosa passing through the CAWS increases with time, the future effects of water quality improvements on E. flexuosa and habitat suitability in the CAWS are uncertain. Therefore, the uncertainty of the species passing through the pathway at this time step remains medium.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
E. flexuosa has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). Physical habitat such as manmade hard substrate is present in the vicinity of Brandon Road Lock and Dam. *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). *Enteromorpha* spp. do well in polluted and eutrophic water (Aguilar-Rosas & Pacheco-Ruiz 1989). Suitable physical habitat is present below Brandon Road Lock and Dam in the form of rocks, manmade hard substrate, and submerged aquatic vegetation. Water quality may be suitable in areas with high urban and agricultural runoff.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can disperse to suitable habitat by vessel transport or by spreading downstream as spores or adults.

Evidence for Probability Rating

Suitable physical habitat for the *E. flexuosa* is present downstream of Brandon Road Lock and Dam (section 4a), particularly in disturbed areas. Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present below Brandon Road Lock and Dam (section 4a). Therefore, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The colonization of *E. flexuosa* in freshwater will depend on the presence of suitable water quality below Brandon Road Lock and Dam, which likely is similar to conditions above the dam. The ability of hydraulic and chemical conditions below Brandon Road Lock and Dam to support *E. flexuosa* is uncertain. Therefore, the uncertainty associated with the species' probability of colonization is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
   E. flexuosa is globally widespread and is tolerant of a wide variety of conditions (Hill 2001; Lougheed & Stevenson 2004).

b. *Type of Mobility/Invasion Speed*
   E. flexuosa has a worldwide distribution. The species is highly invasive, with a rapid growth rate and tolerance to a wide range of environmental conditions (Lougheed & Stevenson 2004).

c. *Fecundity*
   E. flexuosa is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remaining motile for up to 11 days (Hill 2001).

d. *History of Invasion Success*
E. flexuosa is a highly successful invasive species in marine and estuarine habitats. It has been documented in large rivers with appropriate water quality conditions (Holmes & Whitton 1977).

e. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
E. flexuosa is an opportunistic species that specializes in colonizing aquatic macrophytes and disturbed areas. The species has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution. Portions of the MRB with high agricultural and urban runoff may be suitable for this species.

Evidence for Probability Rating

E. flexuosa is globally distributed, so climate in the MRB will likely be suitable (section 5a). The species is found in rivers, reservoirs, and streams with specific water chemistry conditions (section 5f). Within such habitats in the MRB, waters with high anthropogenic nutrient inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present in much of the MRB (section 5f). Overall, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: HIGH

Evidence for Uncertainty Rating

E. flexuosa is considered a marine and brackish water species (section 5f). The suitability of nutrient, conductivity, flow, and light conditions in the MRB for this species is uncertain. Therefore, the uncertainty of spreading is high.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Medium	High	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

E. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

E. flexuosa is a marine attached alga with a worldwide distribution. The spores are released into the water daily and can float for 8 to 11 days (Beach et al. 1995). The species is highly invasive, has a rapid growth rate, and can tolerate a wide range of environmental conditions (Lougheed & Stevenson 2004). The ecological success of *E. flexuosa* is, in part, attributable to the readily available pool of motile unicells that are able to rapidly colonize new areas (Hill 2001). The chance for successful settlement of these cells is greatly enhanced because gametes and zoospores of this species remain viable for 10 or more days after release due to their ability to photosynthesize

(Beach et al. 1995). The adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004). There is recreational and commercial boat traffic between the Calumet Harbor and multiple ports in Lake Michigan (USACE 2011a,b), including Muskegon, Michigan, where grass kelp can be found (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: *E. flexuosa* is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001). A 2003 study indicated *E. flexuosa* was present in Muskegon Lake and in 2 of 11 nearby inland lakes and lagoons that were surveyed (Sturtevant 2011). Overall, the results suggested that, although *E. flexuosa* may not be widespread, local abundance can be high (Lougheed & Stevenson 2004). *E. flexuosa* is an excellent pioneer species, able to colonize newly available strata year-round (Emerson & Zedler 1978). However, it is not good at competing with other successional species. In an experimental study of the recolonization of intertidal algae following a disturbance, Emerson and Zedler (1978) showed that *E. flexuosa* tends to be present at low densities (as measured in percent cover) throughout the year in undisturbed zones. Following disturbance to an area, the density of this species increases dramatically within 2–3 weeks (Emerson & Zedler 1978). However, as other algae become established, the percent cover for this species declines (Emerson & Zedler 1978). This observation suggests that *E. flexuosa* may be unable to maintain dominance in the presence of later successional species such as *Ulva* spp. and other perennial algae that are present in the Great Lakes (Emerson & Zedler 1978).
T_{10}: See T_0. If existing trends continue, *E. flexuosa* may increase in abundance in the Great Lakes.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The closest *E. flexuosa* has been recorded to Calumet Harbor was on the beaches of Muskegon Lake in 2003 (Lougheed & Stevenson 2004). Muskegon Lake is a coastal lake on the eastern shore of, and hydrologically connected to, Lake Michigan (Lougheed & Stevenson 2004). Muskegon Lake is approximately 290 km (180 mi) from the pathway entrance. Water circulation in Lake Michigan is typically counterclockwise (Beletsky &

Schwab 2001). Therefore, currents would transport the species north away from the pathway entrance.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

E. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The species is widespread around the world in inland and coastal waters (Lougheed & Stevenson 2004). The native range of *E. flexuosa* is unknown, but the species is found worldwide; therefore, the climate in southern Lake Michigan is likely to be suitable. *E. flexuosa* is primarily a marine species that is highly tolerant of freshwater conditions. Lougheed and Stevenson (2004) state that industrial activity resulting in increased nutrients and salinity of associated waters may have facilitated the invasion of this marine taxon. It is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). Growth of *E. flexuosa* in outdoor ponds in India showed that this species was able to sustain growth in water temperatures as high as 30°C (86°F) (Mairh et al. 1986). Favorable growth was maintained at temperatures ranging from 15.5 to 30°C (59.9 to 8°F) (Hill 2001). Optimal reproduction occurs at temperatures under 30°C (86°F) in waters with a pH of approximately 8.2 (Hill 2001). Historically, urban runoff has allowed the establishment of several eutrophic and/or marine species offshore of the Chicago area, including *Bangia atrpurpurea* and *Cyclotella cryptic*.
E. flexuosa typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). In Muskegon Lake it was primarily found growing on submerged aquatic macrophytes in windswept, littoral areas of eutrophic and mesotrophic lakes (Lougheed & Stevenson 2004). Submerged macrophytes are not common along the shoreline of southern Lake Michigan, but there are extensive *Cladophora* beds that may provide suitable habitat (MTRI 2012). Calumet Harbor has generally sandy beaches and riprap, which are suitable for the species to colonize.
T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *E. flexuosa* during this time step.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *E. flexuosa*. In particular, mean water temperature is expected to increase (Wuebbles et al. 2010). However, *E. flexuosa* is found in a wide range of water temperatures and is globally distributed (Hill 2001). Therefore, temperature is expected to remain suitable. However, changes in nutrients and conductivity related to future climate change or new environmental regulations may affect the suitability of southern Lake Michigan for this species.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is a highly invasive, highly fecund species (sections 2a, 2c) that can be transferred by boats (section 2b). Calumet Harbor receives cargo vessels and recreational boat activity from Lake Michigan, as well as cargo vessels from many ports in the Great Lakes, including Muskegon, Michigan, where grass kelp can be found. The species has been established in Lake Michigan since 2003, but it has yet to be identified at Calumet Harbor (section 2e). The habitat near Calumet Harbor is likely suitable for *E. flexuosa* due to the higher energy shoreline of Lake Michigan with rocky shoals and hard substrate. The species is opportunistic and may be able to inhabit disturbed areas that lack competitors such as *Cladophora* (section 2f). Historically, urban runoff has supported marine algal species in the vicinity of Calumet Harbor (section 2e). Currently, however, *E. flexuosa* has only been recorded along the eastern shoreline of central Lake Michigan. Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0. *E. flexuosa* is highly invasive, and suitable physical habitat is present in the vicinity of Calumet Harbor. The current of the lake may transport the species away from the pathway entrance; however, transport by boat is also possible. This species is expected to spread over time and the probability of arrival remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: *E. flexuosa* is considered to be a rapid invader (section 2a), and the latest record of its presence is from 2003. Therefore, the current location of the species is uncertain (section 2e). In addition, this is a marine species and the suitability of nutrient and conductivity levels in the vicinity of Calumet Harbor is uncertain. Overall, the uncertainty of the species arriving at the pathway is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. In addition, the future effects of climate change on *E. flexuosa* and habitat suitability in Lake Michigan are uncertain. Therefore, uncertainty remains medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the CAWS pathway entrance.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
E. flexuosa must move downstream to reach Brandon Road Lock and Dam. The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004). Its spores are transported by currents, but the adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa is documented to be transported by boat hulls (Lougheed & Stevenson 2004). Commercial vessel traffic to the Calumet Harbor is lakewise, but there is vessel traffic between Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, which is located just below the Calumet Harbor (USACE 2011a,b). The discharge of ballast water originating from the Great Lakes would not be likely to occur within the CAWS (NBIC 2012), but hull transport to Brandon Road Lock and Dam is possible.

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *E. flexuosa* has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. The species is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010), suggesting that the depth there is suitable. Growth of the species is maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species has been found in turbid water (Sand-Jenson et al. 2008), and turbidity is high in the CAWS (LimnoTech 2010). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution, even as the abundance of other genera decreases. In areas affected by

polluted discharge, *E. flexuosa* can be a highly successful invader (Lougheed & Stevenson 2004). Portions of the CAWS flow through limestone bedrock and there is heavy municipal water discharge into the CAWS; these sources may provide the nutrients and carbonates required by *E. flexuosa*.

Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation, and riprap banks are common. In the Calumet River, the Calumet Sag Channel, and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). There are also ditches and tributaries along the Calumet Sag Channel that may provide suitable habitat.

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012). These changes may reduce habitat suitability in the CAWS.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is thought to have a rapid invasion speed (section 3a) and can move from Lake Michigan to the Calumet River on boat hulls or by floating (section 3b). The planktonic spore stage may facilitate downstream transport to Brandon Road Lock and Dam (section 3a). Habitat is suitable for *E. flexuosa* throughout much of the CAWS (section 3d), and this species has been found in rivers and tributaries where suitable water quality conditions are present (section 3d). The urban runoff entering the CAWS may provide the high nutrient and conductivity levels that this species prefers. However, this is an opportunistic species that may require uncolonized habitat. There is low submerged aquatic macrophyte cover in the CAWS, which is a preferred habitat for this species (section 3d). Within the current time step, *E. flexuosa* spores or fragments may drift from CRCW to Brandon Road Lock and Dam as a result of natural dispersion or becoming attached to vessels. The probability of passage is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Although this species is commonly found in waters that are heavily affected by human uses, it is a marine species and the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support *E. flexuosa* is uncertain. *E. flexuosa* is an opportunistic species that may grow in the CAWS where a disturbance opens up space for the species. The potential rate of spread of this species through the CAWS is uncertain. Therefore, the uncertainty of the species passing through the pathway is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although the probability of E. flexuosa passing through the CAWS increases with time, the future effects of water quality improvements on E. flexuosa and habitat suitability in the CAWS are uncertain. Therefore, the uncertainty of the species passing through the pathway at this time step remains medium.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Consider All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
E. flexuosa has been found in drainage channels with slow water current (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). The species typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). Physical habitat such as manmade hard substrate is present in the vicinity of Brandon Road Lock and Dam. *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). *Enteromorpha* spp. do well in polluted and eutrophic water (Aguilar-Rosas and Pacheco-Ruiz 1989). Suitable physical habitat is present below Brandon Road Lock and Dam in the form of rocks, manmade hard substrate, and submerged aquatic vegetation. Water quality may be suitable in areas with high urban and agricultural runoff.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse to suitable habitat by spreading downstream as spores or adults, or by vessel transport.

Evidence for Probability Rating

Suitable physical habitat for the *E. flexuosa* is present downstream of Brandon Road Lock and Dam (section 4a), especially in disturbed areas. Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present below Brandon Road Lock and Dam (section 4a). Therefore, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The colonization of *E. flexuosa* in freshwater will depend on the presence of suitable water quality below Brandon Road Lock and Dam, which likely is similar to conditions above the dam. The ability of hydraulic and chemical conditions below Brandon Road Lock and Dam to support *E. flexuosa* is uncertain. Therefore, the uncertainty associated with the species' probability of colonization is medium.

5. **P(spreads): MEDIUM**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
E. flexuosa is globally widespread and is tolerant of a wide variety of conditions (Hill 2001; Lougheed & Stevenson 2004).

b. *Type of Mobility/Invasion Speed*
E. flexuosa has a worldwide distribution. The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004).

c. *Fecundity*
E. flexuosa is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001).

d. *History of Invasion Success*
   E. flexuosa is a highly successful invasive species in marine and estuarine habitats. It has been documented in large rivers with the appropriate water quality conditions (Holmes & Whitton 1977).

e. *Human-Mediated Transport through Aquatic Pathways*
   E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   E. flexuosa is an opportunistic species that specializes in colonizing aquatic macrophytes and disturbed areas. The species has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). The species typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution. Portions of the MRB with high agricultural and urban runoff may be suitable for this species.

Evidence for Probability Rating

E. flexuosa is globally distributed, so climate in the MRB will likely be suitable (section 5a). The species is found in rivers, reservoirs, and streams with specific water chemistry conditions (section 5f). Within such habitats in the MRB, waters with high anthropogenic nutrient inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present in much of the MRB (section 5f). Overall, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: HIGH

Evidence for Uncertainty Rating

E. flexuosa is considered a marine and brackish water species (section 5f). The suitability of nutrient, conductivity, flow, and light conditions in the MRB for this species is uncertain. Therefore, the uncertainty of spreading is high.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	Low	High	Low	High	Medium	High	Medium	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
E. flexuosa is a marine attached alga with a worldwide distribution. The spores are released into the water daily and can float for 8 to 11 days (Beach et al. 1995). The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004). The ecological success of *E. flexuosa* is, in part, attributable to the readily available pool of motile unicells that are able to rapidly colonize new areas (Hill 2001). The chance for successful settlement of these cells is greatly enhanced because gametes and zoospores of this species remain viable for 10 or more days after release due to their ability to photosynthesize

(Beach et al. 1995). Adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. Human-Mediated Transport through Aquatic Pathways
E. flexuosa is documented to be transported by boat hulls (Lougheed & Stevenson 2004). There is heavy boat traffic between the Indiana Harbor and multiple ports in Lake Superior and Lake Michigan (USACE 2011a,b), including Muskegon, Michigan, where grass kelp can be found (NBIC 2012).

c. Current Abundance and Reproductive Capacity
T_0: *E. flexuosa* is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001). A 2003 study indicated *E. flexuosa* was present in Muskegon Lake and in 2 of 11 nearby inland lakes and lagoons that were surveyed (Sturtevant 2011). Overall, the results suggested that, although *E. flexuosa* may not be widespread, local abundance can be high (Lougheed & Stevenson 2004). *E. flexuosa* is an excellent pioneer species, able to colonize newly available strata year-round (Emerson & Zedler 1978). However, it is not good at competing with other successional species. In an experimental study of the recolonization of intertidal algae following disturbance, Emerson and Zedler (1978) showed that *E. flexuosa* tends to be present in low densities (as measured in percent cover) throughout the year in undisturbed zones. Following a disturbance to an area, the density of this species increases dramatically within 2–3 weeks (Emerson & Zedler 1978). However, as other algae become established, the percent cover for *E. flexuosa* declines (Emerson & Zedler 1978). This observation suggests that *E. flexuosa* may be unable to maintain dominance in the presence of later successional species such as *Ulva* spp. and other perennial algae that are present in the Great Lakes (Emerson & Zedler 1978).
T_{10}: See T_0. If existing trends continue, *E. flexuosa* may increase in abundance in the Great Lakes.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway
T_0: The closest to Indiana Harbor *E. flexuosa* has been recorded was on the beaches of Muskegon Lake in 2003 (Lougheed & Stevenson 2004). Muskegon Lake is a coastal lake on the eastern shore of, and with a hydrologic connection to, Lake Michigan (Lougheed & Stevenson 2004). Muskegon Lake is approximately 290 km (180 mi) from the pathway entrance. Water circulation in Lake Michigan is typically counterclockwise

(Beletsky & Schwab 2001). Therefore, currents would transport the species north, away from the pathway entrance.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *E. flexuosa* is widespread around the world in inland and/or coastal waters (Lougheed & Stevenson 2004). The native range of the species is unknown, but *E. flexuosa* is found worldwide, and therefore the climate in southern Lake Michigan is likely to be suitable. *E. flexuosa* is primarily a marine species, but it is highly tolerant of freshwater conditions. Lougheed and Stevenson (2004) state that industrial activity resulting in increased nutrients and salinity of associated waters may have facilitated the invasion of this marine taxon. It is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). Growth of this species in outdoor ponds in India showed that *E. flexuosa* was able to sustain growth in water temperatures as high as 30°C (86°F) (Mairh et al. 1986). Favorable growth was maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). Optimal reproduction occurs at temperatures under 30°C (86°F), in waters with a pH of approximately 8.2 (Hill 2001). Historically, urban runoff has allowed the establishment of several eutrophic and/or marine species offshore of the Chicago area, including *Bangia atrpurpurea* and *Cyclotella cryptica*.

E. flexuosa typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). In Muskegon Lake it was primarily found growing on submerged aquatic macrophytes in windswept, littoral areas of eutrophic and mesotrophic lakes (Lougheed & Stevenson 2004). Submerged macrophytes are not common along the shoreline of southern Lake Michigan, but there are extensive *Cladophora* beds that may provide suitable habitat (MTRI 2012). Indiana Harbor has generally sandy beaches and riprap that are suitable for the species to colonize.
T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *E. flexuosa* during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *E. flexuosa*. In particular, mean water temperature is expected to increase (Wuebbles et al. 2010). However, *E. flexuosa* is found in a wide range of water temperatures and is globally distributed (Hill 2001). Therefore, temperature is expected to remain suitable. However, changes in nutrients and conductivity related to future climate change or new environmental regulations may affect the suitability of southern Lake Michigan for this species.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is a highly invasive, highly fecund species (sections 2a, 2c) that can be transferred by boats (section 2b). Indiana Harbor receives heavy cargo vessel traffic from ports in the Great Lakes including Muskegon, Michigan, where grass kelp can be found. The species has been established in Lake Michigan since 2003, but it has yet to be identified at Indiana Harbor (section 2e). The habitat near Indiana Harbor is likely suitable for *E. flexuosa* due to the higher-energy shoreline of Lake Michigan, and its rocky shoals and hard substrate. The species is opportunistic and may be able to populate disturbed areas that remove competitors such as *Cladophora* (section 2f). Historically, urban runoff has supported marine algal species in the vicinity of Indiana Harbor (section 2e). Currently, *E. flexuosa* has only been recorded along the eastern shoreline of central Lake Michigan. Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0. *E. flexuosa* is highly invasive, and suitable physical habitat is present in the vicinity of Indiana Harbor. Therefore, this species is expected to spread to Indiana Harbor over time and the probability of arrival remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: *E. flexuosa* is considered to be a rapid invader (section 2a), and the latest record of its presence is from 2003. Therefore, the current location of the species is uncertain (section 2e). In addition, this is a marine species and the suitability of nutrient and conductivity levels in the vicinity of Indiana Harbor is uncertain. Overall, the uncertainty of the species arriving at the pathway is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. In addition, the future effects of climate change on *E. flexuosa* and habitat suitability in Lake Michigan are uncertain. Therefore, uncertainty remains medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the CAWS pathway entrance.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
E. flexuosa must move downstream to reach Brandon Road Lock and Dam. The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004). Its spores are transported by currents, but adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004). Hull transport to Brandon Road Lock and Dam is possible, but most commercial vessel traffic to Indiana Harbor is lakewise and there is little commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little, if any, vessel traffic in the Grand Calumet River due to its shallow depth.
E. flexuosa could be transported in ballast water, but the discharge of ballast water originating from the Great Lakes would not likely occur within the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *E. flexuosa* has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). Water flows out of Indiana Harbor into Lake Michigan. West of Indiana Harbor Canal, the easternmost sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, grass kelp would have to spread upstream to enter the CAWS and move to the Calumet Sag Channel. The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. The species is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010), suggesting that the depth there is suitable. Growth of the species is maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species has been found in turbid water (Sand-Jenson et al. 2008), and turbidity is high in the CAWS (LimnoTech 2010). *E. flexuosa* can be abundant in rivers and tributaries that have hard water and high nutrient levels (Holmes & Whitton 1977). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution, even as the

abundance of other genera decreases. In areas affected by polluted discharge, *E. flexuosa* can be a highly successful invader (Lougheed & Stevenson 2004). Portions of the CAWS flow through limestone bedrock and there is heavy municipal water discharge into the CAWS; these sources may provide the nutrients and carbonates required by *E. flexuosa*.

Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation, and riprap banks are common. In the Grand Calumet River, the Calumet Sag Channel, and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). There are also ditches and tributaries along the Calumet Sag Channel that may provide suitable habitat.

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012). These changes may reduce habitat suitability in the CAWS.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is thought to have a rapid invasion speed (section 3a) and can move from Lake Michigan to the Grand Calumet River by floating or on boat hulls (section 3b). The planktonic spore stage may facilitate downstream transport to Brandon Road Lock and Dam (section 3a). Habitat is suitable throughout much of the CAWS for *E. flexuosa* (section 3d), and this species has been found in rivers and tributaries where suitable water quality conditions are present (section 3d). The urban runoff entering the CAWS may provide the high nutrient and conductivity levels this species prefers. However, this is an opportunistic species that may require uncolonized habitat. There is low submerged aquatic macrophyte cover, a preferred habitat for this species, in the CAWS (section 3d). The lack of vessel traffic and the need for upstream movement through Indiana Harbor and the Grand Calumet River would likely slow the spread of this species to Brandon Road Lock and Dam. Therefore, the probability of passage is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Over time, *E. flexuosa* may be able to spread upstream through Indiana Harbor and the Grand Calumet River by wind driven currents or aquatic biota, or by spreading along the shoreline if suitable attachment sites are present. *E. flexuosa* is found in canals and rivers that have high nutrients and hard water, and these conditions are likely present in the CAWS (section 3d). This species can be a potentially rapid invader and over time it may spread closer to Brandon Road Lock and Dam. Therefore, the probability of passage increases to medium for this time step (section 3d).

T_{50}: See T_{25}.**Uncertainty of Passage**

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species is commonly found in waters that are heavily affected by human uses, it is a marine species and the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support *E. flexuosa* is uncertain. The potential rate of spread of this species through the CAWS is also uncertain. The lack of vessel traffic and the upstream movement required to move through Indiana Harbor and the Grand Calumet River would slow passage to an uncertain degree. Therefore, the uncertainty of the species passing through the pathway is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Although the probability of *E. flexuosa* passing through the CAWS increases with time, the future effects of water quality improvements on *E. flexuosa* and habitat suitability in the CAWS are uncertain. The ability to move upstream through Indiana Harbor and the Grand Calumet River also remains uncertain. Therefore, the uncertainty of the species passing through the pathway at this time step remains high.

T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

E. flexuosa has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). Physical habitat such as manmade hard substrate is present in the vicinity of Brandon Road Lock and Dam. *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). *Enteromorpha* spp. do well in polluted and eutrophic water (Aguilar-Rosas and Pacheco-Ruiz 1989). Suitable physical habitat is present below Brandon Road Lock and Dam in the form of rocks, manmade hard substrate, and submerged aquatic vegetation. Water quality may be suitable in areas with high urban and agricultural runoff.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse to suitable habitat by spreading downstream as spores or adults, or by vessel transport.

Evidence for Probability Rating

Suitable physical habitat for the *E. flexuosa* is present downstream of Brandon Road Lock and Dam (section 4a). Although *E. flexuosa* has been found in inland rivers that have the appropriate water quality conditions, it has water chemistry requirements that may not be present below Brandon Road Lock and Dam (section 4a). Therefore, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The colonization of *E. flexuosa* in fresh water will depend on the presence of suitable water quality below Brandon Road Lock and Dam, which likely is similar to conditions above the dam. The ability of hydraulic and chemical conditions below Brandon Road Lock and Dam to support *E. flexuosa* is uncertain. Therefore, the uncertainty associated with the species' probability of colonization is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
E. flexuosa is globally widespread and is tolerant of a wide variety of conditions (Hill 2001; Lougheed & Stevenson 2004).

b. *Type of Mobility/Invasion Speed*
E. flexuosa has a worldwide distribution. The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004).

c. *Fecundity*
E. flexuosa is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001).

d. History of Invasion Success
E. flexuosa is a highly successful invasive species in marine and estuarine habitats. It has been documented in large rivers that have appropriate water quality conditions (Holmes & Whitton 1977).

e. Human-Mediated Transport through Aquatic Pathways
E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
E. flexuosa is an opportunistic species that specializes in colonizing aquatic macrophytes and disturbed areas. The species has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). The species typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution. Portions of the MRB with high agricultural and urban runoff may be suitable for this species.

Evidence for Probability Rating

E. flexuosa is globally distributed, so climate in the MRB will likely be suitable (section 5a). The species is found in rivers, reservoirs, and streams that have specific water chemistry conditions (section 5f). Within such habitats in the MRB, waters with high anthropogenic nutrient inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected (section 5f). Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present in much of the MRB (section 5f). Overall, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: HIGH

Evidence for Uncertainty Rating

E. flexuosa is considered a marine and brackish water species (section 5f). The suitability of nutrient, conductivity, flow, and light conditions in the MRB for this species is uncertain. Therefore, the uncertainty of spreading is high.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	Low	High	Low	High	Medium	High	Medium	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
E. flexuosa is a marine attached alga with a worldwide distribution. The spores are released into the water daily and can float for 8–11 days (Beach et al. 1995). The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004). The ecological success of *E. flexuosa* is in part attributable to the readily available pool of motile unicells that are able to rapidly colonize new areas (Hill 2001). The chance for successful settlement of these cells is greatly enhanced because gametes and zoospores of this species remain viable for 10 or more days due to their ability to photosynthesize (Beach et al. 1995).

Adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004). There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic to the adjacent Burns Harbor (USACE 2011a), including traffic from Muskegon, Michigan, where grass kelp can be found (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*
T_0: *E. flexuosa* is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001). A 2003 study indicated *E. flexuosa* was present in Muskegon Lake and in 2 of 11 nearby inland lakes and lagoons that were surveyed (Sturtevant 2011). Overall, the results suggested that, although *E. flexuosa* may not be widespread, local abundance can be high (Lougheed & Stevenson 2004). *E. flexuosa* is an excellent pioneer species, able to colonize newly available strata year-round (Emerson & Zedler 1978). However, it is not good at competing with other successional species. In an experimental study of recolonization of intertidal algae following disturbance, Emerson and Zedler (1978) showed that *E. flexuosa* tends to be present at low densities (as measured in percent cover) throughout the year in undisturbed zones. Following disturbance to an area, the density of this species increases dramatically within 2–3 weeks (Emerson & Zedler 1978). However, as other algae become established, the percent cover for this species declines (Emerson & Zedler 1978). This observation suggests that *E. flexuosa* may be unable to maintain dominance in the presence of later successional species such as *Ulva* spp. and other perennial algae that are present in the Great Lakes (Emerson & Zedler 1978).
T_{10}: See T_0. If existing trends continue, *E. flexuosa* may increase in abundance in the Great Lakes.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The closest *E. flexuosa* has been recorded to BSBH was on the beaches of Muskegon Lake in 2003 (Lougheed & Stevenson 2004). Muskegon Lake is a coastal lake on the eastern shore of, and with a hydrologic connection to, Lake Michigan (Lougheed & Stevenson 2004). Muskegon Lake is approximately 290 km (180 mi) from the pathway entrance. Water circulation in Lake Michigan is typically counterclockwise (Beletsky &

Schwab 2001). Therefore, currents would transport the species north, away from the pathway entrance.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The species is widespread around the world in inland and/or coastal waters (Lougheed & Stevenson 2004). The native range of *E. flexuosa* is unknown, but the species is found worldwide, and therefore the climate in southern Lake Michigan is likely to be suitable. *E. flexuosa* is primarily a marine species, but it is highly tolerant of freshwater conditions. Lougheed and Stevenson (2004) state that industrial activity resulting in increased nutrients and salinity of associated waters may have facilitated the invasion of this marine taxon. It is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). Growth of this species in outdoor ponds in India showed that *E. flexuosa* was able to sustain growth in water temperatures as high as 30°C (86°F) (Mairh et al. 1986). Favorable growth was maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). Optimal reproduction occurs at temperatures under 30°C (86°F) in waters with a pH of approximately 8.2 (Hill 2001). Historically, urban runoff has allowed the establishment of several eutrophic and/or marine species offshore of the Chicago area, including *Bangia atrpurpurea* and *Cyclotella cryptic*.

The species typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). In Muskegon Lake it was primarily found growing on submerged aquatic macrophytes in windswept, littoral areas of eutrophic and mesotrophic lakes (Lougheed & Stevenson 2004). Submerged macrophytes are not common along the shoreline of southern Lake Michigan, but there are extensive *Cladophora* beds that may provide suitable habitat (MTRI 2012). BSBH has generally sandy beaches and riprap that are suitable for the species to colonize.
T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *E. flexuosa* during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *E. flexuosa*. Mean water temperature in particular is expected to increase (Wuebbles et al. 2010). However, *E. flexuosa* is found in a wide range of water temperatures and is globally distributed (Hill 2001). Therefore, temperature is expected to remain suitable. However, changes in nutrients and conductivity related to future climate change or new environmental regulations may affect the suitability of southern Lake Michigan for this species.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is a highly invasive, highly fecund species (sections 2a, 2c) that can be transferred by boats (section 2b). BSBH does not receive cargo vessels, but the adjacent Burns Harbor receives heavy cargo vessel traffic from ports in the Great Lakes including Muskegon, Michigan, where grass kelp can be found. The species has been established in Lake Michigan since 2003, but it has yet to be identified at BSBH (section 2e). The habitat near BSBH is likely suitable for *E. flexuosa* to inhabit due to the higher-energy shoreline of Lake Michigan, which has rocky shoals and hard substrate. The species is opportunistic and may be able to populate disturbed areas that remove competitors such as *Cladophora* (section 2f). Historically, urban runoff has supported marine algal species in the vicinity of BSBH (section 2e). Currently, *E. flexuosa* has only been recorded along the eastern shoreline of central Lake Michigan. Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0. The current of the lake may transport the species away from the pathway entrance; however, transport by boat is possible. This species may spread over time and the probability of arrival remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: *E. flexuosa* is considered to be a rapid invader (section 2a), and the latest record of its presence is from 2003. Therefore, the current location of the species is uncertain (section 2e). In addition, this is a marine species and the suitability of nutrient and conductivity levels in the vicinity of BSBH is uncertain. Overall, the uncertainty of the species arriving at the pathway is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. In addition, the future effects of climate change on *E. flexuosa* and habitat suitability in Lake Michigan are uncertain. Therefore, uncertainty remains medium.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the CAWS pathway entrance.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

E. flexuosa must move downstream to reach Brandon Road Lock and Dam. The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004). Its spores are transported by currents, but adults are attached unless they become dislodged, in which case they can be transported as floating mats (John et al. 2002).

b. Human-Mediated Transport through Aquatic Pathways

E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004). Hull transport to Brandon Road Lock and Dam is possible, but vessel traffic to BSBH is lakewise and there is little commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is no commercial vessel traffic in the south branch of the Little Calumet River due to its shallow depth. This species could be transported in ballast water, but the discharge of ballast water originating from the Great Lakes would not be likely to occur within the CAWS (NBIC 2012).

c. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *E. flexuosa* has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). Water flows out of BSBH into Lake Michigan. The eastern segment of the south Branch of the Little Calumet River also generally flows toward Lake Michigan, while other sections can flow east or west depending on their location (GSWMD 2008). Thus, grass kelp would have to spread upstream to enter the CAWS and move to the Calumet Sag Channel. The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. The species is found at depths ranging from the intertidal zone to approximately 5 m (16.4 ft) below the surface (Beach et al. 1995). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010), suggesting that the depth there is suitable. Growth of the species is maintained at temperatures ranging from 15.5 to 30°C (59.9 to 86°F) (Hill 2001). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species has been found in turbid water (Sand-Jenson et al. 2008), and turbidity is high in the CAWS (LimnoTech 2010). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution, even as the abundance of other genera decreases. In areas affected by polluted discharge, *E. flexuosa* can be a highly successful invader (Lougheed & Stevenson 2004). Portions of the CAWS flow through limestone bedrock and there is heavy municipal water discharge into the CAWS; these sources may provide the nutrients and carbonates required by *E. flexuosa*.

Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). The species typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation, and riprap banks are common. Large sections of the Little Calumet River have overhanging vegetation and may be suitable for the species. In the North Leg of the Little Calumet River, the Calumet Sag Channel, and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). There are also ditches and tributaries along the Calumet Sag Channel that may provide suitable habitat.

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012). These changes may reduce habitat suitability in the CAWS.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *E. flexuosa* is thought to have a rapid invasion speed (section 3a) and can move from Lake Michigan to the Little Calumet River by floating (section 3a). The planktonic spore stage may facilitate downstream transport to Brandon Road Lock and Dam (section 3a). Habitat is suitable throughout much of the CAWS for *E. flexuosa* (section 3d), and this species has been found in rivers and tributaries where suitable water quality conditions are present (section 3d). The urban runoff entering the CAWS may provide the high nutrient and conductivity levels that this species prefers. However, this is an opportunistic species that may require uncolonized habitat. There is low submerged aquatic macrophyte cover, a preferred habitat for this species (section 3d), in the CAWS. The lack of vessel traffic and the need for upstream movement through BSBH and the south branch of the Little Calumet River would likely slow the spread of this species to Brandon Road Lock and Dam. Therefore, the probability of passage is low for this time step.

T_{10}: See T_0.

T_{25}: See T_{10}. Over time, *E. flexuosa* may be able to spread upstream through BSBH and the Little Calumet River by wind driven currents or aquatic biota, or by spreading along the shoreline if suitable attachment sites are present. *E. flexuosa* is found in canals and rivers

that have high nutrients and hard water, and these conditions are likely to be present in the CAWS (section 3d). This species is a potentially rapid invader and over time it may spread closer to Brandon Road Lock and Dam. Therefore, the probability of passage increases to medium for this time step (section 3d).
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species is commonly found in waters that are heavily affected by human uses, it is a marine species and the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support *E. flexuosa* is uncertain. The potential rate of spread of this species through the CAWS is also uncertain. The lack of vessel traffic and the upstream movement required to move through BSBH and the Little Calumet River would slow passage to an uncertain degree. Therefore, the uncertainty of the species passing through the pathway is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although the probability of *E. flexuosa* passing through the CAWS increases with time, the future effects of water quality improvements on *E. flexuosa* and habitat suitability in the CAWS are uncertain. Therefore, the uncertainty of the species passing through the pathway at this time step remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
E. flexuosa has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). Physical habitat such as manmade hard substrate is present in the vicinity of Brandon Road Lock and Dam. *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). *Enteromorpha* spp. do well in polluted and eutrophic water

(Aguilar-Rosas and Pacheco-Ruiz 1989). Suitable physical habitat is present below Brandon Road Lock and Dam in the form of rocks, manmade hard substrate, and submerged aquatic vegetation. Water quality may be suitable in areas with high urban and agricultural runoff.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse to suitable habitat by spreading downstream as spores or adults, or by vessel transport.

Evidence for Probability Rating

Suitable physical habitat for the *E. flexuosa* is present downstream of Brandon Road Lock and Dam (section 4a). Although *E. flexuosa* has been found in inland rivers that have appropriate water quality conditions, it has water chemistry requirements that may not be present below Brandon Road Lock and Dam (section 4a). Therefore, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The colonization of *E. flexuosa* in freshwater will depend on the presence of suitable water quality below Brandon Road Lock and Dam, where water quality is likely similar to conditions above the dam. The ability of hydraulic and chemical conditions below Brandon Road Lock and Dam to support *E. flexuosa* is uncertain. Therefore, the uncertainty associated with the species' probability of colonization is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
E. flexuosa is globally widespread and is tolerant of a wide variety of conditions (Hill 2001; Lougheed & Stevenson 2004).

b. *Type of Mobility/Invasion Speed*
E. flexuosa has a worldwide distribution. The species is highly invasive, has a rapid growth rate, and is tolerant to a wide range of environmental conditions (Lougheed & Stevenson 2004).

c. *Fecundity*
E. flexuosa is highly fecund (Beach et al. 1995); propagule release via mitotic spores and meiotic gametes occurs on a daily basis in lower latitudes (Hill 2001). Spores and

gametes of this species are photosynthetically competent upon release into the water column, and unicells remain motile for up to 11 days (Hill 2001).

d. *History of Invasion Success*
E. flexuosa is a highly successful invasive species in marine and estuarine habitats. It has been documented in large rivers that have appropriate water quality conditions (Holmes & Whitton 1977).

e. *Human-Mediated Transport through Aquatic Pathways*
E. flexuosa has been documented to be transported by boat hulls (Lougheed & Stevenson 2004).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
E. flexuosa is an opportunistic species that specializes in colonizing aquatic macrophytes and disturbed areas. The species has been found in drainage channels with slow water currents (Fernandez et al. 1998), as well as in reservoirs, ponds, and fast- and slow-flowing rivers (John et al. 2002). *E. flexuosa* can be abundant in rivers and tributaries with hard water and high nutrient levels (Holmes & Whitton 1977). Species of this weedy genus are often the first to colonize open substrata (Beach et al. 1995). *E. flexuosa* typically grows in clusters on plant roots, rocks, or wood, or as an epiphyte on other plants (Beach et al. 1995). *E. flexuosa* is primarily a marine species, but it can tolerate freshwater conditions and is considered a euryhaline species (Sturtevant 2011). Aguilar-Rosas and Pacheco-Ruiz (1989) showed that *Enteromorpha* species develop abundantly in zones directly affected by pollution. Portions of the MRB with high agricultural and urban runoff may be suitable for this species.

Evidence for Probability Rating

E. flexuosa is globally distributed so climate in the MRB will likely be suitable (section 5a). The species is found in rivers, reservoirs, and streams that have specific water chemistry conditions (section 5f). Within such habitats in the MRB, waters with high anthropogenic nutrient inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected (section 5f). Although *E. flexuosa* has been found in inland rivers with the appropriate water quality conditions, it has water chemistry requirements that may not be present in much of the MRB (section 5f). Overall, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: HIGH

Evidence for Uncertainty Rating

E. flexuosa is considered a marine and brackish water species (section 5f). The suitability of nutrient, conductivity, flow, and light conditions in the MRB for this species is uncertain, but these conditions are likely to be similar to those above Brandon Road Lock and Dam. Therefore, the uncertainty of spreading is high.

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E.2.3.3 Red Algae - *Bangia atropurpurea*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	High	Medium	High	Medium	High	Medium	High
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Red algae were first recorded from Lake Erie in 1964 (Edwards & Harrold 1970). Rapid spread has been documented for red algae (Edwards & Harrold 1970, Sonzogni et al. 1983). In the Great Lakes, it spread from Lake Erie to southern Lake Michigan within a decade; in Milwaukee, it grew from a few filaments to a high-density community within four years (Lin & Blum 1977). Red algae were documented on the

Canadian side of Lake Huron in 1980 (Jackson 1988). Red algae have a prolonged monospore release that promotes population spread (Sheath et al. 1985).

b. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977). There is recreational boat traffic between Lake Michigan and the WPS, but no commercial traffic (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: None; this species has been found in southern Lake Michigan (Lin & Blum 1977).
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current location of the red algae and the WPS.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: Recent information is not available to assess the species' current abundance. Red algae have a prolonged monospore (Sheath et al. 1985). Red algae produce highest biomass in spring and fall and persist through the summer at low biomass (Kipp 2011). It is a seasonal annual (producing several generations per year) with a four to six week generation time (Sheath & Cole 1980; Sheath et al. 1985). Based on recent data from Lake Michigan, red algae (Division Rhodophyta) are rarely found in the Lake Michigan watershed (Whitman 2012).
T_{10}: See T_0. The distribution and abundance of red algae in the Great Lakes could decrease due to improvements in the water quality of southern Lake Michigan which could reduce the anthropogenic inputs into Lake Michigan preferred by this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). The species has been observed in southern Lake Michigan, including offshore of Wilmette, Illinois (Lin & Blum 1977). Red algae may be present at WPS. However, based on recent data from Lake Michigan, red algae are not frequently found in southern Lake Michigan (Whitman 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Red algae have been found in southern Lake Michigan offshore of the Chicago area. Suitable habitat is present at WPS in the form of a rocky shoreline, consisting of concrete and steel manmade structures (Kipp 2011). The occurrence of red algae is restricted largely to harbor areas, which provide necessary levels of halogens and trace

metals from point and nonpoint sources (Lin & Blum 1977). Harbors exist all along the shoreline of Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for red algae. Mean temperature in particular is expected to increase (Wuebbles et al. 2010). However, red algae is found in a wide range of water temperatures (2–26°C; 35.6–78°F) (Kipp 2011; Garwood 1982) and is globally distributed across wide latitudes from boreal to tropical (Guiry & Guiry 2012).

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Red algae have been found in southern Lake Michigan in the vicinity of the CAWS (section 2e) and there is suitable habitat near and within the harbor adjacent to WPS (section 2f). However, recent surveys suggest that red algae are not frequently found in southern Lake Michigan. Even if red algae are not currently present at WPS, red algae have spread to multiple Great Lakes within a few decades (Kipp 2011), likely by vessel traffic; there is recreational vessel traffic between the northern Great Lakes and the WPS (USACE 2011b). For these reasons, there is a medium probability that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Red algae are tolerant of a wide range of temperatures (section 2f). Therefore appropriate habitat conditions are expected to continue to be present (sections 2f, 2c) along the shoreline of Lake Michigan even considering impacts on habitat related to future climate change (section 2f). As a result, the species' probability of arrival is expected to remain medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although historically present in southern Lake Michigan, recent surveys do not indicate the presence of red algae. Therefore, the uncertainty associated with the species' probability of arrival is high for this time step.
T_{10}: See T_0.

T_{25}: See T_0. The future population trends of red algae are uncertain. The future rate of spread for this species is uncertain. The effects of measures to improve water quality in Lake Michigan on red algae are uncertain. Therefore uncertainty remains high.
T_{50}: See T_{25}. The future effects of climate change on red algae and habitat suitability in Lake Michigan are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Red algae may disperse by passive current transportation. The species must move more than 80.5 km (50 mi) from WPS downstream to Brandon Road Lock and Dam. Rapid spread is possible (Edwards & Harrold 1970; Sonzogni et al. 1983), but the rate of spread through the CAWS by natural dispersion is uncertain. Red algae have been present in southern Lake Michigan for decades and have not been reported in the CAWS.

b. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977). There is no commercial vessel traffic in the North Shore Channel (USACE 2011a). There may be recreational boat traffic in the North Shore Channel, but it is likely to be local and not expected to move south to the CSSC. The discharge of ballast water originating from the Great Lakes would not likely occur within the CAWS (NBIC 2012), but hull transport from the Chicago River to Brandon Road Lock and Dam is possible.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Water depth is adequate throughout the CAWS (LimnoTech 2010). There is a sluice gate separating WPS from Lake Michigan which is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel. Spores or filaments could be pumped into the North Shore Canal.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: This species was reported in southern Lake Michigan in 1968 (Lin & Blum 1977), but no records of red algae colonizing inland areas of the CAWS were found. In Lake Michigan, red algae are typically found in harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). Much of the water in the CAWS is municipal effluent which could contain the nutrients and halogens that promote growth of this species (Lin & Blum 1977; Eloranta & Kwandrans

2004). In Britain, red algae were found in a navigation channel that was 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). There is heavy canopy cover and lack of hard substrate in North Shore Channel, but further downstream in the Chicago River and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). Turbidity is high in the CAWS which could limit photosynthesis (LimnoTech 2010). This species is typically found in flowing water or active intertidal zones. In Lake Michigan, red algae are typically found in the littoral splash zone on exposed permanent rocky substrates (Kipp 2011). Current velocity in the CAWS is typically very low (LimnoTech 2011). However, this species has been found to colonize slow-moving water in sheltered areas, harbors, and freshwater canals (Belcher 1956; Lin & Blum 1977; Sheath & Cole 1980; Reed 1980). Red algae are found in waters from 2 to 26.5°C (35.6 to 79.7°F) (Garwood 1982; Sheath et al. 1985), which is typical of the seasonal temperature of the CAWS (MWRD 2010).

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Red algae could move from Lake Michigan into the North Shore Chanel by water pumping at the WPS (section 3c). Vessel transport in the North Shore Channel is unlikely, but there is vessel traffic between the Chicago River and Brandon Road Lock and Dam that could also transport this species. This species could also be transported downstream to Brandon Road Lock and Dam by natural spread (section 3b).There is suitable habitat for red algae (section 3d) throughout much of the CAWS, although the North Shore Channel may not be suitable due to the heavy canopy cover and lack of hard substrate (section 3d). Red algae has been found in slow-moving inland freshwaters under the appropriate chemical conditions (section 3d). These conditions are likely to be present in the CAWS, given the high municipal inputs. Water temperature in the CAWS is suitable for red algae (section 3d). Therefore, the probability of passage is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species is commonly found in waters that are heavily affected by human uses, the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support red algae is uncertain. The effectiveness of hull transport in spreading this species is not well known. The potential natural spread rate of red algae in the CAWS is not known. In addition, this species was reported in southern Lake Michigan in 1968, but has not been reported in inland areas of the CAWS (section 3d). It is uncertain whether this species was unable to exist in the CAWS or whether its presence was unreported due to lack of surveys. Therefore, there is a high degree of uncertainty associated with the species' probability of passage at this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is uncertain. Over time, red algae are more certain to spread through the CAWS, assuming appropriate conditions are present. However, future efforts to improve water quality in the CAWS may reduce the discharge of municipal effluents that this species requires. The effects of such changes on red algae are unknown. For this reason, the uncertainty of the species' passage remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Physical habitat such as manmade hard substrate is present downstream in the vicinity of Brandon Road Lock and Dam. Red algae prefer fast-moving and turbulent water but they are also found in harbors and slow-moving canals (Belcher 1956; Reed 1980). All of these habitats are present below Brandon Road Lock and Dam. Red algae have specific water quality preferences and they are typically found near harbors and areas influenced by urban runoff and/or seawater. Red algae are also found in fast-moving mountain streams with hard water (Yokono et al. 2012) and they were found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). However, red algae have also been found in slow-moving freshwater canals with minimal saltwater influence (Reed 1980). This species was reported in southern Lake Michigan in 1968 (Lin & Blum 1977), but no records of red algae colonizing inland areas of the CAWS were found.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat such as industrial areas and harbors are found in the vicinity of Brandon Road Lock and Dam and are presumably accessible.

Evidence for Probability Rating

Red algae appear to be capable of occupying a wide range of hydraulic and water chemistry conditions. The appropriate physical habitat (hard substrate) and hydrology (fast-moving water) is present below Brandon Road Lock and Dam. Water chemistry conditions may be appropriate due to urban runoff (section 4a). Most studies have found that freshwater river and lake population of red algae are found in areas influenced by saltwater or urban runoff or in calcareous streams with high alkalinity (section 4a). However, this species has also been found in areas with minimal saltwater influence (section 4a). Overall, there is a medium probability that the species will colonize the pathway.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

This species has been documented in non-tidal navigation channels. However, the availability of hydraulic conditions in the vicinity of Brandon Road Lock and Dam to support red algae is uncertain. Therefore, the uncertainty associated with the species' probability of colonization is medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Red algae typically inhabit temperate climates. The species can tolerate water temperatures up to 31°C (87.8°F) but this would not be optimal; optimal temperatures are between 15 and 20°C (59 and 68°F), but they are found in water ranging from 2 to 26.5°C (35.6 to 79.7°F) (Kipp 2011; Garwood 1982) and are globally distributed across a wide latitude from boreal to tropical (Guiry & Guiry 2012).

b. *Type of Mobility/Invasion Speed*
Red algae can spread quickly and become locally abundant under appropriate conditions and with human-mediated transport (Sonzogni et al. 1983).

c. *Fecundity*
Only asexual plants occur in the Great Lakes (Kipp 2011). Red algae have a four to six week generation time (Sheath & Cole 1980).

d. *History of Invasion Success*
   Red algae have successfully invaded freshwater and become abundant, but typically only under specific salinity, conductivity, and micronutrient conditions (Lin & Blum 1979; Kipp 2011; Yokono 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
   Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977) and there is significant boat traffic between the Upper and Lower MRB (USACE 2011).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Red algae are typically found on hard substrate although they can attach to tree limbs. Although active water and high conductivity water is preferred, it can be found in slow waters (e.g., canals and harbors) as well (Belcher 1956; Lin & Bluhm 1977; Reed 1980). There is suitable habitat at areas with natural and manmade hard substrate and appropriate water quality in areas such as urbanized portions of the MRB (Kipp 2011). There is potential for this species to spread to karst streams with high alkalinity and flowing water (Yokono et al. 2011). Potential red algae habitat such as urbanized segments of rivers and lakes is present throughout the MRB and they are connected by flowing water.

Evidence for Probability Rating

There are several areas in large rivers, smaller streams, and lakes within the MRB that may provide suitable habitat (section 5f) and these areas are hydrologically connected (section 5f). Red algae are globally distributed at high and low latitudes (section 5a) so, spread into the southern MRB is not likely to be limited by temperature. However, red algae are typically only found in inland freshwater under specific water chemistry conditions (section 5d). Overall, the probability of spread by the species is considered to be medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Red algae have been documented in the literature to exist in a variety of freshwater habitats under different chemical and hydraulic conditions. However, the abundance of habitat with suitable water chemistry in the MRB is uncertain, as to what degree the spread of red algae to the southern MRB would be limited by temperature. For these reasons, there is a high degree of uncertainty associated with the species' probability of spread into the MRB.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	High	Medium	High	Medium	High	Medium	High
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next fifty years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Red algae was first recorded from Lake Erie in 1964 (Edwards & Harrold 1970). Rapid spread has been documented for red algae (Edwards & Harrold 1970; Sonzogni et al. 1983). In the Great Lakes, it spread from Lake Erie to southern Lake Michigan within a decade and, in Milwaukee, it grew from a few filaments to a high-density community within four years (Lin & Blum 1977). Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). Red algae have a prolonged monospore release that promotes population spread (Sheath et al. 1985).

b. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977). There is recreational and commercial boat traffic between the CRCW and multiple ports in Lake Michigan where red algae might be found (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: None; this species has been found in southern Lake Michigan (Lin & Blum 1977).
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of red algae and the CRCW.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: Recent information is not available to assess the species' current abundance. Red algae have a prolonged monospore (Sheath et al. 1985). Red algae produce the highest biomass in spring and fall and persist through the summer at low biomass (Kipp 2011). It is a seasonal annual (producing several generations per year) with a four to six week generation time (Sheath & Cole 1980; Sheath et al. 1985). Based on recent data from Lake Michigan, red algae (Division Rhodophyta) are rarely found in the Lake Michigan watershed (Whitman 2012).
T_{10}: The distribution and abundance of red algae in the Great Lakes could decrease due to improvements in the water quality of southern Lake Michigan which could reduce the anthropogenic inputs into Lake Michigan that are preferred by this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). Red algae may be present at the CRCW. It has been observed in southern Lake Michigan including the Chicago area (Lin & Blum 1977). However, based on recent data from Lake Michigan, red algae are not frequently found in southern Lake Michigan (Whitman 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitat is present at the CRCW in the form of rocky shoreline, concrete, and steel manmade structures (Kipp 2011). Red algae's occurrence is restricted largely to harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). Harbors exist all along the shoreline of Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.

T_{50}: See T_0. Future climate change or new environmental regulations may alter physical, chemical, and climatological suitability of the Great Lakes for red algae. Mean temperature in particular is expected to increase (Wuebbles et al. 2010). However, red algae can tolerate a wide range of temperatures 2–26°C (35.6–78°F) (Kipp 2011; Garwood 1982) and they are globally distributed across wide latitudes from boreal to tropical (Guiry & Guiry 2012).

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Red algae have been found in southern Lake Michigan, in the vicinity of the CAWS (section 2e) and there is suitable habitat near and within the harbor adjacent to CRCW (section 2f). However, recent surveys suggest red algae are not frequently found in southern Lake Michigan. Even if red algae are not currently present at the CRCW, it has spread to multiple Great Lakes within a few decades (Kipp 2011), likely by vessel traffic. Vessel traffic between the northern Great Lakes and the CRCW is high (USACE 2011a,b). However, recent surveys do not suggest red algae are found near the CRCW (section 2e). Overall, there is a medium probability that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}. Red algae are tolerant of a wide range of temperatures (section 2f). Red algae have been found in southern Lake Michigan in the vicinity of the CRCW (section 2e), and appropriate habitat conditions are expected to continue to be present (sections 2c, 2f) along the shoreline of Lake Michigan, even considering impacts on habitat related to future climate change (section 2f). Therefore, the probability of arrival is expected to remain medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although historically present in southern Lake Michigan, recent surveys do not indicate the presence of red algae. Therefore, the uncertainty associated with the species' probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future population trends of red algae are uncertain. The future rate of spread for this species is uncertain. The effects of measures to improve water quality in Lake Michigan on red algae are uncertain. Therefore, uncertainty remains high.

T_{50}: See T_{25}. The future effects of climate change on red algae and habitat suitability in Lake Michigan are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high.

4. **P(passage) T_0-T_{50}: HIGH**

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Red algae may disperse by passive current transportation. It is approximately 64 km (40 mi) from the CRCW to Brandon Road Lock and Dam. Rapid spread is possible (Edwards & Harrold 1970; Sonzogni et al. 1983), but the rate of spread through the CAWS by natural dispersion is uncertain. Red algae produce the highest biomass in spring and fall and persist through the summer at low biomass (Kipp 2011). It is a seasonal annual (produce several generations per year [Sheath et al. 1985]). Red algae have been present in southern Lake Michigan for decades and have not been reported in the CAWS.

b. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls may transport red algae through the CAWS (Kipp 2011; Lin & Blum 1977), and there is recreational and commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a,b). The discharge of ballast water originating from the Great Lakes would not likely occur within the CAWS (NBIC 2012), but hull transport from the CRCW to Brandon Road Lock and Dam is possible.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Water depth is adequate throughout the CAWS (LimnoTech 2010). This species has been found in the vicinity of the CRCW and the lock is opened and closed routinely, which would allow this species to pass into the CAWS.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: This species was reported in southern Lake Michigan in 1968 (Lin & Blum 1977), but no records of red algae colonizing inland areas of the CAWS were found. However, much of CAWS water is municipal effluent which could contain the nutrients and halogens that promote growth of this species (Lin & Blum 1977; Eloranta & Kwandrans 2004). In Lake Michigan, red algae is typically found in harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). In Britain, red algae was found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and

chlorides (Belcher 1956). In the Chicago River and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). Turbidity is high in the CAWS which could limit photosynthesis (LimnoTech 2010). This species is typically found in flowing water or active intertidal zones on exposed permanent rocky substrates (Kipp 2011). Current velocity in the CAWS is typically very low (LimnoTech 2011). However, this species has been found to colonize slow-moving water in sheltered areas, harbors, and freshwater canals (Belcher 1956; Lin & Blum 1977; Sheath & Cole 1980; Reed 1980). Red algae are found in waters from 2 to 26.5°C (35.6 to 79.7°F) (Garwood 1982; Sheath et al. 1985), which is typical of the seasonal temperature of the CAWS (MWRD 2010).
T_{10}: See T_0.
T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water quality in the CAWS near downtown Chicago may be suitable for red algae (section 3e). Red algae could move from the Chicago River throughout the CAWS by attaching to the hulls of recreational and commercial boats (section 3b). This species could also be transported downstream to Brandon Road Lock and Dam by natural spread (section 3b). There is suitable habitat for red algae (section 3e) throughout much of the CAWS including the vicinity of Brandon Road Lock and Dam. This species has been found in slow-moving inland freshwaters under the appropriate chemical conditions (section 3e). These conditions are likely to be present in the CAWS given the high municipal pollution inputs. Therefore, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Vessel traffic is known to exist between the CRCW and Brandon Road Lock and Dam (USACE 2011a,b). This species has been found in slow-moving inland freshwaters under the appropriate chemical conditions (section 3e). However, the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support red algae is not known. In addition, this species was reported in southern Lake Michigan in 1968, but has not been reported in inland areas of the CAWS (section 3d). It is uncertain whether this species was unable to exist in the CAWS or whether its presence was unreported due to lack of surveys. The effectiveness of hull transport in spreading this species is not well known. The potential natural spread rate of red algae in the CAWS is not known. For these reasons, there is a high level of uncertainty associated with the species' probability of passage.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not known. Over time, red algae are more certain to spread through the CAWS assuming appropriate conditions are present. However, future efforts to improve water quality in the CAWS may reduce the discharge of municipal effluents that this species requires. The effects of such changes on red algae are unknown. For this reason, the uncertainty of the species' passage remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Physical habitat such as manmade hard substrate is present downstream in the vicinity of Brandon Road Lock and Dam. Red algae prefer fast-moving and turbulent water, but are also found in harbors and slow-moving canals (Belcher 1956; Reed 1980). All of these habitats are present below Brandon Road Lock and Dam. Red algae have specific water quality preferences and are typically found near harbors and areas influenced by urban runoff and/or seawater. Red algae is also found in fast-moving mountain streams with hard water (Yokono et al. 2012) and it was found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). However, red algae have also been found in slow-moving freshwater canals with minimal saltwater influence (Reed 1980). However, this species was reported in southern Lake Michigan in 1968 (Lin & Blum 1977), but no records of red algae colonizing inland areas of the CAWS were found.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat such as industrial areas and harbors are found in the vicinity of Brandon Road Lock and Dam and are presumably accessible.

Evidence for Probability Rating

Red algae appear to be capable of occupying a wide range of hydraulic and water chemistry conditions. Water chemistry conditions may be appropriate. Most studies have found that freshwater river and lake populations of red algae are found in areas influenced by saltwater or urban runoff or in calcareous streams with high alkalinity (section 4a). However, this species has also been found in areas with minimal saltwater influence (section 4a). The appropriate physical habitat (hard substrate) and hydrology (fast-moving water) are present in the vicinity of Brandon Road Lock and Dam. Therefore, the probability of colonization by the species is expected to be medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

This species has been documented in non-tidal navigation channels. However, the availability of hydraulic conditions in the vicinity of Brandon Road Lock and Dam to support red algae is uncertain. For this reason, there is a medium level of uncertainty associated with colonization by the species.

5. **P(spreads): MEDIUM**

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   Red algae typically inhabits temperate climates. It can tolerate water temperatures up to 31°C (87.8°F), but this would not be optimal; optimal temperatures for the species are between 15 and 20°C (59 and 68°F), but it is found in water ranging from 2 to 26.5°C (35.6 to 79.7°F) (Kipp 2011; Garwood 1982) and is globally distributed across wide latitudes from boreal to tropical (Guiry & Guiry 2012).

b. *Type of Mobility/Invasion Speed*
   Red algae can spread quickly and become locally abundant under appropriate conditions and with human-mediated transport (Sonzogni et al. 1983).

c. *Fecundity*
   Only asexual plants occur in the Great Lakes (Kipp 2011). Red algae have a four to six week generation time (Sheath & Cole 1980).

d. *History of Invasion Success*
   Red algae have successfully invaded freshwater and become abundant, but this typically occurs only under specific salinity, conductivity, and micronutrient conditions (Lin & Blum 1979; Kipp 2011; Yokono 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
   Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977) and there is significant boat traffic between the Upper and Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Red algae are typically found on hard substrate, although they can attach to tree limbs. Although active water and high conductivity water is preferred, it can be found in slow waters (e.g., canals and harbors) as well (Belcher 1956; Lin & Blum 1977; Reed 1980). There is suitable habitat at areas with natural and manmade hard substrate and appropriate water quality in areas such as urbanized portions of the MRB (Kipp 2011). There is potential for this species to spread to karst streams with high alkalinity and flowing water (Yokono et al. 2011). Potential red algae habitat such as urbanized segments of rivers and lakes are present throughout the MRB and are connected by flowing water.

Evidence for Probability Rating

There are several areas in large rivers, smaller streams, and lakes within the MRB that may provide suitable habitat (section 5f) and these areas are hydrologically connected (section 5f). Red algae are globally distributed at high and low latitudes (section 5a) so spread into the southern MRB is not likely to be limited by temperature. However, red algae are typically only found in inland freshwater under specific water chemistry conditions (section 5d). Overall, there is a medium probability that the species will spread within the MRB.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Red algae have been documented in the literature to exist in a variety of freshwater habitats under different chemical and hydraulic conditions. However, the abundance of habitat with suitable water chemistry in the MRB is uncertain as to what degree the spread of red algae to the southern MRB would be limited by temperature. For this reason, there is a high level of uncertainty associated with the species' probability of spread.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	High	Medium	High	Medium	High	Medium	High
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Red algae were first recorded from Lake Erie in 1964 (Edwards & Harrold 1970). Rapid spread has been documented for red algae (Edwards & Harrold 1970; Sonzogni et al. 1983). In the Great Lakes, it spread from Lake Erie to southern Lake Michigan within a decade and, in Milwaukee, it grew from a few filaments to a high density community within four years (Lin & Blum 1977). Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). Red algae have a prolonged monospore release that promotes population spread (Sheath et al. 1985).

b. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls might transport red algae (Kipp 2011; Lin & Blum 1977). There is boat traffic between the Calumet Harbor and multiple ports in Lake Michigan where red algae might be found (USACE 2011a,b; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None; this species has been found in southern Lake Michigan (Lin & Blum 1977).
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of red algae and Calumet Harbor.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: Recent information is not available to assess the species' current abundance. Red algae have a prolonged monospore (Sheath et al. 1985). Red algae produce highest biomass in spring and fall and persist through the summer at low biomass (Kipp 2011). It is a seasonal annual (producing several generations per year) with a 4 to 6 week generation time (Sheath & Cole 1980; Sheath et al. 1985). Based on recent data from Lake Michigan, red algae (Division Rhodophyta) are rarely found in the Lake Michigan watershed (Whitman 2012).
T_{10}: See $T_{0.}$ The distribution and abundance of red algae in the Great Lakes could decrease due to improvements in the water quality of southern Lake Michigan which could reduce the anthropogenic inputs into Lake Michigan that are preferred by this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). The species has been observed in southern Lake Michigan (Lin & Blum 1977). Red algae may be present at the Calumet Harbor. However, based on recent data from Lake Michigan, red algae are not frequently found in southern Lake Michigan (Whitman 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Red algae have been found in southern Lake Michigan (Lin & Blum 1977). Suitable habitat is present at the Calumet Harbor in the form of rocky shoreline, concrete, and steel manmade structures (Kipp 2011). Red algae's occurrence is restricted largely to harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). Harbors exist all along the shoreline of Lake Michigan.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for red algae. Mean temperature, in particular, is expected to increase (Wuebbles et al. 2010). However, red algae can tolerate a wide range of temperatures 2–26°C (35.6–78°F) (Kipp 2011; Garwood 1982) and it is globally distributed across wide latitudes from boreal to tropical (Guiry & Guiry 2012).

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Red algae have been found in southern Lake Michigan and there is suitable habitat adjacent to Calumet Harbor (section 2f). Recent surveys suggest red algae are not frequently found in southern Lake Michigan. However, even if red algae are not currently present at Calumet Harbor, it has spread to multiple Great Lakes within a few decades (Kipp 2011) likely by vessel traffic. Vessel traffic between the northern Great Lakes and the Calumet Harbor is high. For these reasons, there is a medium probability that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}. Red algae are tolerant of a wide range of temperatures (section 2f). Red algae have been found in southern Lake Michigan (section 2e) and appropriate habitat conditions are expected to continue to be present (sections 2f, 2c) along the shoreline of Lake Michigan, even considering impacts on habitat related to future climate change (section 2f). Therefore, the species' probability of arrival is expected to remain medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although historically present in southern Lake Michigan, recent surveys do not indicate the presence of red algae. Therefore, the uncertainty associated with the species' probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future population trends of red algae are uncertain. The future rate of spread for this species is uncertain. The effects of measures to improve water quality in Lake Michigan on red algae are uncertain. Therefore uncertainty remains high.

T_{50}: See T_{25}. The future effects of climate change on red algae and habitat suitability in Lake Michigan are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Red algae may disperse by passive current transportation. It is more than 56 km (35 mi) from the Calumet Harbor to Brandon Road Lock and Dam. Rapid spread is possible (Edwards & Harrold 1970; Sonzogni et al. 1983), but the rate of spread through the CAWS, by natural dispersion is uncertain. Red algae produce the highest biomass in spring and fall and persist through the summer at low biomass (Kipp 2011). It is a seasonal annual (produce several generations per year) (Sheath et al. 1985).

b. Human-Mediated Transport through Aquatic Pathways
In the Great Lakes, red algae spread from Lake Erie to southern Lake Michigan within a decade (Lin & Blum 1977). Ballast water and ship hulls may transport red algae through the CAWS (Kipp 2011; Lin & Blum 1977). Vessel traffic to Calumet Harbor is typically lakewise, but there is heavy commercial vessel traffic between Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam which is located downstream of Calumet Harbor (USACE 2011a,b). The discharge of ballast water originating from the Great Lakes would not likely occur within the CAWS (NBIC 2012), but hull transport to Brandon Road Lock and Dam is possible.

c. Existing Physical Human/Natural Barriers
T_0: None. Water depth is adequate throughout the CAWS (LimnoTech 2010). This species has been found in the vicinity of Calumet Harbor and the lock is opened and closed routinely, which would allow this species to pass into the CAWS.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: This species was reported in southern Lake Michigan in 1968 (Lin & Blum 1977), but no records of red algae colonizing inland areas of the CAWS were found. However, much of CAWS water is municipal effluent which could contain the nutrients and halogens that promote growth of this species (Lin & Blum 1977; Eloranta & Kwandrans 2004). In Lake Michigan, red algae is typically found in harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). In Britain, red algae was found in a navigation channel 32.8 km

(10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). In the Calumet River, the Calumet Sag Channel, and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). Turbidity is high in the CAWS which could limit photosynthesis (LimnoTech 2010). This species is typically found in flowing water or active intertidal zones on exposed permanent rocky substrates (Kipp 2011). Current velocity in the CAWS is typically very low (LimnoTech 2011). However, this species has been found to colonize slow-moving water in sheltered areas, harbors, and freshwater canals (Belcher 1956; Lin & Blum 1977; Sheath & Cole 1980; Reed 1980). Red algae are found in waters from 2 to 26.5°C (35.6 to 79.7°F) (Sheath et al. 1985), which is typical of the seasonal temperature of the CAWS (MWRD 2010).

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Red algae could move from Calumet Harbor throughout the CAWS by attaching to the hulls of recreational and commercial boats (section 3b). There is vessel traffic between the T.J. O'Brien Lock and Dam and Brandon Road Lock and Dam that could also transport this species. In addition, this species could be transported downstream to Brandon Road Lock and Dam by natural spread. There is suitable habitat for red algae (section 3e) throughout much of the CAWS, including the vicinity of Brandon Road Lock and Dam. This species has been found in slow-moving inland freshwaters under the appropriate chemical conditions (section 3e). These conditions are likely to be present in the CAWS given the limestone substrate and the high municipal pollution inputs. Water temperature in the CAWS is suitable for red algae (section 3d). Therefore, the probability of passage is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Vessel traffic is known to exist between the Calumet Harbor and Brandon Road Lock and Dam. Although this species is commonly found in waters that are heavily affected by human uses, the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support red algae is uncertain. The effectiveness of hull transport in spreading this species through the CAWS is uncertain. The potential natural spread rate of red algae in the CAWS is uncertain. In addition, this species was reported in southern Lake Michigan in 1968, but has not been reported in inland areas of the CAWS (section 3d). It is uncertain whether this species was unable to exist in the CAWS or whether its presence was unreported due to lack of surveys. For these reasons, there is a high level of uncertainty associated with the species' probability of passage.
T_{10}: See T_0.
T_{25}: See T_0**.** The future rate of spread for this species is not known. Over time, red algae are more certain to spread through the CAWS, assuming appropriate conditions are present. However, the effects of future water quality improvements on red algae and habitat suitability in the CAWS are uncertain. Therefore, uncertainty remains high for this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Physical habitat such as manmade hard substrate is present downstream in the vicinity of Brandon Road Lock and Dam. Red algae prefer fast-moving and turbulent water but are also found in harbors and slow-moving canals (Belcher 1956; Reed 1980). All of these habitats are present below Brandon Road Lock and Dam. Red algae have specific water quality preferences and are typically found near harbors and areas influenced by urban runoff and/or seawater. Red algae is also found in fast-moving mountain streams with hard water (Yokono et al. 2012) and it was found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). However, red algae have also been found in slow-moving freshwater canals with minimal saltwater influence (Reed 1980). However, this species was reported in southern Lake Michigan in 1968 (Lin & Blum 1977), but no records of red algae colonizing inland areas of the CAWS were found.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat such as industrial areas and harbors are found in the vicinity of Brandon Road Lock and Dam and are presumably accessible.

Evidence for Probability Rating

Red algae appear to be capable of occupying a wide range of hydraulic and water chemistry conditions. The water chemistry conditions of the pathway may be appropriate. Most studies have found that freshwater river and lake populations of red algae are found in areas that are influenced by saltwater or urban runoff; or in calcareous streams with high alkalinity (section 4a). However, this species has also been found in areas with minimal saltwater influence (section 4a). The appropriate physical habitat (hard substrate) and hydrology (fast-moving water) is present in the vicinity of Brandon Road Lock and Dam. Water chemistry conditions may be appropriate due to municipal runoff (section 4a). Therefore, the probability of colonization by the species is considered medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

This species has been documented in non-tidal navigation channels. However, the availability of hydraulic conditions in the vicinity of Brandon Road Lock and Dam to support red algae is uncertain. For this reason, the uncertainty of colonization is considered to be medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Red algae typically inhabit temperate climates. The species can tolerate water temperatures up to 31°C (87.8°F) but this would not be optimal; optimal temperatures are between 15 and 20°C (59 and 68°F), but they are found in water ranging from 2 to 26.5°C (35.6 to 79.7°F) (Kipp 2011; Garwood 1982) and the species is globally distributed across a wide latitude range from boreal to tropical (Guiry & Guiry 2012).

b. *Type of Mobility/Invasion Speed*
Red algae can spread quickly and become locally abundant under appropriate conditions and with human-mediated transport (Sonzogni et al. 1983).

c. *Fecundity*
Only asexual plants occur in the Great Lakes (Kipp 2011). Red algae have a four to six week generation time (Sheath & Cole 1980).

d. *History of Invasion Success*
Red algae have successfully invaded freshwater and become abundant, but they typically occur only under specific salinity, conductivity, and micronutrient conditions (Lin & Blum 1979; Kipp 2011; Yokono 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977) and there is significant boat traffic between the upper and Lower MRB (USACE 2011).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Red algae are typically found on hard substrate although they can attach to tree limbs. Although active water and high-conductivity water is preferred, it can be found in slow waters (e.g., canals and harbors) as well (Belcher 1956; Lin & Blum 1977; Reed 1980). There is suitable water quality at areas with natural and manmade hard substrate and appropriate water quality such as that found in urbanized portions of the MRB (Kipp 2011). There is potential for this species to spread to streams with high alkalinity and flowing water (Yokono et al. 2011). Potential red algae habitat, such as urbanized segments of rivers and lakes, is present throughout the MRB and is connected by flowing water.

Evidence for Probability Rating

There are several areas in large rivers, smaller streams, and lakes within the MRB that may provide suitable habitat (section 5f) and these areas are hydrologically connected (section 5f). Red algae are globally distributed at high and low latitudes (section 5a) so, spread into the southern MRB is not likely to be limited by temperature. Red algae are typically found in inland freshwater only under specific water chemistry conditions (section 5d). Overall, the probability of the species spreading in the MRB is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Red algae have been documented in the literature to exist in a variety of freshwater habitats under different chemical and hydraulic conditions. However, the abundance of habitat with suitable water chemistry in the MRB is uncertain as to what degree the spread of red algae to the southern MRB would be limited by temperature. Therefore, there is a high degree of uncertainty associated with the spread of the species.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	High	Medium	High	Medium	High	Medium	High
P(passage)	Low	High	Low	High	Medium	High	Medium	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next fifty years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Red algae were first recorded from Lake Erie in 1964 (Edwards & Harrold 1970). Rapid spread has been documented for red algae (Edwards & Harrold 1970; Sonzogni et al. 1983). In the Great Lakes, it spread from Lake Erie to southern Lake Michigan within a decade and, in Milwaukee, it grew from a few filaments to a high density community within four years (Lin & Blum 1977). Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). Red algae have a prolonged monospore release that promotes population spread (Sheath et al. 1985).

b. Human-Mediated Transport through Aquatic Pathways

Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977). There is heavy boat traffic between the Indiana Harbor and multiple ports in Lake Superior and Lake Michigan where red algae may be found (USACE 2011a,b; NBIC 2012).

c. Existing Physical Human/Natural Barriers

T_0: None; this species has been found in southern Lake Michigan (Lin & Blum 1977).
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of red algae and Indiana Harbor.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Current Abundance and Reproductive Capacity

T_0: Red algae have a prolonged monospore (Sheath et al. 1985). Red algae produce the highest biomass in spring and fall and persist through the summer at low biomass (Kipp 2011). It is a seasonal annual (produce several generations per year) with a four to six week generation time (Sheath & Cole 1980; Sheath et al. 1985). Based on recent data from Lake Michigan, red algae (Division Rhodophyta) are rarely found in the Lake Michigan watershed (Whitman 2012).
T_{10}: The distribution and abundance of red algae in the Great Lakes could decrease due to improvements in the water quality of southern Lake Michigan which could reduce the anthropogenic inputs into Lake Michigan that are preferred by this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. Distance from Pathway

T_0: Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). The species has been observed in southern Lake Michigan (Lin & Blum 1977). Red algae may be present at Indiana Harbor. However, based on recent data from Lake Michigan, red algae are not frequently found in southern Lake Michigan (Whitman 2012).
T_{10}: See T_{10}.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Red algae have been found in southern Lake Michigan in the vicinity of the CAWS. Suitable habitat is present at the Indiana Harbor in the form of rocky shoreline, concrete, and steel manmade structures (Kipp 2011). Red algae's occurrence is restricted largely to harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). Harbors exist all along the shoreline of Lake Michigan.
T_{10}: See T_0.
T_{25}*:* See T_0.

T_{50}: See T_0. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for red algae. Mean temperature, in particular, is expected to increase (Wuebbles et al. 2010). However, red algae is found in a wide range of water temperatures (2–26°C; 35.6–78°F [Kipp 2011; Garwood 1982]) and is globally distributed across a wide latitude range from boreal to tropical (Guiry & Guiry 2012)

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Red algae have been found in southern Lake Michigan and there is suitable habitat adjacent to Indiana Harbor (section 2f). However, recent surveys suggest red algae are not frequently found in southern Lake Michigan. Even if the species is not currently present at Indiana Harbor, it has spread to multiple Great Lakes within a few decades (Kipp 2011) likely by vessel traffic. Vessel traffic between the northern Great Lakes and Indiana Harbor is high. Therefore, there is a medium probability that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Red algae are tolerant of a wide range of temperatures (section 2f). Therefore, appropriate habitat conditions are expected to continue to be present (sections 2f, 2c) along the shoreline of Lake Michigan, even considering the impacts on habitat that are related to future climate change (section 2f). For these reasons, the species' probability of arrival is expected to remain medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although historically present in southern Lake Michigan, recent surveys do not indicate the presence of red algae. Therefore, the uncertainty associated with the species' probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future population trends of red algae are uncertain. The future rate of spread for this species is uncertain. The effects of measures to improve water quality in Lake Michigan on red algae are uncertain. Therefore uncertainty remains high.
T_{50}: See T_{25}. The future effects of climate change on red algae and habitat suitability in Lake Michigan are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high.

4. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Red algae may disperse by passive current transportation. It is more than 56 km (35 mi) from the Indiana Harbor downstream to Brandon Road Lock and Dam. Rapid spread is possible (Edwards & Harrold 1970; Sonzogni et al. 1983), but the rate of spread through the CAWS by natural dispersion is uncertain. Red algae have been present in southern Lake Michigan for decades and have not been reported in the CAWS.

b. *Human-Mediated Transport*
In the Great Lakes, red algae spread from Lake Erie to southern Lake Michigan within a decade (Lin & Blum 1977). Ballast water and ship hulls may transport red algae through the CAWS (Kipp 2011; Lin & Blum 1977). The discharge of ballast water originating from the Great Lakes would not likely occur within the CAWS (NBIC 2012), although transport on boat hulls is possible. Vessel traffic to Indiana Harbor is lakewise, but there is vessel traffic from Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam (USACE 2011a; NBIC 2012) that could transport this species.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Water depth is adequate throughout the CAWS (LimnoTech 2010). There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a barrier during low flows.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Much of CAWS water is municipal effluent which could contain the nutrients and halogens that promote growth of this species (Lin & Blum 1977; Eloranta & Kwandrans 2004). In Lake Michigan, red algae is typically found in harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). In Britain, red algae was found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). In the Indiana Harbor, Grand Calumet River, the Calumet Sag Channel, and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). However, there are marshy reaches of the Grand Calumet River that may not be suitable for this species. Turbidity is high in the CAWS which could limit photosynthesis (LimnoTech 2010). This species is typically found in flowing water or active intertidal zones on exposed permanent rocky substrates (Kipp 2011). Current velocity in the CAWS is typically very low

(LimnoTech 2011). However, this species has been found to colonize slow-moving water in sheltered areas, harbors, and freshwater canals (Belcher 1956; Lin & Blum 1977; Sheath & Cole 1980; Reed 1980). The flow direction and water depth of the Grand Calumet River varies with effluent discharge volumes and water levels in Lake Michigan. Water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern most sections of the Grand Calumet River also generally flow toward Lake Michigan while other sections can flow east or west, depending on location (Weiss et al. 1997). Thus, red algae would have to float upstream to enter the CAWS and move to the Calumet Sag Channel. Red algae are found in waters from 2 to 26.5°C (35.6 to 79.7°F) (Garwood 1982; Sheath et al. 1985), which is typical of the seasonal temperature of the CAWS (MWRD 2010).

T_{10}: See T_0.

T_{25}: See T_0. The discharge of common municipal contaminants such as nutrients, metals, total dissolved solids, and sewage may decrease due to the adoption of water quality standards and effluent discharge limitations that are currently proposed for the CAWS (Raber 2012; Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is suitable habitat for red algae (section 3e) throughout much of the CAWS, including the vicinity of Brandon Road Lock and Dam. Although this species is typically found in high-energy shorelines, it has also been found in slow-moving inland freshwaters under the appropriate chemical conditions (section 3e). These conditions are likely to be present in the CAWS, given the high municipal pollution inputs (section 3e). Water temperature in the CAWS is suitable for red algae (section 3d). There is no vessel traffic in the Grand Calumet River, so red algae would have to disperse naturally from Calumet Harbor to the Little Calumet River. Flow in Indiana Harbor and portions of the Grand Calumet River is toward Lake Michigan, which could inhibit the spread of this species from Indiana Harbor to the Little Calumet River. Once in the Little Calumet River, red algae could float downstream or potentially be transported to Brandon Road Lock and Dam by attaching to the hulls of recreational and commercial boats (section 3b). Overall, red algae are not likely to move from Indiana Harbor to Brandon Road Lock and Dam by natural dispersion within the current time step because of the flow of the Grand Calumet River. Therefore, the probability of passage is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Over time, red algae may be able to spread upstream through the Grand Calumet River by wind-driven currents or aquatic biota, or by spreading along the shoreline if suitable attachment sites are present. Thus, sufficient time may elapse during this time step to allow red algae to spread through the CAWS by natural spread, boat traffic, or a

combination of both. Overall, the habitat in the CAWS is expected to remain suitable for red algae. Overall, the probability of passage is medium for this time step.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species is commonly found in waters that are heavily affected by human uses, the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support red algae is unknown. The direction of flow in Indiana Harbor Canal and the Grand Calumet is toward Lake Michigan and it could inhibit the spread of this species to the Calumet Sag Channel. The potential natural spread rate of red algae in the CAWS is not known. In addition, red algae have been reported in southern Lake Michigan, and it is uncertain why this species has not been reported in the CAWS. For these reasons, the uncertainty associated with spread is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not known. Over time, red algae are more certain to spread through the CAWS, assuming appropriate conditions are present. However, future efforts to improve water quality in the CAWS may reduce the discharge of municipal effluents that this species requires. The effects of such changes on red algae are unknown. For this reason, the uncertainty of the species' passage remains high.
T_{50}: See T_{25}.

3. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Physical habitat such as manmade hard substrate is present downstream in the vicinity of Brandon Road Lock and Dam. Red algae prefer fast-moving and turbulent water, but are also found in harbors and slow-moving canals (Belcher 1956; Reed 1980). All of these habitats are present below Brandon Road Lock and Dam. Red algae has specific water quality preferences and is typically found near harbors and areas influenced by urban runoff and/or seawater. Red algae is also found in fast-moving mountain streams with hard water (Yokono et al. 2012) and it was found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). However, red algae have also been found in slow-moving freshwater canals with minimal saltwater influence (Reed 1980). However, this species

was reported in southern Lake Michigan in 1968 (Lin & Blum 1977), but no records of red algae colonizing inland areas of the CAWS were found.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat, such as industrial areas and harbors, are found in the vicinity of Brandon Road Lock and Dam and they are presumably accessible.

Evidence for Probability Rating

Red algae appear to be capable of occupying a wide range of hydraulic and water chemistry conditions. The appropriate physical habitat (hard substrate) and hydrology (fast-moving water) are present below Brandon Road Lock and Dam. Water chemistry conditions might be appropriate due to urban runoff. Most studies have found that freshwater river and lake populations of red algae are found in areas that are influenced by saltwater or urban runoff; or they are found in calcareous streams with high alkalinity (section 4a). However, this species has also been found in areas with minimal saltwater influence (section 4a). Overall, the probability of colonization by this species is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

This species has been documented in non-tidal navigation channels. However, the availability of hydraulic conditions in the vicinity of Brandon Road Lock and Dam to support red algae is uncertain. For this reason, the probability of colonization has a medium level of uncertainty associated with it.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Red algae typically inhabit temperate climates. The species can tolerate water temperatures up to 31°C (87.8°F), but this would not be optimal; optimal temperatures are between 15 and 20°C (59 and 68°F), but they can be found in water ranging from 2 to 26.5°C (35.6 to 79.7°F) (Kipp 2011; Garwood 1982) and are globally distributed across a wide range of latitudes from boreal to tropical (Guiry & Guiry 2012).

b. *Type of Mobility/Invasion Speed*
Red algae can spread quickly and become locally abundant under appropriate conditions and with human-mediated transport (Sonzogni et al. 1983).

c. *Fecundity*
Only asexual plants occur in the Great Lakes (Kipp 2011). Red algae have a 4 to 6 week generation time (Sheath & Cole 1980).

d. *History of Invasion Success*
The species has successfully invaded freshwater and become abundant, but this occurs typically only under specific salinity, conductivity, and micronutrient conditions (Lin & Blum 1979; Kipp 2011; Yokono 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls might transport red algae (Kipp 2011; Lin & Blum 1977) and there is significant boat traffic between the upper and lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Red algae are typically found on hard substrate although they can attach to tree limbs. Although active water and high conductivity water is preferred, the species can be found in slow waters (e.g., canals and harbors) as well (Belcher 1956; Lin & Blum 1977; Reed 1980). Suitable water quality is present at areas with natural and manmade hard substrate and appropriate water quality such as urbanized portions of the MRB (Kipp 2011). There is potential for this species to spread to streams with high alkalinity and flowing water (Yokono et al. 2011). Potential red algae habitat such as urbanized segments of rivers and lakes is present throughout the MRB and they are connected by flowing water.

Evidence for Probability Rating

There are several areas in large rivers, smaller streams, and lakes within the MRB that may provide suitable habitat (section 5f) and these areas are hydrologically connected (section 5f). Red algae are globally distributed at high and low latitudes (section 5a) so, spread into the southern MRB is not likely to be limited by temperature. However, red algae are typically only found in inland freshwater under specific water chemistry conditions (section 5d). Overall, the probability of the species spreading within the MRB is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Red algae have been documented in the literature to exist in a variety of freshwater habitats under different chemical and hydraulic conditions. However, the abundance of habitat with suitable water chemistry in the MRB is uncertain as to what degree the spread of red algae to the southern MRB would be limited by temperature. As a result, there is a high level of uncertainty associated with the species' spread.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Medium	High	Medium	High	Medium	High	Medium	High
P(passage)	Low	High	Low	High	Medium	High	Medium	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next fifty years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Red algae were first recorded from Lake Erie in 1964 (Edwards & Harrold 1970). Rapid spread has been documented for red algae (Edwards & Harrold 1970, Sonzogni et al. 1983). In the Great Lakes, it spread from Lake Erie to southern Lake Michigan within a decade and, in Milwaukee, it grew from a few filaments to a high density community within four years (Lin & Blum 1977). Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). Red algae have a prolonged monospore release that promotes population spread (Sheath et al. 1985).

b. *Human-Mediated Transport through Aquatic Pathways*
Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977). There is recreational, but not commercial, vessel traffic from the Great Lakes to the BSBH. There is commercial vessel traffic to Burns Harbor which is adjacent to BSBH (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: None; this species has been found in southern Lake Michigan (Lin & Blum 1977).
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the Great Lakes and BSBH.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: Recent information is not available to assess the species' current abundance. Red algae have a prolonged monospore (Sheath et al. 1985). Red algae produce the highest biomass in the spring and fall and they persist through the summer at low biomass (Kipp 2011). It is a seasonal annual (producing several generations per year) with a four to six week generation time (Sheath & Cole 1980; Sheath et al. 1985). Based on recent data from Lake Michigan, red algae (Division Rhodophyta) are rarely found in the Lake Michigan watershed (Whitman 2012).
T_{10}: See T_0. The distribution and abundance of red algae in the Great Lakes could decrease due to improvements in the water quality of southern Lake Michigan which could reduce the anthropogenic inputs into Lake Michigan that are preferred by this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Red algae were documented on the Canadian side of Lake Huron in 1980 (Jackson 1988). Red algae have been observed in southern Lake Michigan (Lin & Blum 1977). However, based on recent data from Lake Michigan, red algae are not frequently found in southern Lake Michigan (Whitman 2012).
T_{10}: The species may be present at BSBH. Alternatively, its range could contract, which would increase its distance from the pathway.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitat is present at the BSBH in the form of rocky shoreline and concrete and steel manmade structures (Kipp 2011). Red algae's occurrence is restricted largely to harbor areas which provide necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). Harbors exist all along the shoreline of Lake Michigan.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0. Future climate change or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for red algae. The species can tolerate a wide range of temperatures.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages

T_0: Red algae have been found in southern Lake Michigan and there is suitable habitat adjacent to BSBH (section 2f). However, recent surveys suggest red algae are not frequently found in southern Lake Michigan. No recent surveys of red algae are available. However, even if it is not currently present at the BSBH, the species has spread to multiple Great Lakes within a few decades (Kipp 2011), likely by vessel traffic. There is vessel traffic between the northern Great Lakes, the BSBH, and the adjacent Burns Harbor. Therefore, there is a medium probability that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Red algae are tolerant of a wide range of temperatures (section 2f). The species has been found in southern Lake Michigan in the vicinity of Indiana Harbor (section 2e), and appropriate habitat conditions are expected to continue to be present (sections 2c, 2f) along the shoreline of Lake Michigan, even considering impacts on habitat related to future climate change (section 2f). For these reasons, the probability of arrival remains medium at this time step.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although historically present in southern Lake Michigan, recent surveys do not indicate the presence of red algae. Therefore, the uncertainty associated with the species' probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future population trends of red algae are uncertain. The future rate of spread for this species is uncertain. The effects of measures to improve water quality in Lake Michigan on red algae are uncertain. Therefore, uncertainty remains high.
T_{50}: See T_{25}. The future effects of climate change on red algae and habitat suitability in Lake Michigan are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Red algae may disperse by passive current transportation. It is more than 64 km (40 mi) from the BSBH to Brandon Road Lock and Dam. Rapid spread is possible (Edwards & Harrold 1970; Sonzogni et al. 1983), but the species' rate of spread through the CAWS by natural dispersion is unknown. Red algae have been present in southern Lake Michigan for decades and they have not been reported in the CAWS.

b. *Human-Mediated Transport*
Ballast water and ship hulls may transport red algae through the CAWS (Kipp 2011; Lin & Blum 1977). Vessel traffic to BSBH and the adjacent Burns Harbor is lakewise. There is vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam (USACE 2011a,b; NBIC 2012). The discharge of ballast water originating from the Great Lakes would not likely occur within the CAWS (NBIC 2012), but hull transport to Brandon Road Lock and Dam is possible.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Water depth is adequate for red algae throughout the CAWS (Kipp 2011; LimnoTech 2010).This species has been found in the vicinity of the BSBH. Lockport Lock and Dam may act as a temporary barrier to natural dispersion, but not to hull mediated transport.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Much of CAWS water is municipal effluent which could contain the nutrients and halogens that promote growth of this species (Lin & Blum 1977; Eloranta & Kwandrans 2004). In Lake Michigan, red algae are typically found in harbor areas which provide the necessary levels of halogens and trace metals from point and nonpoint sources (Lin & Blum 1977). In Britain, red algae were found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). Large sections of the Little Calumet River have overhanging vegetation and may not be suitable for the species. In the North Leg of the Little Calumet River, the Calumet Sag Channel, and the CSSC there is suitable hard substrate in the form of concrete, riprap, pilings, bridges, and sheet pile (LimnoTech 2010). Turbidity is high in the CAWS which could limit photosynthesis (LimnoTech 2010). This species is typically found in flowing water or in active intertidal zones on exposed permanent rocky substrates (Kipp 2011). Current velocity in the

CAWS is typically very low (LimnoTech 2011). However, this species has been found to colonize slow-moving water in sheltered areas, harbors, and freshwater canals (Belcher 1956; Lin & Blum 1977; Sheath & Cole 1980; Reed 1980). Water flows out of BSBH into Lake Michigan. The eastern segment of the south branch Little Calumet River also generally flows toward Lake Michigan, depending on the location and water level in Lake Michigan (GSWMD 2008). Thus, the red algae would have to move upstream to enter the CAWS and move to the Calumet Sag Channel.

T_{10}: See T_0.

T_{25}: Future climate change may alter the physical, chemical, and climatological suitability of the CAWS for red algae. Temperature, in particular, may increase. Red algae have a wide temperature tolerance (Kipp 2011). Efforts to improve water quality in the CAWS will continue under the U.S. Environmental Protection Agency (EPA) mandates.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is suitable habitat for the species (section 3e) throughout much of the CAWS, including in the vicinity of Brandon Road Lock and Dam. This species has also been found in slow-moving inland freshwaters under the appropriate chemical conditions (section 3e). These conditions are likely to be present in the CAWS, given the high municipal pollution inputs. There is no vessel traffic in the south branch of the Little Calumet River (section 3b); therefore, red algae would have to spread naturally through the south branch of the Little Calumet River to the Calumet Sag Channel. Flow in the eastern portion of the south branch of the Little Calumet River is generally toward Lake Michigan. Red algae are not likely to move upstream through BSBH and the south branch of the Little Calumet River. If red algae reach the Calumet Sag Channel, they could be transported to Brandon Road Lock and Dam by natural flow or by attaching to the hulls of recreational and commercial boats (section 3b). Because of the lakeward flow in the south branch of the Little Calumet River, the probability of passage is low for this time step.

T_{10}: See T_0.

T_{25}: Over time, red algae may be able to spread upstream through BSBH and the Little Calumet River by wind-driven currents or aquatic biota, or by spreading along the shoreline if suitable attachment sites are present. Thus, sufficient time may elapse during this time step to allow red algae to spread through the CAWS by natural spread, boats, or a combination of both. Therefore, the probability of passage is medium for this time step.

T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Vessel traffic is known to exist in the CAWS. There may be low potential for transport in ballast water. The effectiveness of hull transport in spreading this species is not certain (section 3b). Although this species is commonly found in waters that are heavily affected by human uses, the ability of hydraulic and chemical conditions in the inland portions of the CAWS to support red algae is unknown. The direction of flow in the south branch of the Little Calumet River could inhibit the spread of this species from Lake Michigan to the Calumet Sag Channel. The potential natural spread rate of the species in the CAWS is not known. In addition, red algae have been reported in southern Lake Michigan, and it is uncertain why this species has not been reported in the CAWS. For these reasons, there is a high level of uncertainty associated with the passage of the species at this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is uncertain. Over time, red algae are more certain to spread through the CAWS, assuming appropriate conditions are present. However, future efforts to improve water quality in the CAWS may reduce the discharge of municipal effluents that this species requires. The effects on red algae of such changes are unknown. For this reason, the uncertainty of the species' passage remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Physical habitat such as manmade hard substrate is present downstream in the vicinity of Brandon Road Lock and Dam. Red algae prefer fast-moving and turbulent water, but are also found in harbors and slow-moving canals (Belcher 1956; Reed 1980). All of these habitats are present below Brandon Road Lock and Dam. The species has specific water quality preferences and it is typically found near harbors and areas influenced by urban runoff and/or seawater. Red algae are also found in fast-moving mountain streams with hard water (Yokono et al. 2012) and they are found in a navigation channel 32.8 km (10 mi) upstream from tidal influence in an area with high alkalinity, sulphates, and chlorides (Belcher 1956). However, the species has also been found in slow-moving freshwater canals with minimal saltwater influence (Reed 1980).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat such as industrial areas and harbors are found in the vicinity of Brandon Road Lock and Dam and they are presumably accessible.

Evidence for Probability Rating

Red algae appear to be capable of occupying a wide range of hydraulic and water chemistry conditions. The appropriate physical habitat (hard substrate) and hydrology (fast-moving water) is present below Brandon Road Lock and Dam. Water chemistry conditions may be appropriate due to urban runoff. Most studies have found that freshwater river and lake populations of red algae are found in areas that are influenced by saltwater or by urban runoff or in calcareous streams with high alkalinity (section 4a). However, this species has also been found in areas with minimal saltwater influence (section 4a). Overall, the probability of spread is considered to be medium for this species.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

This species has been documented in non-tidal navigation channels. However, the availability of hydraulic conditions in the inland portions of the CAWS to support red algae is unknown. For these reasons, the uncertainty regarding colonization by the species is considered to be medium.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Red algae typically inhabit temperate climates. They can tolerate water temperatures up to 31°C (87.8°F) but this would not be optimal; optimal temperatures are less than or equal to 20°C (68°F) (Kipp 2011; Garwood 1982).

b. *Type of Mobility/Invasion Speed*
Red algae can spread quickly and become locally abundant under appropriate conditions and with human-mediated transport (Sonzogni et al. 1983).

c. *Fecundity*
Only asexual plants occur in the Great Lakes (Kipp 2011). Red algae have a four to six week generation time (Sheath & Cole 1980).

d. *History of Invasion Success*
The species has successfully invaded freshwater and become abundant, but typically only under specific salinity, conductivity, and micronutrient conditions (Lin & Blum 1979; Kipp 2011; Yokono 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
   Ballast water and ship hulls may transport red algae (Kipp 2011; Lin & Blum 1977) and there is significant boat traffic between the upper and lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Red algae are typically found on hard substrate, although they can attach to tree limbs. Although active water and high-conductivity water are preferred, it can be found in slow waters (e.g., canals and harbors) as well (Belcher 1956; Lin & Blum 1977; Reed 1980). There is suitable habitat at areas with natural and manmade hard substrate and appropriate water quality in areas such as urbanized portions of the MRB (Kipp 2011). There is potential for this species to spread to karst streams with high alkalinity and flowing water (Yokono et al. 2011). Potential red algae habitat, such as urbanized segments of rivers and lakes, is present throughout the MRB and they are connected by flowing water.

Evidence for Probability Rating

Certain large rivers, smaller streams, and lakes within the MRB may provide suitable habitat (section 5f) and these areas are often hydrologically connected (section 5f). However, spread into the southern MRB may be prevented by temperature (section 5a). Red algae are typically only found in inland freshwater under specific water chemistry conditions (section 5d). Therefore, there is a medium probability that the species will spread in the MRB.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Red algae have been documented in the literature to exist in a variety of freshwater habitats under different chemical and hydraulic conditions. However, the abundance of habitat with suitable water chemistry in the MRB is unknown as to what degree the spread of red algae to the southern MRB would be limited by temperature. Overall, the uncertainty of the species' spread is considered to be high.

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E.2.3.4 Diatom - *Stephanodiscus binderanus*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
   S. binderanus is a planktonic diatom that moves passively by flowing water.
   S. binderanus was first recorded in Lake Michigan in 1938 and appeared in Lake Ontario in the late 1940s to early 1950s (Kipp 2011). It may have been in Lake Erie before the 1930s. It also now occurs in Lake Huron as well as in the Cuyahoga River, suggesting relatively rapid spread (Kipp 2011).

b. Human-Mediated Transport through Aquatic Pathways

S. binderanus is native to the Baltic Sea, so it was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is no commercial vessel traffic from the Great Lakes to the WPS, but there is recreational boat traffic (USACE 2011a,b).

c. Current Abundance and Reproductive Capacity

T_0: In the Great Lakes, *S. binderanus* has a high reproductive capacity and may form dense near-shore blooms in more eutrophic inshore waters, with little invasion of offshore waters. While *S. binderanus* is common in the Great Lakes, it has fluctuated in abundance; its population has declined as nutrient inputs into the Great Lakes declined (Kipp 2011) and possibly from grazing by *Dreissena* spp. (Barbiero et al. 2006). In southern Lake Michigan specifically, it has dramatically declined since the 1960s as Lake Michigan became oligotrophic (Makarewicz & Baybutt 1981; Barbiero et al. 2006; Kipp 2011). This species was not found in 1998 surveys in Lake Michigan but was found in low abundance in 1999 (Barbiero & Tuchman 2001, 2002).

T_{10}: See T_0. Future abundance cannot be predicted with any accuracy; however, reproductive capacity is predicted to remain the same, which can be very high during certain times of the year and with certain nutrient conditions.

T_{25}: See T_{10}. Further reductions in nutrient levels in Lake Michigan may continue to reduce the abundance of this species in southern Lake Michigan.

T_{50}: See T_{25}. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see section 2f).

d. Existing Physical Human/Natural Barriers

T_0: None.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. Distance from Pathway

T_0: No data on the current distribution of *S. binderanus* in the Great Lakes are available (Kipp 2011), but this species historically does occur in Lake Michigan offshore of Chicago (Makarewicz & Baybutt 1981).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *S. binderanus* was been found in southern Lake Michigan offshore of the Chicago area (Kipp 2011), suggesting climate and habitat are suitable. It is most abundant in near-shore areas but is also common in pelagic habitat in Lake Michigan (Stoermer & Yang 1969). However, *S. binderanus* prefers eutrophic waters, and the decline of this species in Lake Michigan mirrored the decline in nutrient levels in Lake Michigan

(Makarewicz & Baybutt 1981). *S. binderanus* also sometimes specifically occurs at river outlets into lakes (Kipp 2011). Resting cells are found in sediment (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0. Reductions in nutrient inputs into Lake Michigan resulting from water treatment upgrades could reduce the habitat suitability for this species.
T_{50}: See T_{25}. Diatoms are sensitive to climatological conditions. Future climate change and/or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *S. binderanus.* Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), and this could increase the productivity of *S. binderanus*. However, future climate change could also affect other variables that determine phytoplankton productivity such as nutrients and water circulation, and the effects of these changes on *S. binderanus* are uncertain.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Conditions in southern Lake Michigan are not generally ideal because of the low nutrient levels (section 2f), but municipal discharge may create localized conditions that are favorable for this species. Although surveys suggest it is not abundant, *S. binderanus* is considered to be established in Lake Michigan and has been found offshore of the Chicago area (section 2e). Therefore, the probability of this species arriving at the WPS is considered to be high.
T_{10}: See T_0. Southern Lake Michigan may remain suitable for *S. binderanus* although abundance may continue to decrease.
***T_{25}*:** See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *S. binderanus* is considered to be established in Lake Michigan and was documented offshore of the Chicago area (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is documented to have declined significantly in Lake Michigan, and this species is not consistently found in phytoplankton surveys (section 2c). Future improvements in water quality in southern Lake Michigan may continue to reduce the

abundance of *S. binderanus* near the WPS. However, the species is not expected to be eliminated. Therefore, the uncertainty of the probability of arrival is considered to be low. **T_{50}:** See T_{25}. Diatoms are sensitive to climatological and water quality conditions, which are a source of uncertainty for this species. The effects of future climate change and new environmental regulations on *S. binderanus* populations are uncertain (section 2f) but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
S. binderanus is a planktonic diatom that can spread rapidly by downstream flow or human-mediated mechanisms. From the WPS, *S. binderanus* must move more than 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. Human-Mediated Transport through Aquatic Pathways
S. binderanus can be carried in ballast water (Kipp 2011), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). In addition, a sluice gate at the WPS prevents the entry of vessel traffic from Lake Michigan into the North Shore Channel. Water from Lake Michigan is periodically pumped into the North Shore Channel, which could transport *S. binderanus* into the CAWS. There is no commercial vessel traffic in the North Shore Channel. Therefore, some natural downstream movement would likely be required to reach the Brandon Road Lock and Dam.

c. Existing Physical Human/Natural Barriers
T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010). There is a sluice gate separating the CAWS from Lake Michigan that is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel, which could transport *S. binderanus* into the CAWS.
T_{10}: See T_0. No changes in human or natural barriers are expected. The sluice gate is expected to continue to operate under current procedures.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *S. binderanus* is typically reported in lakes, but it is established in the Cuyahoga River (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006).

S. binderanus sometimes occurs at in lakes near river outlets (Kipp 2011). Resting cells are found in sediment (Kipp 2011). *S. binderanus* prefers eutrophic waters with high phosphate and a nitrogen-to-phosphate ratio of 7 (Kipp 2011). The CAWS has high nutrient levels due to municipal discharge (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is sensitive to nutrient levels. The discharge of nutrients may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Illinois Pollution Control Board 2012). However, the potential impact from these future water quality changes is uncertain.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *S. binderanus* is typically a lake species, but it has been reported in rivers and water quality may be suitable in the CAWS (section 3d). The high nutrients in the CAWS may promote the productivity of this species. This species could be transported through the WPS and flow downstream to the Brandon Road Lock and Dam. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The hydraulic suitability and light conditions (e.g., turbidity) in the CAWS for *S. binderanus* are uncertain, although this species has been documented in rivers. Suitable habitat potentially exists for *S. binderanus*, and this species is considered to have time to transit to the Brandon Road Lock and Dam during this time step. However, although *S. binderanus* has been in Lake Michigan since 1938, there are no records of it in the CAWS or downstream of the Brandon Road Lock and Dam. The lack of records may be due to habitat in the CAWS being unsuitable or to a lack of phytoplankton surveys in the Illinois waterway. Overall, uncertainty of the probability of this species passing through the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0. Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with

(section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *S. binderanus*. Because of possible changes in the amounts of limiting nutrients, the uncertainty of this species passing through the pathway in the future remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
S. binderanus is typically reported in lakes, but it is established in the Cuyahoga River (Lake Erie) (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Reservoirs may provide suitable habitat. It is found in areas of high nutrient concentrations (Makarewicz & Baybutt 1981; Kipp 2011). This suggests water quality may be suitable downstream of the Brandon Road Lock and Dam in reaches with high agricultural or municipal runoff containing nutrients.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
If suitable habitat is present in the downstream vicinity of the Brandon Road Lock and Dam, it will be accessible by passive dispersal.

Evidence for Probability Rating

S. binderanus has been documented in inland rivers (section 4a), and suitable water quality for *S. binderanus* may be present in areas with anthropogenic inputs downstream of the Brandon Road Lock and Dam (sections 4a, 4b). Although this species is typically found in lakes, it is established in the Cuyahoga River. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions in the Illinois River for this species is not documented. Therefore, there is a medium uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
S. binderanus is globally widespread and is considered eurythermal (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
S. binderanus is a phytoplankton that would spread by drifting downstream through the MRB.

c. *Fecundity*
S. binderanus can form dense blooms under high nutrient conditions. The MRB has high nutrient inputs from agricultural and municipal runoff.

d. *History of Invasion Success*
S. binderanus spread rapidly through the Great Lakes and had strong seasonal blooms (Kipp 2011). Although this species is found in the Cuyahoga River, no data on the rate of spread through river basins were found.

e. *Human-Mediated Transport through Aquatic Pathways*
S. binderanus can be transported in ballast water (Kipp 2011). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
S. binderanus specializes in waters with high nutrient levels (Kipp 2011). *S. binderanus* does best in eutrophic waters (Kipp 2011). It is typically a lake species, but it does exist in large eutrophic rivers such as the Cuyahoga. Many of the dams in the MRB form large lake-like pools upstream (e.g., the numbered pools on the river), which could serve as suitable habitat. Suitable habitat may be present in the MRB in waters affected by anthropogenic inputs that contain elevated nutrients such as urban areas and areas with agricultural or livestock runoff. High nutrient inputs are typical of the MRB.
S. binderanus is not described in the literature as a riverine species. Therefore, hydraulic conditions and light levels in river systems may not be suitable because they are generally turbid.

Evidence for Probability Rating

S. binderanus is globally distributed (section 5a), so climate in the MRB will likely be suitable. *S. binderanus* is found in fresh water in areas with high nutrient levels (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. *S. binderanus* is not described in the literature as a riverine species, although it is present in eutrophic rivers (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of water chemistry, flow, and light conditions in the MRB for this species is uncertain. Therefore, there is a medium uncertainty associated with the probability of this species spreading throughout the MRB.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
S. binderanus is a planktonic diatom that moves passively by flowing water. *S. binderanus* was first recorded in Lake Michigan in 1938 and appeared in Lake Ontario in the late 1940s to early 1950s (Kipp 2011). It may have been in Lake Erie before the 1930s. It also now occurs in Lake Huron as well as in the Cuyahoga River, suggesting relatively rapid spread (Kipp 2011).

b. Human-Mediated Transport through Aquatic Pathways
S. binderanus is native to the Baltic Sea, so it was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is commercial and recreational vessel traffic from the Great Lakes to the CRCW (USACE 2011a,b).

c. Current Abundance and Reproductive Capacity
T_0: In the Great Lakes, *S. binderanus* has a high reproductive capacity and may form dense near-shore blooms in more eutrophic inshore waters, with little invasion of offshore waters. While *S. binderanus* is common in the Great Lakes, it has fluctuated in abundance; its population has declined as nutrient inputs into the Great Lakes declined (Kipp 2011) and possibly from grazing by *Dreissena* spp. (Barbiero et al. 2006). In southern Lake Michigan specifically, it has dramatically declined since the 1960s as Lake Michigan became oligotrophic (Makarewicz & Baybutt 1981; Barbiero et al. 2006; Kipp 2011). This species was not found in 1998 surveys in Lake Michigan but was found in low abundance in 1999 (Barbiero & Tuchman 2001, 2002).
T_{10}: See T_0**.** Future abundance cannot be predicted with any accuracy; however, reproductive capacity is predicted to remain the same, which can be very high during certain times of the year and with certain nutrient conditions.
T_{25}: See T_{10}. Further reductions in nutrient levels in Lake Michigan may continue to reduce the abundance of this species in southern Lake Michigan.
T_{50}: See T_{25}. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see section 2f).

d. Existing Physical Human/Natural Barriers
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No data on the current distribution of *S. binderanus* in the Great Lakes are available (Kipp 2011), but this species historically does occur in Lake Michigan offshore of Chicago (Makarewicz & Baybutt 1981).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *S. binderanus* was been found in southern Lake Michigan offshore of the Chicago area (Kipp 2011), suggesting climate and habitat are suitable. It is most abundant in near-shore areas but also common in pelagic habitat in Lake Michigan (Stoermer & Yang 1969). However, *S. binderanus* prefers eutrophic waters, and the decline of this species in Lake Michigan mirrored the decline in nutrient levels in Lake Michigan (Makarewicz & Baybutt 1981). *S. binderanus* also sometimes specifically occurs at river outlets into lakes (Kipp 2011). Resting cells are found in sediment (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0. Reductions in nutrient inputs in to Lake Michigan resulting from water treatment upgrades could reduce the habitat suitability for this species.
T_{50}: See T_{25}. Diatoms are sensitive to climatological conditions. Future climate change and new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *S. binderanus.* Climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), and this could increase the productivity of *S. binderanus*. However, future climate change could also affect other variables that determine phytoplankton productivity, such as nutrients and water circulation, and the effects of these changes on *S. binderanus* are uncertain.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Conditions in southern Lake Michigan are not generally ideal because of the low nutrient levels (section 2f), but municipal discharge may create localized conditions that are favorable for this species. Although surveys suggest it is not abundant, *S. binderanus* is considered to be established in Lake Michigan and has been found offshore of the Chicago area (section 2e). Therefore, the probability of this species arriving at the CRCW is considered to be high.
T_{10}: See T_0. Southern Lake Michigan may remain suitable for *S. binderanus*, although abundance may continue to decrease.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *S. binderanus* is considered to be established in Lake Michigan and was documented offshore of the Chicago area (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is documented to have declined significantly in Lake Michigan, and this species is not consistently found in phytoplankton surveys (section 2c). Future improvements in water quality in southern Lake Michigan may continue to reduce the abundance of *S. binderanus* near the CRCW. However, the species is not expected to be eliminated. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{50}: See T_{25}. Diatoms are sensitive to climatological and water quality conditions, which are a source of uncertainty for this species. The effects of future climate change and new environmental regulations on *S. binderanus* populations are uncertain (section 2f), but they may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
S. binderanus is a planktonic diatom that can spread rapidly by downstream flow or human-mediated mechanisms. From the CRCW, *S. binderanus* must move more than 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. Human-Mediated Transport through Aquatic Pathways
S. binderanus can be carried in ballast water (Kipp 2012), and there is some commercial vessel traffic between the CRCW and the Brandon Road Lock and Dam (USACE 2011a; NBIC 2012). However, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. Existing Physical Human/Natural Barriers
T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *S. binderanus* is typically reported in lakes, but it is established in the Cuyahoga River (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Resting cells are found in sediment (Kipp 2011). *S. binderanus* prefers eutrophic waters with high phosphate and a nitrogen-to-phosphate ratio of 7 (Kipp 2011). The CAWS has high nutrient levels due to municipal discharge (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is sensitive to nutrient levels. The discharge of nutrients may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Illinois Pollution Control Board 2012). However, the potential impact of these future water quality changes is uncertain.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *S. binderanus* is typically a lake species, but it has been reported in rivers, and water quality may be suitable in the CAWS (section 3d). The high nutrients in the CAWS may promote the productivity of this species. This species could be transported through the CRCW and flow downstream to the Brandon Road Lock and Dam. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species has been documented in rivers (section 3d), the suitability of hydraulic, chemical, and light conditions (e.g., turbidity) in the CAWS for *S. binderanus* is uncertain. Suitable habitat potentially exists for *S. binderanus*, and this species is considered to have time to transit to the Brandon Road Lock and Dam during this time step. However, although it has been in Lake Michigan since 1938, there are no records of

S. binderanus in the CAWS or downstream of the Brandon Road Lock and Dam. The lack of records may be due to habitat in the CAWS being unsuitable or to a lack of phytoplankton surveys in the Illinois waterway. Overall, the uncertainty of the probability of this species passing through the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0. Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *S. binderanus*. Because of possible changes in the amounts of limiting nutrients, the uncertainty of this species passing through the pathway in the future remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   S. binderanus is typically reported in lakes, but it is established in the Cuyahoga River (Lake Erie) (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Reservoirs may provide suitable habitat. It is found in areas of high nutrient concentrations (Makarewicz & Baybutt 1981; Kipp 2011). This suggests water quality may be suitable downstream of the Brandon Road Lock and Dam in reaches with high agricultural or municipal runoff containing nutrients.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   If suitable habitat is present in the downstream vicinity of the Brandon Road Lock and Dam, it will be accessible by passive dispersal.

Evidence for Probability Rating

S. binderanus has been documented in inland rivers (section 4a), and suitable water quality for *S. binderanus* may be present in areas with anthropogenic inputs downstream of the Brandon Road Lock and Dam (sections 4a, 4b). Although this species is typically found in lakes, it is established in the Cuyahoga River and Lake Erie. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions downstream of the Brandon Road Lock and Dam is not documented for this species. Therefore, there is a medium uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
S. binderanus is globally widespread and is considered eurythermal (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. Type of Mobility/Invasion Speed
S. binderanus is a phytoplankton that would spread by drifting downstream through the MRB.

c. Fecundity
S. binderanus can form dense blooms under high nutrient conditions. It is has high productivity under high nutrient conditions.

d. History of Invasion Success
S. binderanus spread rapidly through the Great Lakes and had strong seasonal blooms (Kipp 2011). Although this species is found in the Cuyahoga River, no data on the rate of spread through river basins were found.

e. Human-Mediated Transport through Aquatic Pathways
S. binderanus can be transported in ballast water (Kipp 2011). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
S. binderanus specializes in waters with high nutrient levels (Kipp 2011). *S. binderanus* does best in eutrophic waters (Kipp 2011). It is typically a lake species, but it does exist in large eutrophic rivers such as the Cuyahoga. Many of the dams in the MRB form large lake-like pools upstream (e.g., the numbered pools on the river), which could serve as suitable habitat. Suitable habitat may be present in the MRB in waters affected by anthropogenic inputs that contain elevated nutrients, such as urban areas and areas with agricultural or livestock runoff. High nutrient inputs are typical of the MRB. *S. binderanus* is not described in the literature as a riverine species. Therefore, hydraulic conditions and light levels may not be suitable in river systems because they are generally turbid.

Evidence for Probability Rating

S. binderanus is globally distributed (section 5a), so climate in the MRB will likely be suitable. *S. binderanus* is found in fresh water in areas with high nutrient levels (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f) and these areas are hydrologically connected. *S. binderanus* is not described in the literature as a riverine species, although it is present in eutrophic rivers (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of water chemistry, flow, and light conditions in the MRB for this species is uncertain. Therefore, there is a medium uncertainty associated with the probability of this species spreading throughout the new basin.

PATHWAY: 3 (CALUMET HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	High	High	High	High	High	High	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
S. binderanus is a planktonic diatom that moves passively by flowing water.
S. binderanus was first recorded in Lake Michigan in 1938 and appeared in Lake Ontario in the late 1940s to early 1950s (Kipp 2011). It may have been in Lake Erie before the 1930s. It also now occurs in Lake Huron as well as the Cuyahoga River, suggesting relatively rapid spread (Kipp 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
S. binderanus is native to the Baltic Sea, so it was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is commercial and recreational vessel traffic from the Great Lakes to Calumet Harbor (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: In the Great Lakes, *S. binderanus* has a high reproductive capacity and may form dense near-shore blooms in more eutrophic inshore waters, with little invasion of offshore waters. While *S. binderanus* is common in the Great Lakes, it has fluctuated in abundance; its population has declined as nutrient inputs into the Great Lakes declined (Kipp 2011) and possibly from grazing by *Dreissena* spp. (Barbiero et al. 2006). In southern Lake Michigan specifically, it has dramatically declined since the 1960s as Lake Michigan became oligotrophic (Makarewicz & Baybutt 1981; Barbiero et al. 2006; Kipp 2011). This species was not found in 1998 surveys in Lake Michigan but was found in low abundance in 1999 (Barbiero and Tuchman 2001, 2002).
T_{10}: See T_0. Future abundance cannot be predicted with any accuracy; however, reproductive capacity is predicted to remain the same, which can be very high during certain times of the year and with certain nutrient conditions.
T_{25}: See T_{10}. Further reductions in nutrient levels in Lake Michigan may continue to reduce the abundance of this species in southern Lake Michigan.
T_{50}: See T_{25}. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see section 2f).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: No data on the current distribution of *S. binderanus* in the Great Lakes (Kipp 2011) are available, but this species historically does occur in Lake Michigan offshore of Chicago (Makarewicz & Baybutt 1981).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: *S. binderanus* has been found in southern Lake Michigan offshore of the Chicago area (Kipp 2011), suggesting climate and habitat are suitable. It is most abundant in near-shore areas but also is common in pelagic habitat in Lake Michigan (Stoermer & Yang 1969). However, *S. binderanus* prefers eutrophic waters, and the decline of this species in Lake Michigan mirrored the decline in nutrient levels in Lake Michigan (Makarewicz & Baybutt 1981). *S. binderanus* also sometimes specifically occurs at river outlets into lakes (Kipp 2011). Resting cells are found in sediment (Kipp 2011).

T_{10}: See T_0.

T_{25}: See T_0. Reductions in nutrient inputs in to Lake Michigan resulting from water treatment upgrades could reduce the habitat suitability for this species.

T_{50}: See T_{25}. Diatoms are sensitive to climatological conditions. Future climate change and new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *S. binderanus.* Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could increase the productivity of *S. binderanus*. However, climate change could also affect other variables that determine phytoplankton productivity, such as nutrients and water circulation, and the effects of these changes on *S. binderanus* are uncertain.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Conditions in southern Lake Michigan are not generally ideal because of the low nutrient levels (section 2f), but municipal discharge may create localized conditions that are favorable for this species. Although surveys suggest it is not abundant, *S. binderanus* is considered to be established in Lake Michigan and has been found offshore of the Chicago area (section 2e). Therefore, the probability of this species arriving at Calumet Harbor is considered to be high.

T_{10}: See T_0. Southern Lake Michigan may remain suitable for *S. binderanus*, although abundance may continue to decrease.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *S. binderanus* is considered to be established in Lake Michigan and was documented offshore of the Chicago area (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is documented to have declined significantly in Lake Michigan, and this species is not consistently found in phytoplankton surveys (section 2c). Future improvements in water quality in southern Lake Michigan may continue to reduce the abundance of *S. binderanus* near Calumet Harbor. However, the species is not expected to be eliminated. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{50}: See T_{25}. Diatoms are sensitive to climatological and water quality conditions, which are a source of uncertainty for this species. The effects of future climate change on *S. binderanus* populations are uncertain (section 2f) but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
S. binderanus is a planktonic diatom that can spread rapidly by downstream flow or human-mediated mechanisms. From Calumet Harbor, *S. binderanus* must move approximately 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). *S. binderanus* can be carried in ballast water (Kipp 2011), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *S. binderanus* is typically reported in lakes, but it is established in the Cuyahoga River (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Resting cells are found in sediment (Kipp 2011). *S. binderanus* prefers eutrophic waters with high phosphate and a nitrogen-to-phosphate ratio of 7 (Kipp 2011). The CAWS has high nutrient levels due to municipal discharge (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is sensitive to nutrient levels. The discharge of nutrients may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Illinois Pollution Control Board 2012). However, the potential impact of these future water quality changes is uncertain.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *S. binderanus* is typically a lake species, but it has been reported in rivers, and water quality may be suitable in the CAWS (section 3d). The high nutrient levels in the CAWS may promote the productivity of this species. This species could be transported through Calumet Harbor and downstream to the Brandon Road Lock and Dam by floating or potentially by vessel transport (sections 3a, 3b). Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species has been documented in rivers (section 3d), the suitability of hydraulic, chemical, and light conditions (e.g., turbidity) in the CAWS for *S. binderanus* is uncertain. Suitable habitat potentially exists for *S. binderanus*, and this species is considered to have time to transit to the Brandon Road Lock and Dam during this time step. However, although it has been in Lake Michigan since 1938, there are no records of *S. binderanus* in the CAWS or downstream of the Brandon Road Lock and Dam. The lack of records may be due to habitat in the CAWS being unsuitable or to a lack of phytoplankton surveys in the Illinois waterway. Overall, the uncertainty of the probability of this species passing through the pathway is high.
T_{10}: See T_0.
T_{25}: See T_0. Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *S. binderanus*. Because of possible changes in the amounts of limiting nutrients, the uncertainty of this species passing through the pathway in the future remains high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   S. binderanus is typically reported in lakes, but it is established in the Cuyahoga River (Lake Erie) (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Reservoirs may provide suitable habitat. It is found in areas of high nutrient concentrations (Makarewicz & Baybutt 1981; Kipp 2011). This suggests water quality may be suitable downstream of the Brandon Road Lock and Dam in reaches with high agricultural or municipal runoff containing nutrients.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   If suitable habitat is present in the downstream vicinity of the Brandon Road Lock and Dam, it will be accessible by passive dispersal.

Evidence for Probability Rating

S. binderanus has been documented in inland rivers (section 4a), and suitable water quality for *S. binderanus* may be present in areas with anthropogenic inputs downstream of the Brandon Road Lock and Dam (sections 4a, 4b). Although this species is typically found in lakes, it is established in the Cuyahoga River and Lake Erie. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions downstream of the Brandon Road Lock and Dam is not documented for this species. Therefore, there is a medium uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
S. binderanus is globally widespread and is considered eurythermal (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. Type of Mobility/Invasion Speed
S. binderanus is a phytoplankton that would spread by drifting downstream through the MRB.

c. Fecundity
S. binderanus can form dense blooms under high nutrient conditions. It is has high productivity under high nutrient conditions.

d. History of Invasion Success
S. binderanus spread rapidly through the Great Lakes and had strong seasonal blooms (Kipp 2011). Although this species is found in the Cuyahoga River, no data on the rate of spread through river basins were found.

e. Human-Mediated Transport through Aquatic Pathways
S. binderanus can be transported in ballast water (Kipp 2011). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
S. binderanus specializes in waters with high nutrient levels (Kipp 2011). *S. binderanus* does best in eutrophic waters (Kipp 2011). It is typically a lake species, but it does exist in large eutrophic rivers such as the Cuyahoga. Many of the dams in the MRB form large lake-like pools upstream (e.g., the numbered pools on the river), which could serve as suitable habitat. Suitable habitat may be present in the MRB in waters affected by

anthropogenic inputs that contain elevated nutrients, such as urban areas and areas with agricultural or livestock runoff. High nutrient inputs are typical of the MRB. *S. binderanus* is not described in the literature as a riverine species. Therefore, hydraulic conditions and light levels may not be suitable in river systems because they are generally turbid.

Evidence for Probability Rating

S. binderanus is globally distributed (section 5a), so climate in the MRB will likely be suitable. *S. binderanus* is found in fresh water in areas with high nutrient levels (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. *S. binderanus* is not described in the literature as a riverine species, although it is present in eutrophic rivers (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of water chemistry, flow, and light conditions in the MRB for this species is uncertain. Therefore, there is a medium uncertainty associated with the probability of this species spreading throughout the MRB.

PATHWAY: 4 (INDIANA HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	High	Low	High	Low	High	Medium	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
S. binderanus is a planktonic diatom that moves passively by flowing water. *S. binderanus* was first recorded in Lake Michigan in 1938 and appeared in Lake Ontario in the late 1940s to early 1950s (Kipp 2011). It may have been in Lake Erie since before the 1930s. It also now occurs in Lake Huron as well as in the Cuyahoga River, suggesting relatively rapid spread (Kipp 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
S. binderanus is native to the Baltic Sea, so it was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is heavy commercial vessel traffic from the Great Lakes to Indiana Harbor (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
T_0: In the Laurentian Great Lakes, *S. binderanus* has a high reproductive capacity and may form dense near-shore blooms in more eutrophic inshore waters, with little invasion of offshore waters. While *S. binderanus* is common in the Great Lakes, it has fluctuated in abundance; its population has declined as nutrient inputs into the Great Lakes declined (Kipp 2011) and possibly from *Dreissena* spp. (Barbiero et al. 2006). In southern Lake Michigan specifically, it has dramatically declined since the 1960s as Lake Michigan became oligotrophic (Makarewicz & Baybutt 1981; Barbiero et al. 2006; Kipp 2011). This species was not found in 1998 surveys in Lake Michigan but was found in low abundance in 1999 (Barbiero & Tuchman 2001, 2002).

T_{10}: See T_0**.** Future abundance cannot be predicted with any accuracy; however, reproductive capacity is predicted to remain the same, but can be very high during certain times of the year and with certain nutrient conditions.
T_{25}: See T_{10}. Further reductions in nutrient levels in Lake Michigan may continue to reduce the abundance of this species in southern Lake Michigan.
T_{50}: See T_{25}. Changes in water temperature and rainfall related to future climate change (Wuebbles et al. 2010) could affect the productivity of this species (see section 2f).

d. Existing Physical Human/Natural Barriers
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway
T_0: No data on the current distribution of *S. binderanus* in the Great Lakes (Kipp 2011) are available, but this species historically does occur in Lake Michigan offshore of Chicago (Makarewicz & Baybutt 1981).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *S. binderanus* has been found in southern Lake Michigan offshore of the Chicago area (Kipp 2011), suggesting climate and habitat are suitable. It is most abundant in near-shore areas but is also common in pelagic habitat in Lake Michigan (Stoermer & Yang 1969). However, *S. binderanus* prefers eutrophic waters, and the decline in this species in Lake Michigan mirrored the decline in nutrient levels in Lake Michigan (Makarewicz & Baybutt 1981). *S. binderanus* also sometimes specifically occurs at river outlets into lakes (Kipp 2011). Resting cells are found in sediment (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0. Reductions in nutrient inputs into Lake Michigan resulting from water treatment upgrades could reduce the habitat suitability for this species.
T_{50}: See T_{25}. Diatoms are sensitive to climatological conditions. Future climate change and new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *S. binderanus.* Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could increase the productivity of *S. binderanus*. However, future climate change could also affect other variables that determine phytoplankton productivity, such as nutrients and water circulation, and the effects of these changes on *S. binderanus* are uncertain.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Conditions in southern Lake Michigan are not generally ideal because of the low nutrient levels (section 2f), but municipal discharge may create localized conditions that are favorable for this species. Although surveys suggest it is not abundant, *S. binderanus* is considered to be established in Lake Michigan and has been found offshore of the Chicago area (section 2e). Therefore, the probability of this species arriving at Indiana Harbor is considered to be high.
T_{10}: See T_0. Southern Lake Michigan may remain suitable for *S. binderanus,* although abundance may continue to decrease.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *S. binderanus* is considered to be established in Lake Michigan and was documented offshore of the Chicago area (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is documented to have declined significantly in Lake Michigan, and this species is not consistently found in phytoplankton surveys (section 2c). Future improvements in water quality in southern Lake Michigan may continue to reduce the abundance of *S. binderanus* near Indiana Harbor. However, the species is not expected to be eliminated. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{50}: See T_{25}. Diatoms are sensitive to climatological and water quality conditions, which are a source of uncertainty for this species. The effects of future climate change and new environmental regulations on *S. binderanus* populations are uncertain (section 2f) but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
S. binderanus is a planktonic diatom that can spread rapidly by downstream flow or human-mediated mechanisms. From Indiana Harbor, *S. binderanus* must move approximately 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam.

The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic to Indiana Harbor is primarily lake-wide (USACE 2011a). *S. binderanus* can be carried in ballast water (Kipp 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). There is no vessel traffic in the Grand Calumet River east of Indiana Harbor. Consequently, some natural downstream dispersal would likely be necessary to reach the Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010). There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a temporary barrier, especially under low flows.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T10.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *S. binderanus* is typically reported in lakes, but it is established in the Cuyahoga River (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Resting cells are found in sediment (Kipp 2011). *S. binderanus* prefers eutrophic waters with high phosphate and a nitrogen-to-phosphate ratio of 7 (Kipp 2011). The CAWS has high nutrient levels due to municipal discharge (LimnoTech 2010). Water flows out of Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern-most sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, *S. binderanus* would have to move upstream to enter the CAWS and move to the Calumet Sag Channel.
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is sensitive to nutrient levels. The discharge of nutrients may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Illinois Pollution Control Board 2012). However, the potential impact of these future water quality changes is uncertain.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *S. binderanus* is typically a lake species, but it has been reported in rivers, and water quality may be suitable in the CAWS (section 3d). Because of the lack of vessel traffic (section 3b), natural spread through the Grand Calumet will likely be required for *S. binderanus* to reach the Little Calumet River and the Calumet Sag Channel. Water flow in Indiana Harbor and portions of the Grand Calumet River is toward Lake Michigan, which is likely to inhibit the movement of this species to Brandon Road Lock and Dam. Overall, this species is considered to have a low probability of passing through the pathway at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over time, this species may be able to move upstream (by wind driven currents or by aquatic life) through Indiana Harbor and the Grand Calumet River to navigable sections of the CAWS that flow toward the MRB. Therefore, its probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species has been documented in rivers (section 3d), the suitability of hydraulic, chemical, and light conditions (e.g., turbidity) in the CAWS for *S. binderanus* is uncertain. Although it has been in Lake Michigan since 1938, there are no records of *S. binderanus* in the CAWS or downstream of the Brandon Road Lock and Dam. The lack of records may be due to habitat in the CAWS being unsuitable or to a lack of phytoplankton surveys in the Illinois waterway. The lakeward flow of Indiana Harbor and the Grand Calumet River could decrease or inhibit spread through the pathway (section 3d). Overall, the uncertainty associated with passage during this time step is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0. Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *S. binderanus*. Flow conditions in Indiana Harbor and the Grand Calumet River are expected to remain unfavorable to passage. However, this species is more certain to pass through the CAWS in 25 years compared to the previous time step. Overall, the future uncertainty of this species passing through the pathway is high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   S. binderanus is typically reported in lakes, but it is established in the Cuyahoga River (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Reservoirs may provide suitable habitat. It is found in areas of high nutrient concentrations (Makarewicz & Baybutt 1981; Kipp 2011). This suggests water quality may be suitable downstream of the Brandon Road Lock and Dam in reaches with high agricultural or municipal runoff containing nutrients.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   If suitable habitat is present in the downstream vicinity of the Brandon Road Lock and Dam, it will be accessible by passive dispersal.

Evidence for Probability Rating

S. binderanus has been documented in inland rivers (section 4a), and suitable water quality for *S. binderanus* may be present in areas with anthropogenic inputs downstream of the Brandon Road Lock and Dam (sections 4a, 4b). However, this species is typically found in lakes. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions downstream of the Brandon Road Lock and Dam is not documented for this species. Therefore, there is a medium uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   S. binderanus is globally widespread and is considered eurythermal (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
   S. binderanus is a phytoplankton that would spread by floating downstream through the MRB.

c. *Fecundity*
   S. binderanus can form dense blooms under high nutrient conditions.

d. *History of Invasion Success*
   S. binderanus spread rapidly through the Great Lakes and had strong seasonal blooms (Kipp 2011). Although this species is found in the Cuyahoga River, no data on the rate of spread through river basins were found.

e. *Human-Mediated Transport through Aquatic Pathways*
   S. binderanus can be transported in ballast water (Kipp 2011). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   S. binderanus specializes in waters with high nutrient levels (Kipp 2011). *S. binderanus* does best in eutrophic waters (Kipp 2011). It is typically a lake species, but it does exist in large eutrophic rivers such as the Cuyahoga. The dams in the Mississippi River also form large lake-like pools that could potentially serve as suitable habitat. Suitable habitat may be present in the MRB in waters affected by anthropogenic inputs that contain elevated nutrients such as urban areas and areas with agricultural or livestock runoff. High nutrient inputs are typical of the MRB. *S. binderanus* is not described in the literature as a riverine species. Therefore, hydraulic conditions and light levels in river systems may not be suitable because they are generally turbid.

Evidence for Probability Rating

S. binderanus is globally distributed (section 5a), so climate in the MRB will likely be suitable. *S. binderanus* is found in fresh water in areas with high nutrient levels (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. *S. binderanus* is not described in the literature as a riverine species, although it is present in eutrophic rivers (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of water chemistry, flow, and light conditions in the MRB for this species is uncertain. Therefore, there is a medium uncertainty associated with the probability of this species spreading throughout the new basin.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	High	Low	High	Low	High	Medium	High
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
S. binderanus is a planktonic diatom that moves passively by flowing water.
S. binderanus was first recorded in Lake Michigan in 1938 and appeared in Lake Ontario in the late 1940s to early 1950s (Kipp 2011). It may have been in Lake Erie since before the 1930s. It also now occurs in Lake Huron as well as in the Cuyahoga River, suggesting relatively rapid spread (Kipp 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
S. binderanus is native to the Baltic Sea, so it was very likely introduced into the Great Lakes by ballast water discharge (Kipp 2011). Diatoms are commonly transported in ballast water over long distances (Klein et al. 2010). There is recreational but no commercial vessel traffic from the Great Lakes to the BSBH (USACE 2011a). However, there is heavy commercial traffic to Burns Harbor, which is adjacent to the BSBH.

c. *Current Abundance and Reproductive Capacity*
T_0: In the Great Lakes, *S. binderanus* has a high reproductive capacity and may form dense near-shore blooms in more eutrophic inshore waters, with little invasion of offshore waters. While *S. binderanus* is common in the Great Lakes, it has fluctuated in abundance; its population has declined as nutrient inputs into the Great Lakes declined (Kipp 2011) and possibly from grazing by *Dreissena* spp. (Barbiero et al. 2006). In southern Lake Michigan specifically, it has dramatically declined since the 1960s as Lake Michigan became oligotrophic (Makarewicz & Baybutt 1981; Barbiero et al. 2006; Kipp 2011). This species was not found in 1998 surveys in Lake Michigan but was found in low abundance in 1999 (Barbiero & Tuchman 2001, 2002).
T_{10}: See T_0. Future abundance cannot be predicted with any accuracy; however, reproductive capacity is predicted to remain the same, which can be very high during certain times of the year and with certain nutrient conditions.
T_{25}: See T_{10}. Further reductions in nutrient levels in Lake Michigan may continue to reduce the abundance of this species in southern Lake Michigan.
T_{50}: See T_{25}. Changes in water temperature and rainfall related to future climate change (Wuebbles et al., 2010) could affect the productivity of this species (see section 2f).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: No data on the current distribution of *S. binderanus* in the Great Lakes (Kipp 2011) are available, but this species historically does occur in Lake Michigan offshore of Chicago (Makarewicz & Baybutt 1981).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *S. binderanus* has been found in southern Lake Michigan offshore of the Chicago area (Kipp 2011), suggesting climate and habitat are suitable. It is most abundant in near-shore areas but also common in pelagic habitat in Lake Michigan (Stoermer & Yang 1969). However, *S. binderanus* prefers eutrophic waters, and the decline of this species in Lake Michigan mirrored the decline in nutrient levels in Lake Michigan

(Makarewicz & Baybutt 1981). *S. binderanus* also sometimes occurs specifically at river outlets into lakes (Kipp 2011). Resting cells are found in sediment (Kipp 2011).
T_{10}: See T_0.
T_{25}: See T_0. Reductions in nutrient inputs in to Lake Michigan resulting from water treatment upgrades could reduce the habitat suitability for this species.
T_{50}: See T_{25}. Diatoms are sensitive to climatological conditions. Future climate change and/or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for *S. binderanus.* Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), and this could increase the productivity of *S. binderanus*. However, climate change could also affect other variables that determine phytoplankton productivity, such as nutrients and water circulation, and the effects of these changes on *S. binderanus* are uncertain.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Conditions in southern Lake Michigan are not generally ideal because of the low nutrient levels (section 2f), but municipal discharge may create localized conditions that are favorable for this species. Although surveys suggest it is not abundant, *S. binderanus* is considered to be established in Lake Michigan and has been found offshore of the Chicago area (section 2e). Therefore, the probability of this species arriving at the BSBH is considered to be high.
T_{10}: See T_0. Southern Lake Michigan may remain suitable for *S. binderanus*, although abundance may continue to decrease.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *S. binderanus* is considered to be established in Lake Michigan and was documented offshore of the Chicago area (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is documented to have declined significantly in Lake Michigan, and this species is not consistently found in phytoplankton surveys (section 2c). Future improvements in water quality in southern Lake Michigan may continue to reduce the

abundance of *S. binderanus* near the BSBH. However, the species is not expected to be eliminated. Therefore, the uncertainty of the probability of arrival is considered to be low. **T_{50}:** See T_{25}. Diatoms are sensitive to climatological and water quality conditions, which are a source of uncertainty for this species. The effects of future climate change and new environmental regulations on *S. binderanus* populations are uncertain (section 2f) but may alter the distribution and annual occurrence. Future uncertainty remains low.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

S. binderanus is a planktonic diatom that can spread rapidly by downstream flow or human-mediated mechanisms. From the BSBH, *S. binderanus* must move more than 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. Human-Mediated Transport through Aquatic Pathways

Vessel traffic to the BSBH is primarily lake-wide (USACE 2011a,b). *S. binderanus* can be carried in ballast water (Kipp 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Consequently, some natural downstream dispersal would likely be necessary to reach the Brandon Road Lock and Dam.

c. Existing Physical Human/Natural Barriers

T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *S. binderanus* is typically reported in lakes, but it is established in the Cuyahoga River (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs in lakes near river outlets (Kipp 2011). Resting cells are found in sediment (Kipp 2011). *S. binderanus* prefers eutrophic waters, with high phosphate and a nitrogen-to-phosphate ratio of 7 (Kipp 2011). The CAWS has high nutrient levels due to municipal discharge (LimnoTech 2010). Water flows out of the BSBH into Lake Michigan. The eastern segment of the south branch of the Little Calumet River also generally flows toward Lake Michigan, depending on location and water level in Lake Michigan (GSWMD 2008). To enter and pass through the BSBH, this

species would have to move upstream through Burns Ditch and portions of the south branch of the Little Calumet River, where flow direction is toward Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0. *S. binderanus* is sensitive to nutrients levels. The discharge of nutrients may decrease due to the adoption of water quality standards and effluent discharge limitations currently proposed for the CAWS (Illinois Pollution Control Board 2012). However, the potential impact of these future water quality changes is uncertain.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *S. binderanus* is typically a lake species, but it has been reported in rivers, and water quality may be suitable in the CAWS (section 3d). The high nutrients in the CAWS may promote the productivity of this species. Because of the lack of vessel traffic (section 3b), natural spread through the south branch of the Little Calumet River will likely be required for *S. binderanus* to move from Lake Michigan to the Calumet Sag Channel. Water flow in the BSBH and portions of the Little Calumet River is toward Lake Michigan. *S. binderanus* are phytoplankton and are not likely to move upstream through the BSBH and the south branch of the Little Calumet River (sections 3a, 3b). Overall, this species is considered to have a low probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over time this species may be able to move upstream (by wind-driven currents or by aquatic life) through the BSBH and the Little Calumet River to navigable sections of the CAWS that flow toward the MRB. Therefore, its probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: Although this species has been documented in rivers (section 3d), the suitability of hydraulic, chemical, and light conditions (e.g., turbidity) in the CAWS for *S. binderanus* is uncertain, suitable habitat potentially exists for *S. binderanus*, and this species is considered to have time to transit to the Brandon Road Lock and Dam during this time step. Although it has been in Lake Michigan since 1938, there are no records of *S. binderanus* in the CAWS or downstream of the Brandon Road Lock and Dam. The lack of records may be due to habitat in the CAWS being unsuitable or to a lack of phytoplankton surveys in the Illinois

waterway. The lakeward flow of the BSBH and south branch of the Little Calumet River could decrease or inhibit spread through the pathway (section 3d). Overall, the uncertainty associated with passage during this time step is considered to be high.
T_{10}: See T_0.
T_{25}: See T_0. Future efforts to improve water quality in the CAWS may reduce the concentrations of nutrients and halogens that this species tends to be associated with (section 3d). These changes in water quality may reduce the habitat suitability of the CAWS for *S. binderanus*. Flow conditions in the BSBH and the south branch of the Little Calumet River are expected to remain unfavorable to passage. However, this species is more certain to pass through the CAWS in 25 years compared to the previous time step. Overall, the future uncertainty of this species passing through the pathway is high.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   S. binderanus is typically reported in lakes, but it is established in the Cuyahoga River (Lake Erie) (Kipp 2011) and in European lowland rivers and their tributaries (Hindák et al. 2006). *S. binderanus* sometimes occurs at in lakes near river outlets (Kipp 2011). Reservoirs may provide suitable habitat. It is found in areas of high nutrient concentrations (Markarewicz & Baybutt 1981; Kipp 2011). This suggests water quality may be suitable downstream of the Brandon Road Lock and Dam in reaches with high agricultural or municipal runoff containing nutrients.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal.*
   If suitable habitat is present in the downstream vicinity of the Brandon Road Lock and Dam, it will be accessible by passive dispersal.

Evidence for Probability Rating

S. binderanus has been documented in inland rivers (section 4a), and suitable water quality for *S. binderanus* may be present in areas with anthropogenic inputs downstream of the Brandon Road Lock and Dam (sections 4a, 4b). However, this species is typically found in lakes. Therefore, this species is considered to have a medium probability of colonization after passage through the pathway.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of conductivity, hydraulic, and light conditions downstream of the Brandon Road Lock and Dam is not documented for this species. Therefore, there is a medium uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
S. binderanus is globally widespread and is considered eurythermal (Kipp 2011). Therefore, climate should not restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
S. binderanus is a phytoplankton that would spread by drifting downstream through the MRB.

c. *Fecundity*
S. binderanus can form dense blooms under high nutrient conditions. The MRB has high nutrient inputs from agricultural and municipal runoff.

d. *History of Invasion Success*
S. binderanus spread rapidly through the Great Lakes and had strong seasonal blooms (Kipp 2011). Although this species is found in the Cuyahoga River, no data on the rate of spread through river basins were found.

e. *Human-Mediated Transport through Aquatic Pathways*
S. binderanus can be transported in ballast water (Kipp 2011). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
S. binderanus specializes in waters with high nutrient levels (Kipp 2011). *S. binderanus* does best in eutrophic waters (Kipp 2011). It is typically a lake species, but it does exist in large eutrophic rivers such as the Cuyahoga. Many of the dams in the MRB form large lake-like pools upstream (e.g., the numbered pools on the river), which could serve as suitable habitat. Suitable habitat may be present in the MRB in waters affected by anthropogenic inputs that contain elevated nutrients, such as urban areas and areas with agricultural or livestock runoff. High nutrient inputs are typical of the MRB. *S. binderanus* is not described in the literature as a riverine species. Therefore, hydraulic conditions and light levels in river systems may not be suitable, because they are generally turbid.

Evidence for Probability Rating

S. binderanus is globally distributed (section 5a), so climate in the MRB will likely be suitable. *S. binderanus* is found in fresh water in areas with high nutrient levels (section 5f). Within the MRB, ports, harbors, and urban areas with anthropogenic inputs may provide suitable habitat (section 5f), and these areas are hydrologically connected. *S. binderanus* is not described in the literature as a riverine species, although it is present in eutrophic rivers (section 5f). Therefore, this species is considered to have a medium probability of spreading throughout the new basin.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of water chemistry, flow, and light conditions in the MRB for this species is uncertain. Therefore, there is a medium uncertainty associated with the probability of this species spreading throughout the MRB.

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E.2.4 Macrophytes

E.2.4.1 Swamp Sedge - *Carex acutiformis*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The swamp sedge disperses by floating seeds, rhizomes, and clones (Cao 2012). The swamp sedge invasion speed appears to be slow, given its low abundance in the GLB and time since establishment (1951).

b. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). WPS is not a port with cargo vessel use; however, there is recreational boat use in Wilmette Harbor that could transport this species from the Great Lakes to the WPS.

c. *Current Abundance and Reproductive Capacity*
T_0: The swamp sedge reproduces asexually by rhizomes and clones, as well as sexually by producing seeds (Bernard 1990). This species has high productivity if conditions are appropriate. No data on current abundance in the Great Lakes were found. Only two records of this species were found for the GLB, both in the Lake Michigan sub-basin, but it is considered established (Cao 2012).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The swamp sedge has been collected from an established population in St. Joseph Lake at South Bend, Indiana (not hydrologically connected to Lake Michigan), in 1951 (Cao 2012). A record from Traverse Bay (which is hydrologically connected to Lake Michigan) exists from 1998 (Cao 2012), located approximately 644 km (400 mi) from the pathway entrance.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The swamp sedge was recorded in northern Indiana, so climate is likely to be suitable in southern Lake Michigan, although it has not been recorded there. In addition, this species is native to Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; the shores of ponds, rivers, and lakes; and 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). There are no emergent wetlands near the WPS (Habitat Mapping) and the shoreline conditions in Lake Michigan near the WPS are generally sandy, riprap, or manmade vertical walls. Wilmette Harbor, which abuts WPS on the lake side, has concrete and steel vertical walls; therefore, the swamp sedge may not form a population directly adjacent to WPS, although it could potentially do so on riprap or shoreline areas where organic matter has accumulated.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: The swamp sedge is thought to have a slow invasion speed (section 2a). The species was detected in the GLB in 1951 and is not recorded to have spread in the Great Lakes (section 2e). The closest established population of the species is approximately 644 km (400 mi) from the pathway entrance. The habitat near the WPS may not be suitable for the swamp sedge, due to the presence of Wilmette Harbor (section 2f). Therefore, the probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the swamp sedge from arriving at the pathway entrance, keeping the probability of arrival low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Swamp sedge is located far from the pathway entrance and is unlikely to arrive naturally at the entrance at this time step. There is no documented long-distance transport by vessel. Therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be adequate time for this species to spread to southern Lake Michigan, although spread to the pathway entrance is unlikely. The uncertainty rises to medium given time for the species to disperse.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction (Cao 2012). The plant spreads by rhizomes (asexual), clones, and floating seeds (Bernard 1990; Leck & Schütz 2005).

b. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the swamp sedge may be transported for short distances by vessels (Cao 2012). There is no commercial vessel traffic to WPS from the Great Lakes (USACE 2011a), and the WPS prevents recreational vessel movement from Lake Michigan to the North Shore Chanel. There is limited recreational vessel traffic in the North Shore Channel. However, human-mediated transport is not expected to be significant in passage to Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The sluice gate at the WPS is a barrier that could retard natural dispersion. However, water is pumped from Lake Michigan into the North Shore Channel, which could transport seeds. Lockport Lock and Dam and Brandon Road Lock and Dam may act as barriers because they are primarily manmade nearshore areas.
T_{10}: See T_0. Future use of the WPS is not expected to change.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from the shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Sediment chemical data from the CAWS show the presence of a wide range of chemicals throughout the system, including pesticides, polychlorinated biphenyls (PCBs), and heavy metals (MWRD 2010). Overall, submerged aquatic vegetation is not common in the CAWS, but it is present to a limited extent in the North Shore Channel and the CSSC (LimnoTech 2010). The North Shore Channel has in stream aquatic habitat; however, the banks are mostly shaded (LimnoTech 2010). Swamp sedge prefers sun to partial shade (Cao 2012). Percent emergence (from seed) is very low at shaded sites, possibly due to a relatively high minimum temperature requirement (Cao 2012). Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River is vertical wall with sand, silt, or sludge sediment. Much of the CSSC is vertical limestone or manmade walls with silt, sand, cobble, or bedrock substrate (LimnoTech 2010). Suitable habitat in the CAWS may be present along some shallow shoreline areas and in debris accumulated near bridge abutments and riprap.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Swamp sedge could move into the CAWS as water is pumped from Lake Michigan into the North Shore Channel (section 3c). Although suitable habitat may be present in the North Shore Channel, lack of suitable nearshore habitat, fluctuating hydrography, and heavy vessel use are likely to limit the swamp sedge's ability to traverse the CAWS. In addition, the swamp sedge does not appear to spread rapidly or extensively, even where established (section 3a). Therefore, the swamp sedge has a low passage probability for this time step.
T_{10}: See T_0. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the swamp sedge to invade and pass through the CAWS. This raises the future probability of passage to medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long-distance transport of the species via vessel traffic. This species is documented to spread slowly. Therefore, the uncertainty of probability of the species passing through this pathway is considered to be low.
T_{10}: See T_0. The rate of spread through the CAWS is uncertain. Therefore, it is uncertain whether the swamp sedge could pass through the CAWS during this time step, raising the uncertainty of passage to medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). Emergent and littoral wetland habitats are present downstream of Brandon Road Lock and Dam. Swamp sedge tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can disperse to suitable habitat by spreading downstream or by vessel transport.

Evidence for Probability Rating

Suitable habitat is present for swamp sedge past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, the probability of this species colonizing the MRB is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

A low uncertainty rating is assigned because suitable habitat is present below Brandon Road Lock and Dam and this habitat is accessible to swamp sedge (sections 4a, 4b).

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
   The swamp sedge occurs in Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
   The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction. The species disperses by rhizomes, clones, and floating seeds (Cao 2012).

c. *Fecundity*
   This species reproduces asexually by rhizomes and clones, and sexual reproduction produces floating seeds (Bernard 1990).

d. *History of Invasion Success*
It is suspected that this plant was introduced through hay from Europe (Cao 2012). The species is not widespread in the Great Lakes despite having been present since the 1950s.

e. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). There is heavy vessel traffic in the MRB basin.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Swamp sedge is an obligate wetland plant. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Such habitat is present throughout the MRB.

Evidence for Probability Rating

Climate is expected to be suitable (section 5a).The MRB has suitable habitat for the species to invade and this habitat is accessible (section 5f). The species may spread by floating downstream or by boat transfer. Therefore, the probability of spread is high.

Uncertainty: Low

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB and this habitat is accessible by swamp sedge. Therefore the uncertainty associated with the probability of spread is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible and confirmed and present year round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species disperses by floating seeds, rhizomes, and clones (Cao 2012). The swamp sedge invasion speed appears to be slow, given its low abundance in the GLB and time since establishment (1951).

b. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). Spread by vessel traffic has been the fastest means of spread between the Great Lakes. There is commercial and recreational vessel traffic to the CRCW from Lake Michigan (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: The swamp sedge reproduces asexually by rhizomes and clones, as well as sexually by producing seeds (Bernard 1990). This species has high productivity when conditions are appropriate. No data on its current abundance in the Great Lakes were found. Only two records of this species were found for the GL basin, both in the Lake Michigan subbasin, but it is considered established (Cao 2012).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.

T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The swamp sedge has been collected from an established population in St. Joseph Lake at South Bend, Indiana (not hydrologically connected to Lake Michigan), in 1951 (Cao 2012). A record from Traverse Bay (which is hydrologically connected to Lake Michigan) exists from 1998 (Cao 2012), located approximately 644 km (400 mi) from the pathway entrance.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The swamp sedge was recorded in northern Indiana, so climate is likely to be suitable in southern Lake Michigan, although it has not been recorded there. In addition, this species is native to Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). There are no emergent wetlands near the CRCW (Habitat Mapping) and the shoreline conditions in Lake Michigan near the CRCW are generally concrete and steel vertical walls; therefore, the swamp sedge may not form a population directly adjacent to the CRCW, although it could do so on riprap or shoreline areas where organic matter has accumulated. In addition, there are emergent wetlands offshore of downtown Chicago that could provide habitat for this species.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: The swamp sedge is thought to have a slow invasion speed (section 2a). The species was detected in the GLB in 1951 and is not recorded to have spread in the Great Lakes (section e). The closest established population of the species is approximately 644 km (400 mi) from the pathway entrance. The habitat near the CRCW may not be suitable for the swamp sedge due to the higher energy shoreline of Lake Michigan, the sandy sediments, and the human-modified shoreline (section 2f). Therefore, the probability of arrival is low.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the swamp sedge from arriving at the pathway entrance keeping the probability of arrival low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Swamp sedge is located far from the pathway entrance and is unlikely to arrive naturally at the entrance at this time step. There is no documented long-distance transport by vessel. Therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be adequate time for this species to spread to southern Lake Michigan, although spread to the pathway entrance is unlikely. The uncertainty rises to medium given time for the species to disperse.

3. P(Passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction (Cao 2012). The plant spreads by rhizomes (asexual), clones, and floating seeds (Bernard 1990; Leck & Schütz 2005).

b. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the swamp sedge may be carried for short distances by vessels passing through a stand of this plant (Cao 2012). There is some vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a). however, human-mediated transport is not expected to be significant in passage to Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: The CRCW, Lockport Lock and Dam, and Brandon Road Lock and Dam may act as barriers because they are primarily manmade nearshore areas.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from the shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Sediment chemical data from the CAWS show the presence of a wide range of chemicals throughout the system including pesticides, PCBs, and heavy metals (MWRD 2010). Overall, submerged aquatic vegetation is not common in the CAWS, but it is present to a limited extent in the CSSC (LimnoTech 2010). Swamp sedge prefers sun to partial shade (Cao 2012). Percent emergence (from seed) is very low at shaded sites, possibly due to a relatively high minimum temperature requirement (Cao 2010). Virtually all (>90%) of the Chicago River is vertical wall with sand, silt, or sludge sediment. Much of the CSSC is vertical limestone or manmade walls with silt, sand, cobble, or bedrock substrate (LimnoTech 2010). Suitable habitat in the CAWS may be present along some shallow shoreline areas and in debris accumulated near bridge abutments and riprap.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Swamp sedge could move into the CAWS when the CRCW are open leading into the Chicago River (section 3c). Lack of suitable nearshore habitat, fluctuating hydrography, and heavy vessel use are likely to limit the swamp sedge's ability to traverse the CAWS. In addition, the swamp sedge does not appear to spread rapidly or extensively even where established (section 3a). Therefore, the swamp sedge has a low passage probability for this time step.

T_{10}: See T_0. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the swamp sedge to invade and pass through the CAWS. This raises the future probability of passage to medium.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long-distance transport of the species via vessel traffic. This species is documented to spread slowly. Therefore, the uncertainty of probability of the species passing through this pathway is considered to be low.
T_{10}: See T_0. The rate of spread through the CAWS is uncertain. Therefore, it is uncertain whether the swamp sedge could pass through the CAWS during this time step. Improvements in future water quality could affect the swamp sedge in ways that are uncertain (section 3d), raising the uncertainty of passage to medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). Emergent and littoral wetland habitats are present downstream of Brandon Road Lock and Dam. Swamp sedge tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The species can disperse to suitable habitat by spreading downstream or by vessel transport.

Evidence for Probability Rating

Suitable habitat is present for swamp sedge past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, the probability of this species colonizing the MRB is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

A low uncertainty rating is assigned because suitable habitat is present below Brandon Road Lock and Dam and this habitat is accessible to swamp sedge (sections 4a, 4b). Therefore, the uncertainty associated with the probability of spread is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The swamp sedge occurs in Eurasia and Africa (Cao 2012) suggesting a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction. The species disperses by rhizomes, clones, and floating seeds (Cao 2012).

c. Fecundity
This species reproduces asexually by rhizomes and clones, and sexual reproduction produces floating seeds (Bernard 1990).

d. History of Invasion Success
It is suspected that this plant was introduced through hay from Europe (Cao 2012). The species is not widespread in the Great Lakes, despite having been present since the 1950s.

e. Human-Mediated Transport through Aquatic Pathways
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). There is heavy vessel traffic in the MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Swamp sedge is an obligate wetland plant. It is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Such habitat is present throughout the MRB and this habitat is connected by flowing water.

Evidence for Probability Rating

Climate is expected to be suitable (section 5a).The MRB has suitable habitat for the species to invade and this habitat is accessible (section 5f). The species may spread by floating downstream or by boat transfer. Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB and this habitat is accessible by swamp sedge. Therefore the uncertainty associated with the probability of spread is low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species disperses by floating seeds, rhizomes, and clones (Cao 2012). The swamp sedge invasion speed appears to be slow, given its low abundance in the GLB and time since establishment (1951).

b. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). Spread by vessel traffic has been the fastest means of spread between the Great Lakes. There is heavy commercial vessel traffic to the Calumet Harbor from Lake Michigan (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
T_0: The swamp sedge reproduces asexually by rhizomes and clones, as well as sexually by producing seeds (Bernard 1990). This species has high productivity when conditions are appropriate. No data on its current abundance in the Great Lakes was found. Only two records of this species were found for the GL basin, both in the Lake Michigan sub-basin, but it is considered established (Cao 2012).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The swamp sedge was collected from an established population in St. Joseph Lake at South Bend, Indiana (not hydrologically connected to Lake Michigan), in 1951 (Cao 2012). A record from Traverse Bay (which is hydrologically connected to Lake Michigan) exists from 1998 (Cao 2012), located approximately 644 km (400 mi) from the pathway entrance.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The swamp sedge was recorded in northern Indiana, so climate is likely to be suitable in southern Lake Michigan, although it has not been recorded there. In addition, this species is native to Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; the shores of ponds, rivers, and lakes; and 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). There are no emergent wetlands near the Calumet Harbor that are connected to the CAWS or Lake Michigan (Habitat Mapping) and the shoreline conditions in Lake Michigan near the Calumet Harbor are generally sandy, riprap, or manmade vertical walls; therefore, the swamp sedge may not form a population directly adjacent to the Calumet Harbor, although it could potentially do so on riprap or shoreline areas where organic matter has accumulated.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: The swamp sedge is thought to have a slow invasion speed (section 2a). The species was detected in the GLB in 1951 and is not recorded to have spread in the Great Lakes (section 2e). The closest established population of the species is approximately 644 km (400 mi) from the pathway entrance. The habitat near the Calumet Harbor may not be suitable for the swamp sedge, due to the presence of Calumet Harbor (section 2f). Therefore, the probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the swamp sedge from arriving at the pathway entrance keeping the probability of arrival low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Swamp sedge is located far from the pathway entrance and is unlikely to arrive naturally at the entrance at this time step. There is no documented long distance transport by vessel. Therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be adequate time for this species to spread to southern Lake Michigan, although spread to the pathway entrance is unlikely. The uncertainty rises to medium given time for the species to disperse.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction (Cao 2012). The species spreads by rhizomes (asexual), clones, and floating seeds (Bernard 1990; Leck & Schütz 2005).

b. Human-Mediated Transport through Aquatic Pathways

The seeds, rhizomes, and root masses of the swamp sedge may be carried by vessels passing through a stand of this plant and be transported for short distances (Cao 2012). Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Overall, human-mediated transport is not expected to be significant in passage to Brandon Road Lock and Dam.

c. Existing Physical Human/Natural Barriers

T_0: T.J. O'Brien Lock and Dam, Lockport Lock and Dam, and Brandon Road Lock and Dam may act as barriers because they are primarily manmade nearshore areas.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Sediment chemical data from the CAWS show the presence of a wide range of chemicals throughout the system including pesticides, PCBs, and heavy metals (MWRD 2010). Overall, submerged aquatic vegetation is not common in the CAWS, but it is present to a limited extent in the CSSC (LimnoTech 2010). Swamp sedge prefers sun to partial shade (Cao 2012). Percent emergence (from seed) is very low at shaded sites, possibly due to a relatively high minimum temperature requirement (Cao 2012). The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River with silt, sand, cobble or bedrock substrate, little canopy cover, and no natural floodplain (LimnoTech 2010). Suitable habitat may be present in the CAWS along some shallow shoreline areas and in debris accumulated near bridge abutments and riprap.
T_{10}: See T_0.
T_{25}: See T_0. The swamp sedge requires higher nutrients than other sedges (Verhoeven et al. 1988). Future water quality in the CAWS may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Swamp sedge could move into the CAWS by floating through the Calumet Harbor. Lack of suitable nearshore habitat, fluctuating hydrography, and heavy vessel use are likely to limit the swamp sedge's ability to traverse the CAWS. In addition, the swamp sedge does not appear to spread rapidly or extensively even where established (section 3a). Therefore, the swamp sedge has a low passage probability for this time step.
T_{10}: See T_0. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the swamp sedge to invade and pass through the CAWS. This raises the future probability of passage to medium.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long distance transport of the species via vessel traffic. This species is documented to spread slowly. Therefore, the uncertainty of probability of the species passing through this pathway is considered to be low.
T_{10}: See T_0. The rate of spread through the CAWS is uncertain. Therefore, it is uncertain whether the swamp sedge could pass through the CAWS during this time step, raising the uncertainty of passage to medium.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft)

from shoreline (Cao 2012). Emergent and littoral wetland habitats are present downstream of Brandon Road Lock and Dam. Swamp sedge tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse to suitable habitat by spreading downstream or by vessel transport.

Evidence for Probability Rating

Suitable habitat is present for swamp sedge past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, the probability of this species colonizing the MRB is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

A low uncertainty rating is assigned because suitable habitat is present below Brandon Road Lock and Dam and this habitat is accessible to swamp sedge (sections 4a, 4b). Therefore, the uncertainty associated with the probability of spread is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The swamp sedge occurs in Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction. The species disperses by rhizomes, clones, and floating seeds (Cao 2012).

c. *Fecundity*
This species reproduces asexually by rhizomes and clones, and sexual reproduction produces floating seeds (Bernard 1990).

d. *History of Invasion Success*
It is suspected that this plant was introduced through hay from Europe (Cao 2012). The species is not widespread in the Great Lakes, despite having been present since the 1950s.

e. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). There is heavy vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Swamp sedge is an obligate wetland plant. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Such habitat is present throughout the MRB and this habitat is connected by flowing water.

Evidence for Probability Rating

Climate is expected to be suitable (section 5a).The MRB has suitable habitat for the species to invade and this habitat is accessible (section 5f). The species may spread by floating downstream or by boat transfer. Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB and this habitat is accessible by swamp sedge. Therefore the uncertainty associated with the probability of spread is low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Medium	Low	Medium	Medium	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The swamp sedge disperses by floating seeds, rhizomes, and clones (Cao 2012). The swamp sedge invasion speed appears to be slow, given its low abundance in the GLB and time since establishment (1951).

b. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). Spread by vessel traffic has been the fastest means of dispersion between the Great Lakes. There is no commercial vessel traffic to the Indiana Harbor from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic adjacent to Burns Harbor (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
T_0: The swamp sedge reproduces asexually by rhizomes and clones, as well as sexually by producing seeds (Bernard 1990). This species has high productivity if conditions are appropriate. No data on its current abundance in the Great Lakes were found. Only two records of this species were found for the GL basin, both in the Lake Michigan sub-basin, but it is considered established (Cao 2012).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway

T_0: The swamp sedge was collected from an established population in St. Joseph Lake at South Bend, Indiana (not hydrologically connected to Lake Michigan), in 1951 (Cao 2012). A record from Traverse Bay (which is hydrologically connected to Lake Michigan) exists from 1998 (Cao 2012), located approximately 644 km (400 mi) from the pathway entrance.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The swamp sedge was recorded in northern Indiana, so climate is likely to be suitable in southern Lake Michigan, although it has not been recorded there. In addition, this species is native to Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). There are no emergent wetlands near the Indiana Harbor that are connected to the CAWS or Lake Michigan (Habitat Mapping) and the shoreline conditions in Lake Michigan near the Indiana Harbor are generally sandy, riprap, or manmade vertical walls; therefore, the swamp sedge may not form a population directly adjacent to Indiana Harbor although it could potentially do so on riprap or shoreline areas where organic matter has accumulated.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: The swamp sedge is thought to have a slow invasion speed (section 2a). The species was detected in the GLB in 1951 and is not recorded to have spread in the Great Lakes (section 2e). The closest established population of the species is approximately 644 km (400 mi) from the pathway entrance. The habitat near the Indiana Harbor may not be suitable for the swamp sedge (section 2f). Therefore, the probability of arrival is low.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the swamp sedge from arriving at the pathway entrance keeping the probability of arrival low.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Swamp sedge is located far from the pathway entrance and is unlikely to arrive naturally at the entrance at this time step. There is no documented long-distance transport by vessel. Therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be adequate time for this species to spread to southern Lake Michigan, although spread to the pathway entrance is unlikely. The uncertainty rises to medium given time for the species to disperse.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction (Cao 2012). The species spreads by rhizomes (asexual), clones, and floating, seeds (Bernard 1990; Leck & Schütz 2005).

b. Human-Mediated Transport through Aquatic Pathways
The seeds, rhizomes, and root masses of the swamp sedge may be carried short distances by vessels (Cao 2012). Most commercial vessel traffic to Indiana Harbor is lake-wise and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River due to the shallow depth. However, human-mediated transport is not expected to be significant in passage to Brandon Road Lock and Dam.

c. Existing Physical Human/Natural Barriers
T_0: Lockport Lock and Dam and Brandon Road Lock and Dam may act as barriers because they are primarily manmade nearshore areas.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Sediment chemical data from the CAWS show the presence of a wide range of chemicals throughout the system including pesticides, PCBs, and heavy metals (MWRD 2010). Overall, submerged aquatic vegetation is not common in the CAWS, but it is present to a limited extent in the CSSC (LimnoTech 2010). Swamp sedge prefers sun to partial shade (Cao 2012). Percent emergence (from seed) is very low at shaded sites, possibly due to a relatively high minimum temperature requirement (Cao 2010). Conditions at the Indiana Harbor are highly industrialized. The east branch of the Grand Calumet River is heavily vegetated, but biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments consist of primarily cobble, bedrock or concrete; but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water flows out of Indiana Harbor into Lake Michigan. West of Indiana Harbor Canal, the easternmost sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, swamp sedge would have to spread upstream to enter the CAWS and move to the Calumet Sag Channel. The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River with silt, sand, bedrock, or cobble substrate and little canopy cover (LimnoTech 2010). Suitable habitat may be present in the CAWS along some shallow shoreline areas and in debris accumulated near bridge abutments and riprap.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Swamp sedge is not likely to move upstream through Indiana Harbor and the Grand Calumet River. Although portions of the CAWS, such as the Grand Calumet River, may be suitable for the swamp sedge, lack of suitable nearshore habitat, fluctuating hydrography, and heavy vessel use are likely to limit the swamp sedge's ability to traverse the CAWS. In addition, the swamp sedge does not appear to spread rapidly or extensively even where established (section 3a). Therefore, the swamp sedge has a low passage probability for this time step.

T_{10}: See T_0. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the swamp sedge to spread upstream through Indiana Harbor and the Grand Calumet River and pass through the CAWS. This raises the future probability of passage to medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	High	High

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long distance transport of the species via vessel traffic. Another uncertainty is that the Grand Calumet River can flow east or west, which could increase or decrease the rate of spread through the pathway. This species is documented to spread slowly. Therefore, the uncertainty of probability of the species passing through this pathway is considered to be medium.
T_{10}: See T_0.
T_{25}: See T_0. The ability to move upstream through Indiana Harbor and the Grand Calumet River remains uncertain. Therefore, it is uncertain whether the swamp sedge could pass through the CAWS during this time step, raising the uncertainty of passage to high.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). Emergent and littoral wetland habitats are present downstream of Brandon Road Lock and Dam. Swamp sedge tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The species can disperse to suitable habitat by spreading downstream or by vessel transport.

Evidence for Probability Rating

Suitable habitat is present for swamp sedge past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, the probability of this species colonizing the MRB is high.
Uncertainty: LOW

Evidence for Uncertainty Rating

A low uncertainty rating is assigned because suitable habitat is present below Brandon Road Lock and Dam and this habitat is accessible to swamp sedge (sections 4a, 4b). Therefore, the uncertainty associated with the probability of spread is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The swamp sedge occurs in Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance.

b. *Type of Mobility/Invasion Speed*
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction. The species disperses by rhizomes, clones, and floating seeds (

c. *Fecundity*
This species reproduces asexually by rhizomes and clones, and sexual reproduction produces floating seeds (Bernard 1990).

d. *History of Invasion Success*
It is suspected that this plant was introduced through hay from Europe (Cao 2012). The species is not widespread in the Great Lakes despite having been present since the 1950s.

e. *Human-Mediated Transport through Aquatic Pathways*
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). There is heavy vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Swamp sedge is an obligate wetland plant. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds,

rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Such habitat is present throughout the MRB and this habitat is connected by flowing water.

Evidence for Probability Rating

Climate is expected to be suitable (section 5a).The MRB has suitable habitat for the species to invade and this habitat is accessible (section 5f). The species may spread by floating downstream or by boat transfer. Swamp sedge has a documented low invasion speed in the GLB. Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB and this habitat is accessible to swamp sedge. Therefore the uncertainty associated with the probability of spread is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR (BSBH) TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Medium
P(passage)	Low	Medium	Low	Medium	Medium	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
The swamp sedge disperses by floating seeds, rhizomes, and clones (Cao 2012). The swamp sedge invasion speed appears to be slow, given its low abundance in the GLB and time since establishment (1951).

b. Human-Mediated Transport through Aquatic Pathways
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). Spread by vessel traffic has been the fastest means of dispersion between the Great Lakes. There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic adjacent to Burns Harbor (USACE 2011a).

c. Current Abundance and Reproductive Capacity
T_0: The swamp sedge reproduces asexually by rhizomes and clones, as well as sexually by producing seeds (Bernard 1990). This species has high productivity if conditions are appropriate. No data on its current abundance in the Great Lakes were found. Only two records of this species were found for the GL basin, both in the Lake Michigan sub-basin, but it is considered established (Cao 2012).
T_{10}: See T_0. There are no predicted changes to the reproductive output of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Existing Physical Human/Natural Barriers
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway
T_0: The swamp sedge was collected from an established population in St. Joseph Lake at South Bend, Indiana (not hydrologically connected to Lake Michigan), in 1951 (Cao 2012). A record from Traverse Bay (which is hydrologically connected to Lake Michigan) exists from 1998 (Cao 2012), located approximately 644 km (400 mi) from the pathway entrance.
T_{10}: See T_0. The species may disperse closer to the pathway over time.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The swamp sedge was recorded in northern Indiana, so climate is likely to be suitable in southern Lake Michigan, although it has not been recorded there. In addition, this species is native to Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). There are no emergent wetlands near the BSBH (Habitat Mapping) and the shoreline conditions in Lake Michigan near the BSBH are generally sandy, riprap, or manmade vertical walls. Therefore, the swamp sedge may not form a population directly adjacent to BSBH, although it could potentially do so on riprap or shoreline areas where organic matter has accumulated.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: The swamp sedge is thought to have a slow invasion speed (section 2a). The species was detected in the GLB in 1951 and is not recorded to have spread widely in the Great Lakes (section 2e). The closest established population of the species is approximately 644 km (400 mi) from the pathway entrance. The habitat near the BSBH may not be suitable for the plant to establish (section 2f). Therefore, the probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the swamp sedge from arriving at the pathway entrance, keeping the probability of arrival low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Swamp sedge is located far from the pathway entrance and is unlikely to arrive naturally at the entrance at this time step. There is no documented long distance transport by vessel. Therefore, uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be adequate time for this species to spread to southern Lake Michigan, although spread to the pathway entrance is unlikely. The uncertainty rises to medium given time for the species to disperse.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction (Cao 2012). The species spreads by rhizomes (asexual), clones, and floating seeds (Bernard 1990; Leck & Schütz 2005).

b. Human-Mediated Transport through Aquatic Pathways
The seeds, rhizomes, and root masses of the swamp sedge may be carried short distances by vessels (Cao 2012). Most commercial vessel traffic to BSBH is lake-wise and there is no commercial vessel traffic to inland ports in the CAWS from BSBH (NBIC 2012). Human-mediated transport is not expected to be significant in passage to Brandon Road Lock and Dam.

c. Existing Physical Human/Natural Barriers
T_0: Lockport Lock and Dam and Brandon Road Lock and Dam may act as barriers because they are primarily manmade nearshore areas.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Sediment chemical data from the CAWS show the presence of a wide range of chemicals throughout the system including pesticides, PCBs, and heavy metals (MWRD 2010). Overall, submerged aquatic vegetation is not common in the CAWS, but it is present to a limited extent in the CSSC

(LimnoTech 2010). Swamp sedge prefers sun to partial shade (Cao 2012). Percent emergence (from seed) is very low at shaded sites, possibly due to a relatively high minimum temperature requirement (Cao 2010). The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Water flows out of BSBH into Lake Michigan. The eastern segment of the south Branch of the Little Calumet River also generally flows toward Lake Michigan, while other sections can flow east or west depending on location (GSWMD 2008). Thus, swamp sedge would have to spread upstream to enter the CAWS and move to the Calumet Sag Channel. The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River with silt, sand, bedrock, or cobble substrate, and little canopy cover (LimnoTech 2010). Suitable habitat in the CAWS may be present along some shallow shoreline areas and in debris accumulated near bridge abutments and riprap.

T_{10}: See T_0.

T_{25}: See T_0. The swamp sedge requires more nutrients than other sedges (Verhoeven et al. 1988). Future water quality in the CAWS may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Swamp sedge must move upstream through BSBH and the Little Calumet River. There is no vessel traffic in the south branch of the Little Calumet River that could transport this species. Although the south branch of the Little Calumet River is likely suitable for the swamp sedge, lack of suitable nearshore habitat, fluctuating hydrography, and heavy vessel use are likely to limit the swamp sedge's ability to traverse the CAWS. In addition, the swamp sedge does not appear to spread rapidly or extensively even where established (section 3a). Therefore, the swamp sedge has a low passage probability for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Over time, swamp sedge may be able to spread upstream through BSBH and the Little Calumet River by wind-driven currents and aquatic organisms. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the swamp sedge to invade and pass through the CAWS. This raises the future probability of passage to medium.

T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	High	High

Evidence for Uncertainty Rating

T_0: The lack of vessel traffic and the upstream movement required to move through BSBH and the Little Calumet River would slow passage to an uncertain degree. There is little information on long distance transport of the species via vessel traffic. Another uncertainty is that the south branch of the Little Calumet River can flow east or west, which could increase or decrease the rate of spread through the pathway. This species is documented to spread slowly. Therefore, the uncertainty of probability of the species passing through this pathway is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. The ability to move upstream through BSBH and the Little Calumet River remains uncertain. Therefore, it is uncertain whether the swamp sedge could pass through the CAWS during this time step, raising the uncertainty of passage to high.
T_{50}: See T_{25}.

3. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). Emergent and littoral wetland habitats are present downstream of Brandon Road Lock and Dam. Swamp sedge tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can disperse to suitable habitat by spreading downstream or by vessel transport.

Evidence for Probability Rating

Suitable habitat is present for swamp sedge past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, the probability of this species colonizing the MRB is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

A low uncertainty rating is assigned because suitable habitat is present below Brandon Road Lock and Dam and this habitat is accessible to swamp sedge (sections 4a, 4b). Therefore, the uncertainty associated with the probability of spread is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of colonization is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The swamp sedge occurs in Eurasia and Africa (Cao 2012), suggesting a wide climatological tolerance.

b. Type of Mobility/Invasion Speed
The swamp sedge invasion speed appears to be slow, given its low abundance and time since introduction. The species disperses by rhizomes, clones, and floating seeds (Cao 2012).

c. Fecundity
This species reproduces asexually by rhizomes and clones, and sexual reproduction produces floating seeds (Bernard 1990).

d. History of Invasion Success
It is suspected that this plant was introduced through hay from Europe (Cao 2012). Swamp sedge is not widespread in the Great Lakes, despite having been present since the 1950s.

e. Human-Mediated Transport through Aquatic Pathways
The seeds, rhizomes, and root masses of the plant may become attached to vessels passing through a stand of this plant (Cao 2012). There is heavy vessel traffic in the MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Swamp sedge is an obligate wetland plant. Swamp sedge is found in open swamps; wet, open thickets; marsh edges; sedge meadows; eutrophic fens; and the shores of ponds, rivers, and lakes; 0–300 m (0–984 ft) from shoreline (Cao 2012). It tolerates extremes of soil conditions as long as there is moisture (Evergreen Brick Works undated). Such habitat is present throughout the MRB and this habitat is connected by flowing water.

Evidence for Probability Rating

Climate is expected to be suitable (section 5a).The MRB has suitable habitat for the species to invade and this habitat is accessible (section 5f). The species may spread by floating downstream or by boat transfer. Swamp sedge has a documented low invasion speed in the B. Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB and this habitat is accessible to swamp sedge. Therefore the uncertainty associated with the probability of spread is low.

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E.2.4.2 Reed Sweetgrass - *Glyceria maxima*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, or through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport. In still

water, both naked and enclosed grains may be held almost indefinitely at surface by surface tension; in disturbed water, naked caryopses sink almost immediately, while enclosed grains may remain floating at surface for several hours." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, while others remain dormant for several years (DPIWE 2002). Reed sweetgrass was found in Wisconsin's Racine and Milwaukee counties in the 1970s, and the southernmost record is from Illinois Beach State Park in 2006 (Howard 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments that may be transported short distances by boats (DPIWE 2002). There is recreational boat use in the Wilmette Harbor, but no commercial vessel traffic. Evidence for ballast water transport was not found in the literature.

c. *Current Abundance and Reproductive Capacity*
T_0: The first North American record of reed sweetgrass came from the far west end of Lake Ontario, in the mid-1940s, and it subsequently spread to other areas of Ontario (Howard 2012). It is now established in several counties in Wisconsin. Reed sweetgrass produces vast numbers of dark brown seeds throughout summer and autumn (DPIWE 2002). It forms a sprawling mat of rhizomes, or underground stems (DPIWE 2002). These rhizomes produce vast numbers of shoots to quickly expand the plant's size (DPIWE 2002). The massive root system can extend 0.9 m (3 ft) down and the rhizomes can make up about half of the plants total biomass (Noxious Weeds 2012). Reed sweetgrass typically goes dormant in the winter with seeds germinating the following spring, but some seeds remain dormant in the soil for many years (NBII & ISSG 2008). It is thought that North American reed sweetgrass plants are reproducing mostly by vegetative means and that most seeds are not viable (Washington State Noxious Weed Control Board 2012). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012). Reed sweetgrass is not widespread in Lake Michigan (Howard 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The closest established population is in Oak Creek (a tributary of Lake Michigan) in Milwaukee County, Wisconsin (Howard 2012). The population has been considered established since 1979. In 2006, an isolated established population was discovered growing out of a manhole cover at the Illinois Beach State Park just north of Waukegan,

Illinois. This population was treated with herbicide and monitoring will continue (Howard 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: Reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so the climate range in the southern Great lakes is suitable. The species prefers nutrient-rich soil (NBII & ISSG 2008). It can be found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, the plant forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit the distribution of reed sweetgrass (Wei & Chow-Fraser 2006). The species is found in soils with relatively high concentrations of iron, phosphorus, and nitrogen (Wei & Chow-Fraser 2006). There are no emergent wetlands near the WPS (unpublished data from USACE), and shorelines in Lake Michigan near the WPS and in Wilmette Harbor generally have sandy, riprap, or manmade vertical walls. This species may be able to form populations along the Lake Michigan shoreline above the wave-washed elevations.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Reed sweetgrass was found within 40 km (25 mi) of the WPS pathway, but the population was eradicated and is not known to currently exist (section 2e). Since 2006, the closest known population has been monitored and treated with herbicide to prevent dispersal (section 2e). The plant is dispersed by seeds, roots, or rhizome fragments (section 2a). Reed sweetgrass could float into Wilmette Harbor from Lake Michigan, but populations are not located along the shoreline of Lake Michigan so there is no likely mechanism for doing so. Vessel transport from Milwaukee (where the species is present) to WPS is unlikely because reed sweetgrass populations are inland and may not encounter vessel traffic. This species may be able to form populations along the Lake Michigan shoreline above the wave-washed elevations. This species was found growing out of a manhole cover (section 2e), so it may establish in urban landscapes. If another population appears along the shoreline of southern Lake Michigan, the species may be able to spread closer to the pathway entrance over time. However, only one colony has been detected

near WPS since the 1970s. Eradication efforts may also keep the species from spreading to the WPS. Overall, probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to reach the WPS. Therefore, probability increases to medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Reed sweetgrass is found on the banks of slow-moving waters; Lake Michigan is a high-energy shoreline and there is no emergent wetland habitat documented in the vicinity of the WPS. Human mediated transport of the species is poorly documented, but is highly unlikely (section 2b). There is also little potential for movement into the Wilmette Harbor from Lake Michigan because of the unsuitability of the shoreline of Lake Michigan. The species can have a rapid invasion rate, although it has not been found in the Great Lakes. Eradication efforts at Illinois Beach State Park seem to have slowed the species' spread. Therefore, there is low uncertainty associated with arrival at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to spread to the WPS. Monitoring and eradication efforts are in place, but their long-term effectiveness is uncertain. Overall, there is a medium uncertainty associated with arrival at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Reed sweetgrass has a potentially rapid invasion speed once it encounters a new habitat (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, or through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, while others remain dormant for several years (DPIWE 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments that may be transported by boats for short distances. There is no commercial vessel traffic to WPS (USACE 2011), and the WPS prevents recreational vessel movement from Lake Michigan to the North Shore Chanel. There is recreational vessel traffic in the North Shore Channel.

c. *Existing Physical Human/Natural Barriers*
T_0: The sluice gate at the WPS is a barrier that could retard natural dispersion into the CAWS. However, water is pumped from Lake Michigan into the North Shore Channel, which could transport seeds into the North Shore Channel. Lockport Lock and Dam and Brandon Road Lock and Dam could act as barriers because the shoreline at these locations is heavily modified. Reed sweetgrass grows well in shallow water up to 1.5 m (4.9 ft) deep and in deeper water forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit the distribution of the species. The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Reed sweetgrass prefers nutrient-rich soil (NBII & ISSG 2008) and is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Loo et al. 2009). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas.

Sediment chemical data from the CAWS shows the presence of a wide range of chemicals throughout the system, including pesticides, PCBs and heavy metals. In Scotland it was dense in an area that received sewage (West 1910). Reed sweetgrass was positively related to human population growth, (Wei & Chow-Fraser 2006). The grass is phosphorus limited, so it will spread only into areas with adequate phosphorus levels (Haslam 1978). The CAWS has high nutrients inputs (LimnoTech 2010).

The North Shore Channel has in-stream aquatic habitat; however, the banks are mostly shaded, a habitat the reed sweetgrass avoids. Reed sweetgrass requires full sun and can tolerate only light shade (NBII & ISSG 2008; Loo et al. 2009). Occurrence is less likely under woody, riparian vegetation, especially dense vegetation (Loo et al. 2009). The flow and depth of the North Shore Channel are suitable for the species, so patches of suitable habitat may be present (LimnoTech 2010). Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River has vertical walls with sand, silt, or sludge sediment. Much of the CSSC has vertical limestone or manmade walls with silt, sand, cobble, or bedrock substrate. These habitats would not be suitable for this species. The species was identified in a lowland limestone stream in Ireland (Haslam 1978). Cobble or boulder is also common in the riparian zone of the CSSC.

There is little canopy cover (LimnoTech 2010). Suitable habitat in the CAWS may be intermittently present along some shallow shoreline areas and in debris accumulated near bridge abutments (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. Upgrading wastewater treatment plants and the closing of two power plants should improve future water quality (Illinois Pollution Control Board 2012). Reed sweetgrass appears to benefit from some eutrophication; therefore the suitability of water quality in the CAWS for reed sweetgrass may change. The availability of suitable substrate is not expected to increase.

T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Reed sweetgrass could move into the CAWS as water is pumped from Lake Michigan into the North Shore Channel (section 3c). Although suitable habitat may be present in the North Shore Channel, most of the CAWS, especially the Chicago River and the CSSC, is too deep and lacks suitable sediments and riparian habitat for this species. The species has a rapid invasion speed; however, the CAWS is heavily utilized by vessels and rooting of the reed sweetgrass may be disrupted by canal maintenance and barge wakes (section 3a). Overall, the probability of passage is low for this time step.

T_{10}: See T_0. Despite the generally unfavorable habitat conditions, sufficient time may have passed during this time step for the reed sweetgrass to invade and spread (via growing roots and rhizomes, floating fragments and seeds, and vessel transport) to suitable habitats where available through the CAWS. Therefore, the probability of passage is medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long-distance transport of the species via vessel traffic. The availability of suitable habitat in the CAWS is not documented. This species has been documented at Illinois Beach State Park. Overall, the uncertainty associated with passage is medium for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Although this species may spread through the CAWS over time, improvements in future water quality in the CAWS could affect the reed sweetgrass in ways that are uncertain (section 3d). Therefore, the uncertainty associated with passage is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008). It is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, only tolerating light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.92 ft) deep; in deeper water, the plant forms floating mats that remain partially attached to the banks of stream or ponds (Loo et al. 2009). All of these habitat conditions are widespread below Brandon Road Lock and Dam in the form of large ponds and off-channel floodplain areas. In Europe, reed sweetgrass is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses below Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse to suitable habitat by growing roots and rhizomes, or through dispersal of floating fragments and seeds (DPIWE 2002).

Evidence for Probability Rating

Suitable habitat is present for the reed sweetgrass past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified below Brandon Road Lock and Dam, and this habitat is accessible to the reed sweetgrass (sections 4a, 4b). Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The species is found in temperate climates (Howard 2012), and its temperature range is large.

b. *Type of Mobility/Invasion Speed*
Reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that “in reed swamp, dispersal of grains probably takes place mainly by water transport.” Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002).

c. *Fecundity*
Reed sweetgrass produces vast numbers of dark brown seeds, which are 1.5–2 mm (0.059–0.079 in.) long, throughout summer and autumn (DPIWE 2002). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012).

d. *History of Invasion Success*
The first recorded reed sweetgrass in the United States occurred in 1940 in a marsh on the edge of Lake Ontario; several more populations were recorded between 1940 and 1952 in the same region (IPANE 2004). Reed sweetgrass was first found in Wisconsin’s Racine and Milwaukee counties in the 1970s (Howard 2012). In the early 1990s it was found at three sites in Massachusetts’ Ipswich River Wildlife Sanctuary in Essex county; these sites were subject to aggressive control measures, and only one site required re-treatment as of 2005 (Howard 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported by boats. There is heavy commercial and recreational vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Reed sweetgrass is a wetland obligate (Howard 2012). It is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers

nutrient-rich soil (NBII & ISSG 2008); is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012); and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep (Loo et al. 2009). In deeper water, the plant forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). All of these habitat conditions are widespread in the MRB. In Europe, reed sweetgrass is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses in the MRB.

Evidence for Probability Rating

Reed sweetgrass has a history of a rapid invasion (section 5d) and the ability to spread by roots and rhizomes, floating fragments and seeds, or vessel-mediated transport (section 5b). The MRB has suitable habitat for the species to establish (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB, and this habitat is accessible to the reed sweetgrass. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] “-“ Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that “in reed swamp, dispersal of grains probably takes place mainly by water transport. In still water, both naked and enclosed grains may be held almost indefinitely at surface by surface tension; in disturbed water, naked caryopses sink almost immediately, while enclosed grains may remain floating at surface for several hours.” Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002). Reed sweetgrass was found in Wisconsin’s Racine and Milwaukee counties in the 1970s, and the southernmost record is from Illinois Beach State Park in 2006 (Howard 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments that may be transported by boats for short distances (DPIWE 2002). There is commercial and recreational vessel traffic to the CRCW from Lake Michigan (USACE 2011a,b). Evidence for ballast water transport was not found in the literature.

c. *Current Abundance and Reproductive Capacity*

T_0: Reed sweetgrass produces vast numbers of dark brown seeds throughout summer and autumn (DPIWE 2002). It forms a sprawling mat of rhizomes, or underground stems (DPIWE 2002). These rhizomes produce vast numbers of shoots to quickly expand the plant's size (DPIWE 2002). The massive root system can extend 0.9 m (3 ft) down and the rhizomes can make up about half of the plants total biomass (Noxious Weeds 2012). Reed sweetgrass typically goes dormant in the winter, with seeds germinating the following spring, but some seeds remain dormant in the soil for many years (NBII & ISSG 2008). It is thought that North American reed sweetgrass plants reproduce mostly by vegetative means and that most seeds are not viable (Washington State Noxious Weed Control Board 2012). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012). The species is not widespread in Lake Michigan (Howard 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.

T_{10}: None.

T_{25}: None.

T_{50}: None.

e. *Distance from Pathway*

T_0: The closest established reed sweetgrass population is in Oak Creek (a tributary of Lake Michigan) in Milwaukee County, Wisconsin (Howard 2012). The population has been considered established since 1979. In 2006, an isolated established population was discovered growing out of a manhole cover at the Illinois Beach State Park, just north of Waukegan, Illinois (Howard 2012). This population was treated with herbicide and monitoring will continue (Howard 2012).

T_{10}: See T_0. The species may establish closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so the climate range in the southern Great lakes is suitable. The species prefers nutrient-rich soil (NBII & ISSG 2008); it is found on the bank of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, only tolerating light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep (Loo et al. 2009). In deeper water, the plant forms floating mats that remain partially attached to the banks of the stream or pond (Loo et al. 2009). High water levels limit the distribution of reed sweetgrass (Wei & Chow-Fraser 2006). The species is found in soils with relatively high concentrations of iron, phosphorus, and nitrogen (Wei &

Chow-Fraser 2006). Shorelines in Lake Michigan near the CRCW generally have sandy, riprap, or manmade vertical walls, although there are some emergent wetlands offshore of downtown Chicago. This species may be able to form populations along the Lake Michigan shoreline above the wave-washed elevations.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Reed sweetgrass was found within 72 km (45 mi) of the CRCW pathway, but the population was eradicated and is not known to currently exist (section 2e). Since 2006, the closest known population has been monitored and treated with herbicide to prevent dispersal (section 2e). The plant is dispersed by seeds, roots, or rhizome fragments (section 2a). The reed sweetgrass could float into the CRCW from Lake Michigan, but populations are not located along the shoreline of Lake Michigan, so there is no likely mechanism for doing so. Vessel transport from Milwaukee (where the species is present) to the CRCW is unlikely because existing reed sweetgrass populations are inland and may not receive vessel traffic. This species may be able to form populations along the Lake Michigan shoreline above the wave-washed elevations. Reed sweetgrass was found growing out of a manhole cover (section 2e) so it may establish in urban landscapes. If another population appears along the shoreline of southern Lake Michigan, the species may be able to spread closer to the pathway entrance over time. However, only one colony has been detected near CRCW since the 1970s. Eradication efforts may also keep the species from spreading to the CRCW. Overall, the probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to reach the CRCW. Therefore, the probability increases to medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Reed sweetgrass is found on the banks of slow-moving waters; Lake Michigan is a high-energy shoreline, and there is no emergent wetland habitat documented in the vicinity of the CRCW. There is little potential for transport into the CRCW from Lake Michigan. Human mediated transport of the species is poorly documented, but is highly unlikely (section 2b).

The species can have a rapid invasion rate, although this has not been evidenced in the Great Lakes. Eradication efforts at Illinois Beach State Park seem to have slowed the species' spread. Therefore, there is low uncertainty associated with arrival at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to spread to the CRCW. Monitoring and eradication efforts are in place, but their long-term effectiveness is uncertain. Overall, there is a medium uncertainty associated with arrival at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Reed sweetgrass has a potentially rapid invasion speed once it encounters a new habitat (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). The species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002).

b. Human-Mediated Transport through Aquatic Pathways

Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported by boats for short distances. There is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a).

c. Existing Physical Human/Natural Barriers

T_0: Lockport Lock and Dam and Brandon Road Lock and Dam could act as barriers because the shoreline at these locations is heavily modified. Reed sweetgrass grows well in shallow water up to 1.5 m (4.9 ft) deep, and in deeper water it forms floating mats that remain partially attached to the banks of stream or ponds (Loo et al. 2009). High water levels limit the distribution (Wei & Chow-Fraser 2006). The maximum depth in the CAWS is about 10 m (32.8 ft), and is typically around 5 m (16.4 ft) (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Reed sweetgrass prefers nutrient-rich soil (NBII & ISSG 2008), and is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Loo et al. 2009). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas.

Sediment chemical data from the CAWS shows the presence of a wide range of chemicals throughout the system, including pesticides, PCBs, and heavy metals. In Scotland, reed sweetgrass was dense in an area that received sewage (West 1910). Reed sweetgrass was positively related to human population growth (Wei & Chow-Fraser 2006). The grass is phosphorus limited, so it will spread only into areas with adequate phosphorus levels (Haslam 1978). The CAWS has high nutrient inputs (LimnoTech 2010).

Reed sweetgrass requires full sun and can tolerate only light shade (NBII & ISSG 2008; Loo et al. 2009). Occurrence is less likely under woody, riparian vegetation, especially dense vegetation (Loo et al. 2009). Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River has vertical walls with sand, silt, or sludge sediment. Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). In the CSSC, in-stream habitat varies by location, but is generally limited. Much of the CSSC has vertical limestone or manmade walls with bedrock, cobble, or silty sediment. These habitats would not be suitable for this species. The species was identified in a lowland limestone stream in Ireland (Haslam 1978). Cobble or boulder is also common in the riparian zone of the CSSC. There is little canopy cover (LimnoTech 2010). Suitable habitat in the CAWS may be intermittently present along some shallow shoreline areas and in debris accumulated near bridge abutments (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0. Upgrading wastewater treatment plants and closing two power plants should improve future water quality (Illinois Pollution Control Board 2012). Reed sweetgrass appears to benefit from some eutrophication; therefore the suitability of water quality in the CAWS for reed sweetgrass may change. The availability of suitable substrate is not expected to increase.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Reed sweetgrass could move into the CAWS through the CRCW (section 3c). Most of the CAWS, especially the Chicago River and CSSC, is too deep and lacks suitable sediments and

riparian habitat for this species. The species has a rapid invasion speed; however, the CAWS is heavily utilized by vessels and rooting by the reed sweetgrass may be disrupted by canal maintenance and barge wakes (section 3a). The species may be able to pass through the CAWS while attached to a vessel (section 3b), but this is unlikely given the distance from CRCW to Brandon Road Lock and Dam. Therefore, the probability of passage is low for this time step.
T_{10}: See T_0. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the reed sweetgrass to invade and spread (via growing roots and rhizomes, floating fragments and seeds, and transport by vessels) to suitable habitats where available through the CAWS. Therefore, the probability of passage is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long-distance transport of the species via vessel traffic. The availability of suitable habitat in the CAWS is not documented. This species has been documented at Illinois Beach State Park. Overall, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although this species may spread through the CAWS over time, improvements in future water quality in the CAWS could affect the reed sweetgrass in ways that are uncertain (section 3d). Therefore, the uncertainty associated with passage is medium for this time step.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008); it is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, only tolerating light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in

shallow water up to 1.5 m (4.92 ft) deep, and in deeper water it forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). All of these habitat conditions are widespread below Brandon Road Lock and Dam in the form of large ponds and off-channel floodplain areas. In Europe, reed sweetgrass is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses below Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse to suitable habitat by growing roots and rhizomes and dispersing floating fragments and seeds (DPIWE 2002).

Evidence for Probability Rating

Suitable habitat is present for the reed sweetgrass past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified below Brandon Road Lock and Dam, and this habitat is accessible to the reed sweetgrass (sections 4a, 4b). Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The species is found in temperate climates (Howard 2012), so its temperature range is large.

b. *Type of Mobility/Invasion Speed*
The reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that “in reed swamp, dispersal of grains probably takes place mainly by water transport.” Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002).

c. *Fecundity*
   Reed sweetgrass produces vast numbers of dark brown seeds, which are 1.5–2 mm (0.059–0.079 in.) long, throughout summer and autumn (DPIWE 2002). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012).

d. *History of Invasion Success*
   The first recorded reed sweetgrass in the United States occurred in 1940 in a marsh on the edge of Lake Ontario; several more populations were recorded between 1940 and 1952 in the same region (IPANE 2004). Reed sweetgrass was first found in Wisconsin's Racine and Milwaukee counties in the 1970s (Howard 2012). In the early 1990s it was found at three sites in Massachusetts' Ipswich River Wildlife Sanctuary in Essex county; these sites were subject to aggressive control measures, and only one site required re-treatment as of 2005 (Howard 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
   Reed sweetgrass spreads by seeds, roots, or rhizome fragments that may be transported by boats. There is heavy commercial and recreational vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Reed sweetgrass is a wetland obligate (Howard 2012). It is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008); it is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.92 ft) deep (Loo et al. 2009). In deeper water, the plant forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). All of these habitat conditions are widespread in the MRB. In Europe, reed sweetgrass is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses in the MRB.

Evidence for Probability Rating

Reed sweetgrass has a history of a rapid invasion (section 5d) and the ability to spread by roots and rhizomes, floating fragments and seeds, or vessel-mediated transport (section 5b). The MRB has suitable habitat for the species to establish (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB, and this habitat is accessible to the reed sweetgrass. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and by dispersal of floating

fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2)in 3 years (NatureServe 2010). Reed sweetgrass is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport. In still water, both naked and enclosed grains may be held almost indefinitely at surface by surface tension; in disturbed water, naked caryopses sink almost immediately, while enclosed grains may remain floating at surface for several hours." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002). The reed sweetgrass was found in the 1970s in Wisconsin's Racine and Milwaukee counties, and since that time the southernmost record is from Illinois Beach State Park in 2006 (Howard 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported short distances by boats (DPIWE 2002). There is heavy commercial vessel traffic to the Calumet Harbor from Lake Michigan (USACE 2011). However, evidence for ballast water transport was not found in the literature.

c. *Current Abundance and Reproductive Capacity*
T_0: The first North American occurrence of reed sweetgrass was recorded in the mid-1940s in the far west end of Lake Ontario, and it subsequently spread to other areas of Ontario (Howard 2012). It is currently established in several counties in Wisconsin. Reed sweetgrass produces vast numbers of dark brown seeds throughout summer and autumn (DPIWE 2002). It forms a sprawling mat of rhizomes, or underground stems (DPIWE 2002). These rhizomes produce vast numbers of shoots to quickly expand the plant's size (DPIWE 2002). The massive root system can extend 0.9 m (3 ft) down and the rhizomes can make up about half of the plants total biomass (Noxious Weeds 2012). Reed sweetgrass typically goes dormant in the winter, with seeds germinating the following spring; some seeds remain dormant in the soil for many years (NBII & ISSG 2008). It is thought that North American reed sweetgrass plants reproduce mostly by vegetative means and that most seeds are not viable (Washington State Noxious Weed Control Board 2012). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012). Reed sweetgrass is not widespread in Lake Michigan (Howard 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*

T_0: The closest established population is in Oak Creek (a tributary of Lake Michigan) in Milwaukee County, Wisconsin (Howard 2012). The population has been considered established since 1979. In 2006, an isolated established population was discovered growing out of a manhole cover at the Illinois Beach State Park just north of Waukegan, Illinois. This population was treated with herbicide and monitoring will continue (Howard 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so the climate range in the southern Great lakes is suitable. The species prefers nutrient-rich soil (NBII & ISSG 2008); it is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, only tolerating light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep (Loo et al. 2009); in deeper water, reed sweetgrass forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit the distribution of reed sweetgrass (Wei & Chow-Fraser 2006). The species is found in soils with relatively high concentrations of iron, phosphorus, and nitrogen (Wei & Chow-Fraser 2006). There are no emergent wetlands near the Calumet Harbor (unpublished data from USACE) and shorelines in Lake Michigan near the Calumet Harbor generally have sandy, riprap, or manmade vertical walls.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Reed sweetgrass was found within 80 km (50 mi) of the Calumet Harbor pathway, but the population was eradicated and is not known to currently exist (section 2e). Since 2006, the closest known population has been monitored and treated with herbicide to prevent dispersal (section 2e). The plant is dispersed by seeds, roots, or rhizome fragments (section 2a). The reed sweetgrass could float into the Calumet Harbor from Lake Michigan, but populations are not located along the shoreline of Lake Michigan, so there is not likely a mechanism for this. Vessel transport from Milwaukee (where the species is present) to Calumet Harbor is unlikely because existing reed sweetgrass populations are inland and may not receive vessel traffic. This species may be able to form populations along the Lake

Michigan shoreline above the wave-washed elevations. Reed sweetgrass was found growing out of a manhole cover (section 2e), so it may establish in urban landscapes. If another population appears along the shoreline of southern Lake Michigan, the species may be able to spread closer to the pathway entrance over time. However, only one colony has been detected near Calumet Harbor since the 1970s. Eradication efforts may also keep the species from spreading to the Calumet Harbor. Overall, the probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to reach Calumet Harbor. Therefore, the probability increases to medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Reed sweetgrass is found on the banks of slow-moving waters; Lake Michigan is a high-energy shoreline and there is no emergent wetland habitat documented in the vicinity of the Calumet Harbor. There is little potential for movement into Calumet Harbor from Lake Michigan because of the unsuitability of the shoreline of Lake Michigan. Human mediated transport of the species is poorly documented, but is also highly unlikely (section 2b). The species can have a rapid invasion rate, but this has not been evidenced in the Great Lakes. Eradication efforts at Illinois Beach State Park seem to have slowed the species' spread. Therefore, there is low uncertainty associated with arrival at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See $T_{0.}$ Fifty years may be enough time for this species to spread to the Calumet Harbor. Monitoring and eradication efforts are in place, but their long-term effectiveness is uncertain. Therefore, there is a medium uncertainty associated with arrival at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Reed sweetgrass has a potentially rapid invasion speed once it encounters a new habitat (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and by dispersal of fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (260 ft^2) in 3 years (NatureServe 2010). The species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that “in reed swamp, dispersal of grains probably takes place mainly by water transport.” Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments that may be transported by boats for short distances (DPIWE 2002). Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O’Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: T.J. O’Brien Lock and Dam, Lockport Lock and Dam, and Brandon Road Lock and Dam could act as barriers because the shoreline is heavily modified in these locations. Reed sweetgrass grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, the plant forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit its distribution (Wei & Chow-Fraser 2006). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The reed sweetgrass prefers nutrient-rich soil (NBII & ISSG 2008); the species is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest flow was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas.

Sediment chemical data from the CAWS shows the presence of a wide range of chemicals throughout the system including pesticides, PCBs, and heavy metals. In Scotland, it was dense in an area that received sewage (West 1910). Reed sweetgrass was positively related to human population growth (Wei & Chow-Fraser 2006). The grass is phosphorus limited, so it will spread only into areas with adequate phosphorus levels (Haslam 1978). The CAWS has high nutrients inputs (LimnoTech 2010).

In the Calumet River there is in-stream habitat for aquatic life in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches. Urban, industrial, and commercial riparian land use is also present. Reed sweetgrass requires full sun and can tolerate only light shade (NBII & ISSG 2008; Loo et al. 2009). Occurrence is less likely under woody, riparian vegetation, especially dense vegetation (Loo et al. 2009). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). In the CSSC, in-stream habitat varies by location, but it is generally limited and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but primarily consist of silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010). These habitats would not be suitable for this species. Suitable habitat in the CAWS may be present intermittently along some shallow shoreline areas and in debris accumulated near bridge abutments (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. Upgrading wastewater treatment plants and the closing of two power plants should improve future water quality (Illinois Pollution Control Board 2012). Reed sweetgrass appears to benefit from some eutrophication; therefore the suitability of water quality in the CAWS for reed sweetgrass may change. The availability of suitable substrate is not expected to increase.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The reed sweetgrass could move into the CAWS through the Calumet Harbor (section 3c). Most of the CAWS, especially the CSSC, is too deep and lacks suitable sediments and riparian habitat for this species. The species has a potentially rapid invasion speed; however, the CAWS is heavily utilized by vessels and rooting by the reed sweetgrass may be disrupted by canal maintenance and barge wakes (section 3a). The species may be able to pass through the CAWS while attached to a vessel (section 3b), but this unlikely given the distance from Calumet Harbor to Brandon Road Lock and Dam. Therefore, the probability of passage is low for this time step.

T_{10}: See T_0. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the reed sweetgrass to establish and spread (via growing roots and rhizomes, floating fragments and seeds, and attachment to vessels) to suitable habitats where available through the CAWS. Therefore, the probability of passage is medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long-distance transport of the species via vessel traffic. The availability of suitable habitat in the CAWS is not documented. This species has been documented at Illinois Beach State Park. Overall, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although this species may spread through the CAWS over time, improvements in future water quality in the CAWS could affect the reed sweetgrass in ways that are uncertain (section 3d). Therefore, the uncertainty associated with passage is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008); it can be found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, reed sweetgrass forms floating mats that remain partially attached to the banks of stream or ponds (Loo et al. 2009). All of these habitat conditions are widespread below Brandon Road Lock and Dam in the form of large ponds and off-channel floodplain areas. In Europe, it is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses below Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse to suitable habitat by growing roots and rhizomes, and by dispersal of floating fragments and seeds (DPIWE 2002).

Evidence for Probability Rating

Suitable habitat is present for the reed sweetgrass past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified below Brandon Road Lock and Dam, and this habitat is accessible to the reed sweetgrass (sections 4a, 4b). Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The species is found in temperate climates (Howard 2012), so its temperature range is large.

b. *Type of Mobility/Invasion Speed*
The reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through the dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). The species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002).

c. *Fecundity*
Reed sweetgrass produces vast numbers of dark brown seeds, which are 1.5–2 mm (0.059–0.079 in.) long, throughout summer and autumn (DPIWE 2002). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012).

d. *History of Invasion Success*
The first recorded reed sweetgrass in the United States occurred in 1940 in a marsh on the edge of Lake Ontario; several more populations were recorded between 1940 and 1952 in the same region (IPANE 2004). Reed sweetgrass was first found in Wisconsin's Racine and Milwaukee counties in the 1970s. In the early 1990s it was found at three sites in Massachusetts' Ipswich River Wildlife Sanctuary in Essex county; these sites were subject to aggressive control measures, and only one site required re-treatment as of 2005 (Howard 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported by boats. There is heavy commercial and recreational vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Reed sweetgrass is a wetland obligate (Howard 2012). The reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008); is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012); and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m deep, and in deeper water it forms floating mats that remain partially attached to the banks of stream or ponds (Loo et al. 2009). All of these habitat conditions are widespread in the MRB. In Europe, reed sweetgrass is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses in the MRB.

Evidence for Probability Rating

Reed sweetgrass has a history of a rapid invasion (section 5d) and the ability to spread through roots and rhizomes, floating fragments and seeds, or vessel-mediated transport (section 5b). The MRB has suitable habitat for the species to establish (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB, and this habitat is accessible to the reed sweetgrass. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	Medium	Low	Medium	Medium	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport. In still water, both naked and enclosed grains may be held almost indefinitely at surface by surface tension; in disturbed water, naked caryopses sink almost immediately, while

enclosed grains may remain floating at surface for several hours." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002). Reed sweetgrass was found in the 1970s in Wisconsin's Racine and Milwaukee counties, and since that time the southernmost recorded instance is from Illinois Beach State Park in 2006 (Howard 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported for short distances by boats (DPIWE 2002). There is heavy commercial vessel traffic to the Indiana Harbor from Lake Michigan (USACE 2011). Evidence for ballast water transport was not found in the literature.

c. *Current Abundance and Reproductive Capacity*
T_0: The first recorded occurrence of reed sweetgrass in North America came from the far west end of Lake Ontario in the mid-1940s, and it subsequently spread to other areas of Ontario (Howard 2012). It is currently established in several counties in Wisconsin. Reed sweetgrass produces vast numbers of dark brown seeds throughout summer and autumn (DPIWE 2002). It forms a sprawling mat of rhizomes, or underground stems (DPIWE 2002). These rhizomes produce vast numbers of shoots to quickly expand the plant's size (DPIWE 2002). The massive root system can extend 0.9 m (3 ft) down and the rhizomes can make up about half of the plants total biomass (Noxious Weeds 2012). Reed sweetgrass typically goes dormant in the winter, with seeds germinating the following spring, but some seeds remain dormant in the soil for many years (NBII & ISSG 2008). It is thought that North American reed sweetgrass plants reproduce mostly by vegetative means and that most seeds are not viable (Washington State Noxious Weed Control Board 2012). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012). Reed sweetgrass is not widespread in Lake Michigan (Howard 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The closest established population is in Oak Creek (a tributary of Lake Michigan) in Milwaukee County, Wisconsin (Howard 2012). The population has been considered established since 1979. In 2006, an isolated established population was discovered growing out of a manhole cover at the Illinois Beach State Park, just north of Waukegan,

Illinois (Howard 2012). This population was treated with herbicide and monitoring will continue (Howard 2012).
T_{10}: The species may establish closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: The reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so the climate range in the southern Great Lakes is suitable. The species prefers nutrient-rich soil (NBII & ISSG 2008). It is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weeds Control Board 2012) and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep (Loo et al. 2009). In deeper water, reed sweetgrass forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit the distribution of the species (Wei & Chow-Fraser 2006). The species is found in soils with relatively high concentrations of iron, phosphorus, and nitrogen (Wei & Chow-Fraser 2006). There are only small scattered emergent wetlands near the Indiana Harbor (unpublished data from USACE), and shorelines in Lake Michigan near the Indiana Harbor generally have sandy, riprap, or manmade vertical walls. This species may be able to form populations along the Lake Michigan shoreline above the wave-washed elevations.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The reed sweetgrass was found within 80.5 km (50 mi) of the Indiana Harbor pathway, but this population was eradicated and is not known to currently exist (section 2e). Since 2006, the closest known population has been monitored and treated with herbicide to prevent dispersal (section 2e). The plant is dispersed by seeds, roots, or rhizome fragments (section 2a). Reed sweetgrass could float into Indiana Harbor from Lake Michigan, but populations are not located along the shoreline of Lake Michigan so there is no likely mechanism for this. Vessel transport from Milwaukee (where the species is present) and Indiana Harbor is unlikely because existing reed sweetgrass populations are inland and may not receive vessel traffic. The habitat near Indiana Harbor is not likely suitable for the plant to establish, due to the sandy, higher energy shoreline of Lake Michigan, and the lack of wetland habitat (section 2f). However, this species was found growing out of a manhole cover (section 2e), so it may establish in urban landscapes. If another population appears

along the shoreline of southern Lake Michigan, the species may be able to spread closer to the pathway entrance over time. Eradication efforts may also keep the species from spreading to Indiana Harbor. Overall, probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to reach the CRCW. Therefore, probability increases to medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Reed sweetgrass is found on the banks of slow-moving waters; Lake Michigan is a high-energy shoreline and there is no emergent wetland habitat documented in the vicinity of Indiana Harbor. Human mediated transport of the species is poorly documented, but is highly unlikely (section 2b). There is also little potential for movement into Indiana Harbor from Lake Michigan because of the unsuitability of the shoreline of Lake Michigan. The species can have a rapid invasion rate, this has not been evidenced in the Great Lakes. Therefore, there is low uncertainty associated with arrival at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to spread to Indiana Harbor. Monitoring and eradication efforts are in place, but their long-term effectiveness is uncertain. Overall, there is a medium uncertainty associated with arrival at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Reed sweetgrass has a potentially rapid invasion speed once it encounters a new habitat (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). Reed sweetgrass is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported by boats. Most commercial vessel traffic to Indiana Harbor is lakewise (NBIC 2012). There is little, if any, vessel traffic in the Grand Calumet River due to its shallow depth. However, there is vessel traffic between the Calumet Sag Channel and Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. However, reed sweetgrass could go around the sheetpile during flood conditions. The species grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, it forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit the distribution (Wei & Chow-Fraser 2006). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). Lockport Lock and Dam and Brandon Road Lock and Dam could act as barriers because the shoreline is heavily modified in these locations.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Reed sweetgrass prefers nutrient-rich soil (NBII & ISSG 2008); it is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). Water flows out of Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the easternmost sections of the Grand Calumet River also generally flow toward Lake Michigan, although other sections can flow east or west depending on location (Weiss et al. 1997). Thus, reed sweetgrass would have to spread upstream to enter the CAWS and move to the Calumet Sag Channel.

The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. Sediment chemical data from the CAWS shows the presence of a wide range of chemicals throughout the system, including pesticides, PCBs, and heavy metals. In Scotland, it was dense in an area that received sewage (West 1910). Reed sweetgrass was positively related to human population growth (Wei & Chow-Fraser 2006). The grass is phosphorus limited, so it will spread only into areas with adequate phosphorus levels (Haslam 1978), and the CAWS has high nutrients inputs (LimnoTech 2010).

Conditions at Indiana Harbor are highly industrialized. In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments primarily consist of cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water can flow east or west depending on the water level in Lake Michigan. The Calumet Sag Channel and the Little Calumet River also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). In the CSSC, in-stream habitat varies by location but is generally limited, and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but primarily consist of silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010). These habitats would not be suitable for this species. Reed sweetgrass requires full sun and can tolerate only light shade (NBII & ISSG 2008; Loo et al. 2009). Occurrence is less likely under woody, riparian vegetation, especially dense vegetation (Loo et al. 2009). Suitable habitat in the CAWS may be intermittently present along some shallow shoreline areas and in debris accumulated near bridge abutments (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. Upgrading wastewater treatment plants and closing of two power plants should improve future water quality (Illinois Pollution Control Board 2012). Reed sweetgrass appears to benefit from some eutrophication; therefore the suitability of water quality in the CAWS for reed sweetgrass may change. The availability of suitable substrate is not expected to increase.

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Most of the CAWS, especially the CSSC, is too deep and lacks suitable sediments and riparian habitat for the species to establish. The species can have a rapid invasion speed; however, the CAWS is heavily utilized by vessels and population formation may be disrupted by canal maintenance and barge wakes (section 3a). The lack of vessel traffic and the lakeward flow in the Grand Calumet River may slow the initial spread of reed sweetgrass toward Brandon Road Lock and Dam (sections 3c, 3d). Overall, the probability of passage is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the reed sweetgrass to invade and spread (via growing roots and rhizomes, floating fragments and seeds, and vessel transport) to suitable habitats, where available, through the CAWS. Therefore, the probability of passage is medium for this time step.

T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	High	High

Evidence for Uncertainty Rating

T_0: This species has been documented at Illinois Beach State Park. Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long-distance transport of the species via vessel traffic. The lack of vessel traffic and the upstream movement required to move through Indiana Harbor and the Grand Calumet River would slow passage to an uncertain degree. The availability of suitable habitat in the CAWS is not documented. Overall, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although this species may spread through the CAWS over time, the ability to move upstream through Indiana Harbor and the Grand Calumet River remains uncertain. Improvements in future water quality in the CAWS could affect the reed sweetgrass in ways that are uncertain (section 3d). Therefore, the uncertainty associated with passage is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008). Reed sweetgrass is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, the plant forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). All of these habitat conditions are widespread below Brandon Road Lock and Dam in the form of large ponds and off-channel floodplain areas. In Europe, the species is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses below Brandon Road Lock and Dam.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The species can naturally disperse to suitable habitat by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002).

Evidence for Probability Rating

Suitable habitat is present for the reed sweetgrass past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b).

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified below Brandon Road Lock and Dam, and this habitat is accessible to the reed sweetgrass (sections 4a, 4b). The effectiveness of control measures in the Illinois River is uncertain.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
   The species is found in temperate climates (Howard 2012), so its temperature range is large.

b. *Type of Mobility/Invasion Speed*
   The reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002).

c. *Fecundity*
   Reed sweetgrass produces vast numbers of dark brown seeds, which are 1.5–2 mm (0.059–0.079 in.) long, throughout summer and autumn (DPIWE 2002). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012).

d. *History of Invasion Success*
   The first record of reed sweetgrass in the United States is from 1940 in a marsh on the edge of Lake Ontario; several more populations were recorded between 1940 and 1952 in the same region (IPANE 2004). Reed sweetgrass was first found in Wisconsin's Racine and Milwaukee counties in the 1970s (Howard 2012). In the early 1990s it was found at

three sites in Massachusetts' Ipswich River Wildlife Sanctuary in Essex county; these sites were subject to aggressive control measures, and only one site required re-treatment as of 2005 (Howard 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported by boats. There is heavy commercial and recreational vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Reed sweetgrass is a wetland obligate species (Howard 2012). It is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008), is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, only tolerating light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, reed sweetgrass forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). All of these habitat conditions are widespread in the MRB. In Europe, reed sweetgrass is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses in the MRB.

Evidence for Probability Rating

Reed sweetgrass has a history of a rapid invasion (section 5d) and the ability to spread by roots and rhizomes, floating fragments and seeds, or vessel-mediated transport (section 5b). The MRB has suitable habitat for the species to establish (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB, and this habitat is accessible to the reed sweetgrass.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	Medium	Low	Medium	Medium	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (260 ft^2) in 3 years (NatureServe 2010). This species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport. In still water, both naked and enclosed grains may be held almost indefinitely at surface by surface tension; in disturbed water, naked caryopses sink almost immediately, while

enclosed grains may remain floating at surface for several hours." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (DPIWE 2002). Reed sweetgrass was found in the 1970s in Wisconsin's Racine and Milwaukee counties, and since that time the southernmost recorded occurrence is from Illinois Beach State Park in 2006 (Howard 2012).

b. *Human-Mediated Transport through Aquatic Pathways*

Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported for short distances by boats (DIPWE 2002). There is recreational, but not commercial, vessel traffic to the BSBH from Lake Michigan (USACE 2011a,b). However, there is heavy lakewise commercial traffic to the adjacent Burns Harbor. Evidence for ballast water transport was not found in the literature.

c. *Current Abundance and Reproductive Capacity*

T_0: The first recorded occurrence of reed sweetgrass in North America was in the far west end of Lake Ontario, in the mid-1940s; it subsequently spread to other areas of Ontario (Howard 2012). The species is currently established in several counties in Wisconsin. Reed sweetgrass produces vast numbers of dark brown seeds throughout summer and autumn (DPIWE 2002). It forms a sprawling mat of rhizomes, or underground stems (DPIWE 2002). These rhizomes produce vast numbers of shoots to quickly expand the plant's size (DPIWE 2002). The massive root system can extend 0.9 m (3 ft) down and the rhizomes can make up about half of the plants total biomass (Noxious Weeds 2012). Reed sweetgrass typically goes dormant in the winter, with seeds germinating the following spring; some seeds remain dormant in the soil for many years (NBII & ISSG 2008). It is thought that North American reed sweetgrass plants reproduce mostly by vegetative means and that most seeds are not viable (Washington State Noxious Weed Control Board 2012). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012). Reed sweetgrass is not widespread in Lake Michigan (Howard 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*

T_0: The closest established population is in Oak Creek (a tributary of Lake Michigan) in Milwaukee County, Wisconsin (Howard 2012). The population has been considered established since 1979. In 2006, an isolated established population was discovered

growing out of a manhole cover at the Illinois Beach State Park, just north of Waukegan, Illinois (Howard 2012). This population was treated with herbicide and monitoring will continue (Howard 2012).
T_{10}: The species may establish closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so the climate range in the southern Great lakes is suitable. The species prefers nutrient-rich soil (NBII & ISSG 2008); it is found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012) and requires full sun, tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep (Loo et al. 2009); in deeper water, the plant forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit the distribution of reed sweetgrass (Wei & Chow-Fraser 2006). The species is found in soils with relatively high concentrations of iron, phosphorus, and nitrogen (Wei & Chow-Fraser 2006). There are emergent wetlands inland of Lake Michigan near the BSBH (unpublished data from USACE), but shorelines in Lake Michigan near the BSBH generally have sandy, riprap, or manmade vertical walls.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Reed sweetgrass was found within 80 km (50 mi) of the BSBH pathway, but the population was eradicated and is not known to currently exist (section 2e). Since 2006, the closest known population has been monitored and treated with herbicide to prevent dispersal (section 2e). The plant is dispersed by seeds, roots, or rhizome fragments (section 2a). The reed sweetgrass could float into the BSBH from Lake Michigan, but populations are not located along the shoreline of Lake Michigan, so there is not likely a mechanism for this. Vessel transport from Milwaukee (where the species is present) and BSBH is unlikely because existing reed sweetgrass populations are inland and may not encounter vessel traffic. The habitat near the BSBH is not likely suitable for the plant to establish, due to the sandy, higher energy shoreline of Lake Michigan and the lack of wetland habitat (section 2f). However, this species was found growing out of a manhole cover (section 2e), so it may establish in urban landscapes. If another population appears along the shoreline of southern Lake Michigan, the species may be able to spread closer to

the pathway entrance over time. However, only one colony has been detected near BSBH since the 1970s. Eradication efforts may also keep the species from spreading to the BSBH. Overall, probability of arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. If another population establishes along the shoreline of southern Lake Michigan, the species may be able to establish closer to the pathway entrance over time. Therefore, the probability of arrival is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: Reed sweetgrass is found on the banks of slow-moving waters; Lake Michigan has a high-energy shoreline and there is no emergent wetland habitat documented in the vicinity of the BSBH. Human mediated transport of the species is poorly documented, but is highly unlikely (section 2b). There is also little potential for movement into the Wilmette Harbor from Lake Michigan because of the unsuitability of the shoreline of Lake Michigan. The species can have a rapid invasion rate, but this has not been evidenced in the Great Lakes. Therefore, there is low uncertainty associated with arrival at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Fifty years may be enough time for this species to spread to the BSBH. Monitoring and eradication efforts are in place, but their long-term effectiveness is uncertain. However, there will remain little potential for transport into BSBH from Lake Michigan. Overall, there is a medium uncertainty associated with arrival at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Reed sweetgrass has a potentially rapid invasion speed once it encounters a new habitat (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). The species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately while others remain dormant for several years (DPIWE 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported short distances by boats (DPIWE 2002). Most commercial vessel traffic to BSBH is lakewise and there is no commercial vessel traffic to inland ports in the CAWS from BSBH (NBIC 2012). Therefore, some natural downstream dispersal will likely be required to reach Brandon Road Lock and Dam. Hull fouling could be an important vector for the secondary spread of established freshwater aquatic invasive species within the Great Lakes (Reid & Ruiz 2007). Recreational boating traffic through BSBH, Burns Ditch, and the south branch of Little Calumet River is very minor due to its shallow depth.

c. *Existing Physical Human/Natural Barriers*
T_0: Lockport Lock and Dam and Brandon Road Lock and Dam could act as barriers because the shoreline is heavily modified in these locations. Reed sweetgrass grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, the plant forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). High water levels limit distribution (Wei & Chow-Fraser 2006). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Reed sweetgrass prefers nutrient-rich soil (NBII & ISSG 2008), and is found on the bank of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). Water flows out of BSBH into Lake Michigan. The eastern segment of the south branch Little Calumet River also generally flows toward Lake Michigan, depending on location and water level in Lake Michigan (GSWMD 2008). Thus, reed sweetgrass would have to spread upstream in order to enter the CAWS and move to the Calumet Sag Channel.

The CAWS is a heavily modified channel with little floodplain connection and few shallow marshy areas. Sediment chemical data from the CAWS shows the presence of a wide range of chemicals throughout the system including pesticides, PCBs, and heavy metals. In Scotland, reed sweetgrass was dense in an area that received sewage (West 1910). Reed sweetgrass was positively related to human population growth (Wei & Chow-Fraser 2006). The grass is phosphorus limited, so it will spread only into areas with adequate phosphorus levels (Haslam 1978). The CAWS has high nutrient inputs (LimnoTech 2010).

The banks of the BSBH are primarily riprap and vertical walls. The banks of the south leg of the Little Calumet River are vegetated, and sediments include plant debris, silt, sand, cobble, gravel, and boulders (Gallagher et al. 2011). Reed sweetgrass requires full sun and can tolerate only light shade (NBII & ISSG 2008; Loo et al. 2009). Occurrence is less likely under woody, riparian vegetation, especially dense vegetation (Loo et al. 2009). Inorganic silt and sludge sediments predominate in the Calumet Sag Channel (LimnoTech 2010), and it contains areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). In the CSSC, in-stream habitat varies by location but is generally limited, and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but primarily consist of silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010). These habitats would not be suitable for this species. Suitable habitat in the CAWS may be intermittently present along some shallow shoreline areas and in debris accumulated near bridge abutments (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0. Upgrading wastewater treatment plants and the closing of two power plants should improve future water quality (Illinois Pollution Control Board 2012). Reed sweetgrass appears to benefit from some eutrophication; therefore the suitability of water quality in the CAWS for reed sweetgrass may change. The availability of suitable substrate is not expected to increase.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Most of the CAWS, especially the CSSC, is too deep and lacks suitable sediments and riparian habitat for this species. The species can have a rapid invasion speed; however, the CAWS is heavily utilized by vessels and rooting by the reed sweetgrass may be disrupted by canal maintenance and barge wakes (section 3a). The lack of vessel traffic and the flow toward Lake Michigan in BSBH and the south branch of the Little Calumet River would slow the spread of reed sweetgrass. Overall, the probability of passage is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Over time, reed sweetgrass may be able to move upstream through BSBH and the Little Calumet River using wind driven currents and aquatic organisms. Despite the generally unfavorable habitat conditions, there may be sufficient time in this time step for the reed sweetgrass to establish and spread (via growing roots and rhizomes, floating fragments and seeds, and attachment to vessels) to suitable habitats, where available, through the CAWS. Therefore, the probability of passage is medium for this time step.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	High	High

Evidence for Uncertainty Rating

T_0: Vessel use and upkeep of the CAWS should remain the same over time. There is little information on long-distance transport of the species via vessel traffic. The lack of vessel traffic and the upstream movement required to move through BSBH and the south branch of the Little Calumet River would slow passage to an uncertain degree. The availability of suitable habitat in the CAWS is not documented. Overall, the uncertainty associated with passage is medium for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Reed sweetgrass' ability to move upstream through BSBH and the Little Calumet River remains uncertain. Although this species may spread through the CAWS over time, improvements in future water quality in the CAWS could affect the reed sweetgrass in ways that are uncertain (section 3d). Therefore, the uncertainty associated with passage is high for this time step.

T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Reed sweetgrass is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008); can be found on the banks of slow-moving rivers, streams, and lakes (NBII & ISSG 2008; Washington State Noxious Weed Control Board 2012); and requires full sun and can tolerate only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep; in deeper water, reed sweetgrass forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). All of these habitat conditions are widespread below Brandon Road Lock and Dam in the form of large ponds and off-channel floodplain areas. In Europe, reed sweetgrass is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses below Brandon Road Lock and Dam.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal

The species can naturally disperse to suitable habitat by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002).

Evidence for Probability Rating

Suitable habitat is present for the reed sweetgrass past the Brandon Road Lock and Dam area. The species will be able to float to ideal habitat locations (sections 4a, 4b). Therefore, probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified below Brandon Road Lock and Dam, and this habitat is accessible to the reed sweetgrass (sections 4a, 4b). Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The species is found in temperate climates (Howard 2012), so its temperature range is large.

b. Type of Mobility/Invasion Speed
Reed sweetgrass has a potentially rapid invasion speed (NatureServe 2010). The species colonizes new areas by growing roots and rhizomes, and through dispersal of floating fragments and seeds (DPIWE 2002). A single rootstock may cover 25 m^2 (269 ft^2) in 3 years (NatureServe 2010). The species is considered an aggressive invasive species (Washington State Noxious Weed Control Board 2012). Lambert (1947) states that "in reed swamp, dispersal of grains probably takes place mainly by water transport." Seeds may be spread on water, in mud on machinery, or on livestock, and to a lesser extent by wind (DPIWE 2002). The majority of the seeds are able to germinate immediately, but others remain dormant for several years (NBII & ISSG 2008; DPIWE 2002).

c. Fecundity
Reed sweetgrass produces vast numbers of dark brown seeds, which are 1.5–2 mm (0.059–0.079 in.) long, throughout summer and autumn (DPIWE 2002). Rapid early spring growth gives reed sweetgrass a competitive advantage over other wetland plants (Noxious Weeds 2012).

d. History of Invasion Success
The first recorded occurrence of reed sweetgrass in the United States was in 1940 in a marsh on the edge of Lake Ontario; several more populations were recorded between 1940 and 1952 in the same region (IPANE 2004). Reed sweetgrass was first found in

Wisconsin's Racine and Milwaukee counties in the 1970s (Howard 2012). In the early 1990s it was found at three sites in Massachusetts' Ipswich River Wildlife Sanctuary in Essex county; these sites were subject to aggressive control measures, and only one site required re-treatment as of 2005 (Howard 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
Reed sweetgrass spreads by seeds, roots, or rhizome fragments, which may be transported by boats (DPIWE 2002). There is heavy commercial and recreational vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Reed sweetgrass is a wetland obligate (Howard 2012). It is a large aquatic grass found in temperate areas (Howard 2012), so its climate range is large. The species prefers nutrient-rich soil (NBII & ISSG 2008); it can be found on the banks of slow-moving rivers, streams, and lakes and requires full sun, only tolerating only light shade (NBII & ISSG 2008; Loo et al. 2009). The species grows well in shallow water up to 1.5 m (4.9 ft) deep (Loo et al. 2009). In deeper water, reed sweetgrass forms floating mats that remain partially attached to the banks of streams or ponds (Loo et al. 2009). All of these habitat conditions are widespread in the MRB. In Europe, the species is associated with agriculture and urban sewage discharge (West 1910), which are typical land uses in the MRB.

Evidence for Probability Rating

Reed sweetgrass has a history of a rapid invasion (section 5d) and the ability to spread by growing roots and rhizomes, floating fragments and seeds, or vessel-mediated transport (section 5b). The MRB has suitable habitat for the species to establish (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been identified throughout the MRB, and this habitat is accessible to the reed sweetgrass. Therefore, the uncertainty associated with the probability of spread is low.

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E.2.4.3 Water Chestnut - *Trapa natans*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Low
P(passage)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a potentially rapid invasion speed in some areas and it is documented to be extremely prolific when at low density (NatureServe 2010). However, water chestnut was first reported in the Great Lakes before the late 1950s and it has not spread west from eastern Lake Erie (Cao 2011). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely

aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). It has often been reported that waterfowl or water currents can move the seeds of water chestnuts long distances (IPANE undated). However, the fruits weigh 6 g (0.013 lb) and have been described as falling to the bottom of lakes "like sinkers," making them unlikely to be carried away by birds or downstream by moving water (IPANE undated). Water chestnuts may also disperse by fragmentation. Plant fragments can be carried by water, waterfowl, and boats to new locations (IPANE undated).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation. Plant fragments can be carried for short distances to new locations by boats (IPANE undated). There is recreational boat use in the Wilmette Harbor.

c. *Current Abundance and Reproductive Capacity*
Water chestnuts begin to flower in early-to-mid June (Naylor 2003), with their nuts ripening approximately a month later (NatureServe 2010). Flowering and seed production continue into the fall, until the first frost kills the floating rosettes. When mature, the fruits sink to the bottom of the water body (Pemberton 2002). The water chestnut seeds rapidly (Corkum 2000); seeds can remain dormant for up to 12 years (NatureServe 2010). The seeds overwinter at the bottom of the water body and germinate throughout the warm season (Pemberton 2002), producing shoots that grow to the water surface where the typical rosette is formed (Naylor 2003).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The current range of the water chestnut is from Vermont to Virginia (Cao 2011). It is continuing to expand its range in the Northeast and possibly in the Great Lakes, but following an eradication program in the Chesapeake Bay region, it is relatively rare in that area. The closest established population to WPS is in Erie County, New York in the Tonawanda Creek in eastern Lake Erie (NatureServe 2010).
T_{10}: Species may spread closer to the pathway; however, eradication efforts may prevent or slow spread.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight

(Hummel & Findlay 2006), sluggish, nutrient-rich waters, and soft substrate (Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter and much of the shoreline of Lake Michigan is sand. In addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982) and Lake Michigan has an active shoreline. There are no emergent wetlands near the WPS (Habitat Mapping) and the shoreline conditions in Lake Michigan near the WPS and in Wilmette Harbor are generally sandy beach, riprap, or manmade vertical walls. Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has little or no natural long-distance dispersal capabilities. The Great Lakes water chestnut community closest to the WPS pathway is located in eastern Lake Erie (section 2e). The water chestnut is not documented in Lake Michigan. The water chestnut is not likely dispersed by vessel traffic or currents. This species has been present in the Great Lakes since the 1950s and it has not spread west of Lake Erie. The habitat near the WPS is not likely suitable, due to the higher energy shoreline of Lake Michigan and the sandy sediments (section 2f). Therefore, there is a low likelihood that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the water chestnut from arriving at the pathway entrance. As a result, the probability of its arrival remains low for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The water chestnut is located far from the pathway entrance and it is unlikely to naturally arrive at the entrance at this time step. There is no documented long-distance

transport by a vessel. The water chestnut has been in eastern Lake Erie for more than 50 years and has not yet spread to other parts of that lake or to Lake Michigan. Therefore, the uncertainty associated with the species' arrival is considered low at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density. It outcompetes native plants, does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). When mature, the fruits sink to the sediment and seeds can remain dormant for 12 years (Naylor 2003).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation and these plant fragments can be carried to new locations by attaching to boats (IPANE undated). There is no commercial vessel traffic in the North Shore Channel (USACE 2011a), so some natural spread may be required to reach the Chicago River. There is vessel traffic from the Chicago River to Brandon Road Lock and Dam that could potentially transport this species.

c. *Existing Physical Human/Natural Barriers*
T_0: The sluice gate at the WPS is a barrier which could retard natural dispersion. However, water is pumped from Lake Michigan into the North Shore Channel which could transport seeds. The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki 1980). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and the depth is typically about 5 m (16.4 ft) (LimnoTech 2010), but is more shallow along the channel edge.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel 2004). The water chestnut requires full sunlight (Hummel &

Findlay 2006), sluggish, nutrient-rich waters, and soft substrate (Winne 1950; Kiviat 1993). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas**.** Most flows in the CAWS were <0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). There is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). Water chestnut rarely grows where the substrate is low in organic matter. Sediments in the CAWS are dominated by inorganic silt and bedrock, and the organic soft sediment required by this species is not typical of sediments in the CAWS (LimnoTech 2010). Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River is vertical wall with sand, silt, or sludge sediment (LimnoTech 2010). Much of the CSSC is vertical limestone or manmade walls with silt, bedrock, or cobble substrate and little canopy cover, and no natural floodplain (LimnoTech 2010), which is the preferred habitat of this species. This species could form stands in areas of the CAWS where organic matter has accumulated. In addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). Flow in the CAWS can vary with stormwater inputs (LimnoTech 2010). Barge traffic can also create wakes that disturb the shoreline. Native to Europe, Asia, and Africa water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12–128 mg/L of calcium carbonate (Naylor 2003). Water quality reports show annual mean alkalinity in the CAWS ranging between 100 and 225 mg/L. The water chestnut is considered to be a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010). Temperatures in the CAWS fall within this range (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water chestnut can establish in slow-moving rivers (section 3d). The passage through the WPS and the downstream locks is possible if the water chestnut spreads as a seed or plant fragment. However, the species is unlikely to fully traverse the CAWS due to habitat limitation (section 3d). This may be due to the lack of suitable floodplain and near-shore habitat, a fluctuating hydrograph, and heavy vessel use in the CAWS. There is low macrophyte cover in all areas of the CAWS, suggesting that the CAWS is not suitable habitat for aquatic macrophytes (section 3d), although it could form stands in areas where organic matter has accumulated. Sediments in the CAWS may not be suitable in most locations

(section 3d). Overall, the limited availability of suitable habitat in the CAWS gives the species a low probability of passage at the current time step.
T_{10}: See T_0. The water chestnut may be able to spread by downstream seed dispersal over this time step. Seeds can remain viable in the sediment for over a decade (section 3a). For these reasons, the probability of passage increases to medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is low macrophyte coverage in the CAWS, suggesting that the habitat is unsuitable or very limited in availability for the water chestnut as well. This species can establish in slow-moving lotic systems (section 3d). There is little information on the speed of transport of the water chestnut via natural or human-mediated mechanisms. The potential for transport of plant fragments by vessel is uncertain (section 3d). Therefore, the level of uncertainty associated with the passage of the species is considered to be medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitat is present downstream of Brandon Road Lock and Dam. The water chestnut requires full sunlight (Hummel & Findlay 2006), nutrient-rich waters, and soft substrate (Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse to suitable habitat.

Evidence for Probability Rating

Suitable habitat of low flow, soft substrate rivers are present below Brandon Road Lock and Dam, and this species can disperse naturally or via vessel traffic to this suitable habitat. Therefore, there is a high probability of colonization by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Habitat and water chemistry appear to be suitable for water chestnut downstream of Brandon Road Lock and Dam. Therefore, there is low uncertainty associated with colonization by the species.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010).

b. *Type of Mobility/Invasion Speed*
The plant is capable of rapid expansion by natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010).

c. *Fecundity*
Pollination apparently occurs in the air; however, the pollen vector is unknown. Self-pollination possibly occurs before the flower opens (Hummel & Kiviat 2004). When mature, they sink to the bottom of the water body where the horns may act as anchors, keeping the seeds in suitable water depths (Pemberton 2002). The seeds overwinter at the bottom of the water body and germinate in the warm season (Pemberton 2002).

d. *History of Invasion Success*
The water chestnut was first recorded in North America near Concord, Massachusetts in 1859. Wild populations have since become established in many locations in the Northeastern United States (Cao 2011). Within the Chesapeake Bay watershed, water chestnut first appeared in the Potomac River near Washington, D.C., as a 2-acre patch in 1923. The plant spread rapidly, covering 64.4 km (40 river miles) within a few years (Naylor 2003).

e. *Human-Mediated Transport through Aquatic Pathways*
There is no documented transport. Water chestnuts may disperse by fragmentation. Plant fragments can be carried by boats to new locations (IPANE undated). There is heavy commercial and recreational vessel traffic in the MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The water chestnut is a wetland obligate. Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitats are common in the MRB. The water chestnut requires full sunlight (Hummel & Findlay 2006), nutrient-rich fresh waters, and soft substrate (Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). The water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12–128 mg/L of calcium carbonate (Cao 2011). Waterway sampling sites at the southern end of the CAWS, Lockport Forebay #92, had high alkalinity averaging just over 140 mg/L over a 10 year survey (MWRD 2010).

Evidence for Probability Rating

The water chestnut is considered a temperate and tropical species (section 5a). Therefore, climate in the MRB is expected to be suitable. The water chestnut has a history of rapid spread in temperate river systems (section 5d). Suitable habitat is present throughout the MRB where the species can naturally disperse through the waterways (section 5f). Therefore, there is a high probability of spread by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. The water chestnut is documented to spread through temperate river systems (section 5d). Therefore, there is low uncertainty associated with the spread of the species.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS (CRCW) TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Low
P(passage)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a potentially rapid invasion speed in some areas and it is documented to be extremely prolific when at low density (NatureServe 2010). However, the water chestnut was first reported in the Great Lakes before the late 1950s and has not spread west from eastern Lake Erie (Cao 2011). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control

(NatureServe 2010). It has often been reported that waterfowl or water currents can move the seeds of water chestnuts long distances (IPANE undated). However, the fruits weigh 6 g (0.013 lb) and have been described as falling to the bottom of lakes "like sinkers," making them unlikely to be carried away by birds or downstream by moving water. Water chestnuts may also disperse by fragmentation. Plant fragments can be carried by water, waterfowl, and boats to new locations (IPANE undated).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation. Plant fragments can be carried for short distances to new locations by boats (IPANE undated). Spread by vessel traffic has been the fastest means of spread between the Great Lakes. There is commercial and recreational vessel traffic to the CRCW from Lake Michigan (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
Water chestnuts begin to flower in early-to-mid June (Naylor 2003), with their nuts ripening approximately a month later (NatureServe 2010). Flowering and seed production continue into the fall until the first frost kills the floating rosettes. When mature, the fruits sink to the bottom of the water body (Pemberton 2002). The water chestnut seeds rapidly (Corkum 2000), and seeds can remain dormant for up to 12 years (NatureServe 2010). The seeds overwinter at the bottom of the water body and germinate throughout the warm season (Pemberton 2002), producing shoots that grow to the water surface where the typical rosette is formed (Naylor 2003).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The current range of the water chestnut is from Vermont to Virginia (Cao 2011). It is continuing to expand its range in the Northeast and possibly in the Great Lakes, but following an eradication program in the Chesapeake Bay region, it is relatively rare in that area. The closest established population to the CRCW is in Erie County, New York in the Tonawanda Creek in eastern Lake Erie (NatureServe 2010).
T_{10}: Species may spread closer to the pathway; however, eradication efforts may prevent or slow spread.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight, sluggish, nutrient-rich waters, and soft substrate (Winne 1950; Kiviat 1993). The species grows in

waters 0.3–3.6 m (0.98–11.8 ft) deep but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter and much of the shoreline of Lake Michigan is sand. In addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950, Vuorela & Aalto 1982) and Lake Michigan has an active shoreline. There are no emergent wetlands near the CRCW (Habitat Mapping) and the shoreline conditions in Lake Michigan near the CRCW are generally sandy beach, riprap, or manmade vertical walls, although there are some emergent wetlands offshore of downtown Chicago. Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has little or no natural long-distance dispersal capabilities**.** The closest Great Lakes water chestnut community to the CRCW is located in eastern Lake Erie (section 2e). The water chestnut is not documented in Lake Michigan. The water chestnut is not likely dispersed by vessel traffic or currents. This species has been present in the Great Lakes since the 1950s and has not spread west of Lake Erie. The habitat near the CRCW is not likely suitable, due to the higher energy shoreline of Lake Michigan and the sandy sediments (section 2f). For these reasons, there is a low probability that the species will arrive at the pathway during this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the water chestnut from arriving at the pathway entrance. Therefore, the probability of its arrival remains low for this time step.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The water chestnut is located far from the pathway entrance and is unlikely to naturally arrive at the entrance at this time step. There is no documented long distance transport by a vessel. The water chestnut has been in eastern Lake Erie for more than 50 years and has

not yet spread to other parts of that lake or to Lake Michigan. For these reasons, there is low uncertainty associated with the arrival of the species at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). When mature, the fruits sink to the sediment and seeds can remain dormant for 12 years (Pemberton 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation and these plant fragments can be carried to new locations by attaching to boats (IPANE undated). There is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a).

c. *Existing Physical Human/Natural Barriers*
T_0: The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and depth is typically around 5 m (16.4 ft) (LimnoTech 2010), but is shallower along the channel edge.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight, sluggish, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). Sediments in the CAWS are dominated by inorganic silt and bedrock. The

organic soft sediment required by this species is not typical of the CAWS (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas**.** Most flows in the CAWS were <0.15 m/s (0.49 ft/s), the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). There is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). Water chestnut rarely grows where the substrate is low in organic matter. Virtually all (>90%) of the Chicago River and the Lower North Branch of the Chicago River is vertical wall with sand, silt, or sludge sediment (LimnoTech 2010). Much of the CSSC is vertical limestone or manmade walls with bedrock, cobble, or silty sediment, little canopy cover, and no natural floodplain (LimnoTech 2010), which is the preferred habitat of this species. In addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). Flow in the CAWS can vary with stormwater inputs (LimnoTech 2010). Barge traffic can also create wakes that disturb the shoreline. This species could form stands in areas of the CAWS where organic matter has accumulated. Native to Europe, Asia, and Africa water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12–128 mg/L of calcium carbonate (Cao 2011). Water quality reports show annual mean alkalinity in the CAWS ranging between 100 and 225 mg/l (MWRD 2010). The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010). Temperatures in the CAWS fall within this range (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water chestnut can establish in slow-moving rivers (section 3d). The depth and low flow of the CAWS is suitable for the water chestnut. However, the species is unlikely to fully traverse the CAWS due to habitat limitation (section 3d). This may be due to lack of suitable floodplain and near-shore habitat, a fluctuating hydrograph, and heavy vessel use in the CAWS. There is low macrophyte cover in all areas of the CAWS suggesting that the CAWS is not suitable habitat for aquatic macrophytes, although it could form stands in areas where organic matter has accumulated (section 3d). The passage through the CRCW and the downstream locks is possible if the water chestnut spreads as a seed or plant fragment. Sediments in the CAWS may not be suitable in most locations (section 3d). Overall, the probability of passage is low for this time step.

T_{10}: See T_0. The water chestnut may be able to spread by downstream seed dispersal over this time step. Seeds can remain viable in the sediment for over a decade (section 3a). For these reasons, the probability of passage increases to medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is low macrophyte coverage in the CAWS, suggesting habitat is unsuitable or very limited in availability for the water chestnut as well. However, this species can establish in slow-moving lotic systems (section 3d). There is little information on the speed of transport of the water chestnut via natural or human-mediated mechanisms. The potential for transport of plant fragments by vessel is uncertain. It is uncertain whether alkalinity levels are suitable for the water chestnut (section 3d). Therefore, there is a medium degree of uncertainty associated with the probability of passage at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitat is present downstream of Brandon Road Lock and Dam. The water chestnut requires full sunlight, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winn 1950; Vuorela & Aalto 1982).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse to suitable habitat.

Evidence for Probability Rating

Suitable habitat of low flow, soft-substrate rivers are present below Brandon Lock and Dam, and this species can disperse naturally or via vessel traffic to this suitable habitat. Therefore, there is a high probability of colonization by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Habitat and water chemistry appear to be suitable for water chestnut downstream of Brandon Road Lock and Dam. Therefore, there is low uncertainty associated with colonization by the species

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010).

b. Type of Mobility/Invasion Speed
The plant is capable of rapid expansion by natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010).

c. Fecundity
Pollination apparently occurs in the air; however, the pollen vector is unknown. Self-pollination possibly occurs before the flower opens (Hummel & Kiviat 2004). When mature, they sink to the bottom of the water body where the horns may act as anchors, keeping the seed in suitable water depths (Pemberton 2002). The seeds overwinter at the bottom of the water body and germinate in the warm season (Pemberton 2002).

d. History of Invasion Success
The water chestnut was first recorded in North America near Concord, Massachusetts in 1859. Wild populations have since become established in many locations in the Northeastern United States (Cao 2011). Within the Chesapeake Bay watershed, water

chestnut first appeared in the Potomac River near Washington, D.C. as a 2-acre patch in 1923. The plant spread rapidly, covering 64.4 km (40 river miles) within a few years (Naylor 2003).

e. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation (IPANE undated). Plant fragments can be carried by boats to new locations (IPANE undated). There is heavy commercial and recreational vessel traffic in the MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The water chestnut is a wetland obligate. Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitats are common in the MRB. The water chestnut requires full sunlight, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). The water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12 to 128 mg/L of calcium carbonate (Cao 2011). Waterway sampling sites at the southern end of the CAWS, Lockport Forebay #92, had high alkalinity averaging just over 140 mg/L during a 10 year survey (MWRD 2010).

Evidence for Probability Rating

The water chestnut is considered a temperate and tropical species (section 5a). Therefore, climate in the MRB is expected to be suitable. The water chestnut has a history of rapid spread in temperate river systems (section 5d). Suitable habitat is present throughout the MRB where the species can naturally disperse through the waterways (section 5f). Therefore, there is a high probability of spread by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. The water chestnut is documented to spread through temperate river systems (section 5d). Therefore, there is low uncertainty associated with the spread of the species.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Low
P(passage)	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a potentially rapid invasion speed in some areas and it is documented to be extremely prolific when at low density (NatureServe 2010). However, water chestnut was first reported in the Great Lakes before the late 1950s and has not spread west from eastern Lake Erie (Cao 2011). It outcompetes native plants, does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). It has often been reported that waterfowl or water currents can move the seeds of water

chestnuts long distances (IPANE undated). However, the fruits weigh 6 g (0.013 lb) and have been described as falling to the bottom of lakes "like sinkers," making them unlikely to be carried away by birds or downstream by moving water. Water chestnuts may also disperse by fragmentation. Plant fragments can be carried by water, waterfowl, and boats to new locations (IPANE undated).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation. Plant fragments can be carried short distances to new locations by boats (IPANE undated). Spread by vessel traffic has been the fastest means of spread between the Great Lakes. There is heavy commercial vessel traffic to the Calumet Harbor from Lake Michigan (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
Water chestnuts begin to flower in early-to-mid June (Naylor 2003), with their nuts ripening approximately a month later (NatureServe 2010). Flowering and seed production continue into the fall until the first frost kills the floating rosettes. When mature, the fruits sink to the bottom of the water body (Pemberton 2002). The water chestnut seeds rapidly (Corkum 2000), and seeds can remain dormant for up to 12 years (NatureServe 2010). The seeds overwinter at the bottom of the water body and germinate throughout the warm season (Pemberton 2002) producing shoots that grow to the water surface where the typical rosette is formed (Naylor 2003).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The current range of the water chestnut is from Vermont to Virginia (Cao 2011). It is continuing to expand its range in the Northeast and possibly in the Great Lakes, but following an eradication program in the Chesapeake Bay region, it is relatively rare in that area. The closest established population to Calumet Harbor is in Erie County, New York in the Tonawanda Creek in eastern Lake Erie (NatureServe 2010).
T_{10}: Species may spread closer to the pathway; however, eradication efforts may prevent or slow spread.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight, sluggish, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most

abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter and much of the shoreline of Lake Michigan is sand. In addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winn 1950; Vuorela & Aalto 1982) and Lake Michigan has an active shoreline. There are no emergent wetlands near the Calumet Harbor (Habitat Mapping) and the shoreline conditions in Lake Michigan near the Calumet Harbor are generally sandy beach, riprap, or manmade vertical walls. Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has little or no natural long-distance dispersal capabilities. The closest Great Lakes water chestnut community to the Calumet Harbor is located in eastern Lake Erie (section 2e). The water chestnut is not documented in Lake Michigan. The habitat near the Calumet Harbor is not likely suitable, due to the higher energy shoreline of Lake Michigan. The water chestnut is not likely dispersed by vessel traffic or currents. This species has been present in the Great Lakes since the 1950s and has not spread west of Lake Erie (Cao 2011). The habitat near Calumet Harbor is not likely suitable, due to the higher energy shoreline of Lake Michigan and the sandy sediments (section 2f).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See $T_{0.}$ Habitat is likely to remain unsuitable and keep the water chestnut from arriving at the pathway entrance.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The water chestnut is located far from the pathway entrance and is unlikely to naturally arrive at the entrance at this time step. There is no documented long distance transport by a vessel. The water chestnut has been in eastern Lake Erie for more than 50 years and has not yet spread to other parts of that lake or to Lake Michigan. Therefore, the uncertainty associated with the species' arrival is considered low at this time step.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants, does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). When mature, the fruits sink to the sediment and seeds can remain dormant for 12 years (Pemberton 2002; NatureServe 2010).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation and these plant fragments can be carried to new locations by attaching to boats (IPANE undated). Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: T.J. O'Brien Lock and Dam, Lockport Lock and Dam, and Brandon Road Lock and Dam may act as barriers because they are primarily manmade near-shore areas. The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but it is most abundant in sheltered bodies of water that are about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and the depth is typically about 5 m (16.4 ft) (LimnoTech 2010), but it is more shallow along the channel edge.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight, sluggish, nutrient-rich waters, and soft substrate (Winne 1950; Kiviat 1993). Sediments in the CAWS are dominated by inorganic silt and bedrock, and the organic soft sediment

required by this species is not typical of sediments in the CAWS (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Most flows in the CAWS were <0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). There is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). Water chestnut rarely grows where the substrate is low in organic matter. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech, 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River with silt, sand, cobble, or bedrock substrate and little canopy cover, and no natural floodplain (LimnoTech 2010), which is the preferred habitat of this species (LimnoTech 2010). In addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winn 1950; Vuorela & Aalto 1982). Flow in the CAWS can vary with stormwater inputs (LimnoTech 2010). Barge traffic can also create wakes that disturb the shoreline. This species could form stands in areas of the CAWS where organic matter has accumulated. Native to Europe, Asia, and Africa water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12 to 128 mg/L of calcium carbonate (Cao 2011). Water quality reports show annual mean alkalinity in the CAWS ranging between 100 and 225 mg/L (MWRD 2010). Sediment chemical data from the CAWS shows the presence of a wide range of chemicals throughout the system including pesticides, PCBs, and heavy metals. The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010). Temperatures in the CAWS fall within this range (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0**.** Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water chestnut can establish in slow-moving rivers (section 3d). The passage through the Calumet Harbor and the downstream locks is possible if the water chestnut spreads as a seed or plant fragment. The depth and low flow of the CAWS is suitable for the water chestnut. However, the species is unlikely to spread through much of the CAWS due to habitat limitation (section 3d). This may be due to lack of suitable floodplain and near-shore habitat, a fluctuating hydrograph, and heavy vessel use in the CAWS. There is low macrophyte cover in all areas of the CAWS suggesting that the CAWS is not suitable habitat

for aquatic macrophytes (section 3d). For these reasons, there is a low probability that the species will pass through the pathway at this time step.
T_{10}: See T_0. The water chestnut may be able to spread by downstream seed dispersal over this time step. Seeds can remain viable in the sediment for over a decade (section 3a). Therefore, the probability of passage increases to medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is low macrophyte coverage in the CAWS, suggesting habitat is unsuitable or very limited in availability for the water chestnut as well. However, this species can establish in slow-moving lotic systems (section 3d). There is little information on the speed of transport of the water chestnut via natural or human-mediated mechanisms. The potential for transport of plant fragments by vessel is uncertain. It is uncertain whether alkalinity levels are suitable for the water chestnut (section 3d). Therefore, there is a medium level of uncertainty associated with the probability of passage at this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitat is present downstream of Brandon Road Lock and Dam. The water chestnut requires full sunlight, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winn 1950; Vuorela & Aalto 1982).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse to suitable habitat.

Evidence for Probability Rating

Suitable habitat of low flow, soft substrate rivers are present below Brandon Lock and Dam, and this species can disperse naturally or via vessel traffic to this suitable habitat. Therefore, there is a high probability of colonization by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

It is uncertain whether alkalinity levels are suitable for the water chestnut (section 4a). However, there is suitable habitat present in the pathway; therefore, the uncertainty associated with its colonization is considered low.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010).

b. *Type of Mobility/Invasion Speed*
   The plant is capable of rapid expansion by natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010).

c. *Fecundity*
   Pollination apparently occurs in the air; however, the pollen vector is unknown. Self-pollination possibly occurs before the flower opens (Hummel & Kiviat 2004). When mature, they sink to the bottom of the water body where the horns may act as anchors, keeping the seed in suitable water depths (Pemberton 2002). The seeds overwinter at the bottom of the water body and germinate in the warm season (Pemberton 2002).

d. *History of Invasion Success*
   The water chestnut was first recorded in North America near Concord, Massachusetts in 1859. Wild populations have since become established in many locations in the Northeastern United States (Cao 2011). Within the Chesapeake Bay watershed, water chestnut first appeared in the Potomac River near Washington, D.C., as a 2-acre patch in 1923. The plant spread rapidly, covering 64.4 km (40 river miles) within a few years (Naylor 2003).

e. *Human-Mediated Transport through Aquatic Pathways*
   Water chestnuts may disperse by fragmentation. Plant fragments can be carried by boats to new locations (IPANE undated). There is heavy commercial and recreational vessel traffic in the MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The water chestnut is a wetland obligate. Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitats are common in the MRB. The water chestnut requires full sunlight, nutrient-rich fresh waters, and soft substrate (Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). The water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12 to 128 mg/L of calcium carbonate (Cao 2011). Waterway sampling sites at the southern end of the CAWS, Lockport Forebay #92, had high alkalinity averaging just over 140 mg/L over a 10-year survey (MWRD 2010).

Evidence for Probability Rating

The water chestnut is considered a temperate and tropical species (section 5a). Therefore, climate in the MRB is expected to be suitable. The water chestnut has a history of rapid spread in temperate river systems (section 5d). Suitable habitat is present throughout the MRB where the species can naturally disperse through the waterways (section 5f). Therefore, there is a high probability of spread by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. The water chestnut is documented to spread through temperate river systems (section 5d). Therefore, there is low uncertainty associated with the spread of the species.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Low
P(passage)	Low	Medium	Low	Medium	Medium	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a potentially rapid invasion speed in some areas and it is documented to be extremely prolific when at low density (NatureServe 2010). However, water chestnut was first reported in the Great Lakes before the late 1950s and has not spread west from eastern Lake Erie (Cao 2011). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). The plant is capable of rapid expansion by natural intra-watershed

spread by seeds (Naylor 2003). It has often been reported that waterfowl or water currents can move the seeds of water chestnuts long distances (IPANE undated). However, the fruits weigh 6 g (0.013 lb) and have been described as falling to the bottom of lakes “like sinkers,” making them unlikely to be carried away by birds or downstream by moving water (IPANE undated). Water chestnuts may also disperse by fragmentation. Plant fragments can be carried by water, waterfowl, and boats to new locations (IPANE undated).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation. Plant fragments can be carried for short distances to new locations by boats (IPANE undated). Spread by vessel traffic has been the fastest means of spread between the Great Lakes. There is heavy commercial vessel traffic to the Indiana Harbor from Lake Michigan (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
Water chestnuts begin to flower in early-to-mid June (Naylor 2003), with their nuts ripening approximately a month later (NatureServe 2010). Flowering and seed production continue into the fall until the first frost kills the floating rosettes. When mature, the fruits sink to the bottom of the water body (Pemberton 2002). The water chestnut seeds rapidly (Corkum 2000), and seeds can remain dormant for up to 12 years (NatureServe 2010). The seeds overwinter at the bottom of the water body and germinate throughout the warm season, producing shoots that grow to the water surface where the typical rosette is formed (Naylor 2003).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The water chestnut current range is from Vermont to Virginia (Cao 2011). It is continuing to expand its range in the Northeast and possibly in the Great Lakes, but following an eradication program in the Chesapeake Bay region, it is relatively rare in that area. The closest established population to Indiana Harbor is in Erie County, New York in the Tonawanda Creek in eastern Lake Erie (NatureServe 2010).
T_{10}: The species may spread closer to the pathway; however, eradication efforts may prevent or slow spread.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight, nutrient-

rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter and much of the shoreline of Lake Michigan is sand. In addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982) and Lake Michigan has an active shoreline. There are only small scattered emergent wetlands near the Indiana Harbor (Habitat Mapping) and the shoreline conditions in Lake Michigan near the Indiana Harbor are generally sandy beach, riprap, or manmade vertical walls. Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has little or no natural long-distance dispersal capabilities. The closest Great Lakes water chestnut community to the Indiana Harbor is located in eastern Lake Erie (section 2e). The water chestnut is not documented in Lake Michigan. The water chestnut is not likely dispersed by vessel traffic or currents. This species has been present in the Great Lakes since the 1950s and it has not spread west of Lake Erie. The habitat near the Indiana Harbor is not likely suitable for the water chestnut, due to the higher energy shoreline of Lake Michigan and the sandy sediments (section 2f). Therefore, there is a low probability the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Habitat is likely to remain unsuitable and keep the water chestnut from arriving at the pathway entrance. For this reason, the probability of arrival is expected to remain low.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The water chestnut is located far from the pathway entrance and is unlikely to naturally arrive at the entrance at this time step. There is no documented long distance transport by a vessel. The water chestnut has been in eastern Lake Erie for more than 50 years and has not yet spread to other parts of that lake or to Lake Michigan. For these reasons, there is low uncertainty regarding the species' probability of arrival.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). When mature, the fruits sink to the sediment (Pemberton 2002) and seeds can remain dormant for 12 years (NatureServe 2010).

b. Human-Mediated Transport through Aquatic Pathways

Water chestnuts may disperse by fragmentation and these plant fragments can be carried to new locations by attaching to boats (IPANE undated). Most commercial vessel traffic to Indiana Harbor is lake wise and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little, if any, vessel traffic in the Grand Calumet River due to the shallow depth.

c. Existing Physical Human/Natural Barriers

T_0: The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and depth is typically around 5 m (16.4 ft) (LimnoTech 2010), but is more shallow along the channel edge. Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. However, this species could go around the sheet pile during flood conditions.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight, sluggish, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). Sediments in the CAWS are dominated by inorganic silt and bedrock, and the organic soft sediment required by this species is not typical of sediments in the CAWS (LimnoTech 2010). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). There is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). The Grand Calumet River can be shallow, less than 0.3 m (1 ft) in depth in areas of the West Branch near the state line (LimnoTech 2010). Conditions at the Indiana Harbor are highly industrialized. In the East Branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments consist of primarily cobble, bedrock, or concrete; but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern most sections of the Grand Calumet River also generally flow toward Lake Michigan while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, water chestnut would have to move upstream to enter the CAWS and move to the Calumet Sag Channel. Water chestnut rarely grows where the substrate is low in organic matter. The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River with silt, sand, bedrock, or cobble substrate and little canopy cover (LimnoTech 2010). This species could form stands in areas of the CAWS where organic matter has accumulated. In addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). Flow in the CAWS can vary with stormwater inputs (LimnoTech 2010). Barge traffic can also create wakes that disturb the shoreline. Native to Europe, Asia, and Africa water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12 to 128 mg/L of calcium carbonate (Cao 2011). Water quality reports show annual mean alkalinity in the CAWS ranging between 100 and 225 mg/L (MWRD 2010). The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010). Temperatures in the CAWS fall within this range (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water chestnut can establish in slow-moving rivers (section 3d). The depth and low flow of the CAWS is suitable for the water chestnut. However, the species is unlikely to fully traverse the CAWS due to habitat limitation (section 3d). This may be due to lack of suitable floodplain and near-shore habitat, a fluctuating hydrograph, and heavy vessel use in the CAWS. There is low macrophyte cover in all areas of the CAWS suggesting that the CAWS is not suitable habitat for aquatic macrophytes, although it could form stands in areas where organic matter has accumulated (section 3d). Sediments in the CAWS may not be suitable in most locations (section 3d). The lack of vessel traffic and the upstream movement required to move through Indiana Harbor and the Grand Calumet River would likely slow passage to Brandon Road Lock and Dam. Overall, there is a low probability of passage at the current time step.
T_{10}: See T_0.
T_{25}: See T_0. Over time, the water chestnut may be able to move upstream through Indiana Harbor and the Grand Calumet River by wind-driven currents and aquatic organisms and spread downstream to Brandon Road Lock and Dam. Seeds can remain viable in the sediment for over a decade (section 3a). For these reasons, the probability of passage increases to medium for this time step.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	High	High

Evidence for Uncertainty Rating

T_0: There is low macrophyte coverage in the CAWS, suggesting habitat is unsuitable or very limited in availability for the water chestnut as well. This species can establish in slow-moving lotic systems (section 3d). There is little information on the speed of transport of the water chestnut via natural or human-mediated mechanisms. The lack of vessel traffic and the upstream movement required to move through Indiana Harbor and the Grand Calumet River would slow passage to an uncertain degree. Once in areas of the CAWS with vessel traffic, the potential for transport of plant fragments by vessel is uncertain. It is uncertain whether alkalinity levels are suitable for the water chestnut (section 3d).
T_{10}: See T_0.
T_{25}: See T_0. Future improvements in the water quality of the CAWS and its effects on water chestnut passage are uncertain. The ability to move upstream through Indiana Harbor and the Grand Calumet River remains uncertain. For this reason, the level of uncertainty increases to a high level for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Water chestnut is an annual (Cao 2011), floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitat is present downstream of Brandon Road Lock and Dam. The water chestnut requires full sunlight, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse to suitable habitat.

Evidence for Probability Rating

Suitable habitat of low flow, soft substrate rivers are present below Brandon Lock and Dam and this species can disperse naturally or via vessel traffic to this suitable habitat. Therefore, there is a high probability of colonization by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Habitat and water chemistry appear to be suitable for water chestnut downstream of Brandon Road Lock and Dam. Therefore, there is low uncertainty associated with colonization by the species.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB

The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010).

b. Type of Mobility/Invasion Speed

The plant is capable of rapid expansion by natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010).

c. Fecundity

Pollination apparently occurs in the air; however, the pollen vector is unknown. Self-pollination possibly occurs before the flower opens (Hummel & Kiviat 2004). When mature, they sink to the bottom of the water body where the horns may act as anchors, keeping the seed in suitable water depths (Pemberton 2002). The seeds overwinter at the bottom of the water body and germinate in the warm season (Pemberton 2002).

d. History of Invasion Success

The water chestnut was first recorded in North America near Concord, Massachusetts in 1859. Wild populations have since become established in many locations in the northeastern United States (Cao 2011). Within the Chesapeake Bay watershed, water chestnut first appeared in the Potomac River near Washington, D.C. as a two-acre patch in 1923. The plant spread rapidly, covering 64.4 km (40 river miles) within a few years (Naylor 2003).

e. Human-Mediated Transport through Aquatic Pathways

Water chestnuts may disperse by fragmentation (IPANE undated). Plant fragments can be carried by boats to new locations (IPANE undated). There is heavy commercial and recreational vessel traffic in the MRB (USACE 2011a,b).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The water chestnut is a wetland obligate. Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitats are common in the MRB. The water chestnut requires full sunlight, nutrient-rich, waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). The water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12 to 128 mg/L of calcium carbonate (Cao 2011). Waterway sampling sites at the southern end of the CAWS, Lockport Forebay #92, had high alkalinity averaging just over 140 mg/L over a 10-year survey (MWRD 2010).

Evidence for Probability Rating

The water chestnut is considered a temperate and tropical species (section 5a). Therefore, climate in the MRB is expected to be suitable. The water chestnut has a history of rapid spread in temperate river systems (section 5d). Suitable habitat is present throughout the MRB where the species can naturally disperse through the waterways (section 5f). Therefore, there is a high probability of spread by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. The water chestnut is documented to spread through temperate river systems (section 5d). Therefore, there is low uncertainty associated with the spread of the species.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Low	Low
P(passage)	Low	Medium	Low	Medium	Medium	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a potentially rapid invasion speed in some areas and it is documented to be extremely prolific when at low density (NatureServe 2010). However, water chestnut was first reported in the Great Lakes before the late 1950s and it has not spread west from eastern Lake Erie (Cao 2011). It outcompetes native plants (Cao 2011), does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). It has often been reported that waterfowl or water currents can move the seeds of water chestnuts long distances (IPANE undated). However, the fruits weigh 6 g (0.013 lb) and have been described as falling to the bottom of lakes "like sinkers," making them unlikely to be carried away by birds or downstream by moving water (IPANE undated). Water chestnuts may also disperse by fragmentation. Plant fragments can be carried by water, waterfowl, and boats to new locations (IPANE undated).

b. *Human-Mediated Transport through Aquatic Pathways*
Water chestnuts may disperse by fragmentation (IPANE undated). Plant fragments can be carried for short distances to new locations by boats (IPANE undated). There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic to the adjacent to Burns Harbor (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
Water chestnuts begin to flower in early-to-mid June (Naylor 2003), with their nuts ripening approximately a month later (NatureServe 2010). Flowering and seed production continue into the fall until the first frost kills the floating rosettes. When mature, the fruits sink to the bottom of the water body (Pemberton 2002). The water chestnut seeds rapidly (Corkum 2000) and seeds can remain dormant for up to 12 years (NatureServe 2010). The seeds overwinter at the bottom of the water body and germinate throughout the warm season, producing shoots that grow to the water surface where the typical rosette is formed (Naylor 2003).

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The current range of the water chestnut is from Vermont to Virginia (Cao 2011). It is continuing to expand its range in the Northeast and possibly in the Great Lakes, but following an eradication program in the Chesapeake Bay region, it is relatively rare in that area. The closest established population to Indiana Harbor is in Erie County, New York in the Tonawanda Creek in eastern Lake Erie (NatureServe 2010).
T_{10}: The species may spread closer to the pathway; however, eradication efforts may prevent or slow spread.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel 2004). The water chestnut requires full sunlight, nutrient-rich waters, and soft substrate (Winne 1950; Kiviat 1993). The species grows in waters 0.3-3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980; Cao 2011). Water chestnut rarely grows where the substrate is low in organic matter and much of the shoreline of Lake Michigan is sand. In addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982) and Lake Michigan has an active shoreline. There are emergent wetlands inland of Lake Michigan near the BSBH (Habitat Mapping), but the shoreline conditions in Lake Michigan near the BSBH are generally sandy beach, riprap, or manmade vertical walls. Except for large bays, macrophytes are not typically found on the shore of Lake Michigan, so it is probably not a suitable habitat (MTRI 2012).
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species has little or no natural long-distance dispersal capabilities. The closest Great Lakes water chestnut community to the BSBH is located in eastern Lake Erie (section 2e). The water chestnut is not documented in Lake Michigan. Long distance dispersal is not documented and it is poorly understood for the species. The water chestnut is not likely dispersed by vessel traffic or currents. This species has been present in the Great Lakes since the 1950s and it has not spread west of Lake Erie (Cao 2011). The habitat near the BSBH is not likely suitable, due to the higher energy shoreline of Lake Michigan and the sandy sediments (section 2f). Therefore, there is a low probability that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See $T_{0.}$ Habitat is likely to remain unsuitable and keep the water chestnut from arriving at the pathway entrance. Therefore, its probability of arrival remains low for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The water chestnut is located far from the pathway entrance and is unlikely to naturally arrive at the entrance at this time step. There is no documented long distance transport by a vessel. The water chestnut has been in eastern Lake Erie for more than 50 years and has not yet spread to other parts of that lake or to Lake Michigan. For these reasons, there is low uncertainty associated with the probability of the species' arrival.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The plant is capable of localized natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants, does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010). When mature, the fruits sink to the sediment (Pemberton 2002) and seeds can remain dormant for 12 years (NatureServe 2010).

b. Human-Mediated Transport through Aquatic Pathways

Water chestnuts may disperse by fragmentation and these plant fragments can be carried to new locations by attaching to boats (IPANE undated). Most commercial vessel traffic to BSBH is lake wise and there is no commercial vessel traffic to inland ports in the CAWS from BSBH (NBIC 2012). There is no commercial vessel traffic in the South Branch of the Little Calumet River.

c. Existing Physical Human/Natural Barriers

T_0: Lockport Lock and Dam and Brandon Road Lock and Dam may act as barriers because they are primarily manmade nearshore areas. The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and the depth is typically about 5 m (16.4 ft) (LimnoTech 2010), but is more shallow along the channel edge. The Little Calumet River is shallow (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). The water chestnut requires full sunlight, sluggish, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The CAWS is a heavily modified channel with little floodplain connection or shallow marshy areas. Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). Water flows out of BSBH into Lake Michigan. The eastern segment of the South Branch of the Little Calumet River also generally flows toward Lake Michigan, depending on the location and water level in Lake Michigan (GSWMD 2008). Thus, the water chestnut would have to swim upstream to enter the CAWS and move to the Calumet Sag Channel. There is low macrophyte cover in all areas of the CAWS channel (LimnoTech 2010). Water chestnut rarely grows where the substrate is low in organic matter; the banks of the South Branch of the Little Calumet River are vegetated and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River with silt, bedrock, cobble, and sand substrate and little canopy cover (LimnoTech 2010). This species could form stands in areas of the CAWS where organic matter has accumulated. In addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). Flow in the CAWS can vary with stormwater inputs (LimnoTech 2010). Barge traffic can also create wakes that disturb the shoreline. Native to Europe, Asia, and Africa water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12 to 128 mg/L of calcium carbonate (Cao 2011). Water quality reports show annual mean alkalinity in the CAWS ranging between 100 and 225 mg/L (MWRD 2010). The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010). Temperatures in the CAWS fall within this range (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water chestnut can establish in slow-moving rivers (section 3d). The passage through BSBH and the downstream locks is possible, if the water chestnut spreads as a seed or a plant fragment. The lack of vessel traffic and the upstream movement required to move through BSBH and the Little Calumet River would likely slow passage to Brandon Road Lock and Dam. The depth and low flow of the CAWS is suitable for the water chestnut, although suitable habitat is generally limited (section 3d). This may be due to lack of suitable floodplain and nearshore habitat, a fluctuating hydrograph, and heavy vessel use in the CAWS. There is low macrophyte cover in all areas of the CAWS suggesting that the CAWS is not suitable habitat for aquatic macrophytes (section 3d). Sediments in the CAWS may not be suitable in most locations (section 3d). Overall, the probability of passage is considered to be low at this time step.

T_{10}: See T_0.

T_{25}: See T_0. Over time, the water chestnut may be able to move upstream through BSBH and the Little Calumet River by wind-driven currents and aquatic organisms and spread downstream to Brandon Road Lock and Dam. Seeds can remain viable in the sediment for over a decade (section 3a). Therefore, the probability of passage by the species increases to medium for this time step.

T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	High	High

Evidence for Uncertainty Rating

T_0: There is low macrophyte coverage in the CAWS, suggesting habitat is unsuitable or very limited in availability for the water chestnut as well. This species can establish in slow-moving lotic systems (section 3d). There is little information on the speed of transport of the water chestnut via natural or human-mediated mechanisms. The lack of vessel traffic and the upstream movement required to move through BSBH and the Little Calumet River would slow passage to an uncertain degree. Once in areas of the CAWS with vessel traffic, the potential for transport of plant fragments by vessel is uncertain. It is uncertain whether alkalinity levels are suitable for the water chestnut (section 3d). For these reasons, the uncertainty regarding the species' passage is considered medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Future improvements in the water quality of the CAWS and its effects on water chestnut passage are uncertain. The ability to move upstream through BSBH and the Little Calumet River remains uncertain. Therefore, the uncertainty associated with its passage increases to high for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitat is present downstream of Brandon Road Lock and Dam. The water chestnut requires full sunlight, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuations in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse to suitable habitat.

Evidence for Probability Rating

Suitable habitat of low flow, soft substrate rivers are present below Brandon Lock and Dam and this species can disperse naturally or via vessel traffic to this suitable habitat. Therefore, there is a high probability of colonization by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Habitat and water chemistry appear to be suitable for water chestnut downstream of Brandon Road Lock and Dam. Therefore, there is low uncertainty associated with colonization by the species.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
The water chestnut is considered a temperate and tropical species (Hummel & Kiviat 2004). Studies have shown that temperatures of 4°C (39.2°F) induce seed dormancy (Cozza et al. 1994), while temperatures ranging from 25.8 to 29.2°C (78.4 to 84.6°F) are needed for the plant to flower in June (Kornijow et al. 2010).

b. *Type of Mobility/Invasion Speed*
The plant is capable of rapid expansion by natural intra-watershed spread by seeds (Naylor 2003). The water chestnut has a rapid invasion speed and it is documented to be extremely prolific when at low density (NatureServe 2010). It outcompetes native plants, does not seem to need major disturbance to invade, has extremely aggressive reproductive characteristics, and is difficult and costly to control (NatureServe 2010).

c. *Fecundity*
Pollination apparently occurs in the air; however, the pollen vector is unknown. Self-pollination possibly occurs before the flower opens (Hummel & Kiviat 2004). When mature, they sink to the bottom of the water body where the horns may act as anchors, keeping the seed in suitable water depths (Pemberton 2002). The seeds overwinter at the bottom of the water body and germinate in the warm season (Pemberton 2002).

d. *History of Invasion Success*
The water chestnut was first recorded in North America near Concord, Massachusetts in 1859. Wild populations have since become established in many locations in the Northeastern United States. Within the Chesapeake Bay watershed, water chestnut first appeared in the Potomac River near Washington, D.C., as a 2 acre patch in 1923.

The plant spread rapidly, covering 64.4 km (40 river miles) within a few years (Naylor 2003).

e. Human-Mediated Transport through Aquatic Pathways

Water chestnuts may disperse by fragmentation. Plant fragments can be carried by boats to new locations (IPANE undated). There is heavy commercial and recreational vessel traffic in the MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The water chestnut is a wetland obligate. Water chestnut is an annual, floating-leaved aquatic plant found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers, and fresh or slightly brackish reaches of estuaries (Hummel & Kiviat 2004). Such habitats are common in the MRB. The water chestnut requires full sunlight, nutrient-rich waters, and soft substrate (Hummel & Findlay 2006; Winne 1950; Kiviat 1993). The species grows in waters 0.3–3.6 m (0.98–11.8 ft) deep, but is most abundant in sheltered bodies of water about 2 m (6.6 ft) deep with soft, muddy bottoms (Muenscher 1937; Countryman 1978; Bogucki et al. 1980). Water chestnut rarely grows where the substrate is low in organic matter; in addition, swiftly flowing water and sharp fluctuation in water level can be detrimental to its survival (Winne 1950; Vuorela & Aalto 1982). The water chestnut is generally found in waters with a pH of 6.7–8.2 and an alkalinity of 12 to 128 mg/L of calcium carbonate (Cao 2011). Waterway sampling sites at the southern end of the CAWS, Lockport Forebay #92, had high alkalinity averaging just over 140 mg/L over a 10-year survey (MWRD 2010).

Evidence for Probability Rating

The water chestnut is considered a temperate and tropical species (section 5a). Therefore, climate in the MRB is expected to be suitable. The water chestnut has a history of rapid spread in temperate river systems (section 5d). Suitable habitat is present throughout the MRB where the species can naturally disperse through the waterways (section 5f). Therefore, there is a high probability of spread by the species.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. The water chestnut is documented to spread through temperate river systems (section 5d). Therefore, there is low uncertainty associated with the spread of the species.

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E.2.5 Molluscs

E.2.5.1 Greater European Peaclam – *Pisidium amnicum*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Low	High	Medium	High
P(passage)	Low	High	Low	High	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T0-T50: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011). This species was first recorded in Lake

Ontario in 1897 and has since spread to all five Great Lakes. Species in the genus Pisidium can spread rapidly in lakes (Holopainen & Jonasson 1989).

b. *Human-Mediated Transport through Aquatic Pathways*
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is recreational but no commercial vessel traffic to WPS, so no ballast water discharge is expected at the WPS (USACE 2011a,b). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found.

c. *Current Abundance and Reproductive Capacity*
T_0: Densities in Europe have reached around 1000–3300 clams per m^2 (3280–10,826 ft^2). The species is generally not abundant in the Great Lakes (Mackie et al. 1980), but no recent information on abundance was found. The greater European peaclam is hermaphroditic, oviviparous, and can undergo cross-fertilization. In Europe, it is often semelparous, reproducing once in a lifetime. In the St. Lawrence River, it is iteroparous, reproducing twice, once at age 2 and once at age 3. Life span is typically 1–3 years. The number of embryos per adult varies from 5 to 29 (Kipp et al. 2012). Overall, this species has a low reproductive capacity and produces at most a few dozen offspring per year (Keller et al. 2007). This species has been documented in Lake Michigan as early as 1993. No information on current abundance in Lake Michigan was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The species was first recorded in the Great Lakes in 1897 in Lake Ontario and is now found in all 5 Great Lakes (Kipp et al. 2012). The specific location of the species in relation to WPS is not documented; however, it could occur in inland waters within the GLB.
T_{10}: Given time, the greater European peaclam could move closer to the WPS by spreading through the suitable habitat along Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The greater European peaclam is widely distributed in Eurasia and North Africa between Naples, Siberia, and Algiers (Kipp & Benson 2011), suggesting a wide climatological tolerance. The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. The species is typically rheophilic in its native range but can also occur in lakes. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). The shoreline of Lake Michigan is sandy with dense Cladophora beds that may be suitable for this species (MTRI 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. The 2003 heat wave in Europe was responsible for the sudden decline of the greater European peaclam population in the Saône River in France (Mouthon & Daufresne 2008). Therefore, the increase of global warming predicted by different models could adversely affect the greater European peaclam.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the greater European peaclam near the WPS (section 2f). The species spreads fastest by human-mediated transport via solid ballast, which is no longer used (section 2b). Additionally, there is no lakewise commercial vessel traffic to the WPS. Transport on recreational vessels may be possible (section 2b) but has not been documented in the literature as a significant transport mechanism for this species (section 2b). The species has been established in Lake Michigan for at least two decades and has not spread into the CAWS, suggesting a slow dispersal rate. In addition, the greater European peaclam exists at low densities in Lake Michigan, so propagule pressure is likely to be low (section 2c). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over 50 years, the species could potentially reach the pathway entrance by natural dispersion alone. Appropriate habitat conditions are expected to be present (section 2f). Therefore, the probability of arrival is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The species has been in Lake Michigan since at least 1993 and has not been recorded at the WPS pathway. However, the exact location of the greater European peaclam in Lake Michigan is not documented. The natural rate of spread in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Based on European studies (section 2f), the effects of future climate change and habitat suitability of the greater European peaclam are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011).

b. Human-Mediated Transport through Aquatic Pathways
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found. This is not a fouling species and is unlikely to be transported on vessel surfaces. The sluice gate at the WPS prevents vessel movement between Lake Michigan and the North Shore Channel. There is vessel traffic in the CAWS, but no commercial vessel traffic in the North Shore Channel. Also, the discharge of ballast water does not typically occur at inland ports within the CAWS (USACE 2011a; NBIC 2012). Consequently, some non-vessel active or passive dispersal would likely be required to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round. There is a sluice gate separating WPS from Lake Michigan which is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010), which could transport this species into the North Shore Channel. The Lockport Lock and Dam and the Brandon Road Lock and Dam may also act as barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms (Kipp et al. 2012). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The genus Pisidium is established throughout the CAWS (EA Engineering, Science, and Technology, Inc. 2010), suggesting that the CAWS has suitable habitat. The species has been documented to survive in water temperatures ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) seasonally (MWRD 2010). The species is typically rheophilic in its native range. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes (Kipp et al. 2012). The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). The greater European peaclam prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover, but may be limited in some upper river reaches where temperatures do not exceed 15 to 17°C (59 to 62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). Hence, sites with high organic matter content can sustain high abundance and biomass of the greater European peaclam. Sediment characteristics could be also important in the distribution of this benthic species, a fact already established for other freshwater bivalves (Mellina & Rasmussen 1994; Jones & Ricciardi 2005; Sousa et al. 2008). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. In the North Shore Channel and the upper North Branch of the Chicago River, in-stream there are partly shaded banks with aquatic plants, tree roots, and brush debris jams, and sediments are silt and sand (LimnoTech 2010). Toward downtown Chicago and in the Chicago River, there is a reduction in in-stream habitat and a change to concrete and steel vertical banks, with sediments of concrete, silt, or sludge. Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). The greater European peaclam is documented to be generally sensitive to organic pollution (Mouthon 1996). In the CSSC, in-stream habitat varies by

location, but it generally limited. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sluice gate at the WPS may slow the movement of this species into the North Shore Channel. Although the genus Pisidium is established throughout the CAWS, this species is sensitive to pollution and polluted areas of the CAWS, so the Chicago River may not be suitable. The greater European peaclam appears to spread slowly by natural dispersion, and there is low potential for human-mediated transport from WPS to the Chicago River (section 3b). Given the distance from the WPS to Brandon Road Lock and Dam, the lack of planktonic stage, and the lack of commercial vessel traffic from the WPS, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the probability of passage is low for this time step.
T_{10}: See T_0. This species would likely have to spread through the CAWS by crawling on the sediment surface and sediment resuspension. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over 50 years, the European peaclam has more time to spread downstream from WPS to Brandon Road Lock and Dam. Therefore, the probability of passage increases to medium for this time step.
Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The rate at which European peaclam could pass through the WPS is uncertain, given the presence of the sluice gate. It is known that there is no cargo vessel traffic to Brandon Road Lock and Dam from WPS, so some natural spread may be required for the greater European peaclam to reach Brandon Road Lock and Dam. The natural rate of spread of this species is not well characterized. It is uncertain whether sediment toxicity will slow the passage of this species through the CAWS. The uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable littoral and emergent wetland habitat is present downstream of Brandon Road Lock and Dam (USACE 2012). Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. It prefers sand but has been recorded on mud and gravel (Mackie 1980; Kipp et al. 2012). It can survive anoxic conditions under ice cover, but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can disperse downstream to suitable habitat by drift or by vessel transport.

Evidence for Probability Rating

Suitable habitat for the greater European peaclam is present (section 4a) and accessible (section 4b) in the vicinity of Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the greater European peaclam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   The greater European peaclam survives in water temperatures ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012).

b. *Type of Mobility/Invasion Speed*
   The species appears to have a very slow invasion speed without the aid of human transport.

c. *Fecundity*
   The species has low fecundity. At most, the greater European peaclam will produce a few dozen offspring per year (Keller et al. 2007). Densities in Europe have reached about 1000–3300 clams/m^2. However, it is thought that the species occurs in low densities in regions (Kipp et al. 2012).

d. *History of Invasion Success*
   In the United States, the species was first recorded in the Great Lakes drainage in 1897 from Lake Ontario. Since then, populations have become established within all of the Great Lakes including some tributary streams.

e. *Human-Mediated Transport through Aquatic Pathways*
   There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   This is a generalist species. The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Suitable littoral and emergent wetland habitat is present in the MRB (USACE 2012).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the greater European peaclam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Low	High	Medium	High
P(passage)	Low	High	Low	High	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no

planktonic life stage (Kipp & Benson 2011). This species was first recorded in the Lake Ontario in 1897 and has since spread to all five Great Lakes. Species in the genus Pisidium can spread rapidly in lakes (Holopainen & Jonasson 1989).

b. *Human-Mediated Transport through Aquatic Pathways*
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is commercial and recreational vessel traffic to the CRCW from Lake Michigan (USACE 2011a,b). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found.

c. *Current Abundance and Reproductive Capacity*
T_0: Densities in Europe have reached around 1000–3300 clams per m^2 (3280–10,826 clams per ft^2). The species is generally not abundant in the Great Lakes (Mackie et al. 1980), but no recent information on abundance was found. The greater European peaclam is hermaphroditic, oviviparous, and can undergo cross-fertilization. In Europe, it is often semelparous, reproducing once in a lifetime. In the St. Lawrence River, it is iteroparous, reproducing twice, once at age 2 and once at age 3. Life span is typically 1–3 years. The number of embryos per adult varies from 5 to 29 (Kipp et al. 2012). Overall, this species has a low reproductive capacity and produces at most a few dozen offspring per year (Keller et al. 2007). The species has been documented in Lake Michigan as early as 1993. No information on current abundance in Lake Michigan was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The species was first recorded in the Great Lakes in 1897 in Lake Ontario and is now found in all five Great Lakes (Kipp et al. 2012). The specific location of the species in relation to the CRCW is not documented; however, it could occur in inland waters within the GLB.
T_{10}: Given time, the greater European peaclam could move closer to the CRCW by spreading through the suitable habitat along Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The greater European peaclam is widely distributed in Eurasia and North Africa between Naples, Siberia, and Algiers (Kipp & Benson 2011), suggesting a wide climatological tolerance. The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. The species is typically rheophilic in its native range but can also occur in lakes. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). The shoreline of Lake Michigan is sandy with dense Cladophora beds that may be suitable for this species (MTRI 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: The 2003 heat wave in Europe was responsible for the sudden decline of the greater European peaclam population in the Saône River in France (Mouthon & Daufresne 2008). Therefore, the increase of global warming predicted by different climate models could adversely affect the greater European peaclam.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low`	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the greater European peaclam near the CRCW (section 2f). The species spreads fastest by human-mediated transport via solid ballast, which is no longer used (section 2b). Transport via hull fouling may be possible (section 2b) but has not been documented in the literature as a significant transport mechanism for this species (section 2b). The species has been established in Lake Michigan for at least two decades and has not spread into the CAWS, suggesting a slow dispersal rate. In addition, the greater European peaclam exists at low densities in Lake Michigan, so propagule pressure is likely to be low (section 2c). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over 50 years, the species could potentially reach the pathway entrance by natural dispersion alone. Appropriate habitat conditions are expected to be present (section 2f). Therefore, the probability of arrival is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The species has been in Lake Michigan since at least 1993 and has not arrived at the CRCW pathway. However, the exact location of the greater European peaclam in Lake Michigan is not documented. The natural rate of spread in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The current location and rate of spread of this species in Lake Michigan is uncertain, and 25 years may or may not be enough time to reach the pathway. Therefore, uncertainty remains high.
T_{50}: See T_{25}. Based on European studies (section 2f), the effects of future climate change and habitat suitability of the greater European peaclam are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The greater European peaclam is a small sediment dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found. This is not a fouling species and is unlikely to be transported on vessel surfaces. There is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Consequently, some non-vessel active or passive dispersal would likely be required to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: Water depth in the CAWS is suitable year-round. The CRCW separates the Chicago River from Lake Michigan (LimnoTech 2010). The Lockport Lock and Dam and the Brandon Road Lock and Dam may also act as barriers.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms (Kipp et al. 2012). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The genus Pisidium is established throughout the CAWS (EA Engineering, Science, and Technology, Inc. 2010), suggesting that the CAWS has suitable habitat. The species has been documented to survive in water temperature ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F)for 200 days (Kipp et al. 2012). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) seasonally (MWRD 2010). The species is typically rheophilic in its native range. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes (Kipp et al. 2012). The maximum depth in the CAWS is about 10 m (32.8 ft) deep, and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). The greater European peaclam prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). Hence, sites with high organic matter content can sustain high abundance and biomass of the greater European peaclam. Sediment characteristics could be also important in the distribution of this benthic species, a fact already established for other freshwater bivalves (Mellina & Rasmussen 1994; Jones & Ricciardi 2005; Sousa et al. 2008). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. In the Chicago River, there is little in-stream habitat, and the banks typically have concrete and steel vertical walls, with sediments of concrete, silt, or sludge. Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). The greater European peaclam is documented to be generally sensitive to organic pollution (Mouthon 1996). In the CSSC, sediments vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).

T_{10}: See T_0.

T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Although the genus Pisidium is established throughout the CAWS, this species is sensitive to pollution, so polluted areas of the CAWS such as the Chicago River may not be suitable. The greater European peaclam appears to spread slowly by natural dispersion, and there is low potential for human-mediated transport from CRCW to Brandon Road Lock and Dam (section 3b). Given the distance from the CRCW to Brandon Road Lock and Dam and the lack of planktonic stage, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the probability of passage is low for this time step.
T_{10}: See T_0. This species would likely have to spread through the CAWS by crawling on the sediment surface and sediment resuspension. Therefore, the probability of passage remains low.
T_{25}: See $T_{10.}$
T_{50}: See T_{10}. Over 50 years, the species has more time to spread downstream from CRCW to Brandon Road Lock and Dam. Therefore, the probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species is not well characterized. Given the distance from the CRCW to Brandon Road Lock and Dam and the lack of commercial vessel ballast deposits, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. The potential for commercial vessels in the CAWS to transport this species is uncertain. It is uncertain whether sediment toxicity will slow the passage of this species through the CAWS. Therefore, the uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable littoral and emergent wetland habitat is present downstream of Brandon Road Lock and Dam (USACE 2012). Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. It prefers sand but has been recorded on mud and gravel (Mackie 1980; Kipp et al. 2012). It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal

The species can disperse downstream to suitable habitat by drift or by vessel transport.

Evidence for Probability Rating

Suitable habitat for the greater European peaclam is present (section 4a) and accessible (section 4b) in the vicinity of Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the greater European peaclam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB

The greater European peaclam survives in water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012).

b. *Type of Mobility/Invasion Speed*
The species appears to have a very slow invasion speed without the aid of human transport.

c. *Fecundity*
The species has low fecundity. At most, the greater European peaclam will produce a few dozen offspring per year (Keller et al. 2007). Densities in Europe have reached about 1000–3300 clams per m^2 (3280–10,826 clams per ft^2), although it is thought that the species occurs in low densities in regions (Kipp et al. 2012).

d. *History of Invasion Success*
In the United States, the species was first recorded in the Great Lakes drainage in 1897 from Lake Ontario. Since then, populations have become established within all of the Great Lakes including some tributary streams.

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Suitable littoral and emergent wetland habitat is present in the MRB (USACE 2012).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the greater European peaclam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Low	High	Medium	High
P(passage)	Low	High	Low	High	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011). This species was first recorded in the Lake Ontario in 1897 and has since spread to all five Great Lakes. Species in the genus Pisidium can spread rapidly in lakes (Holopainen & Jonasson 1989).

b. *Human-Mediated Transport through Aquatic Pathways*
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is commercial and recreational vessel traffic to Calumet Harbor from Lake Michigan (USACE 2011a,b). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found.

c. *Current Abundance and Reproductive Capacity*
T_0: Densities in Europe have reached about 1000–3300 clams per m^2 (3280–10,826 clams per ft^2). The species is generally not abundant in the Great Lakes (Mackie et al. 1980), but no recent information on abundance was found. The greater European peaclam is hermaphroditic, oviviparous, and can undergo cross-fertilization. In Europe, it is often semelparous, reproducing once in a lifetime. In the St. Lawrence River, it is iteroparous, reproducing twice, once at age 2 and once at age 3. Its life span is typically 1–3 years. The number of embryos per adult varies from 5 to 29 (Kipp et al. 2012). Overall, this species has a low reproductive capacity and produces at most a few dozen offspring per year (Keller et al. 2007). This species has been documented in Lake Michigan as early as 1993. No information on current abundance in Lake Michigan was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The species was first recorded in the Great Lakes in 1897 in Lake Ontario and is now found in all five Great Lakes (Kipp et al. 2012). The specific location of the species in relation to Calumet Harbor is not documented; however, it could occur in inland waters within the GLB.
T_{10}: Given time, the greater European peaclam could move closer to the Calumet Harbor by spreading through the suitable habitat along Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The greater European peaclam is widely distributed in Eurasia and North Africa between Naples, Siberia, and Algiers (Kipp & Benson 2011), suggesting a wide climatological tolerance. The greater European peaclam is found in freshwater lakes

and slow-moving rivers with soft bottoms. Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. The species is typically rheophilic in its native range but can also occur in lakes. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). The shoreline of Lake Michigan is sandy with dense Cladophora beds that may be suitable for this species (MTRI 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: The 2003 heat wave in Europe was responsible for the sudden decline of the greater European peaclam population in the Saône River in France (Mouthon & Daufresne 2008). Therefore, the increase of global warming predicted by different climate models could adversely affect the greater European peaclam.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the greater European peaclam near Calumet Harbor (section 2f). The species spreads fastest by human-mediated transport via solid ballast, which is no longer used (section 2b). Transport via hull fouling may be possible (section 2b) but has not been documented in the literature as a significant transport mechanism for this species (section 2b). The species has been established in Lake Michigan for at least two decades and has not spread into the CAWS, suggesting a slow dispersal rate. In addition, the greater European peaclam exists at low densities in Lake Michigan, so propagule pressure is likely to be low (section 2c). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over 50 years, the species could potentially reach the pathway entrance by natural dispersion alone. Appropriate habitat conditions are expected to be present (section 2f). Therefore, the probability of arrival is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The species has been in Lake Michigan since at least 1993 and has not been recorded at the Calumet Harbor pathway. However, the exact location of the greater European peaclam in Lake Michigan is not documented. The natural rate of spread in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Based on European studies (section 2f), the effects of future climate change and habitat suitability of the greater European peaclam are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011).

b. Human-Mediated Transport through Aquatic Pathways
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found. This is not a fouling species and is unlikely to be transported on vessel surfaces. Although there is little commercial river traffic from Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between T.J. O'Brien Lock and Dam (which is approximately 8 km [5 mi] south of Calumet Harbor) and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Consequently, some non-vessel active or passive dispersal would likely be required to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: Water depth in the CAWS is suitable year-round. T.J. O'Brien Lock and Dam is about 8 km (5 mi) south of the Calumet Harbor (LimnoTech 2010). The Lockport Lock and Dam and the Brandon Road Lock and Dam may also act as barriers.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms (Kipp et al. 2012). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The genus Pisidium is established throughout the CAWS (EA Engineering, Science, and Technology, Inc. 2010), suggesting that the CAWS has suitable habitat. The species has been documented to survive in water temperature ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) seasonally (MWRD 2010). The species is typically rheophilic in its native range. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes (Kipp et al. 2012). The maximum depth in the CAWS is about 10 m (32.8 ft) deep, and depth is typically about 5 m (16.4 ft) (LimnoTech 2010). The greater European peaclam prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). Hence, sites with high organic matter content can sustain high abundance and biomass of the greater European peaclam. Sediment characteristics could be also important in the distribution of this benthic species, a fact already established for other freshwater bivalves (Mellina & Rasmussen 1994; Jones & Ricciardi 2005; Sousa et al. 2008).

The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. After entering Calumet Harbor, the greater European peaclam would enter the Calumet River. In the Calumet River, there is in-stream habitat for aquatic life in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches. Urban industrial and commercial riparian land use is also present. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River. Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The Calumet Sag

Channel contains areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). The greater European peaclam is documented to be generally sensitive to organic pollution (Mouthon 1996).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board. 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The greater European peaclam appears to spread slowly by natural dispersion, and there is low potential for human-mediated transport from Calumet Harbor to Brandon Road Lock and Dam (section 3b). The organic pollution in the CAWS may keep the species from surviving in the CAWS. Given the distance from Calumet Harbor to Brandon Road Lock and Dam, the lack of a planktonic stage, and the lack of commercial vessel traffic from Calumet Harbor, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the probability of passage is low for this time step.
T_{10}: See T_0. This species would likely have to spread through the CAWS by crawling on the sediment surface and sediment resuspension. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over 50 years, this species may have time to spread downstream from the Calumet Harbor to Brandon Road Lock and Dam. Therefore, the probability of passage increases to medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species is not well characterized. The potential for commercial vessels in the CAWS to transport this species is uncertain. It is uncertain whether sediment toxicity will slow the passage of this species through the CAWS. Given the distance from Calumet Harbor to Brandon Road Lock and Dam and the lack of commercial vessel ballast deposits, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. The uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable littoral and emergent wetland habitat is present downstream of Brandon Road Lock and Dam (USACE 2012). Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. It prefers sand but has been recorded on mud and gravel (Mackie 1980; Kipp et al. 2012). It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can disperse downstream to suitable habitat by drift or by vessel transport.

Evidence for Probability Rating

Suitable habitat for the greater European peaclam is present (section 4a) and accessible (section 4b) in the vicinity of Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the greater European peaclam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB

The greater European peaclam survives in water temperatures ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012).

b. Type of Mobility/Invasion Speed

The species appears to have a very slow invasion speed without the aid of human transport.

c. Fecundity

The species has low fecundity. At most, the greater European peaclam will produce a few dozen offspring per year (Keller et al. 2007). Densities in Europe have reached about 1000–3300 clams per m^2 (3280–10,826 clams per ft^2), although it is thought that the species occurs in low densities in regions (Kipp et al. 2012).

d. History of Invasion Success

In the United States, the species was first recorded in the Great Lakes drainage in 1897 from Lake Ontario. Since then, populations have become established within all of the Great Lakes including some tributary streams.

e. Human-Mediated Transport through Aquatic Pathways

There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Suitable littoral and emergent wetland habitat is present in the MRB (USACE 2012).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the greater European peaclam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Low	High	Medium	High
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp and Benson 2011). This species was first recorded in the Lake

Ontario in 1897 and has since spread to all five Great Lakes. Species in the genus Pisidium can spread rapidly in lakes (Holopainen & Jonasson 1989).

b. *Human-Mediated Transport through Aquatic Pathways*
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is heavy commercial vessel traffic to the Indiana Harbor from Lake Michigan (USACE 2011a). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found.

c. *Current Abundance and Reproductive Capacity*
T_0: Densities in Europe have reached about 1000–3300 clams per m^2 (3280–10,826 clams per ft^2). The species is generally not abundant in the Great Lakes (Mackie et al. 1980), but no recent information on abundance was found. The greater European peaclam is hermaphroditic, oviviparous, and can undergo cross-fertilization. In Europe, it is often semelparous, reproducing once in a lifetime. In the St. Lawrence River, it is iteroparous, reproducing twice, once at age 2 and once at age 3. Its life span is typically 1–3 years. The number of embryos per adult varies from 5 to 29 (Kipp et al. 2012). Overall, this species has a low reproductive capacity and produces at most a few dozen offspring per year (Keller et al. 2007). This species has been documented in Lake Michigan as early as 1993. No information on current abundance in Lake Michigan was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The species was first recorded in the Great Lakes in 1897 in Lake Ontario and is now found in all five Great Lakes (Kipp et al. 2012). The specific location of the species in relation to Indiana Harbor is not documented; however, it could occur in inland waters within the GLB.
T_{10}: Given time, the greater European peaclam could move closer to the Indiana Harbor by spreading through the suitable habitat along Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The greater European peaclam is widely distributed in Eurasia and North Africa between Naples, Siberia, and Algiers (Kipp & Benson 2011), suggesting a wide climatological tolerance. The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. The species is typically rheophilic in its native range but can also occur in lakes. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

Organic matter is likely to be an important factor influencing the distribution the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). The shoreline of Lake Michigan is sandy with dense Cladophora beds that may be suitable for this species (MTRI 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. The 2003 heat wave in Europe was responsible for the sudden decline of the greater European peaclam population in the Saône River in France (Mouthon & Daufresne 2008). Therefore, the increase of global warming predicted by different climate models could adversely affect the greater European peaclam.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the greater European peaclam near Indiana Harbor (section 2f). The species spreads fastest by human-mediated transport via solid ballast, which is no longer used (section 2b). Transport via hull fouling may be possible (section 2b) but has not been documented in the literature as a significant transport mechanism for this species (section 2b). The species has been established in Lake Michigan for at least two decades and has not spread into the CAWS, suggesting a slow dispersal rate. In addition, the greater European peaclam exists at low densities in Lake Michigan so propagule pressure is likely to be low (section 2c). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over 50 years, the species could potentially reach the pathway entrance by natural dispersion alone. Appropriate habitat conditions are expected to be present (section 2f). Therefore, the probability of arrival is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The species has been in Lake Michigan since at least 1993 and has not been recorded at the Indiana Harbor pathway. However, the exact location of the greater European peaclam in Lake Michigan is not documented. The natural rate of spread in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Based on European studies (section 2f), the effects of future climate change and habitat suitability of the greater European peaclam are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found. This is not a fouling species and is unlikely to be transported on vessel surfaces. Most commercial vessel traffic to Indiana Harbor is by lake, and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River, due to the shallow depth. Consequently, some non-vessel active or passive dispersal would likely be required to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: Water depth in the CAWS is suitable year-round. There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a barrier, especially under low flows. The Lockport Lock and Dam and the Brandon Road Lock and Dam may also act as barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms (Kipp et al. 2012). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The genus Pisidium is established throughout the CAWS (EA Engineering, Science, and Technology, Inc. 2010), suggesting that the CAWS has suitable habitat. The species has been documented to survive in water temperatures ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) seasonally (MWRD 2010). The species is typically rheophilic in its native range. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes (Kipp et al. 2012). The maximum depth in the CAWS is about 10 m (32.8 ft) deep, and the depth is typically about 5 m (16.4 ft) (LimnoTech 2010). The greater European peaclam prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). Hence, sites with high organic matter content can sustain high abundance and biomass of the greater European peaclam. Sediment characteristics could be also important in the distribution of this benthic species, a fact already established for other freshwater bivalves (Mellina & Rasmussen 1994; Jones & Ricciardi 2005; Sousa et al. 2008).

Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. Conditions at the Indiana Harbor are highly industrialized. In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments in the Grand Calumet River consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The Calumet Sag Channel and Chicago

Sanitary and Ship Canal have banks of bedrock and steel sheet piling leading to the Des Plaines River. The Calumet Sag Channel contains areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). The greater European peaclam is documented to be generally sensitive to organic pollution (Mouthon 1996).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The greater European peaclam appears to spread slowly by natural dispersion, and there is low potential for human-mediated transport from Indiana Harbor to the Calumet River (section 3b). There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a barrier, especially under low flows. Given the distance from Indiana Harbor to Brandon Road Lock and Dam and the lack of a planktonic stage, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the probability of passage is low for this time step.
T_{10}: See T_0. This species would likely have to spread through the CAWS by crawling on the sediment surface and sediment resuspension. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over 50 years, this species has more time to spread downstream from Indiana Harbor to Brandon Road Lock and Dam using only its natural rate of spread. Therefore, the probability of passage is medium for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species is not well characterized. The potential for commercial vessels in the CAWS to transport this species is uncertain. It is uncertain whether sediment toxicity will slow the passage of this species through the CAWS. Given the distance from Indiana Harbor to Brandon Road Lock and Dam, the sheet pile in the Grand Calumet River, and the lack of vessel traffic in the Grand Calumet River, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the uncertainty associated with the probability of passage is low for this time step.
T_{10}: See T_0.

T_{25}: See T_0. Although 25 years may be enough time to spread to Brandon Road Lock and Dam, the future rate of spread for this species within the CAWS is uncertain. The future water quality of the CAWS and its effects on the greater European peaclam are uncertain. Therefore, the uncertainty associated with the probability of passage increases to medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable littoral and emergent wetland habitat is present downstream of Brandon Road Lock and Dam (USACE 2012). Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. It prefers sand but has been recorded on mud and gravel (Mackie 1980; Kipp et al. 2012). It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17 °C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can disperse downstream to suitable habitat by drift or by vessel transport.

Evidence for Probability Rating

Suitable habitat for the greater European peaclam is present (section 4a) and accessible (section 4b) in the vicinity of Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the greater European peaclam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
The greater European peaclam survives in water temperatures ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012).

b. *Type of Mobility/Invasion Speed*
The species appears to have a very slow invasion speed without the aid of human transport.

c. *Fecundity*
This species has low fecundity. At most, the greater European peaclam will produce a few dozen offspring per year (Keller et al. 2007). Densities in Europe have reached about 1000–3300 clams per m^2 (3280–10,826 clams per ft^2), although it is thought that the species occurs in low densities in regions (Kipp et al. 2012).

d. *History of Invasion Success*
In the United States, the species was first recorded in the Great Lakes drainage in 1897 from Lake Ontario. Since then, populations have become established within all of the Great Lakes including some tributary streams.

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Suitable littoral and emergent wetland habitat is present in the MRB (USACE 2012).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the greater European peaclam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Low	High	Medium	High
P(passage)	Low	Low	Low	Low	Low	Medium	Medium	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011). This species was first recorded in the Lake Ontario in 1897 and has since spread to all five Great Lakes. Species in the genus Pisidium can spread rapidly in lakes (Holopainen & Jonasson 1989).

b. Human-Mediated Transport through Aquatic Pathways

The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is no commercial vessel traffic to the BSBH from Lake Michigan. However, there is heavy commercial traffic to the adjacent Burns Harbor (USACE 2011a). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found.

c. Current Abundance and Reproductive Capacity

T_0: Densities in Europe have reached about 1000–3300 clams per m^2 (3280–10,826 clams per ft^2). The species is generally not abundant in the Great Lakes (Mackie et al. 1980), but no recent information on abundance was found. The greater European peaclam is hermaphroditic, oviviparous, and can undergo cross-fertilization. In Europe, it is often semelparous, reproducing once in a lifetime. In the St. Lawrence River, it is iteroparous, reproducing twice, once at age 2 and once at age 3. Life span is typically 1–3 years. The number of embryos per adult varies from 5 to 29 (Kipp et al. 2012). Overall, this species has a low reproductive capacity and produces at most a few dozen offspring per year (Keller et al. 2007). This species has been documented in Lake Michigan as early as 1993. No information on current abundance in Lake Michigan was found.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None

T_{10}: None

T_{25}: None

T_{50}: None

e. Distance from Pathway

T_0: The species was first recorded in the Great Lakes in 1897 in Lake Ontario and is now found in all five Great Lakes (Kipp et al. 2012). The specific location of the species in relation to BSBH is not documented; however, it could occur in inland waters within the GLB.

T_{10}: Given time, the greater European peaclam could move closer to BSBH by spreading through the suitable habitat along Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The greater European peaclam is widely distributed in Eurasia and North Africa between Naples, Siberia, and Algiers (Kipp & Benson 2011), suggesting a wide climatological tolerance. The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. The species is typically rheophilic in its native range but can also occur in lakes. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Organic matter is likely to be an important factor influencing the distribution the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). The shoreline and of Lake Michigan is sandy with dense Cladophora beds that may be suitable for this species (MTRI 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: The 2003 heat wave in Europe was responsible for the sudden decline of the greater European peaclam population in the Saône River in France (Mouthon & Daufresne 2008). Therefore, the increase of global warming predicted by different climate models could adversely affect the greater European peaclam.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the greater European peaclam near BSBH (section 2f). The species spreads fastest by human-mediated transport via solid ballast, which is no longer used (section 2b). Transport via hull fouling may be possible (section 2b) but has not been documented in the literature as a significant transport mechanism for this species (section 2b). The species has been established in Lake Michigan for at least two decades and has not spread into the CAWS, suggesting a slow dispersal rate. In addition, the greater

European peaclam exists at low densities in Lake Michigan, so propagule pressure is likely to be low (section 2c). Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over 50 years, the species could potentially reach the pathway entrance by natural dispersion alone. Appropriate habitat conditions are expected to be present (section 2f). Therefore, the probability of arrival is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The species has been in Lake Michigan since at least 1993 and has not arrived at the BSBH pathway. However, the exact location of the greater European peaclam in Lake Michigan is not documented. The natural rate of spread in the Great Lakes is uncertain. Therefore, the uncertainty associated with the probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Based on European studies (section 2f), the effects of future climate change and habitat suitability of the greater European peaclam are uncertain. Therefore, the uncertainty associated with the probability of arrival remains high at this time step.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The greater European peaclam is a small sediment-dwelling invertebrate. Eggs are incubated in a brood-sac and released as miniature adults, and therefore have no planktonic life stage (Kipp & Benson 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
The greater European peaclam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no specific documentation for this species was found. This is not a fouling species and is unlikely to be transported on vessel surfaces. Most commercial vessel traffic to BSBH is by means of a lake, and there is no commercial vessel traffic to inland ports in the CAWS from BSBH (NBIC 2012). The south branch of the Little Calumet River

is shallow and likely has only local non-motorized vessel traffic, if any (Little Calumet and Grand Calumet River Corridor Technical Advisory Group and Northeastern Illinois Planning Commission 2011). Consequently, some non-vessel active or passive dispersal would likely be required to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: Water depth in the CAWS is suitable year-round. The Lockport Lock and Dam and the Brandon Road Lock and Dam may also act as barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms (Kipp et al. 2012). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The genus Pisidium is established throughout the CAWS (EA Engineering, Science, and Technology, Inc. 2010), suggesting that the CAWS has suitable habitat. The species has been documented to survive in water temperature ranging from 1 to 21°C (33.85 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012). The water temperature in the CAWS averages 11.3–19.3°C (52.3–66.7°F) seasonally (MWRD 2010). The species is typically rheophilic in its native range. It occurs down to 30 m (98.4 ft) in Europe but only down to 10 m (32.8 ft) in the Great Lakes (Kipp et al. 2012). The maximum depth in the CAWS is about 10 m (32.8 ft) deep, and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). The greater European peaclam prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17 °C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Organic matter is likely to be an important factor influencing the distribution of the greater European peaclam because this clam uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus, and bacteria (Holopainen 1979; Hakenkamp & Palmer 1999; Hakenkamp et al. 2001; Vaughn & Hakenkamp 2001). Hence, sites with high organic matter content can sustain high abundance and biomass of the greater European peaclam. Sediment characteristics could be also important in the distribution of this benthic species, a fact already established for other freshwater bivalves (Mellina & Rasmussen 1994; Jones & Ricciardi 2005; Sousa et al. 2008).

The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. The banks of the BSBH consist primarily of riprap and vertical walls. After passing through the BSBH and Burns Ditch, the greater European peaclam would enter the south branch of the Little Calumet River. The banks of the south branch of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder

(Gallagher et al. 2011). In the Calumet River, in-stream habitat for aquatic life is in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches. Urban industrial and commercial riparian land use is also present. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The Calumet Sag Channel and CSSC have banks of bedrock and steel sheet piling leading to the Des Plaines River. Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The Calumet Sag Channel and the Little Calumet River contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). The greater European peaclam is documented to be generally sensitive to organic pollution (Mouthon 1996).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The greater European peaclam appears to spread slowly by natural dispersion, and there is low potential for human-mediated transport from BSBH to the Calumet River (section 3b). The organic pollution in the CAWS may keep the species from surviving in the CAWS. Given the distance from the BSBH to Brandon Road Lock and Dam, the lack of planktonic stage, and the lack of commercial vessel traffic in the south branch of the Little Calumet River, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the probability of passage is low for this time step.
T_{10}: See T_0. This species would likely have to spread through the CAWS by crawling on the sediment surface and sediment resuspension. Therefore, the probability of passage remains low.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over 50 years, this species has more time to spread downstream from the BSBH to Brandon Road Lock and Dam using only its natural rate of spread. Therefore, the probability of passage increases to medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species is not well characterized. The potential for commercial vessels in the CAWS to transport this species is uncertain. It is uncertain

whether sediment toxicity will slow the passage of this species through the CAWS. Given the distance from BSBH to Brandon Road Lock and Dam and the lack of commercial vessel ballast deposits, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the uncertainty associated with the probability of passage is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although 25 years may be enough time to spread to Brandon Road Lock and Dam, the future rate of spread for this species within the CAWS is uncertain. The future water quality of the CAWS and its effects on the greater European peaclam are uncertain. The uncertainty associated with the probability of passage is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. Suitable littoral and emergent wetland habitat is present downstream of Brandon Road Lock and Dam (USACE 2012). Suitable water temperature ranges from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days. It prefers sand but has been recorded on mud and gravel (Mackie et al. 1980; Kipp et al. 2012). It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal

The species can disperse downstream to suitable habitat by drift or by vessel transport.

Evidence for Probability Rating

Suitable habitat for the greater European peaclam is present (section 4a) and accessible (section 4b) in the vicinity of Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the greater European peaclam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The greater European peaclam survives in water temperatures ranging from 1 to 21°C (33.8 to 69.8°F), and the species can survive at 0°C (32°F) for 200 days (Kipp et al. 2012).

b. Type of Mobility/Invasion Speed
The species appears to have a very slow invasion speed without the aid of human transport.

c. Fecundity
The species has low fecundity. At most, the greater European peaclam will produce a few dozen offspring per year (Keller et al. 2007). Densities in Europe have reached about 1000–3300 clams per m^2 (3280–10,826 clams per ft^2). Although, it is thought that the species occurs in low densities in regions (Kipp et al. 2012).

d. History of Invasion Success
In the United States, the species was first recorded in the Great Lakes drainage in 1897 from Lake Ontario. Since then, populations have become established within all of the Great Lakes including some tributary streams.

e. Human-Mediated Transport through Aquatic Pathways
There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The greater European peaclam is found in freshwater lakes and slow-moving rivers with soft bottoms. It prefers sand but has been recorded on mud and gravel. It can survive anoxic conditions under ice cover but may be limited in some upper river reaches where temperatures do not exceed 15–17°C (59–62.6°F) in July. Similar to other mollusks, the greater European peaclam is a filter feeder, consuming primarily algae and bacteria (Kipp et al. 2012). Suitable littoral and emergent wetland habitat is present in the MRB (unpublished data from the USACE).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the greater European peaclam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

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E.2.5.2 European Fingernail Clam - *Sphaerium corneum*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	High	High	High	High	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). It was first recorded in the Great Lakes drainage in 1897 near the mouth of the Genesee River at Lake Ontario and has since spread to all the other Great Lakes (Kipp et al. 2012).

b. Human-Mediated Transport through Aquatic Pathways

The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003), although Rothlisberger (2009) stated that this species was introduced by ballast water. The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all the Great Lakes (NBIC 2012). There is recreational but no commercial vessel traffic to the WPS, so no ballast water discharge is expected at the WPS (USACE 2011a,b). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no literature was found suggesting this species is transported on the external surfaces of boats. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. Current Abundance and Reproductive Capacity

T_0: The European fingernail clam is hermaphroditic and ovoviviparous (Kipp et al. 2012). Eggs are incubated in a brood sac in the parent; embryos are developed and released as miniature adults (Kipp et al. 2012). Adults carry 1–20 embryos (Kipp et al. 2012). In some German ponds, densities of 51,000–76,500/m^2 can occur (Kipp et al. 2012). In Lake Superior, densities can reach 61/m^2, and in the St. Lawrence River. they can reach 500–8,000/m^2 (Kipp et al. 2012). It is listed as common in localized populations (Mackie 1980), but no recent information on its abundance was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None. The European fingernail clam is in the CAWS.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway

T_0: The specific distribution of the European fingernail clam in the Great Lakes is uncertain. The species was first recorded in the Great Lakes in 1924 in Lake Ontario and is now found in all five Great Lakes but is most common in Lake Erie and Lake Ontario (Kipp et al. 2012). It is uncommon in Lake Huron, where it is uncertain whether populations are permanently established (Kipp et al. 2012). The European fingernail clam was documented as established in Lake Michigan in 1980 (Mackie 1980), but no information on its current distribution within Lake Michigan was found. This species has been documented in the North Shore Channel, although its entry point is unknown (Moore et al. 1998).

T_{10}: See T_0. The European fingernail clam may have arrived at the WPS but is not documented. If it has not already arrived at the WPS, given time, the European fingernail clam could move closer to the WPS.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012). The European fingernail clam is found in freshwater lakes and slow-moving rivers (Boycott 1936) but prefers eutrophic, shallow waters 0 to 1.5 m (0 to 4.9 ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77 °F) (Berezina et al. 2007). The species is found at depths of 10 m (32.8 ft) in Lake Michigan but prefers shallow water (Kipp et al. 2012). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining its presence (Ricciardi 2001; Kipp et al. 2012). The species is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012). The species is abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). The shoreline of Lake Michigan is sandy with dense Cladophora beds, which may be suitable for this species (MTRI 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the European fingernail clam near the WPS (Section 2f). The species spreads fastest by human-mediated transport, but there is no commercial vessel traffic to the WPS. Transport on recreational vessels may be possible but has not been documented in the literature as a significant transport mechanism (section 2b). The density and exact location within Lake Michigan of the European fingernail clam is not documented (sections 2c, 2d). The species has been established in Lake Michigan for three decades and has been documented in the North Shore Channel, suggesting it may have arrived at the WPS (section 2a). Therefore, the probability of arrival is high for this time step.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan. However, the European fingernail clam is globally widespread and appears to be able to tolerate a wide range of climatological conditions, suggesting appropriate habitat conditions will continue (section 2f). Therefore, the probability of arrival remains high for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Suitable habitat is documented near the WPS, but the current distribution and densities of the European fingernail clam in Lake Michigan are not documented. The European fingernail clam has been documented in the North Shore Channel, but it is unknown whether it entered through the WPS. Overall, there is no uncertainty associated with the probability of arrival for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). The European fingernail clam has been documented in the CAWS since at least 1989 (Moore et al. 1998), but there are no records of this species below the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). The sluice gate at the WPS prevents vessel movement between Lake Michigan and the North Shore Channel. There is vessel traffic in the CAWS but no commercial vessel traffic in the North Shore Channel. Also, the discharge of ballast water does not typically occur at inland ports within the CAWS (USACE 2011a; NBIC 2012). Consequently, some non-

vessel active or passive dispersal would likely be required for the species to reach the Brandon Road Lock and Dam. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round. There is a sluice gate separating the WPS from Lake Michigan, which is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010), which could transport this species into the North Shore Channel. The Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be significant barriers to passage.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers, shallow waters 0- to 1.5-m (0- to 4.92-ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993; Boycott 1936) with temperatures ranging from 2 to 25°C (35.6 to 77 °F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant, suggesting that the CAWS is suitable habitat. The pathway from Lake Michigan at the WPS to the Brandon Road Lock and Dam is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The European fingernail clam has been found in the North Shore Channel, the Chicago River, and the CSSC (Moore et al. 1998), suggesting habitat is suitable in the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The European fingernail clam is present in the CSSC. This species may continue to spread through the CAWS, and it may have reached the Brandon Road Lock and Dam already. There are no barriers to passage. Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species in the CAWS is not well characterized. The potential for recreational and commercial boat traffic in the North Shore Channel and its potential to transport this species is also not well characterized. The current distribution of this species in the CAWS and its location in relation to the Brandon Road Lock and Dam is uncertain, but it has been found in the CSSC. Therefore, the uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The European fingernail clam has spread from Lake Michigan through much of the CAWS. If current trends continue, this species is more certain to pass downstream of the Brandon Road Lock and Dam over time. Therefore, uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936), preferring shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant. It does not like dirty water, nor does it live in drying ponds. The European fingernail clam does not live in ephemeral pools and streams (Boycott 1936). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining presence (Ricciardi 2001; Kipp et al. 2012). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979), but it can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and emergent wetland

habitat is present downstream of the Brandon Road Lock and Dam (unpublished data from USACE).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse downstream to suitable habitat by drift or potentially by vessel transport.

Evidence for Probability Rating

Suitable habitat for the European fingernail clam is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the European peaclam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
European fingernail clams have been sampled from waters with temperatures ranging from 2 to 25°C (35.6 to 77 °F) (Berezina et al. 2007), conditions that are present in the MRB. This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012).

b. *Type of Mobility/Invasion Speed*
The species appears to have a very slow invasion speed without the aid of human transport. The European fingernail clam is known to climb up plants and walls (Boycott 1936).

c. *Fecundity*
Adults carry 1–20 embryos (Kipp et al. 2012).

d. *History of Invasion Success*
The European fingernail clam was first recorded in the GLB in Lake Ontario in 1924. It has since been recorded in all five Great Lakes, although it is uncommon in Lake Huron.

e. *Human-Mediated Transport through Aquatic Pathways*
   There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The European fingernail clam is a generalist species. The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936) but prefers shallow waters 0 to 1.5 m (0 to 4.9 ft) deep (Holopainen & Penttinen 1993). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but is abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979), but it can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and wetland habitat is found throughout the MRB (unpublished data from USACE).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there are suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5g). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the European fingernail clam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	High	High	High	High	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	- [a]	High	-	High	-	High	

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). It was first recorded in the Great Lakes drainage in 1897 near the mouth of the Genesee River at Lake Ontario and has since spread to all the other Great Lakes (Kipp et al. 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003), although Rothlisberger (2009) stated that this species was introduced by ballast water. The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all the Great Lakes (NBIC 2012). There is commercial and recreational vessel traffic to the CRCW from Lake Michigan (USACE 2011a,b). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no literature was found suggesting this species is transported on the external surfaces of boats. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Current Abundance and Reproductive Capacity*
T_0: The European fingernail clam is hermaphroditic and ovoviviparous (Kipp et al. 2012). Eggs are incubated in a brood sac in the parent; embryos are developed and released as miniature adults (Kipp et al. 2012). Adults carry 1–20 embryos (Kipp et al. 2012). In some German ponds, densities of 51,000–76,500/m^2 can occur (Kipp et al. 2012). In Lake Superior, densities can reach 61/m^2, and in the St. Lawrence River, 500–8,000/m^2 (Kipp et al. 2012). It is listed as common in localized populations (Mackie 1980), but no recent information on its abundance was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The European fingernail clam is in the CAWS.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The specific distribution of the European fingernail clam is uncertain. The species was first recorded in Lake Ontario and is now found in all five Great Lakes but is most common in Lake Erie and Lake Ontario (Kipp et al. 2012). It is uncommon in Lake Huron, where it is uncertain whether populations are permanently established (Kipp et al. 2012). The European fingernail clam was documented as established in Lake Michigan in 1980 (Mackie et al. 1980), but no information on its current distribution within Lake Michigan was found. This species has been documented in the Chicago River inland of the CRCW (Moore et al. 1998). Therefore, it is likely to have arrived at and passed through the CRCW.
T_{10}: The European fingernail clam may be established at the CRCW but is not documented. Given time, the European fingernail clam could move closer to the CRCW, if it has not already arrived.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012). The European fingernail clam is found in freshwater lakes and slow-moving rivers (Boycott 1936), preferring eutrophic, shallow waters 0- to 1.5-m (0- to 4.9-ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The species is found at depths of 10 m (32.8 ft) in Lake Michigan but prefers shallow water (Kipp et al. 2012). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining presence (Ricciardi 2001; Kipp et al. 2012). The species is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). The shoreline of Lake Michigan is sandy with dense Cladophora beds, which may be suitable for this species (MTRI 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the European fingernail clam near the CRCW (section 2f). The species spreads fastest by human-mediated transport (section 2b). The species has been established in Lake Michigan for three decades and has been documented in the Chicago River just inland of the CRCW, suggesting it has arrived at the CRCW (section 2a). Therefore, the probability of arrival is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0

T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan. However, the European fingernail clam is widespread and appears to be able to tolerate a wide range of climatological conditions, suggesting appropriate habitat conditions will continue (section 2f). Therefore, the probability of arrival remains high for this time step.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Suitable habitat is documented near the CRCW, but the current distribution and densities of the European fingernail clam in Lake Michigan are not certain. The European fingernail clam has been documented in the Chicago River and may have entered through the CRCW. Overall, there is no uncertainty associated with the probability of arrival for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). The European fingernail clam has been documented in the CAWS since at least 1989 (Moore et al. 1998). It has spread from Lake Michigan to the Chicago River and the CSSC, but there are no records of this species below the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). There is some commercial vessel traffic between the CRCW and the Brandon Road Lock and Dam (USACE 2011a; NBIC 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Consequently, some non-vessel active or passive dispersal would likely be required to reach the Brandon Road Lock and Dam. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round. The CRCW separates the Chicago River from Lake Michigan (LimnoTech 2010), but the lock is frequently opened. The

Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be significant barriers to passage.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers, shallow waters 0- to 1.5-m (0- to 4.92-ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993; Boycott 1936) with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant, suggesting that the CAWS is suitable habitat. The pathway from Lake Michigan at the CRCW to the Brandon Road Lock and Dam is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The European fingernail clam has been found in the Chicago River and the CSSC (Moore et al. 1998), suggesting habitat is suitable in the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The European fingernail clam is present in the Chicago River and the CSSC. This species may continue to spread through the CAWS if it has not reached the Brandon Road Lock and Dam already. There are no barriers to passage. Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species in the CAWS is not well characterized. The potential for recreational and commercial boat traffic in the CAWS to transport this species is also not well characterized. The current distribution of this species in the CAWS and its location in relation to the Brandon Road Lock Dam is uncertain, but it has been found in the CSSC. Therefore, the uncertainty associated with the probability of passage is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0. The European fingernail clam has spread from Lake Michigan through much of the CAWS. If current trends continue, this species is more certain to pass downstream of the Brandon Road Lock and Dam over time. Therefore uncertainty is medium for this time step.

T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936), preferring shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant. It does not like dirty water, nor does it live in drying ponds. The European fingernail clam does not live in ephemeral pools and streams (Boycott 1936). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining presence (Ricciardi 2001; Kipp et al. 2012). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979), but it can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and emergent wetland habitat is present downstream of the Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse downstream to suitable habitat by drift or potentially by vessel transport.

Evidence for Probability Rating

Suitable habitat for the European fingernail clam is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the European fingernail clam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
European fingernail clams have been sampled from waters with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007), conditions that are present in the MRB. This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012).

b. Type of Mobility/Invasion Speed
The species appears to have a very slow invasion speed without the aid of human transport. The European fingernail clam is known to climb plants and walls (Boycott 1936).

c. Fecundity
Adults carry 1–20 embryos (Kipp et al. 2012).

d. History of Invasion Success
The European fingernail clam was first recorded in the GLB in Lake Ontario in 1924. It has since been recorded in all five Great Lakes, although it is uncommon in Lake Huron. No data on spread rate through rivers were found.

e. Human-Mediated Transport through Aquatic Pathways
There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The European fingernail clam is a generalist species. The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936) but prefers shallow waters 0 to 1.5 m (0 to 4.9 ft) deep (Holopainen & Penttinen 1993). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979), but it can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and wetland habitat is found throughout the MRB.

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the European fingernail clam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 3 (CALUMET HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	High	High	High	High	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). It was first recorded in the Great Lakes drainage in 1897 near the mouth of the Genesee River at Lake Ontario and has since spread to all the other Great Lakes (Kipp et al. 2012).

b. Human-Mediated Transport through Aquatic Pathways
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003), although Rothlisberger (2009) stated that this species was introduced by ballast water. The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all the Great Lakes (NBIC 2012). There is commercial and recreational vessel traffic to Calumet Harbor from Lake Michigan (USACE 2011a,b). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no literature was found suggesting this species is transported on the external surfaces of boats. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. Current Abundance and Reproductive Capacity
T_0: The European fingernail clam is hermaphroditic and ovoviviparous. Eggs are incubated in a brood sac in the parent; embryos are developed and released as miniature adults (Kipp et al. 2012). Adults carry 1–20 embryos (Kipp et al. 2012). In

some German ponds, densities of 51,000–76,500/m^2 can occur (Kipp et al. 2012). In Lake Superior, densities can reach 61/m^2, and in the St. Lawrence River, 500–8,000/m^2 (Kipp et al. 2012). It is listed as common in localized populations (Mackie 1980), but no recent information on its abundance was found.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None. The European fingernail clam is in the CAWS.

T_{10}: None.

T_{25}: None.

T_{50}: None.

Distance from Pathway

T_0: The specific distribution of the European fingernail clam in the Great Lakes is uncertain. The species was first recorded in the Great Lakes in 1924 in Lake Ontario and is now found in all five Great Lakes but is most common in Lake Erie and Lake Ontario (Kipp et al. 2012). It is uncommon in Lake Huron, where it is uncertain whether populations are permanently established (Kipp et al. 2012). The European fingernail clam was documented as established in Lake Michigan in 1980 (Mackie 1980), but no information on its current distribution within Lake Michigan was found. This species has been documented in the Little Calumet River, the CSSC, and the Calumet River between Calumet Harbor and the Little Calumet River (Moore et al. 1998). Therefore, the European fingernail clam may have arrived at and passed through Calumet Harbor.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012). The European fingernail clam is found in freshwater lakes and slow-moving rivers (Boycott 1936) but prefers eutrophic, shallow waters 0 to 1.5 m (0 to 4.9 ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The species is found at depths of 10 m (32.8 ft) in Lake Michigan but does prefer shallow water (Kipp et al. 2012). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining its presence (Ricciardi 2001; Kipp et al. 2012). The species is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, and organic matter and sometimes on gravel (Kipp et al. 2012), but was found to be abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979), but it can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). The

shoreline of Lake Michigan is sandy with dense Cladophora beds (MTRI 2012), which may be suitable for this species.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the European fingernail clam near Calumet Harbor (section 2f). The species spreads fastest by human-mediated transport (section 2b), and there is heavy lake-wide vessel traffic to Calumet Harbor. The species has been established in Lake Michigan for three decades and has been documented in the Calumet River downstream of Calumet Harbor (section 2a). Therefore, the probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan (section 2f). However, the European fingernail clam is globally widespread and appears to be able to tolerate a wide range of climatological conditions, suggesting appropriate habitat conditions will continue (section 2f). Therefore, the probability of arrival remains high for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: Suitable habitat is documented near the Calumet Harbor, but the current distribution and densities of the European fingernail clam in Lake Michigan are not documented. The species appears to have passed through the Calumet Harbor (section 2e). Therefore, there is no uncertainty associated with the probability of arrival for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, does not tolerate desiccation (Kipp et al. 2012). The European fingernail clam has been documented in the CAWS since at least 1989 (Moore et al. 1998). It has spread from Lake Michigan to the Calumet River and the CSSC, but there are no records of this species below the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Although there is little commercial river traffic from Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between the T.J. O'Brien Lock and Dam (which is approximately 8 km (5 mi) south of Calumet Harbor) and the Brandon Road Lock and Dam (USACE 2011a; NBIC 2012). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Consequently, some non-vessel active or passive dispersal would likely be required for the species to reach the Brandon Road Lock and Dam. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round. The T.J. O'Brien Lock and Dam is about 8 km (5 mi) south of the Calumet Harbor (LimnoTech 2010). The Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be significant barriers to passage.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers, shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993; Boycott 1936) with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant. The

European fingernail clam has been found in the Calumet River, the Little Calumet River, and the CSSC (Moore et al. 1998), suggesting habitat is suitable in the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The European fingernail clam is present in the Calumet River, the Little Calumet River, and the CSSC. This species may continue to spread through the CAWS if it has not reached the Brandon Road Lock and Dam already. Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species in the CAWS is not well characterized. The potential for recreational and commercial boat traffic in the CAWS to transport this species is also not well characterized. The current distribution of this species in the CAWS and its location in relation to the Brandon Road Lock and Dam is uncertain, but it has been found in the CSSC. Therefore, the uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The European fingernail clam has spread from Lake Michigan through much of the CAWS. If current trends continue, this species is more certain to pass downstream of the Brandon Road Lock and Dam over time. Therefore, uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936), with a preference for shallow waters 0- to 1.5-m (0- to 4.92-ft) deep (Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant. It does not like dirty water, nor does it live in drying ponds. The European fingernail clam does not live in ephemeral pools and streams (Boycott 1936). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining presence (Ricciardi 2001; Kipp et al. 2012). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be most abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979), but it can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and emergent wetland habitat is present downstream of the Brandon Road Lock and Dam (unpublished data from USACE).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can disperse downstream to suitable habitat by drift or potentially by vessel transport.

Evidence for Probability Rating

Suitable habitat for the European fingernail clam is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the European fingernail clam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   European fingernail clams have been sampled from waters with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007), conditions that are present in the MRB. This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012).

b. *Type of Mobility/Invasion Speed*
   The species appears to have a very slow invasion speed without the aid of human transport. The European fingernail clam is known to climb up plants and walls (Boycott 1936).

c. *Fecundity*
   Adults carry 1–20 embryos (Kipp et al. 2012).

d. *History of Invasion Success*
   The European fingernail clam was first recorded in the GLB in Lake Ontario in 1924. It has since been recorded in all five Great Lakes, although it is uncommon in Lake Huron.

e. *Human-Mediated Transport through Aquatic Pathways*
   There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936) and prefers shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Holopainen & Penttinen 1993). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be most abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and wetland habitat is found throughout the MRB (USACE, unpublished data).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 4a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the European fingernail clam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 4 (INDIANA HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	High	High	High	High	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and

walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 012). It was first recorded in the Great Lakes drainage in 1897 near the mouth of the Genesee River at Lake Ontario and has since spread to all the other Great Lakes (Kipp et al. 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003), although Rothlisberger (2009) stated that this species was introduced by ballast water. The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is heavy commercial vessel traffic to Indiana Harbor from Lake Michigan (USACE 2011a). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no literature was found suggesting this species is transported on the external surfaces of boats. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Current Abundance and Reproductive Capacity*
T_0: The European fingernail clam is hermaphroditic and ovoviviparous (Kipp et al. 2012). Eggs are incubated in a brood sac in the parent; embryos are developed and released as miniature adults (Kipp et al. 2012). Adults carry 1–20 embryos (Kipp et al. 2012). In some German ponds, densities of 51,000–76,500/m^2 can occur (Kipp et al. 2012). In Lake Superior, densities can reach 61/m^2, and in the St. Lawrence River, 500–8000/m^2 (Kipp et al. 2012). It is listed as common in localized populations (Mackie et al. 1980), but no recent information on its abundance was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The European fingernail clam is in the CAWS.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The specific distribution of the European fingernail clam in the Great Lakes is uncertain. The species was first recorded in the Great Lakes in 1924 in Lake Ontario and is now found in all five Great Lakes but is most common in Lake Erie and Lake Ontario (Kipp et al. 2012). It is uncommon in Lake Huron, where it is uncertain whether populations are permanently established (Kipp et al. 2012). The European fingernail clam was documented as established in Lake Michigan in 1980 (Mackie 1980), but no information on its current distribution within Lake Michigan was found. Although this species is present in the CAWS (Moore et al. 1998), it is unknown whether it is present at Indiana Harbor.

T_{10}: The European fingernail clam may be established at Indiana Harbor but is not documented. Given time, the European fingernail clam could move closer to Indiana Harbor, if it has not already arrived.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012). The European fingernail clam is found in freshwater lakes and slow-moving rivers (Boycott 1936), with a preference for eutrophic, shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The species is found at depths of 10 m (32.8 ft) in Lake Michigan but does prefer shallow water (Kipp et al. 2012). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining its presence (Ricciardi 2001; Kipp et al. 2012). The species is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012) but was found to be abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). The shoreline of Lake Michigan is sandy with dense Cladophora beds that may be suitable for this species (MTRI 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the European fingernail clam near Indiana Harbor (section 2f). The species spreads fastest by human-mediated transport (section 2b). The density and exact location within Lake Michigan of the European fingernail clam is not documented (sections 2c, 2d). The species has been established in Lake Michigan for three decades and is present in the CAWS (section 2a). Therefore, the probability of arrival is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0

T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan. However, the European fingernail clam is widespread and appears to be able to tolerate a wide range of climatological conditions, suggesting appropriate habitat conditions will continue (section 2f). Therefore, the probability of arrival remains high for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The European fingernail clam has been in the Great Lakes for more than a century and is in the CAWS. Suitable habitat is documented near Indiana Harbor. Overall, there is no uncertainty associated with the probability of arrival for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). The European fingernail clam has been documented in the CAWS since at least 1989 (Moore et al. 1998). It has spread from Lake Michigan to the Little Calumet River, the Calumet Sag Channel, and the CSSC, but there are no records of this species below the Brandon Road Lock and Dam.

b. Human-Mediated Transport through Aquatic Pathways
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Most commercial vessel traffic to Indiana Harbor is lake-wide, and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River because of its shallow depth. Consequently, some non-vessel active or passive dispersal would likely be required to reach the Brandon Road Lock and Dam. The European fingernail clam is not

considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Existing Physical Human/Natural Barriers*
T_0: The water depth in the CAWS is suitable year-round. There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a barrier, especially under low flows. The Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be significant barriers to passage.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers, shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993; Boycott 1936) with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant, suggesting that the CAWS is suitable habitat. The pathway from Lake Michigan at Indiana Harbor to the Brandon Road Lock and Dam is a slow-moving eutrophic river with a flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). To spread from Indiana Harbor to the Brandon Road Lock and Dam, the European fingernail clam would have to move southwest through the Grand Calumet River to the Calumet Sag Channel. Conditions at Indiana Harbor are highly industrialized. In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Sediments in the Grand Calumet River consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water can flow east or west depending on the water level in Lake Michigan. Therefore, habitat in the Grand Calumet River may be suitable, although no records of the species were found for this section of the CAWS. The European fingernail clam has been found in the Little Calumet River, the Calumet Sag Channel, and the CSSC (Moore et al. 1998), so conditions are assumed to be suitable in these sections of the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The European fingernail clam is present in the CSSC. This species may continue to spread through the CAWS if it has not reached the Brandon Road Lock and Dam already. There are no barriers to passage. The natural rate of spread of this species is not well characterized. Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species in the CAWS is not well characterized. The potential for recreational and commercial boat traffic in the CAWS to transport this species is also not well characterized. The current distribution of this species in the CAWS and its location in relation to the Brandon Road Lock Dam is uncertain, but it has been found in the CSSC. Although the European fingernail clam is found in the CAWS, it is unknown whether it has entered through Indiana Harbor or whether it is found in the Grand Calumet River. Therefore, the uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The European fingernail clam has spread from Lake Michigan through much of the CAWS. If current trends continue, this species is more certain to pass downstream of the Brandon Road Lock and Dam over time. Therefore uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936) with a preference for shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska

& Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant. It does not like dirty water, nor does it live in drying ponds. The European fingernail clam does not live in ephemeral pools and streams (Boycott 1936). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining its presence (Ricciardi 2001; Kipp et al. 2012). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and emergent wetland habitat is present downstream of the Brandon Road Lock and Dam (unpublished data from USACE).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse downstream to suitable habitat by drift or potentially by vessel transport.

Evidence for Probability Rating

Suitable habitat for the European fingernail clam is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the European fingernail clam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
European fingernail clam have been sampled from waters with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007), conditions that are present in the MRB. This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012).

b. *Type of Mobility/Invasion Speed*
The species appears to have a very slow invasion speed without the aid of human transport. The European fingernail clam is known to climb up plants and walls (Boycott 1936).

c. *Fecundity*
Adults carry 1–20 embryos (Kipp et al. 2012).

d. *History of Invasion Success*
The European fingernail clam was first recorded in the GLB in Lake Ontario in 1924. It has since been recorded in all five Great Lakes, although it is uncommon in Lake Huron. No data on spread rate through rivers were found.

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936) and prefers shallow waters 0- to 1.5-m (0- to 4.92-ft) deep (Holopainen & Penttinen 1993). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but is said to be most abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and wetland habitat is found throughout the MRB (unpublished data from USACE).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there are suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the European fingernail clam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	High	High	High	High	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The European fingernail clam is a small, typically sediment-dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). It was first recorded in the Great Lakes drainage in 1897 near the mouth of the Genesee River at Lake Ontario and has since spread to all the other Great Lakes (Kipp et al. 2012).

b. *Human-Mediated Transport through Aquatic Pathways*

The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003), although Rothlisberger (2009) stated that this species was introduced by ballast water. The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all the Great Lakes (NBIC 2012). There is no commercial vessel traffic to the BSBH from Lake Michigan. However, there is heavy commercial traffic adjacent to the adjacent Burns Harbor (USACE 2011a). Bivalves are known to be transported on the surface of boats (Sylvester & MacIsaac 2010), but no literature was found suggesting this species is transported on the external surfaces of boats. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Current Abundance and Reproductive Capacity*

T_0: The European fingernail clam is hermaphroditic and ovoviviparous (Kipp et al. 2012). Eggs are incubated in a brood sac in the parent; embryos are developed and released as miniature adults (Kipp et al. 2012). Adults carry 1–20 embryos (Kipp et al. 2012). In some German ponds, densities of 51,000–76,500/m^2 can occur (Kipp et al. 2012). In Lake Superior, densities can reach 61/m^2, and in the St. Lawrence River, 500–8,000/m^2 (Kipp et al. 2012). It is listed as common in localized populations (Mackie et al. 1980), but no recent information on its abundance was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None. The European fingernail clam is in the CAWS.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*

T_0: The specific distribution of the European fingernail clam in the Great Lakes is uncertain. The species was first recorded in the Great Lakes in 1924 in Lake Ontario and is now found in all five Great Lakes, but is most common in Lake Erie and Lake Ontario (Kipp et al. 2012). The species is uncommon in Lake Huron, where it is uncertain whether populations are permanently established (Kipp et al. 2012). The European fingernail clam was documented as established in Lake Michigan in 1980 (Mackie et al. 1980), but no information on its current distribution was found. Within the CAWS, it has been documented in the Little Calumet River.
T_{10}: See T_0. The European fingernail clam may be established at the BSBH but is not documented. Given time, the European fingernail clam could move closer to the BSBH, if it has not already arrived.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012). The European fingernail clam is found in freshwater lakes and slow-moving rivers (Boycott 1936) but prefers eutrophic, shallow waters 0 to 1.5 m (0 to 4.9 ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The species is found at depths of 10m (32.8 ft) in Lake Michigan but prefers shallow water (Kipp et al. 2012). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining its presence (Ricciardi 2001; Kipp et al. 2012). The species is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be most abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). The shoreline of Lake Michigan is sandy with dense Cladophora beds that may be suitable for this species (MTRI 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Climate change may alter the chemical, physical, and biological conditions in Lake Michigan.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present for the European fingernail clam near the BSBH (section 2f). The species spreads fastest by human-mediated transport (section 2b). Transport on recreational vessels may be possible but has not been documented in the literature as a significant transport mechanism (section 2b). The density and exact location within Lake Michigan of the European fingernail clam are not documented (sections 2c, 2d). The species has been documented in several locations in the CAWS, including the Little Calumet River. Overall, the probability of arrival is high for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future climate change may alter the chemical, physical, and biological conditions in Lake Michigan. However, the European fingernail clam is widespread and appears to be able to tolerate a wide range of climatological conditions, suggesting appropriate habitat conditions will continue (section 2f). Therefore, the probability of arrival remains high for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The European fingernail clam has been in the Great Lakes for more than a century and is in the CAWS. Suitable habitat is documented near the BSBH. Overall, there is no uncertainty associated with the probability of arrival for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The European fingernail clam is a small, typically sediment dwelling invertebrate. Its eggs are incubated in a brood sac and released as miniature adults and therefore have no planktonic life stage (Kipp et al. 2012). The species is known to climb up plants and walls (Boycott 1936); however, it does not tolerate desiccation (Kipp et al. 2012). The European fingernail clam has been documented in the CAWS since at least 1989 (Moore et al. 1998). It has spread from Lake Michigan to the Little Calumet River, the Calumet Sag Channel, and the CSSC, but there are no records of this species below the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
The European fingernail clam was likely introduced in solid ballast, which was used in the early 1900s in ships entering the GLB (Mills et al. 1993; Grigorovich et al. 2003). Most commercial vessel traffic to the BSBH is lake-wide, and there is no commercial vessel traffic to inland ports in the CAWS from the BSBH (NBIC 2012). Consequently, some non-vessel active or passive dispersal would likely be required to reach the Brandon Road Lock and Dam. The European fingernail clam is not considered a fouling species. However, the species can climb and may be able to attach to boat hulls.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth in the CAWS is suitable year-round for the species. The Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be significant barriers to passage.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers, shallow waters 0 to 1.5 m (0 to 4.92 ft) deep (Kipp et al. 2012; Holopainen & Penttinen 1993; Boycott 1936) with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant, suggesting that the CAWS is suitable habitat. The pathway from Lake Michigan at the BSBH to the Brandon Road Lock and Dam is a slow-moving eutrophic river with a flow of 0.05 to 0.27 m/s (0.16 to 0.89 ft/s) (LimnoTech 2010). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012). To spread from the BSBH to the Brandon Road Lock and Dam, the European fingernail clam would have to move from the BSBH southwest through the south branch of the Little Calumet River to the Calumet Sag Channel. The banks of the south branch of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Therefore, habitat in the south branch of the Little Calumet River appears to be suitable, although no records of the species were found. The European fingernail clam has been found in the Little Calumet River, the Calumet Sag Channel, and the CSSC (Moore et al. 1998), so conditions are assumed to be suitable in these sections of the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The European fingernail clam has spread from Lake Michigan to the CSSC. If current trends continue, this species may continue to spread through the CAWS if it has not already reached the Brandon Road Lock and Dam. There are no barriers to passage. Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of this species in the CAWS is not well characterized. The potential for recreational and commercial boat traffic in the CAWS to transport this species is also not well characterized. Although the European fingernail clam is found in the CAWS, it is unknown whether it has entered through the BSBH or whether it is found in the south branch of the Little Calumet River. The current distribution of this species in the CAWS and its location in relation to the Brandon Road Lock and Dam is uncertain, but it has been found in the CSSC. Therefore, the uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The European fingernail clam has spread from Lake Michigan through much of the CAWS. If current trends continue, this species is more certain to pass downstream of the Brandon Road Lock and Dam over time. Therefore, uncertainty is medium for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936), preferring shallow waters 0- to 1.5-m (0- to 4.92-ft) deep (Holopainen & Penttinen 1993) and temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). The species has been found in most kinds of waters, running and stagnant. It does not like dirty water, nor does it live in drying ponds (Boycott 1936). The European fingernail clam does not live in ephemeral pools and streams (Boycott 1936). The species prefers vegetation and hard waters with high magnesium, calcium, and bicarbonate concentrates, which were significant in determining presence (Ricciardi 2001; Kipp et al. 2012). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be most abundant only where there were rich organic sediments (Dussart 1979). The species is

mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and emergent wetland habitat is present downstream of the Brandon Road Lock and Dam (unpublished data from USACE).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can disperse downstream to suitable habitat by drift or potentially by vessel transport.

Evidence for Probability Rating

Suitable habitat for the European fingernail clam is present (section 4a) and accessible (section 4b) in the vicinity of the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for the European fingernail clam has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
European fingernail clams have been sampled from waters with temperatures ranging from 2 to 25°C (35.6 to 77°F) (Berezina et al. 2007), conditions that are present in the MRB. This species is widespread in Europe and Asia, suggesting it has a wide climatological tolerance (Kipp et al. 2012).

b. *Type of Mobility/Invasion Speed*
The species appears to have a very slow invasion speed without the aid of human transport. The European fingernail clam is known to climb up plants and walls (Boycott 1936).

c. *Fecundity*
Adults carry 1–20 embryos (Kipp et al. 2012).

d. *History of Invasion Success*
The European fingernail clam was first recorded in the GLB in Lake Ontario in 1924. It has since been recorded in all five Great Lakes, although it is uncommon in Lake Huron.

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel use through the MRB. The species is associated with solid ballast transport, which is no longer used.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The European fingernail clam is found in eutrophic, freshwater, slow-moving rivers (Boycott 1936) and prefers shallow waters 0- to 1.5-m (0- to 4.9-ft) deep (Holopainen & Penttinen 1993). The European fingernail clam is documented to develop most numerously in habitats characterized by moderate flow velocity (Jurkiewicz-Karnkowska & Zbikowski 2004). It is known to live in sediment and among vegetation (Heinonen et al. 1997) and has been found in shallow ditches with dense vegetation (Watson & Ormerod 2005). The European fingernail clam has been found on sand, mud, silt, organic matter, and sometimes gravel (Kipp et al. 2012), but was found to be most abundant only where there were rich organic sediments (Dussart 1979). The species is mainly a filter feeder (Dussart 1979) but can also deposit feed on diatoms and other types of phytoplankton (Kipp et al. 2012). Suitable littoral, riverine, and wetland habitat is found throughout the MRB (unpublished data from USACE).

Evidence for Probability Rating

The species appears to be a slow invader (section 5b) with a low fecundity (section 5c). However, there is suitable climate and habitat (sections 5a, 5f) contiguously distributed throughout the MRB (section 5f). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for the European fingernail clam are present in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

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E.2.5.3 European Stream Valvata - *Valvata piscinalis*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Medium	Low	Medium	Medium	Medium
P(passage)	Low	Low	Low	Medium	Medium	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Up until the 1980s, spread of *Valvata piscinalis* has been relatively slow in the Great Lakes (Grigorovich et al. 2005). After first being discovered in Lake Ontario in 1898, it dispersed within forty years to Lake Erie and was recorded in the 1990s and the first decade of the 21st century in Superior Bay in Lake Superior (Minnesota), Lake Michigan (Wisconsin), and Oneida Lake in the Lake Ontario watershed (New York State) (Kipp & Benson 2011). Without human-mediated transport, *V. piscinalis* appears to have a

relatively slow rate of natural spread (Grigorovich et al. 2005). *V. piscinalis* is a small snail that moves along the substrate. It lays attached eggs on stable substrate (Kipp & Benson 2011), and the eggs are not transported by currents.

b. Human-Mediated Transport through Aquatic Pathways

Ship traffic is thought to have facilitated the spread of *V. piscinalis* across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). Therefore, spread by boats is a potentially faster mechanism than natural spreading. There is recreational boat traffic between the Great Lakes and WPS, but no commercial traffic (USACE 2011a,b).

c. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Current Abundance and Reproductive Capacity

T_0: *V. piscinalis* has a high fecundity rate: up to 150 eggs at a time (Grigorovich et al. 2005). Surveys do not suggest a high density of *V. piscinalis* in Lake Michigan (Grigorovich et al. 2005), so propagule pressure may be low. The species can have locally high densities but few individuals were discovered near Milwaukee, which is its southernmost occurrence in Lake Michigan (Grigorovich et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: *V. piscinalis* has been recorded in Lake Michigan north of Milwaukee (USGS 2011a).
T_{10}: Based on current trends, *V. piscinalis* could move closer to the WPS by spreading through the suitable habitat along Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: There are low nutrients in Lake Michigan overall, (EPA 2012), but there are higher nutrient areas along the coast from Wisconsin/Michigan to Chicago (Kerfoot et al. 2010). Also, this species is found in oligotrophic waters in its native range (Kipp & Benson 2011). *V. piscinalis* prefers habitats with fine substrates (mud, silt, and sand) (Kipp & Benson 2011), sandy bottoms, and hard ground (Sereflisan et al. 2009); detritus of plant origin or zebra mussel shell fragments are also preferred habitats for the species (Grigorovich et al. 2005). These habitats are found along the coastline of Lake Michigan from Wisconsin to WPS (USGS 2011b). *V. piscinalis* is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into

southern Lake Michigan. It is found in sediments of Superior Harbor, so it can occupy manmade habitat (USGS 2012).
T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *V. piscinalis*. The natural range of *V. piscinalis* in continental Europe includes climatic zones ranging from the arctic to southern arid zones (Grigorovich et al. 2005). Thus, Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step, given the wide environmental tolerance of this species and its generalist habitat preferences.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: *V. piscinalis* is tolerant of a wide range of temperatures (section 2f), so climate should not limit the movement of this species into southern Lake Michigan. Appropriate habitat conditions for *V. piscinalis* are present (sections 2c, 2f) along the shoreline of Lake Michigan. The harbor at the WPS is suitable habitat (section 2f). However, this species appears to spread slowly by natural dispersion, and there is low potential for human-mediated transport (section 2b). In addition, *V. piscinalis* exists at low densities in Lake Michigan and is located over 150 km (93 mi) from the WPS (section 2e). *V. piscinalis* has spread to multiple Great Lakes within a few decades (Kipp & Benson 2011). However, this species spreads fastest by commercial vessel traffic, which does not travel to the WPS. Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. *V. piscinalis* spread to multiple Great Lakes within a few decades (Kipp & Benson 2011). Over 50 years, this species could potentially reach southern Lake Michigan even by natural dispersion alone. Appropriate habitat conditions are expected to be present (sections 2c, 2f) along the shoreline of Lake Michigan even considering impacts on habitat related to future climate change (section 2f). Therefore, the probability of arrival is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There are no surveys in Lake Michigan for this species after Grigorovich et al. (2005), so its current distribution is not documented. The potential for boat hulls or ballast to transport this species to southern Lake Michigan is not well characterized. Recreational boat traffic between Milwaukee (where the species is located) and WPS is also not well characterized. However, this species has not been transported to the WPS, although it has been in the Great Lakes for over 100 years. In addition, there is no commercial vessel traffic (its primary transport mechanism) to the WPS. Therefore, the uncertainty associated with the probability of arrival is low for this time step.
T_{10}: See T_0. The future population trends of *V. piscinalis* are uncertain. The future rate of spread for this species is uncertain. Therefore, the uncertainty associated with the probability of arrival is Medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The effects of future climate change on *V. piscinalis* and habitat suitability in Lake Michigan are uncertain, but not likely to be significant for this species (section 2f). Therefore, the uncertainty associated with the probability of arrival is still medium for this time step.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
V. piscinalis is a small snail that moves along the substrate. Without human-mediated transport, *V. piscinalis* appears to have a relatively slow rate of natural spread (Grigorovich et al. 2005). *V. piscinalis* is a small snail that lays eggs on stable substrate (Kipp & Benson 2011), and the eggs are not typically transported by currents.

b. *Human-Mediated Transport through Aquatic Pathways*
Ship traffic is thought to have facilitated the spread of *V. piscinalis* across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). There is no vessel traffic between Lake Michigan and the CAWS through the WPS (USACE 2011a,b). Commercial vessels do not travel to WPS from Brandon Road Lock and Dam (USACE 2011a), and any recreational traffic is likely to be local.

c. *Existing Physical Human/Natural Barriers*
T_0: *V. piscinalis* is found in depths anywhere from 0.5 to 23 m (1.6 to 75 ft) in the Great Lakes (Kipp & Benson 2011), so water depth is adequate for *V. piscinalis* throughout the CAWS (LimnoTech 2010). A sluice gate prevents vessel traffic beyond the pumping station into the North Shore Channel, so movement in to the North Shore Channel

would be through natural dispersion. Therefore, the sluice gate may act as a temporary barrier**.**

T_{10}: See T_0. No changes in human or natural barriers are expected. The sluice gate is expected to continue to operate under current procedures.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *V. piscinalis* is found in a wide range of substrate types, which are present in the CAWS (mud, silt, and sand) (Kipp & Benson 2011; LimnoTech 2010), and this species can live in canals and ditches (NatureServe 2010). *V. piscinalis* has wide environmental tolerances including temperature and organic pollution (Grigorovich et al. 2005; Mouthon & Daufresne 2006; Sereflisan et al. 2009). Adults mate in sediment and typically lay eggs on aquatic plants (Ducrot et al. 2006) or potentially on stones (Mouthon & Daufresne 2008). The distribution of aquatic macrophytes is very limited in the CAWS (except in the North Shore Channel), but cobble and boulders are relatively common (LimnoTech 2010). Species of the Valvata genus have been found in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Appropriate habitat conditions are present within the CAWS (section 3e). However, *V. piscinalis* appears to spread slowly by natural dispersion, and there is low potential for human-mediated transport from WPS to Brandon Road Lock and Dam (section 3b). Therefore, the probability of passage is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Over 25 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport (once it reaches the Chicago River), floating downstream, or a combination of the two. Therefore, the probability of passage is medium for this time step.

T_{50}: See T_{25}. Overall, the habitat in the CAWS is expected to remain suitable for *V. piscinalis* during this time step, given the wide environmental tolerance of this species and its generalist habitat preferences. Over 50 years, this species may have time to spread from WPS to Brandon Road Lock and Dam using only its natural rate of spread. Therefore, the probability of passage is high for this time step.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: It is known that there is no cargo vessel traffic to WPS from Brandon Road Lock and Dam, so some natural spread may be required for *V. piscinalis* to reach Brandon Road Lock and Dam. The natural rate of spread of this species is not well characterized. Recreational boat traffic in the North Shore Channel and its potential to transport this species are also not well characterized. The natural rate of spread of *V. piscinalis* is not well characterized. Given the distance from the WPS to Brandon Road Lock and Dam and the lack of commercial vessel traffic from the WPS, this species is unlikely to spread to Brandon Road Lock and Dam during the current time step. Therefore, the uncertainty associated with the probability of passage is low for this time step.
T_{10}: See $T_{0.}$ Although 10 years may be enough time to spread to Brandon Road Lock and Dam, the future rate of spread for this species within the CAWS is uncertain. The natural rate of spread of *V. piscinalis* is not well characterized. Therefore, the uncertainty associated with the probability of passage remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
V. piscinalis is tolerant of a wide range of temperatures (Sereflisan et al. 2009), so climate should not limit the movement of this species into the southern MRB. This species is found in a wide range of freshwater habitats including lakes and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, reservoirs, and harbors (Grigorovich et al. 2005; NatureServe 2010; USGS 2011a). These habitats are present in the vicinity of Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam and is accessible by *V. piscinalis*.

Evidence for Probability Rating

Suitable habitat for *V. piscinalis* is present (section 4a) and accessible (section 4b) in the vicinity of Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Climate should not limit the movement of this species into the southern MRB, due to the wide temperature tolerance of this species (section 4a). Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
V. piscinalis is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into the southern MRB.

b. Type of Mobility/Invasion Speed
This is a small snail that appears to spread slowly without the aid of human transport.

c. Fecundity
This species has a high fecundity rate of up to 150 eggs at a time (Grigorovich et al. 2005).

d. History of Invasion Success
V. piscinalis has achieved high densities locally (Grigorovich et al. 2005).

e. Human-Mediated Transport through Aquatic Pathways
The spread of *V. piscinalis* is closely associated with human activity, particularly shipping (Grigorovich et al. 2005), which is common in the main waterways of the MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
V. piscinalis is a generalist with a wide environmental tolerance (Grigorovich et al. 2005) and is generally insensitive to organic pollution (Mouthon & Daufresne 2006). This species is found in a wide range of freshwater habitats including lakes, large rivers, and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, and reservoirs (Grigorovich et al. 2005; NatureServe 2010). These habitats are present throughout the

MRB. This species does best in eutrophic waters (Grigorovich et al. 2005), which are common in the MRB. *V. piscinalis* is capable of spreading by the dense vessel traffic in the MRB (section 5e).

Evidence for Probability Rating

There is suitable climate (section 5a) and habitat contiguously distributed throughout the MRB (section 5f). *V. piscinalis* is a habitat generalist that does well in the eutrophic conditions (section 5f) common in the MRB. Fecundity is high (section 5c). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions *V. piscinalis* have been documented in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	High	Low
P(passage)	Low	High	Medium	High	Medium	Medium	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Medium	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The spread of *Valvata piscinalis* has been relatively slow in the Great Lakes up until the 1980s (Grigorovich et al. 2005). After first being discovered in Lake Ontario in 1898, it dispersed within forty years to Lake Erie and was recorded in the 1990s and the first decade of the 21st century in Superior Bay in Lake Superior (Minnesota), Lake Michigan (Wisconsin), and Oneida Lake in the Lake Ontario watershed (New York State) (Kipp & Benson 2011). *V. piscinalis* is a small snail with attached eggs (Kipp & Benson 2011) that are not transported by currents.

b. *Human-Mediated Transport through Aquatic Pathways*
Ship traffic is thought to have facilitated the spread of *V. piscinalis* across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). Therefore, spread by boats is a potentially faster spread mechanism than natural spreading. There is commercial traffic between the northern Great Lakes and the CRCW (NBIC 2012), as well as significant recreational boat traffic.

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Current Abundance and Reproductive Capacity*
T_0: *V. piscinalis* has high fecundity of up to 150 eggs at a time (Grigorovich et al. 2005). Surveys do not suggest a high density of *V. piscinalis* in Lake Michigan (Grigorovich et al. 2005), so propagule pressure may be low. The species can have locally high densities, but few individuals were discovered near Milwaukee, which is its southernmost occurrence in Lake Michigan (Grigorovich et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: *V. piscinalis* has been recorded in Lake Michigan north of Milwaukee (USGS 2011a).

T_{10}: Based on current trends, *V. piscinalis* could become closer to the CRCW by spreading through the suitable habitat along Lake Michigan or by vessel transport.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The overall low nutrients in Lake Michigan could act as a barrier, although this species is found in oligotrophic water in its native range (Kipp & Benson 2011), and there are higher nutrient areas along coast from Wisconsin/Michigan to Chicago (EPA 2012; Kerfoot et al. 2010). *V. piscinalis* is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into southern Lake Michigan (Grigorovich et al. 2005; Sereflisan et al. 2009). The species prefers areas with fine substrates (mud, silt, and sand) (Kipp & Benson 2011), sandy bottoms, or hard sediment (Sereflisan et al. 2009); the detritus of plants and zebra mussel shell fragments are also preferred habitats for this species (Grigorovich et al. 2005). These habitats are found along the coastline of Lake Michigan from Wisconsin to the CRCW (USGS 2011b). It is found in sediments of Superior Harbor, so it can occupy manmade habitat (USGS 2012).

T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for V. piscinalis. The natural range of *V. piscinalis* in continental Europe includes climatic zones ranging from the arctic to southern arid zones (Grigorovich et al. 2005). Thus, Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step, given the wide environmental tolerance of this species and its generalist habitat preferences.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *V. piscinalis* is tolerant of a wide range of temperatures (section 2f), so climate should not prevent the movement of this species into southern Lake Michigan. Appropriate habitat conditions are present along the shoreline of Lake Michigan (section 2c). The harbor around the CRCW is suitable habitat (section 2f). However, this species appears to spread slowly by natural dispersion (section 2a). This species exists at low densities in Lake Michigan and is located over 150 km (93 mi) from the CRCW (section 2e). Consequently, propagule pressure is likely low (section 2d). There is the potential for human-mediated transport via boats moving between Lake Michigan and the CRCW (section 2b). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0. *V. piscinalis* spread to multiple Great Lakes within a few decades, likely by commercial vessel traffic (Kipp & Benson 2011), which is common between the Great Lakes and the CRCW. Based on current movement trends, this species may be able to reach the CRCW (section 2e). Therefore, the probability of arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. *V. piscinalis* spread to multiple Great Lakes within a few decades (Kipp & Benson 2011), likely by vessel traffic. Vessel traffic between the northern Great Lakes and the CRCW is heavy. Over 50 years, this species could potentially reach southern Lake Michigan by human-mediated transport or through natural dispersion. Appropriate habitat conditions are expected to be present (sections 2c, 2f) along the shoreline of Lake Michigan, even considering impacts on habitat related to climate change (section 2f). Therefore, the probability of arrival is high for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: There are no surveys in Lake Michigan for this species after Grigorovich et al. (2005), so its current distribution is not documented. The natural rate of spread of this species is not well characterized, but reaching the CRCW by natural dispersal during the current time step is not likely. This species has not been transported to the CRCW, although it has been in the Great Lakes for over 100 years. However, the potential for boat hulls or ballast to transport this species to the CRCW is not well characterized. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.
T_{10}: See T_0. The future population trends of *V. piscinalis* are uncertain. With time, *V. piscinalis* has a higher probability of spreading to the CRCW by vessel traffic. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See $T_{10.}$ The effects of future climate change on *V. piscinalis* and habitat suitability in Lake Michigan are uncertain, but are not likely to be significant for this species (section 2f). Given observed spread trends and likely transport mechanisms, this species is more certain to spread to CRCW over time. Therefore, the uncertainty associated with the probability of arrival is low for this time step.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Without human-mediated transport, *V. piscinalis* appears to have a relatively slow rate of natural spread (Grigorovich et al. 2005). *V. piscinalis* is a small snail that lays eggs on stable substrate (Kipp & Benson 2011), and the eggs are not transported by currents.

b. *Human-Mediated Transport through Aquatic Pathways*
Ship traffic is thought to have facilitated the spread of this species across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). There is some vessel traffic between Brandon Road Lock and Dam and the CRCW (USACE 2011a,b; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: *V. piscinalis* are found in depths anywhere from 0.5 to 23 m (1.6 to 75 ft) in the Great Lakes (Kipp & Benson 2011), so water depth is adequate for *V. piscinalis* throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *V. piscinalis* is found in a wide range of substrate types, which are present in the CAWS from the CRCW to Brandon Road Lock and Dam (mud, silt, and sand; Kipp & Benson 2011; LimnoTech 2010), and this species can live in canals and ditches (NatureServe 2010). This species is generally insensitive to organic pollution (Mouthon & Daufresne 2006), which is common in the CAWS (LimnoTech 2010). Adults mate in sediment and typically lay eggs on aquatic plants (Ducrot et al. 2006) or potentially on stones (Mouthon & Daufresne 2008). The distribution of aquatic macrophytes is very limited in the CAWS, but cobble and boulders are relatively common (LimnoTech 2010). Species of the Valvata genus are found in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Appropriate habitat conditions are present within the CAWS, although reproductive habitat may be limited (section 3e). *V. piscinalis* appears to spread slowly by natural

dispersion, and there is a relatively minor potential for human-mediated transport from the CRCW to Brandon Road Lock and Dam (section 3b). Ballast water is typically not discharged at inland ports within the CAWS, but there is the potential for vessel transport by attaching to boat hulls. Overall, the probability of passage is low for this time step.
T_{10}: See T_0. Over10 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport, floating downstream, or a combination of the two, especially given the vessel traffic between the CRCW and Brandon Road Lock and Dam. Therefore, the probability of passage is medium for this time step.
T_{25}: See T_0.
T_{50}: See T_0. Over time, the probability of passage through the CAWS increases. Within 50 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport or natural downstream dispersion. Therefore, the probability of passage is high for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Low

Evidence for Uncertainty Rating

T_0: There is documented vessel traffic between the CRCW and Brandon Road Lock and Dam. However, the potential for boat hulls or ballast to transport this species to Brandon Road Lock and Dam is not well characterized. Therefore, the uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0. Although 25 years may be enough time to spread from CRCW to Brandon Road Lock and Dam, the future rate of spread for this species within the CAWS is uncertain. The natural rate of spread of *V. piscinalis* is not well characterized. Therefore, the uncertainty associated with the probability of passage is medium for this time step.
T_{50}: See T_{25}. The CAWS provides suitable habitat for *V. piscinalis*; therefore, it is more certain to spread through the CAWS over 50 years. Therefore, the uncertainty associated with the probability of passage is low for this time step.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
V. piscinalis is tolerant of a wide range of temperatures (Sereflisan et al. 2009), including those found in waters of the MRB. This species is found in a wide range of freshwater habitats including lakes and streams (Kipp & Benson 2011), littoral habitats, canals,

ditches, reservoirs, and harbors (Grigorovich et al. 2005; NatureServe 2010; USGS 2011a). These habitats are present in the vicinity of the Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam and is accessible by *V. piscinalis*.

Evidence for Probability Rating

Climate should not limit the movement of *V. piscinalis* into the southern MRB due to the wide temperature tolerance of this species (section 4a). Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climate for *V. piscinalis* are documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
V. piscinalis is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
V. piscinalis is a small snail that appears to spread slowly without the aid of human transport.

c. *Fecundity*
The species has high fecundity with up to 150 eggs at a time (Grigorovich et al. 2005).

d. *History of Invasion Success*
Species has achieved high densities locally (Grigorovich et al. 2005).

e. *Human-Mediated Transport through Aquatic Pathways*
V. piscinalis is closely associated with human activity, particularly shipping (Grigorovich et al. 2005), which is common in the main waterways of the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
V. piscinalis is a generalist with a wide environmental tolerance (Grigorovich et al. 2005) and is generally insensitive to organic pollution (Mouthon & Daufresne 2006).
V. piscinalis is found in a wide range of freshwater habitats including lakes, large rivers, and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, and reservoirs (Grigorovich et al. 2005; NatureServe 2010). These habitats are present throughout the MRB. This species does best in eutrophic waters (Grigorovich et al. 2005), which are common in the MRB. *V. piscinalis* is capable of spreading by the dense vessel traffic in the MRB (section 5e).

Evidence for Probability Rating

There is suitable climate (section 5a) and habitat contiguously distributed throughout the MRB (section 5f). *V. piscinalis* is a habitat generalist and does well in the eutrophic conditions (section 5f) common in the MRB. The fecundity of this species is high (section 5c). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *V. piscinalis* have been documented in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	High	Low
P(passage)	Low	High	Medium	High	Medium	Medium	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Medium	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Spread of *Valvata piscinalis* has been relatively slow in the Great Lakes up until the 1980s (Grigorovich et al. 2005). After first being discovered in Lake Ontario in 1898, it dispersed within forty years to Lake Erie and was recorded in the 1990s and the first decade of the 21st century in Superior Bay in Lake Superior (Minnesota), Lake Michigan (Wisconsin), and Oneida Lake in the Lake Ontario watershed (New York State) (Kipp and Benson 2011). *V. piscinalis* is a small snail with attached eggs (Kipp & Benson 2011) that are not transported by currents.

b. *Human-Mediated Transport through Aquatic Pathways*
Ship traffic is thought to have facilitated the spread of this species across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls. Therefore, spread by boats is a potentially faster spread mechanism than natural spreading. There is heavy cargo boat traffic between the upper Great Lakes and Calumet Harbor (NBIC 2012; USACE 2011a).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Current Abundance and Reproductive Capacity*

T_0: *V. piscinalis* has a high fecundity rate, up to 150 eggs at a time (Grigorovich et al. 2005). Surveys do not suggest a high density of *V. piscinalis* in Lake Michigan (Grigorovich et al. 2005), so propagule pressure may be low. The species can have locally high densities but few individuals were discovered near Milwaukee, which is its southernmost occurrence in Lake Michigan (Grigorovich et al. 2005).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: *V. piscinalis* has been recorded in Lake Michigan north of Milwaukee (USGS 2011a).

T_{10}: Based on current trends, *V. piscinalis* could move closer to Calumet Harbor by spreading through the suitable habitat along Lake Michigan or by vessel transport.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Low overall nutrients in Lake Michigan could act as a barrier, although this species is found in oligotrophic water in its native range (Kipp & Benson 2011; Grigorovich et al. 2005; Sereflisan et al. 2009), and there are higher nutrient areas along the coast from Wisconsin/Michigan to Calumet Harbor (EPA 2012; Kerfoot et al. 2010). *V. piscinalis* is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into southern Lake Michigan (Grigorovich et al. 2005; Sereflisan et al. 2009). *V. piscinalis* is found in fine substrates (mud, silt, and sand) (Kipp & Benson 2011), as well as sandy bottoms and hard sediment (Sereflisan et al. 2009). The detritus of plants and zebra mussel shell fragments are preferred habitats for this species (Grigorovich et al. 2005), and these habitats are found along the coastline of Lake Michigan from Wisconsin to Calumet Harbor (USGS 2011b). It is found in sediments of Superior Harbor, so it can occupy manmade habitat (USGS 2012).

T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. Climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *V. piscinalis*. The natural range of *V. piscinalis* in continental Europe includes climatic zones ranging from the arctic to southern arid zones (Grigorovich et al. 2005). Thus, Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step, given the wide environmental tolerance of this species and its generalist habitat preferences.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *V. piscinalis* is tolerant of a wide range of temperatures (section 2f), so climate should not limit the movement of this species into southern Lake Michigan. Calumet Harbor itself would be suitable habitat (section 2f). Appropriate habitat conditions are present along Lake Michigan (sections 2c, 2f). The rate of natural spread is likely low, given its size and life history traits (section 2a), but human-mediated transport is possible (section 2b). However, this species exists at low densities in Lake Michigan and is located over 150 km (93 mi) from the Calumet Harbor (section 2e). Consequently, propagule pressure is likely low (section 2d). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0. *V. piscinalis* spread to multiple Great Lakes within a few decades, likely by commercial vessel traffic (Kipp & Benson 2011), which is common in between the Great Lakes and Calumet Harbor. Based on current movement trends, this species may be able to reach Calumet Harbor (section 2e). Therefore, the future probability of arrival is medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. *V. piscinalis* spread to multiple Great Lakes within a few decades (Kipp & Benson 2011), likely by vessel traffic. Vessel traffic between the upper Great Lakes and Calumet Harbor is heavy. Over 50 years, this species could reach southern Lake Michigan by human-mediated transport or through natural dispersion. Appropriate habitat conditions are expected to be present (sections 2c, 2f) along the shoreline of Lake Michigan, even considering impacts on habitat related to future climate change (section 2f). Therefore, the future probability of arrival is high for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: There are no surveys in Lake Michigan for this species after Grigorovich et al. (2005), so its current distribution is undocumented. The natural rate of spread of this species is not well characterized. Although there is heavy commercial vessel traffic to Calumet Harbor, the potential for boat hulls or ballast to transport this species to Calumet Harbor is not well characterized. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.

T_{10}: See T_0. Recent trends suggest increasingly rapid spread for *V. piscinalis* (section 2a). However, the future population trends and the future rate of spread of *V. piscinalis* are uncertain. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. The effects of future climate change on *V. piscinalis* and habitat suitability in Lake Michigan are uncertain, but they are not likely to be significant for this species (section 2f). Given observed spread trends and likely transport mechanisms, this species is more certain to spread to Calumet Harbor over time. Therefore, the uncertainty associated with the probability of arrival is low for this time step.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Without human-mediated transport, *V. piscinalis* appears to have a relatively slow rate of natural spread (Grigorovich et al. 2005). *V. piscinalis* is a small snail that lays eggs on stable substrate (Kipp & Benson 2011), and the eggs are not transported by currents.

b. Human-Mediated Transport through Aquatic Pathways
Ship traffic is thought to have facilitated the spread of this species across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Although *V. piscinalis* can be transported in ballast water (Kipp et al. 2012), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. Existing Physical Human/Natural Barriers
T_0: *V. piscinalis* are found in depths anywhere from 0.5 to 23 m (1.6 to 75 ft) in the Great Lakes (Kipp & Benson 2011), so water depth is adequate for *V. piscinalis* throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical , Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *V. piscinalis* has wide environmental tolerances including temperature (Grigorovich et al. 2005; Sereflisan et al. 2009). *V. piscinalis* is found in a wide range of substrate types which are present in the CAWS between Calumet Harbor to Brandon Road Lock and Dam (mud, silt, and sand) (Kipp & Benson 2011; LimnoTech 2010), and this species can live in canals and ditches (NatureServe 2010). This species is generally insensitive to organic pollution (Mouthon & Daufresne 2006), which is common in the CAWS (LimnoTech 2010). Adults mate in sediment and typically lay eggs on aquatic plants (Ducrot et al. 2006) or potentially on stones (Mouthon & Daufresne 2008). The distribution of aquatic macrophytes is very limited in the CAWS, but cobble and boulders are relatively common in the Little Calumet River, the Calumet Sag Channel,

and the Chicago Sanitary and Ship Canal (LimnoTech 2010). Species of the Valvata genus have been found in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Appropriate habitat conditions are present within the CAWS for *V. piscinalis* (section 3e), although reproductive habitat may be limited. *V. piscinalis* appears to spread slowly by natural dispersion. *V. piscinalis* is known to spread by vessel traffic (section 3b), and there is the potential for vessels to transport this species from the T.J. O'Brien Lock and Dam to Brandon Road Lock and Dam (section 3b). Ballast water is typically not discharged at inland ports within the CAWS, but there is the potential for vessel transport by attaching to boat hulls. Overall, the probability of passage is low for this time step.
T_{10}: See T_0. Over10 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport, floating downstream, or a combination of the two, especially given the heavy vessel traffic between T.J. O'Brien Lock and Dam and Brandon Road Lock and Dam. Therefore, the probability of passage is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Over time, the probability of passage through the CAWS increases. Within 50 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport or natural downstream dispersion. Therefore, the probability of passage is high for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of *V. piscinalis* is not well characterized. There is documented vessel traffic between the Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is a few miles south of Calumet Harbor. However, the potential for boat hulls or ballast to transport this species to Brandon Road Lock and Dam is not well characterized. Therefore, the uncertainty associated with the probability of passage is high for this time step.
T_{10}: See T_0.

T_{25}: See T_0. Twenty-five years may be enough time for piscinalis to spread to Brandon Road Lock and Dam. The future rate of spread for this species within the CAWS is uncertain. The natural rate of spread of *V. piscinalis* is not well characterized. The uncertainty associated with the probability of passage is medium for this time step.
T_{50}: See T_{25}. The CAWS provides suitable habitat for *V. piscinalis*; therefore, it is more certain to spread through the CAWS over 50 years. Therefore, the uncertainty associated with the probability of passage is low for this time step.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
V. piscinalis is tolerant of a wide range of temperatures (Sereflisan et al. 2009), including those found in waters of the MRB. This species is found in a wide range of freshwater habitats including lakes and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, reservoirs, and harbors (Grigorovich et al. 2005; NatureServe 2010; USGS 2011a). These habitats are present in the vicinity of Brandon Road Lock and Dam.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is found near Brandon Road Lock and Dam and is accessible by *V. piscinalis.*

Evidence for Probability Rating

Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   V. piscinalis is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
   This is a small snail that appears to spread slowly without the aid of human transport.

c. *Fecundity*
   V. piscinalis has high fecundity, laying up to 150 eggs at a time (Grigorovich et al. 2005).

d. *History of Invasion Success*
   This species has achieved locally dense populations in the Great Lakes (Grigorovich et al. 2005).

e. *Human-Mediated Transport through Aquatic Pathways*
   The spread of *V. piscinalis* is closely associated with human activity, particularly shipping (Grigorovich et al. 2005), which is common in the main waterways of the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   V. piscinalis is a generalist with wide environmental tolerances (Grigorovich et al. 2005) and is generally insensitive to organic pollution (Mouthon & Daufresne 2006). This species is found in a wide range of freshwater habitats including lakes, large rivers, and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, and reservoirs (Grigorovich et al. 2005; NatureServe 2010). These habitats are present throughout the MRB. This species does best in eutrophic waters (Grigorovich et al. 2005), which are common in the MRB. *V. piscinalis* is capable of spreading by the dense vessel traffic in the MRB (section 5e).

Evidence for Probability Rating

There is suitable climate (section 5a) and habitat contiguously distributed throughout the MRB (section 5f). *V. piscinalis* is a habitat generalist and does well in the eutrophic conditions (section 5f) common in the MRB. The fecundity of this species is high (section 5c). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *V. piscinalis* have been documented in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	High	Low
P(passage)	Low	Low	Low	Medium	Medium	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The spread of *Valvata piscinalis* has been relatively slow in the Great Lakes up until the 1980s (Grigorovich et al. 2005). After first being discovered in Lake Ontario in 1898, it dispersed within forty years to Lake Erie and was recorded in the 1990s and the first decade of the 21st century in Superior Bay in Lake Superior (Minnesota), Lake Michigan (Wisconsin), and Oneida Lake in the Lake Ontario watershed (New York State) (Kipp & Benson 2011). *V. piscinalis* is a small snail with attached eggs (Kipp & Benson 2011) that are not transported by currents.

b. *Human-Mediated Transport through Aquatic Pathways*
Ship traffic is thought to have facilitated the spread of *V. piscinalis* across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). Therefore, spreading by boats is a potentially faster mechanism than natural spreading. There is considerable cargo boat traffic between the northern Great Lakes and Indiana Harbor (USACE 2011; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Current Abundance and Reproductive Capacity*
T_0: *V. piscinalis* has a high fecundity, laying up to 150 eggs at a time (Grigorovich et al. 2005). Surveys do not suggest a high density of *V. piscinalis* in Lake Michigan (Grigorovich et al. 2005), so propagule pressure may be low. The species can have locally high densities but few individuals were discovered near Milwaukee, which is its southernmost occurrence in Lake Michigan (Grigorovich et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: *V. piscinalis* has been recorded in Lake Michigan north of Milwaukee (USGS 2011a).
T_{10}: Based on current trends, *V. piscinalis* could move closer to Indiana Harbor by spreading through the suitable habitat along Lake Michigan or by vessel transport.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0 Low nutrients in Lake Michigan overall could act as a barrier, although *V. piscinalis* is found in oligotrophic water in its native range (Kipp & Benson 2011; Grigorovich et al. 2005; Sereflisan et al. 2009), and there are higher nutrient areas along the coast from Wisconsin/Michigan to Chicago (EPA 2012; Kerfoot et al. 2010). *V. piscinalis* prefers fine substrates (mud, silt, and sand) (Kipp & Benson 2011), sandy bottoms, and hard ground (Sereflisan et al. 2009); the detritus of plants and zebra mussel shell fragments are preferred habitats (Grigorovich et al. 2005), and these habitats are found along the coastline of Lake Michigan from Wisconsin to the Indiana Harbor (USGS 2011b). *V. piscinalis* is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into southern Lake Michigan (Grigorovich et al. 2005; Sereflisan et al. 2009). It is found in sediments of Superior Harbor, so it can occupy manmade habitat (USGS 2012).
T_{25}: See T_{10}.

T_{50}: See T_{10}. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *V. piscinalis*. The natural range of *V. piscinalis* in continental Europe includes climatic zones ranging from the arctic to southern arid zones (Grigorovich et al. 2005). Thus, Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step, given the wide environmental tolerance of this species and its generalist habitat preferences.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Appropriate habitat conditions for *V. piscinalis* are present along the shoreline of Lake Michigan (sections 2c, 2f). The rate of natural spread is likely low, given its size and life history traits (section 2a), but human-mediated transport is possible (section 2b). However, this species exists at low densities in Lake Michigan and is located over 150 km (93 mi) from the Indiana Harbor (section 2e). Consequently, propagule pressure is likely low (section 2d). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0. *V. piscinalis* is tolerant of a wide range of temperatures (section 2f), so climate should not limit the movement of this species into southern Lake Michigan. Based on current movement trends, this species may be able to reach the Indiana Harbor (section 2e). *V. piscinalis* has spread to multiple Great Lakes within a few decades, likely by commercial vessel traffic (Kipp & Benson 2011), which is common between the Great Lakes and Indiana Harbor. Therefore, the probability of arrival is medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. *V. piscinalis* has spread to multiple Great Lakes within a few decades (Kipp & Benson 2011), likely by vessel traffic. Vessel traffic between the upper Great Lakes and Indiana Harbor is heavy. Over 50 years, this species could likely reach southern Lake Michigan by human-mediated transport or through natural dispersion. Appropriate habitat conditions are expected to be present (sections 2c, 2f) along the shoreline of Lake Michigan, even considering impacts on habitat related to future climate change (section 2f). Therefore, the probability of arrival is high for this time step.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: There are no surveys in Lake Michigan for this species after Grigorovich et al. (2005), so its current distribution is undocumented. The natural rate of spread of this species is not well characterized. The potential for boat hulls or ballast to transport this species to Indiana

Harbor is not well characterized. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.
T_{10}: See T_0. Recent trends suggest increasingly rapid spread for *V. piscinalis* (section 2a). However, the future population trends and the future rate of spread of this species are uncertain. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The effects of future climate change on *V. piscinalis* and habitat suitability in Lake Michigan are uncertain, but they are not likely to be significant for this species (section 2f). Given observed spread trends and likely transport mechanisms, this species is more certain to spread to Indiana Harbor over time. Therefore, the uncertainty associated with the probability of arrival is low for this time step.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Without human-mediated transport, *V. piscinalis* appears to have a relatively slow rate of natural spread. *V. piscinalis* is a small snail that lays eggs on stable substrate (Kipp & Benson 2011), and the eggs are not transported by currents.

b. *Human-Mediated Transport through Aquatic Pathways*
Ship traffic is thought to have facilitated the spread of *V. piscinalis* across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). Most commercial vessel traffic to Indiana Harbor is from the lake, and there is little or no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River due to the shallow depth.

c. *Existing Physical Human/Natural Barriers*
T_0: Water depth is adequate for *V. piscinalis* throughout the CAWS. Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *V. piscinalis* is found in a wide range of substrate types that are present in the CAWS between Indiana Harbor and Brandon Road Lock and Dam (mud, silt, and sand) (Kipp & Benson 2011; LimnoTech 2010), and this species can live in canals and ditches

(NatureServe 2010) in the vicinity of Indiana Harbor. Conditions at the Indiana Harbor are highly industrialized. Sediments consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). In the East Branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments in the Grand Calumet River consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). There is suitable physical habitat in the Grand Calumet River, although sediment toxicity is high. This species is generally insensitive to organic pollution (Mouthon & Daufresne 2006). Adults mate in sediment and typically lay eggs on aquatic plants (Ducrot et al. 2006) or potentially on stones (Mouthon & Daufresne 2008). The distribution of aquatic macrophytes is very limited in the CAWS, but cobble and boulders are relatively common in the Little Calumet River, the Calumet Sag Channel, and the Chicago Sanitary and Ship Canal (Limnotech 2010). Species of the Valvata genus are found in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).

T_{10}: See T_0. The CAWS is expected to remain suitable habitat for *V. piscinalis.*

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Appropriate habitat conditions are present within the CAWS for *V. piscinalis* (section 3e), although reproductive habitat may be limited. *V. piscinalis* appears to spread slowly by natural dispersion, and there is a low potential for vessels to transport this species from Indiana Harbor to inland portions of the CAWS (section 3b). Because of the lack of vessel traffic (section 3b), natural spread through the Grand Calumet River will likely be required for *V. piscinalis* to reach the Little Calumet River and the Calumet-Sag Channel. In addition, there is sheet pile across the Grand Calumet River that may slow the passage of this species. There is heavy vessel traffic between T.J. O'Brien Lock and Dam and Brandon Road Lock and Dam. Ballast water is typically not discharged at inland ports within the CAWS, but there is the potential for vessel transport by attaching to boat hulls. However, this is a benthic species at all life stages, and attachment to boat hulls seems unlikely. Therefore, the probability of passage is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0. Over 25 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport, natural downstream dispersion, or a combination of the two. Therefore, the probability of passage is medium for this time step.

T_{50}: See T_{25}. Over time, the probability of passage through the CAWS increases. Within 50 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport or natural downstream dispersion. Therefore, the probability of passage is high for this time step.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of *V. piscinalis* is not well characterized. The potential for boat hulls or ballast to transport this species to Brandon Road Lock and Dam is not well characterized. Therefore, the uncertainty associated with the probability of passage is medium for this time step.
T_{10}: See T_0. Although 10 years may be enough time to spread to Brandon Road Lock and Dam, the future rate of spread for this species within the CAWS is uncertain. The natural rate of spread of *V. piscinalis* is not well characterized. Therefore, the uncertainty associated with the probability of passage remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
V. piscinalis is tolerant of a wide range of temperatures (Sereflisan et al. 2009), including those found in waters of the MRB. This species is found in a wide range of freshwater habitats including lakes and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, reservoirs, and harbors (Grigorovich et al. 2005; NatureServe 2010; USGS 2011a). These habitats are present in the vicinity of Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam and is accessible by *V. piscinalis*.

Evidence for Probability Rating

Climate should not limit the movement of this species into the southern MRB, due to the wide temperature tolerance of this species (section 4a). Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
V. piscinalis is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into the southern MRB.

b. Type of Mobility/Invasion Speed
This is a small snail that appears to spread slowly without the aid of human transport.

c. Fecundity
V. piscinalis has high fecundity, laying up to 150 eggs at a time (Grigorovich et al. 2005).

d. History of Invasion Success
This species has achieved locally high densities (Grigorovich et al. 2005).

e. Human-Mediated Transport through Aquatic Pathways
The spread of *V. piscinalis* is closely associated with human activity, particularly shipping (Grigorovich et al. 2005), which is common in the main waterways of the MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
V. piscinalis is a generalist with a wide environmental tolerance (Grigorovich et al. 2005) and is generally insensitive to organic pollution (Mouthon & Daufresne 2006). This species is found in a wide range of freshwater habitats including lakes, large rivers, and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, and reservoirs (Grigorovich et al. 2005; NatureServe 2010). These habitats are present throughout the MRB. This species does best in eutrophic waters (Grigorovich et al. 2005), which are common in the MRB. *V. piscinalis* is capable of spreading by the dense vessel traffic in the MRB (section 5e).

Evidence for Probability Rating

There is suitable climate (section 5a) and habitat contiguously distributed throughout the MRB (section 5f). *V. piscinalis* is a habitat generalist and does well in the eutrophic conditions (section 5f) that are common in the MRB. The fecundity of this species is high (section 5c). Therefore, the probability of spread is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *V. piscinalis* have been documented in the MRB. Therefore, the uncertainty associated with the probability of spread is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

RISK ASSESSMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Medium	Medium	Medium	Medium	Medium	High	Low
P(passage)	Low	Low	Low	Medium	Medium	Medium	High	Medium
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low		Low		Medium		High	

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The spread of *Valvata piscinalis* has been relatively slow in the Great Lakes up until the 1980s (Grigorovich et al. 2005). After being discovered in Lake Ontario in 1898, it dispersed within forty years to Lake Erie and was recorded in the 1990s and the first decade of the 21st century in Superior Bay in Lake Superior (Minnesota), Lake Michigan

(Wisconsin), and Oneida Lake in the Lake Ontario watershed (New York State) (Kipp & Benson 2011). *V. piscinalis* is a small snail with attached eggs (Kipp & Benson 2011) that are not transported by currents.

b. *Human-Mediated Transport through Aquatic Pathways*
Ship traffic is thought to have facilitated the spread of *V. piscinalis* across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported by attaching to boat hulls. Therefore, spreading by boats is a potentially faster spread mechanism than natural spreading (USACE 2011a). There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011b). However, there is cargo boat traffic between the upper Great Lakes, Wisconsin (their current southernmost location), and the adjacent Burns Harbor.

c. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Current Abundance and Reproductive Capacity*
T_0: *V. piscinalis* has high fecundity, laying up to 150 eggs at a time (Grigorovich et al. 2005). Surveys do not suggest a high density of *V. piscinalis* in Lake Michigan (Grigorovich et al. 2005), so propagule pressure may be low. The species can have locally high densities but few individuals were discovered near Milwaukee, which is its southernmost occurrence in Lake Michigan (Grigorovich et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: *V. piscinalis* has been recorded in Lake Michigan north of Milwaukee (USGS 2011a).
T_{10}: Based on current trends, *V. piscinalis* could become closer to BSBH by spreading through the suitable habitat along Lake Michigan or by vessel transport.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Low nutrients in Lake Michigan overall could act as a barrier, although *V. piscinalis* is found in oligotrophic water in its native range (Kipp & Benson 2011; Grigorovich et al. 2005; Sereflisan et al. 2009), and there are higher nutrient areas along the coast from Wisconsin/Michigan to Chicago (EPA 2012; Kerfoot et al. 2010). *V. piscinalis* is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into southern Lake Michigan. *V. piscinalis* prefers fine substrates (mud, silt, and sand) (Kipp & Benson 2011), sandy bottoms, and hard ground (Sereflisan et al. 2009); the detritus of plants and zebra mussel shell fragments are also preferred

habitats of the species (Grigorovich et al. 2005). These habitats are found along the coastline of Lake Michigan from Wisconsin to BSBH (USGS 2011b). It is found in sediments of Superior Harbor, so it can occupy manmade habitat (USGS 2012).
T_{10}: See T_0. The habitat of Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Future climate change may alter the physical, chemical, and climatological suitability of the Great Lakes for *V. piscinalis*. The natural range of *V. piscinalis* in continental Europe includes climatic zones ranging from the arctic to southern arid zones (Grigorovich et al. 2005). Thus, Lake Michigan is expected to remain suitable for *V. piscinalis* during this time step, given the wide environmental tolerance of this species and its generalist habitat preferences.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *V. piscinalis* is tolerant of a wide range of temperatures (section 2f), so climate should not limit the movement of this species into southern Lake Michigan. Appropriate habitat conditions for *V. piscinalis* are present along the shoreline of Lake Michigan (sections 2c, 2f). BSBH is suitable habitat (section 2f). The rate of natural spread is likely low, given its size and life history traits (section 2a), but human-mediated transport is possible (section 2b). However, this species exists at low densities in Lake Michigan and is located over 150 km (93 mi) from BSBH (section 2e). Consequently, propagule pressure is likely low (section 2d). Therefore, the probability of arrival is low for this time step.
T_{10}: See T_0. Based on current movement trends, this species may be able to reach the BSBH (section 2e). *V. piscinalis* has spread to multiple Great Lakes within a few decades, likely by commercial vessel traffic (Kipp & Benson 2011), which is common between the Great Lakes and BSBH. Therefore, the future probability of arrival is medium for this time step.
T_{25}: See $T_{10.}$
T_{50}: See T_{25}. *V. piscinalis* has spread to multiple Great Lakes within a few decades (Kipp & Benson 2011) likely by vessel traffic. While there is no commercial traffic to BSBH via the lake, vessel traffic to the adjacent Burns Harbor is heavy. Over 50 years, this species could likely reach southern Lake Michigan by human-mediated transport or through natural dispersion. Appropriate habitat conditions are expected to be present (sections 2c, 2f) along the shoreline of Lake Michigan, even considering impacts on habitat related to future climate change (section 2f). Therefore, the future probability of arrival is high for this time step.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Medium	Low

Evidence for Uncertainty Rating

T_0: There are no surveys in Lake Michigan for this species after Grigorovich et al. (2005), so its current distribution is uncertain. The natural rate of spread of this species is not well characterized. The potential for boat hulls or ballast to transport this species to southern Lake Michigan is not well characterized. However, this species has not been transported to the Wilmette Pumping Station (WPS), although it has been in the Great Lakes for over 100 years. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.
T_{10}: See T_0. Recent trends suggest increasingly rapid spread for *V. piscinalis* (section 2a). However, the future population trends and the future rate of spread for *V. piscinalis* are uncertain. Therefore, the uncertainty associated with the probability of arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The effects of future climate change on *V. piscinalis* and habitat suitability in Lake Michigan are uncertain, but they are not likely to be significant for this species (section 2f). Given observed spread trends and likely transport mechanisms, this species is more certain to spread to Indiana Harbor over time. Therefore, the uncertainty associated with the probability of arrival is low for this time step.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Without human-mediated transport, *V. piscinalis* appears to have a relatively slow rate of natural spread (Grigorovich et al. 2005). *V. piscinalis* is a small snail that lays eggs on stable substrate (Kipp & Benson 2011), and the eggs are not transported by currents.

b. Human-Mediated Transport through Aquatic Pathways
Ship traffic is thought to have facilitated the spread of *V. piscinalis* across the Great Lakes (Grigorovich et al. 2005). Gastropods may be transported via ballast or by attaching to boat hulls (Sylvester & MacIsaac 2010). Vessel traffic to BSBH is via the lake only. The South Branch of the Little Calumet River is shallow and likely has only local nonmotorized vessel traffic, if any (Little Calumet and Grand Calumet River Corridor Technical Advisory Group and Northeastern Illinois Planning Commission 2011). Although *V. piscinalis* could move to Burns Harbor (which does have commercial vessel traffic), there is no commercial vessel from the Burns Harbor to inland ports in the CAWS, and ballast water is not typically discharged at inland ports in the CAWS (NBIC 2012).

c. Existing Physical Human/Natural Barriers
T_0: Water depth is adequate for *V. piscinalis* throughout the CAWS.

T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *V. piscinalis* are found in depths anywhere from 0.5 to 23 m (1.6 to 75 ft) in the Great Lakes (Kipp & Benson 2011), so water depth is adequate for *V. piscinalis* throughout the CAWS (LimnoTech 2010). The banks of the BSBH primarily consist of riprap and vertical walls. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulders (Gallagher et al. 2011). This species can live in canals and ditches (NatureServe 2010). *V. piscinalis* is generally insensitive to organic pollution (Mouthon & Daufresne 2006), which is common in the CAWS (LimnoTech 2010). Adults mate in sediment and typically lay eggs on aquatic plants (Ducrot et al. 2006) or potentially on stones (Mouthon & Daufresne 2008). The Little Calumet River between Burns Ditch and the Cal-Sag Channel is relatively natural and would provide suitable habitat for natural spread. The distribution of aquatic macrophytes is very limited in the CAWS, but cobble and boulders are relatively common in the Little Calumet River, the Cal-Sag Channel, and the Chicago Sanitary and Ship Canal (LimnoTech 2010). Species of the Valvata genus have been found in the CAWS (EA Engineering, Science, and Technology, Inc. 2010).
T_{10}: See T_0. The CAWS is expected to remain suitable habitat for *V. piscinalis*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Appropriate habitat conditions are present within the CAWS for *V. piscinalis*, although reproductive habitat may be limited (section 3e). *V. piscinalis* appears to spread slowly by natural dispersion. Because there is no commercial vessel traffic, there is a low potential for vessels to transport this species from BSBH to inland portions of the CAWS (section 3b). Because of the lack of vessel traffic (section 3b), natural spread over 48 km (30 mi) through the South Branch of the Little Calumet River will likely be required for *V. piscinalis* to reach the Little Calumet River and the Cal-Sag Channel. Once it reaches the Little Calumet, this species could spread downstream to Brandon Road Lock and Dam by natural spread and/or human-mediated transport. However, ballast water is typically not discharged in at inland ports within the CAWS. Given the distance from BSBH to Brandon Road Lock and Dam and the lack of commercial vessel traffic in the south leg of the Little Calumet River, the probability of passage is low for this time step.
T_{10}: See T_{10}.

T_{25}: Over 25 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport, natural downstream dispersion, or a combination of the two. Therefore, the probability of passage is medium for this time step.
T_{50}: See T_{25}. Over time, the probability of passage through the CAWS increases. Within 50 years, this species may have time to reach Brandon Road Lock and Dam by vessel transport or natural downstream dispersion. Therefore, the probability of passage is high for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: The natural rate of spread of *V. piscinalis* is not well characterized. The potential for boat hulls or ballast to transport this species to Brandon Road Lock and Dam is not well characterized. It is known that there is no cargo vessel traffic to BSBH from Brandon Road Lock and Dam, so some natural spread through the South Branch of the Little Calumet River may be required for *V. piscinalis* to reach Brandon Road Lock and Dam. Given the distance from BSBH to Brandon Road Lock and Dam and the lack of commercial vessel traffic in the south leg of the Little Calumet River, the uncertainty associated with the probability of passage is low for this time step.
T_{10}: See $T_{0.}$ Although 10 years may be enough time to spread to Brandon Road Lock and Dam, the future rate of spread for *V. piscinalis* within the CAWS is uncertain. The natural rate of spread of *V. piscinalis* is not well characterized. Therefore, the uncertainty associated with the probability of passage remains medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
V. piscinalis is tolerant of a wide range of temperatures (Sereflisan et al. 2009), including those found in waters of the MRB. This species is found in a wide range of freshwater habitats including lakes and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, reservoirs, and harbors (Grigorovich et al. 2005; NatureServe 2010; USGS 2011a). These habitats are present in the vicinity of Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is found near Brandon Road Lock and Dam and is accessible by *V. piscinalis*.

Evidence for Probability Rating

Climate should not limit the movement of this species into the southern MRB, due to the wide temperature tolerance of this species (section 4a). Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat for *V. piscinalis* has been documented near the Brandon Road Lock and Dam. Therefore, the uncertainty associated with the probability of colonization is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   V. piscinalis is tolerant of a wide range of temperatures, so climate should not limit the movement of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
   This is a small snail that appears to spread slowly without the aid of human transport.

c. *Fecundity*
   The species has high fecundity, laying up to 150 eggs at a time (Grigorovich et al. 2005).

d. *History of Invasion Success*
   V. piscinalis has achieved high densities locally (Grigorovich et al. 2005).

e. *Human-Mediated Transport through Aquatic Pathways*
   V. piscinalis is closely associated with human activity, particularly shipping (Grigorovich et al. 2005), which is common in the main waterways of the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   V. piscinalis is a generalist with a wide environmental tolerance (Grigorovich et al. 2005) and is generally insensitive to organic pollution (Mouthon & Daufresne 2006). This

species is found in a wide range of freshwater habitats including lakes, large rivers, and streams (Kipp & Benson 2011), littoral habitats, canals, ditches, and reservoirs (Grigorovich et al. 2005; NatureServe 2010). These habitats are present throughout the MRB. This species does best in eutrophic waters (Grigorovich et al. 2005), which are common in the MRB. *V. piscinalis* is capable of spreading by the dense vessel traffic in the MRB (section 5e).

Evidence for Probability Rating

There is suitable climate (section 5a) and habitat contiguously distributed throughout the MRB (section 5f). *V. piscinalis* is a habitat generalist and does well in the eutrophic conditions common in the MRB. The fecundity of this species is high (section 5c).

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and climatological conditions for *V. piscinalis* have been documented in the MRB. Therefore, the probability of spread is high. Thus, the uncertainty associated with the probability of spread is low.

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E.2.6 Crustaceans

E.2.6.1 Fishhook Waterflea - *Cercopagis pengoi*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Medium	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching, after which they are planktonic. The fishhook waterflea has a very rapid invasion speed. It spread to three Great Lakes within 2 years and inland to six of New York's Finger Lakes within a year (Sea Grant New York 2012). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs and a "sticky" caudal process, viability during unfavorable periods, and rapid dispersal all promote rapid population growth.

b. *Human-Mediated Transport through Aquatic Pathways*
The species' invasion of Lake Michigan during 1999 almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. Ships that discharge cargo at a Lake Ontario port will often load lake water as ballast prior to up-bound movement on the Great Lakes. This water is subsequently discharged at the terminal port-of-call and replaced with cargo for the out-bound voyage. WPS is not a port, therefore vessels will not release ballast water at this pathway (USACE 2011a,b). Local dispersal mechanisms potentially include small boat traffic (Makarewicz et al. 2001). This species could be transported to WPS by recreational vessel traffic to Wilmette Harbor.

c. *Current Abundance and Reproductive Capacity*
T_0: Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Following sexual reproduction, sexual females produce between 1 and 4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010). The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012). Resting eggs are resistant to desiccation, freeze-drying and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012). Resting eggs can hatch regardless of whether the carrier female is alive or dead (Benson et al. 2012). In southern Lake Michigan, densities can reach >100 per m^2 during the late summer peak (Charlebois et al. 2001; Cavaletto et al. 2010; Witt et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None, the species is close to or at the WPS pathway entrance (Benson et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The fishhook waterflea was established in Lake Michigan, north of Chicago, Illinois in 1999 (Benson et al. 2012). The exact location and distance from WPS is uncertain, but this species may be at WPS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Suitable habitats include estuarine habitats, lakes, marine habitats, water courses, and wetlands (NBII & ISSG 2010). Location may be variable: some studies found the species at higher densities in central regions of lakes compared to coastal areas (Ojaveer et al. 2001). The species is more likely to invade clear, large lakes (Muirhead et al. 2011). In Lake Michigan, *Cercopagis* is confined largely to nearshore waters (Pichlova-Ptacnikova & Vanderploeg 2009). The species does prefer to inhabit pelagic zones (Crosier & Molloy). The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010), studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The majority of individuals were found within the warm uppermost 20 m (65.6 ft) water layer during both day and night (Ojaveer et al. 2001). Less than 3% of the population occurred at depths greater than 40 m (131 ft) (Ojaveer et al. 2001).

T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future that would affect the arrival of this species.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is established very close to the WPS pathway entrance (section 2e). Human-mediated transport via ballast water is likely not needed for the species to arrive at the pathway (section 2b). Suitable habitat is present (section 2d). Given its time in southern Lake Michigan, this species may be at the pathway entrance. Therefore the probability of arrival is high.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The fishhook waterflea has been documented to be close to the pathway entrance and may drift to the entrance of WPS via current or attachment to recreational vessels. Therefore, the uncertainty of the probability of arrival is considered to be low.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching, after which they are planktonic (NBII & ISSG 2010). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs and a "sticky" caudal process, viability during unfavorable periods, and rapid dispersal all promote rapid population growth. However, although this species was first recorded in southern Lake Michigan in 1999, it has not been recorded in the Illinois River or the CAWS. No recent zooplankton surveys were found for these waterways; therefore, the species may be present but undetected. Once it enters the North Shore Channel, the fishhook waterflea could move toward Brandon Road Lock and Dam with the natural downstream flow.

b. *Human-Mediated Transport through Aquatic Pathways*
The invasion of Lake Michigan by the species in 1999 almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012) and there is no commercial vessel traffic in the North Shore Channel. It is not possible for any vessel to move from Wilmette Harbor to the North Shore Chanel because the WPS separates Lake Michigan from the North Shore Channel. Local dispersal mechanisms for the fishhook waterflea potentially include small boat traffic (Makarewicz et al. 2001). The fishhook waterflea was found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport is possible through the portions of the CAWS with vessel traffic.

c. *Existing Physical Human/Natural Barriers*
T_0: There is a sluice gate separating WPS from Lake Michigan which is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010), which could transport this species into the North Shore Channel. In lake studies, fishhook waterfleas were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundances of fishhook waterflea than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and depth is typically around 5 m (16.4 ft)

(LimnoTech 2010). Surface water is present all year-round and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected. The sluice gate is expected to continue to operate under current procedures.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species has successfully invaded the Rhine River (Cristescu et al. 2001). The low current velocity in the CAWS may be favorable because it is typically a lake species. The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 nephelometric turbidity units (NTU) (Muirhead et al. 2011). The CAWS is turbid (LimnoTech 2010). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with a DO range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011). Annual mean DO in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2010).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality in the CAWS may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dispersal by ballast water is unlikely within the CAWS, although transport on boat hulls is possible (section 3b). Natural downstream dispersal would likely be required in the North Shore Chanel (section 3b). The fishhook waterflea is typically found in lakes, although it has invaded rivers (section 3d). Depth in the CAWS may be shallower than this species prefers (section 3d). Suitable temperature is present for the fishhook waterflea in the CAWS (section 3d). The CAWS is a turbid water system, the fishhook waterflea is likely to invade only low-turbidity water systems (section 3d). This species was first recorded in southern Lake Michigan in 1999 and has not been recorded in the Illinois River (section 3a). Therefore its probability of passage for this time step is low.
T_{10}: See T_0.
T_{25}: See T_0. Given time to disperse naturally or by vessel traffic, this species is more likely to pass through the CAWS. Therefore its probability of passage for this time step is medium.

T_{50}: See T_{25}. The probability of passage is likely to increase with time. The fishhook waterflea has been documented to invade rivers. Therefore its probability of passage for this time step is high.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The depth and water quality suitability of the CAWS is uncertain (section 3d). Fishhook waterflea is a lake species so its potential to exist in canals is uncertain. There is no documentation of the speed of natural dispersal of the fishhook waterflea. The probability and speed of vessel transport is not well documented. Although the potential for passage exists, it is uncertain why this species has not been recorded in the Illinois River despite being in southern Lake Michigan since 1999. Therefore, the uncertainty associated with passage during this time step is considered to be medium.
T_{10}: See T_0.
T_{25}: See T_0. The habitat suitability of the CAWS remains uncertain. However, this species has been documented to move through canals, and this species is more certain to pass through the CAWS in 25 years compared to the previous time step. Water quality improvements may also promote the passage of this species, although this is uncertain. Overall, the uncertainty associated with passage during this time step is considered to be low.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species has successfully invaded the Rhine River (Cristescu et al. 2001). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via ballast water discharge or hull fouling on commercial vessels (Sylvester & MacIsaac 2010).

Evidence for Probability Rating

Suitable habitat is present for the fishhook waterflea below Brandon Road Lock and Dam. The fishhook waterflea may reach suitable habitat by natural dispersal or human-mediated transport. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

This species has been documented to invade rivers (section 4a); therefore, the uncertainty of colonizing the MRB is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010); studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The fishhook waterflea is native to the Black, Caspian, Azov, and Aral seas of South Eastern Europe and Asia. Based on its native distribution, the climate of the MRB is expected to be suitable for this species.

b. *Type of Mobility/Invasion Speed*
As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, viability during unfavorable periods and rapid dispersal all promote rapid population growth and subsequent rapid invasion of new habitats.

c. *Fecundity*
Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Sexual females produce between 1 and 4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010) The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012); resting eggs are

resistant to desiccation, freeze-drying and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012).

d. *History of Invasion Success*
The fishhook waterflea spread to three Great Lakes within 2 years and inland to six of New York's Finger Lakes within a year (NBII & ISSG 2010).

e. *Human-Mediated Transport through Aquatic Pathways*
This species may be spread via ballast water or hull fouling on commercial vessels (Sylvester & MacIsaac 2010). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Fishhook waterflea is a generalist species. The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species has successfully invaded the Dnieper, Don, and Rhine Rivers, particularly the reservoirs associated with these systems (MacIsaac et al. 1999; Cristescu et al. 2001). There are multiple reservoirs in the MRB. Individuals were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundance than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with DO range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011).

Evidence for Probability Rating

Suitable habitat is present and accessible for the fishhook waterflea, which has a high invasion speed (sections 5a, 5b, 5d, 5f). Natural species dispersal coupled with human-mediated dispersal via potential ballast water discharge may assist the species in spreading throughout the MRB giving the species a high probability of spread.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and transport mechanisms have been documented. Therefore, the species has a low uncertainty of spreading through the MRB.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Medium	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching, after which they are planktonic. The fishhook waterflea has a very rapid invasion speed. It spread to three Great Lakes within two years and inland to six of New York's Finger Lakes within a year (Sea Grant New York 2012). As Makarewicz et al. (1999) point out, asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal

process, viability during unfavorable periods, and rapid dispersal promote rapid population growth.

b. *Human-Mediated Transport through Aquatic Pathways*
The species' invasion of Lake Michigan during 1999 almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. Ships that discharge cargo at a Lake Ontario port will often load lake water as ballast prior to up-bound movement on the Great Lakes. This water is subsequently discharged at the terminal port of call and replaced with cargo for the out-bound voyage. There is commercial and recreational vessel traffic to the CRCW from the Great Lakes (USACE 2011a,b) and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012). The fishhook waterflea was also found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport may be possible. Local dispersal mechanisms potentially include small boat traffic (Makarewicz et al. 2001).

c. *Current Abundance and Reproductive Capacity*
T_0: Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Following sexual reproduction, sexual females produce between 1 and 4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010). The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012). Resting eggs are resistant to desiccation, freeze-drying, and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012). Resting eggs can hatch regardless of whether the carrier female is alive or dead (Benson et al. 2012). In southern Lake Michigan, densities may reach more than 100 per m^2 during the late summer peak (Charlebois et al. 2001; Cavaletto et al. 2010; Witt et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None, the species is close to or at the CRCW pathway entrance (Benson et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The fishhook waterflea was established in Lake Michigan, north of Chicago, Illinois in 1999 (Benson et al. 2012). The exact location and distance from the CRCW is uncertain, but this species may be at CRCW.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Suitable habitats include estuarine habitats, lakes, marine habitats, water courses, and wetlands (NBII & ISSG 2010). Locations may be variable: some studies found the species at higher densities in central regions of lakes compared to coastal areas (Ojaveer et al. 2001); however, this species is more likely to invade clear, large lakes (Muirhead et al. 2011). In Lake Michigan, Cercopagis is confined largely to nearshore waters (Pichlova-Ptacnikova & Vanderploeg 2009). The species prefers to inhabit pelagic zones (Crosier & Molloy). The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The majority of individuals were found within the warm uppermost 20 m (65.6 ft) water layer during both day and night (Ojaveer et al. 2001). Less than 3% of the population occurred at depths greater than 40 m (131 ft) (Ojaveer et al. 2001).

T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future that would affect the arrival of this species.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is established very close to the CRCW pathway entrance. Human mediated transport via ballast water is likely not needed for the species to arrive at the pathway (section 2b). Suitable habitat is present (section 2d). Given its time in southern Lake Michigan, this species may be at the pathway entrance. Therefore, the probability of arrival is high.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The fishhook waterflea has been documented to be close to the pathway entrance and may drift to the entrance of CRCW via current or via vessel mediated transport. Therefore, the uncertainty of the probability of arrival is considered to be low.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching, after which they are planktonic (NBII & ISSG 2010). As Makarewicz et al. (1999) point out; asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, as well as viability during unfavorable periods, and rapid dispersal rates promote rapid population growth. However, although this species was first recorded in southern Lake Michigan in 1999, it has not been recorded in the Illinois River or the CAWS. No recent zooplankton surveys were found for these waterways; therefore, the species may be present but undetected. Once it enters the Chicago River, the fishhook waterflea could move toward Brandon Road Lock and Dam with the natural downstream flow.

b. *Human-Mediated Transport through Aquatic Pathways*
The species' invasion of Lake Michigan during 1999 almost certainly resulted from movement of contaminated Lake Ontario ballast water by commercial vessels. There is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012) although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Local dispersal mechanisms for fishhook waterfleas potentially include small boat traffic (Makarewicz et al. 2001). The fishhook waterflea was found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport is possible through portions of the CAWS with vessel traffic.

c. *Existing Physical Human/Natural Barriers*
T_0: In lake studies, fishhook waterfleas were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundances of fishhook waterflea than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). Surface water is present all year-round and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The fishhook waterflea appears to prefer lentic systems, but has also established in rivers (Cristescu et al. 2001); the species has successfully invaded the Rhine River (Cristescu et al. 2001). Low current velocity in the CAWS may be favorable because it is typically a lake species. The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). The CAWS is turbid (LimnoTech 2010). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with dissolved oxygen (DO) range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011). Annual mean DO in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2011).

T_{10}: See T_0.

T_{25}: See T_0. Future water quality in the CAWS may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dispersal by human-mediated transport via ballast water is unlikely within the CAWS, although transport on boats is possible (section 3b). The fishhook waterflea is typically found in lakes, although it has invaded rivers (section 3d). Depth in the CAWS may be shallower than this species prefers (section 3d). Suitable temperature is present for the fishhook waterflea in the CAWS (section 3d). The CAWS is a turbid water system, the fishhook waterflea is likely to invade only low-turbidity water systems (section 3d). This species was first recorded in southern Lake Michigan in 1999 and has not been recorded in the Illinois River (section 3a). Therefore its probability of passage for this time step is low.

T_{10}: See T_0.

T_{25}: See T_0. Given time to disperse naturally or by vessel traffic, this species is more likely to pass through the CAWS. Therefore its probability of passage for this time step is medium.

T_{50}: See T_{25}. The probability of passage is likely to increase with time. The fishhook waterflea has been documented to invade rivers. Therefore, its probability of passage for this time step is high.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The depth and water quality suitability of the CAWS is uncertain (section 3d). Fish-hook water flea is a lake species, so its potential to exist in canals is uncertain. There is no documentation of the speed of natural dispersal of the fishhook waterflea. The probability and speed of vessel transport is not well documented. Although the potential for passage exists, it is uncertain why this species has not been recorded in the Illinois River despite being in southern Lake Michigan since 1999. Therefore, the uncertainty associated with passage during this time step is considered to be medium.
T_{10}: See T_0.
T_{25}: See T_0. The habitat suitability of the CAWS remains uncertain. However, this species has been documented to move through canals, and this species is more certain to pass through the CAWS in 25 years compared to the previous time step. Water quality improvements may also promote the passage of this species, although this is uncertain. Overall, the uncertainty associated with passage during this time step is considered to be low.
T_{50}: See T_{25}.

5. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The fishhook waterflea appears to prefer lentic systems, but has also established in rivers (Cristescu et al. 2001); the species has successfully invaded the Rhine River (Cristescu et al. 2001). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse downstream with the current to suitable habitat or it can use human-mediated transport potential ballast water discharge or hull fouling on commercial vessels (Sylvester & MacIsaac 2010).

Evidence for Probability Rating

Suitable habitat is present for the fishhook waterflea below Brandon Road Lock and Dam. The fishhook waterflea may reach suitable habitat by natural dispersal or human-mediated transport. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

This species has been documented to invade rivers (section 4a); therefore, the uncertainty of colonizing the MRB is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The fishhook waterflea is native to the Black, Caspian, Azov, and Aral seas of southeastern Europe and Asia. Based on its native distribution, the climate of the MRB is expected to be suitable for this species.

b. Type of Mobility/Invasion Speed
As Makarewicz et al. (2001) point out; asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, viability during unfavorable periods, and rapid dispersal rates all promote rapid population growth and subsequent rapid invasion of new habitats.

c. Fecundity
Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Sexual females produce between 1 and 4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010). The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012); resting eggs are resistant to desiccation, freeze-drying, and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012).

d. History of Invasion Success
The fishhook waterflea spread to three Great Lakes within two years and inland to six of New York's Finger Lakes within a year (NBII & ISSG 2010).

e. *Human-Mediated Transport through Aquatic Pathways*
Fish-hook water fleas can be transported via ballast water or hull fouling on commercial vessels (Sylvester & MacIsaac 2010). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This is a generalist species. The fishhook waterflea appears to prefer lentic systems, but has also established in rivers (Cristescu et al. 2001); the species successfully invaded the Dnieper, Don, and Rhine Rivers particularly in reservoirs associated with these systems (MacIsaac et al. 1999; Cristescu et al. 2001). There are multiple reservoirs in the MRB. Individuals were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundance than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The fishhook waterflea is likely to invade low-turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with DO range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011).

Evidence for Probability Rating

Suitable habitat is present and accessible for the fishhook waterflea, which has a high invasion speed (sections 5a, 5b, 5d, 5f). Natural species dispersal coupled with human-mediated dispersal via potential ballast water discharge may assist the species in spreading throughout the MRB giving the species a high-spread probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and transport mechanisms have been documented. Therefore, the species has a low uncertainty of spreading through the MRB.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Medium	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching, after which they are planktonic. The fishhook waterflea has a very rapid invasion speed. It spread to three Great Lakes within 2 years and inland to six of New York's Finger Lakes within a year (Sea Grant New York 2012). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, viability during unfavorable periods and rapid dispersal promote rapid population growth.

b. *Human-Mediated Transport through Aquatic Pathways*
The 1999 invasion of Lake Michigan by the species almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. Ships that discharge cargo at a Lake Ontario port will often load lake water as ballast prior to up-bound movement on the Great Lakes. This water is subsequently discharged at the terminal port-of-call and replaced with cargo for the out-bound voyage. There is heavy commercial vessel traffic to the Calumet Harbor from Lake Michigan (USACE 2011a). Many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012). The fish-hook water flea was also found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport may be possible. Local dispersal mechanisms potentially include small boat traffic (Makarewicz et al. 2001).

c. *Current Abundance and Reproductive Capacity*
T_0: Female fish-hook water fleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Following sexual reproduction sexual females produce 1–4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010). The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012). Resting eggs are resistant to desiccation, freeze-drying and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012). Resting eggs can hatch regardless of whether the carrier female is alive or dead (Benson et al. 2012). In southern Lake Michigan, densities can reach >100 per m^2 during the late summer peak (Charlebois et al. 2001; Cavaletto et al. 2010; Witt et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None, the species is close to or at Calumet Harbor pathway entrance (Benson et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The fishhook waterflea was established in Lake Michigan, north of Chicago, Illinois in 1999 (Benson et al. 2012). The exact location and distance from Calumet Harbor is uncertain, but this species may be at Calumet Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitats include estuarine habitats, lakes, marine habitats, water courses, wetlands (NBII & ISSG 2010). Location for this species is variable: some studies found

the species at higher densities in central regions of lakes compared to coastal areas (Ojaveer et al. 2001); however, the fishhook waterflea is more likely to invade clear, large lakes (Muirhead et al. 2011). In Lake Michigan, Cercopagis is confined largely to nearshore waters (Pichlova-Ptacnikova & Vanderploeg 2009). The species prefers to inhabit pelagic zones (Crosier & Molloy). The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The majority of individuals were found within the warm uppermost 20 m (65.6ft) water layer during both day and night (Ojaveer et al. 2001). Less than 3% of the population occurred at depths greater than 40 m (131 ft) (Ojaveer et al. 2001).
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future that would affect the arrival of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is established very close to the Calumet Harbor pathway entrance. Human mediated transport via ballast water is likely not needed for the species to arrive at the pathway (section 2b). Suitable habitat is present (section 2d). Given its time in southern Lake Michigan, this species may be at the pathway entrance. Therefore, the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The fishhook waterflea has been documented to be close to the pathway entrance and may drift to the entrance of Calumet Harbor pathway via current or via vessel mediated transport. Given its time in southern Lake Michigan, this species may be at the pathway entrance. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching after which they are planktonic (NBII & ISSG 2010). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, viability during unfavorable periods and rapid dispersal promote rapid population growth. However, although this species was first recorded in southern Lake Michigan in 1999, it has not been recorded in the Illinois River or the CAWS. No recent zooplankton surveys were found for these waterways; therefore, the species may be present but undetected. Once it enters Calumet Harbor, the fishhook waterflea could move toward Brandon Road Lock and Dam with the natural downstream flow.

b. *Human-Mediated Transport through Aquatic Pathways*
The species' invasion of Lake Michigan in 1999 almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. Although there is little commercial river traffic through Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Local dispersal mechanisms for the fishhook waterflea potentially include small boat traffic (Makarewicz et al. 2001). The fishhook waterflea was found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport is possible through portions of the CAWS with vessel traffic.

c. *Existing Physical Human/Natural Barriers*
T_0: In lake studies, fishhook waterfleas were found mainly down to a depth of 20 m (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8ft) stations had significantly lower abundances of fishhook waterflea than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). Surface water is present all year-round and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The fishhook waterflea appears to prefer lentic systems, but has also established in rivers (Cristescu et al. 2001); the species successfully invaded the Rhine River (Cristescu et al. 2001). The low current velocity in the CAWS may be favorable because it is typically a lake species. The preferred temperature range for the fishhook waterflea is 16–26 °C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). The CAWS is turbid (LimnoTech 2010). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with dissolved oxygen (DO) range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011). Annual mean dissolved oxygen in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2011).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality in the CAWS may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Dispersal by human-mediated transport via ballast water is unlikely within the CAWS, although transport on boats is possible (section 3b). The fishhook waterflea is typically found in lakes, although it has invaded rivers (section 3d). Depth in the CAWS may be shallower than this species prefers (section 3d). The CAWS is a turbid water system, the fishhook waterflea is likely to invade only low turbidity water systems (section 3d). This species was first recorded in southern Lake Michigan in 1999 and has not been recorded in the Illinois River (section 3a). Therefore its probability of passage for this time step is low.
T_{10}: See T_0.
T_{25}: See T_0. Given time to disperse naturally or by vessel traffic this species is more likely to pass through the CAWS. Therefore its probability of passage for this time step is medium.
T_{50}: See T_{25}. The probability of passage is likely to increase with time. The fishhook waterflea has been documented to invade rivers. Therefore its probability of passage for this time step is high.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The depth and water quality suitability of the CAWS is uncertain (section 3d). Fishhook waterflea is a lake species, so its potential to exist in canals is uncertain. There is no documentation of the speed of natural dispersal of the fishhook waterflea. The probability and speed of vessel transport is not well documented. Although the potential for passage exists, it is uncertain why this species has not been recorded in the Illinois River despite being in southern Lake Michigan since 1999 (section 3a). Therefore, the uncertainty associated with passage during this time step is considered to be medium.
T_{10}: See T_0.
T_{25}: See T_0. The habitat suitability of the CAWS remains uncertain. However, this species has been documented to move through canals, and this species is more certain to pass through the CAWS in 25 years compared to the previous time step Water quality improvements may also promote the passage of this species, although this is uncertain. Overall, the uncertainty associated with passage during this time step is considered to be low.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species successfully invaded the Rhine River (Cristescu et al. 2001). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport through potential ballast water discharge or hull fouling on commercial vessels (Sylvester & MacIsaac 2010).

Evidence for Probability Rating

Suitable habitat is present for the fishhook waterflea below Brandon Road Lock and Dam. The fishhook waterflea may reach suitable habitat by natural dispersal or human-mediated transport. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

This species has been documented to invade rivers (section 4a). Therefore, the uncertainty of colonizing the MRB is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
The fishhook waterflea is native to the Black, Caspian, Azov, and Aral seas of southeastern Europe and Asia. Based on its native distribution, the climate of the MRB is expected to be suitable for this species. The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000).

b. Type of Mobility/Invasion Speed
As Makarewicz et al. (1999) point out, asexual reproduction, high fecundity, the production of resting eggs, a “sticky” caudal process, viability during unfavorable periods, and rapid dispersal all promote rapid population growth.

c. Fecundity
Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Sexual females produce 1–4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010) The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012); resting eggs are resistant to desiccation, freeze-drying and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012).

d. History of Invasion Success
The fishhook waterflea spread to three Great Lakes within 2 years and inland to six of New York’s Finger Lakes within a year (NBII & ISSG 2010).

e. Human-Mediated Transport through Aquatic Pathways
The species can be transported via ballast water or hull fouling on commercial vessels (Sylvester & MacIsaac 2010). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The fishhook waterflea is a generalist species. The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species successfully invaded the

Dnieper, Don, and Rhine Rivers, particularly in reservoirs associated with these systems (MacIsaac et al. 1999; Cristescu et al. 2001). There are multiple reservoirs in the MRB. Individuals were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundance than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). Based on invaded lakes in the U.S., the fishhook waterflea was found in waters with DO range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011).

Evidence for Probability Rating

Suitable habitat is present and accessible for the fishhook waterflea, which has a high invasion speed (sections 5a, 5b, 5d, 5f). Natural species dispersal coupled with human-mediated dispersal via potential ballast water discharge may assist the species in spreading throughout the MRB giving the species a high spread probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and transport mechanisms have been documented. Therefore, the species has a low uncertainty of spreading through the MRB.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching after which they are planktonic. The fishhook waterflea has a very rapid invasion speed. It spread to three Great Lakes within two years and inland to six of New York's Finger Lakes within a year (Sea Grant New York 2012). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, viability during unfavorable periods and rapid dispersal all promote rapid population growth.

b. *Human-Mediated Transport through Aquatic Pathways*
The 1999 invasion of Lake Michigan by the species almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. Ships that discharge cargo at a Lake Ontario port will often load lake water as ballast prior to up-bound movement on the Great Lakes. This water is subsequently discharged at the terminal port-of-call and replaced with cargo for the out-bound voyage. There is heavy commercial vessel traffic to the Indiana Harbor from Lake Michigan (USACE 2011a) and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012). The fishhook waterflea was found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport may be possible. Local dispersal mechanisms potentially include small boat traffic (Makarewicz et al. 2001).

c. *Current Abundance and Reproductive Capacity*

T_0: Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Following sexual reproduction, sexual females produce between 1 and 4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010) The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012). Resting eggs are resistant to desiccation, freeze-drying and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012). Resting eggs can hatch regardless of whether the carrier female is alive or dead (Benson et al. 2012). In southern Lake Michigan, densities can reach more than 100 per m^2 during the late summer peak (Charlebois et al. 2001; Cavaletto et al. 2010; Witt et al. 2005).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: None, the species is close to or at Indiana Harbor pathway entrance (Benson et al. 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The fishhook waterflea was established in Lake Michigan, north of Chicago, Illinois in 1999 (Benson et al. 2012). The exact location and distance from Indiana Harbor is uncertain, but this species may be at Indiana Harbor.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Suitable habitats include estuarine habitats, lakes, marine habitats, water courses, and wetlands (NBII & ISSG 2010). Location appears to be variable: some studies found the species at higher densities in central regions of lakes compared to coastal areas (Ojaveer et al. 2001); however, this species is more likely to invade clear, large lakes (Muirhead et al. 2011). In Lake Michigan, Cercopagis is confined largely to nearshore waters (Pichlova-Ptacnikova & Vanderploeg 2009). Fishhook waterflea prefers to inhabit pelagic zones (Crosier & Molloy). The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The majority of individuals were found within the warm uppermost 20 m (65.6 ft) water layer during both day and night (Ojaveer et al. 2001). Less than 3% of the population occurred at depths greater than 40 m (131 ft) (Ojaveer et al. 2001).

T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future that would affect the arrival of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is established very close to the Indiana Harbor pathway entrance (section 2e). Human mediated transport via ballast water is likely not needed for the species to arrive at the pathway (section 2b). Suitable habitat is present (section 2d). Given its time in southern Lake Michigan, this species may be at the pathway entrance. Therefore the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The fishhook waterflea has been documented to be close to the pathway entrance and may drift to the entrance of Indiana Harbor pathway via current or via vessel mediated transport. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching after

which they are planktonic (NBII & ISSG 2010). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, viability during unfavorable periods, and rapid dispersal all promote rapid population growth. However, although this species was first recorded in southern Lake Michigan in 1999, it has not been recorded in the Illinois River or the CAWS. No recent zooplankton surveys were found for these waterways; therefore, the species may be present but undetected. Once it enters Indiana Harbor, the fish-hook water flea could move toward Brandon Road Lock and Dam with the natural downstream flow.

b. *Human-Mediated Transport through Aquatic Pathways*

The invasion of fishhook waterfleas in Lake Michigan during 1999 almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. Although fishhook waterflea can be transported in ballast water (Kipp et al. 2012), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Most commercial vessel traffic to Indiana Harbor is lake wise and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River due to the shallow depth. Local dispersal mechanisms for fishhook waterfleas potentially include small boat traffic (Makarewicz et al. 2001). The fishhook waterflea was found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport is possible through portions of the CAWS with vessel traffic.

c. *Existing Physical Human/Natural Barriers*

T_0: In lake studies, fishhook waterfleas were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundances of fishhook waterflea than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The maximum depth in the CAWS is about 10 m (32.8 ft) deep and depth is typically around 5 m (16.4 ft), with very shallow depths in the Grand Calumet River (LimnoTech 2010). Surface water is present all year-round and water depth is adequate throughout the CAWS (LimnoTech 2010).

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species has successfully invaded the Rhine River (Cristescu et al. 2001). Low current velocity in the CAWS may be favorable because it is typically a lake species. However, water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern most segment of the Grand Calumet River also generally flows toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, the fishhook waterflea would have to swim upstream to enter the CAWS and move to the Calumet Sag Channel. The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII &

ISSG 2010); studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). The CAWS is turbid (LimnoTech 2010). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with dissolved oxygen (DO) range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011). Annual mean DO in the CAWS typically exceeds 6 mg/L although seasonal hypoxia may occur in portions of the CAWS (MWRD 2011).

T_{10}: See T_0.

T_{25}: See T_0. Future water quality in the CAWS may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The fishhook waterflea is typically found in lakes but it has invaded rivers (section 3d). Dispersal by human-mediated transport via ballast water is not possible through the Indiana Harbor as the passage is too shallow for vessels (section 3b). Depth in the CAWS may be shallower than this species prefers (section 3d). The CAWS is a turbid water system, the fishhook waterflea is only likely to invade low turbidity water systems (section 3d). The fishhook water flea is a zooplankter and is not likely to swim upstream through Indiana Harbor and the Grand Calumet River. This species was first recorded in southern Lake Michigan in 1999 and has not been recorded in the Illinois River (section 3a). Therefore, its probability of passage for this time step is low.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. The probability of passage is likely to increase with time. The fishhook waterflea may pass through the passage given 50 years. Therefore, the probability at this time step is medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: The depth and water quality suitability of the CAWS is uncertain (section 3d). The fishhook waterflea does not actively swim and the upstream flow direction and lack of vessel transport in the Grand Calumet River would inhibit dispersal of this species to

Brandon Road Lock and Dam (section 3d). Therefore, the uncertainty associated with passage during this time step is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take the fishhook waterflea to pass upstream through Indiana Harbor and the Grand Calumet River or if the species is capable of such movement. Therefore, the uncertainty associated with passage during this time step is high.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species successfully invaded the Rhine River (Cristescu et al. 2001). The fishhook waterflea is likely to invade low turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport potential ballast water discharge or hull fouling on commercial vessels (Sylvester & MacIsaac 2010).

Evidence for Probability Rating

Suitable habitat is present for the fishhook waterflea below Brandon Road Lock and Dam. The fishhook waterflea may reach suitable habitat by natural dispersal or human-mediated transport. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

This species has been documented to invade rivers (section 4a); therefore, the uncertainty of colonizing the MRB is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
The fishhook waterflea is native to the Black, Caspian, Azov, and Aral seas of southeastern Europe and Asia. Based on its native distribution, the climate of the MRB is expected to be suitable for this species. The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100.4°F) (Gorokhova et al. 2000).

b. *Type of Mobility/Invasion Speed*
As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting eggs, a "sticky" caudal process, viability during unfavorable periods and rapid dispersal all promote rapid population growth and subsequent rapid invasion of new habitats.

c. *Fecundity*
Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Sexual females produce between 1 and 4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010). The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012); resting eggs are resistant to desiccation, freeze-drying and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012).

d. *History of Invasion Success*
The fishhook waterflea spread to three Great Lakes within 2 years and inland to six of New York's Finger Lakes within a year (NBII & ISSG 2010).

e. *Human-Mediated Transport through Aquatic Pathways*
Fishhook waterfleas can be transported via ballast water or hull fouling on commercial vessels (Sylvester & MacIsaac 2010). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Fishhook waterfleas are a generalist species. The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species successfully invaded the Dnieper, Don, and Rhine Rivers, particularly in reservoirs associated with these systems (MacIsaac et al. 1999; Cristescu et al. 2001). There are multiple reservoirs in the MRB. Individuals were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundances than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The fishhook waterflea is likely to invade low-turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). Based on invaded lakes in the U.S., the fishhook waterflea was found in waters with DO range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011).

Evidence for Probability Rating

Suitable habitat is present and accessible for the fishhook waterflea, which has a high invasion speed (sections 5a, 5b, 5d, 5f). Natural species dispersal coupled with human-mediated dispersal via potential ballast water discharge may assist the species in spreading throughout the MRB giving the species a high spread probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and transport mechanisms have been documented. Therefore, the species has a low uncertainty of spreading through the MRB.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching, after which they are planktonic. The fishhook waterflea has a very rapid invasion speed. It spread to three Great Lakes within 2 years and inland to six of New York's Finger Lakes within a year (Sea Grant New York 2012). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, and production of resting eggs, a "sticky" caudal process, viability during unfavorable periods, and rapid dispersal promote rapid population growth.

b. *Human-Mediated Transport through Aquatic Pathways*
The 1999 invasion of Lake Michigan by the species almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. Ships that discharge cargo at a Lake Ontario port will often load lake water as ballast prior to up-bound movement on the Great Lakes. This water is subsequently discharged at the terminal port-of-call and replaced with cargo for the out-bound voyage. BSBH is not a port; therefore, vessels will not release ballast water at this pathway (USACE 2011a). There is no commercial vessel traffic from the Great Lakes to the BSBH; however, there is heavy commercial traffic to adjacent Burns Harbor. The fishhook waterflea was also found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport may be possible. Local dispersal mechanisms potentially include small boat traffic (Makarewicz et al. 2001).

c. *Current Abundance and Reproductive Capacity*
T_0: Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Following sexual reproduction, females produce 1–4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010) The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012). Resting eggs are resistant to desiccation, freeze-drying, and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012). Resting eggs can hatch regardless of whether the carrier female is alive or dead (Benson et al. 2012). In southern Lake Michigan, densities can reach more than $100/m^2$ during the late summer peak (Charlebois et al. 2001; Cavaletto et al. 2010; Witt et al. 2005).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The fishhook waterflea was established in Lake Michigan, north of Chicago, IL, in 1999 (Benson et al. 2012). The exact location and distance from BSBH is uncertain, but this species may be at BSBH.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Suitable habitats include estuarine habitats, lakes, marine habitats, water courses, and wetlands (NBII & ISSG 2010). Location may be variable as some studies found the species at higher densities in central regions of lakes compared to coastal areas (Ojaveer et al. 2001); however, the species is more likely to invade clear, large lakes (Muirhead et al. 2011). In Lake Michigan, Cercopagis is confined largely to nearshore waters (Pichlova-Ptacnikova & Vanderploeg 2009). The species does prefer to inhabit the pelagic zone (Crosier & Molloy). The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100°F) (Gorokhova et al. 2000). The majority of individuals were found within the warm uppermost 20 m (65.6 ft) water layer during both day and night (Ojaveer et al. 2001). Less than 3% of the population occurred at depths greater than 40 m (131 ft) (Ojaveer et al. 2001).
T_{10}: See T_0. There are no predicted significant differences in habitat components along Lake Michigan in the near or foreseeable future that would affect the arrival of this species.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is established very close to the BSBH pathway entrance (section 2e). Human-mediated transport via ballast water is likely not needed for the species to arrive at the pathway (section 2b). Suitable habitat is present (section 2d). Given its time in southern Lake Michigan, this species may be at the pathway entrance. Therefore, the probability of arrival is high.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The fishhook waterflea has been documented as being close to the pathway entrance and may drift to the entrance of Wilmette Pumping Station (WPS) via current or via vessel-mediated transport. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The fishhook waterflea is planktonic and makes daily vertical migrations in the water column (Benson et al. 2012; NBII & ISSG 2010). Eggs are brooded until hatching, after which they are planktonic (NBII & ISSG 2010). As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity and production of resting eggs, a "sticky" caudal process, viability during unfavorable conditions, and rapid dispersal promote rapid population growth. However, although this species was first recorded in southern Lake Michigan in 1999, it has not been recorded in the Illinois River or the CAWS. No recent zooplankton surveys were found for these waterways; therefore, the species may be present but undetected. Once it enters BSBH, the fishhook waterflea could move toward Brandon Road Lock and Dam with the natural downstream flow.

b. *Human-Mediated Transport through Aquatic Pathways*
The species' invasion of Lake Michigan during 1999 almost certainly resulted from the movement of contaminated Lake Ontario ballast water by commercial vessels. The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). The South Branch of the Little Calumet River is shallow and likely has only local non-motorized vessel traffic, if any (Little Calumet and Grand Calumet River Corridor Technical Advisory Group and Northeastern Illinois Planning Commission 2011). Although the fishhook waterflea could move to Burns Harbor (which does have

commercial vessel traffic), there is no commercial vessel traffic from the Burns Harbor to inland ports in the CAWS (NBIC 2012). Local dispersal mechanisms for the fishhook waterflea potentially include small boat traffic (Makarewicz et al. 2001). The fishhook waterflea was found on commercial vessel hull scrapes (Sylvester & MacIsaac 2010), so vessel transport is possible through portions of the CAWS with vessel traffic.

c. *Existing Physical Human/Natural Barriers*
T_0: In lake studies, fishhook waterfleas were found mainly down to a depth of 20 m (65.6 ft) (Bielecka & Mudrak 2010). Deep (>100 m; 328 ft) and shallow (<10 m; 32.8 ft) stations had significantly lower abundances of fishhook waterflea than stations of intermediate depth (<100 m; 328 ft) (Gorokhova et al. 2000). The maximum depth in the CAWS is about 10 m (32.8 ft), and the depth is typically about 5 m (16.4 ft) (LimnoTech 2010). Surface water is present all year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The fishhook waterflea appears to prefer lentic systems, but has also established in rivers (Cristescu et al. 2001). Low current velocity in the CAWS may be favorable, because it is typically a lake species. However, the water flows out of BSBH into Lake Michigan. The eastern segment of the South Branch of the Little calumet River also generally flows toward Lake Michigan, depending on location and water level in Lake Michigan (GSWMD 2008). Thus, the fishhook waterflea would have to move upstream to enter the CAWS and move to the Cal-Sag Channel. The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100°F) (Gorokhova et al. 2000). The water temperature in the CAWS averages 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). The fishhook waterflea is likely to invade low-turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). The CAWS is turbid (LimnoTech 2010). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with a DO range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011). Annual mean DO in the CAWS typically exceeds 6 mg/L, although seasonal hypoxia may occur in portions of the CAWS (MWRD 2011).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality in the CAWS may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The fishhook waterflea is typically found in lakes, although it has invaded rivers (section 3d). Depth in the CAWS may be shallower than this species prefers (section 3d). Suitable temperature is present for the fishhook waterflea in the CAWS (section 3d). The CAWS is a turbid water system; the fishhook waterflea is likely to invade only low-turbidity water systems (section 3a). This species was first recorded in southern Lake Michigan in 1999 and has not been recorded in the Illinois River (section 3d). The fishhook waterflea is not likely to move upstream through BSBH and the South Branch of the Little Calumet River. The lack of vessel traffic on the Little Calumet would limit the potential for human-mediated transport through the upstream flow. Overall, its probability of passage for this time step is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The probability of passage is likely to increase with time. The fishhook waterflea may pass through the passage, given 50 years. Therefore, the probability at this time step is medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: The depth and water quality suitability of the CAWS are uncertain (section 3d). The fishhook waterflea does not actively swim, and the upstream flow direction and lack of vessel transport in the South Branch of the Little Calumet River would inhibit dispersal of this species to Brandon Road Lock and Dam (section 3d). Therefore, the uncertainty associated with passage during this time step is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take the fishhook waterflea to pass upstream through BSBH and the Little Calumet River or if the species is capable of such movement. Therefore, the uncertainty associated with passage during this time step is high.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The fishhook waterflea appears to prefer lentic systems, but has also established in rivers (Cristescu et al. 2001); the species successfully invaded the Rhine River (Cristescu et al. 2001). The fishhook waterflea is likely to invade low-turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport potential ballast water discharge or hull fouling on commercial vessels (Sylvester & MacIsaac 2010).

Evidence for Probability Rating

Suitable habitat is present for the fishhook waterflea below Brandon Road Lock and Dam. The fishhook waterflea may reach suitable habitat by natural dispersal or human-mediated transport. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

This species has been documented to invade rivers (section 4a); therefore, the uncertainty of colonizing the MRB is low.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   The fishhook waterflea is native to the Black, Caspian, Azov, and Aral Seas of southeastern Europe and Asia. Based on its native distribution, the climate of the MRB is expected to be suitable for this species. The preferred temperature range for the fishhook waterflea is 16–26°C (60.8–78.8°F) (NBII & ISSG 2010). Studies have found a range of 3–38°C (37.4–100°F) (Gorokhova et al. 2000).

b. *Type of Mobility/Invasion Speed*
   As Makarewicz et al. (2001) point out, asexual reproduction, high fecundity, the production of resting egg, a “sticky” caudal process, viability during unfavorable periods,

and rapid dispersal promote rapid population growth and subsequent rapid invasion of new habitats.

c. *Fecundity*
Female fishhook waterfleas reproduce parthenogenically during the summer and gametogenically later in the year (NBII & ISSG 2010). Sexual females produce 1–4 resting eggs, while parthenogenic females produce between 1 and 24 embryos (NBII & ISSG 2010) The species produces resting eggs anytime during the year when environmental conditions become inhospitable (Benson et al. 2012); resting eggs are resistant to desiccation, freeze-drying, and ingestion by predators and replenish the population after hatching in the spring (Benson et al. 2012).

d. *History of Invasion Success*
The fishhook waterflea spread to three Great Lakes within 2 years and inland to six of New York's Finger Lakes within a year (NBII & ISSG 2010).

e. *Human-Mediated Transport through Aquatic Pathways*
Fishhook waterfleas can spread via ballast water or hull fouling on commercial vessels (Sylvester & MacIsaac 2010). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This is a generalist species. The fishhook waterflea appears to prefer lentic systems, but has also established in rivers; the species has successfully invaded the Dnieper, Don, and Rhine Rivers, particularly in reservoirs associated with these systems (MacIsaac et al. 1999; Cristescu et al. 2001). There are multiple reservoirs in the MRB. Individuals were found mainly down to a depth of 20 m (Bielecka & Mudrak 2010). Deep (>100 m) and shallow (<10 m) stations had significantly lower abundance than stations of intermediate depth (<100 m) (Gorokhova et al. 2000). The fishhook waterflea is likely to invade low-turbidity water systems, 4.37–105.16 NTU (Muirhead et al. 2011). Based on invaded lakes in the United States, the fishhook waterflea was found in waters with a DO range of 7.67–14.07 mg/L and pH of 7.32–8.39 (Muirhead et al. 2011).

Evidence for Probability Rating

Suitable habitat is present and accessible for the fishhook waterflea, which has a high invasion speed (sections 5a, 5b, 5d, 5f). Natural species dispersal coupled with human-mediated dispersal via potential ballast water discharge may assist the species in spreading throughout the MRB, giving the species a high spread probability.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat and transport mechanisms have been documented. Therefore, the species has a low uncertainty of spreading through the MRB.

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E.2.6.2 Waterflea - *Daphnia galeata galeata*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Medium	High	Medium	High
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in which case they could be transported passively by strong currents that disturb the sediment. The species was likely introduced to Lake Erie in the 1970s or 1980s; it has not yet reached Lake Michigan (Kipp 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible. There is commercial vessel traffic from Lake Erie to southern Lake Michigan (NBIC 2012). There is no commercial vessel traffic to WPS, but there is recreational vessel traffic (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: Cladocerans are capable of reproducing asexually through parthenogenesis. They can also produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). No information on current densities was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: *D.g. galeata* established in central Lake Erie in 1980 (Kipp 2012).
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* has a near cosmopolitan distribution (Kipp 2012; Taylor & Hebert 1993), suggesting the climate in southern Lake Michigan should be suitable. The species is characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996; Kipp 2012); it is occasionally found in hyporheic water (Dumont & Negrea 1996). In Lake Erie, it was found in nearshore areas (Kipp 2012). Most daphnids prefer large lakes (Kipp 2012); crowding by other zooplankton can reduce growth (Burns 2000). Optimal growth occurs at 20°C (68°F) (Weider 1993). Resting eggs can exist in sediments (Kipp 2012.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is located far from the WPS pathway in Lake Erie (section 2e) and requires human-mediated transport to travel far distances quickly (section 2b). Commercial vessels do not go to WPS, and ballast water will not be discharged in the WPS pathway entrance. Transport on recreational vessels is possible (section 2b). Suitable habitat is present in the vicinity of the WPS (section 2d). *D.g. galeata* is thought to have a high invasion speed in the Great Lakes (section 2a), and it has a preference for large lakes (section 2c). However, the species was introduced to Lake Erie in the 1970s or 1980s and has not yet reached Lake Michigan (section 2a). For this reason and the current distance from the WPS, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. There is heavy vessel traffic between Lake Erie and Lake Michigan, and this species can be transported by vessel traffic. Given time to disperse or relocate via human-mediated transport, the species may arrive at the WPS pathway entrance at this time step, raising the arrival probability to medium.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: This species is transported by vessels. Given the shipping traffic between Lake Erie and Lake Michigan, it is uncertain why this species has not been recorded in Lake Michigan. The species was first discovered in Lake Erie in the 1970s and early 1980s and has yet to be detected in Lake Michigan. Therefore, the uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be sufficient time to expand to the pathway entrance, although the potential rate of spread for this species is highly uncertain.
T_{50}: See T_{25}. The arrival at the WPS is highly uncertain, given the future trends in population size and hybridization with native *D.g. mendotae*.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata can establish quickly (Taylor & Hebert 1993). After *D.g. galeata* was introduced to Lake Erie, it rapidly hybridized with native *D.g. mendotae* (Taylor & Hebert 1993). No information was found for natural spread rates through canals or rivers.

b. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB in ballast water (Taylor & Hebert 1993). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is possible. However, there is no vessel traffic between Lake Michigan and the North Shore Channel through the WPS because of a sluice gate. In addition, there is little if any vessel traffic in the North Shore Channel; therefore, some natural downstream dispersal would likely be required for this species to reach Brandon Road Lock and Dam. There is vessel traffic from the Chicago River to Brandon Road Lock and Dam that could potentially transport this species.

c. *Existing Physical Human/Natural Barriers*
T_0: There is a sluice gate separating WPS from Lake Michigan which is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010), which could transport this species into the North Shore Channel.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996; Kipp 2012). Most daphnids are lake species, but the invasive water flea *Daphnia lumholtzi* has been found in the CAWS (Stoeckel & Charlbois 1999). Most flows in the CAWS were slow [<0.15 m/s, the highest was 0.27 m/s (0.49–0.89 ft/s) (LimnoTech 2010). Optimal growth is at 20°C (68°F) for the species (Weider 1993). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species can produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat may be present for *D.g. galeata* in the CAWS (section 3d). However, this is primarily a lake species, so the CAWS may not be ideal habitat. However, other Daphnids are known to be present in the CAWS, and this species has been recorded in slow-moving rivers (section 3d). The species should pass through the WPS, and downstream flow will assist the species in spreading to Brandon Road Lock and Dam. This species can pass through the CAWS by natural downstream dispersal alone or in combination with vessel transport (section 3b). Therefore, the passage probability for the species is high for the WPS pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *D.g. galeata* is primarily a lake species; therefore, it is uncertain if habitat in the CAWS is suitable. Also, the potential natural rate of spread in the CAWS is uncertain. Therefore, the uncertainty associated with *D.g. galeata* passing through Brandon Road Lock and Dam is medium for this time step.
T_{10}: See T_0. Given time to naturally disperse and the potential for vessel-mediated transport, *D.g. galeata* is more certain to pass through the pathway during this time step compared to T_0; therefore, the uncertainty decreases to low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
D.g. galeata is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, but the invasive water flea *Daphnia lumholtzi* has been found in the Illinois River (Stoeckel & Charlbois 1999). Optimal growth for the species occurs at 20°C (68°F) (Weider 1993).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via hull fouls and potentially ballast water discharge.

Evidence for Probability Rating

This species is found in slow-moving rivers; therefore, suitable habitat is likely to be present downstream of Brandon Road Lock and Dam. *D.g. galeata* may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, this species is considered to have a high probability of colonization after passage of pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

Daphnids, including this species, are known to establish in rivers. Therefore uncertainty is low.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Optimal growth occurs at 20°C (68°F) for the species (Weider 1993).

b. *Type of Mobility/Invasion Speed*
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in which case they could be transported passively by strong currents that disturb the sediment.

c. *Fecundity*
Average clutch size was 2.66 ± 0.86, with 80.5 ± 6.6 percentage of the females ovigerous, and egg development time was 7.98 ± 3.46 days (Maier 1996). Clutch sizes were negatively correlated with total *Daphnia* density in a lake (Maier 1996); clutch size in *Daphnia* increases with body size in well-fed populations (Burns 2000; Petersen 1983). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993) ,and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). This greater fitness could promote spread through the MRB. The species can produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).

d. *History of Invasion Success*
Most daphnids are lake species, but daphnid species such as the invasive *Daphnia lumholtzi* have established in the MRB (Benson et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). There is heavy commercial and recreational vessel traffic in the MRB that could potentially spread this species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
D.g. galeata is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, and there are reservoirs throughout the MRB. In addition, other *daphnia* species such as the invasive water flea *Daphnia lumholtzi* have been found in rivers of the MRB (Stoeckel & Charlbois 1999). Within the water column *Daphnia* spp. are generalist filter feeders on small particles and more selective feeders on larger particles (Kipp 2012). Particle size selection varies with body size (Kipp 2012; Repka 1997).

Evidence for Probability Rating

Suitable habitat conditions appear to be present, connected, and accessible (sections 5e, 5f). There is the potential for this species to be spread in ballast water and vessel transport by the heavy vessel traffic in the MRB. Therefore, this species is considered to have a high probability of spreading throughout the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

D.g. galeata is documented to exist in rivers and especially reservoirs; these habitats are present in the MRB. Therefore, there is a low uncertainty for this species to spread throughout the MRB.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS[CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Medium	High	Medium	High
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	--	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in which case they could be transported passively by strong currents that disturb the sediment. The species was likely introduced to Lake Erie in the 1970s or 1980s; it has not yet reached Lake Michigan (Kipp 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). There is commercial vessel traffic from Lake Erie to southern Lake Michigan, and the ballast water discharged at CAWS ports along Lake Michigan is from other ports in the Great Lakes (NBIC 2012). There is commercial and recreational vessel traffic to the CRCW from Lake Michigan (USACE 2011a,b). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible.

c. *Current Abundance and Reproductive Capacity*
T_0: Cladocerans are capable of reproducing asexually through parthenogenesis. They can also produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). No information on current densities was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: *D.g. galeata* established in central Lake Erie in 1980 (Kipp 2012).
T_{10}: See **T_0**. The species may disperse closer to the pathway over time.
T_{25}: See **T_{10}.**
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* has a near cosmopolitan distribution (Kipp 2012; Taylor & Hebert 1993), suggesting the climate in southern Lake Michigan should be suitable. This species is characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996); it occasionally occurs in hyporheic water (Dumont & Negrea 1996). In Lake Erie, it was found in nearshore areas (Kipp 2012). Most daphnids prefer large lakes. Crowding by other zooplankton can reduce growth (Burns 2000). Optimal growth for the species occurs at 20°C (68°F) (Weider 1993). Resting eggs can exist in sediments (Kipp 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is located far from the CRCW pathway in Lake Erie (section 2e) and requires human-mediated transport to travel far distances quickly (section 2b). Commercial vessels do go to the CRCW, and ballast water may be discharged in the pathway entrance. Transport on recreational vessels is possible (section 2b). Suitable habitat is present in the vicinity of the CRCW (section 2d). *D.g. galeata* is thought to have a high invasion speed in the Great Lakes (section 2a), and it has a preference for large lakes (section 2c). However, the species was introduced to Lake Erie in the 1970s or 1980s and has not yet reached Lake Michigan (section 2a). For this reason and the current distance from the CRCW, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. There is heavy vessel traffic between Lake Erie and Lake Michigan, and this species can be transported by vessel traffic. Given time to disperse or relocate via human-mediated transport, the species may arrive at the CRCW pathway entrance at this time step, raising the arrival probability to medium.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: This species is transported by vessels. Given the shipping traffic between Lake Erie and Lake Michigan, it is uncertain why this species has not been recorded in Lake Michigan. The species was first discovered in Lake Erie in the 1970s or early 1980s and has yet to be detected in Lake Michigan. Therefore, the uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be sufficient time to expand to the pathway entrance, although the potential rate of spread for this species is highly uncertain.
T_{50}: See T_{25}. The arrival at the CRCW is highly uncertain, given the future trends in population size and hybridization with native *D.g. mendotae*.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species

a. Type of Mobility/Invasion Speed
After *D.g. galeata* was introduced to Lake Erie, it rapidly hybridized with native *D.g. mendotae* (Taylor & Hebert 1993). No information was found for natural spread rates through canals or rivers.

b. Human-Mediated Transport through Aquatic Pathways
D.g. galeata was very likely introduced to the GLB in ballast water (Taylor & Hebert 1993). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible. There is some commercial vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012).

c. Existing Physical Human/Natural Barriers
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: *D.g. galeata* is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids are lake species, but the invasive water flea *Daphnia lumholtzi* has been found in the CAWS (Stoeckel & Charlbois 1999). Most flows in the CAWS were slow (<0.15 m/s, the highest was 0.27 m/s [0.49–0.89 ft/s]) (LimnoTech 2010). Optimal growth occurs at 20°C (68°F) for the species (Weider 1993). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species can produce resting eggs that are able to survive periods of desiccation in sediment (Taylor & Hebert 1993).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat may be present for *D.g. galeata* in the CAWS (section 3d). However, this is primarily a lake species, so the CAWS may not be ideal habitat. However, other Daphnids are known to be present in the CAWS, and this species has been recorded in slow-moving rivers (section 3d). This species can pass through the CRCW and downstream to

Brandon Road Lock and Dam by natural downstream dispersal alone or in combination with vessel transport (section 3b). Therefore, the passage probability for the species is high for the CRCW pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *D.g. galeata* is primarily a lake species; therefore, it is uncertain if habitat in the CAWS is suitable. Also, the potential natural rate of spread in the CAWS is uncertain. Therefore, the uncertainty associated with *D.g. galeata* passing through Brandon Road Lock and Dam is medium for this time step.
T_{10}: See T_0. Given time to naturally disperse and the potential for vessel-mediated transport, *D.g. galeata* is more certain to pass through the pathway during this time step compared to T_0; therefore, the uncertainty decreases to low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
D.g. galeata is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, but the invasive water flea, *Daphnia lumholtzi*, has been found in the Illinois River (Stoeckel & Charlbois 1999). Optimal growth is at 20°C (68°F) for the species (Weider 1993).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via hull fouls and potentially ballast water discharge.

Evidence for Probability Rating

This species is found in slow-moving rivers, therefore suitable habitat is likely to be present downstream of Brandon Road Lock and Dam. *D.g. galeata* may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, this species is considered to have a high probability of colonization after passage of pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

Daphnids, including this species, are known to establish in rivers. Therefore, uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Optimal growth is at 20°C (68°F) for the species (Weider 1993).

b. Type of Mobility/Invasion Speed
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in which case they could be transported passively by strong currents that disturb the sediment.

c. Fecundity
Average clutch size was 2.66 ± 0.86, with 80.5 ± 6.6 percentage of the females ovigerous, and egg development time was 7.98 ± 3.46 days (Maier 1996). Clutch sizes were negatively correlated with total *Daphnia* density in lake (Maier 1996); clutch size in *Daphnia* increases with body size in well-fed populations (Burns 2000; Petersen 1983). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). The species can produce resting eggs that are able to survive periods of desiccation in sediment (Taylor & Hebert 1993).

d. History of Invasion Success
Most daphnids are lake species, but daphnid species such as the invasive *Daphnia lumholtzi* have established in the MRB (Benson et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). There is heavy commercial and recreational vessel traffic in the MRB that could potentially spread this species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
D.g. galeata is characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, and there are reservoirs throughout the MRB. In addition, other daphnia species such as the invasive water flea *Daphnia lumholtzi* have been found in rivers of the MRB (Stoeckel & Charlbois 1999). Within the water column, *Daphnia* spp. are generalist filter feeders on small particles and more selective feeders on larger particles (Kipp 2012). Particle size selection varies with body size (Kipp 2012; Repka 1997).

Evidence for Probability Rating

Suitable habitat conditions appear to be present, connected, and accessible (section 5f). There is the potential for this species to be spread in ballast water, and vessel transport by the heavy vessel traffic in the MRB. Therefore, this species is considered to have a high probability of spreading throughout the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

D.g. galeata is documented to exist in rivers and especially reservoirs; these habitats are present in the MRB. Therefore, there is a low uncertainty for this species to spread throughout the MRB.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Medium	High	Medium	High
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in which case they could be transported passively by strong currents that disturb the sediment. However, the species was likely introduced to Lake Erie in the 1970s or 1980s; it has not yet reached Lake Michigan (Kipp 2012).

b. Human-Mediated Transport through Aquatic Pathways
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible. In 2008, 129,000 tons of cargo entered southern Lake Michigan destined to enter the CAWS (USACE 2011a). Ballast water discharged at the CAWS ports along Lake Michigan are from other ports in the Great Lakes (NBIC 2012). There is commercial and recreational vessel traffic to Calumet Harbor from Lake Michigan (USACE 2011a,b).

c. Current Abundance and Reproductive Capacity
T_0: Cladocerans are capable of reproducing asexually through parthenogenesis. They can also produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). No information on current densities was found.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: *D.g. galeata* established in central Lake Erie in 1980 (Kipp 2012).
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* has a near cosmopolitan distribution (Kipp 2012; Taylor & Hebert 1993), suggesting the climate in southern Lake Michigan should be suitable. This species is characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996); it is occasionally found in hyporheic water (Dumont & Negrea 1996). In Lake Erie, it was found in nearshore areas (Kipp 2012). Most daphnids prefer large lakes. Crowding by other zooplankton can reduce growth (Burns 2000). Optimal growth of *D.g. galeata* occurs at 20°C (68°F) (Weider 1993). Resting eggs can exist in sediments (Kipp 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is located far from the Calumet Harbor pathway in Lake Erie (section 2e) and requires human-mediated transport to travel far distances quickly (section 2b). Commercial vessels do go to Calumet Harbor, and ballast water may be discharged in the pathway entrance. Transport on recreational vessels is possible (section 2b). Suitable habitat is present in the vicinity of the Calumet Harbor. *D.g. galeata* has a preference for large lakes (section 2c). However, the species was introduced to Lake Erie in the 1970s or 1980s and has not yet reached Lake Michigan (section 2a). For this reason and the current distance from Calumet Harbor, the probability of arrival is low for this time step.
T_{10}: See T_0.

T_{25}: See T_0. There is heavy vessel traffic between Lake Erie and Lake Michigan, and this species can be transported by vessel traffic. Given time to disperse or relocate via human-mediated transport, the species may arrive at the Calumet Harbor pathway entrance at this time step, raising the arrival probability to medium.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: This species is transported by vessels. Given the shipping traffic between Lake Erie and Lake Michigan, it is uncertain why this species has not been recorded in Lake Michigan. The species was first discovered in Lake Erie in the 1970s or early 1980s and has yet to be detected in Lake Michigan. Therefore, there is a low degree of uncertainty the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be sufficient time for the species to expand to the pathway entrance, although the potential rate of spread for this species is highly uncertain.
T_{50}: See T_{25}. The arrival at the Calumet Harbor is highly uncertain, given the future trends in population size and hybridization with native *D.g. mendotae*.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata can establish quickly (Taylor & Hebert 1993). After *D.g. galeata* was introduced to Lake Erie, it rapidly hybridized with native *D.g. mendotae* (Taylor & Hebert 1993). No information was found for natural spread rates through canals or rivers.

b. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB in ballast water (Taylor & Hebert 1993). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible. Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids are lake species, but the invasive water flea *Daphnia lumholtzi* has been found in the CAWS (Stoeckel & Charlbois 1999). Most flows in the CAWS were slow (<0.15 m/s; the highest was 0.27 m/s [0.49–0.89 ft/s]) (LimnoTech 2010). Optimal growth occurs at 20°C (68°F) for the species (Weider 1993). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species can produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat may be present for *D.g. galeata* in the CAWS (section 3d). However, this is primarily a lake species, so the CAWS may not be ideal habitat. However, other Daphnids are known to be present in the CAWS, and this species has been recorded in slow-moving rivers (section 3d). After passing through Calumet Harbor, downstream flow will assist the species in spreading to Brandon Road Lock and Dam. This species can pass through the CAWS by natural downstream dispersal alone or in combination with vessel transport (section 3b). Therefore, the passage probability for the species is high for the Calumet Harbor pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: *D.g. galeata* is primarily a lake species; therefore, it is uncertain if habitat in the CAWS is suitable. Also, the potential natural rate of spread in the CAWS is uncertain. Therefore, the uncertainty associated with *D.g. galeata* passing through Brandon Road Lock and Dam is medium for this time step.
T_{10}: See T_0. Given time to naturally disperse and the potential for vessel transport, *D.g. galeata* is more certain to pass through the pathway during this time step compared to T_0; therefore the uncertainty decreases to low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

2. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
This species is characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, but the invasive water flea *Daphnia lumholtzi* has been found in the Illinois River (Stoeckel & Charlbois 1999). Crowding by other zooplankton can reduce growth (Burns 2000). Optimal growth occurs at 20°C (68°F) for the species (Weider 1993).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via hull fouls and potentially ballast water discharge.

Evidence for Probability Rating

This species is found in slow-moving rivers; therefore, suitable habitat is likely to be present downstream of Brandon Road Lock and Dam. *D.g. galeata* may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, this species is considered to have a high probability of colonization after passage of pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

Daphnids, including this species, are known to establish in rivers. Therefore, uncertainty is low.

3. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Optimal growth occurs at 20°C (68°F) for the species (Weider 1993).

b. *Type of Mobility/Invasion Speed*
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in which case they could be transported passively by strong currents that disturb the sediment.

c. *Fecundity*
Average clutch size was 2.66 ± 0.86, with 80.5 ± 6.6 percentage of the females ovigerous and egg development time was 7.98 ± 3.46 days (Maier 1996). Clutch sizes were negatively correlated with total *Daphnia* density in the lake (Maier 1996); clutch size in *Daphnia* increases with body size in well-fed populations (Burns 2000; Petersen 1983). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). This greater fitness could promote spread through the MRB. The species can produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).

d. *History of Invasion Success*
Most daphnids are lake species, but daphnid species such as the invasive *Daphnia* lumholtzi have established in the MRB (Benson et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). There is heavy commercial and recreational vessel traffic in the MRB that could potentially spread this species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Within the water column, *Daphnia* spp. are generalist filter feeders on small particles and more selective feeders on larger particles (Kipp 2012). Particle size selection varies with body size (Kipp 2012; Repka 1997). *D.g. galeata* are characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, and there are reservoirs throughout the MRB. In addition, other daphnia species such as the invasive water flea *Daphnia lumholtzi* have been found in rivers of the MRB (Stoeckel & Charlbois 1999).

Evidence for Probability Rating

Suitable habitat conditions appear to be present, connected, and accessible (section 5f). There is the potential for this species to be spread in ballast water and vessel transport by the heavy vessel traffic in the MRB. Therefore, this species is considered to have a high probability of spreading throughout the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

D.g. galeata is documented to exist in rivers and especially reservoirs, and these habitats are present in the MRB. Therefore, there is a low uncertainty for this species to spread throughout the MRB.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Medium	High	Medium	High
P(passage)	Low	Low	Low	Low	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in which case they could be transported passively by strong currents that disturb the sediment. The species was likely introduced to Lake Erie in the 1970s or 1980s; it has not yet reached Lake Michigan (Kipp 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). *Daphnia spp.* have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible. In 2008, 129,000 tons of cargo entered southern Lake Michigan destined to enter the CAWS (USACE 2011a). The ballast water discharged at the CAWS ports along Lake Michigan is primarily from other ports in the Great Lakes (NBIC 2012). There is heavy commercial vessel traffic to Indiana Harbor from Lake Michigan (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
T_0: Cladocerans are capable of reproducing asexually through parthenogenesis. They can also produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). No information on current densities was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: *D.g. galeata* established in central Lake Erie in 1980 (Kipp 2012).
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* has a near cosmopolitan distribution (Kipp 2012; Taylor & Hebert 1993), suggesting the climate in southern Lake Michigan should be suitable. This species is characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996); it can occasionally be found in hyporheic water (Dumont & Negrea 1996). In Lake Erie, it was found in nearshore areas (Kipp 2012). Most daphnids prefer large lakes. Crowding by other zooplankton can reduce growth (Burns 2000). Optimal growth occurs at 20°C (68°F) for the species (Weider 1993). Resting eggs can exist in sediments (Kipp 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is located far from the Indiana Harbor pathway in Lake Erie (section 2e) and requires human-mediated transport to travel far distances quickly (section 2b). Commercial vessels do go to Indiana Harbor, and ballast water may be discharged in the pathway entrance. Transport on recreational vessels is possible (section 2b). Suitable habitat is present in the vicinity of Indiana Harbor (section 2d). The water flea is thought to have a high invasion speed in the Great Lakes (section 2a), and it has a preference for large lakes (section 2c). However, the species was introduced to Lake Erie in the 1970s or 1980s and has not yet reached Lake Michigan (section 2a). For this reason and the current distance from Indiana Harbor, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. There is heavy vessel traffic between Lake Erie and Lake Michigan, and this species can be transported by vessel traffic. Given time to disperse or relocate via human-mediated transport, the species may arrive at the Indiana Harbor pathway entrance at this time step, raising the arrival probability to medium.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: This species is transported by vessels. Given the shipping traffic between Lake Erie and Lake Michigan, it is uncertain why this species has not been recorded in Lake Michigan. The

species was first discovered in Lake Erie in the 1970s or early 1980s and has yet to be detected in Lake Michigan. Therefore, the uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be sufficient time to expand to the pathway entrance, although the potential rate of spread for this species is highly uncertain.
T_{50}: See T25. The arrival at Indiana Harbor is highly uncertain, given the future trends in population size and hybridization with native *D.g. mendotae*.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata can establish quickly (Taylor & Hebert 1993). After *D.g. galeata* was introduced to Lake Erie, it rapidly hybridized with native *D.g. mendotae* (Taylor & Hebert 1993). No information was found for natural spread rates through canals or rivers.

b. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB in ballast water (Taylor & Hebert 1993). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is possible. Most commercial vessel traffic to Indiana Harbor is lakewise (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River due to the shallow depth. There is vessel traffic from the Calumet Sag Channel to Brandon Road Lock and Dam that could potentially transport this species.

c. *Existing Physical Human/Natural Barriers*
T_0: Just to the west of its junction with the Indian Harbor Canal, the Grand Calumet channel is blocked by sheet pile, which could act as a temporary barrier.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids are lake species, but the invasive water flea *Daphnia* lumholtzi has been found in the CAWS (Stoeckel & Charlbois 1999). Water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern most sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus *D.g. galeata* would have to traverse upstream to enter the CAWS and move to the Calumet Sag Channel. Most flows in the

CAWS were slow (<0.15 m/s, the highest was 0.27 m/s [0.49–0.89 ft/s]) (LimnoTech 2010). Optimal growth for this species occurs at 20°C (68°F) (Weider 1993). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species can produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat may be present for *D.g. galeata* in the CAWS (section 3d). This is primarily a lake species, so the CAWS may not be ideal habitat. However, other *Daphnids* are known to be present in the CAWS, and this species has been recorded in slow-moving rivers (section 3d). *D.g. galeata* is not likely to move upstream through Indian Harbor and the Grand Calumet River (sections 3a, 3d). The lack of vessel transport on the Grand Calumet would limit the potential for human-mediated transport through the upstream flow. Therefore, the passage probability for the species is low for the Indiana Harbor pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The probability of passage is likely to increase with time. *D.g. galeata* may pass through the passage, given 50 years. Therefore, the probability at this time step is medium.
Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: *D.g. galeata* does not actively swim, and the upstream flow direction and lack of vessel transport in the Grand Calumet River would inhibit dispersal of this species to Brandon Road Lock and Dam (section 3d). Therefore, the uncertainty associated with *D.g. galeata* passing through Brandon Road Lock and Dam is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take *D.g. galeata* to pass upstream through Indiana Harbor and the Grand Calumet River or if the species is capable of such movement. Therefore, the uncertainty associated with passage during this time step is high.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
D.g. galeata is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, but the invasive water flea *Daphnia lumholtzi* has been found in the Illinois River (Stoeckel & Charlbois 1999).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via hull fouls and potentially ballast water discharge.

Evidence for Probability Rating

This species is found in slow-moving rivers; therefore, suitable habitat is likely to be present downstream of Brandon Road Lock and Dam. *D.g. galeata* may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, this species is considered to have a high probability of colonization after passage of pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

Daphnids including this species are known to establish in rivers. Therefore uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
Optimal growth occurs at 20°C (68°F) for the species (Weider 1993).

b. Type of Mobility/Invasion Speed
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in

which case they could be transported passively by strong currents that disturb the sediment.

c. *Fecundity*
Average clutch size was 2.66 ± 0.86, with 80.5 ± 6.6 percentage of the females ovigerous and egg development time was 7.98 ± 3.46 days (Maier 1996). Clutch sizes were negatively correlated with total *Daphnia* density in the lake (Maier 1996); clutch size in *Daphnia* increases with body size in well-fed populations (Burns 2000; Petersen 1983). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). This greater fitness could promote spread through the MRB. The species can produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).

d. *History of Invasion Success*
Most daphnids are lake species, but daphnid species such as the invasive *Daphnia lumholtzi* have established in the MRB (Benson et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). There is heavy commercial and recreational vessel traffic in the MRB that could potentially spread this species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
D.g. galeata is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, and there are reservoirs throughout the MRB. In addition, other daphnia species such as the invasive water flea *Daphnia lumholtzi* have been found in rivers of the MRB (Stoeckel & Charlbois 1999). Optimal growth occurs at 20°C (68°F) for the species (Weider 1993). Within the water column, *Daphnia* spp. are generalist filter feeders on small particles and more selective feeders on larger particles (Kipp 2012). Particle size selection varies with body size (Repka 1997).

Evidence for Probability Rating

Suitable habitat conditions appear to be present, connected, and accessible (section 5f). There is the potential for this species to be spread in ballast water and vessel transport by the heavy vessel traffic in the MRB. Therefore, this species is considered to have a high probability of spreading throughout the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

D.g. galeata is documented to exist in rivers and especially in reservoirs; these habitats are present in the MRB. Therefore, there is a low uncertainty for this species to spread throughout the MRB.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Medium	High	Medium	High
P(passage)	Low	Low	Low	Low	Low	High	Medium	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: High

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in

which case they could be transported passively by strong currents that disturb the sediment. The species was likely introduced to Lake Erie in the 1970s or 1980s; it has not yet reached Lake Michigan (Kipp 2012).

b. Human-Mediated Transport through Aquatic Pathways

D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). In 2008, 129,000 tons of cargo entered southern Lake Michigan destined to enter the CAWS (USACE 2011a). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible. Ballast water discharged at the CAWS ports along Lake Michigan is primarily from other ports in the Great Lakes (NBIC 2012). There is no commercial vessel traffic to BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic to adjacent Burns Harbor.

c. Current Abundance and Reproductive Capacity

T_0: Cladocerans are capable of reproducing asexually through parthenogenesis. They can also produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). No information on current densities was found.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: *D.g. galeata* established in central Lake Erie in 1980 (Kipp 2012).
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *D.g. galeata* has a near cosmopolitan distribution (Kipp 2012; Taylor & Hebert 1993), suggesting the climate in southern Lake Michigan should be suitable. This species is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996); it can occasionally be found in hyporheic water (Dumont & Negrea 1996). In Lake Erie, it was found in nearshore areas (Kipp 2012).

Most daphnids prefer large lakes. Optimal growth for this species occurs at 20°C (68°F) (Weider 1993). Resting eggs can exist in sediments (Kipp 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is located far from BSBH pathway in Lake Erie (section 2e) and requires human-mediated transport to travel far distances quickly (section 2b). Commercial vessels do not go to BSBH, and ballast water will not be discharged in the pathway entrance. However, ballast water may be released in nearby Burns Harbor. Transport on recreational vessels is possible (section 2b). Suitable habitat is present in the vicinity of BSBH (section 2d). *D.g. galeata* is thought to have a high invasion speed in the Great Lakes (section 2a), and it has a preference for large lakes (section 2c). However, the species was introduced to Lake Erie in the 1970s or 1980s and has not yet reached Lake Michigan (section 2a). For this reason and the current distance from BSBH, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. There is heavy vessel traffic between Lake Erie and Lake Michigan, and this species can be transported by vessel traffic. Given time to disperse or relocate via human-mediated transport, the species may arrive at BSBH pathway entrance at this time step, raising the arrival probability to medium.
T_{50}: See T_{25}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: This species is transported by vessels. Given the shipping traffic between Lake Erie and Lake Michigan, it is uncertain why this species has not been recorded in Lake Michigan. The species was first discovered in Lake Erie in the 1970s or early 1980s and has yet to be detected in Lake Michigan. Therefore, the uncertainty for arrival is low.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be sufficient time for the species to expand to the pathway entrance, although the potential rate of spread for this species is highly uncertain.
T_{50}: See T_{25}. The arrival at the BSBH is highly uncertain, given the future trends in population size and hybridization with native *D g. mendotae*.

3. P(passage) T_0-T_{50}: LOW-MEDIUM

In determining the probability of passage, the species is assumed to have arrived at the pathway

Factors That Influence Passage of Species

a. *Type of Mobility/Invasion Speed*
D.g. galeata can establish quickly (Taylor & Hebert 1993). However, this is primarily a lake species, so establishment in the CAWS may be limited. After *D.g. galeata* was introduced to Lake Erie, it rapidly hybridized with native *D.g. mendotae* (Taylor & Hebert 1993). No information was found for natural spread rates through canals or rivers.

b. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB in ballast water (Taylor & Hebert 1993). The discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). *Daphnia* spp. have been found in boat hull scrapes (Rothlisberger 2009), suggesting external vessel transport is also possible. Vessel traffic to BSBH is lakewise only. The south branch of the Little Calumet River is shallow and likely has only local non-motorized vessel traffic, if any (Little Calumet and Grand Calumet River Corridor Technical Advisory Group and Northeastern Illinois Planning Commission 2011). Although *D.g. galeata* could move to Burns Harbor (which does have commercial vessel traffic), there is no commercial vessel from Burns Harbor to inland ports in the CAWS (NBIC 2012). There is vessel traffic from the Calumet Sag Channel to Brandon Road Lock and Dam that could potentially transport this species.

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *D.g. galeata* is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids are lake species, but the invasive water flea *Daphnia lumholtzi* has been found in the CAWS (Stoeckel & Charlbois 1999). The water flows out of BSBH into Lake Michigan. The eastern segment of the south branch of the Little Calumet River also generally flows toward Lake Michigan, depending on location and water level in Lake Michigan (GSWMD 2008). Thus, the fish hook water flea would have to move upstream to enter the CAWS and move to the Calumet Sag Channel. Most flows in the CAWS were slow (0.15 m/s, the highest was 0.27 m/s [0.49–0.89 ft/s]) (LimnoTech 2010). Optimal growth occurs at 20°C (68°F) for the species (Weider 1993). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The species can produce

resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat may be present for *D.g. galeata* in the CAWS (section 3d). However, this is primarily a lake species, so the CAWS may not be ideal habitat. However, other Daphnids are known to be present in the CAWS, and this species has been recorded in slow-moving rivers (section 3d). *D.g. galeata* is not likely to move upstream through BSBH and the south branch of the Little Calumet River. The lack of vessel traffic on the Little Calumet would limit the potential for human-mediated transport through the upstream flow. Therefore, the passage probability for the species is low for the BSBH pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The probability of passage is likely to increase with time. *D.g. galeata* may pass through the passage, given 50 years. Therefore, the probability at this time step is medium.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: *D.g. galeata* is primarily a lake species; therefore, it is uncertain if habitat in the CAWS is suitable. The species does not actively swim, and the upstream flow direction and lack of vessel transport in the south branch of the Little Calumet River would inhibit dispersal of this species to Brandon Road Lock and Dam (section 3d). Therefore, the uncertainty associated with *D.g. galeata* passing through Brandon Road Lock and Dam is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take *D.g. galeata* to pass upstream through BSBH and the Little Calumet River or if the species is capable of such movement. Therefore, the uncertainty associated with passage during this time step is high.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   D.g. galeata is characteristic of large, eutrophic lakes, but is also found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, but the invasive water flea *Daphnia lumholtzi* has been found in the Illinois River (Stoeckel & Charlbois 1999). Optimal growth occurs at 20°C (68°F) for the species (Weider 1993).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via hull fouls and potentially ballast water discharge.

Evidence for Probability Rating

This species is found in slow-moving rivers; therefore, suitable habitat is likely to be present downstream of Brandon Road Lock and Dam. *D.g. galeata* may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, this species is considered to have a high probability of colonization after passage of pathway.

Uncertainty: **LOW**

Evidence for Uncertainty Rating

Daphnids including this species are known to establish in rivers. Therefore, uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   Optimal growth occurs at 20°C (68°F) for the species (Weider 1993).

b. *Type of Mobility/Invasion Speed*
   D.g. galeata is a small water flea that moves actively (vertical migration) and passively (by currents). Eggs can be attached to the adult or found in the sediment (Kipp 2012), in

which case they could be transported passively by strong currents that disturb the sediment.

c. *Fecundity*
Average clutch size was 2.66 ± 0.86, with 80.5 ± 6.6 percentage of the females ovigerous and egg development time was 7.98 ± 3.46 days (Maier 1996). Clutch sizes were negatively correlated with total *Daphnia* density in the lake (Maier 1996); clutch size in *Daphnia* increases with body size in well-fed populations (Burns 2000; Petersen 1983). *D.g. galeata* hybridizes with native *Daphnia*. *Daphnia* hybrids tend to have greater variation in relative niche breadths (Weider 1993), and it has been suggested that *D.g. galeata* × *D.g. mendotae* clones may be more fit than either parent clone (Taylor & Hebert 1993). This greater fitness could promote spread through the MRB. The species can produce resting eggs that are able to survive periods of desiccation in the sediment (Taylor & Hebert 1993).

d. *History of Invasion Success*
Most daphnids are lake species, but daphnid species like the invasive *Daphnia lumholtzi* have established in the MRB (Benson et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
D.g. galeata was very likely introduced to the GLB by ballast water (Taylor & Hebert 1993). There is heavy commercial and recreational vessel traffic in the MRB that could potentially spread this species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
D.g. galeata is characteristic of large, eutrophic lakes, but can also be found in ponds and even slow running rivers (Dumont & Negrea 1996). Most daphnids prefer large lakes, and there are reservoirs throughout the MRB. In addition, other daphnia species such as the invasive water flea *Daphnia lumholtzi* have been found in rivers of the MRB (Stoeckel & Charlbois 1999). Within the water column, *Daphnia* spp. are generalist filter feeders on small particles and more selective feeders on larger particles (Kipp 2012). Particle size selection varies with body size (Repka 1997).

Evidence for Probability Rating

Suitable habitat conditions appear to be present, connected, and accessible (section 5f). There is the potential for this species to be spread in ballast water and vessel transport by the heavy vessel traffic in the MRB. Therefore, this species is considered to have a high probability of spreading throughout the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

D.g. galeata is documented to exist in rivers and especially in reservoirs; these habitats are present in the MRB. Therefore, there is a low uncertainty for this species to spread throughout the MRB.

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E.2.6.3 Bloody Red Shrimp - *Hemimysis anomala*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). Rapid growth and maturation facilitate the establishment of bloody red shrimp in new habitats (Pothoven et al. 2007). The species can naturally disperse through canals and river systems (Ricciardi et al. 2011). The species has a limited natural dispersal capacity, because it is an egg brooder (eggs are carried by adults, not free-floating) and can hardly swim upstream (Audzijonyte

et al. 2008). It was reported for the first time in 2006 from Lake Ontario and from a channel connecting Muskegon Lake to Lake Michigan, and is now well distributed throughout at least four of the Great Lakes (Marty et al. 2010; Kipp et al. 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel transport is the primary dispersal mechanism in the spread of bloody red shrimp. Initially, the species spread by intentional transfer to freshwater bodies within the former Soviet Union. More recently, it has spread unintentionally by shipping through rivers and canals, and in ballast water (Kipp et al. 2011). The species spread from Europe to the United Kingdom in less than 10 years via shipping (Ricciardi et al. 2011). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism. The highest risk transport vector is ballast water movement (Reid et al. 2007). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). WPS is not a port; therefore vessels will not release ballast water at this pathway. There is recreational but not commercial vessel traffic to the WPS from Lake Michigan (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: The species breeds from April to September/October (Kipp et al. 2011). Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–48.2°F) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006). Bloody red shrimp's relatively low fecundity (Ketelaars et al. 1999) suggests that it may have been present in the Great Lakes for a few years before being discovered.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers; the species is likely already at the pathway.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The species is established in Lake Michigan. The U.S. Geological Survey (USGS) documented the species one nautical mile (1.6 km) offshore of Jackson Harbor in 2007 and just south of Waukegan Harbor a half mile (0.8 km) offshore in 2006 (Kipp et al. 2011). Scientists believe the species has a wider distribution but has not been previously reported, because people either did not recognize it or simply did not see it. Bloody red shrimp are difficult to locate because they are nocturnal, preferring to hide

in rocky cracks and crevices near the bottom along the shoreline during the day (Reid et al. 2007).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Bloody red shrimp are normally found in lentic waters, although the bloody red shrimp has successfully established in European rivers (Kipp et al. 2011). The species prefers slow-moving waters, but has been found along rocky, wave-exposed shorelines (NOAA 2007). It inhabits a broad range of depths (Ricciardi et al. 2011), from 0.5 to 50 m (1.64 to 164 ft), although the species generally inhabits waters 6–10 m (19.7–32.8 ft) deep (Kipp et al. 2011). Water flow may limit the expansion of the organism; sampled areas where the bloody red shrimp was present had velocities ranging from 0 to 0.8 m/s (0 to 2.62 ft/s) (Marty 2007). The species prefers a temperature range of 9–20°C (48.2–68 °F) (Marty 2007) and is mainly found near shore (Walsh et al. 2010). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). It occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is a known establishment of bloody red shrimp less than 32 km (20 mi) from the WPS (section 2e). The rocky shoreline of the WPS is suitable habitat (section 2f). The species is documented to have a rapid invasion rate and the ability to disperse through the Great Lakes (section 2a). Human-mediated transport is not likely needed for the species to arrive at the WPS (section 2b). Bloody red shrimp may have arrived at WPS but have not yet been detected (section 2e). Therefore, the probability of the species arriving at WPS is high.
T_{10}: The species will likely be at the pathway entrance. The probability of the species arriving at WPS is high for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The species was identified as established in Lake Michigan in 2007 (Kipp et al. 2011). It has not yet been identified at WPS; however, whether the species has already arrived is unknown. Concealment behavior makes bloody red shrimp difficult to locate during the day, possibly explaining why it was not found earlier in the Great Lakes (section 2e). Overall, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: The species may be at the pathway entrance. The species' nocturnal behavior inhibits its detection. Therefore, the uncertainty related to the arrival of the bloody red shrimp is low for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). Bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). They are documented to have spread from eastern European rivers to western European rivers and to the United Kingdom in less than a decade (Ricciardi et al. 2011). Rapid growth and maturation facilitate its establishment in new habitats (Pothoven et al. 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
Historically, the species has been transported via ballast water (Reid et al. 2007). However, there is no commercial vessel traffic into the North Shore Channel (USACE 2011a); therefore, some natural downstream dispersal will likely be required for the bloody red shrimp to reach Brandon Road Lock and Dam. The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism. There is vessel traffic from the Chicago River to the Brandon Road Lock and Dam that could transport this species.

c. *Existing Physical Human/Natural Barriers*

T_0: The sluice gate at the WPS is a barrier that could retard natural dispersion. However, water is pumped from Lake Michigan into the North Shore Channel, which could transport the species. The maximum depth in the CAWS is about 10 m (32.8 ft) and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) in depth.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical and Climatological)*

T_0: The bloody red shrimp prefers slow-moving waters but has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents of 0–0.8 m/s (0–2.62 ft/s) velocity (Marty 2007). Most flows in the CAWS were lower than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways, which are designed to be straight and deep. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. In the North Shore Channel and the upper North Branch of the Chicago River in-stream there are partly shaded banks with aquatic plants, tree roots, and brush debris jams, and sediments are silt and sand (LimnoTech 2010). Toward downtown Chicago and in the Chicago River there is a reduction in in-stream habitat and a change to concrete and steel vertical banks, with sediments of concrete, silt, or sludge. Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2011). The Chicago Sanitary and Ship Canal has banks of bedrock and steel sheet piling leading to the Des Plaines River, which should be ideal habitat. Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi 2011).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water is pumped from Lake Michigan into the North Shore Channel, which could transport bloody red shrimp into the CAWS (section 3c). Natural dispersal will likely be required to move through the North Shore Channel (section 3b). The riparian banks of the North Shore Channel are not the ideal hard substrate habitat for the species; however, suitable habitat is present in most of the CAWS (section 3d). This species spread across several European rivers in less than a decade (section 3a). Therefore, its probability of passage for this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The downstream flow will assist the species in reaching suitable habitat. This species is documented to rapidly spread through canals (section 3a). However, the rate of spread through the CAWS is unknown. Overall, the uncertainty associated with passage during this time step is medium.
T_{10}: See T_0. Given time to naturally disperse, the bloody red shrimp is likely to pass through the pathway during this time step. Therefore, the uncertainty of passage during this time step is considered to be low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of spread, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The bloody red shrimp prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water

currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64–164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) in depth. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi 2011). Suitable habitat in the form of piers, ports, and riprap is present downstream of Brandon Road Lock and Dam.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via ballast water discharge.

Evidence for Probability Rating

Suitable habitat is present downstream of Brandon Road Lock and Dam. The bloody red shrimp may reach suitable habitat by natural dispersal or human-mediated transport. The probability of colonization by the bloody red shrimp is therefore considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Areas of natural vegetated banks are less likely to be suitable for the bloody red shrimp. The species prefers a hard substrate, which is present just downstream of Brandon Road Lock and Dam. Therefore, uncertainty of colonization by the species is considered to be low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011) and is widely distributed in Europe.

b. *Type of Mobility/Invasion Speed*
Bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). Rapid growth and maturation facilitate its establishment in new habitats (Pothoven et al. 2007). This species has limited dispersal capacity; it is an egg brooder, and can hardly swim upstream (Audzijonyte et al. 2008).

c. *Fecundity*
Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–49.2 °F) and produce two to four broods per year (Kipp & Ricciardi 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & HIetalahti 1993; Borcherding et al. 2006).

d. *History of Invasion Success*
In the middle of the twentieth century, Ponto-Caspian crustaceans were deliberately introduced to lakes and reservoirs in Eastern Europe with the intention of increasing fish production. A few decades later, several of the introduced species had extended their distribution to Western Europe and the Great Lakes Basin of North America (Marty 2007).

e. *Human-Mediated Transport through Aquatic Pathways*
The highest risk transport vector is ballast water movements (Reid et al. 2007). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The bloody red shrimp is documented to have potentially rapid establishment in new habitats (Pothoven et al. 2007). It prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents of 0–0.8 m/s (0–2.6 ft/s) velocity (Marty 2007). The bloody red shrimp is found in multiple large river basins in Europe, but flow velocity could limit the distribution of bloody red shrimp to low-flow areas within river systems (Ricciardi et al. 2011). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) in depth. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011). Suitable habitat may be present for the bloody red shrimp throughout the MRB, particularly in

river segments flowing through urbanized areas with heavily modified shorelines and manmade structures such as harbors, ports, and piers. These habitats are connected by flowing water and vessel traffic.

Evidence for Probability Rating

Natural species dispersal coupled with human-mediated dispersal via ballast water, may assist the species in spreading throughout the MRB; however, its distribution may be limited to urban areas (section 5f). While aquatic vegetation and areas with higher flow would not be suitable (section 5f), suitable habitat is present and accessible for the bloody red shrimp, which has a high invasion speed (sections 5a, 5b, 5d, 5f). Therefore, the probability of spread by the species is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Natural species dispersal coupled with human-mediated dispersal may assist the species in spreading throughout the MRB although its distribution may be limited to urban areas and areas with modified hard rocky shoreline (section 5f). While aquatic vegetation and areas with higher flow would not be suitable (section 5f), suitable habitat is present and accessible for the bloody red shrimp, which exhibits a high invasion speed (sections 5a, 5b, 5d, 5f). Overall, the uncertainty associated with the probability of spread is considered to be low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). Rapid growth and maturation facilitate the establishment of bloody red shrimp in new habitats (Pothoven et al. 2007). The species can naturally disperse through canals and river systems (Ricciardi et al. 2011). The species has a limited natural dispersal capacity, because it is an egg brooder (eggs are carried by adults, not free-floating) and can hardly swim upstream (Audzijonyte et al. 2008). Bloody red shrimp makes daily migrations in the water column. It was reported for the first time in 2006 from Lake Ontario and a channel connecting Muskegon Lake to Lake Michigan, and is now well distributed throughout at least four of the Great Lakes (Marty et al. 2010; Kipp et al. 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel transport is the primary dispersal mechanism in the spread of bloody red shrimp. Initially, the species spread by intentional transfer to freshwater bodies within the former Soviet Union. More recently, it has spread unintentionally by shipping through rivers and canals, and in ballast water (Kipp et al. 2011). The species spread from Europe to the United Kingdom in less than 10 years via shipping (Ricciardi et al. 2011). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism. There is commercial and recreational vessel traffic to the CRCW from the Great Lakes (USACE 2011a), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012).

c. *Current Abundance and Reproductive Capacity*

T_0: The species breeds from April to September/October (Kipp et al. 2011). Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–48.2 °F) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006). Bloody red shrimp's relatively low fecundity (Ketelaars et al. 1999) suggests that it may have been present in the Great Lakes for a few years before being discovered.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers; the species is likely already at pathway.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The species is established in Lake Michigan. The USGS documented the species one nautical mile (1.6 km) offshore of Jackson Harbor in 2007 and just south of Waukegan Harbor a half mile (0.8 km) offshore in 2006 (Kipp et al. 2011). Scientists believe the species has a wider distribution but its presence has not been previously reported because people either did not recognize it or simply did not see it. Bloody red shrimp are difficult to locate because they are nocturnal, preferring to hide in rocky cracks and crevices near the bottom along the shoreline during the day (Reid et al. 2007).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: This species is normally found in lentic waters, although the bloody red shrimp has successfully established in European rivers (Kipp et al. 2011). It prefers slow-moving waters, but has been found along rocky, wave-exposed shorelines (NOAA 2007). Bloody red shrimp inhabit a broad range of depths (Ricciardi et al. 2011) from 0.5 to 50 m (1.64 to 164 ft) (Kipp et al. 2011), although they generally inhabit waters 6–10 m deep (19.7–32.8 ft) (Kipp et al. 2011). Water flow may limit expansion of the organism; sampled areas where bloody red shrimp was present had velocities ranging from 0 to 0.8 m/s (0 to 2.62 ft/s) (Marty 2007). The species prefers temperature ranges of 9–20°C (48.2–68 °F) (Marty 2007) and is mainly found near shore (Walsh et al. 2010). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011). It occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). During daylight hours, swarms may hide in rock crevices,

boulders, piers, and jetties (Kipp et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is a known establishment of the species less than 32.2 km (10 mi) from CRCW near Jackson Harbor (section 2e). The piers and hard structures at the CRCW are ideal habitat (section 2f). The bloody red shrimp is documented to have a rapid invasion rate and the ability to disperse through the Great Lakes (section 2a). Human mediated transport is not likely needed for the species to arrive at CRCW (section 2b) but may occur due to the high vessel traffic from the GL into the Chicago River (USACE 2011b). Bloody red shrimp may have arrived at Burns Small Boat Harbor (BSBH) but not yet been detected (section 2e). Therefore, the probability of arrival of the species is judged to be high for this time step.
T_{10}: See T_0. The species will likely be at the pathway entrance. Therefore, the probability of arrival is expected to be high.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The species was identified as established in Lake Michigan in 2007 (Kipp et al. 2011). It has not yet been identified at the CRCW; however, whether the species has already arrived at the harbor is unknown. Concealment behavior makes the bloody red shrimp difficult to locate during the day, possibly explaining why it was not found earlier in the Great Lakes (section 2e). Overall, the uncertainty related to the arrival of the bloody red shrimp is considered to be low for this time step.
T_{10}: The species may be at the pathway entrance. The species' nocturnal behavior inhibits its detection. Therefore, the uncertainty of arrival of the bloody red shrimp is low for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). The bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). They are documented to have spread from eastern European to western European rivers and to the United Kingdom in less than a decade (Ricciardi et al. 2011). Rapid growth and maturation rates facilitate its establishment in new habitats (Pothoven et al. 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
The CRCW is heavily utilized by recreational, commercial, and cargo vessels. Based on averaging 2000 through 2010 data, the CRCW saw an average of 711,902 commercial passenger one-way trips and 41,071 non-cargo-vessel one-way trips (USACE 2011b). Historically, the species has been transported via ballast water (Reid et al. 2007). There is cargo vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011a). Ballast water is rarely discharged in inland ports of Illinois (NBIC 2012). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism.

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers. The maximum depth in the CAWS is about 10 m (32.8 ft) and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64–164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) deep.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The bloody red shrimp prefers slow-moving waters but has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents of 0–0.8 m/s (0–2.62 ft/s) velocity (Marty 2007). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways, which are designed to be straight and deep. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3–66.7 °F) (MWRD 2010). The banks of the CAWS are typically a mix of

stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. In the Chicago River there is little in-stream habitat and the banks are typically concrete and steel vertical walls, with sediments of concrete, silt, or sludge (LimnoTech 2010). Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009). The CSSC has banks of concrete and steel sheet piling leading to the Des Plaines River, which should be ideal habitat. Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Cargo vessel traffic from the CRCW may transport the species through the CAWS to Brandon Road Lock and Dam (section 3c). This species spread across several European rivers in less than a decade (section 3a). Suitable habitat is present in the CAWS (section 3d). Since the passage through the harbor is open water, the bloody red shrimp may be able to drift through the pathway with the current as documented in literature (section 3a). Overall, its probability of the passage is considered to be high for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: There is heavy vessel traffic in the CAWS and this species can be transported in ballast water. This species is documented to rapidly spread through canals (section 3a). However, the rate of spread through the CAWS is uncertain. Overall, the uncertainty associated with passage during this time step is medium.

T_{10}: See T_0. Given time to naturally disperse, the bloody red shrimp is likely to pass through the pathway during this time step. Therefore, the uncertainty of passage during this time step is considered to be low.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The bloody red shrimp prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents of 0–0.8 m/s (0–2.62 ft/s) velocity (Marty 2007). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) deep. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittman & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011). Suitable habitat in the form of piers, harbors, ports- and riprap is present downstream of Brandon Road Lock and Dam. The bloody red shrimp is documented to have potentially rapid establishment in new habitats (Pothoven et al. 2007).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via ballast water.

Evidence for Probability Rating

Suitable habitat is present downstream of Brandon Road Lock and Dam. The bloody red shrimp may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, the bloody red shrimp is considered to have a high probability of colonization.

Uncertainty: LOW

Evidence for Uncertainty Rating

Areas of natural vegetated banks are less likely to be suitable for the bloody red shrimp. The species prefers a hard substrate, which is present just downstream of Brandon Road Lock and Dam. Overall, the uncertainty of bloody red shrimp's colonization is considered to be low.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.
Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
Bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011) and is widely distributed in Europe.

b. *Type of Mobility/Invasion Speed*
The bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). Rapid growth and maturation rates facilitate its establishment in new habitats (Pothoven et al. 2007). It has limited dispersal capacity; it is an egg brooder, and can hardly swim upstream (Audzijonyte et al. 2008).

c. *Fecundity*
Sexual maturity occurs in less than 45days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–49.2 °F) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006).

d. *History of Invasion Success*
In the middle of the twentieth century, Ponto-Caspian crustaceans were deliberately introduced to lakes and reservoirs in Eastern Europe with the intention of increasing fish production. A few decades later, several of the introduced species had extended their distribution to Western Europe and the Great Lakes Basin of North America (Marty 2007).

e. *Human-Mediated Transport through Aquatic Pathways*
The highest risk transport vector is ballast water movements (Reid et al. 2007). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

The bloody red shrimp is documented to have potentially rapid establishment in new habitats (Pothoven et al. 2007). It prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.6 ft/s) (Marty 2007). The bloody red shrimp is found in multiple large river basins in Europe, but flow velocity could limit the distribution of bloody red shrimp to low-flow areas within river systems (Ricciardi et al. 2011). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) deep (Kipp et al. 2011). The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant, or scarce, in areas of dense vegetation or high siltation (Kipp et al. 2011). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011). Suitable habitat may be present for the bloody red shrimp throughout the MRB, particularly in river segments flowing through urbanized areas with heavily modified shorelines and manmade structures such as harbors, ports, and piers. These habitats are connected by flowing water and vessel traffic.

Evidence for Probability Rating

Natural species dispersal coupled with human-mediated dispersal via ballast water discharge, may assist the species in spreading throughout the MRB; however, its distribution may be limited to urban areas and areas with modified hard rocky shoreline. While aquatic vegetation and areas with higher flow would not be suitable (section 5f), suitable habitat is present and accessible, and bloody red shrimp have exhibited a high invasion speed (sections 5a, 5b, 5d, 5f). Therefore, its probability of spread is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. However, natural vegetated banks are not ideal habitat for the species; a hard substrate is preferred. There is heavy vessel traffic in the MRB and this species can be transported in ballast water. Overall, the uncertainty associated with the species' spread is considered to be low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). Rapid growth and maturation facilitate the establishment of bloody red shrimp in new habitats (Pothoven et al. 2007). The species can naturally disperse through canals and river systems (Ricciardi et al. 2011). The species has a limited natural dispersal capacity, because it is an egg brooder (eggs are carried by adults, not free-floating) and can hardly swim upstream (Audzijonyte et al. 2008). Bloody red shrimp makes daily migrations in the water column. It was reported for the first time in 2006 from Lake Ontario and from a channel connecting

Muskegon Lake to Lake Michigan, and is now well distributed throughout at least four of the Great Lakes (Marty et al. 2010; Kipp et al. 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel transport is the primary dispersal mechanism in the spread of bloody red shrimp. Initially, the species spread by intentional transfer to freshwater bodies within the former Soviet Union. More recently, it has spread unintentionally by shipping through rivers and canals, and in ballast water (Kipp et al. 2011). It spread from Europe to the United Kingdom in less than 10 years via shipping (Ricciardi et al. 2011). The highest risk transport vector is ballast water movement (Reid et al. 2007). There is heavy commercial vessel traffic to Calumet Harbor from Lake Michigan (USACE 2011a), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: The species breeds from April to September/October (Kipp et al. 2011). Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–48.2 °F) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006). Bloody red shrimp's relatively low fecundity (Ketelaars et al. 1999) suggests that it may have been present in the Great Lakes for a few years before being discovered.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers; the species is likely already at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The species is established in Lake Michigan. The USGS documented the species one nautical mile (1.6 km) offshore of Jackson Harbor in 2007 and just south of Waukegan Harbor a half mile (0.8 km) offshore in 2006 (Kipp et al. 2011). Scientists believe the species has a wider distribution, but its presence has not been previously reported because people either did not recognize it or simply did not see it. Bloody red shrimp are difficult to locate because they are nocturnal, preferring to hide in rocky cracks and crevices near the bottom along the shoreline during the day (Reid et al. 2007).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Bloody red shrimp are normally found in lentic waters, although the bloody red shrimp has successfully established in European rivers (Kipp et al. 2011). The species prefers slow-moving waters, but has been found along rocky, wave-exposed shorelines (NOAA 2007). It inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although the species generally inhabits waters 6–10 m (19.7–32.8 ft) in depth (Kipp et al. 2011). Water flow may limit expansion of the organism; sampled areas where the bloody shrimp was present had velocities ranging from 0 to 0.8 m/s (0 to 2.62 ft/s) (Marty 2007). The species prefers a temperature range of 9–20°C (48.2–68 °F) (Marty 2007) and is mainly found near shore (Walsh et al. 2010). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). It occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is a known establishment of the species less than 32.2 km (10 mi) from Calumet Harbor near Jackson Harbor (section 2e). The rocky shores surrounding Calumet Harbor are ideal habitat (section 2f). The bloody red shrimp is documented to have a rapid invasion rate and the ability to disperse through the Great Lakes (section 2a). Human mediated transport is not likely needed for the species to arrive at Calumet Harbor (section 2b). Bloody red shrimp may have already arrived at Calumet Harbor but not yet been detected (section 2e). Therefore, the species is considered to have a high probability of arrival during this time step.

T_{10}: The species will likely be at the pathway entrance. It is therefore considered to have a high probability of arrival.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The species was identified as established in Lake Michigan in 2007 (Kipp et al. 2011). It has not yet been identified at Calumet Harbor; however, whether the species has already arrived at the harbor is unknown. Concealment behavior makes the bloody red shrimp difficult to locate during the day, possibly explaining why it was not found earlier in the Great Lakes (section 2e). Overall, the uncertainty associated with the species' arrival is deemed to be low for this time step.
T_{10}: The species may be at the pathway entrance. The species' nocturnal behavior inhibits its detection. Therefore, the uncertainty of arrival for this species is considered to be low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). Bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). They are documented to have spread from eastern European to western European rivers and to the United Kingdom in less than a decade (Ricciardi et al. 2011). Rapid growth and maturation facilitate its establishment in new habitats (Pothoven et al. 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
Historically, the species has been transported via ballast water (Reid et al. 2007). Commercial vessel traffic to Calumet Harbor is lakewise (NBIC 2012), but there is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Although bloody red shrimp can be transported in ballast water (Kipp et al. 2011), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism.

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers. The typical depth in the CAWS is around 5 m (16.4 ft), with the maximum depth at about 10 m (32.8 ft) (LimnoTech 2010). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) deep (Kipp et al. 2011).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The bloody red shrimp prefers slow-moving waters but has been found along rocky, wave exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s), with the highest at 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways, which are designed to be straight and deep. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. In the Calumet River there is in-stream habitat for aquatic life in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches. Urban industrial and commercial riparian land use is also present. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The Calumet Sag Channel and Chicago Sanitary and Ship Canal have banks of bedrock and steel sheet piling leading to the Des Plaines River, which should be ideal habitat. Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Cargo vessel traffic from T.J. O'Brien Lock and Dam south of Calumet Harbor may transport the species through the CAWS to Brandon Road Lock and Dam (section 3c). This species spread across several European rivers in less than a decade (section 3a). Suitable habitat is present in the CAWS (section 3d). Since the passage through the harbor is open water, the bloody red shrimp may be able to drift through the pathway with current as documented in literature (section 3a). Overall, the bloody red shrimp is considered to have a high probability of passage during this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: There is heavy vessel traffic in the CAWS; however, the probability and speed of vessel transport in the CAWS for bloody red shrimp is not documented. This species is documented to rapidly spread through canals (section 3a). However, the rate of spread through the CAWS is uncertain. Therefore, the uncertainty of passage is considered to be medium during this time step.

T_{10}: See T_0. Given time to naturally disperse, the bloody red shrimp is likely to pass through the pathway during this time step. Therefore, the uncertainty of passage during this time step is considered to be low.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

The bloody red shrimp prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents of 0–0.8 m/s (0–2.62 ft/s) velocity (Marty 2007). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.61 to 164 ft/s) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft/s) deep (Kipp et al. 2011). The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties

(Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011). Suitable habitat in the form of piers, harbors, ports, and riprap is present downstream of Brandon Road Lock and Dam. The bloody red shrimp is documented to have rapid establishment in new habitats (Pothoven et al. 2007).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse to suitable habitat downstream with the current or use human-mediated transport via ballast water.

Evidence for Probability Rating

Suitable habitat is present downstream of Brandon Road Lock and Dam. The bloody red shrimp may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, its probability of colonization is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Areas with naturally vegetated banks are less likely to be suitable for the bloody red shrimp. The species prefers a hard substrate, which is just downstream of Brandon Road Lock and Dam. Overall, however, the uncertainty of colonization is considered to be low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011) and is widely distributed in Europe.

b. *Type of Mobility/Invasion Speed*
The bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). Rapid growth and maturation rates facilitate its establishment in new habitats (Pothoven et al. 2007). This species has limited dispersal capacity; it is an egg brooder, and can hardly swim upstream (Audzijonyte et al. 2008).

c. *Fecundity*
Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–49.2 °F) and produce two to four broods per year

(Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006).

d. *History of Invasion Success*
In the middle of the twentieth century, Ponto-Caspian crustaceans were deliberately introduced to lakes and reservoirs in Eastern Europe with the intention of increasing fish production. A few decades later, several of the introduced species had extended their distribution to Western Europe and the Great Lakes Basin of North America (Marty 2007).

e. *Human-Mediated Transport through Aquatic Pathways*
The highest risk transport vector is ballast water movements (Reid et al. 2007). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower Mississippi River Basin (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The bloody red shrimp is documented to have rapid establishment in new habitats (Pothoven et al. 2007). It prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.6 ft/s) (Marty 2007). The bloody red shrimp is found in multiple large river basins in Europe, but flow velocity could limit the distribution of bloody red shrimp to low-flow areas within river systems (Ricciardi et al. 2011). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft/s) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft/s) deep (Kipp et al. 2011). The species prefers water temperatures of 9–20°C (48.2–68°F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011). Suitable habitat is potentially present for the bloody red shrimp throughout the MRB, particularly in river segments flowing through urbanized areas with heavily modified shorelines and manmade structures such as harbors, ports, and piers. These habitats are connected by flowing water and vessel traffic.

Evidence for Probability Rating

Natural species dispersal coupled with human-mediated dispersal, may assist the species in spreading throughout the MRB; however, its distribution may be limited to urban areas and areas with modified hard rocky shoreline. While aquatic vegetation and areas with higher flow would not be suitable (section 5f), suitable habitat is present and accessible for the bloody red shrimp, which exhibits a high invasion speed (sections 5a, 5b, 5d, 5f). As a result, the probability of spread by the bloody red shrimp is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. However, natural vegetated banks are not ideal habitat for the species; a hard substrate is preferred. There is heavy vessel traffic in the MRB, and this species can be transported in ballast water. Overall, the uncertainty associated with its spread is considered to be low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Medium	High	High	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). Rapid growth and maturation facilitate the establishment of bloody red shrimp in new habitats (Pothoven et al. 2007). The species can naturally disperse through canals and river systems (Ricciardi et al. 2011). The species has a limited natural dispersal capacity, because it is an egg brooder (eggs are carried by adults, not free-floating) and can hardly swim upstream (Audzijonyte et al. 2008). Bloody red shrimp makes daily migrations in the water column. It was reported for the first time in 2006 from Lake Ontario and from a channel connecting Muskegon Lake to Lake Michigan, and is now well distributed throughout at least four of the Great Lakes (Marty et al. 2010; Kipp et al. 2011).

b. Human-Mediated Transport through Aquatic Pathways

Vessel transport is the primary dispersal mechanism in the spread of bloody red shrimp. Initially, the species spread by intentional transfer to freshwater bodies within the former Soviet Union. More recently, it has spread unintentionally by shipping through rivers and canals, and in ballast water (Kipp et al. 2011). The species spread from Europe to the United Kingdom in less than 10 years via shipping (Ricciardi et al. 2011). The highest risk transport vector is ballast water movement (Reid et al. 2007). There is commercial vessel traffic to the Indiana Harbor from the Great Lakes (USACE 2011a), and many of these boats discharge ballast water from other ports in the Great Lakes (NBIC 2012). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism.

c. Current Abundance and Reproductive Capacity

T_0: The species breeds from April to September/October (Kipp et al. 2011). Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–48.2 °F) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006). Bloody red shrimp's relatively low fecundity (Ketelaars et al. 1999) suggests that it may have been present in the Great Lakes for a few years before being discovered.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers; the species is likely already at pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: The species is established in Lake Michigan. The USGS documented the species one nautical mile (1.6 km) offshore of Jackson Harbor in 2007 and just south of Waukegan Harbor a half mile (0.8 km) offshore in 2006 (Kipp et al. 2011). Scientists believe the species has a wider distribution, but its presence has not been previously reported because people either did not recognize it or simply did not see it. Bloody red shrimp are difficult to locate because they are nocturnal, preferring to hide in rocky cracks and crevices near the bottom along the shoreline during the day (Reid et al. 2007).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The species is normally found in lentic waters, although the bloody red shrimp has successfully established in European rivers (Kipp et al. 2011). It prefers slow-moving waters, but has been found along rocky, wave-exposed shorelines (NOAA 2007). The species inhabits a broad range of depths (Ricciardi et al. 2011) from 0.5 to 50 m (1.64 to 164 ft) (Kipp et al. 2011), although it generally inhabits waters 6–10 m deep (19.7–32.8 ft) (Kipp et al. 2011). Water flow may limit the expansion of the organism; sampled areas where the bloody red shrimp was present had flow rates with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). The species prefers temperature ranges of 9–20°C (48.2–68 °F) (Marty 2007) and is mainly found near shore (Walsh et al. 2010). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011). It occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is a known establishment of the species less than 24.1 km (15 mi) from Indiana Harbor near Jackson Harbor, IL (section 2e). The rock or hard shoreline around Indiana Harbor is ideal habitat (section 2f). The bloody red shrimp is documented to have a rapid invasion rate and the ability to disperse through the Great Lakes (section 2a). Human mediated transport is not likely needed for the species to arrive at Indiana Harbor but may occur due to the high vessel traffic into Indiana Harbor (section 2b). Bloody red shrimp may have already arrived at Indiana Harbor but not yet been detected (section 2e). Therefore, the species is considered to have a high probability of arrival during this time step.
T_{10}: The species will likely be at the pathway entrance. It is therefore considered to have a high probability of arrival.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The species was identified as established in Lake Michigan in 2007 (Kipp et al. 2011). It has not yet been identified at Indiana Harbor; however, whether the species has already arrived at the harbor is unknown. Concealment behavior makes the bloody red shrimp difficult to locate during the day, possibly explaining why it was not found earlier in the Great Lakes (section 2e). Overall, the uncertainty associated with the species' arrival is deemed to be low for this time step.
T_{10}: The species may be at the pathway entrance. The species' nocturnal behavior inhibits its detection. Therefore, the uncertainty of arrival for this species is considered to be low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). This species has limited dispersal capacity; it is an egg brooder, and can hardly swim upstream (Audzijonyte et al. 2008). However, the bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). They are documented to have spread from eastern European to western European rivers and

to the United Kingdom in less than a decade (Ricciardi et al. 2011). Rapid growth and maturation rates facilitate its establishment in new habitats (Pothoven et al. 2007).

b. *Human-Mediated Transport through Aquatic Pathways*
Historically, the species has been transported via ballast water (Reid et al. 2007). Most commercial vessel traffic to Indiana Harbor is lakewise and ballast water is rarely discharged in inland ports of Illinois (NBIC 2012). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism. The Grand Calumet River is too shallow for vessel traffic. There is vessel traffic from the Calumet River to Brandon Road Lock and Dam (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: None. The maximum depth in the CAWS is about 10 m (32.8 ft), and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) deep. Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. However, this species could go around the sheet pile during flood conditions.
T_{10}: None.
T_{25}: None.
T_{50}: None.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern-most sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus the bloody red shrimp would have to swim upstream to enter the CAWS and move to the Calumet Sag Channel. The bloody red shrimp prefers slow-moving waters but has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways, which are designed to be straight and deep. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. Conditions at the Indiana Harbor are highly industrialized. In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). The Calumet Sag Channel and the Little Calumet River also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). The Calumet Sag Channel and Chicago

Sanitary and Ship Canal have banks of bedrock and steel sheet piling leading to the Des Plaines River, which should be ideal habitat. Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present in the CAWS (section 3d); and the species has spread across several European rivers in less than a decade (section 3a). The bloody red shrimp is not likely to move upstream through Indiana Harbor and the Grand Calumet River (sections 3a, 3d). The lack of vessel transport on the Grand Calumet would limit the potential for human-mediated transport through the upstream flow. Overall, the bloody red shrimp is considered to have a low probability of passage during this time step.
T_{10}: See T_0.
T_{25}: See T_0. Given time to disperse naturally or by vessel traffic (once it reaches the Calumet Sag Channel) the bloody red shrimp may pass at this time step. The species can actively swim and the low flow of the Grand Calumet may allow the species to traverse the upstream flow. Therefore, the probability of passage for this time step is medium.
T_{50}: See T_{25}. The probability of passage is likely to increase with time. The bloody red shrimp may pass through the pathway given 50 years. Therefore, the probability at this time step is high.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: The bloody red shrimp is not a strong swimmer, and the upstream flow direction and lack of vessel transport in the Grand Calumet River would inhibit dispersal toward Brandon

Road Lock and Dam (section 3d). For these reasons, the uncertainty associated with passage is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take the bloody red shrimp to pass upstream through Indiana Harbor and the Grand Calumet River or if the species is capable of such movement. Therefore, the uncertainty of passage is high for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The bloody red shrimp prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64–164 ft/s) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) deep (Kipp et al. 2011). The species prefers water temperatures of 9–20°C (48.2–68°F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011). Suitable habitat in the form of piers, harbors, ports, and riprap is present downstream of Brandon Road Lock and Dam. The bloody red shrimp is documented to have rapid establishment in new habitats (Pothoven et al. 2007).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via ballast water.

Evidence for Probability Rating

Natural species dispersal coupled with human-mediated dispersal via ballast water discharge, may assist the species in spreading throughout the MRB; however, its distribution may be limited to urban areas and areas with hard rocky shoreline (section 4f). While aquatic vegetation and areas with higher flow would not be suitable (section 4f), suitable habitat is present and accessible for the bloody red shrimp, which exhibits a high invasion speed (sections 4a, 4b, 4d, 4f). Therefore, its probability of colonization is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Natural vegetated banks are less likely to be suitable for the bloody red shrimp. The species prefers a hard substrate, which is present just downstream of Brandon Road Lock and Dam. Overall, however, the uncertainty of colonization is considered to be low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the pathway. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
Bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011) and is widely distributed in Europe.

b. Type of Mobility/Invasion Speed
The bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). Rapid growth and maturation facilitate its establishment in new habitats (Pothoven et al. 2007). This species has limited dispersal capacity; it is an egg brooder, and can hardly swim upstream (Audzijonyte et al. 2008).

c. Fecundity
Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–49.2 °F) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006).

d. History of Invasion Success
In the middle of the twentieth century, Ponto-Caspian crustaceans were deliberately introduced to lakes and reservoirs in Eastern Europe with the intention of increasing fish production. A few decades later, several of the introduced species had extended their distribution to Western Europe and the Great Lakes Basin of North America (Marty 2007).

e. *Human-Mediated Transport through Aquatic Pathways*
The highest risk transport vector is ballast water movements (Reid et al. 2007). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower Mississippi River Basin (USACE 2011a).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The bloody red shrimp is documented to have rapid establishment in new habitats (Pothoven et al. 2007). It prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). The bloody red shrimp is found in multiple large river basins in Europe, but flow velocity could limit the distribution of bloody red shrimp to low-flow areas within river systems (Ricciardi et al.2011). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64–164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) deep. The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).

Evidence for Probability Rating

The species has a high invasion speed (sections 5a, 5b, 5d, 5f). Natural species dispersal coupled with human-mediated dispersal via ballast water , may assist the species in spreading throughout the MRB; however, its distribution may be limited to urban areas. While aquatic vegetation and areas with higher flow would not be suitable (section 5f), suitable habitat is present and accessible for the bloody red shrimp. As a result, the probability of spread by the bloody red shrimp is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. However, natural vegetated banks are not ideal habitat for the species; a hard substrate is preferred. There is heavy vessel traffic in the MRB, and this species can be transported in ballast water. Overall, the uncertainty associated with its spread is considered to be low.

PATHWAY : 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Low	Low	Low	Medium	High	High	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). Rapid growth and maturation facilitate the establishment of bloody red shrimp in new habitats (Pothoven et al. 2007). The species can naturally disperse through canals and river systems (Ricciardi et al. 2011). The species has a limited natural dispersal capacity, because it is an egg brooder (eggs are carried by adults, not free-floating) and can hardly swim upstream (Audzijonyte et al. 2008). It was reported for the first time in 2006 from Lake Ontario and from a

channel connecting Muskegon Lake to Lake Michigan, and is now well distributed throughout at least four of the Great Lakes (Marty et al. 2010; Kipp et al. 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel transport is the primary dispersal mechanism in the spread of bloody red shrimp. Initially, the species spread by intentional transfer to freshwater bodies within the former Soviet Union. More recently, it has spread unintentionally by shipping through rivers and canals, and in ballast water (Kipp et al. 2011). The species spread from Europe to the United Kingdom in less than 10 years via shipping (Ricciardi et al. 2011). The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism. The highest risk transport vector is ballast water movement (Reid et al. 2007). There is recreational but not commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a,b). However, there is heavy lakewise commercial traffic to the adjacent Burns Harbor.

c. *Current Abundance and Reproductive Capacity*
T_0: The species breeds from April to September/October (Kipp et al. 2011). Sexual maturity occurs in <45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–48.2 °F) (Marty et al. 2010) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006). Bloody red shrimp's relatively low fecundity (Ketelaars et al. 1999) suggests that it may have been present in the Great Lakes for a few years before being discovered.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers, as it is likely to have already arrived at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The species is established in Lake Michigan. The U.S. Geological Survey (USGS) documented the species one nautical mile (1.6 km) offshore of Jackson Harbor in 2007 and just south of Waukegan Harbor a half mile (0.8 km) offshore in 2006 (Kipp et al. 2011). Scientists believe the species has a wider distribution but its presence has not been previously reported because people either did not recognize it or simply did not see it. Bloody red shrimp are difficult to locate because they are nocturnal, preferring to hide in rocky cracks and crevices near the bottom along the shoreline during the day (Reid et al. 2007).
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Bloody red shrimp are normally found in lentic waters, although the shrimp has successfully established itself in European rivers (Kipp et al. 2011). The species prefers slow-moving waters, but has been found along rocky, wave-exposed shorelines (NOAA 2007). It inhabits a broad range of depths (Ricciardi et al. 2011) 0.5 to 50 m (1.64–164 ft), although it generally inhabits waters 6–10 m (19.7–32.8 ft) in depth (Kipp et al. 2011). Water flow may limit the expansion of the organism, with 0–0.8 m/s (0–2.62 ft/s) being the minimum and maximum velocities of sampled areas where the bloody red shrimp were present (Marty 2007). The species prefers temperatures in the range of 9–20°C (48.2–68°F) (Kipp et al. 2011) and is mainly found near shore (Walsh et al. 2010). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). It occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is a known establishment of the species less than 56.3 km (35 mi) from BSBH (section 2e). The rocky shore surrounding BSBH is ideal habitat (section 2f). The species is documented to have a rapid invasion rate and the ability to disperse through the Great Lakes (section 2a). Human mediated transport is not likely needed for the species to arrive at BSBH (section 2b). Bloody red shrimp may have arrived at BSBH but not yet been detected (section 2e). Therefore, the species is considered to have a high probability of arrival during this time step.
T_{10}: The species will likely be at the pathway entrance. It is therefore considered to have a high probability of arrival.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The species was identified as established in Lake Michigan in 2007 (Kipp et al. 2011). It has not yet been identified at BSBH; however, whether the species has already arrived at the harbor is unknown. Concealment behavior makes the bloody red shrimp difficult to locate during the day, possibly explaining why it was not found earlier in the Great Lakes (section 2e). Overall, the uncertainty associated with the species' arrival is deemed to be low for this time step.
T_{10}: The species may be at the pathway entrance. The species' nocturnal behavior inhibits detection. Therefore, the uncertainty of arrival for this species is considered to be low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Bloody red shrimp is benthic and planktonic and makes daily vertical migrations in the water column (Kipp et al. 2011). This species has limited dispersal capacity; it is an egg brooder, and can hardly swim upstream (Audzijonyte et al. 2008). However, the bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). They are documented to have spread from eastern European to western European rivers and to the United Kingdom in less than a decade (Ricciardi et al. 2011). Rapid growth and maturation facilitate its establishment in new habitats (Pothoven et al. 2007).

b. Human-Mediated Transport through Aquatic Pathways
Historically, the species has been transported via ballast water (Reid et al. 2007). Vessel traffic to BSBH is lakewise. Although bloody red shrimp could move to the adjacent Burns Harbor (which does have commercial vessel traffic), there is no commercial vessel from the Burns Harbor to inland ports in the CAWS (NBIC 2012). Therefore, some natural downstream dispersal will likely be required to reach Brandon Road Lock and Dam. Recreational boating traffic through BSBH, Burns Ditch and the south branch of Little Calumet River is very minor due to the shallow depth. The bloody red shrimp is a free swimming species that inhabits bottom habitats and the water column. Given its life history, transport on boat hulls would not be characteristic of this species, and no evidence was found in the literature documenting hull fouling as a significant transport mechanism.

c. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers. The maximum depth in the CAWS is about 10 m (32.8m) and depth is typically around 5 m (16.4 ft) (LimnoTech 2010). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) in depth (Kipp et al. 2011).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Water flows out of BSBH into Lake Michigan. The eastern segment of the south branch Little Calumet River also generally flows toward Lake Michigan (GSWMD 2008). Thus the bloody red shrimp would have to swim upstream to enter the CAWS and move to the Calumet Sag Channel. The bloody red shrimp prefers slow-moving waters but has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). Most flows in the CAWS were lower than 0.15 m/s (0.49 ft/s), and the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010). The habitat in the CAWS consists of mostly (about 75%) manmade waterways, which are designed to be straight and deep (LimnoTech 2010). The species prefers water temperatures of 9–20°C (48.2–68°F) (Kipp et al. 2011). The water temperature in the CAWS averages from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010). The banks of the CAWS are typically a mix of stone blocks, steel sheet piling, and earthen banks with vegetation. Riprap banks are common throughout the CAWS. The banks of the BSBH are primarily riprap and vertical walls. The banks of the south leg of the Little Calumet River are vegetated, and sediments include plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). The Calumet Sag Channel and Chicago Sanitary and Ship Canal have banks of bedrock and steel sheet piling leading to the Des Plaines River, which should be ideal habitat. Sediments in the CAWS can range from gravel to soft sediment (LimnoTech 2010). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011; Wittmann & Ariani 2009). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present in the CAWS (section 3d). The bloody red shrimp is not likely to move upstream through BSBH and the south branch of the Little Calumet River. The lack of vessel traffic on the Little Calumet River would limit the potential for human-mediated transport through the upstream flow. Overall, the bloody red shrimp is considered to have a low probability of passage during this time step.
T_{10}: See T_0.
T_{25}: See T_0. Given time to disperse naturally or by vessel traffic (once it reaches the Calumet Sag Channel) the bloody red shrimp may pass at this time step. The species can actively swim and the low flow of the Little Calumet may allow the species to traverse the upstream flow. Therefore, the probability of passage for this time step is medium.
T_{50}: See T_{25}. The probability of passage is likely to increase with time. The bloody red shrimp may pass through the passage given 50 years. Therefore, the probability at this time step is high.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	High	High

Evidence for Uncertainty Rating

T_0: The bloody red shrimp is not a strong swimmer, and the upstream flow direction and lack of vessel transport in the south branch of the Little Calumet River would inhibit dispersal of this species to Brandon Road Lock and Dam (section 3d). Overall, the uncertainty of passage is considered to be low during this time step.
T_{10}: See T_0.
T_{25}: See T_0. It is uncertain how long it would take the bloody red shrimp to pass upstream through the BSBH and the Little Calumet River or if the species is capable of such movement. Therefore, the uncertainty of passage is high for this time step.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The bloody red shrimp prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) in depth (Kipp et al. 2011). The species prefers water temperatures of 9–20°C (48.2–68 °F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011). During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011). Suitable habitat in the form of piers, harbors, ports, and riprap is present downstream of Brandon Road Lock and Dam. The bloody red shrimp is documented to have rapid establishment in new habitats (Pothoven et al. 2007).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   The species can naturally disperse downstream with the current to suitable habitat or use human-mediated transport via ballast water.

Evidence for Probability Rating

Suitable habitat is present downstream of Brandon Road Lock and Dam. The bloody red shrimp may reach suitable habitat by natural dispersal or human-mediated transport. Therefore, its probability of colonization is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Areas of natural vegetated banks are less likely to be suitable for the bloody red shrimp. The species prefers a hard substrate, which is present just downstream of Brandon Road Lock and Dam. Overall, however, the uncertainty of colonization is considered to be low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011) and is widely distributed in Europe.

b. *Type of Mobility/Invasion Speed*
The bloody red shrimp can disperse through canals and river systems (Ricciardi et al. 2011). Rapid growth and maturation rates facilitate its establishment in new habitats (Pothoven et al. 2007). This species has limited dispersal capacity; it is an egg brooder, and can hardly swim upstream (Audzijonyte et al. 2008).

c. *Fecundity*
Sexual maturity occurs in less than 45 days (Kipp et al. 2011). Females become ovigerous at 8–9°C (46.4–49.2 °F) and produce two to four broods per year (Kipp et al. 2011). Brood size is correlated with female length and ranges from 6 to 70 embryos per individual (Ketelaars et al. 1999; Salemaa & Hietalahti 1993; Borcherding et al. 2006).

d. *History of Invasion Success*
In the middle of the twentieth century, Ponto-Caspian crustaceans were deliberately introduced to lakes and reservoirs in Eastern Europe with the intention of increasing fish production. A few decades later, several of the introduced species had extended their distribution to Western Europe and the Great Lakes Basin of North America (Marty 2007).

e. *Human-Mediated Transport through Aquatic Pathways*
The highest risk transport vector is ballast water movement (Reid et al. 2007). There is heavy vessel traffic between the Brandon Road Lock and Dam and the Lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The bloody red shrimp is documented to have rapid establishment in new habitats (Pothoven et al. 2007). It prefers slow-moving waters and has been found along rocky, wave-exposed shorelines (NOAA 2007). The species has been identified in water currents with velocities of 0–0.8 m/s (0–2.62 ft/s) (Marty 2007). The bloody red shrimp is found in multiple large river basins in Europe, but flow velocity could limit the distribution of bloody red shrimp to low-flow areas within river systems (Ricciardi et al. 2011). The bloody red shrimp inhabits a broad range of depths from 0.5 to 50 m (1.64 to 164 ft) (Ricciardi et al. 2011), although it generally inhabits waters 6–10 m (19.7–32.8 ft) in depth (Kipp et al. 2011). The species prefers water temperatures of 9–20°C (48.2–68°F) (Kipp et al. 2011). The bloody red shrimp occurs most frequently on hard bottom substrates including rocks; less frequently on sand, silt, or mud; and least frequently in the soft bottom profundal (Pothoven et al. 2007). The species is less abundant or scarce in areas of dense vegetation or high siltation (Kipp et al. 2011).

During daylight hours, swarms may hide in rock crevices, boulders, piers, and jetties (Kipp et al. 2011; Ricciardi et al. 2011). The concealment behavior of the species indicates a preference for slow-moving waters (Marty 2007). Swarms are often found in shaded areas near piers and jetties (Ricciardi et al. 2011). The bloody red shrimp can tolerate a broad range of physicochemical conditions (Ricciardi et al. 2011).

Evidence for Probability Rating

Natural species dispersal coupled with human-mediated dispersal via ballast water may assist the species in spreading throughout the MRB; however, its distribution may be limited to urban areas and areas with modified hard rocky shoreline. While aquatic vegetation and areas with higher flow would not be suitable (section 5f), suitable habitat is present and accessible for the bloody red shrimp, which exhibits a high invasion speed (sections 5a, 5b, 5d, 5f). As a result, the probability of spread by the bloody red shrimp is considered to be high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat is present throughout the MRB. However, natural vegetated banks are not ideal habitat for the species; a hard substrate is preferred. There is heavy vessel traffic in the MRB, and this species can be transported in ballast water. Overall, the uncertainty associated with its spread is considered to be low.

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E.2.6.4 Parasitic Copepod - *Neoergasilus japonicas*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Medium	Medium	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*

The species appears to disperse over long distances (probably via both natural and human-mediated mechanisms) rather quickly, spreading across Europe in 20 years and then moving to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living in the water column (Hayden & Rogers 1998). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 1998). The species also has great swimming capabilities and can transfer from one host to another (Hudson & Bowen 2002).

b. Human-Mediated Transport through Aquatic Pathways

The means of introduction for *N. japonicas* to North America are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). The vast majority of ballast water discharged at CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). However, there is no commercial vessel traffic to WPS, but there is recreational vessel traffic (USACE 2011a,b).

c. Current Abundance and Reproductive Capacity

T_0: This species has a rapid reproductive cycle with females capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Spermatozoids can likely be retained for a period of diapause (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway

T_0: Of all recorded species in the genus *Neoergasilus*, *N. japonicas* has the widest geographic distribution (Hayden & Rogers 1998). In 1994, in Saginaw Bay, a southwestern extension of Lake Huron, four species of fish (fathead minnow, *Pimephales promelas*; largemouth bass, *Micropterus salmoides*; pumpkinseed sunfish, *Lepomis gibbosus*; and yellow perch, *Perca flavescens*) were collected with *N. japonicas* (Hudson & Bowen 2002). This ectoparasite is relatively small (0.6–1.0 mm; 0.02–0.04 in.) and probably not obvious to researchers. Field attempts to identify the species using 3 times magnification were suspect (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish. No recent surveys of fish in Lake Michigan were found, so the species' distance from the pathway is not well documented.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). Free-living individuals (i.e., larvae, males, and immature females) feed on algae and zooplankton (Hudson & Bowen 2002; Baud et al. 2004). Gravid females are parasitic, attaching to the fins of freshwater fish species and feeding on their tissue (Abdelhalim et al. 1993). In Lake Huron, it usually attaches to adult fish hosts (Hudson & Bowen 2002; Jordan et al. 2009), most frequently to the dorsal fin (Hudson & Bowen 2002). Host fishes include largemouth bass, smallmouth bass, bluegill, redear sunfish, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Hayden & Rogers 1998; Hudson & Bowen 2002; Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species. When attached to hosts, it is likely that feeding on fish tissue contributes to the diet of the *N. japonicas* (Kipp et al. 2012). In contrast, gut analysis indicate that free-living individuals most likely derive their nutrition from blue-green algae and small invertebrates (Baud et al. 2004; Hudson & Bowen 2002). Sexual maturity is attained more quickly at temperatures of 30°C (86°F) than at 20°C (68°F) (Kipp et al. 2012), although it is documented that the species exhibits a fast life cycle of 21 days to sexual maturity at 20°C (68°F) (Beyer et al. 2005). Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012). After hatching, the larvae pass through 6 nauplius stages and possibly 5 copepodid stages before reaching the adult stage (Kipp et al. 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *N. japonicas* can swim well; it is able to move from one host to another and has a high fecundity (sections 2a, 2c). Suitable habitat is present in southern Lake Michigan near the WPS pathway entrance (section 2f). In conjunction with host movement, the potential for rapid dispersal to new environments outside Saginaw Bay is high. However, the species is located far from the WPS pathway entrance in Lake Huron, and no infected fish were found in the limited surveys of Lake Michigan (section 2e). N. japonicas has been in the Great Lakes since 1994 and has not been recorded in southern Lake Michigan. For this reason, the probability of arrival is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0. *N. japonicas* is documented to have spread across Europe within 20 years. Given this information, the probability of arrival increases to medium.

T_{50}: See T_0. Over 50 years, the probability of arrival increases since *N. japonicas* will have time to spread to the WPS by natural dispersion or by attaching to fish. Therefore, the probability of arrival for this time step is high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Low

Evidence for Uncertainty Rating

T_0: The potential for human-mediated transport for *N. japonicas* is unknown. It is uncertain why it has not been transported to southern Lake Michigan by vessels. It is documented that the species may be overlooked during sampling due to its small size, so its current specific distribution may not be accurate. No recent surveys of Lake Michigan were found. Therefore, the uncertainty associated with the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is more certain that *N. japonicas* will spread to the WPS pathway entrance at this time step, lowering the uncertainty of arrival to medium.
T_{50}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is likely that *N. japonicas* will spread to the WPS pathway entrance at this time step, lowering the uncertainty of arrival to low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then moving on to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Kipp et al. 2012; Hayden & Rogers 1998). The species also has great swimming capabilities (Hudson & Bowen 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
N. japonicas could have been introduced to the Great Lakes through ballast water (Hudson & Bowen 2002). There is no commercial or recreational vessel traffic between WPS and Lockport Lock and Dam (USACE 2011a,b). Therefore, natural downstream

dispersal will likely be the primary mechanism of movement through the CAWS from WPS.

c. *Existing Physical Human/Natural Barriers*
T_0: A sluice gate prevents vessel traffic beyond the WPS in to the North Shore Channel, but *N. japonicas* could be pumped into the North Shore Channel from Lake Michigan. Therefore, the sluice gate may act as a temporary barrier. Lockport Lock and Dam and Brandon Road Lock and Dam could act as barriers to the fish that may be host to *N. japonicas*. The electric barriers above Lockport Lock and Dam would shock larger host fish, but they would continue to be transported via currents downstream. *N. japonicas* would also be able to pass through these barriers while free-living.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). The species has been documented in the Salt River drainage in Colorado (Kipp et al. 2012). Host fishes found in the CAWS include largemouth bass, smallmouth bass, bluegill, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Simon & Moy 1999; LimnoTech 2010). Once *N. japonicas* is established, it can survive on many different host fish species. Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sluice gate would act as a temporary barrier, but water pumped from Lake Michigan into the North Shore Channel could transport *N. japonicas* into the CAWS. Suitable habitat is present throughout the CAWS (section 3d). Human-mediated transport from WPS to Brandon Road Lock and Dam is unlikely (section 3b); therefore, movement through the CAWS may require some natural dispersion. The species appears to disperse over long distances rather quickly (section 3a) by either swimming or attaching to swimming fish. Numerous fish species documented as hosts for *N. japonicas* are found in the CAWS (section 3d). Therefore, the probability of passage at this time step is high.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. The species has been in Saginaw Bay for 3 decades and has not spread to other areas of Lake Huron. For this reason, there is a medium degree of uncertainty associated with the probability of its passage.
T_{10}: The future rate of spread for this species is not well understood. However, it is more certain that *N. japonicas* will move through the CAWS to Brandon Road Lock and Dam in 10 years. Therefore, there is a low degree of uncertainty of its passage during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
N. japonicas is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). There are records of parasitic copepods collected from fish in the Mississippi River in Illinois and Iowa (Lockard & Parsons 1975). Once *N. japonicas* is established, it can survive on many different host fish species such as centrarchids and catfish.

Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present and accessible downstream of Brandon Road Lock and Dam.

Evidence for Probability Rating

Suitable habitat and host fish are present for *N. japonicas* near Brandon Road Lock and Dam (sections 4a, 4b). *N. japonicas* may reach suitable habitat by natural downstream dispersal. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers (section 4a), and suitable host fish are present downstream of Brandon Road Lock and Dam. Therefore, uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
N. japonicas has been found in Alabama and in Colorado (Kipp et al. 2012), suggesting climate will be suitable in the MRB.

b. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then occurring in North America 10 years later (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012; Hayden & Rogers 2002). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 2002). The species also has great swimming capabilities (Hudson & Bowen 2002).

c. *Fecundity*
Females are capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002).

d. *History of Invasion Success*
N. japonicas was first recorded in North America in 1993 from aquaculture ponds at Auburn University in Alabama (Hayden & Rogers 1998). The following year, they were discovered in Saginaw Bay (Lake Huron) and again in the bay in 2001 (Hudson & Bowen 2002). Specimens were found in the Salt River drainage west of Grand Junction, Colorado, attached to the fins of black bullheads (Kipp et al. 2012). In 2011, several specimens were found on green sunfish and bluegill in an Ottawa National Wildlife Refuge wetland of Crane Creek, adjacent to Lake Erie and east of Toledo, Ohio (Kipp et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
The means of introduction for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). There is heavy vessel use from Brandon Road Lock and Dam to the lower MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
N. japonicas is a generalist species. *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species occurring in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species that are present in the MRB including centrarchids and catfish (Kipp et al. 2012).

Evidence for Probability Rating

Suitable habitat conditions appear to be present and connected (section 5f). There is the potential for this species to spread naturally. Therefore, the probability of this species spreading is high.

Uncertainty LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers and suitable host fish are present downstream of Brandon Road Lock and Dam (sections 5a, 5f). Therefore, uncertainty is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Medium	Medium	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances (probably via both natural and human-mediated mechanisms) rather quickly, spreading across Europe in 20 years and then moving to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living in the water column (Hayden & Rogers 1998). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 1998). The species also has great swimming capabilities and can transfer from one host to another (Hudson & Bowen 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
The means of introduction for *N. japonicas* to North America are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). The vast majority of ballast water discharged at CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is commercial and recreational vessel traffic to the CRCW from the Great Lakes (USACE 2011a,b)

c. *Current Abundance and Reproductive Capacity*
T_0: This species has a rapid reproductive cycle with females capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Spermatozoids can likely be retained for a period of diapause (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway

T_0: Of all recorded species in the genus *Neoergasilus*, *N. japonicas* has the widest geographic distribution (Hayden & Rogers 1998). In 1994 in Saginaw Bay of Lake Huron, four species of fish (fathead minnow, *Pimephales promelas*; largemouth bass, *Micropterus salmoides*; pumpkinseed sunfish, *Lepomis gibbosus*; and yellow perch, *Perca flavescens*) were collected with *N. japonicas* (Hudson & Bowen 2002). This ectoparasite is relatively small (0.6–1.0 mm; 0.02–0.04 in.) and probably is not obvious to researchers. Field attempts to identify the species using three times magnification were suspect (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish. No recent surveys of fish in Lake Michigan were found, so the distance from the pathway is not well documented.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). Free-living individuals (i.e. larvae, males, and immature females) feed on algae and zooplankton (Hudson & Bowen 2002; Baud et al. 2004). Gravid females are parasitic, attaching to the fins of freshwater fish species and feeding on their tissue (Abdelhalim et al. 1993). In Lake Huron, it usually attaches to adult fish hosts (Hudson & Bowen 2002; Jordan et al. 2009), most frequently to the dorsal fin (Hudson & Bowen 2002). Host fishes include largemouth bass, smallmouth bass, bluegill, redear sunfish, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Hayden & Rogers 1998; Hudson & Bowen 2002; Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species. When attached to hosts, it is likely that feeding on fish tissue contributes to the diet of the *N. japonicas* (Kipp et al. 2012). In contrast, gut analysis indicate that free-living individuals most likely derive their nutrition from blue-green algae and small invertebrates (Baud et al. 2004; Hudson & Bowen 2002).
Sexual maturity is attained more quickly at temperatures of 30°C (86°F) than at 20°C (68°F) (Kipp et al. 2012), although it is documented that the species exhibits a fast life cycle of 21 days to sexual maturity at 20°C (68°F) (Beyer et al. 2005). Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012). After

hatching, the larvae pass through six nauplius stages and possibly five copepodid stages before reaching the adult stage (Kipp et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *N. japonicas* can swim well; it is able to move from one host to another and has a high fecundity (sections 2a, 2c). Suitable habitat is present in southern Lake Michigan near the CRCW pathway entrance (section 2f). In conjunction with host movement, the potential for rapid dispersal to new environments outside Saginaw Bay is high. However, the species is located far from the CRCW pathway entrance in Lake Huron, and no infected fish were found in the limited surveys of Lake Michigan (section 2e). *N. japonicas* has been in the Great Lakes since 1994 and has not been recorded in southern Lake Michigan. For this reason, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. *N. japonicas* is documented to have spread across Europe within 20 years. Given this information, the probability of arrival increases to medium.
T_{50}: See T_0. Over 50 years, the probability of arrival increases that *N. japonicas* will have time to spread to the CRCW by natural dispersion or by attaching to fish. Therefore, the probability of arrival for this time step is high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Low

Evidence for Uncertainty Rating

T_0: the potential for human-mediated transport is unknown for *N. japonicas*. It is uncertain why it has not been transported to southern Lake Michigan by vessels. It is documented that the species may be overlooked during sampling due to its small size, so the current specific distribution may not be accurate. No recent surveys of Lake Michigan were found. Therefore, the uncertainty associated with the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is more certain that *N. japonicas* will spread to the CRCW pathway entrance at this time step, lowering the uncertainty of arrival to medium.

T_{50}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is likely that *N. japonicas* will spread to the CRCW pathway entrance at this time step, lowering the uncertainty of arrival to low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then moving on to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another. Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Kipp et al. 2012; Hayden & Rogers 1998). The species also has great swimming capabilities (Hudson & Bowen 2002).

b. Human-Mediated Transport through Aquatic Pathways

The means of introduction to North America for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). Ballast water is rarely discharged in inland ports of Illinois (NBIC 2012). The CRCW is heavily used by recreational, commercial, and cargo vessels. Based on averaging 2000 through 2010 data, the CRCW saw an average of 711,902 commercial passenger one-way trips and 41,071 non-cargo vessel one-way trips (USACE 2011b).

c. Existing Physical Human/Natural Barriers

T_0: Lockport Lock and Dam and Brandon Road Lock and Dam could act as a barrier to the fish that may be host to *N. japonicas*. The electric barriers above Lockport Lock and Dam would shock larger host fish, but they would continue to be transported downstream via currents. *N. japonicas* would also be able to pass through these barriers while free-living.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). The species has been documented in the Salt River drainage in Colorado (Kipp et al. 2012). Host fishes found in the CAWS include largemouth bass, smallmouth bass, bluegill, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Simon & Moy 1999; LimnoTech

2010). Once *N. japonicas* is established, it can survive on many different host fish species. Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present throughout the CAWS (section 3d). Human-mediated transport from CRCW to Brandon Road Lock and Dam is unlikely (section 3b); therefore, movement through the CAWS may require some natural dispersion. The species appears to disperse over long distances rather quickly (section 3a) by either swimming or attaching to swimming fish. Numerous fish species documented as hosts for *N. japonicas* are found in the CAWS (section 3d). The Lockport Lock and Dam and the Brandon Road Lock and Dam could act as a barrier to the fish that host the species; however, the free-living species could pass through the barrier (section 3c). Therefore, the probability of passage at this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. The species has been in Saginaw Bay for 3 decades and has not spread to other areas of Lake Huron. For these reasons, there is a medium degree of uncertainty associated with the probability of its passage.
T_{10}: The future rate of spread for this species is not well understood. However, it is more certain that *N. japonicas* will move through the CAWS to the Brandon Road Lock and Dam in 10 years. Therefore, there is a low degree of uncertainty of its passage during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
N. japonicas is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species being in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). There are records of parasitic copepods collected from fish in the Mississippi River in Illinois and Iowa (Lockard & Parsons 1975). Once *N. japonicas* is established, it can survive on many different host fish species such as centrarchids and catfish.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present and accessible downstream of the Brandon Road Lock and Dam.

Evidence for Probability Rating

Suitable habitat and host fish are present for *N. japonicas* near the Brandon Road Lock and Dam (sections 4a, 4b). *N. japonicas* may reach suitable habitat by natural downstream dispersal. The probability of the species colonizing near the Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers (section 4a), and suitable host fish are present downstream of the Brandon Road Lock and Dam. Therefore, uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
N. japonicas has been found in Alabama and in Colorado (Kipp et al. 2012), suggesting climate will be suitable in the MRB.

b. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then occurring in North America 10 years later (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 2002). The species also has great swimming capabilities (Hudson & Bowen 2002).

c. *Fecundity*
Females are capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002).

d. *History of Invasion Success*
N. japonicas was first recorded in North America in 1993 from aquaculture ponds at Auburn University in Alabama (Hayden & Rogers 1998). The following year, they were discovered in Saginaw Bay (Lake Huron) and again in the bay in 2001 (Hudson & Bowen 2002). Specimens were found in the Salt River drainage west of Grand Junction, Colorado, attached to the fins of black bullheads (Kipp et al. 2012). In 2011, several specimens were found on green sunfish and bluegill in an Ottawa National Wildlife Refuge wetland of Crane Creek, adjacent to Lake Erie and east of Toledo, Ohio (Kipp et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
The means of introduction for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). There is heavy vessel use from the Brandon Road Lock and Dam to the lower MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
N. japonicas is a generalist, freshwater species of eutrophic and polluted aquatic environments. There are records of the species being present in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species that are present in the MRB including centrarchids and catfish (Kipp et al. 2012).

Evidence for Probability Rating

Suitable habitat conditions appear to be present and connected (section 5f). There is the potential for this species to spread naturally. Therefore, the probability of this species spreading is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers, and suitable host fish are present downstream of the Brandon Road Lock and Dam (sections 5a, 5f). Therefore, uncertainty is low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Medium	Medium	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances (probably via both natural and human-mediated mechanisms) rather quickly, spreading across Europe in 20 years and then moving to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to

another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living in the water column (Hayden & Rogers 1998). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 1998). The species also has great swimming capabilities and can transfer from one host to another (Hudson & Bowen 2002).

b. Human-Mediated Transport through Aquatic Pathways

The means of introduction to North America for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). The vast majority of ballast water discharged at CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is heavy commercial vessel traffic to Calumet Harbor from Lake Michigan (USACE 2011a).

c. Current Abundance and Reproductive Capacity

T_0: This species has a rapid reproductive cycle with females capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Spermatozoids can likely be retained for a period of diapause (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. Distance from Pathway

T_0: Of all recorded species in the genus *Neoergasilus*, *N. japonicas* has the widest geographic distribution (Hayden & Rogers 1998). In 1994 in Saginaw Bay(Lake Huron), four species of fish (fathead minnow, *Pimephales promelas*; largemouth bass, *Micropterus salmoides*; pumpkinseed sunfish, *Lepomis gibbosus*; and yellow perch, *Perca flavescens*) were collected with *N. japonicas* (Hudson & Bowen 2002). This ectoparasite is relatively small (0.6–1.0 mm; 0.02–0.04 in.) and probably not obvious to researchers. Field attempts to identify the species using 3 times magnification were suspect (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish. No recent surveys of fish in Lake Michigan were found, so the distance from the pathway is not well documented.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). Free-living individuals (i.e., larvae, males, and immature females) feed on algae and zooplankton (Hudson & Bowen 2002; Baud et al. 2004). Gravid females are parasitic, attaching to the fins of freshwater fish species and feeding on their tissue (Abdelhalim et al. 1993). In Lake Huron, it usually attaches to adult fish hosts (Hudson & Bowen 2002; Jordan et al. 2009), most frequently to the dorsal fin (Hudson & Bowen 2002). Host fishes include largemouth bass, smallmouth bass, bluegill, redear sunfish, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Hayden & Rogers 1998; Hudson & Bowen 2002; Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species. When attached to hosts, it is likely that feeding on fish tissue contributes to the diet of the *N. japonicas* (Kipp et al. 2012). In contrast, gut analysis indicates that free-living individuals most likely derive their nutrition from blue-green algae and small invertebrates (Baud et al. 2004; Hudson & Bowen 2002).

Sexual maturity is attained more quickly at temperatures of 30°C (86°F) than at 20°C (68°F) (Kipp et al. 2012), although it is documented that the species exhibits a fast life cycle of 21 days to sexual maturity at 20°C (68°F) (Beyer et al. 2005). Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012). After hatching, the larvae pass through six nauplius stages and possibly five copepodid stages before reaching the adult stage (Kipp et al. 2012).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *N. japonicas* can swim well; it is able to move from one host to another and has a high fecundity (sections 2a, 2c). Suitable habitat is present in southern Lake Michigan near the Calumet Harbor pathway entrance (section 2f). In conjunction with host movement, the potential for rapid dispersal to new environments outside Saginaw Bay is high. However, the species is located far from the Calumet Harbor pathway entrance in Lake Huron, and no infected fish were found in the limited surveys of Lake Michigan (section 2e). *N. japonicas* has been in the Great Lakes since 1994 and has not been recorded in southern Lake Michigan. For this reason, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. *N. japonicas* is documented to have spread across Europe within 20 years. Given this information, the probability of arrival increases to medium.

T_{50}: See T_0. Over 50 years, the probability of arrival increases that *N. japonicas* will have time to spread to the Calumet Harbor by natural dispersion or by attaching to fish. Therefore, the probability of arrival for this time step is high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Low

Evidence for Uncertainty Rating

T_0: The potential for human-mediated transport is unknown for *N. japonicas*. It is uncertain why it has not been transported to southern Lake Michigan by vessels. It is documented that the species may be overlooked during sampling due to its small size, so the current specific distribution may not be accurate. No recent surveys of Lake Michigan were found. Therefore, the uncertainty associated with the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is more certain that *N. japonicas* will spread to the Calumet Harbor pathway entrance at this time step, lowering the uncertainty of arrival to medium.
T_{50}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is likely that *N. japonicas* will spread to the Calumet Harbor pathway entrance at this time step, lowering the uncertainty of arrival to low.

3. P(passage) T_0-T_{50} : HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then moving on to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another. Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Kipp et al. 2012; Hayden & Rogers 1998). The species also has great swimming capabilities (Hudson & Bowen 2002).

b. Human-Mediated Transport through Aquatic Pathways

The means of introduction for *N. japonicas* to North America are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). Ballast water is rarely discharged in inland ports of Illinois (NBIC 2012). Although there is little commercial river traffic from Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between T.J. O'Brien Lock and Dam (which is approximately 8 km [5 mi] south of Calumet Harbor) and Brandon Road Lock and Dam (USACE 2011a; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: T.J. O'Brien Lock and Dam, Lockport Lock and Dam, and Brandon Road Lock and Dam could act as a barrier to the fish that may be host to *N. japonicas*. The electric barriers above Lockport Lock and Dam would shock larger host fish, but they would continue to be transported downstream via currents. However, *N. japonicas* would be able to pass through these barriers while free-living.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). The species has been documented in the Salt River drainage in Colorado (Kipp et al. 2012). Host fishes found in the CAWS include largemouth bass, smallmouth bass, bluegill, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Simon & Moy 1999; LimnoTech 2010). Once *N. japonicas* is established, it can survive on many different host fish species. Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present throughout the CAWS (section 3d). Human-mediated transport from Calumet Harbor to Brandon Road Lock and Dam is unlikely (section 3b); therefore, movement through the CAWS may require some natural dispersion. The species appears to disperse over long distances rather quickly (section 3a) by either swimming or attaching to swimming fish. Numerous fish species documented as hosts for *N. japonicas* are found in the CAWS (section 3d). The lock and dams could act as a barrier to the fish that host the species; however, the free-living species could pass through the barrier (section 3c). Therefore, the probability of passage at this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. The species has been in Saginaw Bay for three decades and has not spread to other areas of Lake Huron. For these reasons, there is a medium degree of uncertainty associated with the probability of its passage.
T_{10}: The future rate of spread for this species is not well understood. However, it is more certain that *N. japonicas* will move through the CAWS to Brandon Road Lock and Dam in 10 years. Therefore, there is a low degree of uncertainty of its passage during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
N. japonicas is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species being present in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). There are records of parasitic copepods collected from fish in the Mississippi River in Illinois and Iowa (Lockard & Parsons 1975). Once *N. japonicas* is established, it can survive on many different host fish species such as centrarchids and catfish.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present and accessible downstream of Brandon Road Lock and Dam.

Evidence for Probability Rating

Suitable habitat and host fish are present for *N. japonicas* near Brandon Road Lock and Dam (sections 4a, 4b). *N. japonicas* may reach suitable habitat by natural downstream dispersal. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers (section 4a), and suitable host fish are present downstream of Brandon Road Lock and Dam. Therefore, uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
N. japonicas has been found in Alabama and in Colorado (Kipp et al. 2012), suggesting climate will be suitable in the MRB.

b. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then occurring in North America 10 years later (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012; Hayden & Rogers 2002). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 2002). The species also has great swimming capabilities (Hudson & Bowen 2002).

c. *Fecundity*
Females are capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002).

d. *History of Invasion Success*
N. japonicas was first recorded in North America in 1993 from aquaculture ponds at Auburn University in Alabama (Hayden & Rodgers 1998). The following year, they were discovered in Saginaw Bay (Lake Huron) and again in the bay in 2001 (Hudson & Bowen 2002). Specimens were found in the Salt River drainage west of Grand Junction, Colorado, attached to the fins of black bullheads (Kipp et al. 2012). In 2011, several specimens were found on green sunfish and bluegill in an Ottawa National Wildlife Refuge wetland of Crane Creek, adjacent to Lake Erie and east of Toledo, Ohio (Kipp et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
The means of introduction for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). There is heavy vessel use from Brandon Road Lock and Dam to the lower MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
N. japonicas is a generalist species. *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments. There are records of the species being present in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species that are present in the MRB including centrarchids and catfish (Kipp et al. 2012).

Evidence for Probability Rating

Suitable habitat conditions appear to be present and connected (section 5f). There is the potential for this species to spread naturally. Therefore, the probability of this species spreading is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers, and suitable host fish are present downstream of Brandon Road Lock and Dam (sections 5a, 5f). Therefore, uncertainty is low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Medium	Medium	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
The species appears to disperse over long distances (probably via both natural and human-mediated mechanisms) rather quickly, spreading across Europe in 20 years and then moving to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living in the water column (Hayden & Rogers 1998). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 1998). The species also has great swimming capabilities and can transfer from one host to another (Hudson & Bowen 2002).

b. Human-Mediated Transport through Aquatic Pathways
The means of introduction for *N. japonicas* to North America are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is heavy commercial vessel traffic to the Indiana Harbor from Lake Michigan (USACE 2011a).

c. Current Abundance and Reproductive Capacity
T_0: This species has a rapid reproductive cycle with females capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Spermatozoids can likely be retained for a period of diapause (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*

T_0: Of all recorded species in the genus *Neoergasilus*, *N. japonicas* has the widest geographic distribution (Hayden & Rogers 1998). In 1994 in Saginaw Bay, Lake Huron, Michigan four species of fish (fathead minnow, *Pimephales promelas*; largemouth bass, *Micropterus salmoides*; pumpkinseed sunfish, *Lepomis gibbosus*; and yellow perch, *Perca flavescens*) were collected with *N. japonicas* (Hudson & Bowen 2002). This ectoparasite is relatively small (0.6–1.0 mm; 0.02–0.04in.) and probably not obvious to researchers. Field attempts to identify the species using three times magnification were suspect (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish. No recent surveys of fish in Lake Michigan were found so the distance from the pathway is not well documented.

T_{10}: See T_0. The species may disperse closer to the pathway over time.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). Free living individuals (i.e. larvae, males, and immature females) feed on algae and zooplankton (Hudson & Bowen 2002; Baud et al. 2004). Gravid females are parasitic, attaching to the fins of freshwater fish species and feeding on their tissue (Abdelhalim et al. 1993). In Lake Huron, it usually attaches to adult fish hosts (Hudson & Bowen 2002; Jordan et al. 2009), most frequently to the dorsal fin (Hudson & Bowen 2002). Host fishes include largemouth bass, smallmouth bass, bluegill, redear sunfish, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Hayden & Rogers 1998; Hudson & Bowen 2002; Kipp et al. 2012). Once *N. japonicas* is established it can survive on many different host fish species. When attached to hosts, it is likely that feeding on fish tissue contributes to the diet of the *N. japonicas* (Kipp et al. 2012). In contrast, gut analysis indicate that free living individuals most likely derive their nutrition from blue-green algae and small invertebrates (Baud et al. 2004; Hudson & Bowen 2002).

Sexual maturity is attained more quickly at temperatures of 30°C (86°F) than at 20°C (68°F) (Kipp et al. 2012), although it is documented that the species exhibits a fast life cycle of 21 days to sexual maturity at 20°C (68°F) (Beyer et al. 2005). Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012). After hatching the larvae pass through 6 nauplius stages and around 5 copepodid stages before reaching the adult stage (Kipp et al. 2012).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *N. japonicas* can swim well, it is able to move from one host to another and has a high fecundity (sections 2a, 2c). Suitable habitat is present in southern Lake Michigan near the Indiana Harbor pathway entrance (section 2f). In conjunction with host movement, the potential for rapid dispersal to new environments outside Saginaw Bay is high. However, the species is located far from the Indiana Harbor pathway entrance in Lake Huron and no infected fish were found in the limited surveys of Lake Michigan (section 2e). *N. japonicas* has been in the Great Lakes since 1994 and has not been recorded in southern Lake Michigan. For this reason the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. *N. japonicas* is documented to have spread across Europe within 20 years. Given this information the probability of arrival raises to medium.
T_{50}: See T_0. Over 50 years the probability of arrival increases that *N. japonicas* will have time to spread to the Indiana Harbor by natural dispersion or by attaching to fish. Therefore the probability of arrival for this time step is high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Low

Evidence for Uncertainty Rating

T_0: The potential for human-mediated transport is unknown for *N. japonicas*. It is uncertain why it has not been transported to southern Lake Michigan by vessels. It is documented that the species may be overlooked during sampling due to its small size so its current specific distribution may not be accurate. No recent surveys of Lake Michigan were found. Therefore, the uncertainty associated with the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is more certain that *N. japonicas* will spread to the Indiana Harbor pathway entrance at this time step lowering the uncertainty of arrival to medium.
T_{50}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is likely that *N. japonicas* will spread to the Indiana Harbor pathway entrance at this time step lowering the uncertainty of arrival to low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then moving on the North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another. Larvae, males, and immature females do not live as parasites and are free living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Kipp et al. 2012; Hayden & Rogers 1998). The species also has great swimming capabilities (Hudson & Bowen 2002).

b. Human-Mediated Transport through Aquatic Pathways

The means of introduction for *N. japonicas* to North America are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). Ballast water is rarely discharged in inland ports of Illinois (NBIC 2012). Most commercial vessel traffic to Indiana Harbor is lake-wise, and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River due to the shallow depth.

c. Existing Physical Human/Natural Barriers

T_0: Lockport Lock and Dam and Brandon Road Lock and Dam could act as a barrier to the fish that may be host to *N. japonicas*. The electric barriers above Lockport Lock and Dam would shock larger host fish, but they would continue to be transported downstream via currents. *N. japonicas* would also be able to pass through these barriers while free-living.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). The species has been documented in the Salt River drainage in Colorado (Kipp et al. 2012). Host fishes found in the CAWS include largemouth bass, smallmouth bass, bluegill, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Simon & Moy 1999; LimnoTech 2010). Once *N. japonicas* is established, it can survive on many different host fish species. Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012). Water flows out of the Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the eastern-most sections of the Grand Calumet River also generally flow toward Lake Michigan, while other sections can flow east or west depending on location (Weiss et al. 1997). Thus, free-living *N. japonicas* would have to traverse upstream to enter the CAWS and move to the Calumet Sag Channel. However, the females transported by fish would not have a problem traversing the upstream flow while attached to their host.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present throughout the CAWS (section 3d). The species appears to disperse over long distances rather quickly (section 3a) by either swimming or attaching to swimming fish. The free-floating individuals would not be likely to traverse upstream through Indiana Harbor and the Grand Calumet River. However, females attached to hosts will be able to traverse the upstream flow. The lock and dams could act as a barrier to the fish that host the species; however, the free-living species could pass through the barrier. Numerous fish species documented as hosts for *N. japonicas* are found in the CAWS (section 3d). Therefore the probability of passage at this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. The species has been in Saginaw Bay for 3 decades and has not spread to other areas of Lake Huron. For these reasons, there is a medium degree of uncertainty associated with the probability of its passage.
T_{10}: The future rate of spread for this species is not well understood. However, it is more certain that *N. japonicas* will move through the CAWS to Brandon Road Lock and Dam in 10 years. Therefore, there is a low degree of uncertainty of its passage during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   N. japonicas is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species being present in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). There are records of parasitic copepods collected from fish in the Mississippi River in Illinois and Iowa (Lockard & Parsons 1975). Once *N. japonicas* is established, it can survive on many different host fish species such as centrarchids and catfish.

   Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
   Suitable habitat is present and accessible downstream of Brandon Road Lock and Dam.

Evidence for Probability Rating

Suitable habitat and host fish are present for *N. japonicas* near Brandon Road Lock and Dam (sections 4a, 4b). *N. japonicas* may reach suitable habitat by natural downstream dispersal. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers (section 4a), and suitable host fish are present downstream of Brandon Road Lock and Dam. Therefore, uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
   N. japonicas has been found in Alabama and in Colorado (Kipp et al. 2012), suggesting climate will be suitable in the MRB.

b. *Type of Mobility/Invasion Speed*
   The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then occurring in North America 10 years later (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts

(Hayden & Rogers 2002). The species also has great swimming capabilities (Hudson & Bowen 2002).

c. *Fecundity*
Females are capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002).

d. *History of Invasion Success*
N. japonicas was first recorded in North America in 1993 from aquaculture ponds at Auburn University in Alabama (Hayden & Rogers 1998). The following year, they were discovered in Saginaw Bay (Lake Huron) and again in the bay in 2001 (Hudson & Bowen 2002). Specimens were found in the Salt River drainage west of Grand Junction, Colorado, attached to the fins of black bullheads (Kipp et al. 2012). In 2011, several specimens were found on green sunfish and bluegill in an Ottawa National Wildlife Refuge wetland of Crane Creek, adjacent to Lake Erie and east of Toledo, Ohio (Kipp et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
The means of introduction for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). There is heavy vessel use from Brandon Road Lock and Dam to the lower MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
N. japonicas is a generalist species. *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species being present in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species that are present in the MRB including centrarchids and catfish (Kipp et al. 2012).

Evidence for Probability Rating

Suitable habitat conditions appear to be present and connected (section 5f). There is the potential for this species to spread naturally. Therefore, the probability of this species spreading is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers, and suitable host fish are present downstream of Brandon Road Lock and Dam (sections 5a, 5f). Therefore, uncertainty is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	High	Low	High	Medium	Medium	High	Low
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances (probably via both natural and human-mediated mechanisms) rather quickly, spreading across Europe in 20 years and then moving to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living in the water column (Hayden & Rogers 1998). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to

hosts (Hayden & Rogers 1998). The species also has great swimming capabilities and can transfer from one host to another (Hudson & Bowen 2002).

b. *Human-Mediated Transport through Aquatic Pathways*
The means of introduction for *N. japonicas* to North America are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). The vast majority of ballast water discharged at the CAWS ports along Lake Michigan is from other ports in all of the Great Lakes (NBIC 2012). There is no commercial vessel traffic to the BSBH from Lake Michigan; however, there is heavy commercial traffic to the adjacent Burns Harbor (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
T_0: This species has a rapid reproductive cycle with females capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Spermatozoids can likely be retained for a period of diapause (Kipp et al. 2012). Development to sexual maturity is less than 21 days (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: Of all recorded species in the genus *Neoergasilus, N. japonicas* has the widest geographic distribution (Hayden & Rogers 1998). In 1994 in Saginaw Bay (Lake Huron), four species of fish (fathead minnow, *Pimephales promelas*; largemouth bass, *Micropterus salmoides*; pumpkinseed sunfish, *Lepomis gibbosus*; and yellow perch, *Perca flavescens*) were collected with *N. japonicas* (Hudson & Bowen 2002). This ectoparasite is relatively small (0.6–1.0 mm; 0.02–0.04 in.) and probably not obvious to researchers. Field attempts to identify the species using 3 times magnification were suspect (Hudson & Bowen 2002). Surveys from 1993 to 1995 along the eastern shore of central and northern Lake Michigan did not reveal infected fish. No recent surveys of fish in Lake Michigan were found, so the distance from the pathway is not well documented.
T_{10}: See T_0. The species may disperse closer to the pathway over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). Free-living individuals (i.e., larvae, males, and immature females) feed on algae and zooplankton (Hudson & Bowen 2002; Baud et al. 2004). Gravid females are parasitic, attaching to the fins of freshwater fish species and feeding on their tissue (Abdelhalim et al. 1993). In Lake Huron, it usually attaches to adult fish hosts (Hudson & Bowen 2002; Jordan et al. 2009), most frequently to the dorsal fin (Hudson & Bowen 2002). Host fishes include largemouth bass, smallmouth bass, bluegill, redear sunfish, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Hayden & Rogers 1998; Hudson & Bowen 2002; Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species. When attached to hosts, it is likely that feeding on fish tissue contributes to the diet of the *N. japonicas* (Kipp eta l. 2012). In contrast, gut analysis indicates that free-living individuals most likely derive their nutrition from blue-green algae and small invertebrates (Baud et al. 2004; Hudson & Bowen 2002).

Sexual maturity is attained more quickly at temperatures of 30°C (86°F) than at 20°C (68°F) (Kipp et al. 2012), although it is documented that the species exhibits a fast life cycle of 21 days to sexual maturity at 20°C (68°F) (Beyer et al. 2005). Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012). After hatching, the larvae pass through six nauplius stages and possibly five copepodid stages before reaching the adult stage (Kipp et al. 2012).

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *N. japonicas* can swim well; it is able to move from one host to another and has a high fecundity (sections 2a, 2c). Suitable habitat is present in southern Lake Michigan near the BSBH pathway entrance (section 2f). In conjunction with host movement, the potential for rapid dispersal to new environments outside Saginaw Bay is high. However, the species is located far from the BSBH pathway entrance in Lake Huron, and no infected fish were found in the limited surveys of Lake Michigan (section 2e). *N. japonicas* has been in the Great Lakes since 1994 and has not been recorded in southern Lake Michigan. For this reason, the probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0. *N. japonicas* is documented to have spread across Europe within 20 years. Given this information, the probability of arrival increases to medium.

T_{50}: See T_0. Over 50 years, the probability of arrival increases that *N. japonicas* will have time to spread to the BSBH by natural dispersion or by attaching to fish. Therefore, the probability of arrival for this time step is high.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	Medium	Low

Evidence for Uncertainty Rating

T_0: The potential for human-mediated transport is unknown for *N. japonicas*. It is uncertain why it has not been transported to southern Lake Michigan by vessels. It is documented that the species may be overlooked during sampling due to its small size, so its current specific distribution may not be accurate. No recent surveys of Lake Michigan were found. Therefore, the uncertainty associated with the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is more certain that *N. japonicas* will spread to the BSBH pathways entrance at this time step. lowering the uncertainty of arrival to medium.
T_{50}: See T_0. Assuming the rapid invasion speed documented for the species is accurate, it is likely that *N. japonicas* will spread to the BSBH pathways entrance at this time step, lowering the uncertainty of arrival to low.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then moving on to North America in a span of 10 years (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Kipp et al. 2012; Hayden & Rogers 1998). The species also has great swimming capabilities (Hudson & Bowen 2002).

b. Human-Mediated Transport through Aquatic Pathways
The means of introduction to North America for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). Ballast water is rarely discharged in inland ports of Illinois (NBIC 2012). Most commercial vessel traffic to BSBH is lake-wise, and there is no commercial vessel traffic to inland ports in the

CAWS from BSBH (NBIC 2012). The south branch of the Little Calumet River is shallow and likely has only local non-motorized vessel traffic, if any (Little Calumet and Grand Calumet River Corridor Technical Advisory Group and Northeastern Illinois Planning Commission 2011).

c. *Existing Physical Human/Natural Barriers*

T_0: Lockport Lock and Dam and Brandon Road Lock and Dam could act as barriers to the fish that may be host to *N. japonicas*. The electric barriers above Lockport Lock and Dam would shock larger host fish, but they would continue to be transported downstream via currents. However, *N. japonicas* would be able to pass through these barriers while free-living.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). The species has been documented in the Salt River drainage in Colorado (Kipp et al. 2012). Host fishes found in the CAWS include largemouth bass, smallmouth bass, bluegill, pumpkinseed, yellow perch, green sunfish, rock bass, channel catfish, common carp, goldfish, and fathead minnows (Simon & Moy 1999/2000; LimnoTech 2010). Once *N. japonicas* is established, it can survive on many different host fish species. Population levels slow during the cold winter months, but increase in the spring (Kipp et al. 2012). The water flows out of BSBH into Lake Michigan. The eastern segment of the south branch of the Little Calumet River also generally flows toward Lake Michigan depending on location and water level in Lake Michigan (GSWMD 2008). Thus, free-living *N. japonicas* would have to traverse upstream to enter the CAWS and move to the Calumet Sag Channel. However, the females transported by fish would not have a problem traversing the upstream flow while attached to their host.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Suitable habitat is present throughout the CAWS (section 3d). The species appears to disperse over long distances rather quickly (section 3a) by either swimming or attaching to swimming fish. The free-floating individuals would not be likely to traverse upstream through BSBH and the Little Calumet River. However, females attached to hosts will be able to traverse the upstream flow. The lock and dams could act as a barrier to the fish that host

the species; however, the free-living species could pass through the barrier. Numerous fish species documented as hosts for *N. japonicas* are found in the CAWS (section 3d). Therefore, the probability of passage at this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. The species has been in Saginaw Bay for three decades and has not spread to other areas of Lake Huron. For these reasons, there is a medium degree of uncertainty associated with the probability of its passage.
T_{10}: The future rate of spread for this species is not well understood. However, it is more certain that *N. japonicas* will move through the CAWS to Brandon Road Lock and Dam in 10 years. Therefore, there is a low degree of uncertainty of its passage during this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
N. japonicas is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species being present in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). There are records of parasitic copepods collected from fish in the Mississippi River in Illinois and Iowa (Lockard & Parsons 1975). Once *N. japonicas* is established, it can survive on many different host fish species such as centrarchids and catfish (Kipp et al. 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is present and accessible downstream of Brandon Road Lock and Dam.

Evidence for Probability Rating

Suitable habitat and host fish are present for *N. japonicas* near Brandon Road Lock and Dam (sections 4a, 4b). *N. japonicas* may reach suitable habitat by natural downstream dispersal. The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers (section 4a), and suitable host fish are present downstream of Brandon Road Lock and Dam. Therefore, uncertainty is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
N. japonicas has been found in Alabama and in Colorado (Kipp et al. 2012), suggesting climate will be suitable in the MRB.

b. *Type of Mobility/Invasion Speed*
The species appears to disperse over long distances rather quickly, spreading across Europe in 20 years and then occurring in North America 10 years later (Hudson & Bowen 2002). *N. japonicas* attaches to freshwater fish and can then transfer from one individual fish to another (Kipp et al. 2012). Larvae, males, and immature females do not live as parasites and are free-living (Kipp et al. 2012). Only ovigerous females require a host, while those that are non-ovigerous can detach and reattach to hosts (Hayden & Rogers 2002). The species also has great swimming capabilities (Hudson & Bowen 2002).

c. *Fecundity*
Females are capable of producing 1500–2000 eggs over their lifetime (Kipp et al. 2012). Development to sexual maturity occurs in less than 21 days (Hudson & Bowen 2002).

d. *History of Invasion Success*
N. japonicas was first recorded in North America in 1993 from aquaculture ponds at Auburn University in Alabama (Hayden & Rogers 1998). The following year, they were discovered in Saginaw Bay (Lake Huron) and again in the bay in 2001 (Hudson & Bowen 2002). Specimens were found in the Salt River drainage west of Grand Junction, Colorado, attached to the fins of black bullheads (Kipp et al. 2012). In 2011, several specimens were found on green sunfish and bluegill in an Ottawa National Wildlife

Refuge wetland of Crane Creek, adjacent to Lake Erie and east of Toledo, Ohio (Kipp et al. 2012).

e. Human-Mediated Transport through Aquatic Pathways
The means of introduction for *N. japonicas* are unknown. However, it could have occurred through ballast water (Hudson & Bowen 2002). There is heavy vessel use from Brandon Road Lock and Dam to the lower MRB.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
N. japonicas is a generalist species. *N. japonicas* is a freshwater species of eutrophic and polluted aquatic environments (Kipp et al. 2012). There are records of the species being present in the Salt River drainage in Colorado and Crane Creek adjacent to Lake Erie (Kipp et al. 2012). Once *N. japonicas* is established, it can survive on many different host fish species that are present in the MRB including centrarchids and catfish (Kipp et al. 2012).

Evidence for Probability Rating

Suitable habitat conditions appear to be present and connected (section 5f). There is the potential for this species to spread naturally. Therefore, the probability of this species spreading is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

N. japonicas is known to establish in rivers, and suitable host fish are present downstream of Brandon Road Lock and Dam (sections 5a, 5f). Therefore, uncertainty is low.

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E.2.6.5 Harpacticoid Copepod - *Schizopera borutzkyi*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	High	Low	High	Medium	High	High	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi is a small copepod that lives in the sediment. The eggs are attached to the adult, and it has no planktonic life stage (Kipp et al. 2012). Therefore, current-mediated transport is not expected to be a significant transport mechanism. It spread from Lake Michigan to Lake Erie in less than 5 years (Kipp et al. 2012). Its ability to diapause may contribute to its survival in ship ballast tanks (Kipp et al. 2012).

b. Human-Mediated Transport through Aquatic Pathways

Schizopera borutzkyi was introduced to the Great Lakes by ballast water release (Horvath et al. 2001). Spread by vessel traffic has been the fastest means of spread among the Great Lakes. There is no commercial vessel traffic to the WPS, but there is recreational vessel traffic (USACE 2011a,b).

c. Current Abundance and Reproductive Capacity

T_0: In surveys in southern Lake Michigan between 1999 and 2000, *Schizopera borutzkyi* was found to dominate the harpacticoid copepod community in deep sites (at 15 m [49.2 ft]) (Horvath et al. 2001) and has been found to reach densities of 3,700/m^2 in sediment (Garza & Whitman 2004). Reproductive females carry two eggs sacs ventrally (Lesko et al. 2003).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: None. *Schizopera borutzkyi* is along the shoreline of southern Lake Michigan.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. Distance from Pathway

T_0: In southern Lake Michigan, it was found in near-shore waters in Michigan City, Indiana (Garza & Whitman 2004) and in Indiana Dunes National Lakeshore and has been reported in Chicago between Diversey Harbor and Belmont Harbor within 16 km (10 mi) of the WPS (Horvath et al. 2001).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Climate is suitable. *Schizopera borutzkyi* has been found in southern Lake Michigan between 2 and 15 m (6.6 and 49.2 ft), and it can be the dominant species at depths of 15 m (49.2 ft) (Horvath et al. 2001). In Lake Michigan, this species prefers shallow muds and sands (Horvath et al. 2001). Sandy sediments are present in Lake Michigan in the vicinity of the WPS.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Schizopera borutzkyi* is found in southern Lake Michigan and can be the dominant species (sections 2e, 2f). It has been documented less than 16 km (10 mi) from the WPS, and habitat conditions are suitable near the WPS (section 2f). Therefore, the probability of arrival for the species at this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been documented numerous times in southern Lake Michigan. While its current distance from the WPS is uncertain and no surveys are available after 2000, *Schizopera borutzkyi* has been documented less than 16 km (10 mi) from the WPS. Therefore, the uncertainty of the species' arrival at the WPS is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} :

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Schizopera borutzkyi is a small copepod that lives in the sediment. *Schizopera borutzkyi* has spread from Lake Michigan to Lake Ontario in less than 5 years by ship traffic. *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (Kipp et al. 2012), although this may be due to lack of surveys for meiofauna.

b. Human-Mediated Transport through Aquatic Pathways
Schizopera borutzkyi can be transported in ballast water (Kipp et al. 2012). There is no commercial vessel traffic in the North Shore Channel, and the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for transport via attachment to boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Schizopera borutzkyi* based on its depth distribution in Lake Michigan (Kipp et al. 2012). There is a sluice gate separating the WPS from Lake Michigan, which is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel (LimnoTech 2010) and could transport this species into the North Shore Channel if it was suspended in the water column by boat traffic or storms.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. *Schizopera borutzkyi* is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012). In the North Shore Channel and the upper north branch of the Chicago River, in-stream aquatic habitat in the form of aquatic plants, tree roots, and brush debris jams, with sediments of silt and sand, is present along the partly shaded banks (LimnoTech 2010). Toward downtown Chicago and in the Chicago River, there is a reduction in in-stream habitat and a change to concrete and steel vertical banks, with sediments of concrete, silt, or sludge. Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009) and likely reduce habitat quality in some areas. In the CSSC, in-stream habitat varies by location but is generally limited. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).
T_{10}: See T_0. The CAWS is expected to remain suitable habitat for *Schizopera borutzkyi*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There are areas of suitable habitat for *Schizopera borutzkyi* throughout the CAWS (section 3d). This species could spread naturally downstream through the CAWS, while *Schizopera borutzkyi* can also be transported in ballast water (section 3b). However, there is no commercial traffic to the WPS, and the discharge of ballast water originating from the Great Lakes does not typically occur within the CAWS (section 3b). Therefore, some natural downstream spread from the WPS would be required to reach the Brandon Road Lock and Dam. *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been

reported in the CAWS or the Illinois River (section 3a). Therefore, the probability of passage for this species at this time step is low.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be sufficient time for *Schizopera borutzkyi* to spread downstream to the Brandon Road Lock and Dam. Therefore, for this time step the probability of arrival is medium.
T_{50}: See T_{25}. Over 50 years *Schizopera borutzkyi* has a higher probability of reaching the Brandon Road Lock and Dam.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. The natural rate of spread for *Schizopera borutzkyi* is uncertain. The potential for transport on boat hulls is uncertain. The ability of this species to tolerate the sediment contaminants, stormwater runoff, and dissolved oxygen levels in the CAWS is uncertain. The ability of this low-mobility species to transit stretches of the CAWS (especially the CSSC) that have little or no suitable habitat is unknown. *Schizopera borutzkyi* is documented in large river systems in Europe. Why this species has not been detected in the CAWS despite being present in southern Lake Michigan is uncertain. It is uncertain whether benthic surveys conducted in the CAWS or the Illinois River would have detected meiofauna given their small size. Therefore, the species may be present but undetected. Overall, the uncertainty of passage for the species is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Schizopera borutzkyi is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present and accessible downstream of the Brandon Road Lock and Dam.

Evidence for Probability Rating

Because *Schizopera borutzkyi* is native to large river systems in Europe (section 4a), the probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam. The species has been documented in rivers. Therefore, the uncertainty of colonization for this species is medium.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Schizopera borutzkyi is native to the delta of the Danube River and the Black Sea basin (Kipp et al. 2012). Therefore, climate should be suitable in the MRB.

b. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi may spread rapidly if transported by ballast water.

c. *Fecundity*
Females carry two egg sacs (Lesko et al. 2003).

d. *History of Invasion Success*
This species became dominant and spread rapidly in the Great Lakes likely by vessel transport (Kipp et al. 2012). No data on the spread rate of *Schizopera borutzkyi* in rivers were found.

e. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi can be transported in ballast water. There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Schizopera borutzkyi appears to be a benthic generalist. *Schizopera borutzkyi* is native to large river systems in Europe. Little data on specific habitat preferences in rivers are available. In the Great Lakes, this species is associated with shallow sandy and muddy sediments (Kipp et al. 2011). Sandy and muddy sediments are distributed throughout the MRB.

Evidence for Probability Rating

Schizopera borutzkyi is native to large river systems in Europe. Suitable sediment conditions appear to be present and connected (section 5f). There is the potential for this species to be spread in ballast water. Therefore, the probability of this species spreading is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

The species is documented in rivers. Thus, the uncertainty of spread by this species is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	High	Low	High	Medium	High	High	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi is a small copepod that lives in the sediment. The eggs are attached to the adult, and it has no planktonic life stage (Kipp et al. 2012). Therefore, current-mediated transport is not expected to be a significant transport mechanism. It spread from Lake Michigan to Lake Erie in less than 5 years [Kipp et al. 2012]). Its ability to diapause may contribute to its survival in ship ballast tanks (Kipp et al. 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi was introduced to the Great Lakes by ballast water release (Horvath et al. 2001). Spread by vessel traffic has been the fastest means of spread among the Great Lakes. There is commercial and recreational vessel traffic to the CRCW from Lake Michigan (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: In surveys of southern Lake Michigan between 1999 and 2000, *Schizopera borutzkyi* was found to dominate the harpacticoid copepod community in deep sites (at 15 m [49.2 ft]) (Horvath et al. 2001) and to reach densities of 3,700/m^2 in the sediment (Garza & Whitman 2004). Reproductive females carry two eggs sacs ventrally (Lesko et al. 2003).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. *Schizopera borutzkyi* is along the shoreline of southern Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In southern Lake Michigan, *Schizopera borutzkyi* was found in nearshore waters in Michigan City, Indiana (Garza & Whitman 2004), in Indiana Dunes National Lakeshore, and in Chicago between Diversey Harbor and Belmont Harbor (less than 16 km [10 mi] from the CRCW) between 2 and 15 m (6.6 and 49.2 ft) (Horvath et al. 2001).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Climate is suitable. *Schizopera borutzkyi* has been found in southern Lake Michigan between 2 and 15 m (6.6 and 49.2 ft), and it can be the dominant species at depths of 15 m (49.2 ft) (Horvath et al. 2001). In Lake Michigan, this species prefers shallow muds and sands (Horvath et al. 2001). Sandy sediments are present in Lake Michigan in the vicinity of the CRCW.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Schizopera borutzkyi* is found in southern Lake Michigan and can be the dominant species (sections 2e, 2f). It has been documented less than 16 km (10 mi) from the CRCW, and habitat conditions are suitable near the CRCW (section 2f). Therefore, its probability of arrival at the Brandon Road Lock and Dam is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been documented numerous times in southern Lake Michigan. While its current distance from the CRCW is uncertain and no surveys are available after 2000, *Schizopera borutzkyi* has been documented less than 16 km (10 mi) from the CRCW. Therefore, the uncertainty of this species arrival for this time step is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi is a small copepod that lives in the sediment. *Schizopera borutzkyi* has spread from Lake Michigan to Lake Ontario in less than 5 years by ship traffic. *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (Kipp et al. 2012), although this may be due to lack of surveys for meiofauna.

b. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi can be transported in ballast water (Kipp et al. 2012). There is some commercial vessel traffic between the CRCW and the Brandon Road Lock and Dam (USACE 2011a; NBIC 2012), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for transport via attachment to boat hulls was not found in the literature.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Schizopera borutzkyi* based on its depth distribution in Lake Michigan (Kipp et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. *Schizopera borutzkyi* is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012). In the Chicago River, there is little in-stream habitat, and the banks are typically concrete and steel vertical walls, with sediments of concrete, silt, or sludge. Toxic organic and inorganic pollutants are also present in the Chicago River (Gallagher et al. 2009) and likely reduce habitat quality in some areas. In the CSSC, in-stream habitat varies by location but is generally limited. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).
T_{10}: See T_0. The CAWS is expected to remain suitable habitat for *Schizopera borutzkyi*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There are areas of suitable habitat for *Schizopera borutzkyi* throughout the CAWS (section 3d). This species could spread naturally downstream through the CAWS. *Schizopera borutzkyi* can also be transported in ballast water, and there is some potential for vessel-mediated transport (section 3b). However, the discharge of ballast water originating from the Great Lakes does not typically occur within the CAWS. *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (section 3a). Therefore, the probability of this species passing through the Brandon Road Lock and Dam is low.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be sufficient time for *Schizopera borutzkyi* to spread downstream to the Brandon Road Lock and Dam; therefore, the probability of passage for this species raises to medium.
T_{50}: See $T_{25.}$ Over 50 years *Schizopera borutzkyi* has a higher probability of reaching the Brandon Road Lock and Dam.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. The natural rate of spread for *Schizopera borutzkyi* is uncertain. The potential for transport on boat hulls or in ballast water is uncertain. The ability of this species to tolerate the sediment contaminants, stormwater runoff, and dissolved oxygen levels in the CAWS is uncertain. *Schizopera borutzkyi* is documented in large river systems in Europe. Why this species has not been detected in the CAWS despite being present in southern Lake Michigan is uncertain. It is uncertain whether benthic surveys conducted in the CAWS or the Illinois River would have detected meiofauna given their small size. Therefore, the species may be present but undetected. Overall, the uncertainty of passage for the species is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Schizopera borutzkyi is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is present and accessible downstream of the Brandon Road Lock and Dam.

Evidence for Probability Rating

Because *Schizopera borutzkyi* is native to large river systems in Europe (section 4a), its probability of colonization is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat below the Brandon Lock and Dam has been documented. The species has been documented in rivers. Therefore, the uncertainty related to the colonization of this species is medium.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   Schizopera borutzkyi is native to the delta of the Danube River and the Black Sea basin (Kipp et al. 2012); therefore, climate in the MRB should be suitable.

b. *Type of Mobility/Invasion Speed*
   Schizopera borutzkyi may spread rapidly if transported by ballast water.

c. *Fecundity*
   Females carry two egg sacs (Lesko et al. 2003).

d. *History of Invasion Success*
   This species became dominant and spread rapidly in the Great Lakes likely by vessel transport (Kipp et al. 2012). No data on the spread rate of *Schizopera borutzkyi* in rivers were found.

e. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi can be transported in ballast water. There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Schizopera borutzkyi is native to large river systems in Europe. Little data on specific habitat preferences in rivers are available. In the Great Lakes, this species is associated with shallow sandy and muddy sediments (Kipp et al. 2011). Sandy and muddy sediments are distributed throughout the MRB.

Evidence for Probability Rating

Schizopera borutzkyi is native to large river systems in Europe. Suitable sediment conditions appear to be present and connected (section 5f). There is the potential for this species to be spread in ballast water. Therefore, the probability of spread by this species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

The species is documented in rivers. Thus, the uncertainty of spread by the species is low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	High	Low	High	Medium	High	High	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi is a small copepod that lives in the sediment. The eggs are attached to the adult, and it has no planktonic life stage (Kipp et al. 2012) Therefore, current-mediated transport is not expected to be a significant transport mechanism. It spread from Lake Michigan to Lake Erie in less than 5 years (Kipp et al. 2012). Its ability to diapause may contribute to its survival in ship ballast tanks (Kipp et al. 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi was introduced to the Great Lakes by ballast water release (Horvath et al. 2001). Spread by vessel traffic has been the fastest means of spread among the Great Lakes. There is heavy commercial vessel traffic to the Calumet Harbor from Lake Michigan (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
T_0: In surveys of southern Lake Michigan between 1999 and 2000, *Schizopera borutzkyi* was found to dominate the harpacticoid copepod community in deep sites (at 15 m [49.2 ft]) (Horvath et al. 2001) and has been found to reach densities of 3,700/m^2 in the sediment (Garza & Whitman 2004). Reproductive females carry two eggs sacs ventrally (Lesko et al. 2003).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. *Schizopera borutzkyi* is along the shoreline of southern Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In southern Lake Michigan, *Schizopera borutzkyi* was found in near-shore waters in Michigan City, Indiana (less than 80.5 km [50 mi] southeast of Calumet Harbor) (Garza & Whitman 2004) and in Chicago between Diversey Harbor and Belmont Harbor (less than 32 km [20 mi] north of Calumet Harbor) (Horvath et al. 2001).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Climate is suitable. *Schizopera borutzkyi* has been found in southern Lake Michigan between 2 and 15 m (6.6 and 49.2 ft), and it can be the dominant species at depths of 15 m (49.2 ft) (Horvath et al. 2001). In Lake Michigan, this species prefers shallow muds and sands (Horvath et al. 2001). Sandy sediments are present in Lake Michigan in the vicinity of Calumet Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Schizopera borutzkyi* is found in southern Lake Michigan and can be the dominant species (sections 2e, 2f). It has been documented on both sides of Calumet Harbor, and habitat conditions are suitable near the Calumet Harbor (section 2f). Therefore, the probability of the species' arrival is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been documented numerous times in southern Lake Michigan. While its current distance from the Calumet Harbor is uncertain and no surveys are available after 2000, *Schizopera borutzkyi* has been documented less than 32 km (20 mi) from Calumet Harbor. Therefore, the uncertainty of this species' arrival is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Schizopera borutzkyi is a small copepod that lives in the sediment. *Schizopera borutzkyi* has spread from Lake Michigan to Lake Ontario in less than 5 years by ship traffic. *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (Kipp et al. 2012), although this may be due to lack of surveys for meiofauna.

b. Human-Mediated Transport through Aquatic Pathways
Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, a distance of approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Although *Schizopera borutzkyi* can be transported in ballast water (Kipp et al. 2012), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Evidence for transport via attachment to boat hulls was not found in the literature.

c. Existing Physical Human/Natural Barriers
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Schizopera borutzkyi* based on its depth distribution in Lake Michigan (Kipp et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. *Schizopera borutzkyi* is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp

et al. 2012). In the Calumet River, there is in-stream habitat for aquatic life in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches. Urban industrial and commercial riparian land use is also present. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). The Calumet River, the Little Calumet River, and the Calumet Sag Channel also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011), which likely reduce habitat quality in some areas. In the CSSC, in-stream habitat varies by location but is generally limited, and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).
T_{10}: See T_0. The CAWS is expected to remain suitable habitat for *Schizopera borutzkyi*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There are areas of suitable habitat for *Schizopera borutzkyi* throughout the CAWS (section 3d). This species could spread naturally downstream through the CAWS or by vessel transport (section 3). However, the discharge of ballast water originating from the Great Lakes does not typically occur within the CAWS. *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (section 3a). Therefore, the probability of passage for the species is low at this time step.
T_{10}: See T_0.
T_{25}: See T_{10}. Twenty-five years may be sufficient time for *Schizopera borutzkyi* to spread downstream to the Brandon Road Lock and Dam; therefore, the probability of passage for this species raises to medium.
T_{50}: See $T_{25.}$ Over 50 years *Schizopera borutzkyi* has a higher probability of reaching the Brandon Road Lock and Dam.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. The natural rate of spread for *Schizopera borutzkyi* is uncertain. The

potential for transport on boat hulls or in ballast water is uncertain. The ability of this species to tolerate the sediment contaminants, stormwater runoff, and dissolved oxygen levels in the CAWS is uncertain. *Schizopera borutzkyi* is documented in large river systems in Europe. Why this species has not been detected in the CAWS despite being present in southern Lake Michigan is uncertain. It is uncertain whether benthic surveys conducted in the CAWS or the Illinois River would have detected meiofauna given their small size. Therefore, the species may be present but undetected. Therefore, the uncertainty of passage for the species is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.
Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Schizopera borutzkyi is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present and accessible downstream of the Brandon Road Lock and Dam.

Evidence for Probability Rating

Because *Schizopera borutzkyi* is native to large river systems in Europe (section 4a), the probability of colonization by this species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat below the Brandon Lock and Dam has been documented. The species has been documented in rivers. Therefore, the uncertainty of colonization by this species is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Schizopera borutzkyi is native to the delta of the Danube River and the Black Sea basin (Kipp et al. 2012); therefore, climate in the MRB should be suitable.

b. Type of Mobility/Invasion Speed
Schizopera borutzkyi may spread rapidly if transported by ballast water.

c. Fecundity
Females carry two egg sacs (Lesko et al. 2003).

d. History of Invasion Success
This species became dominant and spread rapidly in the Great Lakes likely by vessel transport (Kipp et al. 2012). No data on the spread rate of *Schizopera borutzkyi* in rivers were found.

e. Human-Mediated Transport through Aquatic Pathways
Schizopera borutzkyi can be transported in ballast water. There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Schizopera borutzkyi is native to large river systems in Europe. Little data on specific habitat preferences in rivers are available. In the Great Lakes, this species is associated with shallow sandy and muddy sediments (Kipp et al. 2011). Sandy and muddy sediments are distributed throughout the MRB.

Evidence for Probability Rating

Schizopera borutzkyi is native to large river systems in Europe. Suitable sediment conditions appear to be present and connected (section 5f). There is the potential for this species to be spread in ballast water. Therefore, the probability of spread by this species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

The species is documented in rivers. Thus, the uncertainty of spread by the species is low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	High	Low	High	Medium	High	High	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi is a small copepod that lives in the sediment. The eggs are attached to the adult, and it has no planktonic life stage (Kipp et al. 2012). Therefore, current-mediated transport is not expected to be a significant transport mechanism. It spread from Lake Michigan to Lake Erie in less than 5 years (Kipp et al. 2012). Its ability to diapause may contribute to its survival in ship ballast tanks (Kipp et al. 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi was introduced to the Great Lakes by ballast water release (Horvath et al. 2001). Spread by vessel traffic has been the fastest means of spread among the Great Lakes. There is heavy commercial vessel traffic to the Indiana Harbor from Lake Michigan (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*
T_0: In surveys of southern Lake Michigan between 1999 and 2000, *Schizopera borutzkyi* was found to dominate the harpacticoid copepod community in deep sites (at 15 m [49.2 ft]) (Horvath et al. 2001) and has been found to reach densities of 3,700/m^2 in the sediment (Garza & Whitman 2004). Reproductive females carry two eggs sacs ventrally (Lesko et al. 2003).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. *Schizopera borutzkyi* is along the shoreline of southern Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In southern Lake Michigan *Schizopera borutzkyi* was found in near-shore waters in Michigan City, Indiana (Garza & Whitman 2004), in Indiana Dunes National Lakeshore (approximately 48 km [30 mi] southeast of Indiana Harbor), and in Chicago between Diversey Harbor and Belmont Harbor (less than 48 km [30 mi] north of Indiana Harbor) (Horvath et al. 2001).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Climate is suitable. *Schizopera borutzkyi* is found in southern Lake Michigan at depths of 2 to 15 m (6.6 to 49.2 ft) and is often the dominant species at depths of 15 m (49.2 ft) (Horvath et al. 2001). In Lake Michigan this species prefers shallow muds and sands (Horvath et al. 2001). Sandy sediments are present in Lake Michigan in the vicinity of the Indiana Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Schizopera borutzkyi* is found in southern Lake Michigan and can be the dominant species (sections 2e, 2f). It has been documented on both sides of Indiana Harbor, and habitat conditions near the Indiana Harbor are suitable (section 2f). Therefore, the probability of the species arriving at the pathway is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been documented numerous times in southern Lake Michigan. While its current distance from Indiana Harbor is uncertain and no surveys are available after 2000, the species has been documented less than 48 km (30 mi) from Indiana Harbor. Therefore, the uncertainty of *Schizopera borutzkyi* arriving at the pathway is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Schizopera borutzkyi is a small copepod that lives in the sediment. *Schizopera borutzkyi* has spread from Lake Michigan to Lake Ontario in less than 5 years by ship traffic (Kipp et al. 2012). This species has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (Kipp et al. 2012), although this may be due to lack of surveys for meiofauna.

b. *Human-Mediated Transport through Aquatic Pathways*
Although *Schizopera borutzkyi* can be transported in ballast water (Kipp et al. 2012), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Most commercial vessel traffic to Indiana Harbor is lake-wide (NBIC 2012). Evidence for transport via attachment to boat hulls was not found in the literature. There is little if any vessel traffic in the Grand Calumet River because of the shallow depth.

c. *Existing Physical Human/Natural Barriers*
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Schizopera borutzkyi*, based on its depth distribution in Lake Michigan (Kipp et al. 2012). Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. However, there are leaks in the sheet pile where the species may pass.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. *Schizopera borutzkyi* is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012). Conditions at the Indiana Harbor are highly industrialized. Sediments consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). Sediments in the Grand Calumet consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011) and likely reduce habitat quality in some areas. The Calumet Sag Channel and the Little Calumet River also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). In the CSSC, in-stream habitat varies by location, but it is generally limited, and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).
T_{10}: See T_0. The CAWS is expected to remain suitable habitat for *Schizopera borutzkyi*.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There is a low potential for vessels to transport this species from Indiana Harbor to inland portions of the CAWS (section 3b). Because of the lack of vessel traffic (section 3b), natural spread through the Grand Calumet will likely be required for *Schizopera borutzkyi* to reach the Little Calumet River and the Calumet Sag Channel. Initial establishment in the Grand Calumet River may be inhibited by high sediment toxicity (section 3d). The sheetpile in the Grand Calumet River may slow the initial spread of *Schizopera borutzkyi* toward the Brandon Road Lock and Dam (sections 3c, 3d). There are areas of suitable habitat for *Schizopera borutzkyi* throughout the CAWS (section 3d). However, *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (section 3a). Therefore, the probability of passage by the species is low.
T_{10}: See T_0.
T_{25}: See T_0. Twenty-five years may be enough time for *Schizopera borutzkyi* to move through the CAWS to the Brandon Road Lock and Dam; therefore, the likelihood of passage rises to medium.
T_{50}: See T_{25}. Over 50 years, *Schizopera borutzkyi* has a higher probability of reaching the Brandon Road Lock and Dam. Therefore, the probability of passage by the species is high.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. The natural rate of spread for *Schizopera borutzkyi* is uncertain. The ability of this species to tolerate the sediment contaminants, stormwater runoff, and dissolved oxygen levels in the CAWS is uncertain. *Schizopera borutzkyi* is documented in large river systems in Europe. Why this species has not been detected in the CAWS despite being present in southern Lake Michigan is uncertain. It is uncertain whether benthic surveys conducted in the CAWS or the Illinois River would have detected meiofauna given their small size. Therefore, the species may be present but undetected. Therefore, the uncertainty of passage for the species is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Schizopera borutzkyi is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is present and accessible downstream of the Brandon Road Lock and Dam.

Evidence for Probability Rating

Because *Schizopera borutzkyi* is native to large river systems in Europe (section 4a), the probability of colonization by the species is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat below the Brandon Lock and Dam has been documented. The species has been documented in rivers. Therefore, the uncertainty related to colonization by the species is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Schizopera borutzkyi is native to the delta of the Danube River and the Black Sea basin (Kipp et al. 2012); therefore, climate in the MRB should be suitable.

b. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi may spread rapidly if transported by ballast water.

c. *Fecundity*
Females carry two egg sacs (Lesko et al. 2003).

d. *History of Invasion Success*
This species became dominant and spread rapidly in the Great Lakes likely by vessel transport (Kipp et al. 2012). No data on the spread rate of *Schizopera borutzkyi* in rivers were found.

e. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi can be transported in ballast water. There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Schizopera borutzkyi is native to large river systems in Europe. Little data are available on specific habitat preferences in rivers. In the Great Lakes this species is associated with shallow sandy and muddy sediments (Kipp et al. 2011). Sandy and muddy sediments are distributed throughout the MRB.

Evidence for Probability Rating

Schizopera borutzkyi is native to large river systems in Europe. Suitable sediment conditions appear to be present and connected (section 5f). There is the potential for this species to be spread in ballast water. Therefore, the probability of this species spreading is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

The species has been documented in rivers. Thus, the uncertainty of spread by the species is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	High	Low	High	Medium	High	High	High
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	Low	-[a]	Low	-	Medium	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Schizopera borutzkyi is a small copepod that lives in the sediment. The eggs are attached to the adult, and it has no planktonic life stage (Kipp et al. 2012). It spread from Lake Michigan to Lake Erie in less than 5 years (Kipp et al. 2012). Its ability to enter diapause may contribute to its survival in ship ballast tanks (Kipp et al. 2012).

b. *Human-Mediated Transport through Aquatic Pathways*
Schizopera borutzkyi was introduced to the Great Lakes by ballast water release (Horvath et al. 2001). Spread by vessel traffic has been the fastest means of spread among the Great Lakes. There is no commercial vessel traffic to the BSBH from Lake Michigan (USACE 2011a). However, there is heavy commercial traffic to the adjacent Burns Harbor.

c. *Current Abundance and Reproductive Capacity*
T_0: In surveys of southern Lake Michigan between 1999 and 2000, *Schizopera borutzkyi* was found to dominate the harpacticoid copepod community in deep sites (at 15 m [49.2 ft]) (Horvath et al. 2001) and has been found to reach densities of 3,700/m^2 in the sediment (Garza & Whitman 2004). Reproductive females carry two eggs sacs ventrally (Lesko et al. 2003).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. *Schizopera borutzkyi* is along the shoreline of southern Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In southern Lake Michigan *Schizopera borutzkyi* was found in nearshore waters in Michigan City, Indiana, and Indiana Dunes National Lakeshore located less than 24 km (15 mi) northeast of BSBH (Horvath et al. 2001; Garza & Whitman 2004).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Climate is suitable. *Schizopera borutzkyi* has been found in southern Lake Michigan at depths of 2 to 15 m (6.6 to 49.2 ft) and is often the dominant species at depths of 15 m (49.2 ft) (Horvath et al. 2001). In Lake Michigan this species prefers shallow muds and sands (Horvath et al. 2001). Sandy sediments are present in Lake Michigan in the vicinity of the BSBH.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: *Schizopera borutzkyi* is found in southern Lake Michigan and can be the dominant species (sections 2e, 2f). It has been documented near the BSBH, and habitat conditions are suitable at the BSBH (section 2f). Therefore, the probability of arrival for the species at this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: This species has been documented numerous times in southern Lake Michigan. While its current distance from the BSBH is uncertain and no surveys are available after 2000, *Schizopera borutzkyi* has been documented less than 24 km (15 mi) from the BSBH. Therefore, the uncertainty of arrival by the species is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50} : LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
Schizopera borutzkyi is a small copepod that lives in the sediment. *Schizopera borutzkyi* has spread from Lake Michigan to Lake Ontario in less than 5 years by ship traffic (Kipp et al. 2012). *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (Kipp et al. 2012), although this may be due to lack of surveys for meiofauna.

b. Human-Mediated Transport through Aquatic Pathways
Although *Schizopera borutzkyi* can be transported in ballast water (Kipp et al. 2012), the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Vessel traffic to BSBH is lake-wide only. The south branch of the Little Calumet River is shallow and likely has only local nonmotorized vessel traffic, if any (Little Calumet and Grand Calumet River Corridor Technical Advisory Group and Northeastern Illinois Planning Commission 2011).

c. Existing Physical Human/Natural Barriers
T_0: None. The 1.2- to 9.1-m (4- to 30-ft) water depth found in the CAWS (LimnoTech 2010) is adequate for *Schizopera borutzkyi* based on its depth distribution in Lake Michigan (Kipp et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. *Schizopera borutzkyi* is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012). The banks of the BSBH are primarily riprap and vertical walls. The banks of

the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Inorganic silt and sludge sediments predominate in the Calumet Sag Channel (LimnoTech 2010). The Calumet Sag Channel contains areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). In the CSSC, in-stream habitat varies by location but is generally limited, and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).

T_{10}: See T_0. The CAWS is expected to remain suitable habitat for *Schizopera borutzkyi*.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: There are areas of suitable habitat for *Schizopera borutzkyi* throughout the CAWS (section 3d). Because there is no commercial vessel traffic, there is a low potential for vessels to transport this species from the BSBH to inland portions of the CAWS (section 3b). Because of the lack of vessel traffic (section 3b), natural spread will likely be required for *Schizopera borutzkyi* to reach the Brandon Road Lock and Dam. *Schizopera borutzkyi* has been in southern Lake Michigan since 1998 but has not been reported in the CAWS or the Illinois River (section 3a). Overall, the probability of passage for the species is low at this time step.

T_{10}: See T_0.

T_{25}: See T_0. Twenty-five years may be enough time for *Schizopera borutzkyi* to move through the CAWS to the Brandon Road Lock and Dam; therefore, the probability of passage is medium.

T_{50}: See T_{25}. Over 50 years *Schizopera borutzkyi* has a higher probability of reaching the Brandon Road Lock and Dam. Therefore, the probability of passage is high for this time step.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: The physical and chemical habitat preferences of *Schizopera borutzkyi* are not well documented. The natural rate of spread for *Schizopera borutzkyi* is uncertain. The potential for transport on boat hulls is uncertain. The ability of this species to tolerate the sediment contaminants, stormwater runoff, and dissolved oxygen levels in the CAWS is

uncertain. Why this species has not been detected in the CAWS despite being present in southern Lake Michigan is uncertain. It is uncertain whether benthic surveys conducted in the CAWS or the Illinois River would have detected meiofauna given their small size. Therefore, species may be present but undetected. Therefore, the uncertainty of passage for the species is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Schizopera borutzkyi is native to large river systems in Europe and is found in silty and sandy sediments in the Great Lakes (Horvath et al. 2001; Kipp et al. 2012).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present and accessible downstream of the Brandon Road Lock and Dam.

Evidence for Probability Rating

Because *Schizopera borutzkyi* is native to large river systems in Europe (section 4a), the probability of the species colonizing is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat below the Brandon Lock and Dam has been documented. The species has been documented in rivers. Therefore, the uncertainty of the species colonizing is low.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
   Schizopera borutzkyi is native to the delta of the Danube River and the Black Sea basin (Kipp et al. 2012); therefore, climate in the MRB should be suitable.

b. *Type of Mobility/Invasion Speed*
   Schizopera borutzkyi may spread rapidly if transported by ballast water.

c. *Fecundity*
   Females carry two egg sacs (Lesko et al. 2003).

d. *History of Invasion Success*
   This species became dominant and spread rapidly in the Great Lakes, likely by vessel transport (Kipp et al. 2012). No data on the spread rate of *Schizopera borutzkyi* in rivers were found.

e. *Human-Mediated Transport through Aquatic Pathways*
   Schizopera borutzkyi can be transported in ballast water. There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Schizopera borutzkyi is native to large river systems in Europe (Kipp et al. 2011). Little data on specific habitat preferences in rivers are available. In the Great Lakes this species is associated with shallow sandy and muddy sediments (Kipp et al. 2011). Sandy and muddy sediments are distributed throughout the MRB.

Evidence for Probability Rating

Schizopera borutzkyi is native to large river systems in Europe. Suitable sediment conditions appear to be present and connected (section 5f). There is the potential for this species to be spread in ballast water. Therefore, the species has a high probability of spread.

Uncertainty: LOW

Evidence for Uncertainty Rating

The species is documented in rivers. Thus, the uncertainty associated with the probability of this species spreading is low.

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E.2.7 Fish

E.2.7.1 Threespine Stickleback - *Gasterosteus aculeatus*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The threespine stickleback is an actively swimming fish that forms schools. It lays eggs in a nest on the bottom (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance. The threespine stickleback reached Illinois accidentally as the result of the Welland Canal, built in the 1820s (Laird & Page 1996).

b. *Human-Mediated Transport through Aquatic Pathways*
There is recreational vessel traffic to the WPS (USACE 2011b). Although transport in ballast water is possible for this species, it was not described in the literature as a transport mechanism for the threespine stickleback.

c. *Current Abundance and Reproductive Capacity*
T_0: All eggs within a clutch are laid as a single batch in the nest of a single male (Wootton 2009). There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated). The threespine stickleback is considered established in southern Lake Michigan and it has been found in the North Shore Channel, which connects to the WPS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The threespine stickleback has arrived at the WPS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: In addition to being established in southern Lake Michigan, the threespine stickleback was found in the North Shore Channel in 1988 (Johnston 1991). The Illinois Natural History survey has found the threespine stickleback near Lockport Lock and Dam (INHS undated).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback is found from Arctic to temperate climates. The native range of the threespine stickleback is Arctic and Atlantic drainages from Baffin Island and the western side of Hudson Bay to Cape Fear Estuary, North Carolina (Page & Burr 1991), and Pacific drainages from Alaska to Baja California (Fuller 2011). Eastern freshwater populations are found far inland, including Lake Ontario (Fuller 2011). In the Great Lakes, the species is native only below Niagara Falls (Smith 1985). The threespine stickleback inhabits coastal marine, brackish, and an array of freshwater habitats ranging from tiny ephemeral streams in arid desert regions to large Arctic lakes (Willacker et al. 2010); populations can be wholly marine, anadromous, or strict

residents of freshwater (Willacker et al. 2010). The species is found in sluggish waters of lakes, ponds, large lowland rivers, estuaries, and marine coastlines. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in freshwater in shallow, soft bottoms (Laird & Page 1996). These fish are small (to 10 cm [3.9 in.]), visual predators (Gill & Hart 1994) that feed on invertebrates such as crustaceans and insect larvae, as well as fish eggs, fish larvae and plant matter (Wootton 1976). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).
T_{10}: See T_0. Habitat is expected to remain suitable for the threespine stickleback.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback is documented as established in southern Lake Michigan and has been found in the CAWS (Section 2e). Suitable habitat is present in the vicinity of the WPS and this species has been found in the North Shore Channel (Section 2f). Therefore, the threespine stickleback is considered to have arrived at the pathway.
T_{10}: See T_0. No changes in the habitat of Lake Michigan are expected to alter the probability of arrival at the WPS.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The species has been documented in the North Shore Channel, just beyond the entrance to the WPS pathway. Therefore, there is no uncertainty associated with its arrival at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species is an actively swimming fish that forms schools. It lays eggs in a nest (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance.

b. *Human-Mediated Transport through Aquatic Pathways*
Although not documented in the literature, the threespine stickleback potentially may be transported in ballast water. However, there is no commercial vessel traffic from the WPS (USACE 2011a,b). Threespine sticklebacks actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS.

c. *Existing Physical Human/Natural Barriers*
T_0: There is a sluice gate separating Lake Michigan from the North Shore Channel. However, the gate is opened periodically and water is pumped periodically from Lake Michigan into the North Shore Channel, which could transport this species. The threespine stickleback has been found within the North Shore Channel (Johnston 1991). The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, adult threespine sticklebacks that are shocked would flow downstream through the barrier. So, there is a high potential that adults may pass the barrier at the current setting. Also, eggs/larvae that are resuspended in the water column by boat propellers may pass through the Electric Dispersal Barrier System. Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to control the passage of this species through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback typically inhabits weedy pools or backwaters, or occurs among emergent plants at stream edges (NatureServe 2010). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC and the North Shore Channel in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003). Threespine sticklebacks have been recorded in the CAWS, including the North Shore

Channel, CSSC, Burns Harbor, and Calumet Harbor (Johnston 1991; Barnes 1999) down to Lockport Lock and Dam (INHS undated). Therefore, habitat is assumed to be suitable in the CAWS.
T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable for the threespine stickleback.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback has been found in multiple locations in the CAWS, therefore suitable habitat is present (Section 3d). It is found in the CSSC as far south as the Lockport Lock and Dam which is less than 11.3 km (7 mi) from Brandon Road Lock and Dam. The species may be small enough to pass through the Electric Dispersal Barrier System, and no other barriers are expected to control the downstream movement of this species (Section 3c). Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The threespine stickleback has been present in the CAWS since 1988 and there do not appear to be any significant barriers to passage. However, this species has yet to be identified in the MRB below Brandon Road Lock and Dam. Why this species has not established in the MRB is uncertain, although it may be present in the MRB and not yet detected. Surveys of the lower Illinois River are required to determine if the species is present at this time step. Overall, the uncertainty of passage during this time step is medium.
T_{10}: See T_0. Given the documented proximity of this species to Brandon Road Lock and Dam and the lack of barriers to passage, it is more certain that over time, this species will pass downstream of Brandon Road Lock and Dam. Therefore, the uncertainty of passage during this time step is low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is found near Brandon Road Lock and Dam. The threespine stickleback could swim to suitable habitat.

Evidence for Probability Rating

Suitable habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been documented near the Brandon Road Lock and Dam. Therefore, there is low uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The threespine stickleback has a circumpolar distribution in the Northern Hemisphere (Laird & Page 1996). It is found from Arctic to temperate climates, suggesting climate in the MRB will be suitable.

b. *Type of Mobility/Invasion Speed*
This species is considered highly invasive, but no information was found on rate of spread through river basins.

c. *Fecundity*
There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated).

d. *History of Invasion Success*
The threespine stickleback is naturally widely distributed in the United States. It has successfully invaded inland water bodies like the Great Lakes and has been successfully introduced to several river drainages in the United States (Fuller 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel traffic in the MRB (USACE 2011a,b). Although transport in ballast water is possible for this species, vessel-mediated transport is not described in the literature as a significant transport mechanism for the threespine stickleback.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This species is a generalist; therefore, it can occupy a wide range of habitats.
The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010) but seems to prefer low velocities (Copp & Kovac 2003). It has established in several river basins in the United States (Fuller 2012). Reservoirs in the MRB would also be suitable habitat.

Evidence for Probability Rating

The threespine stickleback has been successfully introduced to several river drainages in the United States. There is suitable habitat contiguously distributed throughout the MRB (section 5f). The threespine stickleback can spread quickly and reach high abundance (section 5d), considering its high fecundity (section 5c). Overall, there is a high probability of spread by the threespine stickleback in the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is suitable habitat in the MRB and the threespine stickleback has been documented to establish in river basins. Therefore, once the threespine stickleback colonizes below Brandon Road Lock and Dam, there is a low uncertainty associated with the probability of it spreading in the MRB.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The threespine stickleback is an actively swimming fish that forms schools. It lays eggs in a nest on the bottom (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance. The threespine stickleback reached Illinois accidentally as the result of the Welland Canal, built in the 1820s (Laird & Page 1996).

b. *Human-Mediated Transport through Aquatic Pathways*
There is commercial and recreational vessel traffic to the CRCW (USACE 2011a,b). Although transport in ballast water is possible for this species, it was not described in the literature as a transport mechanism for the threespine stickleback.

c. *Current Abundance and Reproductive Capacity*
T_0: All eggs within a clutch are laid as a single batch in the nest of a single male (Wootton 2009). There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated). Threespine stickleback is considered established in southern Lake Michigan, which connects to the CRCW.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The threespine stickleback has arrived at the CRCW.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The threespine stickleback is considered established in southern Lake Michigan (Johnston 1991). It was found near the CRCW in 1988 (Fuller 2011) and has been found in the CAWS (Johnston 1991; INHS undated).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback is found from Arctic to temperate climates. The native range of the threespine stickleback is Arctic and Atlantic drainages from Baffin Island and the western side of Hudson Bay to the Cape Fear Estuary, North Carolina (Page & Burr 1991), and Pacific drainages from Alaska to Baja California (Fuller 2011). Eastern freshwater populations are found far inland, including Lake Ontario (Fuller 2011). In the

Great Lakes, the species is native only below Niagara Falls (Smith 1985). The threespine stickleback inhabits coastal marine, brackish, and an array of freshwater habitats ranging from tiny ephemeral streams in arid desert regions to large Arctic lakes (Willacker et al. 2010); populations can be wholly marine, anadromous, or strict residents of fresh water (Willacker et al. 2010). The species is found in sluggish waters of lakes, ponds, large lowland rivers, estuaries, and marine coastlines. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in freshwater in shallow, soft bottoms (Laird & Page 1996). These fish are small (to 10 cm [3.9 in]), visual predators (Gill & Hart 1994) that feed on invertebrates such as crustaceans and insect larvae, as well as fish eggs, fish larvae, and plant matter (Wootton 1976). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).
T_{10}: See T_0. Habitat near the CRCW is expected to remain suitable for the threespine stickleback.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback is documented as established in southern Lake Michigan and has been found in the CAWS (section 2e). Suitable habitat is present in the vicinity of the CRCW (section 2f). Therefore, the threespine stickleback is considered to have arrived at the pathway.
T_{10}: See T_0. No changes in the habitat of Lake Michigan are expected to alter the probability of arrival at the CRCW.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The species is documented near the CRCW pathway. Therefore, there is no uncertainty associated with its arrival at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species is an actively swimming fish that forms schools. It lays eggs in a nest (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance.

b. *Human-Mediated Transport through Aquatic Pathways*
Although not documented in the literature, the threespine stickleback potentially may be transported in ballast water, and there is commercial and recreational vessel traffic from the CRCW to Brandon Road Lock and Dam (USACE 2011a,b). Threespine sticklebacks actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS.

c. *Existing Physical Human/Natural Barriers*
T_0: The threespine stickleback is found within the CAWS (Johnston 1991; Barnes 1999). Within the CAWS, the Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, adult threespine sticklebacks that are shocked would flow downstream through the barrier. So, there is a high potential that adults may pass the barrier at the current setting. In addition, eggs/larvae that are resuspended in the water column by boat propellers may pass through the Electric Dispersal Barrier System. Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to control the passage of this species through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback typically inhabits weedy pools or backwaters, or occurs among emergent plants at stream edges (NatureServe 2010). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003). Threespine sticklebacks have been recorded in the CAWS, including the North Shore Channel, Calumet River, CSSC, Burns

Harbor, and Calumet Harbor (Johnston 1991; Barnes 1999) down to Lockport Lock and Dam (INHS undated). Therefore, habitat is assumed to be suitable in the CAWS.
T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable for the threespine stickleback.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback has been found in multiple locations in the CAWS, therefore, suitable habitat is present (section 3d). It is found in the CSSC as far south as the Lockport Lock and Dam which is less than 11.3 km (7 mi) from Brandon Road Lock and Dam. The species may be small enough to pass through the Electric Dispersal Barrier System, and no other barriers are expected to control the downstream movement of this species (section 3c). Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The threespine stickleback has been present in the CAWS since 1988 and there do not appear to be any significant barriers to passage. However, this species has yet to be identified in the MRB below Brandon Road Lock and Dam. Why this species has not established in the MRB is uncertain, although it may be present in the MRB, but not yet detected. Surveys of the lower Illinois River are required to determine if the species is present at this time step. Overall, the uncertainty of passage during this time step is medium.
T_{10}: See T_0. Given the documented proximity of this species to Brandon Road Lock and Dam and the lack of barriers to passage, it is more certain that over time this species will pass downstream of Brandon Road Lock and Dam. Therefore, the uncertainty of passage during this time step is low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is found near Brandon Road Lock and Dam. The threespine stickleback could swim to suitable habitat.

Evidence for Probability Rating

Suitable habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been documented near the Brandon Road Lock and Dam. Therefore, there is low uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
   The threespine stickleback has a circumpolar distribution in the Northern Hemisphere (Laird & Page 1996). It is found from Arctic to temperate climates, suggesting climate in the GLB will be suitable.

b. *Type of Mobility/Invasion Speed*
This species is considered highly invasive, but no information was found on rate of spread through river basins.

c. *Fecundity*
There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated).

d. *History of Invasion Success*
The threespine stickleback is naturally widely distributed in the United States. It has successfully invaded inland water bodies like the Great Lakes and has been successfully introduced to several river drainages in the United States (Fuller 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel traffic in the MRB (USACE 2011a,b). Although transport in ballast water is possible for this species, vessel-mediated transport is not described in the literature as a significant transport mechanism for the threespine stickleback.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This species is a generalist; therefore, it can occupy a wide range of habitats. The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003). It has established in several river basins in the United States (Fuller 2011). Reservoirs in the MRB would also be suitable habitat.

Evidence for Probability Rating

The threespine stickleback has been introduced successfully to several river drainages in the United States. There is suitable habitat contiguously distributed throughout the MRB (section 5f). The threespine stickleback can spread quickly and reach high abundance (section 5d), considering its high fecundity (section 5c). Overall, there is a high probability of spread by the threespine stickleback in the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is suitable habitat in the MRB and the threespine stickleback has been documented to establish in river basins. Therefore, once the threespine stickleback colonizes below Brandon Road Lock and Dam, there is a low uncertainty associated with the probability of it spreading in the MRB.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The threespine stickleback is an actively swimming fish that forms schools. It lays eggs in a nest on the bottom (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance. The threespine stickleback reached Illinois accidentally as the result of the Welland Canal, built in the 1820s (Laird & Page 1996).

b. *Human-Mediated Transport through Aquatic Pathways*
There is heavy commercial vessel traffic to the Calumet Harbor (USACE 2011a). Although transport in ballast water is possible for this species, it was not described in the literature as a significant transport mechanism for the threespine stickleback.

c. *Current Abundance and Reproductive Capacity*
T_0: All eggs within a clutch are laid as a single batch in the nest of a single male (Wootton 2009). There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated). The threespine stickleback is considered established in southern Lake Michigan, which connects to Calumet Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The threespine stickleback has arrived at Calumet Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The threespine stickleback is considered established in southern Lake Michigan. It was found near the Calumet Harbor and within the Calumet River in 1988–1989 (Fuller 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback is found from Arctic to temperate climates. The native range of the threespine stickleback is Arctic and Atlantic drainages from Baffin Island and the western side of Hudson Bay to Cape Fear Estuary, North Carolina (Page & Burr 1991), and Pacific drainages from Alaska to Baja California (Fuller 2011). Eastern freshwater populations are found far inland, including Lake Ontario (Fuller 2011). In the Great Lakes, the species is native only below Niagara Falls (Smith 1985). The threespine stickleback inhabits coastal marine, brackish, and an array of freshwater habitats ranging from tiny ephemeral streams in arid desert regions to large Arctic lakes (Willacker et al. 2010); populations can be wholly marine, anadromous, or strict residents of fresh water (Willacker et al. 2010). The species is found in sluggish waters of lakes, ponds, large lowland rivers, estuaries, and marine coastlines. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in freshwater in shallow, soft bottoms (Laird & Page 1996). These fish are small (to 10 cm; 3.9 in.), visual predators (Gill & Hart 1994) that feed on

invertebrates such as crustaceans and insect larvae, as well as fish eggs, fish larvae, and plant matter (Wootton 1976). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).
T_{10}: See T_0. Habitat near Calumet Harbor is expected to remain suitable for the threespine stickleback.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback is documented as established in southern Lake Michigan and has been found in the CAWS (section 2e). Suitable habitat is present in the vicinity of Calumet Harbor and it has been documented at the Calumet Harbor and the Calumet River (section 2f). Therefore, the threespine stickleback is considered to have arrived at the pathway.
T_{10}: See T_0. No changes in the habitat of Lake Michigan are expected to alter the probability of arrival at Calumet Harbor.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The species is documented near the Calumet Harbor pathway. Therefore, there is no uncertainty associated with its arrival at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species is an actively swimming fish that forms schools. It lays eggs in a nest (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance.

b. *Human-Mediated Transport through Aquatic Pathways*
Although not documented in the literature, the threespine stickleback may potentially be transported in ballast water, and there is commercial and recreational vessel traffic from Calumet Harbor to Brandon Road Lock and Dam (USACE 2011a,b). Threespine sticklebacks actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS.

c. *Existing Physical Human/Natural Barriers*
T_0: The threespine stickleback is found within the CAWS, including Calumet Harbor and the Calumet River (Johnston 1991; Barnes 1999). Within the CAWS, the Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, adult threespine sticklebacks that are shocked would flow downstream through the barrier. So, there is a high potential that adults may pass the barrier at the current setting. Also, eggs/larvae that are resuspended in the water column by boat propellers may pass through the Electric Dispersal Barrier System. Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to control the passage of this species through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback typically inhabits weedy pools or backwaters, or occurs among emergent plants at stream edges (NatureServe 2010). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS, although it is not a dominant substrate component (LimnoTech 2010). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003). Threespine sticklebacks have been recorded in the CAWS, including the North Shore Channel, Calumet River, CSSC, Burns Harbor, and Calumet Harbor (Johnston 1991; Barnes 1999) down to Lockport Lock and Dam (INHS undated). Therefore, habitat is assumed to be suitable in the CAWS.
T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable for the threespine stickleback.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback has been found in multiple locations in the CAWS; therefore suitable habitat is present (section 3d). It is found in the CSSC as far south as the Lockport Lock and Dam which is less than 11.3 km (7 mi) from Brandon Road Lock and Dam. The species may be small enough to pass through the Electric Dispersal Barrier System, and no other barriers are expected to control the downstream movement of this species (section 3c). Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The threespine stickleback has been present in the CAWS since 1988 and there do not appear to be any significant barriers to passage. However, this species has yet to be identified in the MRB below Brandon Road Lock and Dam. Why this species has not established in the MRB is uncertain, although it may be present in the MRB, but not yet detected. Surveys of the lower Illinois River are required to determine if the species is present at this time step. Overall, the uncertainty of passage during this time step is medium.
T_{10}: See T_0. Given the documented proximity of this species to Brandon Road Lock and Dam and the lack of barriers to passage, it is more certain that over time, this species will pass downstream of Brandon Road Lock and Dam. Therefore, the uncertainty of passage during this time step is low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam. The threespine stickleback could swim to suitable habitat.

Evidence for Probability Rating

Suitable habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been documented near the Brandon Road Lock and Dam. Therefore, there is low uncertainty regarding the probability of the colonization of this pathway.

5. **P(spreads): HIGH**

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in New Basin*
The threespine stickleback has a circumpolar distribution in the Northern Hemisphere (Laird & Page 1996). It is found from Arctic to temperate climates, suggesting climate in the GLB will be suitable.

b. *Type of Mobility/Invasion Speed*
This species is considered highly invasive, but no information was found on rate of spread through river basins.

c. *Fecundity*
There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per

female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated).

d. History of Invasion Success
The threespine stickleback is naturally widely distributed in the United States. It has successfully invaded inland water bodies like the Great Lakes and has been successfully introduced to several river drainages in the United States (Fuller 2011).

e. Human-Mediated Transport through Aquatic Pathways
There is heavy vessel traffic in the MRB. Although transport in ballast water is possible for this species, vessel-mediated transport is not described in the literature as a significant transport mechanism for the threespine stickleback.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
This species is a generalist; therefore, it can occupy a wide range of habitat. The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003). It has established in several river basins in the United States (Fuller 2011). Reservoirs in the MRB would also be suitable habitat.

Evidence for Probability Rating

The threespine stickleback has been successfully introduced to several river drainages in the United States. There is suitable habitat contiguously distributed throughout the MRB (section 5f). The threespine stickleback can spread quickly and reach high abundance (section 5d), considering its high fecundity (section 5c). Overall, there is a high probability of spread by the threespine stickleback in the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is suitable habitat in the MRB and the threespine stickleback has been documented to establish in river basins. Therefore, once the threespine stickleback colonizes below Brandon Road Lock and Dam, there is a low uncertainty associated with the probability of spreading in the MRB.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The threespine stickleback is an actively swimming fish that forms schools. It lays eggs in a nest on the bottom (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance. The threespine stickleback reached Illinois accidentally as the result of the Welland Canal, built in the 1820s (Laird & Page 1996).

b. *Human-Mediated Transport through Aquatic Pathways*
There is heavy lakewise commercial vessel traffic to the Indiana Harbor (USACE 2011b). Although transport in ballast water is possible for this species, it was not described in the literature as transport mechanism for the threespine stickleback.

c. *Current Abundance and Reproductive Capacity*
T_0: All eggs within a clutch are laid as a single batch in the nest of a single male (Wootton 2009). There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated). The threespine stickleback is considered established in southern Lake Michigan, which connects to the Indiana Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The threespine stickleback has arrived at Indiana Harbor.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The threespine stickleback is considered established in southern Lake Michigan. It was found near the Indiana Harbor at the Indiana Dunes National Lakeshore and within the Calumet River (Fuller 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback is found from Arctic to temperate climates. The native range of the threespine stickleback is Arctic and Atlantic drainages from Baffin Island and the western side of Hudson Bay to Cape Fear Estuary, North Carolina (Page & Burr 1991), and Pacific drainages from Alaska to Baja California (Fuller 2011). Eastern freshwater populations are found far inland, including Lake Ontario (Fuller 2011). In the Great Lakes, the species is native only below Niagara Falls (Smith 1985). The threespine stickleback inhabits coastal marine, brackish, and an array of freshwater habitats ranging from tiny ephemeral streams in arid desert regions to large Arctic lakes (Willacker et al. 2010); populations can be wholly marine, anadromous, or strict residents of fresh water (Willacker et al. 2010). The species is found in sluggish waters of lakes, ponds, large lowland rivers, estuaries, and marine coastlines. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in freshwater in shallow, soft bottoms (Laird & Page 1996). These fish are small (to 10 cm [3.9 in.]), visual predators (Gill & Hart & 1994) that feed on

invertebrates such as crustaceans and insect larvae, as well as fish eggs, fish larvae and plant matter (Wootton 1976). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).
T_{10}: See T_0. Habitat near Indiana Harbor is expected to remain suitable for the threespine stickleback.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback is documented as established in southern Lake Michigan and it has been found in the CAWS (section 2e). Suitable habitat is present in the vicinity of the Indiana Harbor and it has been documented near Indiana Harbor (section 2f). Therefore, the threespine stickleback is considered to have arrived at the pathway.
T_{10}: See T_0. No changes in the habitat of Lake Michigan are expected to alter the probability of arrival at Indiana Harbor.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The species is documented near the Indiana Harbor pathway (section 2e). Therefore, there is no uncertainty associated with its arrival at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The species is an actively swimming fish that forms schools. It lays eggs in a nest (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance.

b. *Human-Mediated Transport through Aquatic Pathways*
Although not documented in the literature, the threespine stickleback may potentially be transported in ballast water, and there is only lakewise commercial vessel traffic to and from the Indiana Harbor (USACE 2011a,b). Threespine sticklebacks actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS.

c. *Existing Physical Human/Natural Barriers*
T_0: The threespine stickleback is found within the CAWS and has been found as far south as Lockport (Johnston 1991; Barnes 1999; INHS undated). The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier within the CAWS by repelling adult fish. However, adult threespine sticklebacks that are shocked would flow downstream through the barrier. So, there is a high potential that adults may pass the barrier at the current setting. Also, eggs/larvae that are resuspended in the water column by boat propellers may pass through the Electric Dispersal Barrier System. Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to control the passage of this species through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback typically inhabits weedy pools or backwaters, or occurs among emergent plants at stream edges (NatureServe 2010). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The species is found in a wide range of flowing and still water habitats (Rushbrook et al. 2010), but seem to prefer low velocities (Copp & Kovac 2003). Threespine sticklebacks have been recorded in the CAWS, including the North Shore Channel, Calumet River, CSSC, Burns Harbor and Calumet Harbor (Johnston 1991, Barnes 1999) down to Lockport Lock and Dam (INHS undated). Therefore, habitat is assumed to be suitable in the CAWS.
T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable for the threespine stickleback.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback has been found in multiple locations in the CAWS; therefore, suitable habitat is present (section 3d). It is found in the CSSC as far south as the Lockport Lock and Dam which is less than 11.3km (7 mi) from Brandon Road Lock and Dam. The species may be small enough to pass through the Electric Dispersal Barrier System, and no other barriers are expected to control the downstream movement of this species (section 3c). Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The threespine stickleback has been present in the CAWS since 1988 and there do not appear to be any significant barriers to passage. However, this species has yet to be identified in the MRB below Brandon Road Lock and Dam. Why this species has not established in the MRB is uncertain, although it may be present in the MRB but not yet detected. Surveys of the lower Illinois River are required to determine if the species is present at this time step. Overall, the uncertainty of passage during this time step is medium.
T_{10}: See T_0. Given the documented proximity of this species to Brandon Road Lock and Dam and the lack of barriers to passage, it is more certain that over time this species will pass downstream of Brandon Road Lock and Dam. Therefore, the uncertainty of passage during this time step is low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and still water habitats (Rushbrook et al. 2010), but seem to prefer low velocities (Copp & Kovac 2003).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is found near Brandon Road Lock and Dam. The threespine stickleback could swim to suitable habitat.

Evidence for Probability Rating

Suitable habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been documented near the Brandon Road Lock and Dam. Therefore, there is low uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The threespine stickleback has a circumpolar distribution in the Northern Hemisphere (Laird & Page 1996). It is found from Arctic to temperate climates, suggesting climate in the GLB will be suitable.

b. Type of Mobility/Invasion Speed
This species is considered highly invasive, but no information was found on rate of spread through river basins.

c. Fecundity
There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per

female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated).

d. *History of Invasion Success*
The threespine stickleback is naturally widely distributed in the United States. It has successfully invaded inland water bodies like the Great Lakes and has been successfully introduced to several river drainages in the United States (Fuller 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel traffic in the MRB (USACE 2011a,b). Although transport in ballast water is possible for this species, vessel-mediated transport is not described in the literature as a significant transport mechanism for the threespine stickleback.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This species is a generalist; therefore, it can occupy a wide range of habitat. The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and still water habitats (Rushbrook et al. 2010) seem to prefer low velocities (Copp & Kovac 2003). It has established in several river basins in the United States (Fuller 2011). Reservoirs in the MRB would also be suitable habitat.

Evidence for Probability Rating

The threespine stickleback has been successfully introduced to several river drainages in the United States. There is suitable habitat contiguously distributed throughout the MRB (section 5f). The threespine stickleback can spread quickly and reach high abundance (section 5d), considering its high fecundity (section 5c). Overall, there is a high probability of spread by the threespine stickleback in the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is suitable habitat in the MRB and the threespine stickleback has been documented to establish in river basins. Therefore, once the threespine stickleback colonizes below Brandon Road Lock and Dam, there is a low uncertainty associated with the probability of it spreading in the MRB.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	None	High	None	High	None	High	None
P(passage)	High	Medium	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	High	Low	High	Low	High	Low	High	Low
P(establishment)	High	-[a]	High	-	High	-	High	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The threespine stickleback is an actively swimming fish that forms schools. It lays eggs in a nest on the bottom (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance. The threespine stickleback reached Illinois accidentally as the result of the Welland Canal, built in the 1820s (Laird & Page 1996).

b. *Human-Mediated Transport through Aquatic Pathways*
There is lakewise recreational vessel traffic to the BSBH (USACE 2011b). Although transport in ballast water is possible for this species, it was not described in the literature as a transport mechanism for the threespine stickleback.

c. *Current Abundance and Reproductive Capacity*
T_0: All eggs within a clutch are laid as a single batch in the nest of a single male (Wootton 2009). There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated). They are considered established in southern Lake Michigan which connects to the BSBH.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: None. The threespine stickleback has arrived at the BSBH.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: The threespine stickleback is considered established in southern Lake Michigan and the CAWS. It was found near the BSBH at the Indiana Dunes National Lakeshore (Fuller 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: The threespine stickleback is found from Arctic to temperate climates. The native range of the threespine stickleback is Arctic and Atlantic drainages from Baffin Island and the western side of Hudson Bay to Cape Fear Estuary, North Carolina (Page & Burr 1991), and Pacific drainages from Alaska to Baja California (Fuller 2011). Eastern freshwater populations are found far inland, including Lake Ontario (Fuller 2011). In the Great Lakes, the species is native only below Niagara Falls (Smith 1985). The threespine stickleback inhabits coastal marine, brackish, and an array of freshwater habitats ranging from tiny ephemeral streams in arid desert regions to large Arctic lakes (Willacker et al. 2010); populations can be wholly marine, anadromous, or strict residents of fresh water (Willacker et al. 2010). The species is found in sluggish waters of lakes, ponds, large lowland rivers, estuaries, and marine coastlines. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in freshwater in shallow, soft bottoms (Laird & Page 1996). These fish are small (to 10 cm [3.9 in]), visual predators (Gill & Hart & 1994) that feed on

invertebrates such as crustaceans and insect larvae, as well as fish eggs, fish larvae, and plant matter (Wootton 1976). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003).
T_{10}: See T_0. Habitat near the BSBH is expected to remain suitable for the threespine stickleback.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback is documented as established in southern Lake Michigan and it has been found in the CAWS (section 2e). Suitable habitat is present in the vicinity of the BSBH (section 2f). Therefore, the threespine stickleback is considered to have arrived at the pathway.
T_{10}: See T_0. No changes in the habitat of Lake Michigan are expected to alter the probability of arrival at the BSBH.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	None	None	None	None

Evidence for Uncertainty Rating

T_0: The species is documented near the BSBH pathway and is established in the CAWS. Therefore, there is no uncertainty associated with its arrival at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The species is an actively swimming fish that forms schools. It lays eggs in a nest (NatureServe 2010); therefore, eggs and larvae are not expected to be transported by currents unless resuspended into the water column by a disturbance.

b. Human-Mediated Transport through Aquatic Pathways

Although not documented in the literature, the threespine stickleback may potentially be transported in ballast water. There is only lakewise commercial vessel traffic to and from the BSBH (USACE 2011a,b). Threespine sticklebacks actively swim and do not require humans for dispersal. Therefore, natural dispersal by swimming will likely be the primary mechanism of movement through the CAWS

c. Existing Physical Human/Natural Barriers

T_0: The threespine stickleback is found within the CAWS (Johnston 1991; Barnes 1999). The Electric Dispersal Barrier System located north of Lockport Lock and Dam may act as a barrier within the CAWS by repelling adult fish. However adult threespine sticklebacks that are shocked would flow downstream through the barrier. So, there is a high potential that adults may pass the barrier at the current setting. In addition, eggs/larvae that are resuspended in the water column by boat propellers may pass through the Electric Dispersal Barrier System. Brandon Road Lock and Dam and Lockport Lock and Dam are not expected to control the passage of this species through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The threespine stickleback typically inhabits weedy pools or backwaters, or occurs among emergent plants at stream edges (NatureServe 2010). Although living submerged aquatic vegetation is not common in the CAWS, it is found in the CSSC in low density (LimnoTech 2010). Plant debris is present in the CAWS although it is not a dominant substrate component (LimnoTech 2010). The CAWS is a turbid water system with a low flow of 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010). The species is found in a wide range of flowing and still water habitats (Rushbrook et al. 2010), but seem to prefer low velocities (Copp & Kovac 2003). Threespine sticklebacks have been recorded in the CAWS, including the North Shore Channel, Calumet River, CSSC, Burns Harbor, and Calumet Harbor (Johnston 1991; Barnes 1999) down to Lockport Lock and Dam (INHS undated). Therefore, habitat is assumed to be suitable in the CAWS.
T_{10}: See T_0. Habitat in the CAWS is expected to remain suitable for the threespine stickleback.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The threespine stickleback has been found in multiple locations in the CAWS, therefore suitable habitat is present (section 3d). It is found in the CSSC as far south as the Lockport Lock and Dam which is less than 11.3 km (7 mi) from Brandon Road Lock and Dam. The species may be small enough to pass through the Electric Dispersal Barrier System, and no other barriers are expected to control the downstream movement of this species (section 3c). Overall, the probability of passage is high for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The threespine stickleback has been present in the CAWS since 1988 and there do not appear to be any significant barriers to passage. However, this species has yet to be identified in the MRB below Brandon Road Lock and Dam. Why this species has not established in the MRB is uncertain, although it may be present in the MRB, but not yet detected. Surveys of the lower Illinois River are required to determine if the species is present at this time step. Overall, the uncertainty of passage during this time step is medium.
T_{10}: See T_0. Given the documented proximity of this species to Brandon Road Lock and Dam and the lack of barriers to passage, it is more certain that over time, this species will pass downstream of Brandon Road Lock and Dam. Therefore, the uncertainty of passage during this time step is low.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and still water habitats (Rushbrook et al. 2010), but seem to prefer low velocities (Copp & Kovac 2003).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is found near Brandon Road Lock and Dam. The threespine stickleback could swim to suitable habitat.

Evidence for Probability Rating

Suitable habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). The probability of the species colonizing near Brandon Road Lock and Dam is high.

Uncertainty: LOW

Evidence for Uncertainty Rating

Suitable habitat has been documented near the Brandon Road Lock and Dam. Therefore, there is low uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): HIGH

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in New Basin
The threespine stickleback has a circumpolar distribution in the Northern Hemisphere (Laird & Page 1996). It is found from Arctic to temperate climates, suggesting climate in the GLB will be suitable.

b. Type of Mobility/Invasion Speed
The threespine stickleback is considered highly invasive, but no information was found on its rate of spread through river basins.

c. Fecundity
There may be 15 eggs in a very small female to more than 1000 eggs in exceptionally large females (Baker et al. 2008). Mean breeding season fecundity equals 2060 eggs per

female (Copp & Kovac 2003). Minimum population doubling time is less than 15 months (Fishbase undated).

d. *History of Invasion Success*
The threespine stickleback is naturally widely distributed in the United States. It has successfully invaded inland water bodies like the Great Lakes and has been successfully introduced to several river drainages in the United States (Fuller 2011).

e. *Human-Mediated Transport through Aquatic Pathways*
There is heavy vessel traffic in the MRB (USACE 2011a,b). Although transport in ballast water is possible for this species, vessel-mediated transport is not described in the literature as a significant transport mechanism for the threespine stickleback.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
This species is a generalist; therefore, it can occupy a wide range of habitats. The species is found in sluggish waters of rivers. Freshwater populations usually inhabit shallow vegetated water (NatureServe 2010). All populations spawn in shallow, soft bottoms (Laird & Page 1996). The species is found in a wide range of flowing and stillwater habitats (Rushbrook et al. 2010), but seems to prefer low velocities (Copp & Kovac 2003). It has established in several river basins in the United States (Fuller 2011). Reservoirs in the MRB would also be suitable habitat.

Evidence for Probability Rating

The threespine stickleback has been successfully introduced to several river drainages in the United States. There is suitable habitat contiguously distributed throughout the MRB (section 5f). The threespine stickleback can spread quickly and reach high abundance (Section 5d), considering its high fecundity (section 5c). Overall, there is a high probability of spread by the threespine stickleback in the MRB.

Uncertainty: LOW

Evidence for Uncertainty Rating

There is suitable habitat in the MRB and the threespine stickleback has been documented to establish in river basins. Therefore, once the threespine stickleback colonizes below Brandon Road Lock and Dam, there is a low uncertainty associated with the probability of spreading in the MRB.

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E.2.7.2 Ruffe - *Gymnocephalus cernuus*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Medium	Low	Medium	Medium	High
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The rates of natural dispersion of the ruffe are not well known because ballast water transport has been the key spread vector in the Great Lakes (USFWS 1996). Ruffe can spread quickly by vessel transport and can quickly become abundant (USFWS 1996; Bauer et al. 2007), having spread across the northern Great Lakes in a decade (Fuller et al. 2012). However, within Lake Michigan, the ruffe has not spread beyond Green Bay in the 9 years since its detection in that area (Bowen & Goehle 2011). The eggs and

larvae of the species are benthic, not free-floating (Ogle 1998), so the transport of eggs by currents is unlikely.

b. *Human-Mediated Transport through Aquatic Pathways*
Ruffe can spread quickly by vessel transport and can quickly become abundant (USFWS 1996; Bauer et al. 2007); human-mediated transport is likely to be more important for arrival at the southern Great Lakes than natural dispersion. The species can be transported in ballast water (Pratt et al. 1992), but there is no cargo vessel traffic between northern Lake Michigan and WPS (USACE 2011a). However, recreational boat traffic is present and there is lakewise commercial vessel traffic and ballast water discharge at other CAWS ports in southern Lake Michigan.

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of the ruffe and WPS.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: The species is not widespread, and there are no high-density populations in Lake Michigan (Bowen & Goehle 2011). Females produce up to 200,000 eggs in the first batch, and up to 6,000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002). Over the last decade, the abundance of ruffe has declined and/or leveled off in many locations where the fish is currently established (Bowen & Goehle 2011). Ruffe populations are currently monitored. Past control efforts such as stocking predators and removal by trawling were not considered effective (Jensen 2006).
T_{10}: The abundance of the ruffe at its current locations could increase or decrease owing to natural population fluctuations or interactions with other species such as round goby (Bowen & Goehle 2011).
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, ruffe abundance could increase or decrease (Bowen & Goehle 2011). Examples of future changes potentially affecting the abundance of ruffe include natural population fluctuations, climate change, new diseases, and control measures.

e. *Distance from Pathway*
T_0: Ruffe exist in northern Lake Michigan in Green Bay/Bay de Noc and have not been detected outside of Green Bay (Bowen & Goehle 2011).
T_{10}: See T_0. Ruffe could move closer to WPS by spreading through the suitable habitat along Lake Michigan or by vessel transport to southern Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, the distance of the ruffe from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of ruffe in the Great Lakes include natural population growth, climate change, new diseases, and control measures.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), ruffe appears to be more of a cold-water species. Ruffe prefer still or slow-moving water (Fishbase 2010), and the exposed high-energy shoreline along most of Lake Michigan may not be suitable habitat. The numerous river mouths along the shoreline of Lake Michigan and deeper offshore waters would be suitable (White 2002; Peterson et al. 2011; Schleuter & Eckmann 2008). The harbor at the WPS may be a suitable habitat, as are other harbors in the Great Lakes. Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical and climatological suitability of the Great Lakes and their tributaries for the ruffe. Water temperatures, and stream flows in particular, may be altered, potentially affecting the distribution of this species. On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), ruffe appears to be more of a cold-water species, and temperature increases related to future climate change (Wuebbles et al. 2010) may affect its spread south from the upper Great Lakes and affect its probability of arriving at the CAWS.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is not currently located near WPS and has not spread from Green Bay (sections 2d, 2e), suggesting that there is currently low propagule pressure for the species. However, suitable habitat is present near WPS (sections 2c, 2f). Ruffe can potentially be transported via ballast water to southern Lake Michigan (sections 2a, 2b), but there is no cargo vessel traffic to the WPS (section 2b). However, the ruffe could be transported to southern Lake Michigan by vessel traffic to other CAWS ports. Existing control measures are unlikely to reduce the abundance of ruffe in its current locations. This species is unlikely to spread from Green Bay to WPS during the current time step, given that it has not been detected in southern Lake Michigan during a decade of monitoring (section 2a). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over 50 years, the probability increases that ruffe will have time to spread to the WPS by natural dispersion alone or a combination of human-mediated transport to the southern Great Lakes and natural dispersion to the WPS. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: The natural dispersal speed of the ruffe is not well characterized. It is uncertain why this species has not spread more widely into southern Lake Michigan. However, this species is not documented to have spread into southern Lake Michigan over the last decade. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. The future population trends and future rate of spread of the ruffe are uncertain. The arrival of the ruffe at WPS could increase or decrease over time, depending on the trends in the distribution and abundance of ruffe populations in the Great Lakes. Ruffe have fluctuated in abundance over time and they are subject to control measures. Therefore, over time, trends in future populations and spread rates become less certain. Ruffe have not spread to southern Lake Michigan in the last decade, although they may move closer to the WPS with time. Overall, the uncertainty of the species' arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. On the basis of its native distribution, ruffe appears to be more of a cold-water species and temperature increases related to climate change may affect its distribution (section 2f). Thus, climate change could limit the movement of ruffe into southern Lake Michigan (section 2f). Therefore, the uncertainty of the species' arrival at the pathway is high.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The ruffe is a small fish. Rates of natural dispersion are not well known because ballast water transport has been a key spread vector (UDFWS 1996). The species can quickly become abundant (USFWS; Bauer et al. 2007). The eggs and larvae of the species are benthic, not free-floating (Ogle 1998), so the transport of eggs by currents is unlikely.

b. Human-Mediated Transport through Aquatic Pathways
The distance from the WPS to Brandon Road Lock and Dam is greater than 64 km (40 mi). While the species can be transported in ballast water (Dawson et al. 2006), there is no commercial or recreational vessel traffic between WPS and Brandon Road Lock and Dam (USACE 2011a,b). Therefore, natural dispersal will likely be the primary mechanism of movement through the CAWS from WPS.

c. Existing Physical Human/Natural Barriers

T_0: Ruffe could be transported from Lake Michigan into the North Shore Channel via water pumped from the lake into the channel. Depending on their life stage (Kovac 1998), the season and the time of day (Brown et al. 1998; White 2002; Peterson et al. 2011), ruffe move from shallow (<10 m; 32.8 ft) to deep water (<80 m; 262 ft). The water depth in the Chicago River and CSSC is less than 9.1 m (30 ft) and less than 4.6 m (15 ft), respectively, in many areas. The Electric Barrier Dispersal System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, electric barriers do not appear to be highly effective against ruffe (Dawson et al. 2006), and adults that are shocked could flow downstream through the barrier. So there is a high potential that adults may pass the barrier at its current setting. Also, eggs/larvae that are resuspended in the water column by boat propellers may pass through the electric barrier.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The North Shore Canal has riprap banks, macrophyte cover, and bank pocket areas (LimnoTech 2010) that could provide physical habitat suitable for ruffe (Fullerton & Lamberti 2006; Bauer et al. 2007). The CAWS has abundant soft bottom and sand, which is the preferred substrate for this species (Fishbase 2010). Ruffe prefer still or slow-flowing water (Fishbase 2010), which is typical of the CAWS except during high flows. Generalist fish like the ruffe are found throughout the CAWS (LimnoTech 2010). Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River. DO in the CAWS may be too low in certain areas or during certain times of the year, but overall DO is adequate (Crosier & Malloy 2005; MWRD 2010) and does not explain fish distribution well (LimnoTech 2010). The ruffe can spawn in multiple habitat types found in the CAWS, including submerged plants, logs, branches, gravel, and rocks (Ogle 1998; LimnoTech 2010). The ruffe likely expanded its range in Europe through canals, and it is found throughout canals in Europe (Indiana Department of Natural Resources 2005; Zoetemeyer 2007).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sluice gate at the WPS would act as a temporary barrier, but water pumped from Lake Michigan into the North Shore Channel could transport ruffe into the CAWS. Human-mediated transport from WPS to Brandon Road Lock and Dam is unlikely (section 3b); therefore, movement through the CAWS would require some natural dispersion. Ruffe spread through canals (section 3d). Suitable adult and reproductive habitat is present throughout the CAWS (section 3e). The Electric Dispersal Barrier System is not likely to control downstream passage (section 3c). Therefore, its probability of passage for this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. Although habitat may not be optimal, it may not prohibit passage. As a result, the uncertainty associated with passage is considered to be medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, it is more likely that ruffe will move through the CAWS to Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty associated with its arrival decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Suitable habitat includes low-order streams, vegetated and unvegetated shoreline, and manmade structures (see Habitat Matrix). All of these habitats are present near Brandon Road Lock and Dam. However, Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is found near Brandon Road Lock and Dam and the ruffe is capable of swimming to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the ruffe is a cool-water species, it may be able to exist below Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish itself. Therefore, the probability of the ruffe colonizing downstream of Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The ruffe has been documented to spread through large river systems (section 4a). However, it is uncertain whether the temperature preferences of the ruffe will prevent the permanent, year-round establishment of this species below Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   The ruffe prefers water temperatures lower than 30°C (86°F) (Crosier & Malloy 2005; Holker & Thiel 1998). Its native range includes the Caspian, Black, Baltic and North Sea basins; Great Britain; and north to about 69°N in Scandinavia (Fishbase 2011); therefore, movement into the southern MRB may be limited by warm temperatures. Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River, which could in turn slow its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
   This species can become abundant quickly (USFWS 1996; Bauer et al. 2007).

c. *Fecundity*
   The ruffe has high fecundity (White 2002), with females producing up to 200,000 eggs in the first batch and up to 6,000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002).

d. *History of Invasion Success*
   The species has spread rapidly in the Great Lakes and achieved locally high abundance in Lake Superior.

e. *Human-Mediated Transport through Aquatic Pathways*
   This species can be transferred by boat ballast.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, and Chemical)*
   Suitable habitat is present through much of the basin in the form of low-gradient streams and rivers, reservoirs and pools, and back-channel aquatic habitats (Fishbase 2010; Fuller & Jacobs 2011; Peterson et al. 2011).

Evidence for Probability Rating

There is suitable habitat contiguously distributed throughout the MRB (sections 5e, 5f). The ruffe is a habitat generalist (section 5f) and can spread quickly and reach high abundance (section 5d), given its high fecundity (section 5c). Ruffe can occupy high-elevation habitats. However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread by the ruffe.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting its movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the ruffe.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Medium	Low	Medium	Medium	High
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Rates of natural dispersion of the ruffe are not well known because ballast water transport has been the key spread vector in the Great Lakes (USFWS 1996). Ruffe can spread quickly by vessel transport and can quickly become abundant (USFWS 1996; Bauer et al. 2007), having spread across the northern Great Lakes in a decade (Fuller et al. 2012). However, within Lake Michigan the ruffe has not spread beyond Green Bay in the 9 years since its detection in that area (Bowen & Goehle 2011). Its eggs and

larvae are benthic, not free-floating (Ogle 1998), so the transport of eggs by currents is unlikely.

b. *Human-Mediated Transport through Aquatic Pathways*
Ruffe can spread quickly by vessel transport and can become abundant quickly (USFWS 1996; Bauer et al. 2007); human-mediated transport is likely to be more important for its arrival at the southern Great Lakes than natural dispersion. This species can be transported in ballast water (Pratt et al. 1992), and there is vessel traffic between CRCW and areas of the Great Lakes where the ruffe is located (USACE 2011; NBIC 2012) and these vessels may discharge ballast water at CRCW (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of the ruffe in the Great Lakes and the CRCW.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: The species is not widespread, and there are no high-density populations in Lake Michigan (Bowen & Goehle 2011). Females produce up to 200,000 eggs in the first batch, and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002). Over the last decade, the abundance of ruffe has declined and/or leveled off in many locations where the fish is currently established (Bowen & Goehle 2011). Ruffe populations are currently monitored. Past control efforts such as stocking predators and removal by trawling were not considered effective (Jensen 2006).
T_{10}: See T_0. The abundance of the ruffe at its current locations could increase or decrease owing to natural population fluctuations or interactions with other species such as round goby (Bowen & Goehle 2011).
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, ruffe abundance could increase or decrease (Bowen & Goehle 2011). Examples of future changes potentially affecting the abundance of ruffe include natural population fluctuations, climate change, new diseases, and control measures.

e. *Distance from Pathway*
T_0: Ruffe exists in northern Lake Michigan in Green Bay/Bay de Noc and has not been detected outside of Green Bay (Bowen & Goehle 2011).
T_{10}: See T_0. Ruffe could move closer to the CRCW by spreading through the suitable habitat along Lake Michigan or by vessel transport to southern Lake Michigan.
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, the distance of the ruffe from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of ruffe in the Great Lakes include natural population growth, climate change, new diseases, and new aquatic nuisance species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), ruffe appears to be more of a cold-water species. Ruffe prefer still or slow-moving water (Fishbase 2010), and the exposed high-energy shoreline along most of Lake Michigan may not be suitable habitat. The numerous river mouths along the shoreline of Lake Michigan and deeper offshore waters would be suitable (White 2002; Peterson et al. 2011; Schleuter & Eckmann 2008). The harbors around the CRCW may be suitable habitat, as are other harbors in the Great Lakes.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical and climatological suitability of the Great Lakes and their tributaries for ruffe. Water temperatures, and stream flows in particular, may be altered, potentially affecting the distribution of this species. On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), the ruffe appears to be more of a cold-water species, and temperature increases related to future climate change (Wuebbles et al. 2010) may affect its spread south from the upper Great Lakes and affect its probability of arriving at the CAWS.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is not currently located near the CRCW and has not spread from Green Bay (sections 2d, 2e), suggesting that there is currently low propagule pressure for the species. However, suitable habitat is present near CRCW (sections 2c, 2f). Ruffe can potentially be transported via ballast water to southern Lake Michigan (sections 2a, 2b), and there is cargo vessel traffic to the CRCW (section 2b). Existing control measures are unlikely to reduce the abundance of ruffe in its current locations. Natural dispersion is not well characterized, but this species is unlikely to spread from Green Bay to the CRCW during the current time step, given that it has not been detected in southern Lake Michigan during a decade of monitoring (section 2a). Therefore, the probability of arrival is low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over 50 years, the probability increases that ruffe will have time to spread to the CRCW by natural dispersion alone or a combination of human-mediated transport to the southern Great Lakes and natural dispersion to the CRCW. Therefore, the probability of the ruffe's arriving at the pathway is medium for this time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: This species can be transported by ballast water, and it is known that there is vessel traffic between the CAWS and areas where the ruffe is located. The potential for ruffe to be transported to the CRCW in ballast water is not well understood. Natural dispersal speed is not well characterized. It is uncertain why this species has not spread more widely into southern Lake Michigan. However, this species is not documented to have spread into southern Lake Michigan over the last decade. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. Ruffe have spread across the northern Great Lakes in a decade by vessel traffic (section 2a), and there is known vessel traffic between the northern Great Lakes and the CRCW (section 2b). The future population trends and future rate of spread of the ruffe are uncertain. Therefore, the arrival of the ruffe at CRCW could increase or decrease over time, depending on the trends in the distribution and abundance of ruffe populations in the Great Lakes. However, ruffe have not spread to southern Lake Michigan in the last decade. Overall, the uncertainty of the species' arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. On the basis of its native distribution, ruffe appears to be more of a cold-water species and temperature increases related to climate change may affect its distribution (section 2f). Thus, climate change could limit the movement of ruffe into southern Lake Michigan (section 2f). Therefore, the uncertainty of the species' arrival at the pathway is high.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The ruffe is a small fish. The distance from the CRCW to Brandon Road Lock and Dam is greater than 64 km (40 mi). The rates of natural dispersion of the species are not well known because ballast water transport has been a key spread vector (USFWS 1996). This species is capable of becoming abundant quickly (USFWS 1996; Bauer et al. 2007). Its eggs and larvae are benthic, not free-floating (Ogle 1998), so the transport of eggs by currents is unlikely.

b. *Human-Mediated Transport*

Ruffe can be transported in ballast water (Dawson et al. 2006), but there is little vessel traffic between the CRCW and Brandon Road Lock and Dam (USACE 2011), and ballast water originating from the Great Lakes is not likely to be discharged in inland ports of the MRB (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers. Depending on the life stage (Kovac 1998), the season and the time of day (Brown et al. 1998; White 2002; Peterson et al. 2011), ruffe move from shallow (<10 m; 32.8 ft) to deep water (<80 m; 262.5 ft). The water depth in the Chicago River and Chicago Sanitary and Ship Canal is less than 9.1 m (30 ft) and less than 4.6 m (15 ft), respectively, in many areas. The Electric Barrier Dispersal System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, electric barriers do not appear to be highly effective against ruffe (Dawson et al. 2006), and adults that are shocked could flow downstream through the barrier. So there is a high potential that adults may pass the barrier at its current setting. In addition, eggs/larvae that are resuspended in the water column by boat propellers may pass through the electric barrier.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: CRCW is an urbanized area with primarily concrete or vertical steel walls lining the channel, but there are scattered areas of natural bank with rock and woody debris located in the South Branch of the Chicago River. The CAWS has a soft silt and/or sand bottom, which are the preferred substrates for this species (LimnoTech 2010; Fishbase 2010). Ruffe prefer eutrophic, still or slow-flowing water (Fishbase 2010), which is typical of the CAWS except during high flows (LimnoTech 2010). Generalist fish like the ruffe are found throughout the CAWS (LimnoTech 2010). Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River. DO in the CAWS may be too low in certain areas or during certain times of the year, but overall DO is adequate (Crosier & Malloy 2005; MWRD 2010) and does not explain fish distribution well (LimnoTech 2010). The ruffe can spawn in multiple habitat types found in the CAWS, including submerged plants, logs, branches, gravel, and rocks (Ogle 1998; LimnoTech 2010). The ruffe likely expanded its range in Europe through canals, and it is found throughout canals in Europe (Indiana Department of Natural Resources 2005; Zoetemeyer 2007).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: It is over 64 km (40 mi) from the CRCW to Brandon Road Lock and Dam. It is unlikely that the ruffe would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading to the Brandon Road Lock and Dam. The Electric Dispersal Barrier System is not likely to control downstream passage (section 3c). Suitable habitat is present throughout the CAWS. Therefore, its probability of passage during this time step is high.
T_{10}: See T_0.
T_{25}: See T_0. .
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. As a result, the uncertainty associated with passage is considered to be medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more likely that ruffe will move through the CAWS to Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty associated with its arrival decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Suitable habitat includes low-order streams, vegetated and unvegetated shoreline, and manmade structures (see Habitat Matrix). All of these habitats are present near Brandon Road Lock and Dam. However, Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C (50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam and the ruffe is capable of swimming to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the ruffe is a cool-water species, it may be able to exist below Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the ruffe’s colonizing downstream of Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The ruffe has been documented to spread through large river systems (section 4a). However, it is uncertain whether the temperature preferences of the ruffe will prevent the permanent, year-round establishment of this species below Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
The ruffe prefers water temperatures less than 30°C (86°F) (Crosier & Malloy 2005; Holker & Thiel 1998). Its native range includes the Caspian, Black, Baltic and North Sea basins; Great Britain; and north to about 69°N in Scandinavia (Fishbase 2011); therefore, movement into the southern MRB may be limited by warm temperatures. Rasmussen

(2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River, which could in turn slow its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
This species can become abundant quickly (USFWS 1996; Bauer et al. 2007), and there is plentiful suitable physical habitat in the MRB.

c. *Fecundity*
The ruffe has high fecundity (White 2002), with females producing up to 200,000 eggs in the first batch and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002).

d. *History of Invasion Success*
The species has spread rapidly in the Great Lakes and achieved locally high abundance in Lake Superior.

e. *Human-Mediated Transport through Aquatic Pathways*
This species can be transferred by boat ballast.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The ruffe is a habitat generalist (Global Invasive Species Database 2006; Fishbase 2011). Suitable habitat is present through much of the basin in the form of low-gradient streams and rivers, reservoirs and pools, and back-channel aquatic habitats (Fishbase 2010; Fuller & Jacobs 2011; Peterson et al. 2011).

Evidence for Probability Rating

There is suitable habitat contiguously distributed throughout the MRB (section 5f). The ruffe is a habitat generalist (section 5f) and can spread quickly and reach high abundance (section 5d), given its high fecundity (section 5c). Ruffe can occupy high-elevation habitats. However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread by the ruffe.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting its movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the ruffe.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Medium	Low	Medium	Medium	High
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The ruffe is a small fish. Its rate of natural dispersion is not well known because ballast water transport has been a key spread vector (USFWS 1996). Ruffe can spread quickly by vessel transport and quickly become abundant (USFWS 1996; Bauer et al. 2007). However, within Lake Michigan, the ruffe has not spread beyond Green Bay in the 9 years since its detection in that area and populations have been trending down (Bowen & Goehle 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
The ruffe can be transported in ballast water (Pratt et al. 1992), and there is vessel traffic between Calumet Harbor and areas of the Great Lakes where the ruffe is located (USACE 2011a; NBIC 2012); these vessels discharge ballast water at Calumet Harbor (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See **T_0**. No activities or events are anticipated that would increase or decrease barriers between the Great Lakes and Calumet Harbor.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: The species is not widespread, and there are no high-density populations in Lake Michigan (Bowen & Goehle 2011). Females produce up to 200,000 eggs in the first batch, and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in 2 or 3 years, and in 1 year in warmer waters (White 2002). Over the last decade, the abundance of ruffe has declined and/or leveled off in many locations where it is currently established (Bowen & Goehle 2011). Ruffe populations are currently monitored. Past control efforts such as stocking predators and removal by trawling were not considered effective (Jensen 2006).
T_{10}: The abundance of the ruffe at its current locations could increase or decrease owing to natural population fluctuations or interactions with other species such as round goby (Bowen & Goehle 2011).
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, ruffe abundance could increase or decrease (Bowen & Goehle 2011). Examples of future changes potentially affecting the abundance of ruffe include natural population fluctuations, climate change, new diseases, and control measures.

e. *Distance from Pathway*
T_0: Ruffe exists in northern Lake Michigan in Green Bay/Bay de Noc and has not been detected outside of Green Bay (Bowen & Goehle 2011).
T_{10}: Ruffe could move closer to Calumet Harbor by spreading through the suitable habitat along Lake Michigan or by vessel transport. Alternatively, its range could contract, decreasing the probability of arriving.
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, the distance of the ruffe from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of ruffe in the Great Lakes include natural population growth, climate change, new diseases, and new aquatic nuisance species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), the ruffe appears to be more of a cold-water species. Ruffe prefer still or slow-

moving water (Fishbase 2010), and the exposed high-energy shoreline along most of Lake Michigan may not be suitable habitat. The numerous river mouths along the shoreline of Lake Michigan and deeper offshore waters would be suitable (White 2002; Peterson et al. 2011; Schleuter & Eckmann 2008). The Calumet Harbor may be suitable habitat, as are other harbors in the Great Lakes.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical, and climatological suitability of the Great Lakes and its tributaries for the ruffe. Water temperatures, and stream flows in particular, may be altered, potentially affecting the distribution of this species. On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), ruffe appears to be more of a cold-water species and temperature increases related to future climate change (Wuebbles et al. 2010) may affect its spread south from the upper Great Lakes and affect its probability of arriving at the CAWS.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is not currently located near Calumet Harbor and has not spread from Green Bay (sections 2d, 2e), suggesting that there is currently low propagule pressure for the species. Existing control measures are unlikely to reduce the abundance of ruffe in its current locations. Suitable habitat is present along the pathway (section 2f). Vessel transport via ballast water is a possibility (sections 2a, 2b). There is the potential for vessel-mediated transport to the Calumet Harbor (section 2b), However, ruffe are unlikely to spread from Green Bay to Calumet Harbor during the current time period, as this species has not been detected in southern Lake Michigan during a decade of monitoring (section 2a). Therefore, its probability of arrival is low for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over 50 years, the probability increases that ruffe will have time to spread to Calumet Harbor by natural dispersion alone or a combination of human-mediated transport to the southern Great Lakes and natural dispersion to Calumet Harbor. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: This species can be transported by ballast water and it is known that there is vessel traffic between the CAWS and areas where the ruffe is located. The potential for ruffe to be transported to the Calumet Harbor in ballast water is not well understood. The species' natural dispersal speed is not well characterized. It is uncertain why this species has not spread more widely into southern Lake Michigan. However, this species is not documented to have spread into southern Lake Michigan over the last decade. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. The future population trends and future rate of spread of the ruffe are uncertain. The arrival of the ruffe at Calumet Harbor could increase or decrease over time, depending on the trends in the distribution and abundance of ruffe populations in the Great Lakes. Ruffe have fluctuated in abundance over time and they are subject to control measures. Therefore, over time, trends in future populations and spread rates become less certain. Ruffe have not spread to southern Lake Michigan in the last decade, although they may move closer to Calumet Harbor with time. Overall, the uncertainty of the species' arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. On the basis of their native distribution, ruffe appear to be more of a cold-water species and temperature increases related to climate change may affect their distribution (section 2f). Thus, climate change could limit the movement of ruffe into southern Lake Michigan (section 2f). Therefore, the uncertainty of the species' arrival at the pathway is high.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The ruffe is a small fish. The distance from the Calumet Harbor to Brandon Road Lock and Dam is greater than 56.3 km (35 mi). The rate of natural dispersion of the ruffe is not well known because ballast water transport has been a key spread vector (USFWS 1996). The species can become abundant quickly (USFWS 1996; Bauer et al. 2007).

b. *Human-Mediated Transport*
There is a relatively small amount of southbound vessel traffic between Calumet Harbor and Brandon Road Lock and Dam (USACE 2011a,b; NBIC 2012). There is heavy commercial vessel traffic between Brandon Road Lock and Dam and T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). Ruffe can be transported in ballast water (Dawson et al. 2006), but ballast water originating from the Great Lakes is not likely to be discharged in inland ports of the MRB (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*

T_0: The Electric Barrier Dispersal System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, electric barriers do not appear to be highly effective against ruffe (Dawson et al. 2006), and adults that are shocked could flow downstream through the barrier. So there is a high potential that adults may pass the barrier at the current setting. Also, eggs/larvae that are resuspended in the water column by boat propellers may pass through the electric barrier.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Calumet Harbor is an industrial canal with primarily concrete or vertical steel banks, but there is unvegetated rocky shoreline and lake habitat within close proximity to the harbor. The CAWS has a soft silt and/or sand bottom, which is the preferred substrate for this species (LimnoTech 2010; Fishbase 2010). Ruffe prefer still or slow-flowing water (Fishbase 2010), which is typical of the CAWS except during high flows (LimnoTech 2010). Generalist fish like the ruffe are found throughout the CAWS (LimnoTech 2010). Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River. DO in the CAWS may be too low in certain areas or during certain times of the year, but overall DO is adequate (Crosier & Malloy 2005; MWRD 2010) and does not explain fish distribution well (LimnoTech 2010). The ruffe can spawn in multiple habitat types found in the CAWS, including submerged plants, logs, branches, gravel, and rocks (Ogle 1998; LimnoTech 2010). The ruffe likely expanded its range in Europe through canals and it is found throughout canals in Europe (Indiana Department of Natural Resources; Zoetemeyer 2007).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: It is over 48.3 km (30 mi) from the Calumet Harbor to Brandon Road Lock and Dam. It is unlikely that the ruffe would be transported through the CAWS by ballast water (section 3b), therefore, natural dispersion would be the most likely means of spreading from Calumet Harbor to the Brandon Road Lock and Dam. Suitable habitat is present throughout the CAWS. Therefore, its probability of passage during this time step is high.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion in the CAWS is unknown. As a result, there is a medium level of uncertainty associated with the passage of this species at this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not known. However, habitat in the CAWS is suitable, and it is more certain that ruffe will move through the CAWS to Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty of its passage decreases to low during this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Suitable habitat includes low-order streams, vegetated and unvegetated shoreline, and manmade structures (see Habitat Matrix). All of these habitats are present near Brandon Road Lock and Dam. However, Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam, and the ruffe is capable of swimming to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is documented below Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the ruffe is a cool-water species, it may be able to exist below Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the ruffe's colonizing downstream of Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The ruffe has been documented to spread through large river systems (section 4a). However, it is uncertain whether the temperature preferences of the ruffe will prevent the permanent, year-round establishment of this species below Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB

The ruffe prefers water temperatures less than 30°C (86°F) (Crosier & Malloy 2005; Holker & Thiel 1998). Its native range includes the Caspian, Black, Baltic and North Sea basins; Great Britain; and north to about 69°N in Scandinavia (Fishbase 2010). Therefore, movement into the southern MRB may be limited by warm temperatures. Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River, which could in turn slow its expansion into other parts of the MRB.

b. Type of Mobility/Invasion Speed

This species can become abundant quickly (USFWS 1996; Bauer et al. 2007), and there is plentiful suitable physical habitat in the MRB.

c. Fecundity

The ruffe has high fecundity (White 2002), with females producing up to 200,000 eggs in the first batch and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002).

d. History of Invasion Success
The species has spread rapidly in the Great Lakes and achieved locally high abundance in Lake Superior.

e. Human-Mediated Transport through Aquatic Pathways
This species can be transferred by boat ballast.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
The ruffe is a habitat generalist (Global Invasive Species Database 2006; Fishbase 2010). Suitable habitat is present through much of the basin in the form of low-gradient streams and rivers, reservoirs and pools, and back-channel aquatic habitats (Fishbase 2010; Fuller & Jacobs 2011; Peterson et al. 2011).

Evidence for Probability Rating

There is suitable habitat contiguously distributed throughout the MRB (section 5f). The ruffe is a habitat generalist (section 5f) and can spread quickly and reach high abundance (section 5d), given its high fecundity (section 5c). Ruffe can occupy high-elevation habitats. However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread by the ruffe.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the ruffe.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Medium	Low	Medium	Medium	High
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The ruffe is a small benthic fish. The eggs and larvae of the species are benthic, not free-floating (Ogle 1998), so the transport of eggs by currents is unlikely. Its rates of natural dispersion are not well known because ballast water transport has been a key spread vector for the species (USFWS 1996). The species can become abundant quickly (USFWS 1996; Bauer et al. 2007). However, within Lake Michigan, the ruffe has not spread beyond Green Bay in the 9 years since its detection in that area and populations have been trending down (Bowen & Goehle 2011).

b. *Human-Mediated Transport through Aquatic Pathways*
The ruffe can be transported in ballast water (Pratt et al. 1992), and there is vessel traffic between Indiana Harbor and areas of the Great Lakes where the ruffe is located (USACE 2011a; NBIC 2012); these vessels discharge ballast water at Indiana Harbor (NBIC 2012). Less than 120 vessels have discharged ballast water at Indiana Harbor, and most of these were not from areas where ruffe are known to exist. However, vessels from ports along western Lake Michigan and Green Bay did discharge ballast water at Indiana Harbor (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing physical barriers.
T_{10}: See **T_0.** No activities or events are anticipated that would increase or decrease barriers between the Great Lakes and Indiana Harbor.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Current Abundance and Reproductive Capacity

T_0: The species is not widespread, and there are no high-density populations in Lake Michigan (Bowen & Goehle 2011). Females produce up to 200,000 eggs in the first batch and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002). Over the last decade, the abundance of ruffe has declined and/or leveled off in many locations where it is currently established (Bowen & Goehle 2011). Ruffe populations are currently monitored. Past control efforts such as stocking predators and removal by trawling were not considered effective (Jensen 2006).

T_{10}: See T_0. The abundance of the ruffe at its current locations could increase or decrease owing to natural population fluctuations or interactions with other species such as round goby (Bowen & Goehle 2011).

T_{25}: See T_{10}.

T_{50}: See T_{10}. In the future, ruffe abundance could increase or decrease (Bowen & Goehle 2011). Examples of future changes potentially affecting the abundance of ruffe include natural population fluctuations, climate change, new diseases, and control measures.

e. Distance from Pathway

T_0: The ruffe exists in northern Lake Michigan in Green Bay/Bay de Noc and has not been detected outside of Green Bay (Bowen & Goehle 2011).

T_{10}: See T_0. Ruffe could move closer to Indiana Harbor by spreading through the suitable habitat along Lake Michigan or by vessel transport. Alternatively, its range could contract, decreasing its probability of arriving.

T_{25}: See T_{10}.

T_{50}: See T_{10}. In the future, the distance of the ruffe from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of ruffe in the Great Lakes include natural population growth, climate change, new diseases, and new aquatic nuisance species.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), the ruffe appears to be more of a coldwater species. The ruffe prefers still or slow-moving water (Fishbase 2010), and the exposed high-energy shoreline along most of Lake Michigan may not be suitable habitat. The numerous river mouths along the shoreline of Lake Michigan and deeper offshore waters would be suitable (White 2002; Peterson et al. 2011; Schleuter & Eckmann 2008). The Indiana Harbor may be suitable habitat, as are other harbors in the Great Lakes.

T_{10}: See T_0.

T_{25}: See T_0. Future climate change may alter the physical, hydraulic, chemical and climatological suitability of the Great Lakes and its tributaries for ruffe. Water temperatures, stream flows, and water depth in particular may be altered, potentially affecting the distribution of this species. On the basis of its native distribution in northern Europe and Asia (Fuller & Jacobs 2011), ruffe appears to be more of a cold-water species, and temperature increases related to future climate change

(Wuebbles et al. 2010) may affect its spread south from the upper Great Lakes and affect its probability of arriving at the CAWS.

T_{50}: See T_{25}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is not currently located near Indiana Harbor and has not spread from Green Bay (section 2e). On the basis of its restricted distribution, propagule pressure relative to the CAWS appears to be low (section 2d). Existing control measures are unlikely to reduce the abundance of ruffe in its current locations. Suitable habitat is present along the pathway (section 2f). Vessel transport via ballast water is a possibility (sections 2a, 2b). Despite the potential for vessel-mediated transport to the CAWS (section 2b), this species has not been detected in southern Lake Michigan since its discovery in Lake Michigan (section 2a). As such, the probability of the species' arrival at the pathway is considered low for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Given time to naturally disperse, the species may be able to reach the pathway over a 50-year period. Therefore, the probability of the species' arrival is medium at the 50-year time step.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

T_0: This species can be transported by ballast water, and it is known that there is vessel traffic between the CAWS and areas where the ruffe is located, although the potential for ruffe to be transported to the Indiana Harbor in ballast water is not well understood. It is uncertain why this species has not spread more widely into southern Lake Michigan. However, this species is not documented to have spread into southern Lake Michigan over the last decade. Overall, the level of uncertainty of arrival is low for this time step.

T_{10}: See T_0. The future population trends and future rate of spread of the ruffe are uncertain. The arrival of the ruffe at Indiana Harbor could increase or decrease over time, depending on the trends in the distribution and abundance of ruffe populations in the Great Lakes. Ruffe have fluctuated in abundance over time and they are subject to control measures. Therefore, over time, trends in future populations and spread rates become less certain. Ruffe have not spread to southern Lake Michigan in the last decade, although they may move closer to the Indiana Harbor with time. Overall, the uncertainty of the species' arrival is medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{25}.On the basis of its native distribution, ruffe appears to be more of a cold-water species, and temperature increases related to climate change may affect its distribution (section 2f). Thus, climate change could limit the movement of ruffe into southern Lake Michigan (section 2f). Therefore, the uncertainty of the species' arrival at the pathway is high.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The ruffe is a small fish. The distance from the Indiana Harbor to Brandon Road Lock and Dam is greater than 56.3 km (35 mi). Rates of natural dispersion for the species are not well known because ballast water transport has been a key spread vector (USFWS 1996). The ruffe can become abundant quickly (USFWS 1996; Bauer et al. 2007).

b. *Human-Mediated Transport*
Most commercial vessel traffic to Indiana Harbor is lakewise (NBIC 2012). There is no vessel traffic in the Grand Calumet River east of the Indiana Harbor. Ruffe can be transported in ballast water (Dawson et al. 2006), but ballast water originating from the Great Lakes is not likely to be discharged in inland ports of the MRB (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: Just to the west of its junction with the Indiana Harbor Canal, the Grand Calumet channel is blocked by sheet pile. The Electric Barrier Dispersal System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, electric barriers do not appear to be highly effective against ruffe (Dawson et al. 2006), and adults that are shocked could flow downstream through the barrier. So there is a high potential that adults may pass the barrier at its current setting. In addition, eggs/larvae that are resuspended in the water column by boat propellers may pass through the electric barrier.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See $T_{10.}$

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Indiana Harbor is an industrial canal with primarily concrete or vertical steel banks, but there is vegetated and rocky shoreline within close proximity to the Harbor. Overall, the CAWS has a soft bottom and sand, which are the preferred substrates for this species (LimnoTech 2010; Fishbase 2010). Ruffe prefer still or slow-flowing water (Fishbase 2010), which is typical of the CAWS except during high flows (LimnoTech 2010). Generalist fish like the ruffe are found throughout the CAWS (LimnoTech 2010).

Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River. DO in the CAWS may be too low in certain areas or during certain times of the year, but overall DO is adequate (Crosier & Malloy 2005; MWRD 2010) and does not explain fish distribution well (LimnoTech 2010). The ruffe can spawn in multiple habitat types found in the CAWS, including submerged plants, logs, branches, gravel, and rocks (Ogle 1998; LimnoTech 2010). The ruffe likely expanded its range in Europe through canals and it is found throughout canals in Europe (Indiana Department of Natural Resources 2005; Zoetemeyer 2007).
T_{10}: See T_0.
T_{25}: See T_0
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: It is over 48.3 km (30 mi) from the Indiana Harbor to Brandon Road Lock and Dam. It is unlikely that the ruffe would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading to the Brandon Road Lock and Dam. Suitable habitat is present throughout the CAWS, but the sheet pile in the Grand Calumet River and the variable flow direction may slow the initial spread of the ruffe toward Brandon Road Lock and Dam (sections 3c, 3d). Overall, however, its probability of passage during this time step is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. As a result, the uncertainty associated with passage is considered to be medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more certain that ruffe will move through the CAWS to Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty associated with its arrival decreases to low.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Suitable habitat includes low-order streams, vegetated and unvegetated shoreline, and manmade structures (see Habitat Matrix). All of these habitats are present near Brandon Road Lock and Dam. However, Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam, and the ruffe is capable of swimming to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the ruffe is a cool-water species, it may be able to exist below Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the ruffe’s colonizing downstream of Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The ruffe has been documented to spread through large river systems (section 4a). However, it is uncertain whether the temperature preferences of the ruffe will prevent the permanent, year-round establishment of this species below Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   The ruffe prefers water temperatures less than 30°C (86°F) (Crosier & Malloy 2005; Holker & Thiel 1998). Its native range includes the Caspian, Black, Baltic and North Sea basins; Great Britain; and north to about 69°N in Scandinavia (Fishbase 2010). Therefore, movement into the southern MRB may be limited by warm temperatures. Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River, which could in turn slow its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
   This species can become abundant quickly (USFWS 1996; Bauer et al. 2007), and there is plentiful suitable physical habitat in the MRB.

c. *Fecundity*
   The ruffe has high fecundity (White 2002), with females producing up to 200,000 eggs in the first batch and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002).

d. *History of Invasion Success*
   The species has spread rapidly in the Great Lakes and achieved locally high abundance in Lake Superior.

e. *Human-Mediated Transport through Aquatic Pathways*
   This species can be transferred by boat ballast.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The ruffe is a habitat generalist (Global Invasive Species Database 2006; Fishbase 2010). Suitable habitat is present through much of the basin in the form of low-gradient streams and rivers, reservoirs and pools, and back-channel aquatic habitats (Fishbase 2010; Fuller & Jacobs 2011; Peterson et al. 2011).

Evidence for Probability Rating

There is suitable habitat contiguously distributed throughout the MRB (section 5f). The ruffe is a habitat generalist (section 5f) and can spread quickly and reach high abundance (section 5d), given its high fecundity (section 5c). Ruffe can occupy high-elevation habitats. However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread by the ruffe.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the ruffe.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Medium	Low	Medium	Medium	High
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Low	-	Low	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The ruffe is a small fish. Its rates of natural dispersion are not well known because ballast water transport has been a key spread vector (USFWS 1996). Ruffe can spread quickly by vessel transport and can become abundant quickly (USFWS 1996; Bauer et al. 2007). However, within Lake Michigan, the ruffe has not spread beyond Green Bay in the 9 years since its detection in that area, and populations have been trending down (Bowen & Goehle 2011).

b. *Human-Mediated Transport*
The ruffe can be transported in ballast water (Pratt et al. 1992). There is recreational but not commercial vessel traffic from the Great Lakes to the BSBH. There is commercial vessel traffic to Burns Harbor, which is adjacent to BSBH (USACE 2011a,b). Since 2004, fewer than 110 vessels have discharged ballast water at Burns Harbor, and most of these were not from areas where ruffe are known to exist (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0. No activities or events are anticipated that would increase or decrease barriers between the Great Lakes and BSBH.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Current Abundance and Reproductive Capacity*
T_0: The species is not widespread, and there are no high-density populations in Lake Michigan (Bowen & Goehle 2011). Females produce up to 200,000 eggs in the first batch and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002). Over the last decade, the abundance of ruffe has declined and/or leveled off in many locations where it is currently established (Bowen & Goehle 2011). Ruffe populations are currently monitored. Past control efforts such as stocking predators and removal by trawling were not considered effective (Jensen 2006).
T_{10}: See T_0. The abundance of the ruffe at its current locations could increase or decrease owing to natural population fluctuations or interactions with other species such as round goby (Bowen & Goehle 2011).
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, ruffe abundance could increase or decrease (Bowen & Goehle 2011). Examples of future changes potentially affecting the abundance of ruffe include natural population fluctuations, climate change, new diseases, and control measures.

e. *Distance from Pathway*
T_0: The ruffe exists in northern Lake Michigan in Green Bay/Bay de Noc and has not been detected outside of Green Bay (Bowen & Goehle 2011).

T_{10}: See T_0. Ruffe could become closer to BSBH by spreading through the suitable habitat along Lake Michigan or by vessel transport. Alternatively, its range could contract, decreasing its probability of arriving.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Ruffe prefer still or slow-moving water (Fishbase 2010), and the exposed high-energy shoreline along most of Lake Michigan may not be suitable habitat. The numerous river mouths along the shoreline of Lake Michigan and deeper offshore waters would be suitable (White 2002; Peterson et al. 2011; Schleuter & Eckmann 2008). The BSBH may be suitable habitat, as would other harbors in the Great Lakes.
T_{10}: See T_0.
T_{25}: See T_0. Climate change may alter the physical, hydraulic, chemical and climatological suitability of the Great Lakes and its tributaries for ruffe. Water temperatures, stream flows, and water depth in particular may be altered, potentially affecting the distribution of this species.
T_{50}: See T_{25}.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: The species is not currently located near BSBH and has not spread from Green Bay (section 2e), suggesting that there is currently low propagule pressure for the species. Existing control measures are unlikely to reduce the abundance of ruffe in its current locations. Suitable habitat is present along the pathway (section 2f). Despite the potential for vessel-mediated transport to the CAWS (section 2b), this species has not been detected in southern Lake Michigan since its discovery in Lake Michigan (section 2a). Therefore, there is a low probability that the species will arrive at the pathway during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over 50 years, the probability increases that ruffe will have time to spread to the BSBH by natural dispersion alone or a combination of human-mediated transport to the southern Great Lakes and natural dispersion to the BSBH. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	High

Evidence for Uncertainty Rating

T_0: This species can be transported by ballast water and it is known that there is vessel traffic between the CAWS and areas where the ruffe is located. The potential for ruffe to be transported to the BSBH in ballast water is not well understood. Natural dispersal speed of the species is not well characterized. It is uncertain why this species has not spread more widely into southern Lake Michigan. However, this species is not documented to have spread into southern Lake Michigan over the last decade. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See $T_{0.}$ The future population trends and future rate of spread of the ruffe are uncertain. The arrival of the ruffe at the BSBH could increase or decrease over time, depending on the trends in the distribution and abundance of ruffe populations in the Great Lakes. Ruffe have fluctuated in abundance over time and they are subject to control measures. Therefore, over time, trends in future populations and spread rates become less certain. Ruffe have not spread to southern Lake Michigan in the last decade, although they may move closer to the BSBH with time. Overall, the uncertainty of the species' arrival is medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. Based on their native distribution, ruffe appear to be more of a cold-water species, and temperature increases related to climate change may affect their distribution (section 2f). Thus, climate change could limit the movement of ruffe into southern Lake Michigan (section 2f). Therefore, the uncertainty of the species' arrival at the pathway is high.

3. P(passage) T_0-T_{50}: LOW-HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
The ruffe is a small fish. The distance from the BSBH to Brandon Road Lock and Dam is greater than 64 km (40 mi). Rates of natural dispersion of the species are not well known because ballast water transport has been a key spread vector (USFWS 1996). The ruffe can become abundant quickly (USFWS 1996; Bauer et al. 2007).

b. Human-Mediated Transport
Vessel traffic to BSBH and the adjacent Burns Harbor is lakewise. Ruffe can be transported in ballast water (Dawson et al. 2006), but ballast water originating from the Great Lakes is not likely to be discharged in inland ports of the MRB (NBIC 2012). Consequently, some natural downstream dispersal would likely be necessary to reach Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: The Electric Barrier Dispersal System located north of Lockport Lock and Dam may act as a barrier to some degree by repelling adult fish. However, electric barriers do not appear to be highly effective against ruffe (Dawson et al. 2006), and adults that are shocked could flow downstream through the barrier. So there is a high potential that adults may pass the barrier at its current setting. Also, eggs/larvae that are resuspended in the water column by boat propellers may pass through the electric barrier.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: BSBH is an industrial canal with primarily concrete or vertical steel banks, but there is vegetated and rocky shoreline within close proximity to the harbor. Overall, the CAWS has a soft bottom and sand, which are the preferred substrates for this species (LimnoTech 2010; Fishbase 2010). Ruffe prefer still or slow-flowing water (Fishbase 2010), which is typical of the CAWS except during high flows (LimnoTech 2010). Generalist fish like the ruffe are found throughout the CAWS (LimnoTech 2010). Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River. Dissolved oxygen (DO) in the CAWS may be too low in certain areas or during certain times of the year, but overall DO is adequate (Crosier & Malloy 2005; MWRD 2010) and does not explain fish distribution well (LimnoTech 2010). The ruffe can spawn in multiple habitat types found in the CAWS, including submerged plants, logs, branches, gravel, and rocks (Ogle 1998; LimnoTech 2010). The ruffe likely expanded its range in Europe through canals and it is found throughout canals in Europe (Indiana Department of Natural Resources 2005; Zoetemeyer 2007).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The distance from the BSBH to Brandon Road Lock and Dam is over 64 km (40 mi). It is unlikely that the ruffe would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading to the Brandon Road Lock and Dam. Suitable habitat is present throughout the CAWS. Therefore, its probability of passage during this time step is high.

T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The potential speed of natural dispersion through the CAWS is uncertain. As a result, the uncertainty associated with passage is considered to be medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more certain that ruffe will move through the CAWS to Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty associated with its arrival decreases to low for this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Suitable habitat includes low-order streams, vegetated and unvegetated shoreline, and manmade structures (see Habitat Matrix). All of these habitats are present near Brandon Road Lock and Dam. However, Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is found near Brandon Road Lock and Dam, and the ruffe is capable of swimming to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the ruffe is a cool-water species, it may be able to exist below Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the ruffe's colonizing downstream of Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The ruffe has been documented to spread through large river systems (section 4a). However, it is uncertain whether the temperature preferences of the ruffe will prevent the permanent, year-round establishment of this species below Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the new basin. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
The ruffe prefers water temperatures less than 30°C (86°F) (Crosier & Malloy 2005; Holker & Thiel 1998). Its native range includes the Caspian, Black, Baltic and North Sea basins; Great Britain; and north to about 69°N in Scandinavia (Fishbase 2010); therefore, movement into the southern MRB may be limited by warm temperatures. Rasmussen (2002) states that the ruffe is a true cool-water species (it prefers water temperatures between 10 and 20°C [50 and 68°F]), and that temperature preference may limit movement south into the Illinois River, which could in turn slow its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
This species can become abundant quickly (USFWS 1996; Bauer et al. 2007), and there is plentiful suitable physical habitat in the MRB.

c. *Fecundity*
The ruffe has high fecundity (White 2002), with females producing up to 200,000 eggs in the first batch and up to 6000 eggs per subsequent batch (Global Invasive Species Database 2006). Ruffe reach sexual maturity in two or three years, and in one year in warmer waters (White 2002).

d. *History of Invasion Success*
The species has spread rapidly in the Great Lakes and achieved locally high abundance in Lake Superior.

e. *Human-Mediated Transport through Aquatic Pathways*
This species can be transferred by boat ballast.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The ruffe is a habitat generalist (Global Invasive Species Database 2006; Fishbase 2010). Suitable habitat is present through much of the basin in the form of low-gradient streams and rivers, reservoirs and pools, and back-channel aquatic habitats (Fishbase 2010; Fuller & Jacobs 2011; Peterson et al. 2011).

Evidence for Probability Rating

There is suitable habitat contiguously distributed throughout the MRB (section 5f). The ruffe is a habitat generalist (section 5f) and can spread quickly and reach high abundance (section 5d), given its high fecundity (section 5c). Ruffe can occupy high-elevation habitats. However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread by the ruffe.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the ruffe.

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E.2.7.3 Sea Lamprey - *Petromyzon marinus*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Low	Low	Low	Low	Low	Low	Low	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). Adults are parasitic, using their sharp teeth to attach themselves to cetaceans and large fish and feed off their host's blood, body fluids and flesh for several days (Kottelat & Freyhof 2007). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008)). Since 1957, larval sea lampreys have

been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980).

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008).

c. *Current Abundance and Reproductive Capacity*
T_0: Sea lampreys produce between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010). There are ongoing efforts to suppress sea lamprey populations, and lampricides have been generally successful in reducing the sea lamprey population (Fuller et al. 2011).
T_{10}: See T_0. Lamprey populations may fluctuate due to natural ecological changes and ongoing management measures to suppress their number.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The sea lamprey has been established in lower Lake Michigan since 1936 (Fuller et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Lake Michigan is known to be suitable habitat for the species, because it has been established there since 1936.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sea lamprey has been in lower Lake Michigan since 1936 (sections 2e, 2f) and is therefore considered to have arrived at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The sea lamprey has been documented in lower Lake Michigan since 1936 (sections 2e, 2f); therefore uncertainty is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Sea lampreys move by swimming or by attaching to other fish. Eggs and larvae are benthic, not free-floating (Fuller et al. 2012), so transport of eggs by currents is unlikely. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Interconnecting waterways are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Mature adults enter rivers and streams to spawn in spring (Hardisty 1986; Muus et al. 1999; Kelly & King 2001). Movements from the sea to spawning sites may cover distances from 19 to 805 km (12 to 500 mi) inland (Hardisty 1986). It is less than 80 km (50 mi) from the WPS to the Brandon Road Lock and Dam. After spawning, adults normally die (Rochard & Elie 1994). Upon metamorphosis, which may take 5 or more years in the Great Lakes (Potter 1981), individuals migrate into open water. However, since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980). Surveys of Illinois rivers in the 1960s produced only one potential specimen.

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). Interconnecting waterways and attachment to fishes and boats are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). There is no commercial vessel traffic in the North Shore Channel, but there is vessel traffic between the Chicago River and the Brandon Road Lock and Dam (USACE 2011a,b). Therefore, natural dispersal will be required for movement through the CAWS from the WPS.

c. *Existing Physical Human/Natural Barriers*
T_0: The WPS sluice gate may act as a barrier to movement. Sea lampreys could be transported from Lake Michigan into the North Shore Channel via water pumped from the Lake into the channel or during periods when the sluice gate is open. Physical barriers, such as dams, have been recognized as limiting to the upstream movements of sea lampreys (Morman et al. 1980). Therefore, the Lockport Lock and Dam may act as a temporary barrier. Water depth does not seem to be a critical factor in the distribution of lamprey spawning. Water depth at 32 northern Michigan streams ranged from 5 to 152 cm (2 to 60 in.) (Applegate 1950). The CAWS has perennial flow and a water depth that supports navigation; therefore, water depth is not expected to inhibit movement. The electric barriers upstream of the Lockport Lock and Dam could shock sea lamprey moving downstream, but they would continue to float downstream. Therefore, the barriers are not likely to control passage.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Many environmental conditions influence the distribution of sea lampreys. Stream flow and water temperature are of major importance. There is no hydraulic attractive flow that would draw sea lamprey into the WPS. The dispersal of spawning adults within streams is influenced mainly by blockages, water temperature, flow, sediment, and presence of lakes. In a survey of streams in northern Indiana and the Lower Peninsula of Michigan, the absence or scarcity of larvae in streams was attributed to intermittent and unstable stream flows (U.S. Fish and Wildlife Service, Ludington, Michigan, unpublished records; Morman et al. 1980). Pollution, sedimentation, and hard or unstable bottoms also contributed to the absence or scarcity of lamprey (Morman et al. 1980). Temperature tolerances of adults are not well characterized, but they are documented to tolerate a range of 1–20°C (3.8–68°F) (Beamish 1980). Temperatures of 31.4°C (88.5°F) are lethal to ammocoetes (Beamish 1980). Water temperature is probably the most important factor affecting the development of embryos. Water temperatures of 11–25°C (51.8–77°F) appear essential for successful spawning (Morman et al. 1980). These temperatures are within the range of the CAWS (MWRD 2010). The median low flow of 74 streams that contained populations of sea lamprey ammocoetes in the Lower Peninsula of Michigan was 0.4 m/s (1.31 ft/s) (Morman et al. 1980). However, others have stated that velocities of 0.5–1.5 m/s

(1.64–4.92 ft/s) were suitable for spawning (Manion & Hanson 1980). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010).

The distribution of larval lampreys is also limited by hard stream bottom and pollution, but larvae have been found in a wide range of habitats exhibiting these conditions (Morman et al. 1980). Spawning typically occurs over sand or gravel (Morman et al. 1980), both of which are common substrates in portions of the CAWS (LimnoTech 2010). After hatching, ammocoetes, lamprey larvae, drift downstream and bury in detritus-rich mud, silt, or sand-silt bottoms (Kottelat & Freyhof 2007; Hardisty & Potter 1971) for 5.5–8 years, often at the edges of rivers and streams where currents are slow (Gallant et al. 2006; Kottelat & Freyhof 2007). In the North Shore Channel and the upper north branch of the Chicago River, sediments are silt and sand (LimnoTech 2010). Toward downtown Chicago and in the Chicago River, there is a reduction in in-stream habitat and a change to concrete and steel vertical banks, with sediments of concrete, silt, or sludge. The CSSC has banks of bedrock and steel sheet piling leading to the Des Plaines River. Most sediments in the CSSC are silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010), which would not be suitable spawning habitat.

Pollution, turbidity, and/or sedimentation were mentioned as major limiting factors for the absence or scarcity of larvae in streams in Illinois and Michigan (Starret et al. 1960; Morman et al. 1980). Contaminants, although diluted in stream water, may reach toxic levels as they accumulate in sediment and thereby cause mortality of larval lampreys. The influence of stream pollution on spawning runs is poorly understood. Adult lampreys may be more tolerant of some pollutants than embryonic or larval lampreys, because they run polluted streams in which larvae have never been detected (Morman et al. 1980). Toxic organic and inorganic pollutants are present in the Chicago River (Gallagher et al. 2009).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adults will move into the CAWS only to spawn in the CAWS itself or to move to spawning areas farther downstream (section 3a). Sea lampreys are capable of traveling great distances to spawning grounds, so they could move through the CAWS during this time step (section 3a). Water depth in the CAWS is adequate for sea lamprey spawning, and there are no physical barriers that they could not pass eventually, although they may slow passage (section 2d). Suitable spawning and juvenile habitat may be present in the CAWS

(section 2d). The stream hydraulics of the CAWS do not provide “attractive flow” to draw sea lamprey into the CAWS. Pollution, sedimentation, and dissolved oxygen in portions of the CAWS may be unsuitable for larval development (section 2d). Sea lampreys are historically very rare in Illinois rivers (section 2a) potentially because of silt and turbidity (section 2d). Sea lampreys have not been found in the CAWS, suggesting the CAWS would not be a pathway for this species (section 2a). Consequently, probability of passage is low.
T_{10}: See T_0. Hydraulics are expected to remain unsuitable.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Why sea lampreys are not found in Illinois rivers despite being in Lake Michigan for 70+ years is not fully understood. However, suitable conditions for passage appear to be present. Therefore uncertainty is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The uncertainty of habitat suitability associated with the improvement of habitat conditions increases over time. However, the hydraulics will remain unsuitable. Therefore, uncertainty remains medium.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Sea lamprey would be present in rivers of the MRB only for spawning or early life stage development. Adults do not occupy riverine habitat except to spawn. Sea lampreys require mostly gravel (15–115 mm [0.59–4.53 in.] diameter) for constructing nests, although they use other materials such as rubble, clam shells, and lumps of clay when gravel is scarce or absent (Morman et al. 1980). Gravel at highway or railroad crossings provides lampreys with spawning sites. In such streams spawning may be limited to only one small area (Morman et al. 1980). The larvae of sea lamprey occur most frequently in soft bottoms containing mixtures of silt and sand (NBII & ISSG 2008; Morman et al. 1980). However, Morman et al. (1980) referred to the scarcity of ammocoetes in the lower sections of some streams in spite of soft bottoms, suggesting that heavy siltation and slow currents were unfavorable. Below the Brandon Road Lock

and Dam, there are streams that could provide suitable spawning habitat. However, extensive surveys in Illinois rivers found no sea lampreys, and there is only one dubious record from the Du Page River (Starret et al. 1960).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal.*
Juveniles on the migration to Lake Michigan could be blocked by the electric barriers above the Lockport Lock and Dam.

Evidence for Probability Rating

Adults will move into the rivers only to spawn and are capable of traveling great distances to spawning ground (section 4a). Larval and juvenile stages develop in rivers, and suitable habitat may be present downstream of the Brandon Road Lock and Dam (section 4a). However, sea lamprey are historically very rare in Illinois rivers (section 4a) potentially because of silt and turbidity (section 4a), suggesting they would not be present downstream of the Brandon Road Lock and Dam (section 4a). Overall, the probability of colonization is medium.

Uncertainty: LOW

Evidence for Uncertainty Rating

The suitability of sediment conditions for spawning is uncertain. Sea lamprey are capable of traveling great distances to spawning grounds (section 4a), and why sea lamprey are not found in Illinois rivers despite being in Lake Michigan for 70 or more years is not fully understood. Overall, the uncertainty associated with colonization is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Temperatures between 10 and 27°C (50 and 80.6°F) are considered appropriate for larval and juvenile development (Morman et al. 1980). Consequently, the climate of the MRB should be suitable.

b. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish.

c. *Fecundity*
Sea lampreys lay anywhere between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010).

d. *History of Invasion Success*
Sea lampreys are native to the east coast of the United States and the majority of the European coast but have been introduced to the Great Lakes through the canal system (NBII & ISSG 2008). Sea lampreys entered the Great Lakes in the 1800s through manmade locks and shipping canals. Prior to the opening of the Welland Canal in 1829 and prior to the modification of Niagara Falls in 1919, Niagara Falls served as a natural barrier to keep sea lampreys out of the Great Lakes (GLFC 2000). Although sea lampreys have been established in Lake Michigan since the 1930s, there are no confirmed records of them in Illinois rivers (Starrett et al. 1960).

e. *Human-Mediated Transport through Aquatic Pathways*
Human-mediated transport is not required.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Sea lampreys occupy lakes and oceans as adults and would exist only in river habitat as spawning adults or during early life stages. Sea lampreys could potentially colonize reservoirs within the MRB.

Evidence for Probability Rating

Adults will move only into the rivers to spawn (section 5a), but they could potentially occupy reservoirs/navigation pools in the MRB. Sea lampreys are capable of swimming to spawning grounds (section 5b), and suitable spawning habitat is present in the MRB (section 5f). However, sea lampreys are historically very rare in Illinois rivers (section 5a) potentially because of silt and turbidity (section 5d). Sea lampreys are an anadromous fish that prefer large lentic systems. Consequently, probability of spread is low.

Uncertainty: LOW

Evidence for Uncertainty Rating

Why sea lampreys are not found in the MRB despite being in Lake Michigan for 70 or more years is not fully understood. The suitability of reservoirs/navigation pools and the ability of sea lamprey to reach these reservoirs are unknown. However, based on their historical absence in the MRB, the uncertainty associated with spread is low.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Low	Low	Low	Low	Low	Low	Low	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). Adults are parasitic, using their sharp teeth to attach themselves to cetaceans and large fish and feed off their host's blood, body fluids, and flesh for several days (Kottelat & Freyhof 2007). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Since 1957, larval sea lampreys have been

detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980).

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008).

c. *Current Abundance and Reproductive Capacity*
T_0: Sea lampreys have been reported to produce between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010). There are ongoing efforts to suppress sea lamprey populations, and lampricides have been generally successful in reducing the sea lamprey population (Fuller et al. 2011).
T_{10}: See T_0. Lamprey populations may fluctuate due to natural ecological changes and ongoing management measures to suppress their number.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The sea lamprey has been established in lower Lake Michigan since 1936 (Fuller et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Lake Michigan is known to be suitable habitat for the species, because it has been established there since 1936.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sea lamprey has been in lower Lake Michigan since 1936 (sections 2e, 2f) and is therefore considered to have arrived at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The sea lamprey has been documented in lower Lake Michigan since 1936 (sections 2e, 2f) therefore uncertainty is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Sea lampreys move by swimming or by attaching to other fish. Eggs and larvae are benthic, not free-floating (Fuller et al. 2011), so transport of eggs by currents is unlikely. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Interconnecting waterways are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Mature adults enter rivers and streams to spawn in spring (Hardisty 1986; Muus et al. 1999; Kelly & King 2001). Movements from the sea to spawning sites may cover distances from 19.3 to 805 km (12 to 500 mi) inland (Hardisty 1986). It is less than 64.4 km (40 mi) from the CRCW to the Brandon Road Lock and Dam. After spawning, adults normally die (Rochard & Elie 1994). Upon metamorphosis, which may take 5 or more years in the Great Lakes (Potter 1981), individuals migrate into open water. However, since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980). Surveys of Illinois rivers in the 1960s produced only one potential specimen.

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). Interconnecting waterways and attachment to fishes and boats are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). There is commercial and recreational vessel traffic between the CRCW and the Brandon Road Lock and Dam (USACE 2011a,b). It is distributed in selected tributaries in Illinois, Indiana, Michigan, Minnesota, Ohio, Pennsylvania, and Wisconsin.

c. *Existing Physical Human/Natural Barriers*
T_0: Physical barriers, such as dams, have been recognized as limiting to the upstream movements of sea lampreys (Morman et al. 1980). Therefore, the Lockport Lock and Dam may act as a temporary barrier. Water depth does not seem to be a critical factor in the distribution of lamprey spawning. Water depth at 32 northern Michigan streams ranged from 5 to 152 cm (2 to 60 in.) (Applegate 1950). The CAWS has perennial flow and a water depth that supports navigation; therefore, water depth is not expected to inhibit movement. The electric barriers upstream of the Lockport Lock and Dam could shock sea lamprey moving downstream, but they would continue to float downstream. Therefore, the barriers are not likely to control passage.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Many environmental conditions influence the distribution of sea lampreys. Stream flow and water temperature are of major importance. There is no hydraulic attractive flow that would draw sea lamprey into the CRCW. The dispersal of spawning adults within streams is influenced mainly by blockages, water temperature, flow, sediment, and presence of lakes. In a survey of streams in northern Indiana and the Lower Peninsula of Michigan, the absence or scarcity of larvae in streams was attributed to intermittent and unstable stream flows (USFWS, Ludington, Michigan, unpublished records; Morman et al. 1980). Pollution, sedimentation, and hard or unstable bottoms also contributed to the absence or scarcity of lamprey (Morman et al. 1980). Temperature tolerances of adults are not well characterized, but they are documented to tolerate a range of 1–20°C (3.8–68°F) (Beamish 1980). Temperatures of 31.4°C (88.5°F) are lethal to ammocoetes (Beamish 1980). Water temperature is probably the most important factor affecting the development of embryos. Water temperatures of 11–25°C (51.8–77°F) appear essential for successful spawning (Morman et al. 1980). These temperatures are within the range of the CAWS (MWRD 2011). The median low flow of 74 streams that contained populations of sea lamprey ammocoetes in the Lower Peninsula of Michigan was 0.4 m/s (1.31ft/s) (Morman et al. 1980). However, others have stated that velocities of 0.5–1.5 m/s (1.64–4.92 ft/s) were suitable for spawning (Manion & Hanson 1980). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010).

The distributions of larval lampreys are also limited by hard stream bottom and pollution, but larvae have been found in a wide range of habitats exhibiting these conditions (Morman et al. 1980). Spawning typically occurs over sand or gravel (Morman et al. 1980), both of which are common substrates in portions of the CAWS (LimnoTech 2010). After hatching, ammocoetes, lamprey larvae, drift downstream and bury in detritus-rich mud, silt, or sand-silt bottoms (Kottelat & Freyhof 2007; Hardisty & Potter 1971) for 5.5–8 years, often at the edges of rivers and streams where currents are slow (Gallant et al. 2006; Kottelat & Freyhof 2007). Toward downtown Chicago and in the Chicago River, there is a reduction in in-stream habitat and a change to concrete and steel vertical banks, with sediments of concrete, silt, or sludge. The CSSC has banks of bedrock and steel sheet piling leading to the Des Plaines River. Most sediments in the CSSC are silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010).

Pollution, turbidity, and/or sedimentation were mentioned as major limiting factors for the absence or scarcity of larvae in streams in Illinois and Michigan (Starret et al. 1960; Morman et al. 1980). Contaminants, although diluted in stream water, may reach toxic levels as they accumulate in sediment and thereby cause mortality of larval lampreys. The influence of stream pollution on spawning runs is poorly understood. Adult lampreys may be more tolerant of some pollutants than embryonic or larval lampreys, because they run polluted streams in which larvae have never been detected (Morman et al. 1980). Toxic organic and inorganic pollutants are present in the Chicago River (Gallagher et al. 2009).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adults will move into the CAWS only to spawn in the CAWS itself or to move to spawning areas farther downstream (section 3a). Sea lamprey are capable of traveling great distances to spawning grounds, so they could move through the CAWS during this time step (section 2a). Water depth in the CAWS is adequate for spawning of sea lampreys, and there are no physical barriers that they could not pass eventually, although barriers may slow passage (section 2d). Suitable spawning and juvenile habitat may be present in the CAWS (section 2d). The stream hydraulics of the CAWS do not provide “attractive flow” to draw sea lamprey into the CAWS. Pollution, sedimentation, and dissolved oxygen in portions of the CAWS may be unsuitable for larval development (section 2d). Sea lampreys are historically very rare in Illinois rivers (section 2a) potentially because of silt and turbidity

(section 2d). Sea lampreys have not been found in the CAWS, suggesting the CAWS would not be a pathway for this species (section 2a). Consequently, probability of passage is low.
T_{10}: See T_0. Hydraulics are expected to remain unsuitable.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Why sea lampreys are not found in Illinois rivers despite being in Lake Michigan for 70+ years is not fully understood. However, suitable conditions for passage appear to be present. Therefore, uncertainty is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The uncertainty of habitat suitability associated with the improvement of habitat conditions increases over time. However, the hydraulics will remain unsuitable. Therefore, uncertainty remains medium.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Sea lamprey would be present in rivers of the MRB only for spawning or early life stage development. Adults do not occupy riverine habitat except to spawn. Sea lampreys require mostly gravel (15–115 mm [0.59–4.53 in.] diameter) for constructing nests, although they use other materials, such as rubble, clam shells, and lumps of clay, when gravel is scarce or absent (Morman et al. 1980). Gravel at highway or railroad crossings provides lampreys with spawning sites. In such streams spawning may be limited to only one small area (Morman et al. 1980). The larvae of sea lamprey occur most frequently in soft bottoms containing mixtures of silt and sand (NBII & ISSG 2008; Morman et al. 1980). However, Morman et al. (1980) referred to the scarcity of ammocoetes in the lower sections of some streams in spite of soft bottoms, suggesting that heavy siltation and slow currents were unfavorable. Below the Brandon Road Lock and Dam, there are streams that could provide suitable spawning habitat. Extensive surveys in Illinois rivers found no sea lampreys, and there is only one dubious record from the Du Page River (Starret et al. 1960).

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Juveniles on the migration to Lake Michigan could be blocked by the electric barriers above the Lockport Lock and Dam.

Evidence for Probability Rating

Adults will move into the rivers only to spawn (section 4a). Larval and juvenile stages develop in rivers. Sea lampreys are capable of traveling great distances to spawning grounds (section 4a). However, sea lamprey are historically very rare in Illinois rivers (section 4a) potentially because of silt and turbidity (section 4a), suggesting they would not be present downstream of the Brandon Road Lock and Dam (section 4a). Overall, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of sediment conditions for spawning is uncertain. Sea lamprey are capable of traveling great distances to spawning grounds (section 4a), and why sea lamprey are not found in Illinois rivers despite being in Lake Michigan for 70 or more years is not fully understood. Overall, the uncertainty associated with colonization is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the MRB
Temperatures between 10 and 27°C (50 and 80.6°F) are considered appropriate for larval and juvenile development (Morman et al. 1980). Consequently the climate of the MRB should be suitable.

b. Type of Mobility/Invasion Speed
Sea lampreys move by swimming or by attaching to other fish. Movements from the sea to spawning sites may cover distances from 19.3 to 805 km (12 to 500 mi) inland (Hardisty 1986).

c. Fecundity
Sea lampreys have been reported to lay anywhere between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010).

d. *History of Invasion Success*
   Sea lampreys are native to the east coast of the United States and the majority of the European coast but have been introduced to the Great Lakes through the canal system (NBII & ISSG 2008). Sea lampreys entered the Great Lakes in the 1800s through manmade locks and shipping canals. Prior to the opening of the Welland Canal in 1829 and prior to the modification of Niagara Falls in 1919, Niagara Falls served as a natural barrier to keep sea lampreys out of the Great Lakes (GLFC 2000). Although the sea lamprey has been established in Lake Michigan since the 1930s, there are no confirmed records of it in Illinois rivers (Starrett et al. 1960).

e. *Human-Mediated Transport through Aquatic Pathways*
   Human-mediated transport is not required.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Sea lamprey is a specialist species. Sea lampreys occupy lakes and oceans as adults and would exist in river habitat only as spawning adults or during early life stages. Sea lamprey could potentially colonize reservoirs within the MRB.

Evidence for Probability Rating

Adults will move into the rivers only to spawn (section 5a), but they could potentially occupy reservoirs/navigation pools in the MRB. Sea lampreys are capable of swimming to spawning grounds (section 5b), and suitable spawning habitat is present in the MRB (section 5f). However, sea lampreys are historically very rare in Illinois rivers (section 5a) potentially because of silt and turbidity (section 5d). Sea lampreys are an anadromous fish that prefer large lentic systems. Consequently, probability of spread is low.

Uncertainty: LOW

Evidence for Uncertainty Rating

Why sea lampreys are not found in in the MRB despite being in Lake Michigan for 70 or more years is not fully understood. The suitability of navigation pools and the ability of sea lamprey to reach these reservoirs are unknown. However, based on their historical absence in the MRB, the uncertainty associated with spread is low.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Low	Low	Low	Low	Low	Low	Low	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish. Sea lampreys are believed to have migrated through the Erie, Welland and St. Lawrence canal systems (NBII & ISSG 2008). Adults are parasitic, using their sharp teeth to attach themselves to cetaceans and large fish and feed off their host's blood, body fluids and flesh for several days (Kottelat & Freyhof 2007). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980).

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). There is heavy lake-wide commercial vessel traffic to Calumet Harbor (USACE 2011a). However, this species primarily relies on swimming or attaching to hosts for movement.

c. *Current Abundance and Reproductive Capacity*
T_0: Sea lampreys have been reported to produce between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010). There are ongoing efforts to suppress sea lamprey populations, and lampricides have been generally successful in reducing the sea lamprey population (Fuller et al. 2011).
T_{10}: See T_0. Lamprey populations may fluctuate due to natural ecological changes and ongoing management measures to suppress their number.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The sea lamprey has been established in lower Lake Michigan since 1936 (Fuller et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Lake Michigan is known to be suitable habitat for the species, because it has been established there since 1936.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sea lamprey has been in lower Lake Michigan since 1936 (sections 2e, 2f) and is therefore considered to have arrived at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The sea lamprey has been documented in lower Lake Michigan since 1936 (sections 2e, 2f); therefore, uncertainty is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish. Eggs and larvae are benthic, not free-floating (Fuller et al. 2011), so transport of eggs by currents is unlikely. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Interconnecting waterways are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Mature adults enter rivers and streams to spawn in spring (Hardisty 1986; Muus et al. 1999; Kelly & King 2001). Movements from the sea to spawning sites may cover distances from 19.3 to 805 km (12 to 500 mi) inland (Hardisty 1986). It is less than 64 km (40 mi) from Calumet Harbor to the Brandon Road Lock and Dam. After spawning, adults normally die (Rochard & Elie 1994). Upon metamorphosis, which may take 5 or more years in the Great Lakes (Potter 1981), individuals migrate into open water. However, since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980). Surveys of Illinois rivers in the 1960s produced only one potential specimen.

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). Interconnecting waterways and attachment to fishes and boats are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Vessel traffic to Calumet Harbor is lake-wide rather than from the CAWS. However, there is heavy commercial and recreational vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, which is located 8 km (5 mi) south of Calumet Harbor (USACE 2011a,b).

c. *Existing Physical Human/Natural Barriers*
T_0: Physical barriers, such as dams, have been recognized as limiting to the upstream movement of sea lampreys (Morman et al. 1980). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to passage. Water depth does not seem to be a critical factor in the distribution of lamprey spawning. Water depth at 32 northern Michigan streams ranged from 5 to 152 cm (2 to 59.8 in.) (Applegate 1950). The CAWS has perennial flow and a water depth that supports navigation; therefore, water depth is not expected to inhibit movement. The electric barriers upstream of the Lockport Lock and Dam could shock sea lamprey moving downstream, but they would continue to float downstream. Therefore, the barriers are not likely to control passage.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Many environmental conditions influence the distribution of sea lampreys. Stream flow and water temperature are of major importance. There is no hydraulic attractive flow that would draw sea lamprey into Calumet Harbor. The dispersal of spawning adults within streams is influenced mainly by blockages, water temperature, flow, sediment, and presence of lakes. In a survey of streams in northern Indiana and the Lower Peninsula of Michigan, the absence or scarcity of larvae in streams was attributed to intermittent and unstable stream flows (USFWS, Ludington, Michigan, unpublished records; Morman et al. 1980). Pollution, sedimentation, and hard or unstable bottoms also contributed to the absence or scarcity of lamprey (Morman et al. 1980). Temperature tolerances of adults are not well characterized, but they are documented to tolerate a range of 1–20°C (3.8–68°F) (Beamish 1980). Temperatures of 31.4°C (88.5°F) are lethal to ammocoetes (Beamish 1980). Water temperature is probably the most important factor affecting the development of embryos. Water temperatures of 11–25°C (51.8–77°F) appear essential for successful spawning (Morman et al. 1980). These temperatures are within the range of the CAWS (MWRD 2011). The median low flow of 74 streams that contained populations of sea lamprey ammocoetes in the Lower Peninsula of Michigan was 0.4 m/s (1.31ft/s) (Morman et al. 1980). However, others have stated that velocities of 0.5–1.5 m/s (1.64–4.92 ft/s) were suitable for spawning (Manion & Hanson 1980). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010).

The distribution of larval lampreys is also limited by hard stream bottom and pollution, but larvae have been found in a wide range of habitats exhibiting these conditions (Morman et al. 1980). Spawning typically occurs over sand or gravel (Morman et al. 1980), both of which are common substrates in portions of the CAWS (LimnoTech 2010). After hatching, ammocoetes, lamprey larvae, drift downstream and bury in detritus-rich mud, silt, or sand-silt bottoms (Kottelat & Freyhof 2007; Hardisty & Potter1971) for 5.5–8 years, often at the edges of rivers and streams where currents are slow (Gallant et al. 2006; Kottelat & Freyhof 2007). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). The CSSC has banks of bedrock and steel sheet piling leading to the Des Plaines River. Most sediments in the CSSC are silt or bedrock or a combination of silt and sand, gravel, or cobble (LimnoTech 2010).

Pollution, turbidity, and/or sedimentation were mentioned as major limiting factors for the absence or scarcity of larvae in streams in Illinois and Michigan (Starret et al. 1960; Morman et al. 1980). Contaminants, although diluted in stream water, may reach toxic levels as they accumulate in sediment and thereby cause mortality of larval lampreys. The influence of stream pollution on spawning runs is poorly understood. Adult lampreys may be more tolerant of some pollutants than embryonic or larval lampreys, because they run polluted streams in which larvae have never been detected (Morman et al. 1980). The Calumet River, the Little Calumet River, and the Calumet Sag Channel also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adults will move into the CAWS only to spawn in the CAWS itself or to move to spawning areas farther downstream (section 3a). Sea lampreys are capable of traveling great distances to spawning grounds, so they could move through the CAWS during this time step (section 3a). Water depth in the CAWS is adequate for spawning of sea lampreys, and there are no physical barriers that they could not pass eventually, although barriers may slow passage (section 2d). Suitable spawning and juvenile habitat may be present in the CAWS (section 2d). The stream hydraulics of the CAWS do not provide “attractive flow” to draw sea lamprey into the CAWS. Pollution, sedimentation, and dissolved oxygen in portions of the CAWS may be unsuitable for larval development (section 2d). Sea lampreys are historically very rare in Illinois rivers (section 2a) potentially because of silt and turbidity

(section 2d). Sea lampreys have not been found in the CAWS, suggesting the CAWS would not be a pathway for this species (section 2a). Consequently, probability of passage is low.
T_{10}: See T_0. Hydraulics are expected to remain unsuitable.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Why sea lampreys are not found in Illinois rivers despite being in Lake Michigan for 70+ years is not fully understood. However, suitable conditions for passage appear to be present. Therefore, uncertainty is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. The uncertainty of habitat suitability associated with the improvement of habitat conditions increases over time. However, the hydraulics will remain unsuitable.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Sea lampreys would be present in rivers of the MRB only for spawning or early life stage development. Adults do not occupy riverine habitat except to spawn. Sea lampreys require mostly gravel (15–115 mm [0.59–4.53 in.] diameter) for constructing nests, although they use other materials such as rubble, clam shells, and lumps of clay when gravel is scarce or absent (Morman et al. 1980). Gravel at highway or railroad crossings provides lampreys with spawning sites. In such streams spawning may be limited to only one small area (Morman et al. 1980). The larvae of sea lamprey occur most frequently in soft bottoms containing mixtures of silt and sand (NBII & ISSG 2008; Morman et al. 1980). However, Morman et al. (1980) referred to the scarcity of ammocoetes in the lower sections of some streams in spite of soft bottoms, suggesting that heavy siltation and slow currents were unfavorable. Below the Brandon Road Lock and Dam, there are streams that could provide suitable spawning habitat. However, extensive surveys in Illinois rivers found no sea lampreys, and there is only one dubious record from the Du Page River (Starret et al. 1960).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Movements from the sea to spawning sites may cover distances from 19.3 to 805 km (12 to 500 mi) inland (Hardisty 1986), suggesting sea lampreys could swim to suitable spawning habitat if they were present. Juveniles on the migration to Lake Michigan could be blocked by the electric barriers above the Lockport Lock and Dam.

Evidence for Probability Rating

Adults will move into the rivers only to spawn and are capable of traveling great distances to spawning ground (section 4a). Larval and juvenile stages develop in rivers, and suitable habitat may be present downstream of the Brandon Road Lock and Dam (section 4a). However, sea lamprey are historically very rare in Illinois rivers (section 4a) potentially because of silt and turbidity (section 4a), suggesting they would not be present downstream of the Brandon Road Lock and Dam (section 4a). Overall, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of sediment conditions for spawning is uncertain. Sea lampreys are capable of traveling great distances to spawning grounds (section 4a), and why sea lamprey are not found in Illinois rivers despite being in Lake Michigan for 70 or more years is not fully understood. Overall, the uncertainty associated with colonization is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
   Temperatures between 10 and 27 °C (50 and 80.6 °F) are considered appropriate for larval and juvenile development (Morman et al. 1980). Consequently, the climate of the MRB should be suitable.

b. *Type of Mobility/Invasion Speed*
   Sea lampreys move by swimming or by attaching to other fish.

c. *Fecundity*
   Sea lampreys have been reported to lay between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010).

d. *History of Invasion Success*
Sea lampreys are native to the east coast of the United States, and the majority of the European coast but have been introduced to the Great Lakes through the canal system (NBII & ISSG 2008). Sea lampreys entered the Great Lakes in the 1800s through manmade locks and shipping canals. Prior to the opening of the Welland Canal in 1829 and prior to modification of Niagara Falls in 1919, Niagara Falls served as a natural barrier to keep sea lampreys out of the Great Lakes (GLFC 2000). Although sea lampreys have been established in Lake Michigan since the 1930s, there are no confirmed records of them in Illinois rivers (Starrett et al. 1960).

e. *Human-Mediated Transport through Aquatic Pathways*
Human-mediated transport is not required.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Sea lampreys occupy lakes and oceans as adults and would exist in river habitat only as spawning adults or during early life stages. Sea lampreys could potentially colonize reservoirs within the MRB.

Evidence for Probability Rating

Adults will move into the rivers only to spawn (section 5a), but they could potentially occupy reservoirs/navigation pools in the MRB. Sea lampreys are capable of swimming to spawning grounds (section 5b), and suitable spawning habitat is present in the MRB (section 5f). However, sea lampreys are historically very rare in Illinois rivers (section 5a) potentially because of silt and turbidity (section 5d). Sea lampreys are an anadromous fish that prefers large lentic systems. Consequently, probability of spread is low.

Uncertainty: LOW

Evidence for Uncertainty Rating

Why sea lampreys are not found in the MRB despite being in Lake Michigan for 70 or more years is not fully understood. The suitability of reservoirs/navigation pools and the ability of sea lamprey to reach these reservoirs are unknown. However, based on the historical absence of sea lampreys in the MRB, the uncertainty associated with spread is low.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Low	Low	Low	Low	Low	Low	Low	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). Adults are parasitic, using their sharp teeth to attach themselves to cetaceans and large fish and feed off their host's blood, body fluids and flesh for several days (Kottelat & Freyhof 2007). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980).

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). There is heavy lake-wide commercial vessel traffic to the Indiana Harbor (USACE 2011a). However, this species primarily relies on swimming or attaching to hosts for movement.

c. *Current Abundance and Reproductive Capacity*
T_0: Sea lampreys have been reported to produce between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010). There are ongoing efforts to suppress sea lamprey populations, and lampricides have been generally successful in reducing the sea lamprey population (Fuller et al. 2011).
T_{10}: See T_0. Lamprey populations may fluctuate due to natural ecological changes and ongoing management measures to suppress their number.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The sea lamprey has been established in lower Lake Michigan since 1936 (Fuller et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Lake Michigan is known to be suitable habitat for the species, because it has been established there since 1936.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sea lamprey has been in lower Lake Michigan since 1936 (sections 2e, 2f) and is therefore considered to have arrived at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The sea lamprey has been documented in lower Lake Michigan since 1936 (sections 2e, 2f); therefore, uncertainty is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Sea lampreys move by swimming or by attaching to other fish. Eggs and larvae are benthic, not free-floating (Fuller et al. 2011), so transport of eggs by currents is unlikely. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Interconnecting waterways are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Mature adults enter rivers and streams to spawn in spring (Hardisty 1986; Muus et al. 1999; Kelly & King 2001). After spawning adults normally die (Rochard & Elie 1994). Upon metamorphosis, which may take 5 or more years in the Great Lakes (Potter 1981), individuals migrate into open water. However, since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980). Surveys of Illinois rivers in the 1960s produced only one potential specimen.

b. Human-Mediated Transport through Aquatic Pathways

Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). Interconnecting waterways and attachment to fishes and boats are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Vessel traffic to the Indiana Harbor is lake-wide rather than from the CAWS, and there is no commercial vessel traffic to inland ports in the CAWS from Indiana Harbor (NBIC 2012). There is little if any vessel traffic in the Grand Calumet River due to the shallow depth.

c. *Existing Physical Human/Natural Barriers*

T_0: There is sheet pile across the Grand Calumet River between the Indiana Harbor Canal and the Calumet River that could act as a barrier, especially under low flows. Physical barriers, such as dams, have been recognized as limiting to the upstream movement of sea lampreys (Morman et al. 1980). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to passage. Water depth does not seem to be a critical factor in the distribution of lamprey spawning. Water depth at 32 northern Michigan streams ranged from 5 to 152 cm (2 to 60 in.) (Applegate 1950). The CAWS has perennial flow and a water depth that supports navigation; therefore, water depth is not expected to inhibit movement. The electric barriers upstream of the Lockport Lock and Dam could shock sea lamprey moving downstream, but they would continue to float downstream. Therefore, the barriers are not likely to control passage.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Many environmental conditions influence the distribution of sea lampreys. Stream flow and water temperature are of major importance. Water flows toward Lake Michigan in Indiana Harbor, which may provide attractive flow to this species. The dispersal of spawning adults within streams is influenced mainly by blockages, water temperature, flow, sediment and presence of lakes. In a survey of streams in northern Indiana and the Lower Peninsula of Michigan, the absence or scarcity of larvae in streams was attributed to intermittent and unstable stream flows (USFWS, Ludington, Michigan, unpublished records; Morman et al. 1980). Pollution, sedimentation, and hard or unstable bottoms also contributed to the absence or scarcity of lamprey (Morman et al. 1980). Temperature tolerances of adults are not well characterized, but they are documented to tolerate a range of 1–20°C (3.8–68°F) (Beamish 1980). Temperatures of 31.4°C (88.5°F) are lethal to ammocoetes (Beamish 1980). Water temperature is probably the most important factor affecting the development of embryos. Water temperatures of 11–25°C (51.8–77°F) appear essential for successful spawning (Morman et al. 1980). These temperatures are within the range of the CAWS (MWRD 2011). The median low flow of 74 streams that contained populations of sea lamprey ammocoetes in the Lower Peninsula of Michigan was 0.4 m/s (1.31ft/s) (Morman et al. 1980). However, others have stated that velocities of 0.5–1.5 m/s (1.64–4.92 ft/s) were suitable for spawning (Manion & Hanson 1980). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010).

The distributions of larval lampreys are also limited by hard stream bottom and pollution, but larvae have been found in a wide range of habitats exhibiting these conditions (Morman et al. 1980). Spawning typically occurs over sand or gravel (Morman et al. 1980), both of which are common substrates in portions of the CAWS (LimnoTech 2010). After hatching, ammocoetes, lamprey larvae, drift downstream and bury in detritus-rich mud, silt, or sand-silt bottoms (Kottelat & Freyhof 2007; Hardisty & Potter 1971) for 5.5–8 years, often at the edges of rivers and streams where currents are slow (Gallant et al. 2006; Kottelat & Freyhof 2007). Conditions at Indiana Harbor are highly industrialized. Sediments in the Grand Calumet consist of primarily cobble, bedrock, or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water can flow east or west depending on the water level in Lake Michigan. The Calumet Sag Channel and the Little Calumet River also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). In the CSSC, in-stream habitat varies by location, but it is generally limited, and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).

Pollution, turbidity, and/or sedimentation were mentioned as major limiting factors for the absence or scarcity of larvae in streams in Illinois and Michigan (Starret et al. 1960; Morman et al. 1980). Contaminants, although diluted in stream water, may reach toxic levels as they accumulate in sediment and thereby cause mortality of larval lampreys. The influence of stream pollution on spawning runs is poorly understood. Adult lampreys may be more tolerant of some pollutants than embryonic or larval lampreys, because they run polluted streams in which larvae have never been detected (Morman et al. 1980). In the east branch of the Grand Calumet River, biological integrity is poor and sediment toxicity is high (Gallagher et al. 2011). The Calumet River, the Little Calumet River, and the Calumet Sag Channel also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011).
T_{10}: See T_0.
T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adults will move into the CAWS only to spawn in the CAWS itself or to move to spawning areas farther downstream (section 3a). Sea lampreys are capable of traveling great distances to spawning grounds, so they could move through the CAWS during this time step

(section 3a). Water depth in the CAWS is adequate for spawning of sea lampreys, and there are no physical barriers that they could not pass eventually, although the barriers may slow passage (section 2d). Suitable spawning and juvenile habitat may be present in the CAWS (section 2d). Hydrologic conditions in the CAWS appear to be suitable, although pollution, sedimentation, and dissolved oxygen in portions of the CAWS may be unsuitable for larval development (section 2d). Sea lampreys are historically very rare in Illinois rivers (section 2a) potentially because of silt and turbidity (section 2d). Sea lampreys have not been found in the CAWS, suggesting the CAWS would not be a pathway for this species (section 2a). Consequently, probability of passage is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Why sea lampreys are not found in Illinois rivers despite being in Lake Michigan for 70 or more years is not fully understood. However, suitable conditions for passage appear to be present. Therefore, uncertainty is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Sea lampreys would be present in rivers of the MRB only for spawning or early life stage development. Adults do not occupy riverine habitat except to spawn. Sea lampreys require mostly gravel (15–115 mm [0.59–4.53 in,] diameter) for constructing nests, although they use other materials such as rubble, clam shells, and lumps of clay when gravel is scarce or absent (Morman et al. 1980). Gravel at highway or railroad crossings provides lampreys with spawning sites. In such streams spawning may be limited to only one small area (Morman et al. 1980). The larvae of sea lamprey occur most frequently in soft bottoms containing mixtures of silt and sand (NBII & ISSG 2008; Morman et al. 1980). However, Morman et al. (1980) referred to the scarcity of ammocoetes in the lower sections of some streams in spite of soft bottoms, suggesting that heavy siltation and slow currents were unfavorable. Below Brandon Road Lock and Dam, there are streams that could provide suitable spawning habitat. However, extensive surveys in Illinois Rivers found no sea lampreys, and there is only one dubious record from the DuPage River (Starret et al. 1960).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Juveniles on the migration to Lake Michigan could be blocked by the electric barriers above the Lockport Lock and Dam.

Evidence for Probability Rating

Adults will move into the rivers only to spawn and are capable of traveling great distances to spawning ground (section 4a). Larval and juvenile stages develop in rivers, and suitable habitat may be present downstream of the Brandon Road Lock and Dam (section 4a). However, sea lamprey are historically very rare in Illinois rivers (section 4a) potentially because of silt and turbidity (section 4a), suggesting they would not be present downstream of the Brandon Road Lock and Dam (section 2a). Overall, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

The suitability of sediment conditions for spawning is uncertain. Sea lampreys are capable of traveling great distances to spawning grounds (section 4a), and why sea lamprey are not found in Illinois rivers despite being in Lake Michigan for 70 or more years is not fully understood. Overall, the uncertainty associated with colonization is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Temperatures between 10 and 27 °C (50 and 80.6°F) are considered appropriate for larval and juvenile development (Morman et al. 1980). Consequently, the climate of the MRB should be suitable.

b. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish.

c. *Fecundity*
Sea lampreys have been reported to lay anywhere between 35,000–100,000 (NBII & ISSG 208) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010).

d. *History of Invasion Success*
Sea lampreys are native to the east coast of the United States and the majority of the European coast but have been introduced to the Great Lakes through the canal system (NBII & ISSG 2008). Sea lampreys entered the Great Lakes in the 1800s through manmade locks and shipping canals. Prior to the opening of the Welland Canal in 1829 and prior to the modification of Niagara Fall in 1919, Niagara Falls served as a natural barrier to keep sea lampreys out of the Great Lakes (GLFC 2000). Although sea lamprey s have been established in Lake Michigan since the 1930s, there are no confirmed records of them in Illinois rivers (Starrett et al. 1960).

e. *Human-Mediated Transport through Aquatic Pathways*
Human-mediated transport is not required.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Sea lampreys occupy lakes and oceans as adults and would exist in river habitat only as spawning adults or during early life stages. Sea lampreys could potentially colonize reservoirs within the MRB.

Evidence for Probability Rating

Adults will move into the rivers only to spawn (section 5a), but they could potentially occupy reservoirs/navigation pools in the MRB. Sea lampreys are capable of swimming to spawning grounds (section 5b), and suitable spawning habitat is present in the MRB (section 5f). However, sea lampreys are historically very rare in Illinois rivers (section 5a) potentially because of silt and turbidity (section 5d). Sea lampreys are an anadromous fish that prefers large lentic systems. Consequently, probability of spread is low.

Uncertainty: LOW

Evidence for Uncertainty Rating

Why sea lamprey are not found in the MRB despite being in Lake Michigan for 70 or more years is not fully understood. The suitability of reservoirs/navigation pools and the ability of sea lampreys to reach these reservoirs are unknown. However, based on the historical absence of sea lampreys in the MRB, the uncertainty associated with their spread is low.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	Low	Medium	Low	Medium	Low	Medium	Low	Medium
P(colonizes)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(spreads)	Low	Low	Low	Low	Low	Low	Low	Low
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). Adults are parasitic, using their sharp teeth to attach themselves to cetaceans and large fish and feed off their host's blood, body fluids and flesh for several days (Kottelat & Freyhof 2007). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980).

b. *Human-Mediated Transport through Aquatic Pathways*
Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). There is recreational but not commercial vessel traffic to the BSBH (USACE 2011a,b). However, this species primarily relies on swimming or attaching to hosts for movement.

c. *Current Abundance and Reproductive Capacity*
T_0: Sea lampreys have been reported to produce between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010). There are ongoing efforts to suppress sea lamprey populations, and lampricides have been generally successful in reducing the sea lamprey population (Fuller et al. 2011).
T_{10}: See T_0. Lamprey populations may fluctuate due to natural ecological changes and ongoing management measures to suppress their number.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: None.
T_{25}: None.
T_{50}: None.

e. *Distance from Pathway*
T_0: The sea lamprey has been established in lower Lake Michigan since 1936 (Fuller et al. 2012).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Lake Michigan is known to be suitable habitat for the species, because it has been established there since 1936.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sea lamprey has been in lower Lake Michigan since 1936 (sections 2e, 2f) and is therefore considered to have arrived at the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: The sea lamprey has been documented in lower Lake Michigan since 1936 (sections 2e, 2f); therefore, uncertainty is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish. Eggs and larvae are benthic, not free-floating (Fuller et al. 2011), so transport of eggs by currents is unlikely. Sea lampreys are believed to have migrated through the Erie, Welland, and St. Lawrence canal systems (NBII & ISSG 2008). The species is known to travel long distances while attached to other fish (NBII & ISSG 2008). Interconnecting waterways are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Mature adults enter rivers and streams to spawn in spring (Hardisty 1986; Muus et al.1999; Kelly & King 2001). Movements from the sea to spawning sites may cover distances from 19.3 to 805 km (12 to 500 mi) inland (Hardisty 1986). It is less than 64.4 km (40 mi) from the BSBH to the Brandon Road Lock and Dam. After spawning, adults normally die (Rochard & Elie1994). Upon metamorphosis, which may take 5 or more years in the Great Lakes (Potter 1981), individuals migrate into open water. However, since 1957, larval sea lampreys have been detected in only 433 (7.5%) of the 5747 streams and tributaries of the GLB (Morman et al. 1980). Surveys of Illinois rivers in the 1960s produced only one potential specimen.

b. *Human-Mediated Transport through Aquatic Pathways*

Sea lampreys may have attached to boats going through canal systems (NBII & ISSG 2008). Interconnecting waterways and attachment to fishes and boats are considered major factors in the lake movements of parasitic-phase lampreys (Morman et al. 1980). Vessel traffic to the BSBH is lake-wide rather than from the CAWS, and there is no commercial vessel traffic to inland ports in the CAWS from the BSBH (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*

T_0: Physical barriers, such as dams, have been recognized as limiting to the upstream movement of sea lampreys (Morman et al. 1980). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to passage. Water depth does not seem to be a critical factor in the distribution of lamprey spawning. Water depth at 32 northern Michigan streams ranged from 5 to 152 cm (2 to 60 in.) (Applegate 1950). The CAWS has perennial flow and a water depth that supports navigation; therefore, water depth is not expected to inhibit movement. The electric barriers upstream of the Lockport Lock and Dam could shock sea lamprey moving downstream, but they would continue to float downstream. Therefore, the barriers are not likely to control passage.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_0.

T_{50}: See T_0.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Many environmental conditions influence the distribution of sea lampreys. Stream flow and water temperature are of major importance. Water flows toward Lake Michigan in Indiana Harbor, which may provide attractive flow to this species. The dispersal of spawning adults within streams is influenced mainly by blockages, water temperature, flow, sediment and presence of lakes. In a survey of streams in northern Indiana and the Lower Peninsula of Michigan, the absence or scarcity of larvae in streams was attributed to intermittent and unstable stream flows (USFWS, Ludington, Michigan, unpublished records; Morman et al. 1980). Pollution, sedimentation, and hard or unstable bottoms also contributed to the absence or scarcity of lamprey (Morman et al. 1980). Temperature tolerances of adults are not well characterized, but they are documented to tolerate a range of 1–20°C (3.8–68°F) (Beamish 1980). Temperatures of 31.4°C (88.5°F) are lethal to ammocoetes (Beamish 1980). Water temperature is probably the most important factor affecting the development of embryos. Water temperatures of 11–25°C (51.8–77°F) appear essential for successful spawning (Morman et al. 1980). These temperatures are within the range of the CAWS (MWRD 2011). The median low flow of 74 streams that contained populations of sea lamprey ammocoetes in the Lower Peninsula of Michigan was 0.4 m/s (1.31ft/s) (Morman et al. 1980). However, others have stated that velocities of 0.5–1.5 m/s (1.64–4.92 ft/s) were suitable for spawning (Manion & Hanson 1980). Most flows in the CAWS were less than 0.15 m/s (0.49 ft/s); the highest was 0.27 m/s (0.89 ft/s) (LimnoTech 2010).

The distribution of larval lampreys is also limited by hard stream bottom and pollution, but larvae have been found in a wide range of habitats exhibiting these conditions (Morman et al. 1980).Spawning typically occurs over sand or gravel (Morman et al. 1980), both of which are common substrates in portions of the CAWS (LimnoTech 2010). After hatching, ammocoetes, lamprey larvae, drift downstream and bury in detritus-rich mud, silt or sand-silt bottoms (Kottelat & Freyhof 2007; Hardisty & Potter 1971) for 5.5–8 years, often at the edges of rivers and streams where currents are slow (Gallant et al. 2006; Kottelat & Freyhof 2007). The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). Inorganic silt sediments predominate in the Calumet Sag Channel as well. Bedrock sediments are also present (LimnoTech 2010). In the CSSC, in-stream habitat varies by location, but it is generally limited, and vertical bank walls are common along the shoreline. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand, with scattered cobble (LimnoTech 2010).

Pollution, turbidity, and/or sedimentation were mentioned as major limiting factors for the absence or scarcity of larvae in streams in Illinois and Michigan (Starret et al. 1960; Morman et al. 1980). Contaminants, although diluted in stream water, may reach toxic levels as they accumulate in sediment and thereby cause mortality of larval lampreys. The influence of stream pollution on spawning runs is poorly understood. Adult lampreys may be more tolerant of some pollutants than embryonic or larval lampreys, because they run polluted streams in which larvae have never been detected (Morman et al. 1980). The Calumet River, the Little Calumet River, and the Calumet Sag Channel also contain areas with potentially toxic sediment contaminant levels (Gallagher et al. 2011).

T_{10}: See T_0.

T_{25}: See T_0. Future water quality may improve with current plans to close two power plants and update wastewater treatment (Illinois Pollution Control Board 2012).

T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adults will move into the CAWS only to spawn in the CAWS itself or to move to spawning areas farther downstream (section 3a). Sea lamprey are capable of traveling great distances to spawning grounds, so they could move through the CAWS during this time step (section 3a). Water depth in the CAWS is adequate for spawning of sea lampreys, and there are no physical barriers that they could not pass eventually, although barriers may slow passage (section 3d). Suitable spawning and juvenile habitat may be present in the CAWS (section 3d). Hydrologic conditions in the CAWS appear to be suitable, although pollution,

sedimentation, and dissolved oxygen in portions of the CAWS may be unsuitable for larval development (section 3d). Sea lampreys are historically very rare in Illinois rivers (section 3a) potentially because of silt and turbidity (section 3d). Sea lampreys have not been found in the CAWS, suggesting the CAWS would not be a pathway for this species (section 3a). Consequently, probability of passage is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: Why sea lampreys are not found in Illinois rivers despite being in Lake Michigan for 70 or more years is not fully understood. However, suitable conditions for passage appear to be present. Therefore, uncertainty is medium.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

Sea lampreys would be present in rivers of the MRB only for spawning or early life stage development. Adults do not occupy riverine habitat except to spawn. Sea lampreys require mostly gravel (15–115 mm [0.59–4.53 in.] diameter) for constructing nests, although they use other materials such as rubble, clam shells, and lumps of clay when gravel is scarce or absent (Morman et al. 1980). Gravel at highway or railroad crossings provides lampreys with spawning sites. In such streams spawning may be limited to only one small area (Morman et al. 1980). The larvae of sea lamprey occur most frequently in soft bottoms containing mixtures of silt and sand (NBII & ISSG 2008; Morman et al. 1980). However, Morman et al. (1980) referred to the scarcity of ammocoetes in the lower sections of some streams in spite of soft bottoms, suggesting that heavy siltation and slow currents were unfavorable. Below the Brandon Road Lock and Dam, there are streams that could provide suitable spawning habitat. However, extensive surveys in Illinois rivers found no sea lampreys, and there is only one dubious record from the Du Page River (Starret et al. 1960).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Juveniles on the migration to Lake Michigan could be blocked by the electric barriers above Lockport Lock and Dam.

Evidence for Probability Rating

Adults will move into the rivers only to spawn and are capable of traveling great distances to spawning ground (section 4a). Larval and juvenile stages develop in rivers, and suitable habitat may be present downstream of the Brandon Road Lock and Dam (section 4a). However, sea lampreys are historically very rare in Illinois rivers (section 4a) potentially because of silt and turbidity (section 4a), suggesting they would not be present downstream of the Brandon Road Lock and Dam (section 4a). Overall, the probability of colonization is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating:

The suitability of sediment conditions for spawning is uncertain. Sea lampreys are capable of traveling great distances to spawning grounds (section 4a), and why sea lamprey are not found in Illinois rivers despite being in Lake Michigan for 70 or more years is not fully understood. Overall, the uncertainty associated with colonization is medium.

5. P(spreads): LOW

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Temperatures between 10 and 27°C (50 and 0.6°F) are considered appropriate for larval and juvenile development (Morman et al. 1980). Consequently, the climate of the MRB should be suitable.

b. *Type of Mobility/Invasion Speed*
Sea lampreys move by swimming or by attaching to other fish.

c. *Fecundity*
Sea lampreys have been reported to lay anywhere between 35,000–100,000 (NBII & ISSG 2008) and 120,000–260,000 eggs (Fishbase 2010); the minimum population doubling time is 4.5–14 years (Fishbase 2010).

d. *History of Invasion Success*
Sea lampreys are native to the east coast of the United States and the majority of the European coast but have been introduced to the Great Lakes through the canal system

(NBII & ISSG 2008). Sea lampreys entered the Great Lakes in the 1800s through manmade locks and shipping canals. Prior to the opening of the Welland Canal in 1829 and prior to the modification of Niagara Falls in 1919, Niagara Falls served as a natural barrier to keep sea lampreys out of the Great Lakes (GLFC 2000). Although sea lampreys have been established in Lake Michigan since the 1930s, there are no confirmed records of them in Illinois rivers (Starrett et al. 1960).

e. Human-Mediated Transport through Aquatic Pathways
Human-mediated transport is not required by the species.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Sea lampreys occupy lakes and oceans as adults and would exist only in river habitat as spawning adults or during early life stages. Sea lampreys could potentially colonize reservoirs within the MRB.

Evidence for Probability Rating

Adults will move into the rivers only to spawn (section 5a), but they could potentially occupy reservoirs/navigation pools in the MRB. Sea Lamprey are capable of swimming to spawning grounds (section 5b), and suitable spawning habitat is present in the MRB (section 5f). However, sea lampreys are historically very rare in Illinois rivers (section 5a) potentially because of silt and turbidity (section 5d). Sea lampreys are an anadromous fish that prefers large lentic systems. Consequently, probability of spread is low.

Uncertainty: LOW

Evidence for Uncertainty Rating

Why sea lamprey are not found in the MRB despite being in Lake Michigan for 70+ years is not fully understood. The suitability of reservoirs/navigation pools and the ability of sea lampreys to reach these reservoirs are unknown. However, based on the historical absence of sea lampreys in the MRB, the uncertainty associated with spread is low.

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E.2.7.4 Tubenose Goby - *Proterorhinus semilunaris*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The tubenose goby is a small, benthic fish. The tubenose goby exhibits a slow invasion speed and has not spread rapidly in the GLB (Vanderploeg et al. 2002; Rasmussen 2002; Fuller et al. 2012). The species invaded the Laurentian Great Lakes in the 1990s, presumably via ballast water from transoceanic cargo ships (Jude et al. 1992). Jump dispersal by the tubenose goby from the lower Great Lakes to Lake Superior can be

explained by ship transport (Dopazo et al. 2008). This species is less successful than the round goby, Neogobius melanostomus, in terms of spread and population growth (Dillon & Stepien 2001). The decline in wetland habitat may explain the low occurrence of tubenose goby in the Great Lakes (Dopazo et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*

Human-mediated transport is likely to be a faster mechanism than natural dispersion in the spread of the species. The species can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992), but there is no cargo vessel traffic to the WPS (USACE 2011a). There is heavy commercial vessel traffic between Duluth-Superior (where this species is located) and ports in southern Lake Michigan (NBIC 2012) that could transport this species closer to the WPS.

c. *Current Abundance and Reproductive Capacity*

T_0: There is a low abundance of the species in the GLB (Dopazo et al. 2008). The tubenose goby has spread throughout Lake St. Clair in Michigan and its tributaries (Jude et al. 1992), as well as the Detroit River system, and is commonly collected in the Duluth-Superior harbor of Lake Superior (Kocovsky et al. 2011). A population of tubenose gobies has become established and self-sustaining in the western basin of Lake Erie (Kocovsky et al. 2011). Tubenose gobies reach maturity in 1–2 years (Freyhof & Kottelat 2008). The females of the species spawn more than once during a season (Freyhof & Kottelat 2008) and likely have a protracted spawning period (Leslie et al. 2002).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers.
T_{10}: See T_0. No activities or events are anticipated that would increase or decrease barriers between the current locations of the tubenose goby and the WPS.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: Tubenose goby is established in the western basin of Lake Erie (Kocovsky et al. 2011), Lake St. Clair (Jude et al. 1992), and the St. Louis River, which empties into Lake Superior (Fuller et al. 2012). The species is located approximately 4828 km (3000 river miles) from the pathway entrance. It is commonly collected in the Duluth-Superior harbor of Lake Superior (Kocovsky et al. 2011). No records were found for this species being collected in Lake Michigan. The U.S. Environmental Protection Agency (EPA 2008) states that the species may be able to occupy all shallow waters of all five Great Lakes.
T_{10}: See T_0. Tubenose goby could become closer to the WPS by vessel transport or natural dispersion to southern Lake Michigan. The species may be able to occupy shallow waters of all five Great Lakes (EPA 2008).
T_{25}: See T_{10}.

T_{50}: See T_{10}. In the future, the distance of the species from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of tubenose goby in the Great Lakes include natural population growth, climate change, or new aquatic nuisance species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The native range of tubenose goby includes slightly brackish to fresh waters of Eurasia, primarily in rivers and estuaries of the Black Sea basin and rivers of the northern Aegean (Fuller et al. 2012; Neilson & Stepien 2009). The species is considered a cool-water species, preferring temperatures ranging from 10 to 20°C (50 to 68°F). Rasmussen (2002) and the EPA (2008) suggested southern Lake Michigan may be suitable based on temperature preferences. Tubenose goby prefer benthic habitats in low-salinity estuaries, lakes, rivers, and wetlands (Dopazo et al. 2008); they typically dwell in shallow near-shore waters (Dopazo et al. 2008). Adults of this species inhabit waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012), with maximum densities in western Lake Erie being reached in waters less than 1.5 m (4.9 ft) deep (Kocovsky et al. 2011). Densities of the species were significantly greater in riprap habitat than in sandy and macrophyte habitats (Jude & DeBoe 1996). Leslie et al. (2002) collected the species in water with no or slow flow. Tubenose goby spawn on the underside of fixed objects like rocks (Kocovsky et al. 2011); there is rocky habitat in the vicinity of the WPS as well as sandy habitat and Cladophora beds (MTRI 2012) that may be suitable.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is not currently located in Lake Michigan and is reported to have a slow rate of spread and low abundance (Fuller et al. 2012; Vanderploeg et al. 2002). Tubenose goby can be transported via ballast water (sections 2a, 2b), but there is no cargo vessel traffic to the WPS, so some natural dispersal may be required. Natural dispersion for this species is not well characterized in the Great Lakes, but this species is unlikely to spread from its current locations during the current time step given that it has not yet been detected in southern Lake Michigan despite being detected in the Great Lakes since the 1990s (section 2a). Therefore, there is a low probability the species will arrive at the WPS during the current time step.

T_{10}: See T_0. Although there is no commercial vessel transport to the WPS, over time, the probability increases that the species will have time to spread to the WPS by human-mediated transport to ports in southern Lake Michigan coupled with natural dispersal to the WPS. Therefore, its probability of arrival for this time step is medium.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is no commercial vessel traffic between Lake Michigan and the WPS, so the potential for ballast water transport is low. In addition, the natural dispersal speed of the tubenose goby is not well characterized, but the species has low abundance where established and has been slow to spread in the Great Lakes compared to other invasive gobies. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. The tubenose goby may be able to reach the WPS within 10 years. However, this species is documented to be relatively uncommon in the GLB. Therefore, over time, trends in future populations and spread rates become less certain. In addition, this species has been established in the GLB since the 1990s, and it is uncertain why it has not been detected in southern Lake Michigan despite suitable habitat being present. As a result, its uncertainty of arrival is considered medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The tubenose goby may be more certain to reach the WPS over 50 years. However, based on its native distribution, tubenose goby appear to be more of a cool-water species, and temperature increases related to future climate change may affect their distribution (section 2f). Thus, future climate change could affect the movement of tubenose goby into southern Lake Michigan depending on whether the environment becomes more or less favorable to this species. Therefore, the uncertainty of the species' arrival at the pathway is medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the WPS end of the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The tubenose goby is a small fish. Little is known about the species in the Great Lakes because of its low abundance (Dopazo et al. 2008). The invasion of the species into the Laurentian Great Lakes presumably occurred via ballast water from transoceanic cargo ships (Jude et al. 1992). Eggs are laid on the undersides of fixed objects like rocks (Kocovsky et al. 2011), making transport by currents unlikely; it has also been reported that tubenose lay their eggs in eel grass (Dopazo et al. 2008) and that eggs attached to vegetation can be transported when the vegetation is uprooted. In its invasion of the

Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
The distance from the WPS to the Brandon Road Lock and Dam is more than 64 km (40 mi). While the tubenose goby can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992), there is no commercial vessel traffic from the WPS (USACE 2011a,b). In addition, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: A sluice gate separates Lake Michigan from the CAWS. However, tubenose goby could be transported from Lake Michigan into the North Shore Channel via water pumped from the lake into the channel. This species prefers waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012). The water depth in the Chicago River and the CSSC is less than 9.1 m (30 ft) and less than 4.6 m (15 ft) in many areas. The Electric Dispersal Barrier System, located north of the Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, adults that are shocked and early life stages could float downstream through the barrier. Tubenose goby eggs are benthic, but they could move through the barrier if resuspended in the water column. So there is a high potential that adults and early life stages may pass the barrier at the current setting. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be a barrier to passage.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Tubenose goby are found along rocky and/or vegetated shallow waters as well as on sandy sediment. All these habitats are present in the CAWS (LimnoTech 2010). The North Shore Canal has riprap banks (LimnoTech 2010), which is a preferred habitat of the species (Jude & Deboe 1996; Von Landwust 2006) and also a preferred spawning habitat (Kocovsky et al. 2011). The upper north branch of the Chicago River and the North Shore Channel are more natural habitat with cobble banks and woody debris (LimnoTech 2010). The Chicago River is more than 90% vertical wall and has a sludge or silt bottom. The banks of the CSSC are vertical walls, rock, and some vegetative debris. Sediments in the CSSC can be rock to soft sediment and sand. Submerged aquatic vegetation is also present in portions of the CSSC (LimnoTech 2010). Tubenose goby prefer still or slow-flowing water (Dopazo et al. 2008), which is typical of the CAWS except during high flows. The tubenose goby is considered a cool-water species, preferring waters within the temperature range of 10 to 20°C (50 to 68 °F) (Rasmussen 2002), although the western basin of Lake Erie where this species has become successfully established regularly exceeds this temperature range in summer (20–25°C

[68–77°F]) (EPA Great Lakes National Program Office, unpublished data). Therefore, water in the CAWS would be suitable at least seasonally.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: The sluice gate at the WPS would act as a temporary barrier, but water pumped from Lake Michigan into the North Shore Channel could transport tubenose goby into the CAWS. It is more than 64 km (40 mi) from the WPS to the Brandon Road Lock and Dam. Suitable adult and reproductive habitat is present throughout the CAWS (section 3e). The Electric Dispersal Barrier System is not likely to reduce downstream movement (section 3c). It is unlikely that the tubenose goby would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading from the WPS to the Brandon Road Lock and Dam. Overall, there is a high probability of passage for this time step.
T_{10}: See T_0.
T_{25}: See T_0 .
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The tubenose goby may be able to pass through the Brandon Road Lock and Dam during this time step, but this species' potential speed of natural dispersion through the CAWS is uncertain. Therefore, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more certain that the tubenose goby will move through the CAWS to the Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty of its passage decreases to low during this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway.

The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Suitable habitat includes slightly brackish and fresh waters, including rivers and estuaries (Rasmussen 2002). The species prefers shallow (less than 5 m [16.4 ft]) (Fuller et al. 2012), slow or no-flow waters (Dopazo et al. 2008) often with vegetation. The tubenose goby is capable of spreading through large river systems (Von Landwust 2006). However, Rasmussen (2002) states that the tubenose goby is a true cool-water species (prefers water temperature between 10 and 20°C [50 and 68°F]), and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is present downstream of the Brandon Road Lock and Dam. The tubenose goby is an active swimmer and would be able to move to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at the Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the tubenose goby is a cool-water species, it may be able to exist below the Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the tubenose goby colonizing downstream of the Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The tubenose goby has been documented to spread through large river systems (section 4a). However, temperature preferences may prevent the permanent, year-round establishment of this species below the Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Rasmussen (2002) states that the tubenose goby is a true cool-water species, and that temperature preference may discourage movement south into the Illinois River, which could in turn limit its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
This species has spread through large river basins in Europe. This species spread by active migration through the Rhine River basin across large dam and lock systems (Von Landwust 2006).

c. *Fecundity*
The tubenose goby likely has a protracted spawning period (Leslie et al. 2002) and can spawn multiple times during a season (Freyhof & Kottelat 2008).

d. *History of Invasion Success*
The tubenose goby has spread slowly in the Great Lakes, becoming established in the western basin of Lake Erie and in the St. Clair River (Kocovsky et al. 2011; Jude et al. 1992). However, the species is still considered to be rare in the St. Clair River (Fuller et al. 2012). The tubenose goby has spread through large river basins in Europe.

e. *Human-Mediated Transport through Aquatic Pathways*
In the Great Lakes, their spread has been attributed to human-mediated transport via ballast water (Dopazo et al. 2008; Jude et al. 1992). This species can be transferred by boat ballast. There is heavy vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The tubenose goby is a generalist species and could make use of most riverine habitat types. Tubenose goby can establish in large rivers and floodplain/oxbow habitat (Von Landwust 2006), so the MRB is vulnerable to some degree of invasion and establishment by the species. The species has a preference for shallow water sites with riprap, overhanging vegetation, and macrophytes (Von Landwust 2006). Such habitat is abundant in the MRB.

Evidence for Probability Rating

The tubenose goby is capable of invading large river systems (sections 5b, 5d). There is suitable physical habitat in the MRB, and it is accessible by the tubenose goby (section 5f).

However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the tubenose goby.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*

The tubenose goby is a small, benthic fish. The tubenose goby exhibits a slow invasion speed and has not spread rapidly in the GLB (Vanderploeg et al. 2002; Rasmussen 2002; Fuller et al. 2012). The species invaded the Laurentian Great Lakes in the 1990s, presumably via ballast water from transoceanic cargo ships (Jude et al. 1992). Jump dispersal by the tubenose goby from the lower Great Lakes to Lake Superior can be explained by ship transport (Dopazo et al. 2008). This species is less successful than the round goby, Neogobius melanostomus, in terms of spread and population growth (Dillon & Stepien 2001). The decline in wetland habitat may explain the low occurrence of tubenose gobies in the Great Lakes (Dopazo et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*

Human-mediated transport is likely to be a faster mechanism than natural dispersion in the spread of this species. The species can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992), and there is recreational and cargo vessel traffic between northern Lake Michigan and the CRCW (USACE 2011a). There is also heavy commercial vessel traffic between Duluth-Superior (where this species is located) and ports in southern Lake Michigan (including the CRCW) (NBIC 2012) that could transport this species closer to the CRCW.

c. *Current Abundance and Reproductive Capacity*

T_0: There is a low abundance of the species in the GLB (Dopazo et al. 2008). The tubenose goby has spread throughout Lake St. Clair in Michigan and its tributaries (Jude et al. 1992), as well as the Detroit River system, and is commonly collected in the Duluth-Superior Harbor of Lake Superior (Kocovsky et al. 2011). A population of tubenose gobies has become established and self-sustaining in the western basin of Lake Erie (Kocovsky et al. 2011). Tubenose gobies reach maturity in 1–2 years (Freyhof & Kottelat 2008). The females of the species spawn more than once during a season (Freyhof & Kottelat 2008) and likely have a protracted spawning period (Leslie et al. 2002).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers.
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of the tubenose goby and the CRCW.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: Tubenose goby is established in the western basin of Lake Erie (Kocovsky et al. 2011), Lake St. Clair (Jude et al. 1992), and the St. Louis River, which empties into Lake Superior (Fuller et al. 2012), approximately 4828 km (3,000 river miles) away from the pathway entrance. It is commonly collected in the Duluth-Superior Harbor of Lake Superior (Kocovsky et al. 2011). No records were found for this species being collected in Lake Michigan. The Environmental Protection Agency (EPA 2008) states that the species may be able to occupy all shallow waters of all five Great Lakes.

T_{10}: See T_0. Tubenose goby could become closer to the CRCW by vessel transport or natural dispersion to southern Lake Michigan. The species may be able to occupy shallow waters of all five Great Lakes (EPA 2008).

T_{25}: See T_{10}.

T_{50}: See T_{10}. In the future, the distance of the species from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of tubenose goby in the Great Lakes include natural population growth, climate change, or new aquatic nuisance species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The native range of tubenose goby includes slightly brackish to fresh waters of Eurasia, primarily in rivers and estuaries of the Black Sea basin and rivers of the northern Aegean Sea (Fuller et al. 2012; Neilson & Stepien 2009). The species is considered a cool water species, preferring temperatures ranging from 10 to 20°C (50 to 68°F). Rasmussen (2002) and the EPA (2008) suggested southern Lake Michigan may be suitable based on temperature preferences. Tubenose goby prefers benthic habitats in low-salinity estuaries, lakes, rivers, and wetlands (Dopazo et al. 2008); it typically dwells in shallow nearshore waters (Dopazo et al. 2008). Adults of this species inhabit waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012), with maximum densities in western Lake Erie being reached in waters less than 1.5 m (4.9 ft) deep (Kocovsky et al. 2011). Densities of the species were significantly greater in riprap habitat than in sandy and macrophyte habitats (Jude & DeBoe 1996). Leslie et al. (2002) collected the species in water with no or slow flow. Tubenose goby spawns on the underside of fixed objects like rocks (Kocovsky et al. 2011); there is rocky habitat in the vicinity of the CRCW as well as sandy habitat and Cladophora beds (MTRI 2012) that may be suitable.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is not currently in Lake Michigan and is reported to have a slow rate of spread and low abundance (Fuller et al. 2012; Vanderploeg et al. 2002). Tubenose goby can be transported via ballast water (sections 2a, 2b), and there is cargo vessel traffic to the CRCW that could transport this species. Natural dispersion for this species in the Great Lakes is not well characterized, but this species is unlikely to spread from its current locations during the current time step, given that it has not yet been detected in southern Lake Michigan despite being detected in the Great Lakes since the 1990s (section 2a). Therefore, there is a low probability the species will arrive at the CRCW during the current time step.
T_{10}: See T_0. There is commercial vessel transport to the CRCW from ports where the tubenose goby is located (section 2b). Over time, the probability increases that the species will have time to spread to the CRCW by natural dispersion alone or by a combination of human-mediated transport and natural dispersion. Overall, its probability of arrival for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is commercial vessel traffic between areas where the tubenose goby is located and the CRCW, so the potential for ballast water transport is high. However, the tubenose goby has not been documented in Lake Michigan, and the natural dispersal speed of the tubenose goby is not well characterized. The tubenose goby is documented to have low abundance where established and has been slow to spread in the Great Lakes compared to other invasive gobies. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. With the heavy vessel traffic to the CRCW, the tubenose goby may be able to reach the CRCW within 10 years. However, this species is documented to be relatively uncommon in the GLB. Therefore, over time, trends in future populations and spread rates become less certain. In addition, this species has been established in the GLB since the 1990s, and it is uncertain why it has not been detected in southern Lake Michigan despite suitable habitat being present. As a result, its uncertainty of arrival is considered medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The tubenose goby may be more certain to reach the CRCW over 50 years. However, based on its native distribution, tubenose goby appears to be more of a cool-water species, and temperature increases related to future climate change may affect its distribution (section 2f). Thus, future climate change could affect the movement of tubenose goby into southern Lake Michigan depending on whether the environment

becomes more or less favorable to this species. Therefore, the uncertainty of the species' arrival at the pathway is medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the end of the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The tubenose goby is a small fish. Little is known about the species in the Great Lakes because of its low abundance (Dopazo et al. 2008). The invasion of the species into the Laurentian Great Lakes presumably occurred via ballast water from transoceanic cargo ships (Jude et al. 1992). Eggs are laid on the undersides of fixed objects like rocks (Kocovsky et al. 2011), making transport by currents unlikely; it has also been reported that tubenose goby lay their eggs in eel grass (Dopazo et al. 2008) and that eggs attached to vegetation can be transported when the vegetation is uprooted. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
The distance from the CRCW to the Brandon Road Lock and Dam is greater than 64 km (40 mi). The tubenose goby can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992), and there is commercial vessel traffic from the CRCW to the Brandon Road Lock and Dam (USACE 2011a,b). However, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: This species prefers waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012). The water depth in the Chicago River and the CSSC is less than 9.1 m (30 ft) and less than 4.6 m (15 ft) in many areas. The Electric Dispersal Barrier System, located north of Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, the barrier may not be effective in shocking small fish like the tubenose goby, and adults that are shocked and early life stages could flow downstream through the barrier. Tubenose goby eggs are benthic, but they could move through the barrier if resuspended in the water column. So there is a high potential that adults and early life stages may pass the barrier at the current setting. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be barriers to passage.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Tubenose goby is found along rocky and/or vegetated shallow waters as well as on sandy sediment. All these habitats are present in the CAWS (LimnoTech 2010). The Chicago River and the south branch of the Chicago River are more than 90% vertical wall and have a concrete, sludge, or silt bottom. The banks of the CSSC are vertical walls, rock, and some vegetative debris. Sediments in the CSSC can be rock to soft sediment and sand. Submerged aquatic vegetation is also present in portions of the CSSC (LimnoTech 2010). Tubenose goby prefers still or slow-flowing water (Dopazo et al. 2008), which is typical of the CAWS except during high flows. The tubenose goby is considered a cool-water species, preferring waters within the temperature range of 10 to 20°C (50 to 68°F) (Rasmussen 2002), although the western basin of Lake Erie where this species has become successfully established regularly exceeds this temperature range in summer (20–25°C [68–77°F]) (EPA Great Lakes National Program Office, unpublished data). Therefore, water temperatures in the CAWS may not be suitable during the warmest months of the year.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: It is more than 64 km (40 mi) from the CRCW to the Brandon Road Lock and Dam. Suitable adult and reproductive habitat is present throughout the CAWS (section 3e). It is unlikely that the tubenose goby would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading from the CRCW to the Brandon Road Lock and Dam. The Electric Dispersal Barrier System is not likely to reduce downstream movement (section 3c). There is an overall high probability of passage for this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The tubenose goby may be able to pass through the Brandon Road Lock and Dam during this time step, but this species' potential speed of natural dispersion through the CAWS is uncertain. Therefore, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more certain that the tubenose goby will move through the CAWS to the Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty of its passage decreases to low during this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical and Climatological)
Suitable habitat includes slightly brackish and fresh waters, including rivers and estuaries (Rasmussen 2002). The species prefers shallow (less than 5 m [16.4 ft]) (Fuller et al. 2012), slow or no-flow waters (Dopazo et al. 2008) often with vegetation. The tubenose goby is capable of spreading through large river systems (Von Landwust 2006). However, Rasmussen (2002) states that the tubenose goby is a true cool-water species, and that temperature preference may discourage movement south into the Illinois River.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present downstream of the Brandon Road Lock and Dam. The tubenose goby is an active swimmer and would be able to move to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at the Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the tubenose goby is a cool-water species, it may be able to exist below the Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the tubenose goby colonizing downstream of the Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam, and suitable habitat is accessible (sections 4a, 4b). The tubenose goby has been documented to spread through large river systems (section 4a). However, temperature preferences may prevent the permanent, year-round establishment of this species below the Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Rasmussen (2002) states that the tubenose goby is a true cool-water species, and that temperature preference may discourage movement south into the Illinois River, which could in turn limit its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
This species has spread through large river basins in Europe. This species spread by active migration through the Rhine River basin across large dam and lock systems (Von Landwust 2006).

c. *Fecundity*
The tubenose goby likely has a protracted spawning period (Leslie et al. 2002) and can spawn multiple times during a season (Freyhof & Kottelat 2008).

d. *History of Invasion Success*
The tubenose goby has spread slowly in the GLB, becoming established in the western basin of Lake Erie and in the St. Clair River (Kocovsky et al. 2011; Jude et al. 1992). However, the species is still considered to be rare in the St. Clair River (Fuller et al. 2012). The tubenose goby has spread through large river basins in Europe.

e. *Human-Mediated Transport through Aquatic Pathways*
In the Great Lakes, its spread has been attributed to human-mediated transport via ballast water (Dopazo et al. 2008; Jude et al. 1992). This species can be transferred by boat ballast. There is heavy vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The tubenose goby is a generalist species and could make use of most riverine habitat types. Tubenose goby can establish in large rivers and floodplain/oxbow habitat (Von Landwust 2006), so the MRB is vulnerable to some degree of invasion and establishment

by the species. The species has a preference for shallow water sites with riprap, overhanging vegetation, and macrophytes (Von Landwust 2006). Such habitat is abundant in the MRB.

Evidence for Probability Rating

The tubenose goby is capable of invading large river systems (sections 5b, 5d). There is suitable physical habitat in the MRB, and it is accessible by the tubenose goby (section 5f). However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the tubenose goby.

PATHWAY: 3 (CALUMET HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The tubenose goby is a small, benthic fish. The tubenose goby exhibits a slow invasion speed and has not spread rapidly in the GLB (Vanderploeg et al. 2002; Rasmussen 2002; Fuller et al. 2012). The species invaded the Laurentian Great Lakes in the 1990s, presumably via ballast water from transoceanic cargo ships (Jude et al. 1992). Jump dispersal by the tubenose goby from the lower Great Lakes to Lake Superior can be explained by ship transport (Dopazo et al. 2008). This species is less successful than the round goby, Neogobius melanostomus, in terms of spread and population growth (Dillon & Stepien 2001). The decline in wetland habitat may explain the low occurrence of tubenose gobies in the Great Lakes (Dopazo et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
Human-mediated transport is likely to be a faster mechanism than natural dispersion in the spread of this species. The species can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992). There is recreational and cargo vessel traffic to Calumet Harbor, and there is commercial vessel traffic between Lake Erie (where this species is located) and ports in southern Lake Michigan (including the Calumet Harbor) (USACE 2011a; NBIC 2012) that could transport this species closer to the Calumet Harbor.

c. *Current Abundance and Reproductive Capacity*
T_0: There is a low abundance of the species in the GLB (Dopazo et al. 2008). The tubenose goby has spread throughout Lake St. Clair in Michigan and its tributaries (Jude et al. 1992), as well as the Detroit River system, and is commonly collected in the Duluth-Superior Harbor of Lake Superior (Kocovsky et al. 2011). A population of tubenose gobies has become established and self-sustaining in the western basin of Lake Erie (Kocovsky et al. 2011). Tubenose gobies reach maturity in 1–2 years (Freyhof & Kottelat 2008). The females of the species spawn more than once during a season (Freyhof & Kottelat 2008) and likely have a protracted spawning period (Leslie et al. 2002).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers.

T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of the tubenose goby and Calumet Harbor.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. *Distance from Pathway*

T_0: Tubenose goby is established in the western basin of Lake Erie (Kocovsky et al. 2011), Lake St. Clair (Jude et al. 1992), and the St. Louis River, which empties into Lake Superior (Fuller et al. 2012), approximately 4828 km (3000 river miles) away from the pathway entrance. It is commonly collected in the Duluth-Superior Harbor of Lake Superior (Kocovsky et al. 2011). No records were found for this species being collected in Lake Michigan. The Environmental Protection Agency (EPA 2008) states that the species may be able to occupy all shallow waters of all five Great Lakes.

T_{10}: See T_0. Tubenose goby could become closer to Calumet Harbor by vessel transport or natural dispersion to southern Lake Michigan. The species may be able to occupy shallow waters of all five Great Lakes (EPA 2008).

T_{25}: See T_{10}.

T_{50}: See T_{10}. In the future, the distance of the species from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of tubenose goby in the Great Lakes include natural population growth, climate change, or new aquatic nuisance species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The native range of tubenose goby includes slightly brackish to fresh waters of Eurasia, primarily in rivers and estuaries of the Black Sea basin and rivers of the northern Aegean Sea (Fuller et al. 2012; Neilson & Stepien 2009). The species is considered a cool-water species, preferring temperatures ranging from 10 to 20°C (50 to 68°F) (Rasmussen 2002). Rasmussen (2002) and the EPA (2008) suggested southern Lake Michigan may be suitable based on temperature preferences. Tubenose goby prefers benthic habitats in low-salinity estuaries, lakes, rivers, and wetlands (Dopazo et al. 2008); it typically dwells in shallow near-shore waters (Dopazo et al. 2008). Adults of this species inhabit waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012), with maximum densities in western Lake Erie being reached in waters less than 1.5 m (4.9 ft) deep (Kocovsky et al. 2011). Densities of the species were significantly greater in riprap habitat than in sandy and macrophyte habitats (Jude & DeBoe 1996). Leslie et al. (2002) collected the species in water with no or slow flow. Tubenose goby spawn on the underside of fixed objects like rocks (Kocovsky et al. 2011); there is rocky habitat in the vicinity of the Calumet Harbor as well as sandy habitat and Cladophora beds (MTRI 2012) that may be suitable.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is not currently in Lake Michigan and is reported to have a slow rate of spread and low abundance (Fuller et al. 2012; Vanderploeg et al. 2002). Tubenose goby can be transported via ballast water (sections 2a, 2b), and there is cargo vessel traffic to the Calumet Harbor that could transport this species (section 2b). Natural dispersion for this species in the Great Lakes is not well characterized, but this species is unlikely to spread from its current locations during the current time step, given that it has not yet been detected in southern Lake Michigan despite being in the Great Lakes since the 1990s (section 2a). Therefore, there is a low probability the species will arrive at Calumet Harbor during the current time step.
T_{10}: See T_0. There is commercial vessel transport to Calumet Harbor from ports where the tubenose goby is located. Over time, the probability increases that the species will have time to spread to the Calumet Harbor by natural dispersion alone or by a combination of human-mediated transport and natural dispersion. However, this species has not spread rapidly in the Great Lakes (section 2a). Overall, its probability of arrival for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is commercial vessel traffic between areas where the tubenose goby is located and Calumet Harbor, so the potential for ballast water transport is high. However, despite being present in the Great Lakes since the 1990s, the tubenose goby has not been documented in Lake Michigan, and the natural dispersal speed of the tubenose goby is not well characterized. The tubenose goby is documented to have low abundance where established and has been slow to spread in the Great Lakes compared to other invasive gobies. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. With the heavy vessel traffic to Calumet Harbor, the tubenose goby may be able to reach Calumet Harbor within 10 years. However, this species is documented to be relatively uncommon in the GLB. Therefore, over time, trends in future populations and spread rates become less certain. In addition, this species has been established in the GLB since the 1990s, and it is uncertain why it has not been detected in southern Lake Michigan

despite suitable habitat being present. As a result, its uncertainty of arrival is considered medium for this time step.

T_{25}: See T_{10}.

T_{50}: See T_{10}. The tubenose goby may be more certain to reach Calumet Harbor over 50 years. However, based on its native distribution, tubenose goby appear to be more of a cool-water species, and temperature increases related to future climate change may affect its distribution (section 2f). Thus, future climate change could affect the movement of tubenose goby into southern Lake Michigan depending on whether the environment becomes more or less favorable to this species. Therefore, the uncertainty of the species' arrival at the pathway is medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the end of the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The tubenose goby is a small fish. Little is known about the species in the Great Lakes because of its low abundance (Dopazo et al. 2008). The invasion of the species into the Laurentian Great Lakes presumably occurred via ballast water from transoceanic cargo ships (Jude et al. 1992). Eggs are laid on the undersides of fixed objects like rocks (Kocovsky et al. 2011), making transport by currents unlikely; it has also been reported that tubenose lay their eggs in eel grass (Dopazo et al. 2008) and that eggs attached to vegetation can be transported when the vegetation is uprooted. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
The distance from the Calumet Harbor to the Brandon Road Lock and Dam is approximately 64 km (40 mi). The tubenose goby can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992), and there is commercial vessel traffic from the Brandon Road Lock and Dam to the T.J. O'Brien Lock and Dam, which is just south of Calumet Harbor (USACE 2011a,b). However, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: This species prefers waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012). The water depth in the Chicago River and the CSSC is less than 9.1 m (30 ft) and less than 4.6 m (15 ft) in many areas. The Electric Dispersal Barrier System, located north of the Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, the barrier may not be effective in shocking small fish like the tubenose goby, and adults that are shocked and early life stages could float downstream through the barrier. Tubenose goby eggs are benthic, but they could move through the barrier if resuspended in the water column. So there is a high potential that adults and early life

stages may pass the barrier at the current setting. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be barriers to passage.

T_{10}: See T_0. No changes in human or natural barriers are expected.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Tubenose goby is found along rocky and/or vegetated shallow waters as well as on sandy sediment. All these habitats are present in the CAWS (LimnoTech 2010). After entering Calumet Harbor, the tubenose goby will enter the Calumet River. In the Calumet River, there is in-stream habitat for aquatic life in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation in some reaches. Urban industrial and commercial riparian land use is also present. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The banks of the CSSC are vertical walls, rock, and some vegetative debris. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Submerged aquatic vegetation is also present in portions of the CSSC (LimnoTech 2010). Tubenose goby prefer still or slow-flowing water (Dopazo et al. 2008), which is typical of the CAWS except during high flows (LimnoTech 2010). The tubenose goby is considered a cool-water species, preferring waters within the temperature range of 10 to 20°C (50 to 68°F) (Rasmussen 2002), although the western basin of Lake Erie where this species has become successfully established regularly exceeds this temperature range in summer (20–25°C [68–77 °F]) (EPA Great Lakes National Program Office, unpublished data). Therefore, water temperatures in the CAWS may not be suitable during the warmest months of the year.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: It is more than 64 km (40 mi) from Calumet Harbor to the Brandon Road Lock and Dam. Suitable adult and reproductive habitat is present throughout the CAWS (section 3e). It is unlikely that the tubenose goby would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading from Calumet Harbor to the Brandon Road Lock and Dam. The Electric Dispersal Barrier

System is not likely to reduce downstream movement (section 3c). There is an overall low probability of passage for this time step.
T_{10}: See T_0. Over time, the tubenose goby has a higher probability of spreading through the CAWS by natural dispersion. There do not appear to be any significant barriers to downstream movement. Therefore, the probability of passage during this time step increases to medium.
T_{25}: See T_{10}. The tubenose goby has a higher probability of spreading through the CAWS by natural dispersion over a 25-year time frame. Therefore, the probability of passage during this time step increases to high.
T_{50}: See T_{25}.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The tubenose goby may be able to pass through the Brandon Road Lock and Dam during this time step, but this species' potential speed of natural dispersion through the CAWS is uncertain. Therefore, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more certain that the tubenose goby will move through the CAWS to the Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty of its passage decreases to low during this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Suitable habitat includes slightly brackish and fresh waters, including rivers and estuaries (Rasmussen 2002). The species prefers shallow (less than 5 m [16.4 ft]) (Fuller et al. 2012), slow or no-flow waters (Dopazo et al. 2008) often with vegetation. The tubenose goby is capable of spreading through large river systems (Von Landwust 2006). However, Rasmussen (2002) states that the tubenose goby is a true cool-water species, and that temperature preference may discourage movement south into the Illinois River.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Suitable habitat is present downstream of the Brandon Road Lock and Dam. The tubenose goby is an active swimmer and would be able to move to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at the Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the tubenose goby is a cool-water species, it may be able to exist below the Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the tubenose goby colonizing downstream of the Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam, and suitable habitat is accessible (sections 4a, 4b). The tubenose goby has been documented to spread through large river systems (section 4a). However, temperature preferences may prevent the permanent, year-round establishment of this species below the Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in the NRB
Rasmussen (2002) states that the tubenose goby is a true cool-water species, and that temperature preference may discourage movement south into the Illinois River, which could in turn limit its expansion into other parts of the MRB.

b. Type of Mobility/Invasion Speed
This species has spread through large river basins in Europe. This species spread by active migration through the Rhine River basin across large dam and lock systems (Von Landwust 2006).

c. Fecundity
The tubenose goby likely has a protracted spawning period (Leslie et al. 2002) and can spawn multiple times during a season (Freyhof & Kottelat 2008).

d. *History of Invasion Success*
   The tubenose goby has spread slowly in the Great Lakes, becoming established in the western basin of Lake Erie and in the St. Clair River (Kocovsky et al. 2011; Jude et al. 1992). However, the species is still considered to be rare in the St. Clair River (Fuller et al. 2012). The tubenose goby has spread through large river basins in Europe.

e. *Human-Mediated Transport through Aquatic Pathways*
   In the Great Lakes, its spread has been attributed to human-mediated transport via ballast water (Dopazo et al. 2008; Jude et al. 1992). This species can be transferred by boat ballast. There is heavy vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   The tubenose goby is a generalist species and could make use of most riverine habitat types. Tubenose goby can establish in large rivers and floodplain/oxbow habitat (Von Landwust 2006), so the MRB is vulnerable to some degree of invasion and establishment by the species. The species has a preference for shallow water sites with riprap, overhanging vegetation, and macrophytes (Von Landwust 2006). Such habitat is abundant in the MRB.

Evidence for Probability Rating

The tubenose goby is capable of invading large river systems (sections 5b, 5d). There is suitable physical habitat in the MRB, and it is accessible by the tubenose goby (section 5f). However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the tubenose goby.

PATHWAY: 4 (INDIANA HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T0-T50: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
The tubenose goby is a small, benthic fish. The tubenose goby has not spread widely in the GLB (Vanderploeg et al. 2002; Rasmussen 2002; Fuller et al. 2012). The species invaded the Laurentian Great Lakes in the 1990s, presumably via ballast water from transoceanic cargo ships (Jude et al. 1992). Dispersal by the tubenose goby from the lower Great Lakes to Lake Superior can be explained by ship transport (Dopazo et al. 2008). This species is less successful than the round goby, Neogobius melanostomus, in terms of spread and population growth (Dillon & Stepien 2001). The

decline in wetland habitat may explain the low occurrence of tubenose gobies in the Great Lakes (Dopazo et al. 2008).

b. *Human-Mediated Transport through Aquatic Pathways*
Human-mediated transport is likely to be a faster mechanism than natural dispersion by swimming. The species can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992). There is cargo vessel traffic to Indiana Harbor from Duluth-Superior Harbor, where this species is located (USACE 2011a; NBIC 2012) that could transport this species closer to Indiana Harbor.

c. *Current Abundance and Reproductive Capacity*
T_0: The abundance of the tubenose goby is low in the GLB (Dopazo et al. 2008). The tubenose goby has spread throughout Lake St. Clair in Michigan and its tributaries (Jude et al. 1992), as well as the Detroit River system, and is commonly collected in the Duluth-Superior Harbor of Lake Superior (Kocovsky et al. 2011). A population of tubenose gobies has become established and self-sustaining in the western basin of Lake Erie (Kocovsky et al. 2011). Tubenose gobies reach maturity in 1–2 years (Freyhof & Kottelat 2008). The females of the species spawn more than once during a season (Freyhof & Kottelat 2008) and likely have a protracted spawning period (Leslie et al. 2002).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: No activities or events are anticipated that would increase or decrease barriers between the current locations of the tubenose goby and Indiana Harbor.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

e. *Distance from Pathway*
T_0: Tubenose goby is established in the western basin of Lake Erie (Kocovsky et al. 2011), Lake St. Clair (Jude et al. 1992), and the St. Louis River, which empties into Lake Superior (Fuller et al. 2012), approximately 4828 km (3000 river miles) away from the pathway entrance. It is commonly collected in the Duluth-Superior Harbor of Lake Superior (Kocovsky et al. 2011). No records were found for this species being collected in Lake Michigan.
T_{10}: See T_0. Tubenose goby could become closer to Indiana Harbor by vessel transport or swimming to southern Lake Michigan. The species may be able to occupy shallow waters of all five Great Lakes (EPA 2008).
T_{25}: See T_{10}.
T_{50}: See T_{10}. In the future, the distance of the species from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of tubenose goby in the Great Lakes include natural population growth, climate change, or new aquatic nuisance species.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: The native range of tubenose goby includes slightly brackish to fresh waters of Eurasia, primarily in rivers and estuaries of the Black Sea basin and rivers of the northern Aegean (Fuller et al. 2012; Neilson & Stepien 2009). The species is considered a cool-water species, preferring temperatures ranging from 10 to 0°C (50 to 68°F). Rasmussen (2002) and the Environmental Protection Agency (EPA 2008) suggested southern Lake Michigan may be suitable based on temperature preferences. Tubenose goby prefer benthic habitats in low salinity estuaries, lakes, rivers, and wetlands (Dopazo et al. 2008); it typically dwells in shallow near-shore waters (Dopazo et al. 2008). Adults of this species inhabit waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012), with maximum densities in western Lake Erie being reached in waters less than 1.5 m (4.9 ft) deep (Kocovsky et al. 2011). Densities of the species were significantly greater in riprap habitat than in sandy and macrophyte habitats (Jude & DeBoe 1996). Leslie et al. (2002) collected the species in water with no or slow flow. Tubenose goby spawn on the underside of fixed objects like rocks (Kocovsky et al. 2011); there is rocky habitat in the vicinity of the Indiana Harbor as well as sandy habitat and Cladophora beds (MTRI 2012) that may be suitable. The EPA (2008) states that the species may be able to occupy all shallow waters of all five Great Lakes.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is not currently in Lake Michigan and is reported to have a slow rate of spread and low abundance (Fuller et al. 2012; Vanderploeg et al. 2002). Tubenose goby can be transported via ballast water (sections 2a, 2b), and there is cargo vessel traffic to Indiana Harbor that could transport this species (section 2b). Natural dispersion for this species is not well characterized in the Great Lakes, but this species is unlikely to spread from its current locations during the current time step, given that it has not yet been detected in southern Lake Michigan despite being in the Great Lakes since the 1990s (section 2a). Therefore, there is a low probability the species will arrive at Indiana Harbor during the current time step.

T_{10}: See T_0. There is commercial vessel transport to Indiana Harbor from ports where the tubenose goby is located (section 2b). Over time, the probability increases that the species will have time to spread to Indiana Harbor by natural dispersion alone or by a combination of human-mediated transport and natural dispersion. However, this species has not spread rapidly in the Great Lakes (section 2a). Overall, its probability of arrival for this time step is medium.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is commercial vessel traffic between areas where the tubenose goby is located and the Indiana Harbor, so the potential for ballast water transport is potentially high. However, despite being present in the Great Lakes since the 1990s, the tubenose goby has not been documented in Lake Michigan, and the natural dispersal speed of the tubenose goby is not well characterized. The tubenose goby is documented to have low abundance where established and has been slow to spread in the Great Lakes compared to other invasive gobies. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. With the heavy vessel traffic to the Indiana Harbor, the tubenose goby may be able to reach Indiana Harbor within 10 years. However, this species is documented to be relatively uncommon in the GLB. Therefore, over time, trends in future populations and spread rates become less certain. In addition, this species has been established in the GLB since the 1990s, and it is uncertain why it has not been detected in southern Lake Michigan despite suitable habitat being present. As a result, its uncertainty of arrival is considered medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The tubenose goby may be more certain to reach Indiana Harbor over 50 years. However, based on its native distribution, tubenose goby appear to be more of a cool-water species, and temperature increases related to future climate change may affect its distribution (section 2f). Thus, future climate change could affect the movement of tubenose goby into southern Lake Michigan depending on whether the environment becomes more or less favorable to this species. Therefore, the uncertainty of the species' arrival at the pathway is medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the end of the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

The tubenose goby is a small fish. Little is known about the species in the Great Lakes because of its low abundance (Dopazo et al. 2008). The invasion of the species into the Laurentian Great Lakes presumably occurred via ballast water from transoceanic cargo ships (Jude et al. 1992). Eggs are laid on the undersides of fixed objects like rocks

(Kocovsky et al. 2011), making transport by currents unlikely; it has also been reported that tubenose lay their eggs in eel grass (Dopazo et al. 2008) and that eggs attached to vegetation can be transported when the vegetation is uprooted. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
The distance from Indiana Harbor to the Brandon Road Lock and Dam is approximately 64 km (40 mi). The tubenose goby can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992), but there is only lake-wide vessel traffic to Indiana Harbor (USACE 2011a,b), and the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: This species prefers waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012). The water depth in the Chicago River and CSSC is less than 9.1 m (30 ft) and less than 4.6 m (15 ft) in many areas, suggesting depth is suitable in the CAWS. The Electric Dispersal Barrier System, located north of the Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, the barrier may not be effective in shocking small fish like the tubenose goby, and adults that are shocked and early life stages could float downstream through the barrier. Tubenose goby eggs are benthic, but they could move through the barrier if resuspended in the water column. So there is a high potential that adults and early life stages may pass the barrier at the current setting. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be barriers to passage.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Tubenose goby is found along rocky and/or vegetated shallow waters as well as on sandy sediment. All these habitats are present in the CAWS (LimnoTech 2010). After entering Indiana Harbor and passing through the Indiana Harbor Ship Canal, tubenose goby would enter the Grand Calumet River. Sediments in the Grand Calumet consist of primarily cobble, bedrock or concrete, but silt, sludge, and plant debris are also present (Gallagher et al. 2011). Water can flow east or west depending on the water level in Lake Michigan. Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The banks of the CSSC are vertical walls, rock, and some vegetative debris. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Submerged aquatic vegetation is also present in portions of the CSSC (LimnoTech 2010). Tubenose goby prefer still or slow-flowing water (Dopazo et al. 2008), which is typical of the CAWS except during high flows (LimnoTech 2010). The tubenose goby is considered

a cool-water species, preferring waters within the temperature range of 10 to 20°C (50 to 68°F) (Rasmussen 2002), although the western basin of Lake Erie where this species has become successfully established regularly exceeds this temperature range in summer (20–25°C [68–77°F]) (EPA Great Lakes National Program Office, unpublished data). Therefore, water temperatures in the CAWS may be suitable during the warmest months of the year.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: It is more than 64 km (40 mi) from the Indiana Harbor to the Brandon Road Lock and Dam. Suitable adult and reproductive habitat is present throughout the CAWS (section 3e). It is unlikely that the tubenose goby would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading from Indiana Harbor to the Brandon Road Lock and Dam. The Electric Dispersal Barrier System is not likely to reduce downstream movement (section 3c). There is an overall high probability of passage for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The tubenose goby may be able to pass through the Brandon Road Lock and Dam during this time step, but this species' potential speed of natural dispersion through the CAWS is uncertain, as is the potential for passive transport of adults and early life stages through the electric barrier system. Therefore, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more certain that the tubenose goby could move through the CAWS to the Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty of its passage decreases to low during this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Suitable habitat includes slightly brackish and fresh waters, including rivers and estuaries (Rasmussen 2002). The species prefers shallow (less than 5 m [16.4 ft]) (Fuller et al. 2012), slow or no-flow waters (Dopazo et al. 2008) often with vegetation. The tubenose goby is capable of spreading through large river systems (Von Landwust 2006). However, Rasmussen (2002) states that the tubenose goby is a true cool-water species and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Suitable habitat is present downstream of the Brandon Road Lock and Dam. The tubenose goby is an active swimmer and would be able to move to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at the Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the tubenose goby is a cool-water species, it may be able to exist below the Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the tubenose goby colonizing downstream of the Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The tubenose goby has been documented to spread through large river systems (section 4a). However, temperature preferences may prevent the permanent, year-round, establishment of this species below the Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Rasmussen (2002) states that the tubenose goby is a true cool-water species (prefers water temperature between 10 and 20°C [50 and 68°F]) and that temperature preference may discourage movement south into the Illinois River, and this could in turn limit its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
This species has spread through large river basins in Europe. This species spread by active migration through the Rhine River basin across large dam and lock systems (Von Landwust 2006).

c. *Fecundity*
The tubenose goby likely has a protracted spawning period (Leslie et al. 2002) and can spawn multiple times during a season (Freyhof & Kottelat 2008).

d. *History of Invasion Success*
The tubenose goby has spread slowly in the Great Lakes, becoming established in the western basin of Lake Erie and in the St. Clair River (Kocovsky et al. 2011; Jude et al. 1992). However, the species is still considered to be rare in the St. Clair River (Fuller et al. 2012). The tubenose goby has spread through large river basins in Europe.

e. *Human-Mediated Transport through Aquatic Pathways*
In the Great Lakes, its spread has been attributed to human-mediated transport via ballast water (Dopazo et al. 2008; Jude et al. 1992). This species can be transferred by boat ballast. There is heavy vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The tubenose goby is a generalist species and could make use of most riverine habitat types. Tubenose goby can establish in large rivers and floodplain/oxbow habitat (Von Landwust 2006), so the MRB is vulnerable to some degree of invasion and establishment by the species. The species has a preference for shallow water sites with riprap, overhanging vegetation, and macrophytes (Von Landwust 2006). Such habitat is abundant in the MRB.

Evidence for Probability Rating

The tubenose goby is capable of invading large river systems (sections 5b, 5d). There is suitable physical habitat in the MRB, and it is accessible by the tubenose goby (section 5f). However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the tubenose goby.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
P(passage)	High	Medium	High	Medium	High	Low	High	Low
P(colonizes)	Medium	High	Medium	High	Medium	High	Medium	High
P(spreads)	Medium	High	Medium	High	Medium	High	Medium	High
P(establishment)	Low	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW-MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed

The tubenose goby is a small, benthic fish. It exhibits a slow invasion speed and has not spread rapidly in the GLB (Vanderploeg et al. 2002; Rasmussen 2002; Fuller et al. 2012). The species invaded the Laurentian Great Lakes in the 1990s, presumably via ballast water from transoceanic cargo ships (Jude et al. 1992). Jump dispersal by the tubenose goby from the lower Great Lakes to Lake Superior can be explained by ship transport (Dopazo et al. 2008). This species is less successful than the round goby, Neogobius melanostomus, in terms of spread and population growth (Dillon & Stepien 2001). The decline in wetland habitat may explain the low occurrence of tubenose gobies in the Great Lakes (Dopazo et al. 2008).

b. Human-Mediated Transport through Aquatic Pathways

Human-mediated transport is likely to be a faster mechanism in the spread of this species than natural dispersion. The species can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992). There is recreational but no commercial vessel traffic to the BSBH from the Great Lakes (USACE 2011a,b). However, there is commercial vessel traffic to the adjacent Burns Harbor from Duluth-Superior Harbor, where this species is located (USACE 2011a; NBIC 2012), which could transport this species closer to the BSBH.

c. Current Abundance and Reproductive Capacity

T_0: The abundance of the tubenose goby in the GLB is low (Dopazo et al. 2008). The tubenose goby has spread throughout Lake St. Clair in Michigan and its tributaries (Jude et al. 1992), as well as the Detroit River system, and is commonly collected in the Duluth-Superior Harbor of Lake Superior (Kocovsky et al. 2011). A population of tubenose gobies has become established and self-sustaining in the western basin of Lake Erie (Kocovsky et al. 2011). Tubenose gobies reach maturity in 1–2 years (Freyhof & Kottelat 2008). The females of the species spawn more than once during a season (Freyhof & Kottelat 2008) and likely have a protracted spawning period (Leslie et al. 2002).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: There are no existing barriers.

T_{10}: See T_0: No activities or events are anticipated that would increase or decrease barriers between the current locations of the tubenose goby and the BSBH.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

e. Distance from Pathway

T_0: Tubenose goby is established in the western basin of Lake Erie (Kocovsky et al. 2011), in Lake St. Clair (Jude et al. 1992), and in the St. Louis River, which empties into Lake

Superior (Fuller et al. 2012), approximately 4828 km (3000 river miles) away from the pathway entrance. It is commonly collected in the Duluth-Superior harbor of Lake Superior (Kocovsky et al. 2011). No records were found for this species being collected in Lake Michigan. The Environmental Protection Agency (EPA 2008) states that the species may be able to occupy all shallow waters of all five Great Lakes.

T_{10}: See T_0. Tubenose goby could become closer to the BSBH by vessel transport or natural dispersion to southern Lake Michigan. The species may be able to occupy shallow waters of all five Great Lakes (EPA 2008).

T_{25}: See T_{10}.

T_{50}: See T_{10}. In the future, the distance of the species from the CAWS could increase or decrease. Examples of future changes potentially affecting the distribution of tubenose goby in the Great Lakes include natural population growth, climate change, or new aquatic nuisance species.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: The native range of tubenose goby includes slightly brackish to fresh waters of Eurasia, primarily in rivers and estuaries of the Black Sea basin and rivers of the northern Aegean (Fuller et al. 2012; Neilson & Stepien 2009). The species is considered a cool-water species, preferring temperatures ranging from 10 to 20°C (50 to 68°F). Rasmussen (2002) and the EPA (2008) suggested southern Lake Michigan may be suitable based on temperature preferences. Tubenose goby prefers benthic habitats in low salinity estuaries, lakes, rivers and wetlands (Dopazo et al. 2008); it typically dwells in shallow near-shore waters (Dopazo et al. 2008). Adults of this species inhabit waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012), with maximum densities in western Lake Erie being reached in waters less than 1.5 m (4.9 ft) deep (Kocovsky et al. 2011). Densities of the species were significantly greater in riprap habitat than in sandy and macrophyte habitats (Jude & DeBoe 1996). Leslie et al. (2002) collected the species in water with no or slow flow. Tubenose goby spawns on the underside of fixed objects like rocks (Kocovsky et al. 2011); there is rocky habitat in the vicinity of the BSBH as well as sandy habitat and Cladophora beds (MTRI 2012) that may be suitable.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is not currently in Lake Michigan and is reported to have a slow rate of spread and low abundance (Fuller et al. 2012; Vanderploeg et al. 2002). Tubenose goby can be transported via ballast water (sections 2a, 2b), and there is cargo vessel traffic to Burns Harbor that could transport this species to the vicinity of the BSBH (section 2b). Natural

dispersion for this species is not well characterized in the Great Lakes, but this species is unlikely to spread from its current locations during the current time step given that it has not yet been detected in southern Lake Michigan despite being in the Great Lakes since the 1990s (section 2a). Therefore, there is a low probability the species will arrive at the BSBH during the current time step.
T_{10}: See T_0. There is commercial vessel transport from ports where the tubenose goby is located to ports adjacent to the BSBH (section 2b). Over time, the probability increases that the species will have time to spread to the BSBH by natural dispersion alone or by a combination of human-mediated transport and natural dispersion. However, this species has not spread rapidly in the Great Lakes (section 2a). Overall, its probability of arrival for this time step is medium.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Medium	Medium	Medium

Evidence for Uncertainty Rating

T_0: There is commercial vessel traffic between areas where the tubenose goby is located and the vicinity of the BSBH, so the potential for ballast water transport is potentially high. However, despite being present in the Great Lakes since the 1990s, the tubenose goby has not been documented in Lake Michigan, and the natural dispersal speed of the tubenose goby is not well characterized. The tubenose goby is documented to have low abundance where established and has been slow to spread in the Great Lakes compared to other invasive gobies. Therefore, the uncertainty associated with the arrival of the species is low for this time step.
T_{10}: See T_0. With the heavy vessel traffic to the Burns Harbor, the tubenose goby may be able to reach the BSBH within 10 years. However, this species is documented to be relatively uncommon in the GLB. Therefore, over time, trends in future populations and spread rates become less certain. In addition, this species has been established in the GLB since the 1990s, and it is uncertain why it has not been detected in southern Lake Michigan despite suitable habitat being present. As a result, its uncertainty of arrival is considered medium for this time step.
T_{25}: See T_{10}.
T_{50}: See T_{10}. The tubenose goby may be more certain to reach the BSBH over 50 years. However, based on its native distribution, tubenose goby appears to be more of a cool-water species, and temperature increases related to future climate change may affect its distribution (section 2f). Thus, future climate change could affect the movement of tubenose goby into southern Lake Michigan depending on whether the environment becomes more or less favorable to this species. Therefore, the uncertainty of the species' arrival at the pathway is medium.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the end of the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
The tubenose goby is a small fish. Little is known about the species in the Great Lakes because of its low abundance (Dopazo et al. 2008). The invasion of the species into the Laurentian Great Lakes presumably occurred via ballast water from transoceanic cargo ships (Jude et al. 1992). Eggs are laid on the undersides of fixed objects like rocks (Kocovsky et al. 2011), making transport by currents unlikely; it has also been reported that tubenose lays eggs in eel grass (Dopazo et al. 2008) and that eggs attached to vegetation can be transported when the vegetation is uprooted. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006).

b. *Human-Mediated Transport through Aquatic Pathways*
The distance from the BSBH to the Brandon Road Lock and Dam is greater than 64 km (40 mi). The tubenose goby can be transported in ballast water (Dopazo et al. 2008; Jude et al. 1992), but there is generally only lake-wide vessel traffic to the BSBH and the adjacent Burns Harbor, and the discharge of ballast water does not typically occur at inland ports within the CAWS (USACE 2011a,b; NBIC 2012).

c. *Existing Physical Human/Natural Barriers*
T_0: This species prefers waters less than 5 m (16.4 ft) in depth (Fuller et al. 2012). The water depth in the Chicago River and the CSSC is less than 9.1 m (30 ft) and less than 4.6 m (15 ft) in many areas. The Electric Dispersal Barrier System, located north of the Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, the barrier may not be effective in shocking small fish like the tubenose goby, and adults that are shocked and early life stages could flow downstream through the barrier. Tubenose goby eggs are benthic, but they could move through the barrier if resuspended in the water column. So there is a high potential that adults and early life stages may pass the barrier at the current setting. In its invasion of the Rhine River basin, this species exhibited active upstream migration across large dam and lock systems (Von Landwust 2006). Therefore, the Lockport Lock and Dam and the Brandon Road Lock and Dam are not expected to be a barrier to passage.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Tubenose goby are found along rocky and/or vegetated shallow waters as well as on sandy sediment. All these habitats are present in the CAWS (LimnoTech 2010). After

entering the BSBH and passing through Burns Ditch, the tubenose goby would enter the south branch of the Little Calumet River. The banks of the south leg of the Little Calumet River are vegetated, and sediments are plant debris, silt, sand, cobble, gravel, and boulder (Gallagher et al. 2011). Sediments in the Little Calumet River are primarily inorganic silt, but areas of sand and gravel are also present (LimnoTech 2010). The banks of the CSSC are vertical walls, rock, and some vegetative debris. Sediments in the CSSC vary but are primarily silt, sludge, bedrock, and sand with scattered cobble (LimnoTech 2010). Submerged aquatic vegetation is also present in portions of the CSSC (LimnoTech 2010). Tubenose goby prefers still or slow-flowing water (Dopazo et al. 2008), which is typical of the CAWS except during high flows (LimnoTech 2010). The tubenose goby is considered a cool-water species, preferring waters within the temperature range of 10 to 20°C (50 to 68°F) (Rasmussen 2002), although the western basin of Lake Erie where this species has become successfully established regularly exceeds this temperature range in summer (20 to 25°C [68 to 77°F]) (EPA Great Lakes National Program Office, unpublished data). Therefore, water temperatures in the CAWS may not be suitable during the warmest months of the year.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: It is more than 64 km (40 mi) from the BSBH to the Brandon Road Lock and Dam. Suitable adult and reproductive habitat is present throughout the CAWS (section 3e). It is unlikely that the tubenose goby would be transported through the CAWS by ballast water (section 3b); therefore, natural dispersion would be the most likely means of spreading from the BSBH to the Brandon Road Lock and Dam. The Electric Dispersal Barrier System is not likely to reduce downstream movement (section 3c). There is an overall high probability of passage for this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Medium	Medium	Low	Low

Evidence for Uncertainty Rating

T_0: The tubenose goby may be able to pass through the Brandon Road Lock and Dam during this time step, but this species' potential speed of natural dispersion through the CAWS is uncertain, as is the potential for passive transport of adults and early life stages through the electric barrier system. Therefore, the uncertainty associated with passage is medium for this time step.
T_{10}: See T_0.
T_{25}: See T_0. The future rate of spread for this species is not well understood. However, habitat in the CAWS is suitable, and it is more certain that the tubenose goby will move through the CAWS to the Brandon Road Lock and Dam in 25 years compared to 10 years. Therefore, the uncertainty of its passage decreases to low during this time step.
T_{50}: See T_{25}.

4. P(colonizes): MEDIUM

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Suitable habitat includes slightly brackish and fresh waters, including rivers and estuaries (Rasmussen 2002). The species prefers shallow (less than 5 m [16.4 ft]) (Fuller et al. 2012), slow or no-flow waters (Dopazo et al. 2008) often with vegetation. The tubenose goby is capable of spreading through large river systems (Von Landwust 2006). However, Rasmussen (2002) states that the tubenose goby is a true cool-water species and that temperature preference may discourage movement south into the Illinois River.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Suitable habitat is present downstream of the Brandon Road Lock and Dam. The tubenose goby is an active swimmer and would be able to move to suitable habitat.

Evidence for Probability Rating

Suitable physical habitat is present at the Brandon Road Lock and Dam (section 4a) and is accessible (section 4b). Although the tubenose goby is a cool-water species, it may be able to exist below the Brandon Road Lock and Dam during the colder months of the year. However, given its temperature preferences, a permanent population may not establish. Therefore, the probability of the tubenose goby colonizing downstream of the Brandon Road Lock and Dam is medium.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Suitable habitat has been documented below the Brandon Road Lock and Dam and suitable habitat is accessible (sections 4a, 4b). The tubenose goby has been documented to spread through large river systems (section 4a). However, temperature preferences may prevent the permanent, year-round establishment of this species below the Brandon Road Lock and Dam (section 4a). Therefore, there is high uncertainty regarding the probability of the colonization of this pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
Rasmussen (2002) states that the tubenose goby is a true cool-water species and that temperature preference may discourage movement south into the Illinois River, and this could in turn limit its expansion into other parts of the MRB.

b. *Type of Mobility/Invasion Speed*
This species has spread through large river basins in Europe. This species spread by active migration through the Rhine River basin across large dam and lock systems (Von Landwust 2006).

c. *Fecundity*
The tubenose goby likely has a protracted spawning period (Leslie et al. 2002) and can spawn multiple times during a season (Freyhof & Kottelat 2008).

d. *History of Invasion Success*
The tubenose goby has spread slowly in the Great Lakes, becoming established in the western basin of Lake Erie and in the St. Clair River (Kocovsky et al. 2011; Jude et al. 1992). However, the species is still considered to be rare in the St. Clair River (Fuller et al. 2012). The tubenose goby has spread through large river basins in Europe.

e. *Human-Mediated Transport through Aquatic Pathways*
In the Great Lakes, its spread has been attributed to human-mediated transport via ballast water (Dopazo et al. 2008; Jude et al. 1992). This species can be transferred by boat ballast. There is heavy vessel traffic in the MRB.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
The tubenose goby is a generalist species and could make use of most riverine habitat types. Tubenose goby can establish in large rivers and floodplain/oxbow habitat (Von Landwust 2006), so the MRB is vulnerable to some degree of invasion and establishment

by the species. The species has a preference for shallow water sites with riprap, overhanging vegetation, and macrophytes (Von Landwust 2006). Such habitat is abundant in the MRB.

Evidence for Probability Rating

The tubenose goby is capable of invading large river systems (sections 5b, 5d). There is suitable physical habitat in the MRB, and it is accessible by the tubenose goby (section 5f). However, movement into the southern MRB may be limited by warm temperatures (section 5a). Overall, there is a medium probability of spread.

Uncertainty: HIGH

Evidence for Uncertainty Rating

Although this species is documented to have spread through large river basins in Europe, it is uncertain whether temperature will be a significant barrier in limiting movement into the lower MRB. Therefore, there is a high level of uncertainty regarding the spread of the tubenose goby.

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E.2.7.5 Blueback Herring - *Alosa aestivalis*

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	High	Low	High	Low	High	Low	High
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between WPS and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW – MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. Human-Mediated Transport through Aquatic Pathways

Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. Current Abundance and Reproductive Capacity

T_0: Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953). The native range of the blueback herring is the Atlantic Coast from Cape Breton, Nova Scotia to the St. Johns River, Florida. The species ascends coastal rivers during spawning season (Page & Burr 1991). This species has been collected in the Tennessee River in Georgia and Tennessee (Rasmussen 1998); Oneida Lake, the Oswego River in Minetto, Lake Champlain, and the upper Mohawk River upstream of Cohoes Falls, New York (Greeley 1935; Limburg et al. 2001). The spread of the blueback herring through the Great Lakes may not be possible in areas with high densities of predatory fish (Owens et al. 1998).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

d. Existing Physical Human/Natural Barriers

T_0: There are no existing barriers.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. Distance from Pathway

T_0: Two juvenile blueback herring were documented near Oswego, NY in Lake Ontario in 1995 over 2090 km (1300 river miles) from the WPS pathway entrance (Fuller et al. 2012). It has been stated that the species could enter Lake Erie; however, the cold temperatures may prevent establishment (Fuller et al. 2012).

T_{10}: See T_0. The species may, over time, spread and move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: Blueback herrings are anadromous marine clupeids found along the Atlantic coast in marine, estuarine, and riverine habitats, depending on life stage (Pardue 1983). Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate upstream to spawn once a year in the spring or early summer (Raney & Massmann 1953). They prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F) (Loesch & Lund 1977; Pardue 1983). Eggs are demersal in still water and adhesive or pelagic in running water (Loesch & Lund 1977). After water hardening, the eggs become pelagic and lose their adhesive properties (Pardue 1983). Larvae and juveniles remain in the surface water near the spawning site.

Adults are primarily pelagic, preferring temperatures ranging from 2 to 17°C (35.6 to 62.6°F) (Pardue 1983). There is evidence from species records in Lake Champlain that the blueback herring may not be able to colonize northern latitude lakes due to the low temperatures (Owens et al. 1986). Alewives in the Great Lakes sometimes suffer mass mortalities from cold water in severe winters (O'Gorman & Schneider 1986; Bergstedt & O'Gorman 1989) and they have failed to establish large populations in Lake Superior, the coldest of the Great Lakes (Bronte et al. 1991). The distribution of alewives extends farther northward than that of the blueback herring, suggesting that alewives may be more tolerant of cold temperatures (Owens et al. 1998).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical, and climatological suitability of the Great Lakes and its tributaries for the blueback herring. Water temperatures and stream flows, in particular, may be altered, potentially affecting the distribution of this species. Based on its native distribution in coastal Atlantic waters (Fuller et al. 2012), blueback herring appear to be more of a warm-water species and temperature increases related to future climate change (Wuebbles et al. 2010) may improve their spread throughout the GLB and affect their probability of arriving at the CAWS.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is located in western Lake Ontario (section 2d), far from the WPS pathway entrance. The only mode of transportation for the blueback herring is by swimming. It is thought that the northern latitudes may be too cold for the species to colonize and spread (section 2f). Competition for resources with native and established fish populations may also prevent colonization throughout the GLB. It has been present in this region since 1994 and has not spread to the west. Therefore, it is unlikely to spread to the CAWS during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over 50 years, the probability increases that the blueback herring will have time to spread to the WPS by natural dispersion. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The blueback herring is unlikely to reach the pathway entrance at this time step due to the distance it would have to swim. The uncertainty associated with arrival is low, as this species has not spread to the CAWS in the more than 10 years that it has been present in Lake Ontario.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. It is uncertain why the blueback herring has not spread through the GLB since its discovery in 1995. Temperature or competition are thought to be constraints; however, these are not documented. Given 50 years, the species may be able to reach the pathway by natural dispersal. The uncertainty increases to medium for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. *Existing Physical Human/Natural Barriers*
T_0: A sluice gate separates Lake Michigan from the CAWS. However, blueback herring could be transported from Lake Michigan into the North Shore Channel via water pumped from the Lake into the channel. The Electric Dispersal Barrier System, located north of Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, adults that are shocked and blueback herring in their early life stages could float downstream through the barrier. Blueback herring eggs could move through the barrier in the water column. So, there is a high potential that adults and early life stages may pass the barrier at the current setting. Lock and dam structures are known to act as barriers to the upstream movement of herring (Pardue 1983). The Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to downstream passage, although it is not known to what extent these structures may inhibit downstream movement. Alewives have been present in southern Lake Michigan and the CAWS for decades and they have not moved downstream beyond Brandon Road Lock and Dam (Savitz et al. 1996). Blueback herring have similar migratory patterns and they may behave similarly.
T_{10}: See T_0. Lock operations are not expected to change over time.

T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrological, Hydraulic, Chemical, and Climatological)

T_0: Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). Alewife, a species of herring, have been documented in the CAWS (LimnoTech 2010), suggesting that the blueback herring could also enter the CAWS. Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). The CAWS is a low-flow water system with temperatures ranging from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010; LimnoTech 2010). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). Larvae and juveniles remain in the surface water near the spawning site (Pardue 1983). Blueback herring larvae require more than 5.0 mg/L DO (Klauda et al. 1991). DO in the CAWS may be too low in certain areas or during certain times of the year.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adult blueback herring do not occupy riverine habitat except to spawn. The CAWS does not contain ideal spawning habitat. The flow is too slow and the temperature may be too low for larvae (section 2f). Blueback herring are strong swimmers and are capable of migrating upstream into tributary rivers to spawn (section 3a). Consequently, they would likely be capable of passage during this time step, although Lockport Lock and Dam and Brandon Road Lock and Dam may act as temporary barriers to passage (section 3c). However, alewives, which have migrations patterns similar to blueback herring, have been present in the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam. Overall, the probability of passage is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: It is uncertain if the blueback herring would behave in the same manner as the alewife and not pass through the pathway. Alewives have not made temporary migrations into Illinois rivers despite being in Lake Michigan for more than 50 years. The reason for this is not fully understood. There are no studies of the behavior of blueback herring in the CAWS. Therefore the uncertainty of passage is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. However, they could potentially colonize reservoirs and lakes in the MRB.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Blueback herring are active swimmers capable of upstream migration, and they should be capable of swimming downstream of Brandon Road Lock and Dam. Blueback herring could potentially colonize lakes and reservoirs within the MRB, if these surface waters are connected to riverine habitats containing blueback herring. However, there is no evidence that they would travel the distance inland necessary to reach these reservoirs. In addition, alewife, another herring species similar to blueback herring, are historically not found below Brandon Road Lock and Dam, despite being present in the CAWS. This suggests blueback herring are also unlikely to spread downstream of Brandon Road Lock and Dam (section 4a).

Evidence for Probability Rating

Adult blueback herring are pelagic and only move into the rivers to spawn (section 4a). Therefore, no permanent colonization of riverine habitat would be expected. Larval and juvenile stages develop in rivers and suitable habitat may be present downstream of Brandon Road Lock and Dam (section 4a). Blueback herring could potentially colonize lakes and reservoirs within the MRB, although there is no evidence that they would travel the distance inland necessary to reach these reservoirs. Based on the behavior of alewife, blueback herring are also unlikely to spread downstream of Brandon Road Lock and Dam (section 4b). Consequently, the probability of colonization below Brandon Road Lock and Dam is low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether blueback herring could swim to suitable reservoir habitat in the MRB. Therefore, the uncertainty associated with the probability of colonization is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
Blueback herring prefer temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Pardue 1983).

b. Type of Mobility/Invasion Speed
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

c. Fecundity
Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953).

d. History of Invasion Success
In Tennessee, blueback herring were stocked in a few reservoirs initially, and they have since spread by "bait bucket" transfer to other water bodies in Tennessee (Tennessee Wildlife Resources Agency 2012). Blueback herring have been found in the Melton Hill, Tellico, and Boone reservoirs (Tennessee Wildlife Resources Agency 2012), which impound the Clinch River, Little Tennessee River, and the South Fork Holston River, respectively. Although blueback herring have been reported from reservoirs in the MRB, they are not considered established (Fiss 2012). Blueback herring have established in inland river basins in the Carolinas and Virginia (Fuller et al. 2012).

e. Human-Mediated Transport through Aquatic Pathways
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal

temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Such habitats are present and accessible in the MRB.

Evidence for Probability Rating

Adult blueback herrings prefer lotic habitats and only move into the rivers to spawn (section 5a). Blueback herring are capable of traveling upstream to spawning grounds (section 5b), and suitable habitat is present in the MRB. They have established in large reservoirs and river systems outside of their native range (section 5d). However, spread depends on the connectivity of suitable lentic habitat. Consequently, if colonization occurs, the probability of spread is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Blueback herring are established in inland river basins outside of their native range (section 5d). However, it is uncertain whether suitable habitat is hydrologically connected in a way that would allow the spread of the blueback herring. Consequently, the uncertainty associated with blueback herring spreading in the MRB is medium.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	High	Low	High	Low	High	Low	High
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between CRCW and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW - MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Blueback Herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Blueback Herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953). The native range of the blueback herring is the Atlantic Coast from Cape Breton, Nova Scotia to the St. Johns River, Florida. The species ascends coastal rivers during spawning season (Page & Burr 1991). This species has been collected in the Tennessee River in Georgia and Tennessee (Rasmussen 1998); and in Oneida Lake, the Oswego River in Minetto, Lake Champlain, and the upper Mohawk River upstream of Cohoes Falls, New York (Greeley 1935; Limburg et al. 2001). The spread of the blueback herring through the Great Lakes may not be possible in areas with high densities of predatory fish (Owens et al. 1998).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Two juvenile blueback herring were documented near Oswego, NY in Lake Ontario in 1995 over 2090 km (1300 river miles) from the CRCW pathway entrance (Fuller et al. 2012). It has been stated that the species could enter Lake Erie; however, the cold temperatures may prevent establishment (Fuller et al. 2012).
T_{10}: See T_0. The species may, over time, spread and move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Blueback herrings are anadromous, marine clupeids found along the Atlantic coast in marine, estuarine, and riverine habitats, depending on life stage (Pardue 1983). Adult blueback herring prefer deep open waters of lakes for most of the year. They migrate upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). They prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F) (Loesch & Lund 1977; Pardue 1983). Eggs are demersal in still water and adhesive or pelagic in running water (Loesch & Lund 1977). After water hardening, the eggs become pelagic and lose their adhesive properties (Pardue 1983). Larvae and juveniles remain in the surface water near the spawning site. Adults are primarily pelagic, preferring temperatures ranging from 2 to 17°C (35.6 to 62.6°F) (Pardue 1983). There is evidence from species records in Lake Champlain that the blueback herring may not be able to colonize northern latitude lakes due to low temperatures (Owens et al. 1986). Alewives in the Great Lakes sometimes suffer mass mortalities from cold water in severe winters (O'Gorman & Schneider 1986, Bergstedt & O'Gorman 1989) and they have failed to establish large populations in Lake Superior, the coldest of the Great Lakes (Bronte et al. 1991). The distribution of alewives extends farther northward than that of the blueback herring, suggesting that alewives may be more tolerant of cold temperatures (Owens et al. 1998).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical, and climatological suitability of the Great Lakes and its tributaries for the blueback herring. Water temperatures and stream flows, in particular, may be altered, potentially affecting the distribution of this species. Based on its native distribution in coastal Atlantic waters (Fuller et al. 2012), blueback herring appear to be more of a warm water species and temperature increases related to future climate change (Wuebbles et al. 2010) may improve their spread throughout the GLB and affect their probability of arriving at the CAWS.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Medium	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is located in western Lake Ontario (section 2d), far from the CRCW pathway entrance. The only mode of transportation for the blueback herring is swimming. It is thought that the northern latitudes may be too cold for the species to colonize and spread (section 2f). Competition for resources with native and established fish populations may also prevent colonization throughout the GLB. It has been present in this region since 1994 and has not spread to the west. Therefore, it is unlikely to spread to the CAWS during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over 50 years, the probability increases that the blueback herring will have time to spread to the CRCW by natural (e.g., swimming) dispersion. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The blueback herring is unlikely to reach the pathway entrance at this time step due to the distance it would have to swim. The uncertainty associated with arrival is low, as this species has not spread to CAWS in the more than 10 years it has been present in Lake Ontario.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. It is uncertain why the blueback herring has not spread through the GLB since its discovery in 1995. Temperature or competition are thought to be constraints; however, this is not documented. Given 50 years, the species may be able to reach the pathway by natural dispersal. The uncertainty increases to medium for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. Human-Mediated Transport through Aquatic Pathways

Blueback herring might have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. Existing Physical Human/Natural Barriers

T_0: The Electric Dispersal Barrier System, located north of Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, adults that are shocked and early life stages could float downstream through the barrier. Blueback herring eggs could move through the barrier in the water column. So, there is a high potential that adults and early life stages may pass the barrier at the current setting. Lock and dam structures are known to act as barriers to the upstream movement of herring (Pardue 1983). The Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to downstream passage, although it is not known to what extent these structures may inhibit downstream movement. Alewives have been present in southern Lake Michigan and the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam (Savitz et al. 1996). Blueback herring have similar migratory patterns and they may behave similarly.

T_{10}: See T_0. Lock operations are not expected to change over time.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrological, Hydraulic, Chemical, and Climatological)

T_0: Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). Alewife, a species of herring, have been documented in the CAWS (LimnoTech 2010), suggesting that the blueback herring could also enter the CAWS.

Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). The CAWS is a low-flow water system with temperatures ranging from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010; LimnoTech 2010). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). Larvae and juveniles remain in the surface water near the spawning site (Pardue 1983). Blueback herring larvae require more than 5.0 mg/L DO (Klauda et al. 1991). Dissolved oxygen in the CAWS may be too low in certain areas or during certain times of the year.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adult blueback herring do not occupy riverine habitat except to spawn. The CAWS does not contain ideal spawning habitat. The flow is too slow and the temperature and DO may be too low for larvae (section 3f). Blueback herring are strong swimmers and are capable of migrating upstream into tributary rivers to spawn (section 3a). Consequently, they would likely be capable of passage during this time step, although Lockport Lock and Dam and Brandon Road Lock and Dam may act as temporary barriers to passage (section 3c). However, alewives, which have migration patterns similar to blueback herring, have been present in the CAWS for decades and they have not moved downstream beyond Brandon Road Lock and Dam. Overall, the probability of passage is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: It is uncertain if the blueback herring would behave in the same manner as the alewife and not pass through the pathway. Alewives have not made temporary migrations into Illinois rivers despite being in Lake Michigan for more than 50 years. The reason for this is not fully understood. There are no studies of the behavior of blueback herring in the CAWS. Therefore, the uncertainty of passage is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. However, they could potentially colonize reservoirs and lakes in the MRB.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Blueback herring are active swimmers capable of upstream migration, and they should be capable of swimming downstream of Brandon Road Lock and Dam. Blueback herring could potentially colonize lakes and reservoirs within the MRB if these surface waters are connected to riverine habitats containing blueback herring. However, there is no evidence that they would travel the distance inland necessary to reach these reservoirs. In addition, alewife, another herring species similar to blueback herring, are historically not found below Brandon Road Lock and Dam despite being present in the CAWS. This suggests blueback herring are also unlikely to spread downstream of Brandon Road Lock and Dam (section 4a).

Evidence for Probability Rating

Adult blueback herring are pelagic and only move into the rivers to spawn (section 4a). Therefore, no permanent colonization of riverine habitat would be expected. Larval and juvenile stages develop in rivers and suitable habitat may be present downstream of Brandon Road Lock and Dam (section 4a). Blueback herring could potentially colonize lakes and reservoirs within the MRB, although there is no evidence that they would travel the distance from the Great Lakes necessary to reach these reservoirs. Based on the behavior of alewife, blueback herring are unlikely to spread downstream of Brandon Road Lock and Dam (section 4b). Consequently, the probability of colonization below Brandon Road Lock and Dam is low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether blueback herring could swim to suitable reservoir habitat in the MRB. Therefore, the uncertainty associated with the probability of colonization is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
Blueback herring prefer temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Pardue 1983).

b. Type of Mobility/Invasion Speed
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

c. Fecundity
Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953).

d. History of Invasion Success
In Tennessee, blueback herring were stocked in a few reservoirs initially, and they have since spread by "bait bucket" transfer to other water bodies in Tennessee (Tennessee Wildlife Resources Agency 2012). Blueback herring have been found in the Melton Hill, Tellico, and Boone reservoirs (Tennessee Wildlife Resources Agency 2012), which impound the Clinch River, Little Tennessee River, and the South Fork Holston River, respectively. Although blueback herring have been reported from reservoirs in the MRB, they are not considered established (Fiss 2012). Blueback herring have established in inland river basins in the Carolinas and Virginia (Fuller et al. 2012).

e. Human-Mediated Transport through Aquatic Pathways
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Such habitats are present and accessible in the MRB.

Evidence for Probability Rating

Adult blueback herrings prefer lotic habitats and only move into rivers to spawn (section 5a). Blueback herring are capable of traveling upstream to spawning grounds (section 5b), and suitable habitat is present in the MRB. They have established in large reservoirs and river systems outside their native range (section 5d). Consequently, if colonization occurs, the probability of spread is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Blueback herring are established in inland river basins outside of their native range (section 5d). However, it is uncertain whether suitable habitat is hydrologically connected in a way that would allow the spread of the blueback herring. Consequently, the uncertainty associated with blueback herring spreading in the MRB is medium.

PATHWAY: 3 (CALUMET HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	High	Low	High	Low	High	Low	High
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW – MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953). The native range of the blueback herring is the Atlantic Coast from Cape Breton, Nova Scotia to the St. Johns River, Florida. The species ascends coastal rivers during spawning season (Page & Burr 1991). This species has been collected in the Tennessee River in Georgia and Tennessee (Rasmussen 1998); and also in Oneida Lake, the Oswego River in Minetto, Lake Champlain, and the upper Mohawk River upstream of Cohoes Falls, New York (Greeley 1935; Limburg et al. 2001). The spread of the blueback herring through the Great Lakes may not be possible in areas with high densities of predatory fish (Owens et al. 1998).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Two juvenile blueback herring were documented near Oswego, NY in Lake Ontario in 1995 over 2090 km (1300 river miles) from the Calumet Harbor pathway entrance (Fuller et al. 2012). It has been stated that the species could enter Lake Erie; however, the cold temperatures may prevent establishment (Fuller et al. 2012).
T_{10}: See T_0. The species may, over time, spread and move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Blueback herrings are anadromous, marine clupeids found along the Atlantic coast in marine, estuarine, and riverine habitats, depending on life stage (Pardue 1983). Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate

upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). They prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F) (Loesch & Lund 1977; Pardue 1983). Eggs are demersal in still water and adhesive or pelagic in running water (Loesch & Lund 1977). After water hardening, the eggs become pelagic and lose their adhesive properties (Pardue 1983). Larvae and juveniles remain in the surface water near the spawning site. Adults are primarily pelagic, preferring temperatures ranging from 2 to 17°C (35.6 to 62.6°F) (Pardue 1983). There is evidence from species records in Lake Champlain that the blueback herring may not be able to colonize northern latitude lakes due to low temperatures (Owens et al. 1986). Alewives in the Great Lakes sometimes suffer mass mortalities from cold water in severe winters (O'Gorman & Schneider 1986, Bergstedt & O'Gorman 1989) and they have failed to establish large populations in Lake Superior, the coldest of the Great Lakes (Bronte et al. 1991). The distribution of alewives extends farther northward than that of the blueback herring suggesting that alewives may be more tolerant of cold temperatures (Owens et al. 1998).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical, and climatological suitability of the Great Lakes and its tributaries for the blueback herring. Water temperatures and stream flows, in particular, may be altered, potentially affecting the distribution of this species. Based on its native distribution in coastal Atlantic waters (Fuller et al. 2012), blueback herring appear to be more of a warm water species and temperature increases related to future climate change (Wuebbles et al. 2010) may improve their spread throughout the GLB and affect their probability of arriving at the CAWS.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is located in western Lake Ontario (section 2d), far from the Calumet Harbor pathway entrance. The only mode of transportation for the blueback herring is swimming. It is thought that the northern latitudes may be too cold for the species to colonize and spread (section 2f). Competition for resources with native and established fish populations may also prevent colonization throughout the GLB. It has been present in this region since 1994 and has not spread to the west. Therefore, it is unlikely to spread to the CAWS during this time step.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Over 50 years, the probability increases that the blueback herring will have time to spread to Calumet Harbor by natural (e.g., swimming) dispersion. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The blueback herring is unlikely to reach the pathway entrance at this time step due to the distance it would have to swim. The uncertainty associated with arrival is low, as this species has not spread to CAWS in the more than 10 years it has been present in Lake Ontario.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. It is uncertain why the blueback herring has not spread through the GLB since its discovery in 1995. Temperature or competition are thought to be constraints; however, this is not documented. Given 50 years, the species may be able to reach the pathway by natural dispersal. The uncertainty increases to medium for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. *Existing Physical Human/Natural Barriers*
T_0: The pathway from Calumet Harbor to Brandon Road Lock and Dam is a shallow, slow-moving, eutrophic river (LimnoTech 2010) and may be too slow for the species which spawns in fast currents (Fuller et al. 2012). The Electric Dispersal Barrier System, located north of Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, adults that are shocked and early life stages could float downstream through the barrier. Blueback herring eggs could move through the barrier in the water column. So, there is a high potential that adults and early life stages may pass the barrier at the current setting. Lock and dam structures are known to act as barriers to the upstream movement of herring (Pardue 1983). The Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to downstream passage, although it is not known to what extent these structures may

inhibit downstream movement. Alewives have been present in southern Lake Michigan and the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam (Savitz et al. 1996). Blueback herring have similar migratory patterns and they may behave similarly.
T_{10}: See T_0. Lock operations are not expected to change over time.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrological, Hydraulic, Chemical, and Climatological)*
T_0: Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). Alewife, a species of herring, have been documented in the CAWS (LimnoTech 2010), suggesting that the blueback herring could also enter the CAWS.
Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). However, the pathway from Calumet Harbor to Brandon Road Lock and Dam is a slow-moving eutrophic river with a flow of approximately 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) which might be too slow for the species. The mean annual water temperature of the CAWS ranges from 11.3 to 19.3°C (52.3 to 66.7°F) (MWRD 2010), which might be too cold for larvae. Larvae and juveniles remain in the surface water near the spawning site (Pardue 1983). Blueback herring larvae require more than 5.0 mg/L DO (Klauda et al. 1991). Dissolved oxygen in the CAWS may be too low in certain areas or during certain times of the year.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adult blueback herring do not occupy riverine habitat except to spawn. The CAWS does not contain ideal spawning habitat. The flow is too slow and the temperature may be too low for larvae (section 3f). Blueback herring are strong swimmers and are capable of migrating upstream into tributary rivers to spawn (section 3a). Consequently, they would likely be capable of passage during this time step, although Lockport Lock and Dam and Brandon Road Lock and Dam may act as temporary barriers to passage (section 3c). However, alewives, which have migration patterns similar to blueback herring, have been present in the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam. Overall, the probability of passage is low.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: It is uncertain if the blueback herring would behave in the same manner as the alewife and not pass through the pathway. Alewives have not made temporary migrations into Illinois rivers despite being in Lake Michigan for more than 50 years. The reason for this is not fully understood. There are no studies of the behavior of blueback herring in the CAWS. Therefore, the uncertainty of passage is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages):

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. However, they could potentially colonize reservoirs and lakes in the MRB.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
Blueback herring are active swimmers capable of upstream migration, and they should be capable of swimming downstream of Brandon Road Lock and Dam. Blueback herring could potentially colonize lakes and reservoirs within the MRB if these surface waters are connected to riverine habitats containing blueback herring. However, there is no evidence that they would travel the distance inland necessary to reach these reservoirs. In addition, alewife, another herring species similar to blueback herring, are historically not found below Brandon Road Lock and Dam despite being present in the CAWS. This suggests that blueback herring are also unlikely to spread downstream of Brandon Road Lock and Dam (section 4a).

Evidence for Probability Rating

Adult blueback herring are pelagic and only move into the rivers to spawn (section 4a). Therefore, no permanent colonization of riverine habitat would be expected. Larval and juvenile stages develop in rivers and suitable habitat may be present downstream of Brandon Road Lock and Dam (section 4a). Blueback herring could potentially colonize lakes and reservoirs within the MRB, although there is no evidence that they would travel the distance from the Great Lakes necessary to reach these reservoirs. Based on the behavior of alewife, blueback herring are unlikely to spread downstream of Brandon Road Lock and Dam (section 4b). Consequently, the probability of colonization below Brandon Road Lock and Dam is low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether blueback herring could swim to suitable reservoir habitat in the MRB. Therefore, the uncertainty associated with the probability of colonization is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in MRB*
Blueback herring prefer temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Pardue 1983).

b. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

c. *Fecundity*
Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953).

d. *History of Invasion Success*
In Tennessee, blueback herring were stocked in a few reservoirs initially, and they have since spread by “bait bucket” transfer to other water bodies in Tennessee (Tennessee Wildlife Resources Agency 2012). Blueback herring have been found in the Melton Hill, Tellico, and Boone reservoirs (Tennessee Wildlife Resources Agency 2012), which impound the Clinch River, Little Tennessee River, and the South Fork Holston River, respectively. Although blueback herring have been reported from reservoirs in the MRB, they are not considered established (Fiss 2012). Blueback herring have established in inland river basins in the Carolinas and Virginia (Fuller et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Such habitats are present and accessible in the MRB.

Evidence for Probability Rating

Adult blueback herrings prefer lotic habitats and they only move into the rivers to spawn (section 5a). Blueback herring are capable of traveling upstream to spawning grounds (section 5b) and suitable habitat is present in the MRB. They have established in large reservoirs and river systems outside their native range (section 5d). Consequently, if colonization occurs, the probability of spread is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Blueback herring are established in inland river basins outside of their native range (section 5d). However, it is uncertain whether suitable habitat is hydrologically connected in a way that would allow the spread of the blueback herring. Consequently, the uncertainty associated with blueback herring spreading in the MRB is medium.

PATHWAY: 4 (INDIANA HARBOR TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	High	Low	High	Low	High	Low	High
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW – MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953). The native range of the blueback herring is the Atlantic Coast from Cape Breton, Nova Scotia to the St. Johns River, Florida. The species ascends coastal rivers during spawning season (Page & Burr 1991). This species has been collected in the Tennessee River in Georgia and Tennessee (Rasmussen 1998); and in Oneida Lake, the Oswego River in Minetto, Lake Champlain, and the upper Mohawk River upstream of Cohoes Falls, New York (Greeley 1935; Limburg et al. 2001). The spread of the blueback herring through the Great lakes may not be possible in areas with high densities of predatory fish (Owens et al. 1998).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*

T_0: There are no existing barriers.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: Two juvenile blueback herring were documented near Oswego, NY in Lake Ontario in 1995 approximately 2090 km (1300 river miles) from the Indiana Harbor pathway entrance (Fuller et al. 2012). It has been stated that the species could enter Lake Erie; however, the cold temperatures might prevent establishment (Fuller et al. 2012).

T_{10}: See T_0. The species might, over time, spread and move closer to the pathway entrance.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: Blueback herrings are anadromous, marine clupeids found along the Atlantic coast in marine, estuarine, and riverine habitats, depending on life stage (Pardue 1983). Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). They prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F) (Loesch & Lund 1977; Pardue 1983). Eggs are demersal in still water and adhesive or pelagic in running water (Loesch & Lund 1977). After water hardening, the eggs become pelagic and lose their adhesive properties (Pardue 1983). Larvae and juveniles remain in the surface water near the spawning site. Adults are primarily pelagic, preferring temperatures ranging from 2 to 17°C (35.6 to 62.6°F) (Pardue 1983). There is evidence from species records in Lake Champlain that the blueback herring may not be able to colonize northern latitude lakes due to low temperatures (Owens et al. 1986). Alewives in the Great Lakes sometimes suffer mass mortalities from cold water in severe winters (O'Gorman & Schneider 1986, Bergstedt & O'Gorman 1989) and they have failed to establish large populations in Lake Superior, the coldest of the Great Lakes (Bronte et al. 1991). The distribution of alewives extends farther northward than that of the blueback herring, suggesting that alewives may be more tolerant of cold temperatures (Owens et al. 1998).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical, and climatological suitability of the Great Lakes and its tributaries for the blueback herring. Water temperatures and stream flows, in particular, might be altered, potentially affecting the distribution of this species. Based on its native distribution in coastal Atlantic waters (Fuller et al. 2012), blueback herring appear to be more of a warm water species and temperature increases related to future climate change (Wuebbles et al. 2010) may improve their spread throughout the GLB and affect their probability of arriving at the CAWS.

Probability of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is located in western Lake Ontario (section 2d) far from the Indiana Harbor pathway entrance. The only mode of transportation for the blueback herring is swimming. It is thought that the northern latitudes may be too cold for the species to colonize and spread (section 2f). Competition for resources with native and established fish populations may also prevent colonization throughout the GLB. It has been present in this region since 1994 and has not spread to the west. Therefore, it is unlikely to spread to the CAWS during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over 50 years, the probability increases that the blueback herring will have time to spread to Indiana Harbor by natural (e.g., swimming) dispersion. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The blueback herring is unlikely to reach the pathway entrance at this time step due to the distance it would have to swim. The uncertainty associated with arrival is low, as this species has not spread to CAWS in the more than 10 years it has been present in Lake Ontario.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. It is uncertain why the blueback herring has not spread through the GLB since its discovery in 1995. Temperature or competition are thought to be constraints; however, this is not documented. Given 50 years, the species might be able to reach the pathway by natural dispersal. The uncertainty increases to medium for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed

Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. Human-Mediated Transport through Aquatic Pathways

Blueback herring might have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. Existing Physical Human/Natural Barriers

T_0: The pathway from Indiana Harbor to Brandon Road Lock and Dam is a shallow, eutrophic river with a flow of approximately 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) and might be too slow for the species which spawns in fast currents (Fuller et al. 2012). The Electric Dispersal Barrier System, located north of Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, adults that are shocked and early life stages could float downstream through the barrier. Blueback herring eggs could move through the barrier in the water column. So, there is a high potential that adults and early life stages may pass the barrier at the current setting. The Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to downstream passage, although it is not known to what extent these structures may inhibit downstream movement. Alewives have been present in southern Lake Michigan and the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam (Savitz et al. 1996). Blueback herring have similar migratory patterns and they may behave similarly. Lock and dam structures are known to act as barriers to the upstream movement of herring (Pardue 1983).

T_{10}: See T_0. Lock operations are not expected to change over time.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrological, Hydraulic, Chemical, and Climatological)

T_0: Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). Alewife, a species of herring, have been documented in the CAWS (LimnoTech 2010), including the Grand Calumet River, suggesting that the blueback herring could also enter the CAWS.

Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Sediments in the CAWS can range from bedrock to soft sediment (LimnoTech 2010). The pathway from Indiana Harbor to Brandon Road Lock and Dam is a slow-moving eutrophic river with a flow of approximately 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) with a mean annual water temperature of 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). Larvae and juveniles remain in the surface water near the spawning site (Pardue 1983). Blueback herring

larvae require more than 5.0 mg/L DO (Klauda et al. 1991). Dissolved oxygen in the CAWS may be too low in certain areas or during certain times of the year.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adult blueback herring do not occupy riverine habitat except to spawn. The CAWS does not contain ideal spawning habitat. The flow is too slow and the temperature may be too low for larvae (section 3f). Blueback herring are strong swimmers and are capable of migrating upstream into tributary rivers to spawn (section 3a). Consequently, they would likely be capable of passage during this time step, although Lockport Lock and Dam and Brandon Road Lock and Dam may act as temporary barriers to passage (section 3c). However, alewives, which have migration patterns similar to blueback herring, have been present in the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam. Overall, the probability of passage is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: It is uncertain if the blueback herring would behave in the same manner as the alewife and not pass through the pathway. Alewives have not made temporary migrations into Illinois rivers despite being in Lake Michigan for more than 50 years. The reason for this is not fully understood. There are no studies of the behavior of blueback herring in the CAWS. Therefore, the uncertainty of passage is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. However, they could potentially colonize reservoirs and lakes in the MRB.

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   Blueback herring are active swimmers capable of upstream migration and they should be capable of swimming downstream of Brandon Road Lock and Dam. Blueback herring could potentially colonize lakes and reservoirs within the MRB if these surface waters are connected to riverine habitats containing blueback herring. However, there is no evidence that they would travel the distance inland necessary to reach these reservoirs. In addition, alewife, another herring species similar to blueback herring, are historically not found below Brandon Road Lock and Dam despite being present in the CAWS. This suggests that blueback herring are also unlikely to spread downstream of Brandon Road Lock and Dam (section 4a).

Evidence for Probability Rating

Adult blueback herring are pelagic and only move into the rivers to spawn (section 4a). Therefore, no permanent colonization of riverine habitat would be expected. Larval and juvenile stages develop in rivers and suitable habitat may be present downstream of Brandon Road Lock and Dam (section 4a). Blueback herring could potentially colonize lakes and reservoirs within the MRB, although there is no evidence that they would travel the distance from the Great Lakes necessary to reach these reservoirs. Based on the behavior of alewife, blueback herring are unlikely to spread downstream of Brandon Road Lock and Dam (section 4b). Consequently, probability of colonization below Brandon Road Lock and Dam is low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether blueback herring could swim to suitable reservoir habitat in the MRB. Therefore, the uncertainty associated with the probability of colonization is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
Blueback herring prefer temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Pardue 1983).

b. Type of Mobility/Invasion Speed
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

c. Fecundity
Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953).

d. History of Invasion Success
In Tennessee, blueback herring were stocked in a few reservoirs initially, and they have since spread by "bait bucket" transfer to other water bodies in Tennessee (Tennessee Wildlife Resources Agency 2012). Blueback herring have been found in the Melton Hill, Tellico, and Boone reservoirs (Tennessee Wildlife Resources Agency 2012), which impound the Clinch River, Little Tennessee River, and the South Fork Holston River, respectively. Although blueback herring have been reported from reservoirs in the MRB, they are not considered established (Fiss 2012). Blueback herring have established in inland river basins in the Carolinas and Virginia (Fuller et al. 2012).

e. Human-Mediated Transport through Aquatic Pathways
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Such habitats are present and accessible in the MRB.

Evidence for Probability Rating

Adult blueback herrings prefer lotic habitats and only move into the rivers to spawn (section 5a). Blueback herring are capable of traveling upstream to spawning grounds (section 5b) and suitable habitat is present in the MRB. They have established in large reservoirs and river systems outside their native range (section 5d). Consequently, if colonization occurs, the probability of spread is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Blueback herring are established in inland river basins outside of their native range (section 5d). However, it is uncertain whether suitable habitat is hydrologically connected in a way that would allow the spread of the blueback herring. Consequently, the uncertainty associated with blueback herring spreading in the MRB is medium.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	Low	Low	Low	Low	Low	Low	Medium	Medium
P(passage)	Low	High	Low	High	Low	High	Low	High
P(colonizes)	Low	High	Low	High	Low	High	Low	High
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Low	-[a]	Low	-	Low	-	Low	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between BSBH and Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: LOW – MEDIUM

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. *Current Abundance and Reproductive Capacity*
T_0: Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953). The native range of the blueback herring is the Atlantic Coast from Cape Breton, Nova Scotia to the St. Johns River, Florida. The species ascends coastal rivers during spawning season (Page & Burr 1991). This species has been collected in the Tennessee River in Georgia and Tennessee (Rasmussen 1998) and in Oneida Lake, the Oswego River in Minetto, Lake Champlain, and the upper Mohawk River upstream of Cohoes Falls, New York (Greeley 1935; Limburg et al. 2001). The spread of the blueback herring through the Great Lakes may not be possible in areas with high densities of predatory fish (Owens et al. 1998).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

d. *Existing Physical Human/Natural Barriers*
T_0: There are no existing barriers.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: Two juvenile blueback herring are documented near Oswego, NY in Lake Ontario in 1995 a distance of over 2090 km (1300 river miles) from the BSBH pathway entrance (Fuller et al. 2012). It has been stated that the species could enter Lake Erie; however, the cold temperatures may prevent establishment (Fuller et al. 2012).
T_{10}: See T_0. The species may, over time, spread and move closer to the pathway entrance.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: Blueback herrings are anadromous, marine clupeids found along the Atlantic coast in marine, estuarine, and riverine habitats, depending on life stage (Pardue 1983). Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate

upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). They prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F) (Loesch & Lund 1977; Pardue 1983). Eggs are demersal in still water and adhesive or pelagic in running water (Loesch & Lund 1977). After water hardening, the eggs become pelagic and lose their adhesive properties (Pardue 1983). Larvae and juveniles remain in the surface water near the spawning site. Adults are primarily pelagic, preferring temperatures ranging from 2 to 17°C (35.6 to 62.6°F) (Pardue 1983). There is evidence from species records in Lake Champlain that the blueback herring may not be able to colonize northern latitude lakes due to low temperatures (Owens et al. 1986). Alewives in the Great Lakes sometimes suffer mass mortalities from cold water in severe winters (O'Gorman & Schneider 1986, Bergstedt & O'Gorman 1989) and they have failed to establish large populations in Lake Superior, the coldest of the Great Lakes (Bronte et al. 1991). The distribution of alewives extends farther northward than that of the blueback herring, suggesting that alewives may be more tolerant of cold temperatures (Owens et al. 1998).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Future climate change may alter the physical, hydraulic, chemical, and climatological suitability of the Great Lakes and its tributaries for the blueback herring. Water temperatures and stream flows, in particular, might be altered, potentially affecting the distribution of this species. Based on its native distribution in coastal Atlantic waters (Fuller et al. 2012), blueback herring appear to be more of a warm water species and temperature increases related to future climate change (Wuebbles et al. 2010) may improve their spread throughout the GLB and affect their probability of arriving at the CAWS.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Probability Rating (Considering All Life Stages)

T_0: This species is located in western Lake Ontario (section 2d), far from the BSBH pathway entrance. The only mode of transportation for the blueback herring is swimming. It is thought that the northern latitudes may be too cold for the species to colonize and spread (section 2f). Competition for resources with native and established fish populations may also prevent colonization throughout the GLB. It has been present in this region since 1994 and has not spread to the west. Therefore, it is unlikely to spread to the CAWS during this time step.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Over 50 years, the probability increases that the blueback herring will have time to spread to BSBH by natural (e.g., swimming) dispersion. Therefore, its probability of passage for this time step is medium.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Medium

Evidence for Uncertainty Rating

T_0: The blueback herring is unlikely to reach the pathway entrance at this time step due to the distance it would have to swim. The uncertainty associated with arrival is low, as this species has not spread to CAWS in the more than 10 years it has been present in Lake Ontario.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. It is uncertain why the blueback herring has not spread through the GLB since its discovery in 1995. Temperature or competition are thought to be constraints; however, this is not documented. Given 50 years, the species may be able to reach the pathway by natural dispersal. The uncertainty increases to medium for this time step.

3. P(passage) T_0-T_{50}: LOW

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

b. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

c. *Existing Physical Human/Natural Barriers*
T_0: The flow of the pathway from BSBH to Brandon Road Lock and Dam may be too slow for this species, which spawns in fast currents (Fuller et al. 2012). The Electric Dispersal Barrier System, located north of Lockport Lock and Dam, may act as a barrier to some degree by repelling adult fish. However, adults that are shocked and early life stages could float downstream through the barrier. Blueback herring eggs could move through the barrier in the water column. So, there is a high potential that adults and early life stages may pass the barrier at the current setting. Lock and dam structures are known to act as barriers to the upstream movement of herring (Pardue 1983). The Lockport Lock and Dam and the Brandon Road Lock and Dam may act as temporary barriers to downstream passage, although it is not known to what extent these structures may inhibit downstream movement. Alewives have been present in southern Lake Michigan

and the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam (Savitz et al. 1996). Blueback herring have similar migratory patterns and they may behave similarly.

T_{10}: See T_0. Lock operations are not expected to change over time.

T_{25}: See T_{10}.

T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrological, Hydraulic, Chemical, and Climatological)*

T_0: Adult blueback herring prefer deep open waters of lakes for most of the year; they migrate upstream to spawn once a year in spring or early summer (Raney & Massmann 1953). Alewife, a species of herring, have been documented in the CAWS (LimnoTech 2010), suggesting that the blueback herring could also enter the CAWS. Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Substrate in the CAWS can range from bedrock to soft sediment (LimnoTech 2010); the pathway from BSBH to Brandon Road Lock and Dam is a slow-moving eutrophic river with a flow of approximately 0.05–0.27 m/s (0.16–0.89 ft/s) (LimnoTech 2010) with a mean annual water temperature of 11.3–19.3°C (52.3–66.7°F) (MWRD 2010). Larvae and juveniles remain in the surface water near the spawning site (Pardue 1983). Blueback herring larvae require more than 5.0 mg/L DO (Klauda et al. 1991). Dissolved oxygen in the CAWS may be too low in certain areas or during certain times of the year.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Probability Rating (Considering All Life Stages)

T_0: Adult blueback herring do not occupy riverine habitat except to spawn. The CAWS does not contain ideal spawning habitat. The flow is too slow and the temperature may be too low for larvae (section 3f). Blueback herring are strong swimmers and are capable of migrating upstream into tributary rivers to spawn (section 3a). Consequently, they would likely be capable of passage during this time step, although Lockport Lock and Dam and Brandon Road Lock and Dam may act as temporary barriers to passage (section 3c). However, alewives, which have migration patterns similar to blueback herring, have been present in the CAWS for decades and have not moved downstream beyond Brandon Road Lock and Dam. Overall, the probability of passage is low.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Uncertainty Rating

T_0: It is uncertain if the blueback herring would behave in the same manner as the alewife and not pass through the pathway. Alewives have not made temporary migrations into Illinois rivers despite being in Lake Michigan for more than 50 years. The reason for this is not fully understood. There are no studies of the behavior of blueback herring in the CAWS. Therefore, the uncertainty of passage is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): LOW

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. However, they could potentially colonize reservoirs and lakes in the MRB.

b. Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal
Blueback herring are active swimmers capable of upstream migration and they should be capable of swimming downstream of Brandon Road Lock and Dam. Blueback herring could potentially colonize lakes and reservoirs within the MRB if these surface waters are connected to riverine habitats containing blueback herring. However, there is no evidence that they would travel the distance inland necessary to reach these reservoirs. In addition, alewife, another herring species similar to blueback herring, are historically not found below Brandon Road Lock and Dam despite being present in the CAWS. This suggests blueback herring are also unlikely to spread downstream of Brandon Road Lock and Dam (section 4a).

Evidence for Probability Rating

Adult blueback herring are pelagic and only move into the rivers to spawn (section 4a). Therefore, no permanent colonization of riverine habitat would be expected. Larval and juvenile stages develop in rivers and suitable habitat may be present downstream of Brandon Road Lock and Dam (section 4a). Blueback herring could potentially colonize lakes and reservoirs within the MRB, although there is no evidence that they would travel the distance from the Great Lakes necessary to reach these reservoirs. Based on the behavior of alewife, blueback herring are unlikely to spread downstream of Brandon Road Lock and Dam (section 4b). Consequently, probability of colonization below Brandon Road Lock and Dam is low.

Uncertainty: HIGH

Evidence for Uncertainty Rating

It is uncertain whether blueback herring could swim to suitable reservoir habitat in the MRB. Therefore, the uncertainty associated with the probability of colonization is high.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. Suitable Climate in MRB
Blueback herring prefer temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Pardue 1983).

b. Type of Mobility/Invasion Speed
Blueback herring are active swimmers that migrate upstream for spawning. Eggs become pelagic and can drift in the water column (Pardue 1983).

c. Fecundity
Females produce 45,200 to 349,700 eggs annually (Raney & Massmann 1953).

d. History of Invasion Success
In Tennessee, blueback herring were stocked in a few reservoirs initially, and they have since spread by “bait bucket” transfer to other water bodies in Tennessee (Tennessee Wildlife Resources Agency 2012). Blueback herring have been found in the Melton Hill, Tellico, and Boone reservoirs (Tennessee Wildlife Resources Agency 2012), which impound the Clinch River, Little Tennessee River, and the South Fork Holston River, respectively. Although blueback herring have been reported from reservoirs in the MRB, they are not considered established (Fiss 2012). Blueback herring have established in inland river basins in the Carolinas and Virginia (Fuller et al. 2012).

e. *Human-Mediated Transport through Aquatic Pathways*
Blueback herring may have spread to the Great Lakes via manmade canals (Fuller et al. 2012). This species is an active swimmer; therefore, vessel transport is not a primary spread mechanism.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
Blueback herring would only be present in rivers of the MRB for spawning or early life-stage development. Blueback herring prefer to spawn in fast currents over hard substrate in temperatures ranging from 14 to 27°C (57.2 to 80.6°F); the optimal temperature for larvae is 26.3°C (79.3°F) (Loesch & Lund 1977; Pardue 1983). Such habitats are present and accessible in the MRB.

Evidence for Probability Rating

Adult blueback herrings prefer lotic habitats and only move into rivers to spawn (section 5a). Blueback herring are capable of traveling upstream to spawning grounds (section 5b) and suitable habitat is present in the MRB. They have established in large reservoirs and river systems outside their native range (section 5d). Consequently, if colonization occurs, the probability of spread is medium.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

Blueback herring are established in inland river basins outside of their native range (section 5d). However, it is uncertain whether suitable habitat is hydrologically connected in a way that would allow the spread of the blueback herring. Consequently, the uncertainty associated with blueback herring spreading in the MRB is medium.

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E.2.8 Viruses

E.2.8.1 Viral Hemorrhagic Septicemia (VHSv)

PATHWAY: 1 (WILMETTE PUMPING STATION [WPS] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	**T_0**		**T_{10}**		**T_{25}**		**T_{50}**	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the WPS and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. Type of Mobility/Invasion Speed
Viral hemorrhagic septicemia (VHSv) is a viral disease of freshwater and marine fish. Until the 1980s, VHSv was believed to be isolated to freshwaters of Europe (Wolf 1988). Since that time, four genotypes of the virus have been found in various marine and freshwater habitats, including water bodies in Europe, North America, Korea, and Japan

(Nishizawa et al. 2002; Skall et al. 2005). It was first reported in the Great Lakes in 2003 from Lake St. Clair (Elsayed et al. 2006), and by 2010 it had spread to all five Great Lakes (MNDR 2010). Viral hemorrhagic septicemia genotype IVb has now been confirmed in five coldwater species and 19 coolwater species in the Great Lakes (Whelan 2009); 28 species of fish from the Great Lakes basin are considered at risk from the virus, including smallmouth bass, walleye, and bluegill (Dudis 2011). Susceptible fish contract the virus by close proximity to other infected individuals, or by ingesting infected material. Affected fish shed the virus into the surrounding environment through urine and reproductive fluids (Meyers & Winton 1995); the virus can enter the body through the gills, open wounds, or ingestion (Whelan 2009). Survivors of viral infection are carriers and continue to shed virus particles for extended periods of time (Kim & Faisal 2012). Ingesting infected prey fish or invertebrates harboring the virus can also lead to infection (Ahne 1980; Skall et al. 2005; Faisal & Winters 2011). VHSv can exist for extended periods of time in freshwater without a host, depending on temperature (Whelan 2009; Hawley & Garver 2008); contact with water containing the virus is also a means of spread (Castric & de Kinkelin 1980; Muroga et al. 2004). Infected females can also shed the virus during egg deposition; the virus can persist for a long enough period to infect progeny (Tuttle-Lau et al. 2010). Blood-sucking leeches are also potential transmitters of the virus to fish (Faisal & Schulz 2009).

b. *Human-Mediated Transport through Aquatic Pathways*
Potential spread mechanisms include the movement of infected fish (baitfish or gamefish) to new water bodies; transporting contaminated waters, fish, or fish parts in ballast water or in bilges of recreational boats; or the movement of contaminated fishing equipment (Whelan 2009; Warren 1983). Ship ballast has been shown to be a transport mechanism of non-native bacteria and viruses (Drake et al. 2007); however, the current distribution of the virus does not suggest shipping-related transport (Bain et al. 2010). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. There is no commercial vessel traffic from the Great Lakes to the WPS, but there is recreational boat traffic (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: The North American strain of the virus has established populations in all five Great Lakes since its discovery in 2003, and has been found in several inland waters of New York, Ohio, Michigan, and Wisconsin (Kipp et al. 2013). Once the virus is established in a region, it will become widespread, hosted by fish without disease symptoms, and capable of persistence at low but detectable levels (Bain et al. 2010). Benthic macroinvertebrates sampled in Lake Michigan have tested positive for the virus (Faisal et al. 2012). We did not find any documented fish kills in Lake Michigan resulting from VHSv.
T_{10}: See T_0.
T_{25}: See T_{10}.
T_{50}: See T_{25}. Changes in water temperature related to future climate change (Wuebbles et al. 2010) could affect the spread or virulence of this species.

d. *Existing Physical Human/Natural Barriers*

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*

T_0: VHSv was reported in Lake Michigan near Waukegan, Illinois, and at Green Bay, Little Sturgeon Bay, Algoma, and Milwaukee in Wisconsin (Kipp 2013; Whelan 2009).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: VHSv has been detected in southwestern Lake Michigan at Waukegan and Winthrop harbors (Dudis 2011), suggesting climate is suitable. The pathogen replicates at temperatures of 2-15°C (35.6-59°F) (Wolf 1988; McAllister 1990; Meyers & Winton 1995); peak viral activity in the Great Lakes corresponds to spring spawning periods and in winter when temperatures are suitable (Eckerlin et al. 2011). Optimum replication temperature is 14-15°C, and can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and almost nonexistent at 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990). The virus is adapted to colder waters and becomes inactive after 24 hours in water temperatures greater than 20°C (CFSPH 2003; Hawley & Garver 2008). The Great Lakes genotype IVb has been confirmed in five coldwater and 19 coolwater species (Whelan 2009), and 28 species of fish from the Great Lakes basin are considered at risk (Dudis 2011). Fish are most susceptible to the virus during times of stress, in crowded conditions, during early life stages, and at cold temperatures (9-15°C; 48.2-59°F [Smail 1999]).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}. VHSv is sensitive to climatological conditions. Future climate change and/or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for VHSv. Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could reduce the productivity of VHSv.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv has spread throughout the Great Lakes in less than a decade. It has been documented in Lake Michigan as far south as Waukegan. There are no barriers to the movement of this species by boat, current, or host fish. Therefore, the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: Viral hemorrhagic septicemia is considered to be established in Lake Michigan and was documented offshore of the Waukegan and Winthrop harbors in Illinois (section 2e). Its ability to spread rapidly in the Great Lakes has been documented. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
VHSv can be transported by the movement of infected fish or eggs, or through the movement of contaminated water (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008). The virus has a history of quickly invading through waterways, rivers, and lakes (Fisheries Technical Committee 2009). From the WPS, VHSv must move more than 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
VHSv can potentially be transported via ballast water (Whelan 2009; Elsayed et al. 2006), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). In addition, a sluice gate at the WPS prevents the entry of vessel traffic from Lake Michigan into the North Shore Channel. Water from

Lake Michigan is periodically pumped into the North Shore Channel, which could transport the virus into the CAWS. While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. There is no commercial vessel traffic in the North Shore Channel. Therefore, some natural downstream movement would likely be required for VHSv to reach the Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*

T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010). There is a sluice gate separating the CAWS from Lake Michigan that is periodically opened and closed. Water from Lake Michigan is periodically pumped into the North Shore Channel, which could transport VHSv into the CAWS.
T_{10}: See T_0. No changes in human or natural barriers are expected. The sluice gate is expected to continue to operate under current procedures.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011), and many of these species are found in the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv could be transported through the WPS and move downstream to the Brandon Road Lock and Dam through gravity flow or fish hosts. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is well documented to move through waterways. There are fish species in the CAWS that could serve as hosts for VHSv and transport VHSv downstream. Overall, the uncertainty of the probability of this species passing through the pathway is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011), and many of these species are also present in the Mississippi River Basin (e.g., rockbass, perch, drum). The virus spread to the Ohio River Basin (Clear Fork Reservoir) in 2008 (Kipp 2013).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
VHSv could move downstream of Brandon Road Lock and Dam by passive dispersal or by being carried by a fish host.

Evidence for Probability Rating

There are no barriers keeping VHSv from moving downstream of Brandon Road Lock and Dam. This species is documented to spread through rivers. Reservoirs may also provide suitable habitat. The virus spread to the Ohio River Basin (Clear Fork Reservoir) in 2008 (Kipp 2013). There are also suitable fish hosts in the MRB. Therefore, this species is considered to have a high probability of colonization after passage through the pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

VHSv is documented to spread through freshwater. There are no documented barriers to spread that would control this species colonizing the MRB. Therefore, there is a low uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
VHSv is globally widespread and prefers cool temperatures (Kipp 2013). Therefore, climate may restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters, or by human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008).

c. *Fecundity*
VHSv can spread rapidly through waterways (Meyers & Winton 1995) and has multiple transmission vectors. The virus can persist in cold water without a host for an extended period and can continually be shed by asymptomatic carriers (Whelan 2009).

d. *History of Invasion Success*
VHSv spread rapidly through the Great Lakes since being discovered in 2003 and causes occasional large-scale mortalities of fish (Bain et al. 2010). The virus was found in the Ohio River Basin in 2008 (Kipp 2013).

e. *Human-Mediated Transport through Aquatic Pathways*
VHSv may be transported in ballast water (Kipp 2013). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (10-15°C; Hawley & Garver 2008; Whelan 2009). At high water temperatures (>20°C), the virus becomes inactivated within 1 day (CFSPH 2003; Hawley & Garver 2008). Within the Mississippi River basin centrarchids, perch, and gizzard shad are among the species that are documented to serve as suitable hosts (http://www.miseagrant.umich.edu/files/2012/12/07-700-fs-VHSv.pdf; Dudis 2011). VHSv has been detected in Clear Creek Reservoir, which drains into the Ohio River and is

part of the MRB (Kipp et al. 2013). VHSv survives best in cold waters. Optimum replication temperature is 14-15°C, and VHSv can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and the virus becomes inactive after 24 hours in water temperatures greater than 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990; CFSPH 2003; Hawley & Garver 2008). Considering these temperature restrictions, VHSv may not spread to the lower MRB.

Evidence for Probability Rating

VHSv has invaded the Ohio River Basin, suggesting it can also invade the MRB. VHSv is known to infect several species found in the MRB. VHSv could spread via host fish and by the significant vessel traffic between the upper and lower MRB. However, the temperature sensitivity of this species may reduce its spread south into the middle and lower MRB. Therefore, there is a medium probability of the VHSv spreading through the MRB.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

VHSv has been documented to readily spread through freshwater river basins. However, existing studies indicate that water temperatures south of the upper MRB may be unsuitable for VHSv. The ability of VHSv to adapt to warmer temperatures is uncertain. Therefore, the uncertainty associated with the probability of spread is medium.

PATHWAY: 2 (CHICAGO RIVER CONTROLLING WORKS [CRCW] TO BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	**U**	**P**	**U**	**P**	**U**	**P**	**U**
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the CRCW and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Viral hemorrhagic septicemia (VHSv) is a viral disease of freshwater and marine fish. Until the 1980s, VHSv was believed to be isolated to freshwaters of Europe (Wolf 1988). Since that time, four genotypes of the virus have been found in various marine and freshwater habitats, including water bodies in Europe, North America, Korea, and Japan (Nishizawa et al. 2002; Skall et al. 2005). It was first reported in the Great Lakes in 2003 from Lake St. Clair (Elsayed et al. 2006), and by 2010 it had spread to all five Great Lakes (MNDR 2010). Viral hemorrhagic septicemia genotype IVb has now been confirmed in five coldwater species and 19 coolwater species in the Great Lakes (Whelan 2009); 28 species of fish from the Great Lakes basin are considered at risk from the virus, including smallmouth bass, walleye, and bluegill (Dudis 2011). Susceptible fish contract the virus by close proximity to other infected individuals, or by ingesting infected material. Affected fish shed the virus into the surrounding environment through urine and reproductive fluids (Meyers & Winton 1995); the virus can enter the body through the gills, open wounds, or ingestion (Whelan 2009). Survivors of viral infection are carriers and continue to shed virus particles for extended periods of time (Kim & Faisal 2012). Ingesting infected prey fish or invertebrates harboring the virus can also lead to infection (Ahne 1980; Skall et al. 2005; Faisal & Winters 2011). VHSv can exist for extended periods of time in freshwater without a host, depending on temperature (Whelan 2009; Hawley & Garver 2008); contact with water containing the virus is also a means of spread (Castric & de Kinkelin 1980; Muroga et al. 2004). Infected females can also shed the virus during egg deposition; the virus can persist for a long enough period to infect progeny (Tuttle-Lau et al. 2010). Blood-sucking leeches are also potential transmitters of the virus to fish (Faisal & Schulz 2009).

b. *Human-Mediated Transport through Aquatic Pathways*
Potential spread mechanisms include the movement of infected fish (baitfish or gamefish) to new water bodies; transporting contaminated waters, fish, or fish parts in ballast water or in bilges of recreational boats; or the movement of contaminated fishing equipment (Whelan 2009; Warren 1983). Ship ballast has been shown to be a transport mechanism of non-native bacteria and viruses (Drake et al. 2007); however, the current distribution of the virus does not suggest shipping-related transport (Bain et al. 2010). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. There is commercial and recreational vessel traffic from the Great Lakes to the CRCW (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*
T_0: The North American strain of the virus has established populations in all five Great Lakes since its discovery in 2003, and has been found in several inland waters of New York, Ohio, Michigan, and Wisconsin (Kipp et al. 2013). Once the virus is established in a region, it will become widespread, hosted by fish without disease symptoms, and capable of persistence at low but detectable levels (Bain et al. 2010). Benthic macroinvertebrates sampled in Lake Michigan have tested positive for the virus (Faisal et al. 2012). We did not find any documented fish kills in Lake Michigan resulting from VHSv.
T_{10}: See T_0.
T_{25}: See T_{10}.
T_{50}: See T_{25}. Changes in water temperature related to future climate change (Wuebbles et al. 2010) could affect the spread or virulence of this species in Lake Michigan.

d. *Existing Physical Human/Natural Barriers*
T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: VHSv was reported in Lake Michigan near Waukegan, Illinois, and at Green Bay, Little Sturgeon Bay, Algoma, and Milwaukee in Wisconsin (Kipp 2013; Whelan 2009).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: VHSv has been detected in southwestern Lake Michigan at Waukegan and Winthrop harbors (Dudis 2011), suggesting climate is suitable. The pathogen replicates at temperatures of 2-15°C (35.6-59°F) (Wolf 1988; McAllister 1990; Meyers & Winton 1995); peak viral activity in the Great Lakes corresponds to spring spawning periods and in winter when temperatures are suitable (Eckerlin et al. 2011). Optimum replication

temperature is 14-15°C, and can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and almost nonexistent at 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990). The virus is adapted to colder waters and becomes inactive after 24 hours in water temperatures greater than 20°C (CFSPH 2003; Hawley & Garver 2008). The Great Lakes genotype IVb has been confirmed in five coldwater and 19 coolwater species (Whelan 2009), and 28 species of fish from the Great Lakes basin are considered at risk (Dudis 2011). Fish are most susceptible to the virus during times of stress, in crowded conditions, during early life stages, and at cold temperatures (9-15°C; 48.2-59°F [Smail 1999]).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}. VHSv is sensitive to climatological conditions. Future climate change and/or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for VHSv. Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could reduce the productivity of VHSv.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv has spread throughout the Great Lakes in less than a decade. It has been documented in Lake Michigan as far south as Waukegan. There are no barriers to the movement of this species by boat, current, or host fish. Therefore, the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is considered to be established in Lake Michigan and was documented offshore of the Waukegan and Winthrop harbors in Illinois (section 2e). Its ability to spread rapidly in the Great Lakes has been documented. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters, or human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008). The virus has a history of quickly invading through waterways, rivers, and lakes (Fisheries Technical Committee 2009). From the CRCW, VHSv must move more than 80 km (50 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
VHSv may be transported in ballast water (Whelan 2009; Elsayed et al. 2006), and there is some commercial vessel traffic between the CRCW and the Brandon Road Lock and Dam (USACE 2011a; NBIC 2012). However, the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Surface water is present year-round. There are no barriers to this species moving to Brandon Road Lock and Dam from the CRCW.
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011), and many of these species are found in the CAWS.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv could be transported through the CRCW and move downstream to the Brandon Road Lock and Dam through gravity flow or fish hosts. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	T_0	T_{10}	T_{25}	T_{50}
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is well documented to move through waterways. There are fish species in the CAWS that could serve as hosts for VHSv and transport VHSv downstream. Overall, uncertainty of the probability of this species passing through the pathway is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)
VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011). Survivors of the virus continually shed the virus in urine and reproductive fluids throughout their lifetime (Whelan 2009). The virus spread into the Ohio River Basin (Clear Fork Reservoir) in 2008 (Kipp 2013).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
VHSv could move downstream of Brandon Road Lock and Dam by passive dispersal or by being carried by a fish host.

Evidence for Probability Rating

There are no barriers keeping VHSv from moving downstream of Brandon Road Lock and Dam. This species is documented to spread through rivers. Reservoirs may also provide suitable habitat. There are also suitable fish hosts in the MRB. Therefore, this species is considered to have a high probability of colonization after passage through the pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

VHSv is documented to spread through freshwater. There are no documented barriers to spread that would keep this species from colonizing the MRB. Therefore, there is a low uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
VHSv is globally widespread and prefers cool temperatures (Kipp 2013). Therefore, climate may restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters, or by human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008).

c. *Fecundity*
VHSv can spread rapidly through waterways (Meyers & Winton 1995) and has multiple transmission vectors. The virus can persist in cold water without a host for an extended period and can continually be shed by asymptomatic carriers (Whelan 2009).

d. *History of Invasion Success*
VHSv spread rapidly through the Great Lakes since being discovered in 2003 and causes occasional large-scale mortalities of fish (Bain et al. 2010). The virus was found in the Ohio River Basin in 2008 (Kipp 2013).

e. *Human-Mediated Transport through Aquatic Pathways*
   VHSv may be transported in ballast water (Kipp 2013). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Mississippi River basin centrarchids, perch, and gizzard shad are among the species that are documented to serve as suitable hosts (http://www.miseagrant.umich.edu/files/2012/12/07-700-fs-VHSv.pdf; Dudis 2011). VHSv has been detected in Clear Creek Reservoir, which drains into the Ohio River and is part of the MRB (Kipp et al. 2013). VHSv survives best in cold waters. Optimum replication temperature is 14-15°C, and VHSv can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and the virus becomes inactive after 24 hours in water temperatures greater than 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990; CFSPH 2003; Hawley & Garver 2008). Considering these temperature restrictions, VHSv may not spread to the lower MRB.

Evidence for Probability Rating

VHSv has invaded the Ohio River Basin, suggesting it can also invade the MRB. VHSv is known to infect several species found in the MRB. VHSv could spread via host fish and by the significant vessel traffic between the upper and lower MRB. However, the temperature sensitivity of this species may reduce its spread south into the middle and lower MRB. Therefore, there is a medium probability of the VHSv spreading through the MRB.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

VHSv has been documented to readily spread through freshwater river basins. However, existing studies indicate that water temperatures south of the upper MRB may be unsuitable for VHSv. The ability of VHSv to adapt to warmer temperatures is uncertain. Therefore, the uncertainty associated with the probability of spread is medium.

PATHWAY: 3 (CALUMET HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Calumet Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Viral hemorrhagic septicemia (VHSv) is a viral disease of freshwater and marine fish. Until the 1980s, VHSv was believed to be isolated to freshwaters of Europe (Wolf 1988). Since that time, four genotypes of the virus have been found in various marine and freshwater habitats, including water bodies in Europe, North America, Korea, and Japan (Nishizawa et al. 2002; Skall et al. 2005). It was first reported in the Great Lakes in 2003 from Lake St. Clair (Elsayed et al. 2006), and by 2010 it had spread to all five Great Lakes (MNDR 2010). Viral hemorrhagic septicemia genotype IVb has now been confirmed in five coldwater species and 19 coolwater species in the Great Lakes (Whelan 2009);

28 species of fish from the Great Lakes basin are considered at risk from the virus, including smallmouth bass, walleye, and bluegill (Dudis 2011). Susceptible fish contract the virus by close proximity to other infected individuals, or by ingesting infected material. Affected fish shed the virus into the surrounding environment through urine and reproductive fluids (Meyers & Winton 1995); the virus can enter the body through the gills, open wounds, or ingestion (Whelan 2009). Survivors of viral infection are carriers and continue to shed virus particles for extended periods of time (Kim & Faisal 2012). Ingesting infected prey fish or invertebrates harboring the virus can also lead to infection (Ahne 1980; Skall et al. 2005; Faisal & Winters 2011). VHSv can exist for extended periods of time in freshwater without a host, depending on temperature (Whelan 2009; Hawley & Garver 2008); contact with water containing the virus is also a means of spread (Castric & de Kinkelin 1980; Muroga et al. 2004). Infected females can also shed the virus during egg deposition; the virus can persist for a long enough period to infect progeny (Tuttle-Lau et al. 2010). Blood-sucking leeches are also potential transmitters of the virus to fish (Faisal & Schulz 2009).

b. *Human-Mediated Transport through Aquatic Pathways*

Potential spread mechanisms include the movement of infected fish (baitfish or gamefish) to new water bodies; transporting contaminated waters, fish, or fish parts in ballast water or in bilges of recreational boats; or the movement of contaminated fishing equipment (Whelan 2009; Warren 1983). Ship ballast has been shown to be a transport mechanism of non-native bacteria and viruses (Drake et al. 2007); however, the current distribution of the virus does not suggest shipping-related transport (Bain et al. 2010). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. There is commercial and recreational vessel traffic from the Great Lakes to Calumet Harbor (USACE 2011a,b).

c. *Current Abundance and Reproductive Capacity*

T_0: The North American strain of the virus has established populations in all five Great Lakes since its discovery in 2003, and has been found in several inland waters of New York, Ohio, Michigan, and Wisconsin (Kipp et al. 2013). Once the virus is established in a region, it will become widespread, hosted by fish without disease symptoms, and capable of persistence at low but detectable levels (Bain et al. 2010). Benthic macroinvertebrates sampled in Lake Michigan have tested positive for the virus (Faisal et al. 2012). We did not find any documented fish kills in Lake Michigan resulting from VHSv.

T_{10}: See T_0.

T_{25}: See T_{10}.

T_{50}: See T_{25}. Changes in water temperature related to future climate change (Wuebbles et al. 2010) could affect the spread or virulence of this species in Lake Michigan.

d. *Existing Physical Human/Natural Barriers*

T_0: None.

T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

e. Distance from Pathway

T_0: As of 2009, VHSv was reported in Lake Michigan near Waukegan and Winthrop harbors in Illinois, and at Green Bay, Little Sturgeon Bay, Algoma, and Milwaukee in Wisconsin (Kipp 2013; Whelan 2009).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: VHSv has been detected in southwestern Lake Michigan at Waukegan and Winthrop harbors (Dudis 2011), suggesting climate is suitable. The pathogen replicates at temperatures of 2-15°C (35.6-59°F) (Wolf 1988; McAllister 1990; Meyers & Winton 1995); peak viral activity in the Great Lakes corresponds to spring spawning periods and in winter when temperatures are suitable (Eckerlin et al. 2011). Optimum replication temperature is 14-15°C, and can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and almost nonexistent at 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990). The virus is adapted to colder waters and becomes inactive after 24 hours in water temperatures greater than 20°C (CFSPH 2003; Hawley & Garver 2008). The Great Lakes genotype IVb has been confirmed in five coldwater and 19 coolwater species (Whelan 2009), and 28 species of fish from the Great Lakes basin are considered at risk (Dudis 2011). Fish are most susceptible to the virus during times of stress, in crowded conditions, during early life stages, and at cold temperatures (9-15°C; 48.2-59°F [Smail 1999]).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. VHSv is sensitive to climatological conditions. Future climate change and/or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for VHSv. Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could reduce the productivity of viral hemorrhagic septicemia.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv has spread throughout the Great Lakes in less than a decade. It has been documented in Lake Michigan as far south as Waukegan. There are no barriers to the

movement of this species by boat, current, or host fish. Therefore, the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is considered to be established in Lake Michigan and was documented offshore of the Waukegan and Winthrop harbors in Illinois (section 2e). Its ability to spread rapidly in the Great Lakes has been documented. Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. Type of Mobility/Invasion Speed
VHSv can be transported by the movement of infected fish or eggs, or through the movement of contaminated water (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008). The virus has a history of quickly invading through waterways, rivers, and lakes (Fisheries Technical Committee 2009). From Calumet Harbor, VHSv must move approximately 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. Human-Mediated Transport through Aquatic Pathways
Although there is little commercial river traffic to Calumet Harbor (NBIC 2012), there is heavy commercial vessel traffic between the Brandon Road Lock and Dam and the T.J. O'Brien Lock and Dam, which is approximately 8 km (5 mi) south of Calumet Harbor (USACE 2011a; NBIC 2012). VHSv may be transported in ballast water (Whelan 2009; Elsayed et al. 2006), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv could be transported through Calumet Harbor and move downstream to the Brandon Road Lock and Dam by gravity flow or fish hosts. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is well documented to move through waterways. There are fish species in the CAWS that could serve as hosts for VHSv and transport VHSv downstream. Overall, uncertainty of the probability of this species passing through the pathway is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
   VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011), and many of these species are also present in the Mississippi River Basin (e.g., rockbass, perch, drum). The virus spread to the Ohio River Basin (Clear Fork Reservoir) in 2008 (Kipp 2013).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
   VHSv could move downstream of Brandon Road Lock and Dam by passive dispersal or by being carried by a fish host.

Evidence for Probability Rating

There are no barriers keeping VHSv from moving downstream of Brandon Road Lock and Dam. This species is documented to spread through rivers. Reservoirs may also provide suitable habitat. There are also suitable fish hosts in the MRB. Therefore, this species is considered to have a high probability of colonization after passage through the pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

VHSv is documented to spread through freshwater. There are no documented barriers to spread that would keep this species from colonizing the MRB. Therefore, there is a low uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
VHSv is globally widespread and prefers cool temperatures (Kipp 2013). Therefore, climate may restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters or human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008).

c. *Fecundity*
VHSv can spread rapidly through waterways (Meyers & Winton 1995), and has multiple transmission vectors. The virus can persist in cold water without a host for an extended period and can continually be shed by asymptomatic carriers (Whelan 2009).

d. *History of Invasion Success*
VHSv spread rapidly through the Great Lakes since being discovered in 2003 and experiences occasional large-scale mortalities of fish (Bain et al. 2010). The virus was found in the Ohio River Basin in 2008 (Kipp 2013).

e. *Human-Mediated Transport through Aquatic Pathways*
VHSv may be transported in ballast water (Kipp 2013). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Mississippi River basin centrarchids, perch, and gizzard shad are among the species that are documented to serve as suitable hosts (http://www.miseagrant.umich.edu/files/2012/12/07-700-fs-VHSv.pdf; Dudis 2011). VHSv has been detected in Clear Creek Reservoir, which drains into the Ohio River and is part of the MRB (Kipp et al. 2013). VHSv survives best in cold waters. Optimum replication temperature is 14-15°C, and VHSv can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and the virus becomes inactive after 24 hours in water temperatures greater than 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990; CFSPH 2003; Hawley & Garver 2008). Considering these temperature restrictions, VHSv may not spread to the lower MRB.

Evidence for Probability Rating

VHSv has invaded the Ohio River Basin, suggesting it can also invade the MRB. VHSv is known to infect several species found in the MRB. VHSv could spread via host fish and by the significant vessel traffic between the upper and lower MRB. However, the temperature sensitivity of this species may reduce its spread south into the middle and lower MRB. Therefore, there is a medium probability of the VHSv spreading through the MRB.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

VHSv has been documented to readily spread through freshwater river basins. However, existing studies indicate that water temperatures south of the upper MRB may be unsuitable for VHSv. The ability of VHSv to adapt to warmer temperatures is uncertain. Therefore, the uncertainty associated with the probability of spread is medium.

PATHWAY: 4 (INDIANA HARBOR TO THE BRANDON ROAD LOCK AND DAM)

PROBABILITY OF ESTABLISHMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium	-[a]	Medium	-	Medium	-	Medium	-

[a] "-" Indicates an uncertainty rating was not assigned to P(establishment) because there is no objective way to characterize overall uncertainty for an aggregate rating.

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between Indiana Harbor and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Viral hemorrhagic septicemia (VHSv) is a viral disease of freshwater and marine fish. Until the 1980s, VHSv was believed to be isolated to freshwaters of Europe (Wolf 1988). Since that time, four genotypes of the virus have been found in various marine and freshwater habitats, including water bodies in Europe, North America, Korea, and Japan (Nishizawa et al. 2002; Skall et al. 2005), with the first known report in the Great Lakes in 2003 from Lake St. Clair (Elsayed et al. 2006). The virus has now reached all five Great Lakes after being reported in Lake Superior in 2010 (MNDR 2010). Viral hemorrhagic septicemia genotype IVb has now been confirmed in five coldwater species and 19 coolwater species in the Great Lakes (Whelan 2009); 28 species of fish from the Great Lakes basin are considered at risk from the virus, including smallmouth bass, walleye, and bluegill (Dudis 2011). VHSv can be transmitted horizontally and vertically amongst fish populations (Whelan 2009). Chronically infected fish shed the virus through urine and reproductive fluids (Meyers & Winton 1995); ingesting infected prey fish or invertebrates harboring the virus can also lead to infection (Ahne 1980; Skall et al. 2005; Faisal & Winters 2011). VHSv can exist for extended periods of time in freshwater without a host, depending on temperature (Whelan 2009; Hawley & Garver 2008); contact with water containing the virus is also a means of spread (Castric & de Kinkelin 1980; Muroga et al. 2004). Infected females can also shed the virus during egg deposition; the virus can persist for a long enough period to infect progeny (Tuttle-Lau et al. 2010). Blood-sucking leeches are also potential transmitters of the virus to fish (Faisal & Schulz 2009).

b. *Human-Mediated Transport through Aquatic Pathways*
Potential spread mechanisms include the movement of infected fish (baitfish or gamefish) to new water bodies; transporting contaminated waters, fish, or fish parts in ballast water or in bilges of recreational boats; or the movement of contaminated fishing equipment (Whelan 2009; Warren 1983). Ship ballast has been shown to be a transport mechanism of non-native bacteria and viruses (Drake et al. 2007); however, the current distribution of the virus does not suggest shipping-related transport (Bain et al. 2010). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. There is heavy commercial vessel traffic from the Great Lakes to Indiana Harbor (USACE 2011a).

c. *Current Abundance and Reproductive Capacity*

T_0: The North American strain of the virus has established populations in all five Great Lakes since its discovery in 2003, and has been found in several inland waters of New York, Ohio, Michigan and Wisconsin (Kipp et al. 2013). Once the virus is established in a region, it will become widespread, hosted by fish without disease symptoms, and capable of persistence at low but detectable levels (Bain et al. 2010). Benthic macroinvertebrates sampled in Lake Michigan have tested positive for the virus (Faisal et al. 2012). We did not find any documented fish kills in Lake Michigan resulting from VHSv.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0. Changes in water temperature related to future climate change (Wuebbles et al. 2010) could affect the spread or virulence of this species in Lake Michigan.

d. *Existing Physical Human/Natural Barriers*

T_0: None.

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

e. *Distance from Pathway*

T_0: VHSv was reported in Lake Michigan near Waukegan, Illinois, and at Green Bay, Little Sturgeon Bay, Algoma, and Milwaukee in Wisconsin (Kipp 2013; Whelan 2009).

T_{10}: See T_0.

T_{25}: See T_0.

T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*

T_0: VHSv has been detected in southwestern Lake Michigan at Waukegan and Winthrop harbors (Dudis 2011), suggesting climate is suitable. The pathogen replicates at temperatures of 2-15°C (35.6-59°F) (Wolf 1988; McAllister 1990; Meyers & Winton 1995); peak viral activity in the Great Lakes corresponds to spring spawning periods and in winter when temperatures are suitable (Eckerlin et al. 2011). Optimum replication temperature is 14-15°C, and VHSv can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and almost nonexistent at 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990). The virus is adapted to colder waters and becomes inactive after 24 hours in water temperatures greater than 20°C (CFSPH 2003; Hawley & Garver 2008). The Great Lakes genotype IVb has been confirmed in five coldwater and 19 coolwater species (Whelan 2009), and 28 species of fish from the Great Lakes basin are considered at risk (Dudis 2011). Fish are most susceptible to the virus during times of stress, in crowded conditions, during early life stages, and at cold temperatures (9-15°C; 48.2-59°F [Smail 1999]).

T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_{25}. VHSv is sensitive to climatological conditions. Future climate change and/or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for VHSv. Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), which could reduce the productivity of VHSv.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv has spread throughout the Great Lakes in less than a decade. It has been documented in Lake Michigan as far south as Waukegan. There are no barriers to the movement of this species by boat, current, or host fish. Therefore, the probability of arrival is high.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is considered to be established in Lake Michigan and was documented offshore of the Waukegan and Winthrop harbors in Illinois, but has not yet been reported from southern Lake Michigan (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters, or human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008). The virus has a history of quickly invading through waterways, rivers, and lakes (Fisheries Technical Committee 2009). From Indiana Harbor, VHSv must move to reach the Brandon Road Lock and Dam. The downstream flow of water and fish hosts would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic to Indiana Harbor is primarily lake-wide (USACE 2011a). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. VHSv may be transported in ballast water (Whelan 2009; Elsayed et al. 2006), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). There is no vessel traffic in the Grand Calumet River east of Indiana Harbor. Consequently, some natural downstream dispersal would likely be necessary to reach the Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010).
T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011). Survivors of the virus continually shed the virus in urine and reproductive fluids throughout their lifetime (Whelan 2009). Water flows out of Indiana Harbor into Lake Michigan. West of the Indiana Harbor Canal, the easternmost sections of the Grand Calumet River also generally flow toward Lake Michigan, and other sections can flow east or west depending on location (Weiss et al. 1997). Thus, the virus would have to move upstream via infected fish to enter the CAWS and move to the Calumet Sag Channel.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv could be transported through the Indiana Harbor and move downstream to the Brandon Road Lock and Dam by gravity flow or fish hosts. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is well documented to move through waterways. There are fish species in the CAWS that could serve as hosts for VHSv and transport VHSv downstream. Overall, uncertainty of the probability of this species passing through the pathway is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within one day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011), and many of these species are also present in the Mississippi River Basin (e.g., rockbass, perch, drum). The virus spread to the Ohio River Basin (Clear Fork Reservoir) in 2008 (Kipp 2013).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal*
VHSv could move downstream of Brandon Road Lock and Dam by passive dispersal or by being carried by a fish host.

Evidence for Probability Rating

There are no barriers keeping VHSv from moving downstream of Brandon Road Lock and Dam. This species is documented to spread through rivers. Reservoirs may also provide suitable habitat. There are also suitable fish hosts in the MRB. Therefore, this species is considered to have a high probability of colonization after passage through the pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

VHSv is documented to spread through freshwater. There are no documented barriers to spread that would keep this species from colonizing the MRB. Therefore, there is a low uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
VHSv is globally widespread and prefers cool temperatures (Kipp 2013). Therefore, climate may restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters or human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008).

c. *Fecundity*
VHSv can spread rapidly through waterways (Meyers & Winton 1995), and has multiple transmission vectors. The virus can persist in cold water without a host for an extended period and can continually be shed by asymptomatic carriers (Whelan 2009).

d. *History of Invasion Success*
VHSv spread rapidly through the Great Lakes since being discovered in 2003 and causes occasional large-scale mortalities of fish (Bain et al. 2010). The virus was found in the Ohio River Basin in 2008 (Kipp 2013).

e. *Human-Mediated Transport through Aquatic Pathways*
VHSv may be transported in ballast water (Kipp 2013). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Mississippi River basin centrarchids, perch, and gizzard shad are among the species that are documented to serve as suitable hosts (http://www.miseagrant.umich.edu/files/2012/12/07-700-fs-VHSv.pdf; Dudis 2011). VHSv has been detected in Clear Creek Reservoir, which drains into the Ohio River and is part of the MRB (Kipp et al. 2013). VHSv survives best in cold waters. Optimum replication temperature is 14-15°C, and VHSv can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and the virus becomes inactive after 24 hours in water temperatures greater than 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990; CFSPH 2003; Hawley & Garver 2008). Considering these temperature restrictions, VHSv may not spread to the lower MRB.

Evidence for Probability Rating

VHSv has invaded the Ohio River Basin, suggesting it can also invade the MRB. VHSv is known to infect several species found in the MRB. VHSv could spread via host fish and by the significant vessel traffic between the upper and lower MRB. However, the temperature sensitivity of this species may reduce its spread south into the middle and lower MRB. Therefore, there is a medium probability of the VHSv spreading through the MRB.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

VHSv has been documented to readily spread through freshwater river basins. However, existing studies indicate that water temperatures south of the upper MRB may be unsuitable for VHSv. The ability of VHSv to adapt to warmer temperatures is uncertain. Therefore, the uncertainty associated with the probability of spread is medium.

PATHWAY: 5 (BURNS SMALL BOAT HARBOR [BSBH] TO THE BRANDON ROAD LOCK AND DAM)

RISK ASSESSMENT SUMMARY

Probability Element	T_0		T_{10}		T_{25}		T_{50}	
	P	U	P	U	P	U	P	U
P(pathway)	High	None	High	None	High	None	High	None
P(arrival)	High	Low	High	Low	High	Low	High	Low
P(passage)	High	Low	High	Low	High	Low	High	Low
P(colonizes)	High	Low	High	Low	High	Low	High	Low
P(spreads)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P(establishment)	Medium		Medium		Medium		Medium	

EVIDENCE FOR ESTIMATING THE PROBABILITY OF ESTABLISHMENT/UNCERTAINTY

1. P(pathway) T_0-T_{50}: HIGH

Evidence for Probability Rating

Pathway is visible, confirmed, and present year-round. No activities or events are anticipated that would reduce or eliminate the hydrologic connection between the BSBH and the Brandon Road Lock and Dam over the next 50 years.

Uncertainty: NONE

Evidence for Uncertainty Rating

The existence of the pathway has been confirmed with certainty.

2. P(arrival) T_0-T_{50}: HIGH

In determining the probability of arrival, the pathway is assumed to exist.

Factors That Influence Arrival of Species

a. *Type of Mobility/Invasion Speed*
Viral hemorrhagic septicemia (VHSv) is a viral disease of freshwater and marine fish. Until the 1980s, VHSv was believed to be isolated to freshwaters of Europe (Wolf 1988). Since that time, four genotypes of the virus have been found in various marine and freshwater habitats, including water bodies in Europe, North America, Korea, and Japan (Nishizawa et al. 2002; Skall et al. 2005). It was first reported in the Great Lakes in 2003 from Lake St. Clair (Elsayed et al. 2006), and by 2010 it had spread to all five Great Lakes (MNDR 2010). Viral hemorrhagic septicemia genotype IVb has now been confirmed in five coldwater species and 19 coolwater species in the Great Lakes (Whelan 2009); 28 species of fish from the Great Lakes basin are considered at risk from the virus, including smallmouth bass, walleye, and bluegill (Dudis 2011). Susceptible fish contract the virus by close proximity to other infected individuals, or by ingesting infected

material. Affected fish shed the virus into the surrounding environment through urine and reproductive fluids (Meyers & Winton 1995); the virus can enter the body through the gills, open wounds, or ingestion (Whelan 2009). Survivors of viral infection are carriers and continue to shed virus particles for extended periods of time (Kim & Faisal 2012). Ingesting infected prey fish or invertebrates harboring the virus can also lead to infection (Ahne 1980; Skall et al. 2005; Faisal & Winters 2011). VHSv can exist for extended periods of time in freshwater without a host, depending on temperature (Whelan 2009; Hawley & Garver 2008); contact with water containing the virus is also a means of spread (Castric & de Kinkelin 1980; Muroga et al. 2004). Infected females can also shed the virus during egg deposition; the virus can persist for a long enough period to infect progeny (Tuttle-Lau et al. 2010). Blood-sucking leeches are also potential transmitters of the virus to fish (Faisal & Schulz 2009).

b. Human-Mediated Transport through Aquatic Pathways

Potential spread mechanisms include the movement of infected fish (baitfish or gamefish) to new water bodies; transporting contaminated waters, fish, or fish parts in ballast water or in bilges of recreational boats; or the movement of contaminated fishing equipment (Whelan 2009; Warren 1983). Ship ballast has been shown to be a transport mechanism of non-native bacteria and viruses (Drake et al. 2007); however, the current distribution of the virus does not suggest shipping-related transport (Bain et al. 2010). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. There is recreational but no commercial vessel traffic from the Great Lakes to the BSBH (USACE 2011a). However, there is heavy commercial traffic to Burns Harbor, which is adjacent to the BSBH.

c. Current Abundance and Reproductive Capacity

T_0: The North American strain of the virus has established populations in all five Great Lakes since its discovery in 2003, and has been found in several inland waters of New York, Ohio, Michigan, and Wisconsin (Kipp et al. 2013). Once the virus is established in a region, it will become widespread, hosted by fish without disease symptoms, and capable of persistence at low but detectable levels (Bain et al. 2010). Benthic macroinvertebrates sampled in Lake Michigan have tested positive for the virus (Faisal et al. 2012). We did not find any documented fish kills in Lake Michigan resulting from VHSv.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0. Changes in water temperature related to future climate change (Wuebbles et al. 2010) could affect the spread or virulence of this species in Lake Michigan.

d. Existing Physical Human/Natural Barriers

T_0: None.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

e. *Distance from Pathway*
T_0: As of 2009, VHSv had been reported in Lake Michigan near Waukegan and Winthrop harbors in Illinois, and at Green Bay, Little Sturgeon Bay, Algoma, and Milwaukee in Wisconsin (Kipp 2013; Whelan 2009).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
T_0: VHSv has been detected in southwestern Lake Michigan at Waukegan and Winthrop harbors (Dudis 2011), suggesting climate is suitable. The pathogen replicates at temperatures of 2-15°C (35.6-59°F) (Wolf 1988; McAllister 1990; Meyers & Winton 1995); peak viral activity in the Great Lakes corresponds to spring spawning periods and in winter when temperatures are suitable (Eckerlin et al. 2011). Optimum replication temperature is 14-15°C, and VHSv can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and almost nonexistent at 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister 1990). The virus is adapted to colder waters and becomes inactive after 24 hours in water temperatures greater than 20°C (CFSPH 2003; Hawley & Garver 2008). The Great Lakes genotype IVb has been confirmed in five coldwater and 19 coolwater species (Whelan 2009), and 28 species of fish from the Great Lakes basin are considered at risk (Dudis 2011). Fish are most susceptible to the virus during times of stress, in crowded conditions, during early life stages, and at cold temperatures (9-15°C; 48.2-59°F [Smail 1999]).
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}. VHSv is sensitive to climatological conditions. Future climate change and/or new environmental regulations may alter the physical, chemical, and climatological suitability of the Great Lakes for VHSv. Future climate change is projected to increase water temperature in the Great Lakes (Wuebbles et al. 2010), and this could affect the virulence, spread, or abundance of VHSv.

Probability of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: VHSv has spread throughout the Great Lakes in less than a decade. It has been documented in Lake Michigan as far south as Waukegan. There are no barriers to the movement of this species by boat, current, or host fish. Therefore, the probability of arrival is high.
T_{10}: See T_0.

T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Arrival

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is considered to be established in Lake Michigan and was documented offshore of the Waukegan and Winthrop harbors in Illinois, but has not been reported from southern Lake Michigan (section 2e). Therefore, the uncertainty of the probability of arrival is considered to be low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

3. P(passage) T_0-T_{50}: HIGH

In determining the probability of passage, the species is assumed to have arrived at the pathway.

Factors That Influence Passage of Species (Considering All Life Stages)

a. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters, or human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008). The virus has a history of quickly invading through waterways, rivers, and lakes (Fisheries Technical Committee 2009). From the BSBH, VHSv must move more than 64 km (40 mi) downstream to reach the Brandon Road Lock and Dam. The downstream flow of water and fish hosts would facilitate the transport of this species downstream of the Brandon Road Lock and Dam.

b. *Human-Mediated Transport through Aquatic Pathways*
Vessel traffic to the BSBH is primarily lake-wide (USACE 2011a,b). While VHSv is not a sedentary hull-fouling species, it could be transported on hulls either in a host invertebrate or as part of the microbial encrusting community. VHSv may be transported in ballast water (Whelan 2009; Elsayed et al. 2006), although the discharge of ballast water does not typically occur at inland ports within the CAWS (NBIC 2012). Consequently, some natural downstream dispersal would likely be necessary to reach the Brandon Road Lock and Dam.

c. *Existing Physical Human/Natural Barriers*
T_0: None. Surface water is present year-round, and water depth is adequate throughout the CAWS (LimnoTech 2010).

T_{10}: See T_0. No changes in human or natural barriers are expected.
T_{25}: See T_{10}.
T_{50}: See T_{10}.

d. Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)

T_0: VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011), and many of these species are found in the CAWS. Water flows out of the BSBH into Lake Michigan. The eastern segment of the south branch of the Little Calumet River also generally flows toward Lake Michigan, depending on location and water level in Lake Michigan (GSWMD 2008). To enter and pass through the BSBH, this species would have to move upstream through Burns Ditch and portions of the south branch of the Little Calumet River, where flow direction is toward Lake Michigan.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_{25}.

Probability of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	High	High	High	High

Evidence for Probability Rating (Considering All Life Stages)

T_0: Water flow in the BSBH and portions of the Little Calumet River is toward Lake Michigan. Because of the lack of vessel traffic (section 3b), natural spread via fish hosts through the south branch of the Little Calumet River will likely be required for VHSv to move from Lake Michigan to the Calumet Sag Channel. After reaching the Calumet Sag Channel, VHSv could move to Brandon Road Lock and Dam by gravity flow or fish hosts. Overall, this species is considered to have a high probability of passing through the pathway.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

Uncertainty of Passage

Time Step	**T_0**	**T_{10}**	**T_{25}**	**T_{50}**
Rating	Low	Low	Low	Low

Evidence for Uncertainty Rating

T_0: VHSv is well documented to move through waterways. There are fish species in the CAWS that could serve as hosts for VHSv and transport VHSv downstream. Overall, uncertainty of the probability of this species passing through the pathway is low.
T_{10}: See T_0.
T_{25}: See T_0.
T_{50}: See T_0.

4. P(colonizes): HIGH

In determining the probability of colonization, the species is assumed to have passed through the pathway. The probability of colonization is the same for all time steps.

Factors That Influence Colonization of Species (Considering All Life Stages)

a. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Great Lakes basin, 28 fish species are at risk from the virus (Dudis 2011), and many of these species are also present in the Mississippi River Basin (e.g., rockbass, perch, drum). The virus spread to the Ohio River Basin (Clear Fork Reservoir) in 2008 (Kipp 2013).

b. *Ability of the Species to Reach Suitable Habitat by Natural or Human-Mediated Dispersal.*
VHSv could move downstream of Brandon Road Lock and Dam by passive dispersal or by being carried by a fish host.

Evidence for Probability Rating

There are no barriers keeping VHSv from moving downstream of Brandon Road Lock and Dam. This species is documented to spread through rivers. Reservoirs may also provide suitable habitat. There are also suitable fish hosts in the MRB. Therefore, this species is considered to have a high probability of colonization after passage through the pathway.

Uncertainty: LOW

Evidence for Uncertainty Rating

VHSv is documented to spread through freshwater. There are no documented barriers to spread that would keep this species from colonizing the MRB. Therefore, there is a low uncertainty of colonization after passage through the pathway.

5. P(spreads): MEDIUM

In determining the probability of spread, the species is assumed to have colonized in the MRB. The probability of spread is the same for all time steps.

Factors That Influence Spread of Species

a. *Suitable Climate in the MRB*
VHSv is globally widespread and prefers cool temperatures (Kipp 2013). Therefore, climate may restrict the spread of this species into the southern MRB.

b. *Type of Mobility/Invasion Speed*
VHSv has a history of rapid spread through waterways by movement of infected fish or virus-containing waters or human-mediated mechanisms (Meyers & Winton 1995; Whelan 2009; Hawley & Garver 2008).

c. *Fecundity*
VHSv can spread rapidly through waterways (Meyers & Winton 1995), and has multiple transmission vectors. The virus can persist in cold water without a host for an extended period and can continually be shed by asymptomatic carriers (Whelan 2009).

d. *History of Invasion Success*
VHSv spread rapidly through the Great Lakes since being discovered in 2003 and experiences occasional large-scale mortalities of fish (Bain et al. 2010). The virus was found in the Ohio River Basin in 2008 (Kipp 2013).

e. *Human-Mediated Transport through Aquatic Pathways*
VHSv may be transported in ballast water (Kipp 2013). There is heavy vessel traffic between the Brandon Road Lock and Dam and the lower MRB (USACE 2011a,b).

f. *Suitable Habitat (Physical, Structural, Hydrologic, Hydraulic, Chemical, and Climatological)*
VHSv has been reported from both freshwater and marine environments (Kipp 2013). The virus can exist in freshwater for extended periods of time without a host, particularly at cool water temperatures (Hawley & Garver 2008). At high water temperatures (30°C; 86°F), the virus becomes inactivated within 1 day (Hawley & Garver 2008). Within the Mississippi River basin centrarchids, perch, and gizzard shad are among the species that are documented to serve as suitable hosts (http://www.miseagrant.umich.edu/files/2012/12/07-700-fs-VHSv.pdf; Dudis 2011). VHSv has been detected in Clear Creek Reservoir, which drains into the Ohio River and is part of the MRB (Kipp et al. 2013). VHSv survives best in cold waters. Optimum replication temperature is 14-15°C, and VHSv can last a few weeks in freshwater at moderate temperatures (10-15°C; 59°F) without a host (Hawley & Garver 2008; Whelan 2009). Replication is low at 6°C and the virus becomes inactive after 24 hours in water temperatures greater than 20°C (de Kinkelin et al. 1980; Bernard et al. 1983; McAllister

1990; CFSPH 2003; Hawley & Garver 2008). Considering these temperature restrictions, VHSv may not spread to the lower MRB.

Evidence for Probability Rating

VHSv has invaded the Ohio River Basin, suggesting it can also invade the MRB. VHSv is known to infect several species found in the MRB. VHSv could spread via host fish and by the significant vessel traffic between the upper and lower MRB. However, the temperature sensitivity of this species may reduce its spread south into the mid and lower MRB. Therefore, there is a medium probability of the VHSv spreading through the MRB.

Uncertainty: MEDIUM

Evidence for Uncertainty Rating

VHSv has been documented to readily spread through freshwater river basins. However, existing studies indicate that water temperatures south of the upper MRB may be unsuitable for VHSv. The ability of VHSv to adapt to warmer temperatures is uncertain. Therefore, the uncertainty associated with the probability of spread is medium.

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