Appendix C

ANS Control Fact Sheets

Accelerated Water Velocity

ANS Control: Accelerated Water Velocity

Targeted Species: Accelerated Water Velocity may be effective in preventing the upstream transfer of all ANS of Concern – CAWS[1] via aquatic pathways. For more information, see *General Effectiveness* and *Operating Constraints* sections of this fact sheet.

Selectivity: Accelerated water velocity is a unidirectional barrier, meaning that it prevents only upstream movement of organisms and is non-selective.

Developer/Manufacturer/Researcher: Velocity barriers have been used by a variety of Federal and state natural resource agencies. New applications for this technology are being researched by Theodore Castro-Santos of the Conte Anadromous Fish Lab.

Accelerated water velocity channels must be smooth to prevent the formation of low velocity flow zones near the walls.

Brief Description: Accelerated water velocity works by generating a zone of water that flows faster downstream than an organism can swim upstream, thus creating a barrier. For this to work, the water velocity must correlate with the swimming performance of the ANS. Swimming performance of fish is defined as the capability plus the behavioral motivation to swim at a maximum rate of speed (McPhee & Watts 1976). This can be broken down into three activity levels: burst, prolonged, and sustained. Burst speeds are variably defined as swim speeds that can be maintained for only "a few seconds," less than 20 seconds, less than 30 seconds, and less than 60 seconds, depending on the research and fish species considered. Burst speeds, however, are typically two to four times greater than maximum sustained and prolonged swim speeds. Prolonged swimming, with periods of cruising and occasional bursts, can be maintained for 15 seconds to 200 minutes. Sustained swimming activity can be maintained for longer than 200 minutes (Blaxter 1969; Farlinger & Beamish 1977). The wall material of the accelerated water velocity channel should be smooth and solid to minimize drag along the edges that could slow flow and allow organisms to pass.

Many factors such as species, body length, form, physiological condition, conditioning to currents, motivation and behavior, water temperature, concentration of dissolved gases, turbidity, and light influence the swimming performance of fishes (Bainbridge 1960; Dahlberg et al. 1968; Farlinger & Beamish 1977; Gray 1957; Hocutt 1973; McPhee & Watts 1976). Substrate size and roughness also facilitate station holding and influence swimming performance by creating boundary layers and areas of turbulence, which fish use to navigate through fast-flowing waters. Younger life stages of migratory species have slower swimming speeds, given their shorter length, and schooling fish have a hydromechanical advantage and may be able to make progress against faster currents as a school rather than when swimming individually.

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[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Prior Applications: Accelerated water velocity barriers have been constructed in the Great Lakes Region to block spawning runs of sea lampreys, while still allowing desirable fish to pass and reach their spawning grounds (Great Lakes Fishery Commission 2000). Accelerated velocity barriers have been widely studied at road culverts and dams, which prevent upstream movement of fish to habitats critical for species survival. Though most of this research was conducted to better enable migratory species to pass obstacles, it could be applied to prevent the upstream movement of ANS.

General Effectiveness: When properly designed, high-velocity barriers work well to control the movement of upstream movement of organisms but cannot prevent their downstream movement.

Operating Constraints: For an accelerated water velocity barrier to be effective, a constant velocity must be maintained throughout the water column under a wide range of channel discharges. This technology is best suited for use at dams, road culverts, and small canals. The effectiveness of accelerated water velocity channels is reduced in frequently flooded areas because ANS can swim past if floodwaters submerge the barrier and spill onto the floodplain. Under certain circumstances, a desired velocity may be achieved by installing riffles, relatively shallow and coarsely-bedded lengths of a river or stream, over which flows are at higher velocity and higher turbulence than the average stream flow velocity.

Velocity barriers must have a length and flow velocity greater than the fish's leaping ability and swimming endurance. Generally, a minimum flow of 7 feet per second over a distance of 180 feet would prevent upstream fish movement in the CAWS. Structures needed to maintain the required minimum velocity could interfere with navigation. Accelerated water velocity channels prevent upstream movement of non-target aquatic organisms.

Cost Considerations:

Implementation: The implementation of this Control would include planning, design, and construction of high-velocity channels. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Velocity barriers would require periodic monitoring, debris removal and replacement of worn sections.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

Bainbridge, R. 1960. Speed and stamina in three fish. *The Journal of Experimental Biology*, vol. 37, pp. 129-153

Blaxter, J.H.S. 1969. Swimming speeds of fish. *FAO Fisheries Report*, vol. 62(2), pp. 69-100

Castro-Santos, T. 2005. Optimal swim speeds for traversing velocity barriers: an analysis of volitional high-speed swimming behavior of migratory fishes. *The Journal of Experimental Biology,* vol 208, pp. 421-432

Dahlberg, M.L., D.L. Shumway, & P. Doudoroff. 1968. Influence of dissolved oxygen and carbon dioxide on swimming performance of largemouth bass and coho salmon. *Journal of the Fisheries Research Board of Canada,* vol. 25, pp. 49-70

Farlinger, S. & F.W.H. Beamish. 1977. Effects of time and velocity increments on the critical swimming speed of largemouth bass (*Micropterus salmoides*). *Transactions of the American Fisheries Society,* vol. 106, pp. 436-439

Gray, J. 1957. How fishes swim. *Scientific American,* vol. 197(2), pp. 48-65

Great Lakes Fishery Commission. 2000. Sea lamprey barriers new technologies help solve an old problem. Great Lakes Fisheries Commission Fact Sheet 5. Ann Arbor, MI. Accessed December 18, 2011. http://www.glfc.org/pubs/FACT_5.pdf

Hocutt, C.H. 1973. Swimming performance of three warmwater fishes exposed to rapid temperature change. *Chesapeake Science,* vol. 14(1), pp. 11-16

McPhee C. & F.J. Watts. 1976. Swimming performance of Arctic grayling in highway culverts. University of Idaho College of Forestry, Wildlife and Range Sciences Bulletin 13, Moscow, ID

Acoustic Fish Deterrents

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control Technology:
Acoustic Fish Deterrents – Continuous Wave and Pulsed Pressure Wave.

USGS researchers and their associates observe Asian carp.

Targeted Species: This Control may be effective for fish of the ANS of Concern – CAWS [1], namely: alewife (*A. pseudoharengus*), bighead carp (*H. nobilis*), black carp (*Mylopharyngodon piceus*), blueback herring (*Alosa aestivalis*), inland silverside (*Menidia beryllina*), northern snakehead (*Channa argus*), ruffe (*Gymnocephalus cernuus*), sea lamprey (*Petromyzon marinus*), silver carp (*H. molitrix*), skipjack herring (*A. chrysochloris*), threespine stickleback (*Gasterosteus aculeatus*), and tubenose goby (*Proterorhinus marmoratus*).

Selectivity: This Control was developed to specifically target fish and is generally non-selective among fish species. There is no information on its effects on aquatic invertebrates.

Developer/Manufacturer/Researcher: The main manufacturers of seismic technology are Bolt Technology, Sercel, and Ion Geophysical Corp[2]; currently the only developer of water gun technology is Bolt Technology. The U.S. Geological Survey (USGS) Illinois Water Science Center is evaluating the effects of sound technology on physical structures in water, e.g. lock and dams, and to accurately map the pressure gradients generated from water gun operation. The USGS Great Lakes Science Center and USGS Upper Midwest Environmental Sciences Center are completing research to evaluate the use of water guns to alter fish behavior, including evaluations as potential barriers to the movement of Asian carp.

Brief Description: There are two general types of acoustic fish deterrents: continuous wave and pulsed wave. These deterrents use sound/pressure waves (noise) to influence the behavior of or injure aquatic organisms. The Controls presented in this fact sheet have the potential to be lethal if the organism is close to the source of the pressure wave, though most are not considered lethal for animals located at distance from the sound source. Acoustic fish deterrents can be stationary or semi-portable. The compressor required to operate the larger pulsed pressure wave water guns for any length of time weighs about 3,000 lbs, however smaller configurations have been used experimentally in the CAWS.

It has been shown that underwater ensonification at the resonant frequency of the lung can damage and even kill aquatic organisms. This is due to the resonance of the wave creating disturbances within air-filled cavities, which leads to tissue damage. For fish, the most vulnerable to underwater sound are

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

those with swim bladders. Carp fit into this category and thus are expected to be sensitive to underwater sound at the resonant frequency of the swim bladder.

The use of underwater ensonification could be effective in controlling carp movement within restricted waterways, where the sound could not be avoided. If the swim bladder of the Asian carp is susceptible to specific frequencies, this approach may have the advantage of specifically targeting carp and not affecting other species.

Continuous Wave – Continuous wave sonar uses high intensity, low-frequency sonar waves generated from a Low Frequency Active (LFA) sonar source array. The LFA sonar source array is a set of acoustic transmitters that produce sound that is irritating to fish. Continuous wave sonar was originally developed by the United States Navy to identify submarines (Tyler 1992), but is now being tested to determine if it can be used as a deterrent or as part of a fish guidance system or barrier.

Pulsed Pressure Wave - Pulsed pressure waves are high intensity sound/pressure waves generated by a sound source (hydro gun, air gun, blast explosive) to irritate, harm, or kill aquatic organisms. A hydro gun produces sound waves using a pneumatically- or hydraulically-powered piston. In contrast, an air gun produces sound waves by the explosive release of high pressure air directly into the surrounding water. Blast explosives (e.g. primacord), on the other hand, send a concussive shock wave through the water. Hydro guns produce shorter, cleaner implosive pressure waves which produce higher frequencies than the air gun. Air guns are superior for oil exploration as they produce more low frequency waves and deep penetration of the water column (Hutchinson & Detrick 1984). Since output pressures are dependent on input air pressure, very low operating pressures at a sub-lethal level may motivate fish to move from the direction of the source. The pressure gradient surrounding a gun will be dependent on the input pressure to the gun – that is, a given gradient of constant pressure will be further from a gun fired at 2,000 PSI vs. the same gun fired at 1,000 PSI. Similarly, a given pressure gradient may be further from a large gun than a small gun even if operated at the same pressure. Air guns and hydro guns may be fired in repeated bursts. Blast explosives are less suited for continuous application due to the chronic need to reset charges and the possible release of toxic residues.

Prior Applications:

Continuous Wave – The effects of continuous wave sonar have been widely studied on marine mammals and fish; however, its use as a fish deterrent is a new approach in freshwater.

Pulsed Pressure Wave - Air guns were developed in the 1960s and are used for a variety of purposes, including marine petroleum exploration and as a fish deterrent in both freshwater and marine environments. Hydro guns were developed in the 1980s for the same purposes and are presently being studied in the Chicago Sanitary and Ship Canal by USGS. The USGS is studying the effects of water guns to alter the behavior of invasive Asian carp as a means to inhibit movement (e.g. to herd fish toward commercial fishing nets) and stop dispersal (i.e. to create a barrier). Initial studies will determine the effects of different sound wave frequencies on various age classes of Asian carp, at a range of distances from the sound source. The magnitude of the sound wave will be measured in order to quantify fish response to sound impacts. Initial and delayed lethality will be assessed, as well as sub-lethal evading behaviors (Asian Carp Regional Coordinating Committee 2011). Blast explosives are commonly used at construction areas to protect fish near work zones (Keevin & Hempen 1997).

General Effectiveness: The response of fish to loud noises ranges from no response, short term avoidance (moving away from the sound source), long term avoidance (altering behavior to avoid the sound), physiological damage (hearing loss), and even death (tissue disruption). A variety of factors including frequency of pressure waves, intensity, duration, and distance from acoustic source influences effectiveness (Popper 2003; Halvorsen et al. 2011).

Continuous Wave **–** The LFA sonar source array has been shown to have a non-lethal behavioral effect on rainbow trout. However, the results varied with different groups of trout, suggesting developmental and or genetic impacts on how sound exposure affects hearing (Popper et al. 2007).

Pulsed Pressure Wave – The effectiveness of pulsed pressure waves is mixed—incidental observations during blasting operations indicate that individual blast explosions are not very effective in "scaring" fish from the blast zone for long periods of time (Ferguson 1962; Nix & Chapman 1985; Falk & Lawrence 1973; Keevin & Hempen 1997), and the sound of the air gun had little effect on the day-to-day behavior of the resident fish and invertebrates in a marine environment (Wardle et al. 2001). However, the pulsed pressure waves are lethal to adults, eggs and larvae, although larval fish are less sensitive than those in which the swim bladder has developed (California Department of Fish and Game 2002). The lethality of pulsed pressure waves varies with fish size, species, orientation of the fish relative to the shock wave, amount and type of explosive, detonation depth, target depth, water depth, and bottom type (Wright 1982).

Operating Constraints The repeated use of these technologies may have a deleterious effect on canal walls and underwater structures, would impact navigation, and may present safety issues, possibly requiring public access restrictions. Considerations include the quantity of explosives that could be used safely in one session, water flow and turbidity in the vicinity of explosives placement, navigation blockage, and safety issues. The repeated use of explosives could result in an accumulation of explosive residue that may impact water quality downstream of the treatment area.

Cost Considerations: Both Controls may require the armoring and shoring of canal walls and underwater structures to withstand repeated shock waves.

Continuous Wave –

Implementation: The LFA sonar source array is being tested experimentally. If successful, full implementation would involve the development of a land-based project site for mounting and operating this Control.

Planning and design activities in the implementation phase may include research and development of the technology, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: This Control would require maintenance of mechanical devices, electricity, and monitoring of equipment and fish populations.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Pulsed Pressure Wave –

Implementation: The water gun is being tested experimentally. If successful, full implementation would involve the development of a land-based project site for mounting and operating this technology. The USGS is exploring different methods to also deploy the gun from mobile locations. The implementation cost of this Control depends on the quantity and type of blast explosives used, as well as possible long-term effects of blast explosives in the body of water and surrounding areas. If hydro guns are used there wouldn't be any residues remaining.

Planning and design activities in the implementation phase may include research and development of the technology, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: This Control would require maintenance of mechanical devices and monitoring of equipment, surrounding infrastructure, and fish populations to gauge the effect of repeated pressure waves.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

Asian Carp Regional Coordinating Committee. 2011. 2011 Asian carp control strategy framework. Council on Environmental Quality, Washington, D.C.

California Department of Fish and Game. 2002. Use of detonation cord in Lake Davis to control population of northern pike. California Department of Fish and Game, Sacramento, CA

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Halvorsen, M.B., T.J. Carlson, A.N. Popper, B.M. Casper, & C.M. Woodley. 2011. Hydroacoustic impacts on fish from pile installation. Research Results Digest 363, National Cooperative Highway Research Program, Transportation Board of the National Academies, Washington D.C.

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Keevin, T.M. & G.L. Hempen. 1997. The Environmental Effects of Underwater Explosions With Methods To Mitigate Impacts. U.S. Army Corps of Engineers, St. Louis District, St. Louis, MO

Nix, P., & P. Chapman. 1985. Monitoring of underwater blasting operations in False Creek, B.C. pp 194-211 in G. D. Greene, F. R. Engelhardt and R. J. Paterson, editors. Proceedings of the workshop on effects of explosive use in the marine environment, 29-31 January 1985, Environmental Protection Branch Technical Report No. 5, Canada Oil and Gas Lands Administration, Ottawa, Ontario

Popper, A.N., 2003. Effects of anthropogenic sounds on fishes. *Fisheries*, vol. 28(10), pp 24-31

Tyler, G.D. 1992. The emergence of low-frequency active acoustics as a critical antisubmarine warfare technology. *Johns Hopkins APL Technical Digest*, vo1. 3(1), pp 145-159

Wardle C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, & D. Mackie. 2001. Effects of seismic air guns on marine fish. *Continental Shelf Research*, vol. 21(8-10), pp 1005-1027

Wright, D. G. 1982. A discussion paper on the effects of explosives on fish and marine mammals in the waters of the Northwest Territories. Canadian Technical Report of Fisheries and Aquatic Sciences: 1052. Winnipeg, Manitoba

ANS Control: Algaecides – Copper Sulfate, Chelated Copper Formulations, Endothall (as the mono (N,N-dimethylalkylamine) salt), and Algaecides containing Sodium Carbonate Peroxyhydrate

Targeted Species: Algaecides (or algicides) are used to control or suppress many species of planktonic, filamentous, and branched algae. Specific ANS of Concern – CAWS[1] that may be controlled or suppressed with algaecides include red macro-algae (*Bangia atropurpurea*), diatoms (*Cyclotella cryptica*, *C. pseudostelligera* and *Stephanodiscus binderanus*)[2], and grass kelp (*Enteromorpha flexuosa*).

Algaecides can be applied as a spray directed onto floating mats of algae, sprayed or injected directly into the water column, or applied as granular crystals or pellets dispensed to the water surface.

Selectivity: Algaecides can be selective or non-selective against algae. Selectivity depends on species, dose and timing of application, product formulation, and water chemistry (Cooke et al. 1993).

Developer/Manufacturer/Researcher: There are numerous formulations and manufacturers of algaecides registered by the U.S. Environmental Protection Agency (USEPA) for use in and around aquatic habitats. A list of most of the currently available algaecides and their respective manufacturers can be found in Appendix F of Gettys et al. (2009).

Pesticide Registration/Application: Pesticides, including algaecides, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: Algaecides are chemical substances that are specifically used to control or kill algae. Registered algaecides include copper sulfate, copper chelates (ethanolamines, ethylene diamines, triethanolamines, triethanolamine + ethylene diamine, and copper citrate/gluconate), endothall (as the mono (N,N-dimethylalkylamine) salt), and formulations containing the active ingredient sodium carbonate peroxyhydrate.

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Cryptic algae (*Cyclotella cryptica*), cylindrical algae (*C. pseudostelligera*), and diatom (*Stephanodiscus binderanus*) are three (3) species of algae that belong to the algal subcategory of diatoms. For the purpose of this fact sheet, they will be referred to collectively as diatoms.

Similar to herbicides[3], algaecides must come in contact with and enter algal cells to be effective. Algaecides vary in their mechanism of action, but they are all considered "contact" pesticides, meaning they cause injury to only the algal cells or filaments that come in contact with or are exposed to dissolved algaecide, with little intercellular movement. Algaecides are used primarily to control algal growth in impounded waters, lakes, ponds, reservoirs, stock tanks, and irrigation conveyance systems. They can be applied as a spray directed onto an algal mat, sprayed or injected directly into the water column, or applied as granular crystals or pellets.

The mechanism of action for most algaecides is not well understood, but copper-based products are believed to target specific physiological processes such as electron transport in photosystem I, cell division and nitrogen fixation (Cooke et al. 1993; Senseman 2007). Endothall has been shown to cause electrolyte leakage from cell membranes and may also play a role in inhibition of lipid and protein biosynthesis (Senseman 2007). Algaecides containing sodium carbonate peroxyhydrate act to destroy algal cell membranes by forming hydroxyl free radicals.

Prior Applications: Algaecides can be used to control many species of algae, but they are typically applied once algae have been identified and are present in a body of water. They are not used in permanent chemical barriers. Algaecides can reduce the risk of nuisance algae spread, however, algaecide application typically does not result in eradication of algae. The following information summarizes what has been reported in literature on the use and effectiveness of algaecides for each ANS of concern – CAWS.

Red macro-algae, "Bangia atropurpurea": There is no published literature documenting algaecide effectiveness against this filamentous red macro-alga, however, it is likely that endothall and chelated copper-based algaecides will effectively control this species. The label for Hydrothol 191®[4], which contains the mono (N,N-dimethylalkylamine) salt of endothall, identifies product efficacy on a broad range of filamentous algae (United Phosphorus, Inc. 2010). Based on the structural character of *B. atropurpurea*, chelated copper formulations such as K-Tea™ (triethanolamine; SePRO Corporation) and Captain™ (copper carbonate; SePRO Corporation) will likely have activity against this species (West Bishop, SePRO Corporation, E-mail communication, 2011).

Diatoms, "Cyclotella cryptica," "C. pseudostelligera," and "Stephanodiscus binderanus": There is little published literature on algaecide effectiveness against these diatom species, but many diatom species are susceptible to copper sulfate and chelated copper formulations. The genus *Stephanodiscus* is included on many copper sulfate and chelated copper product labels as a sensitive genera which can be controlled by these compounds. Button et al. (1977) reported that an algal bloom in Hoover Reservoir, Franklin County, Ohio, composed primarily of diatoms including the genera *Stephanodiscus*, was controlled by copper sulfate. Non-copper algaecides containing endothall (as the mono (N,N-dimethylalkylamine) salt) and sodium carbonate

[3] For more information on this control technology, please see the fact sheet titled "Aquatic Herbicides."
[4] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U. S. Army Corps of Engineers or its employees.

peroxyhydrate have broad spectrum activity against planktonic algae and may be effective on these invasive diatom species.

Grass kelp, "Enteromorpha flexuosa": There is no published literature documenting algaecide effectiveness against grass kelp. The genus *Enteromorpha*, however, is included on many copper sulfate and chelated copper product labels as being susceptible to these algaecides. Non-copper algaecides containing sodium carbonate peroxyhydrate and endothall (as the mono (N,N-dimethylalkylamine) salt) have broad spectrum activity against green algae (Chlorophyta) and may be effective on grass kelp.

General Effectiveness: When properly applied, and in accordance with product label directions, algaecides can be effective for controlling or reducing the growth of unwanted algae. Due to their ability to reproduce quickly, however, algae are difficult to control long term. Once a body of water becomes infested with algae, it is unlikely that algaecides will eliminate all algae or their spores (algae reproduce by cell division and/or by formation of spores (Lembi 2009)). The efficacy of algaecides is short-lived in water and regrowth almost always occurs; as a result, re-treatment with algaecides is required (Ross & Lembi 1985; Cooke et al. 1993; Lembi 2009).

The efficacy of copper-containing algaecides can be impacted under certain environmental conditions. Copper is less effective in waters with high alkalinity and pH; it is also ineffective when water temperatures are less than 15 °C (Cooke et al. 1993).

Operating Constraints: Constraints for using algaecides in aquatic environments are defined on the manufacturer's product label and may include: restrictions for water use after algaecide application; when, where, and how the product can be applied; frequency and maximum rate of application; conditions that can reduce product efficacy; and potential impacts to sensitive, non-target species. Appropriate state and local regulatory agencies must be contacted and manufacturer product label directions followed prior to application of an algaecide to any body of water. Some states may require applicators of algaecides to be licensed and certified. Environmental conditions such as high pH and alkalinity, or water temperatures below 15 °C, will reduce the effectiveness of copper-containing algaecide formulations. Continuous use of copper-based algaecides may result in an accumulation of copper in sediments and, consequently, may restrict sediment reuse and disposal.

Cost Considerations: Cost of algaecide and application varies with product choice, method and rate of application, and management or treatment objective.

Implementation: Implementation costs would include the development of a management plan, purchase and application of the algaecide, and potential costs associated with monitoring residues in water (if required to determine Maximum Contamination Levels related to water use restrictions imposed by the algaecide label). Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operation and maintenance costs would include monitoring effectiveness of algaecide treatment and reapplication when algae begin to reappear.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

Button, K.S., H.P. Hostetter, & D.M. Mair. 1977. Copper dispersal in a water supply reservoir. *Water Research*. vol 11, pp: 539-544

Cooke, G.D., E.B. Welch, S.A. Peterson, & P.R. Newroth. 1993. Chapter 10, "Copper Sulfate." pp. 247-257 in *Restoration and Management of Lakes and Reservoirs*, 2nd Edition. Lewis Publishers. Boca Raton, FL. 548 pp

Gettys, L.A., W.T. Haller, & M. Bellaud (eds.). 2009. *Biology and Control of Aquatic Plants: A Best Management Handbook.* Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pp

Lembi, C.A. 2009. Chapter 12, "The Biology and Management of Algae." Pp. 79-85 in *Biology and Control of Aquatic Plants: A Best Management Handbook*, L.A. Gettys, W.T. Haller, & M. Bellaud (eds.) Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pp

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Senseman, S. (ed.). 2007. *Herbicide Handbook*, 9th Edition. Weed Science Society of America, Lawrence, KS. 458 pp

United Phosphorus, Inc. 2010. Hydrothol 191® Aquatic Algicide and Herbicide Product Label. Accessed November 22, 2011. http://www.cdms.net/LDat/ld225006.pdf

Alteration of Water Quality

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Alternation of Water Quality – carbon dioxide (CO_2), ozone, nitrogen, alum, and sodium thiosulfate

Oxygen gas is bubbled through a stream to improve water quality. Alternatively, the Controls identified in this fact sheet may be used to degrade water quality to prevent the movement of aquatic nuisance species.

Targeted Species: These controls may be effective for use in preventing both upstream and downstream movement of organisms. Specific species recognized as ANS of Concern – CAWS[1] could include those listed below, dependent on the Control.

Alum – Algae included in ANS of Concern – CAWS

Sodium Thiosulfate – Annelids, bryozoans, copepods, crustaceans, fish, mollusks, and protozoans included in ANS of Concern – CAWS

Carbon Dioxide – Annelids, bryozoans, copepods, fish, and protozoans included in ANS of Concern – CAWS

Ozone – Algae, annelids, bryozoans, copepods, fish, and protozoans included in ANS of Concern – CAWS

Nitrogen – Annelids, bryozoans, copepods, fish, and protozoans included in ANS of Concern – CAWS

Selectivity: Alum is selective for algae. Sodium thiosulfate, carbon dioxide and ozone are non-selective. Nitrogen and its by-products are non-selective for most aquatic organisms. Activity on the non-selective species is dependent upon concentration, method and timing of application, and length of exposure.

Developer/Manufacturer/Researcher: Carbon dioxide, ozone, nitrogen, alum, and sodium thiosulfate are produced for a variety of commercial purposes. Suppliers are available in most metropolitan areas. The University of Illinois at Urbana-Champaign (UIUC) and the Illinois Natural History Survey are conducting research on oxygen depletion and carbon dioxide treatments on silver and bighead carp (Cory Suski, UIUC, E-mail communication, 2011).

Pesticide Registration/Application: Pesticides, including carbon dioxide, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: A variety of chemical compounds can be used to alter water quality to prevent the movement of ANS through an aquatic pathway. Many species can tolerate inhospitable environments for short periods of time. The concentration of a chemical compound and the duration of the exposure must be determined to maximize effectiveness for a specific species. Individuals may be injured but survive sub-lethal doses or inadequate exposure times.

Carbon Dioxide – In a desktop exercise, the U.S. Army Engineer Research and Development Center (ERDC) simulated injecting carbon dioxide gas at the bottom of the Chicago Sanitary and Ship Canal, using a bubbler delivery system, through anchored tubing near the bottom of a waterway. High CO_2 levels usually correlate with low dissolved oxygen (DO), which increases CO_2 toxicity to fish (Fivelstad et al. 1999). The toxicity of CO_2 results from lowering an organism's blood pH (acidemia), creating irreversible cell damage and death. High CO_2 levels can also cause other water quality changes that may impact aquatic species, such as water pH and metal solubility changes.

Ozone – Ozone is commonly used in drinking water and waste water treatment and in industrial settings to disinfect water and disinfect surfaces. The stable form of oxygen is made up of two oxygen atoms, while the unstable ozone is made up of three. When ozone breaks down it gives rise to oxygen free radicals, which are highly reactive and capable of damaging many organic molecules through the process of oxidation. Ozone oxidation is toxic to most small waterborne organisms (Leynen et al. 1998) and has been found to destroy the epithelium covering the gill lamella in bluegill fish. Destruction of the epithelium can cause either immediate mortality or leave the fish highly susceptible to microbial infections (Paller & Heidinger 1979).

There are several ways to create ozone for water treatment, most commonly by using high voltage sparks or intense ultraviolet light. Once created, the ozone gas is then applied using porous diffusers, radial diffusers, or venturi injectors.

Nitrogen – Nitrogen supersaturation can cause health deterioration in fish. Supersaturation occurs when the partial pressure of one or more gases becomes greater than the atmospheric pressure and the water contains excess dissolved nitrogen. Once the tissue and organs of fish reach equilibrium with the supersaturated environment, supersaturated gases may leave solution and form nitrogen bubble embolisms. This condition, referred to as gas bubble disease, physically blocks blood circulation in the fish and eventually leads to death.

Alum (aluminum sulfate) – There is a direct relationship between the amount of phosphorus in a lake and the amount of algae growing in the lake. The amount of algae increases as phosphorus levels increase. Alum forms an aluminum hydroxide precipitate on contact with water, which reacts with phosphorus to form an aluminum phosphate compound. This compound binds with phosphorus, making this essential nutrient unavailable to algae. Alum is commonly used in lakes for algae control (Kennedy & Cooke 1982).

Sodium Thiosulfate – Sodium thiosulfate has been investigated as one method of reducing dissolved oxygen in water to prevent the transfer of ANS (Malchoff et al. 2005). Dissolved oxygen is required for aquatic organisms to respire. Dissolved oxygen levels are lethal for many fish species below 0.3 parts per million (Piper et al. 1986). However, it is commonly accepted that Asian carp are tolerant of DO less than 3 parts per million (ppm) (Oregon Sea Grant 2011).

Prior Applications:

Carbon Dioxide – Carbon dioxide has a variety of industrial and food uses, but it is currently not used operationally for controlling ANS movements. Carbon dioxide is being tested experimentally in the laboratory and in lakes to determine physiological and behavioral reactions of silver and bighead carp to different levels of exposure (Cory Suski, UIUC, E-mail communication, 2011).

Ozone – Ozone is commonly used at fish hatcheries and water treatment facilities to prevent contamination from bacteria. It is also used for disinfection of drinking water and treatment of wastewater, and for microbial control or advanced oxidation of trace chemicals.

Nitrogen – Unintentional nitrogen supersaturation commonly occurs in both fish hatcheries and below dams. Nitrogen has not been commonly used to control ANS.

Alum (aluminum sulfate) – Alum is a nontoxic material commonly used in water treatment plants to clarify drinking water. In lakes, alum is used to control the amount of the nutrient phosphorus in the water. The effectiveness of alum treatments depends on the amount of alum applied, the lake's existing chemical conditions (water quality), and the sedimentation rate and external phosphorus loading contributed to the lake from its watershed after the treatment. Depending on these factors, the effectiveness can range from less than 1 year to 21 years (Welch & Cooke 1999). Alum in not used to control algae in large open flowing systems (Kennedy & Cooke 1982).

Sodium Thiosulfate – Sodium thiosulfate has been used in fish hatcheries for dechlorination following disinfection (Waldrop et al. 2009) and for reducing dissolved oxygen in boiler systems (Cavano 1997).

General Effectiveness: The effectiveness of the aforementioned Controls depends on the concentration and exposure time. If applied in an open flowing system, exposure time is greater for upstream movement as compared with downstream movement. Many species can tolerate inhospitable environments for short periods of time. Species that are exposed to sub-lethal concentrations or for too short of time, may be injured but may survive. Application of high concentrations of gases in an open, flowing system may be difficult to control.

With respect to fish, the effectiveness of dissolved gases for controlling ANS fish depends upon the species of fish, size of the fish, and duration of exposure. In general, most fish begin to experience stress when dissolved oxygen levels are less than 5 ppm, nitrogen levels are greater than 100% saturation (supersaturation), or carbon dioxide levels are greater than 10 ppm (Piper et al. 1986). However, many of the fish species within the CAWS are tolerant to a broad range of gas concentrations and may not be affected by moderate exceedance of these thresholds. Field and laboratory studies indicate that many fish species tolerate substantially lower levels of DO. Smale and

Rabeni (1995) showed that headwater fishes survived short-term when exposed to 1.5 ppm DO, and it is commonly accepted that Asian carp are tolerant of DO less than 3 ppm (Oregon Sea Grant 2011). Sub-lethal levels of carbon dioxide are currently being studied to determine if they act as a behavioral barrier for invasive species of fish in the CAWS.

Carbon Dioxide – Application of CO_2 in high concentrations would potentially be effective against many invasive animal species, but it is non-selective and would also affect non-target species in the treatment area. Fish utilize special sensory cells on their gill arches to determine the presence of carbon dioxide (Perry & Reid 2002). Some early life stages of fish are more CO_2 tolerant than other fish in later life stages (Kikkawa et al. 2003). High levels of dissolved oxygen could inhibit the effectiveness of CO_2 because fish can tolerate considerably higher levels of CO_2 for short periods, even when dissolved oxygen is near saturation (Ross et al. 2001; Ishimatsu et al. 2005). High CO_2 levels would also stimulate growth of some aquatic plant species (Idso et al. 1987).

Ozone – Depending on concentration and exposure time, ozone is capable of killing ANS. The chemical is toxic to all life stages of fish, however, it is less toxic to eggs than to the larval stages of several fish species (Asbury & Coler 1980).

Nitrogen – Nitrogen gas is less lethal to fish than CO_2 and ozone. Adult fish are more tolerant of nitrogen supersaturation than young fish (Ebel 1969).

Alum (aluminum sulfate) – Alum treatment of an open flowing system may not be an effective method to control algae. Nutrient inactivation using alum is only appropriate where internal loading (sources from within the lake, such as decomposing organic material or resuspension of bed sediments) is a significant phosphorus source (Cooke et al. 2005). In systems that have a continuous elevated phosphorus loading from external sources, such as wastewater treatment plants and urban runoff (fertilizers), alum treatment may not be effective (Welch & Cooke 1999). Additionally, under anoxic conditions, phosphorous can be re-released, which can decrease the effectiveness of alum.

Sodium Thiosulfate – Factors determining the rate at which sodium thiosulfate reacts with water include the purity of the water (the potential for side reactions), the residence time in a system, the location of the chemical feed, the applied concentration, the temperature of the water, and the water's pH.

Operating Constraints: In a flowing system, maintaining an effective concentration and exposure time for these Controls may be constrained by the system's non static conditions such as fluctuations in volume and flow velocity during dry and wet weather conditions, inconsistent flow direction, variability in water density throughout channel depth, removal of water by users, addition of effluent from dischargers to the waterway, and the variability of sediment conditions along the targeted area. In addition, control of gas application in an open environment would be difficult at best, due to the tendency of the gases to move into the atmosphere.

Carbon Dioxide – In its desktop exercise, ERDC calculated approximately two atmospheres of pressure created; CO_2 solubility in water was measured in the range of 2500 mg/L. ERDC estimated that achieving a concentration of 100 mg/L CO_2 in the Chicago Sanitary and Ship Canal at the Electric

Fish Barrier site in Lockport, IL would require approximately 2,100,000 pounds of CO_2 per day. The largest tank truck available holds only 40,000 pounds of liquid CO_2. Supplying the aforementioned quantity of gas to the channel would require 35 tank truckloads of CO_2 per day (equal to a semitrailer delivery to the barrier site every 41 minutes). The largest bulk storage tank currently available is 70,000 pounds, so onsite storage would not be a practical solution.

CO_2 is a greenhouse gas, and introducing the quantity of CO_2 identified by ERDC would reduce the pH of the waterway to below five. If applied in an open system, prolonged exposure to acidified water from elevated CO_2 concentrations may injure submersed structures and channel walls and may alter sediment chemistry releasing sediment bound contaminants into the water column. Introducing the required quantity of CO_2 into the waterway may reduce the water's temperature. Due to its gaseous properties, CO_2 may prove to be ineffective in open flowing systems.

Ozone – Ozone must be produced onsite. Ozone may prove to be ineffective in open flowing systems, due to its gaseous properties and high reactivity. If applied in an open flowing system, diffused ozone, a reactive gas, may impact nearby plants and buildings, and pose a risk to human health. Ozone is a component of photochemical smog; however, unlike other chemical disinfectants or biocides, ozonation does not leave any objectionable by-products. Upon degradation in a waterway, ozone would increase dissolved oxygen in the waterway.

Nitrogen – The operating constraints of nitrogen are similar to those of carbon dioxide. Supersaturation of open flowing systems may not be possible. Nitrogen gas infusions may increase ammonia levels in a waterway and could spur nuisance plant growth in nitrogen limited systems.

Alum (aluminum sulfate) – Guidelines for alum application require that the pH remain within the 5.5-9.0 range (Kennedy & Cooke 1982). Alum would work only in the non-flowing connections of the CAWS. Alum coagulates dissolved and suspended solids in water, and these coagulated solids then settle. If applied in an open system, coagulated solids, if not collected and removed, would settle and add to the sediment layer within the waterbody.

Sodium Thiosulfate – Most prior applications of sodium thiosulfate have been employed in closed systems, and therefore, this control may not be effective in an open flowing system. The addition of oxygen depleting substances will reduce dissolved oxygen concentrations within a body of water; however, in an open system, the water will also absorb oxygen from the atmosphere continuously. This may result in larger input requirements of sodium thiosulfate.

Cost Considerations: The following are general cost considerations for these controls.

Carbon Dioxide –

Implementation: Implementation would include the construction of a CO_2 generation plant or procurement of a delivery contact. Planning and design activities in this phase may include research and development of this Control (regarding concentration and exposure times, effectiveness for specific species), modeling, site selection, site-specific regulatory approval, development of plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, infrastructure impacts from acid degradation, and required mitigation measures.

Operations and Maintenance: Operations and maintenance would include maintenance of the piping and bubbler system and continuous monitoring of water quality to ensure effective mixing. Possible canal wall maintenance and downstream pH adjustment may be necessary.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Ozone –

Implementation: Ozone equipment size and cost varies by the amount of water being treated. Implementation costs may include the construction of an ozone generation and treatment plant, and distribution system. Planning and design activities in this phase may include research and development of this Control (regarding concentration and exposure times, effectiveness for specific species), modeling, site selection, site-specific regulatory approval, development of plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance would include maintenance of the ozone generation plant and treatment plant. Additionally, the onsite generation of ozone is energy intensive, therefore, energy would be an ongoing operation cost.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Nitrogen – The cost considerations for nitrogen are expected to be similar to those of carbon dioxide.

Alum (aluminum sulfate) –

Implementation: The implementation cost for alum treatment is greatly varied, depending upon the amount of water being treated, site characteristics (i.e. ease of access), equipment requirements and whether the pH must be adjusted.

Planning and design activities in this phase may include research and development of this Control (regarding concentration and exposure times, effectiveness for specific species), modeling, site selection, site-specific regulatory approval, development of plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance would include application of the chemical and monitoring of phosphorous levels to determine when reapplication is required.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Sodium Thiosulfate –

Implementation: A supplier would need to be found and a method of application developed for each system to ensure the target concentration is met throughout the water column.

Planning and design activities in the implementation phase may include research and development of this Control (regarding concentration and exposure times, effectiveness for specific species), modeling, site selection, site-specific regulatory approval, development of plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance would include application of the chemical(s) monitoring to ensure the targeted dissolved oxygen concentration is met and tested to ensure effectiveness of application in open flowing systems.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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ANS Control: Aquatic Herbicides – 2,4-D (both the amine and butoxy-ethyl ester formulations), Diquat, Fluridone, Glyphosate, Imazapyr, and Triclopyr

Targeted Species: Herbicides are used to control plants. Specific ANS of Concern – CAWS[1] that may be controlled with aquatic herbicides include Cuban bulrush (*Oxycaryum cubense*), dotted duckweed (*Landoltia* (*Spirodela*) *punctata*), marsh dewflower (*Murdannia keisak*), reed sweetgrass (*Glyceria maxima*), swamp sedge (*Carex acutiformis*), and water chestnut (*Trapa natans*).

Aquatic herbicides can be applied as a foliar spray to control emergent vegetation.

Selectivity: Aquatic herbicides can be selective or non-selective against plant species. Selectivity among plants species is dependent upon product selection, dose and timing of application, contact time (duration a herbicide is exposed to the plant), and plant species.

Developer/Manufacturer/Researcher: There are about 300 herbicides registered by the U.S. Environmental Protection Agency (USEPA); however, only 13 active ingredients (copper, endothall, diquat, carfentrazone-ethyl, flumioxazin, 2,4-D, triclopyr, glyphosate, imazapyr, imazamox, fluridone, penoxsulam, and bispyribac-sodium) are registered by the USEPA for use in and around aquatic habitats (Netherland 2009). Six of these 13 active ingredients can be considered as viable control technologies against ANS of Concern – CAWS. These six active ingredients include: imazapyr, diquat, fluridone, glyphosate, 2,4-D (both the amine and butoxy-ethyl ester formulations), and triclopyr[2]. There are numerous formulations and manufacturers of these active ingredients; a list of some of the aquatic herbicide formulations and their respective manufacturers can be found in Appendix F of Gettys et al. (2009).

Pesticide Registration/Application: Pesticides, including aquatic herbicides, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: Herbicides are pesticides that are specifically used to kill or suppress the growth of plants (Klingman et al. 1982; Ross & Lembi 1985). To be effective, herbicides must enter the plant through leaves and roots. Once inside the plant, herbicides target specific physiological processes

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

such as inhibiting enzymes involved in amino acid synthesis, disrupting photosynthesis or mitosis (cell division), or interrupting the synthesis of important plant pigments. Herbicides are classified in many ways, either by their chemical family (e.g. triazines, imidazolinones, sulfonylureas, etc.), their mode and/or mechanism of action (e.g., photosystem II inhibitors, carotenoid biosynthesis inhibitors, etc.) or by their time of application in relation to growth of the weed (e.g. pre-emergence or post-emergence) (Netherland 2009). Herbicides can also be characterized as either "contact" or "systemic" products. A contact herbicide causes injury to only the plant tissues to which it is applied with little or no movement inside plant tissues (Ross & Lembi 1985; Senseman 2007). Contact herbicides are fast-acting and generally kill susceptible plants within hours or days of application. In contrast, systemic herbicides are those products which translocate downward into underground plant parts, from leaves to roots and rhizomes; activity is slow and death occurs within days to weeks (Ross & Lembi 1985; Senseman 2007). If herbicides are applied at the right dose and in accordance with application guidelines defined in the herbicide or product label, they can provide effective weed control at a reasonable cost. Aquatic herbicides can be applied as a foliar spray, sprayed or injected directly into the water column, or applied as a granular pellet.

2,4-D (both the amine and butoxy-ethyl ester formulations) – 2,4-D is a selective systemic herbicide that acts similarly to the endogenous plant hormone auxin. Although the true mechanism of action is not well understood, the primary action of 2,4-D is that it affects cell wall plasticity and nucleic acid metabolism in plants (Senseman 2009). Plant death occurs slowly in susceptible plants, usually within 3 to 5 weeks. The liquid amine formulation of 2,4-D is typically used to control emergent and submersed plants and the granular butoxy-ehtyl ester formulation is used for submersed weeds only. 2,4-D has been registered by the USEPA for use in aquatic environments since 1959, and is active against Cuban bulrush and water chestnut.

Diquat – Diquat is a fast-acting contact herbicide that disrupts photosynthesis and destroys cell membranes in susceptible plants (Senseman 2009). Rapid wilting and desiccation of affected plant tissues occurs within hours of application and plant death occurs in1 to 3 days. Diquat is applied post-emergence and is primarily used for controlling submersed and free-floating aquatic plants. It is often mixed with copper-based herbicides to improve control and to expand the range of use on other target plants. Diquat was initially registered by the USEPA for use in aquatic environments in 1961; it can be used to control duckweed species including dotted duckweed and can be tank mixed with 2,4-D for control of Cuban bulrush.

Fluridone – Fluridone is a systemic herbicide used exclusively for control of unwanted aquatic vegetation. Fluridone inhibits the plant enzyme phytoene desaturase, which is a key enzyme in the synthesis of carotenoid pigments. Carotenoids are plant pigments that protect chlorophyll pigments from being destroyed by sunlight (photooxidation). Characteristic symptoms appear in 7 to 10 days as white or pink new growth. Fluridone is a slow acting herbicide and target plants must be exposed to a

Aerial application of aquatic herbicides

lethal dose for a minimum of 45 days (Netherland 2009). Under optimum conditions, plant death occurs within 30 to 90 days after exposure (Senseman 2007). Fluridone was registered by the USEPA for use in aquatic environments in 1986. Fluridone can be used to control duckweed species including dotted duckweed.

Glyphosate – Glyphosate is a widely used herbicide in agriculture, turf, and other specialty markets, and was registered by the USEPA for use on aquatic weeds in 1977. Glyphosate is a non-selective, systemic herbicide that inhibits the plant enzyme enolpyruvyl shikimate-3-phosphate synthase, which is required for the synthesis of aromatic amino acids; this subsequently disrupts protein production in plants (Senseman 2009). Growth of susceptible plants is inhibited soon after application, followed by foliar chlorosis (yellowing) within 4 to 7 days, and plant death within 10 to 21 days. Glyphosate has no soil activity and cannot be applied directly into water. It is applied post-emergence as a foliar spray and is primarily used to control emergent aquatic plant species. Glyphosate can be used to control marsh dewflower, reed sweetgrass and swamp sedge and can be tank mixed with 2,4-D for control of Cuban bulrush.

Imazapyr – Imazapyr is a systemic herbicide that inhibits the plant-specific enzyme, acetolactate synthase, which plays a critical role in production of branched chain amino acids (Senseman 2009). Inhibition of amino acids impacts protein biosynthesis in plants. Growth of susceptible plants stops within a few hours of application, but injury symptoms and plant death do not occur until weeks later. Imazapyr is typically applied post-emergence and is active on some floating and emergent aquatic weeds. It also has soil activity, and some aquatic formulations can be applied as draw-down treatments in certain areas described in the product label. Imazapyr was registered by the USEPA for use in aquatic environments in 2003, and can be used to control reed sweetgrass, Cuban bulrush, and most sedge species.

Triclopyr – Triclopyr is a selective systemic herbicide similar in activity to 2,4-D (auxin mimic) and was registered by the USEPA for aquatic use in 2002. Both liquid and granular formulations of triclopyr amine are available; triclopyr controls submersed, floating, and emergent dicotyledonous (and some broadleaf monocotyledonous) aquatic plants. The use of triclopyr in public waters is permitted in some states where 2,4-D use is not allowed (Netherland 2009). Triclopyr can be used to manage water chestnut.

Prior Applications: Herbicides can be used to control many invasive plant species, but they are typically applied once the plant has been identified and is present on a site. Aquatic herbicides are not used as a “preventative” control measure or as a permanent chemical barrier. Using herbicides to control or eradicate plants can reduce the risk of spread, however, monitoring the success of herbicide treatments is important to identify any surviving plants and or “skips” in application technique. Re-application may be necessary to achieve long-term control and/or eradication of the weed species being treated. Aquatic herbicides will not kill seeds of plants; however, seed dispersal can be reduced if herbicides are applied before plants produce seed. The following information summarizes what has been reported in literature on the use and effectiveness of aquatic herbicides for each ANS of Concern – CAWS.

Swamp sedge, "Carex acutiformis": There is currently no peer-reviewed, published literature specifically describing the use and/or effectiveness of herbicides against swamp sedge, however, the Center for Ecology and Hydrology [(CEH) 2004] reported that all rushes, reeds and sedges are susceptible to glyphosate. Applying glyphosate to actively growing plants in mid to late summer maximizes translocation and control of underground rhizomes (CEH 2004). Imazapyr is also effective for controlling some sedge species and may have activity on swamp sedge.

Reed sweetgrass, "Glyceria maxima": Imazapyr and glyphosate can be used to control reed sweetgrass [The Nature Conservancy Global Invasive Species Team (TNC-GIST) 2005; Department of Primary Industries, Parks, Water and Environment (DPIPWE) 2002; King County Noxious Weeds 2011]. Imazapyr (rate of application not reported in publication) is best applied in summer or early fall, when water levels are low and plant stems are not submerged. Efficacy is reduced if more than one third of stem height is flooded (King County Noxious Weeds 2011). A 3% solution of glyphosate applied to foliage during early to late summer will control this weed; additionally, follow-up treatment the year after application is recommended to eliminate re-growth from surviving rhizomes (TNC-GIST 2005). Barrett (1976) reported that glyphosate applied at a rate of 2 kg ai (active ingredient)/ha (equivalent to 1.78 lbs ai/acre) controlled 96% of *G. maxima* in England. Studies by Loo et al. (2009) found that glyphosate was cost-effective for controlling reed sweetgrass and recommended that small, young populations be eradicated as soon as detected. Glyphosate has also been effective for reed sweetgrass control in Tasmania (DPIPWE 2002). Reed sweetgrass is a perennial grass species, and large, well-established populations may require follow-up treatment for 2 to 3 years to completely kill plants (King County Noxious Weeds 2011; Loo et al. 2009).

Dotted duckweed, "Landoltia (Spirodela) punctata": The herbicides diquat and fluridone are most often used to control duckweed species and are efficacious on dotted duckweed (Grodowitz et al. 2009; Lembi 2009; Netherland 2009). Diquat applied as a foliar spray at a rate of 1 to 2 gallons of formulated product per surface acre will control duckweeds (Lembi 2009). Multiple diquat applications are required during the growing season to keep this plant in check. Diquat has been successfully used to control duckweeds in Florida for more than 20 years, however, in 2006, a population of dotted duckweed was identified in Lake County, Florida that had developed resistance to this herbicide (Koschnick et al. 2006). Studies by Koschnick and Haller (2006) found that applying copper chelating agents with diquat can enhance the activity of diquat on diquat-resistant dotted duckweed. While diquat resistant dotted duckweed is currently confined to Florida, care should be taken to rotate the use of effective herbicides on this plant to prevent the development and potential spread of new resistant populations.

Fluridone will control duckweed if applied as an in-water treatment at a rate of 1 quart formulated product per surface acre in a split application, 10 to 14 days apart (Lembi 2009). Fluridone works best on duckweed when applied as soon as plants appear, typically in the early spring growing season.

Marsh dewflower, "Murdannia keisak": Chemical treatment, with glyphosate applied to actively growing plants prior to seed set, can be effective against this annual weed species (Swearingen et al. 2010). Repeat applications of glyphosate will be required to eradicate this plant if a significant seed bank is present (i.e., germinating seed will cause re-infestation).

Cuban bulrush, "Oxycaryum cubense": Although there is currently no peer-reviewed, published literature on herbicide effectiveness against Cuban bulrush, this invasive perennial plant has been successfully managed with herbicides in Florida and Alabama. In Florida, Cuban bulrush is often managed with 2,4-D applied alone or in combination with diquat or glyphosate (Jeff Schardt, Florida Fish and Wildlife Conservation Commission, E-mail communication, 2011). High rates of 2,4-D (2 to 4 quarts of formulated product/acre) applied to foliage early in the growing season (March-April) is effective against Cuban bulrush in Florida; however, the efficacy of 2,4-D is reduced if applied later in the growing season. 2,4-D is often tank mixed with diquat (0.5 gal/acre 2,4-D + 0.25 gal/acre diquat) or glyphosate (0.5 gal/acre 2,4-D + 0.25 gal/acre glyphosate) to improve efficacy when treating dense, well established stands of Cuban bulrush. Imazapyr applied to foliage at a rate of 48 oz of formulated product/acre in late summer or fall was effective for controlling Cuban bulrush in Alabama wetlands (Mike Netherland, USACE-ERDC, E-mail communication, 2011). The Aquatic Plant Information System also contains guidance for using imazapyr and 2,4-D to control this plant (Grodowitz et al. 2009).

Water chestnut, "Trapa natans": The most widely used herbicide to manage water chestnut is 2,4-D; triclopyr is used to a lesser extent (Hummel & Kiviat 2004, Poovey & Getsinger 2007; Kishbaugh 2009; Grodowitz et al. 2009; Rector 2010). Countryman (1978) reported that 2,4-D was used to successfully reduce water chestnut populations in Lake Champlain, Vermont. Both the liquid and granular formulations of 2,4-D can be used against water chestnut (Rector 2010). According to Kishbaugh (2009), applying 2,4-D in early summer, when water chestnut plants are just reaching the water surface, will provide the best results. The maximum level of water chestnut control achieved in laboratory studies when 2,4-D and triclopyr were applied as a subsurface injection, was 66% (Poovey & Getsinger 2007).

General Effectiveness: When properly applied and in accordance with product label directions, herbicides can be effective for controlling unwanted vegetation. According to Ross and Lembi (1985), the most frequently used method of aquatic weed control in the United States is the application of aquatic herbicides.

Operating Constraints: Constraints for using herbicides in aquatic environments will be defined on the manufacturer product label and may include: restrictions on water use after herbicide application (e.g. potable water and irrigation uses); when, where, and how a herbicide can be applied; frequency and maximum rate of application; conditions that can reduce herbicide efficacy (e.g. flowing water, turbidity, pH, temperature, etc.); and potential impacts to sensitive, non-target species. Appropriate state and local regulatory agencies must be contacted and manufacturer product label directions followed prior to application of an aquatic herbicide to any body of water. Some states may require applicators of aquatic herbicides to be certified and licensed.

Herbicide resistance can develop in some plant species after continuous use of a single herbicide, and has been reported in dotted duckweed in Florida (Koschnick et al. 2006). Resistance to fluridone has also been reported in another aquatic plant, hydrilla (*Hydrilla verticillata*) (Michel et al. 2004). Therefore, rotating the use of herbicides with different mechanisms of action is important for preventing further development of resistance in any plant species.

Cost Considerations: Cost of herbicide and application varies with product choice, size of area to be treated, water depth (if treating a submersed weed), method of application, density and age of plants to be treated, and management objective.

Implementation: Implementation costs would include development of a management plan, purchase and application of aquatic herbicide, potential costs associated with monitoring residues in water (if required to determine Maximum Contamination Levels related to water use restrictions imposed by the label), and possible costs for obtaining required permits. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include monitoring effectiveness of herbicide treatment and reapplication if target plants reappear.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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ANS Control: Benthic Barriers – textile or plastics and silt.

Bottom screening material being prepared prior to installation around a boat dock

Targeted Species: Species controlled by this technology include, fish, macroinvertebrates, and rooted aquatic plants, both submersed and emergent. Specifically, ANS of Concern – CAWS[1] species including Cuban bulrush (*Oxycaryum cubense*), marsh dewflower *(Murdannia keisak)*, reed sweetgrass *(Glyceria maxima)*, and swamp sedge *(Carex acutiformis)*.

Selectivity: Benthic barriers are not selective. Benthic barriers will impact all target and non-target organisms dependent on or living in sediment.

Developer/Manufacturer/Researcher: Manufacturers and installers of benthic barriers are readily available throughout the United States.

Brief Description: A benthic barrier is a system designed to prevent the establishment of plants, control existing plants, and to interfere with respiration in fish and macroinvertebrates. The method is applicable in water bodies of all types, but water bodies with higher velocity flows, such as rivers, streams, and canals, present additional challenges in implementation. There are two general types of benthic barriers:

Textile or plastic – Benthic barriers to control invasive plant consist of an anchored textile or plastic material, which is placed over existing vegetation, or in a location to prevent the establishment of aquatic vegetation. These barrier systems range from simple designs (such as a nylon tarp with cinderblocks for anchors and PVC poles for markers), to more complex nylon or fiberglass materials, with anchors built into the edges of the fabric, and buoys for navigational markers. Any number of materials and anchors can be utilized to effectively implement the system, however, materials and markers should be chosen to match the environmental and hydrologic conditions in a given water body.

Silt – Benthic barriers can also be created by applying excessive silt or sand to smother bottom-dwelling organisms. Biotic impacts may result directly from sediment in suspension or through the deposition of fine sediment either on, or within, the river bed. Some organisms are very sensitive to excessive sediment during early life stages. A range of factors influence the impacts of sediments on

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

aquatic biota, including concentration, duration of exposure, composition and particle size (Collins et al. 2011).

Prior Applications:

Textile or plastic – Benthic barriers are used worldwide to control aquatic plants in many ways, including creating open "swimming" areas in lakes, preventing the establishment of submersed aquatic plants, and allowing for habitat restoration (Gettys et al. 2009). Benthic barriers are primarily used in lake settings, but have been placed in river systems and canals in South Florida to control submersed aquatic vegetation. Subject to the availability of funding, the U.S. Army Corps of Engineers' (USACE) Pilot Swales Project within the Comprehensive Everglades Restoration Project is considering a study to construct benthic barriers in the swales between Water Conservation Area 3 and Everglades National Park, with the intent of controlling and preventing the establishment of rooted vegetation in these areas (Angie Huebner & Sue Wilcox, USACE, Personal communication, 2011).

Silt – Erosion from anthropogenic sources (i.e. construction, timber harvest and farming) is regulated and its effects on native aquatic organisms are well known; however, the application of silt to control invasive species has not been widely studied. Silt was proposed as a physical strategy for controlling invasive lake trout (*Salvelinus namaycush*) in Yellowstone Lake, Wyoming to smother eggs and early life stages of fish at the redd (nest) site (Gross et al. 2010). Other applications have not been identified.

General Effectiveness:

Textile or plastic – Benthic barriers may be extremely effective at limiting plant growth and establishment, and are often used as a low cost rapid response tool to control establishment of new species (Gettys et al. 2009). When implemented and properly maintained, textile and plastic benthic barriers can provide 100% control of existing covered vegetation. The barrier effectively starves plants of sunlight, blocking the ability to photosynthesize (Gettys et al. 2009).

A benefit of benthic barriers is that the area where the barrier is installed will not harbor floating vegetation, and the lack of emergent and submersed vegetation will prevent floating vegetation from collecting. One negative consequence of benthic barriers is that they do not allow establishment of native vegetation in the area of the barrier.

Though textile or plastic benthic barriers are primarily used to control submersed aquatic vegetation, the University of California, Davis' Tahoe Environmental Research Center and the University of Nevada, Reno's Aquatic Ecosystem Analysis Laboratory are researching the use of benthic barriers to control invasive mollusks. At this time, researchers have not concluded whether benthic barriers are an effective ANS Control for certain mollusk species (Marion Wittman, Personal communication, 2011).

Silt – The effectiveness of silt for controlling invasive species in the CAWS depends upon if the invasive species is susceptible to suspended sediment or siltation and could be contained within a treatment area. If applied in an open flowing system, exposure time is greater for upstream movement as compared with downstream movement. Many species can tolerate inhospitable environments for short periods of time. The reaction of an organism to suspended silt can range from feeding inhibition, reduced metabolism, avoidance, or mortality (Table 1). Since many invasive species are silt-tolerant, it is unlikely that increasing suspended sediment concentrations would greatly reduce their abundance.

Table 1. Examples of the Results of Sediment Dose–Response Experiments for Fish and Macroinvertebrates (adapted from Collins et al. 2011)

Organism	Suspended sediment concentration (mg l^{-1})	Duration (h)	Impact	Reference
Fish - Chinook salmon	207 000	1	100% mortality of juveniles	Newcomb & Flagg 1983
Fish - cyprinids	100 000	168	Some survival	Wallen 1951
Copepod - Cladocera	25 000	unknown	Feeding inhibition	Alabaster & Lloyd 1982
Mollusk - Bivalvia	600	unknown	Feeding inhibition and reduced metabolism	Aldridge et al. 1987
Various benthic invertebrates	743	unknown	Reduced population (85%)	Wagener & LaPerriere 1985

Application of high concentrations of silt in an open, flowing system may be difficult to control.

Operating Constraints: Benthic barriers have operating constraints, including a barrier's impact on non-target organisms that live in or depend on sediment, the scale of the ANS infestation, barrier maintenance, and barrier location.

Textile or plastic – Because textile or plastic benthic barriers completely separate the water column from the sediment, plants dependent on sediment and other non-target organisms living in or dependent on sediment may be adversely impacted.

Because the material used to construct a barrier and the means of anchoring the system become extremely cumbersome as the barrier grows in size, benthic barriers are more suitable for small-scale applications. Current consensus on best design and construction practices notes that barriers should be held to a size of less than one acre to be effectively managed, however, even a barrier one acre in size may be very difficult to maintain (Gettys et al. 2009).

Additional constraints are related to ensuring that a barrier is properly anchored for site-specific conditions, to ensure that it remains in place. Barriers need to be sufficiently weighted to withstand high flow in waterways; additionally, barriers in water bodies that are highly susceptible to seiche[2] effects must be properly anchored (Bellaud 2009). Not only will a barrier be ineffective if it is not properly anchored, but if the barrier is freed from its anchorage, it may become detrimental to desired aquatic vegetation or a hazard to boats. Breakdown of vegetative material may produce significant quantities of methane gas beneath the barrier; commonly, barriers must be 'burped' to allow for the release of gases trapped beneath the barrier.

[2] A seiche is the process of water being drawn from one side of the lake and 'stacked' on the other side due to wind; when winds subside, the water rushes back, creating violent waves.

Benthic barriers must be removed, cleaned and inspected, and reset in order to maintain effectiveness over time. The time required to complete this cycle for maintenance varies greatly, and is highly dependent on site-specific environmental conditions, as well as the size and material type of a barrier. A barrier will become completely ineffective if silt and soil buildup occurs on its upper surface. Vegetation will establish in the accumulated material and compromise the intended purpose. Holes in the barrier would also allow vegetation to establish.

Silt – In a flowing system, maintaining an effective concentration and exposure time for silt would be constrained by the system's non static conditions such as fluctuations in volume and flow velocity during dry and wet weather conditions, inconsistent flow direction, variability in water density throughout channel depth, removal of water by users, addition of effluent from dischargers to the waterway, and the variability of sediment conditions along the targeted area.

Cost Considerations:

Textile or plastic –

Implementation: Implementation costs would include planning, design, and materials and installation for each barrier and anchoring system. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operation and Maintenance: Cost considerations include the maintenance of the barriers such as monitoring to ensure they are properly anchored, repair of torn or ripped barrier material, monitoring for and release of methane build up beneath the barrier, and removal of accumulated soil, sediment and debris from the barrier.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Silt –

Implementation: Implementation costs would include planning, design, and materials and installation for each silt barrier. Planning and design activities in the implementation phase may include research and development of this Control (regarding such items as coverage requirements and effectiveness for specific species), modeling, site selection, site-specific regulatory approval, development of plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance would include application of the silt and monitoring to ensure effectiveness of application in open flowing systems.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Biocides for Industrial Use

ANS Controls: See Table 1 of this fact sheet for a list of biocides.

Targeted Species: Biocides may control many types of species. See Table 2 of this fact sheet for the types of Organisms of Concern – CAWS that may be controlled by biocides.[1]

Selectivity: Biocides are non-selective. See Table 2 for more details.

Developer/ Manufacturer/ Researcher: There are many manufactures of biocides.

Pesticide Registration/Application: Pesticides, including biocides, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Biocides are chemicals designed to kill all sizes and life stages of organisms, especially microorganisms.

Brief Description: Biocides are chemicals designed to kill all sizes and life stages of organisms, especially microorganisms, and the effectiveness of biocides varies with the concentration of a biocide and duration of the exposure. Species that are exposed to sub-lethal concentrations, or for too short of time, may be injured but may survive.

Biocides are used for drinking water treatment, wastewater treatment, ship ballast water treatment, disinfectants and as antifouling agents that prevent mollusks from accumulating in industrial pipes. Biocides are produced in liquid and powder forms, in ready-to-use formulations or as concentrates, and are applied using a variety of techniques. Table 1 provides a list of biocides that have been evaluated to potentially control or inactivate ANS in ballast water. Though examined for use in ballast water treatment, these biocides may be effective at controlling select Organisms of Concern – CAWS[2] (Bowman et al. 1998, Chattopadhyay et al. 2004, TenEyek 2009). See Table 2 and the *General Effectiveness* and *Operating Constraints* sections of this fact sheet for more information on biocide effectiveness.

[1] For a list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

[2] Algaecides, herbicides, molluscicides and piscicides are also considered biocides. They are each covered in more detail in separate fact sheets (titled "Algaecides," "Aquatic Herbicides," "Molluscicides," and "Piscicides").

Depending on the type of biocide, ship ballast water treated with biocides must be detoxified using methods that avoid discharging unwanted concentrations of residual biocide and toxic byproducts into the environment (Chattopadhyay et al. 2004). Many biocide applications for ballast water treatment require chemical neutralization prior to discharge. Most ships neutralize treated ballast water before discharge, but some rely on minimum hold times to provide an opportunity for sufficient degradation of residuals (Lloyd's Register 2010). Water temperature and salinity affect the rate at which chemical biocides function and break down (Albert et. al. 2010).

Prior Applications: Biocides are widely used in the health, food, and water treatment industries. Biocides have been studied as a means to prevent ANS introductions in ballast water via international shipping (Chattopadhyay et al. 2004).

General Effectiveness: Biocides used in industry can be effective at controlling ANS when used properly. Factors that influence the efficacy of biocides on microorganisms and other aquatic species include the biocide's chemical properties, the size and characteristics of the organism, biocide concentration, treatment/application process, contact time, and water quality (e.g., salinity, pH, temperature, oxygen content) (Chattopadhyay et al. 2004).

The U.S. Coast Guard (USGS) Research and Development Center conducted a qualitative assessment of potential ballast water biocides and their effect on different organisms (Table 2). For this qualitative assessment, this evaluation of biocide effectiveness does not consider conditions under which the biocide was tested; rather the evaluation considers only whether the outcome of the study resulted in the desired effect. Except for otherwise noted, the information on biocide effectiveness referenced in this fact sheet was obtained from literature search conducted to complete USGS's assessment and was not the result of scientific research targeted specifically for ballast water treatment or use in an open flowing system, and must be used cautiously (Chattopadhyay et al. 2004).

Operating Constraints: Biocides have specific use restrictions and requirements, which are found on the product label. The following are only a few of the numerous operating constraints that would require consideration. To be effective, target concentrations and specific contact times must be obtained throughout the water column. Additionally, depending on the selected biocide, it may be necessary to deactivate or neutralize the biocide to avoid killing non-target organisms upon release of treated water, or downstream of a treatment area. Certain biocides may create toxic by-products, persist in the environment and accumulate in sediment, making sediment reuse or disposal problematic.

A compilation of the physiochemical properties, treatment efficacy against target organisms, environmental acceptability, and other vendor information for many biocides can be found in Chattopadhyay et al. (2004).

Table 1. Biocides Considered for Potential Treatment of Ballast Water
(adapted from Table 3-1 and Table 3-3, Chattopadhyay 2004[3] unless otherwise noted in footnote)

Biocide	Common Application	General Characteristics
Metal		
Silver (ionic or salts)	Disinfection of industrial water systems	• Limited applications of metal ions or salts • Not generally used due to human side effect risk
Oxidizing – *Halogen containing compounds*		
Bromine Chlorine (free chlorine, hypochlorous acid, hypochlorite salts) Chlorine dioxide Iodine Sodium chlorite	Disinfection of drinking water, cooling systems, and surfaces	• Corrosive • Presence of organic matter limits the effectiveness and may require higher dosage • Residuals remain in water after treatment • Possibly create harmful byproducts • Requires frequent applications • Presence of organic matter limits the effectiveness and may require higher dosage
Oxidizing – *Non-halogen containing compounds*		
Hydrogen peroxide Potassium permanganate	Disinfection of drinking water, cooling systems, and surfaces	• Presence of organic matter limits the effectiveness and may require higher dosage • Moderately corrosive • Some residuals remain in water after treatment
Oxidizing – *Acids*		
Peracetic acid (Peraclean®)	Wastewater treatment	• Effective disinfectant with no known toxic residual • More potent than hydrogen peroxide • Rapidly active at low concentrations against a wide range of microorganisms • Corrosive • Highly efficient in presence of organic matter
Non-oxidizing Biocides – *Aldehydes*		
Glutaraldehyde	Disinfectant in hospitals, laboratories, and biological fixatives	• Slight to moderate efficiency in presence of organic matter • Some residuals remain in water after treatment

[3] Of the biocides that are identified in the *Chattopadhyay,2004* paper, only ones that are not identified in a different fact sheet or that have been found to be effective on the ANS of Concern – CAWS are included. Biocides identified in *Chattopadhyay,2004* but are found in other fact sheets are copper compounds found in the "Algaecides" and "Molluscicides" fact sheets, and ozone found in the "Alteration of Water Quality" fact sheets. Biocides listed in the *Chattopadhyay,2004* report that were not included because they were not effective on the ANS of Concern – CAWS are the following: cationic surfactants, Grotan, and zinc pyrithione. Formaldehyde was not included as it was classified as a carcinogen in the 2011 National Toxicology Program in it Twelfth Report on Carcinogens.

Table 1 (cont.). Biocides Considered for Potential Treatment of Ballast Water
(adapted from Table 3-1 and Table 3-3, Chattopadhyay 2004[4] unless otherwise noted by footnote)

Biocide	Common Application	General Characteristics
Non-oxidizing Biocides - *Amines and halogenated amides*		
Dibromonitrilopropionamide (DBNPA)	Pulp and paper water treatment systems; disinfection of industrial water systems	
Fatty amines (Mexel® 432)	Corrosion inhibitor; scale dispersant	• Rapid degradation in the environment
Non-oxidizing Biocides - *Heterocyclic ketones*		
Polyhexamethylene biguanide (PHMB)	Disinfection of industrial water systems	
Isothiazolone (Sea-Nine®)	Antifouling agent	• Proposed as alternative to organotin compounds (chemical compounds that contain at least one bond between tin and carbon)
Other Biocides		
2-Thiocyanomethylthio benzothiazole (TCMTB)	Disinfection of industrial water systems; antifouling agent	• Proposed as alternative to organotin compounds (chemical compounds that contain at least one bond between tin and carbon)
Benzalkonium chloride	Disinfection of industrial water systems	• Corrosive
Chlorothalonil	Fungicide	• Proposed as alternative to organotin compounds (chemical compounds that contain at least one bond between tin and carbon)
Dichlofluanid	Antifouling agent	• Proposed as alternative to organotin compounds (chemical compounds that contain at least one bond between tin and carbon)
1-(3-Chloroallyl)-3,5,7-triaza-1-azoniaadamantane chloride	Metalworking fluids, preservative for paints	• Not persistent and degrades rapidly under acidic conditions
2-Methylthio-4-tertbutylamino-6-cyclo-propylamino-striazine (Irgarol® 1051)	Antifouling agent	• Proposed as alternative to organotin compounds (chemical compounds that contain at least one bond between tin and carbon)
Phenol	Disinfectant	• Low corrosivity • Little or no residuals remain in water after treatment
Vitamin K (SeaKleen®)	Ballast water treatment	• Toxic to a broad spectrum of marine and freshwater organisms (fish larvae and eggs, planktonic crustaceans, bivalve larvae, *Vibrio* bacteria, and dinoflagellates)
Sodium hydroxide [5]	Saponification; food preparation, cleaning agent, industrial drilling, paper making	• Also known as lye, caustic soda, and sodium hydrate • Caustic washing
Triclosan	Wastewater treatment	• Stable and incompatible with strong oxidizing agents
Zineb (thiocarbamate)	Disinfection of industrial water systems; antifouling agent	

[4] Of the biocides that are identified in the *Chattopadhyay,2004* paper, only ones that are not identified in a different fact sheet or that have been found to be effective on the ANS of Concern – CAWS are included. Biocides identified in *Chattopadhyay,2004* but are found in other fact sheets are copper compounds found in the "Algaecides" and "Molluscicides" fact sheets, and ozone found in the "Alteration of Water Quality" fact sheets. Biocides listed in the *Chattopadhyay,2004* report that were not included because they were not effective on the ANS of Concern – CAWS are the following: cationic surfactants, Grotan, and zinc pyrithione.

[5] (Bowman et. al. 1998), (TenEyek 2009)

Table 2. Summary of Biocides Considered for Ballast Water Treatment Adapted From Chattopadhyay 2004[6] Unless Otherwise Noted by Footnote

	May Be Effective on ANS of Concern – CAWS							
Biocide	**Algae**	**Annelid**	**Bryozoan**	**Crustacean**	**Fish**	**Mollusk**	**Plant**	**Protozoan**
Metal								
Silver	x							
Oxidizing								
Halogen containing compounds								
Bromine		x		x	x	x		
Chlorine (free chlorine, hypochlorous acid, hypochlorite salts)	x	x		x	x	x		
Chlorine Dioxide		x			x	x		
Iodine				x		x		
Sodium Chlorite	x	x		x	x	x		
Non-halogen containing compounds								
Hydrogen Peroxide	x	x		x		x		
Potassium Permanganate	x	x		x		x		
Non-oxidizing								
Acids								
Peraclean (peracetic acid)					x			
Aldehydes								
Formaldehyde	x	x		x	x	x		
Glutaraldehyde	x	x				x		
Amines and halogenated amides								
Dibromonitrilopropionamide (DBNPA)	x			x				
Mexel® 432 (fatty amines)		x				x		
Heterocyclic ketones								
Polyhexamethylene biguanide (PHMB)		x				x		
Sea-Nine (isothiazolone)	x	x		x		x		
Others								
2-thiocyanomethylthio benzothiazole (TCMTB)		x		x	x	x		
Benalkonium chloride		x		x	x	x		
Chlorothalonil				x				
Diclofluanid		x			x	x		
Dowicil® 75 (N-(3-chloroallyl)hexaminium chloride)				x				
Irgarol® 1051 (2-methylthio-4-tert-butylamino-6-cyclo-propylamino-s-triazine)					x			
Phenol		x						
SeaKleen® (Vitamin K)	x	x		x	x	x		
Sodium Hydroxide[7]	x	x		x	x	x		
Triclosan					x			
Zineb (thiocarbamate)					x			

[6] Except for sodium hydroxide, a biocide was considered effective and designated with a "X" if the LC50 (i.e., the biocide concentration that is lethal to 50 percent of the tested organisms) was determined to be 1,000 micrograms per liter (µg/L) or less, if the EC50 (i.e., the effective biocide concentration at which 50% of the tested organisms are impacted) included mortality of the organism as an impact, or if the reviewed literature designated the biocide as "effective." "May Be Effective on ANS of Concern – CAWS" was designated with an "X" in this Table and Appendix A if the above criteria were met.

[7] (Bowman 1998), (TenEyek 2009)

Cost Considerations:

Implementation: Implementation costs of biocide applications would include the cost of the biocide, the detoxicant (if required to neutralize the biocide), and the application method. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include application of the biocide and detoxicant, and effectiveness and water quality monitoring programs.

Mitigation: Design and cost for mitigation measures required address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

Albert, R., R. Everett, J. Lishman, & D. Smith. 2010. Availability and efficiency of ballast water treatment technology: background issue paper. Science Advisory Board, USEPA, Wash, DC. 73 pp

Bowman, M.F. and R.C. Bailey. 1998. Upper pH tolerance limit of the zebra mussel (*Dreissena polymorpha*). *Canadian Journal of Zoology*, vol. 76, pp. 2119-2123

Chattopadhyay, S., C. Hunt, P. Rodgers, A. Swiecichowski, & C. Wisneski. 2004. Evaluation of biocides for potential treatment of ballast water. United States Coast Guard Research and Development Center, Groton, CT

Greenman, D., K. Mullen, & S. Parmar. 1997. Ballast water treatment systems: a feasibility study. United States Coast Guard Office of Response, Worcester Polytechnic Institute

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ANS Control: Biological Control[1,2] –Introduced Predatory Fish Species (Triploid Grass Carp,and Molluscivorous and Piscivorous Fish), Introduced Predatory Insect Species, *Pseudomonas fluorescens* CL 145A, and Targeted Disease Agents.

Targeted Species: The use of predatory species, including insects and triploid grass carp (*Ctenopharyngodon idella*), as biological control agents has been developed for management of both aquatic and terrestrial plants. Dotted duckweed (*Landoltia* (*Spirodela*) *punctata*) and water chestnut (*Trapa natans*) are the only ANS of Concern – CAWS[3] that can be controlled by triploid grass carp. There has been considerable research on the use of insect agents to control water chestnut; however, to date, none of these insect agents have been approved for release in the U.S.

Triploid grass carp are herbivorous fish commonly used to control unwanted aquatic vegetation.

Introduced predatory fish species and targeted disease agents have been considered for controlling silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobilis*). Molluscivorous fish may be effective for control of the greater European pea clam (*Pisidium amnicum*), European fingernail clam (*Sphaerium corneum*), and the European stream valvata (*Valvata piscinalis*).

Pseudomonas fluorescens CL 145A, is under development as a biopesticide for controlling mollusks; possible ANS of Concern – CAWS that may be affected by *P. fluorescens* CL 145A include greater European pea clam, European fingernail clam , and European stream valvata.

Selectivity: Insect biological control agents approved for release in the U.S. have undergone extensive host-specificity testing and are considered selective for their target host. Triploid grass carp are non-selective feeders and will consume most aquatic vegetation. Predatory carnivorous fish species eat small fish, mussels, and other invertebrates, and targeted disease agents are currently being researched for application in the wild to affect the minnow family of fishes. *Pseudomonas fluorescens* CL 145A was developed specifically for control of *Dreissena* mussels but has activity on golden mussels (*Limnoperna fortunei*) as well and may have activity on other mollusk species.

Developer/Manufacturer/Researcher: The use of insects for biological control applications must follow strict procedures and regulations specified by the U.S. Department of Agriculture (USDA). Currently, there are no vendors for insect biological control agents that can be used for control of plant ANS of Concern – CAWS. There are numerous State natural resource agencies and commercial

[1] A common name for the term biological control is 'biocontrol.'
[2] Some forms of biological control have been addressed in separate fact sheets. Please see the fact sheet labeled "Deleterious Gene Spread" for information on genetic methods for biological control of non-native fishes.
[3] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

vendors that could supply live predatory fish. Examples of certified triploid grass carp suppliers include J. M. Malone & Sons (Lonoke, Arkansas) and Keo Fish Farms (Keo, Arkansas).[4] Targeted disease agents are in the conceptual stage of development and there are currently no manufacturers of this control technology. Marrone Bio Innovations (Davis, California) is the developer of *P. fluorescens* CL 145A.

Pesticide Registration/Application: Pesticides, including microbial biopesticides, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: Biological control is broadly defined as the planned introduction of one organism (the biocontrol agent) to reduce pest populations of another organism (the target species) to economically acceptable levels (Ross & Lembi 1985; Perry et al. 2000; Cuda 2009a). Biological control rarely results in eradication of the target pest species, but rather, suppresses growth and reproduction of the target species. Schooler et al. (2004) reported that a successful biological control agent will reduce the density of a target species to a desired level and maintain it there with minimal risk of damage to non-target species. Often, biocontrol agents are imported from the native range of the target species (i.e., a "natural enemy"). It is critical that a biological control agent prey specifically on the target species and not on native, non-target organisms. Substantial research, planning, and care are needed to avoid introducing additional pest species (Cox 2004).

Biological control agents currently used for management of invasive plants include insects, pathogens (bacteria, fungi and viruses), herbivorous fish (triploid grass carp and tilapia), and grazing animals (goats and sheep) (Ross & Lembi 1985; McIntosh et al. 2003; Coombs et al. 2004; Cuda 2009a; Colle 2009). Pathogen biological control agents have not been developed or approved for use on plant species identified as ANS of Concern – CAWS. Grazing animals have not been widely used to control aquatic and wetland plants such as those identified as ANS of Concern – CAWS.

Biological control for fishes includes the introduction of carnivorous fish species (e.g., northern pike (*Esox lucius*), walleye (*Sander vitreus*), largemouth bass (*Micropterus salmoides*)), species in the Salmonidae family (hereafter referred to as salmonids), and the development of targeted disease agents as biological control agents against invasive fish. In addition, microbial biopesticides (e.g., *P. fluorescens* CL 145A) have been investigated and are under development as a biological control alternative for managing invasive mollusks.

There has been considerable research on the development of insect agents to control water chestnut. Pemberton (1999, 2002) conducted extensive surveys for natural insect enemies of water chestnut in Northeast Asia and Europe. Of the insects found, a leaf beetle (*Galerucella birmanica*) was the most common and the most damaging species in Asia, causing complete defoliation of water chestnut plants

[4] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

(Pemberton 1999; Ding et al. 2006a; Ding et al. 2006b). Although water chestnut continues to be a problem in North America, biological control research on this species in the U.S. was suspended in 2002 (Pemberton 2002), primarily due to lack of program funding.

Introduced Predatory Fish Species –

Triploid Grass Carp: Grass carp were initially imported into the U.S. in 1963 by the United States Fish and Wildlife Service (USFWS) as a biological control alternative to chemical control methods for aquatic vegetation. This fish is native to Eastern Asia and has specialized grinding teeth (called pharyngeal teeth) and a long intestine, which allow it to shred and digest aquatic plants as its principal food source (Sanders et al. 1991). Grass carp can survive for up to 25 years and can grow as much as 10 lbs in a year if adequate food is available (Colle 2009). Triploid grass carp have three sets of chromosomes and are incapable of producing viable offspring (Sanders et al. 1991), which minimizes the risk of stocking a non-native fish. They are produced by combining eggs and sperm from diploid grass carp (diploid having two sets of chromosomes) and then shocking the fertilized eggs in the early stages of development, using temperature, pressure, or chemicals (Sanders et al. 1991; Colle 2009). The USFWS offers a National Triploid Grass Carp Inspection and Certification Program for resource agencies in the United States and in other countries to help agencies protect their aquatic habitats (U.S. Fish and Wildlife Service, 2011). This inspection and certification program provides assurance that shipments of grass carp alleged to be triploid do not, within the confidence limits of the inspection program, contain reproducing diploids.

Triploid grass carp are considered general herbivores and will consume almost any plant material (including grass clippings); however, they have preferences for some plants over others (Colle 2009). Once the preferred plants have been depleted, triploid grass carp will consume most other plants, with the exception of Eurasian watermilfoil (*Myriophyllum spicatum*). For a list of the preferred plant species consumed and controlled by grass carp, see Miller & Decell (1984) and Sanders et al. (1991). The only ANS of Concern – CAWS listed as a preferred food source of triploid grass carp are duckweed species (*Lemna* and *Landoltia*). While not a preferred food source, Krupauer (1971) reported that repeat stocking of grass carp controlled 80 to 100% of submersed aquatic plants in Central and Eastern Europe, including water chestnut.

Caution should be used when considering grass carp as a control strategy because of their potential to become a high impact invasive species. Grass carp can be detrimental to native vegetation.

To achieve effective control of nuisance aquatic vegetation, triploid grass carp must be stocked in sufficient numbers such that the rate of consumption by the fish is equal to or greater than the growth rates of plants (Sanders et al. 1991). Stocking proper numbers of fish is important and depends on several factors, including size and age of fish, density and species of plants to be consumed, size of the waterbody, seasonal water temperature, and whether other control practices (herbicide or mechanical treatments) are employed (Sanders et al.

1991; Lewis 1998). Simulation models which consider these parameters are available and can be used to determine suitable stocking rates (Stewart & Boyd 1999). Lewis (1998) reported that proper stocking of triploid grass carp can result in a 75 to 90% reduction of target plant species in 3 to 4 years.

Grass carp can be used in conjunction with other management strategies, such as mechanical harvesting or aquatic herbicides. Typically, herbicide application or mechanical harvesting is utilized prior to stocking of fish (Sanders et al. 1991). Because triploid grass carp are non-selective herbivores, there may be instances where native vegetation should be protected.

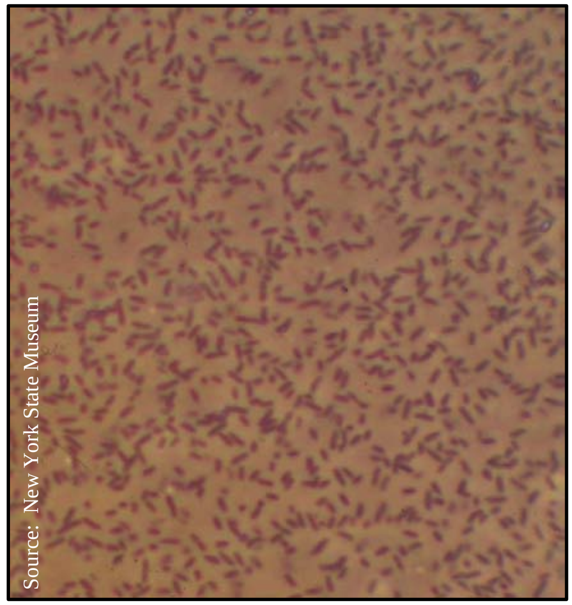
Piscivorous Fish: Natural resource managers have stocked piscivorous fish species in the U.S. for over a century for the purpose of enhancing recreational fishing opportunities (Nielsen 2010). This technique has been used to control invasive fish species in the Great Lakes (Mills et al. 1993). There are two common outcomes of stocking fish predators: replacement of native predators or an increase in predator species richness (Eby et al. 2006). In created aquatic environments, such as the Chicago Sanitary and Ship Canal, there are no native species; however, stocked piscivorous fish may migrate into the tributaries that flow into created aquatic environments, disrupting ecosystems outside of the treatment area.

Molluscivorous Fish: Natural resource managers could increase the abundance of several fish species already present in the CAWS that eat mollusks through stocking propagated fish. Native molluscivorous fish species include the freshwater drum (*Aplodinotus grunniens*) and pumpkinseed (*Lepomis gibbosus*), and non-native molluscivorous fish species include the common carp (*Cyprinus carpio*) or round goby (*Neogobius melanostomus*) (Kirk et al. 2001). If not contained, molluscivorous fish have the potential to migrate to adjacent habitats and disrupt ecosystems outside of the treatment area.

Introduced Predatory Insect Species – Numerous insect biocontrol agents have been developed and approved for release on more than 25 invasive target plants in the U.S. (Coombs et al. 2004). Of these 25 target plants, only eight are aquatic and/or wetland species. The USDA's Animal and Plant Health Inspection Service, Plant Protection and Quarantine is responsible for controlling introductions of species brought into the U.S. for biological control of plants, in accordance with the requirements of several plant quarantine laws, the National Environmental Policy Act, and the Endangered Species Act. Petitions for release of plant biological control agents are evaluated by a Technical Advisory Group, which represents the interests of a diverse set of federal and non-Federal agencies (Cofrancesco & Shearer 2004; Horner 2004; Cuda 2009b).

Pseudomonas fluorescens CL 145A – The bacterium, *P. fluorescens* CL 145A, is under development as a commercial biopesticide (proposed product name, Zequanox™). *Pseudomonas fluorescens*, a common soil microbe with worldwide distribution, is naturally present in all North American aquatic sediments and typically functions to protect plant roots from disease. In laboratory screening trials, Dr. Dan Molloy of the New York State Museum discovered a strain of *P. fluorescens*, CL 145A, with lethal activity against *Dreissena* species (Molloy 1998). Cells of *P. fluorescens* CL 145A contain a natural byproduct that acts as a toxin to destroy epithelial cells in the digestive system of susceptible mussels (Molloy 2001; Molloy & Mayer 2009). As filter feeders, susceptible mussels readily ingest the bacterial cells; exposure causes no adverse reaction to feeding, as opposed to typical chlorination treatments which cause mussels to close their inhalant siphon tube (Molloy & Mayer 2007). As a result of this discovery, Dr. Molloy obtained patents in both the U.S. (Molloy 2001) and Canada (Molloy 2004) for use of *P. fluorescens* CL 145A as a method for controlling invasive *Dreissena* mussels.

Marrone Bio Innovations is currently developing *P. fluorescens* CL 145A as a biopesticide (Zequanox™) for invasive mussel control (Marrone Bio Innovations 2011). The biopesticide formulation will contain dead cells of *P. fluorescens* CL 145A, since it was shown in laboratory studies that dead cells of this bacterial strain were equally lethal against *Dreissena* species as live cells (Molloy & Mayer 2007, 2009). Marrone Bio Innovations received approval (Section 3 registration) for the active ingredient, *P. fluorescens* CL 145A, from the USEPA in July 2011 (Marrone Bio Innovations 2011). USEPA-approval of the commercial formulation of this product (Zequanox™) is pending, but is expected in March 2012.



Pseudomonas fluorescens **strain CL 145A, active ingredient in Zequanox™, a new biopesticide under development for control of invasive mollusks**

Targeted Disease Agents – There are three different diseases that mainly affect the minnow family (Cyprinidae), which includes silver and bighead carp: spring viremia of carp (SVC), koi herpes virus (KHV), and carp pox. Spring viremia of carp was first reported in North America in 2002 (Goodwin 2002) and confirmed in common carp taken from the Calumet-Sag Channel near Chicago in 2003 (Nelson 2003). Ideally, the proliferation of these diseases in the CAWS could reduce the health and abundance of common, silver, and bighead carp without affecting non-target organisms.

Prior Applications:

Introduced Predatory Fish Species –

Triploid Grass Carp: Triploid grass carp are widely used to control unwanted aquatic vegetation throughout the U.S. Grass carp have been so effective at aquatic weed control that they are now used in 35 different states (Colle 2009). Their primary use is in aquaculture and closed public and private waterbodies, but they are also used in large lakes and reservoirs.

Piscivorous Fish: Stocking predatory fishes (e.g. northern pike, walleyes, and largemouth bass) has been used commonly by fisheries managers in the past to control early life stages of common carp. Several species of non-native salmonids were successfully introduced into the Great Lakes beginning in the mid-1960s to control invasive rainbow smelt (*Osmerus mordax*) and alewife (*Alosa pseudoharengus*) (Stewart et al. 1981). However, these fish control projects have highly variable effectiveness and have rarely included adequate monitoring to determine success (Meronek et al. 1996). A review of manipulative field studies showed that in about 75% of cases, generalist predators, whether single species or species assemblages, reduced pest numbers significantly (Symondson et al. 2002). Programs to stock predators as a means of reducing prey populations must consider the size and abundance of the predator, the size and abundance of the target prey, the size and abundance of alternative prey, and the physical-chemical characteristics of the habitat. Unfortunately, little is known about the susceptibility of bighead, black, grass, and silver carps, to native piscivores (Conover et al. 2007).

Molluscivorous fish: Fishery hatchery managers have used molluscivorous fish to control snails in fish culture ponds (Carothers & Allison 1968). Computer simulation models have been used to estimate the effect of molluscivorous fish as a control for zebra mussels. Bioenergetics modeling suggested that there is a strong correlation between the effectiveness of molluscivorous fish and water temperature. Model results indicate that fishes in southern latitudes consumed up to 100 percent more food than those in northern systems because of increased metabolism. (Eggleton et al 2003).

Introduced Predatory Insect Species – The use of insects as biological control agents for aquatic nuisance plant species has yielded mixed results. Currently, alligatorweed (*Alternanthera philoxeroides*), purple loosestrife (*Lythrym salicaria*) and melaleuca (*Melaleuca quinquenervia*) are being successfully controlled using insects released as biocontrol agents (Cuda 2009b). Gangstad (1976) reported that the total acreage of alligatorweed controlled by the USACE was significantly reduced over a 10-year period as a result of releasing the alligatorweed flea beetle (*Agasicles hygrophila*). In addition, the cost of using herbicides to control this weed was reduced by 75% after agent release. Insect biological controls are commonly utilized in combination with other control technologies in an integrated pest management (IPM) approach.

Pseudomonas fluorescens CL 145A – Preliminary laboratory and facility trials showed that a 6-hour exposure of 50-100 parts per million (ppm) dry bacterial mass per unit volume consistently provided > 90% mussel mortality (Molloy & Mayer 2007). Pilot-scale facility treatments and field demonstrations are ongoing at: Davis Dam, Bullhead City, AZ (Nibling et al. 2010); Ontario Power Generation; and DeCew II Generating Station near Niagara Falls (Van Oostrom et al. 2010). To date, the results of these trials showed 53.5% adult mortality (2+ year-old mussels) and 82.5-100% mortality of pediveligers and other juvenile life stages of *Dreissenid* mussels following treatment with *P. fluorescens* CL 145A. To date, this control technology has not been evaluated over a wide variety of field conditions, such as open water systems.

Targeted Disease Agents – The introduction of targeted diseases has been widely discussed, however, natural resource agency managers are reluctant to introduce a disease that cannot be controlled in the wild and whose effects are not fully known. Targeted diseases would likely be highly regulated and only considered on an experimental level.

General Effectiveness:

Introduced Predatory Fish Species –

Triploid Grass Carp: Triploid grass carp consumption rates, which are measured as the daily percentage of body weight eaten, are affected by the size of the fish and environmental factors such as water temperature, oxygen content and salinity levels (Colle 2009). Colle (2009) reported that large grass carp (> 15 lbs) consume up to 30% of their body weight daily, whereas smaller fish (< 10 lbs) can consume as much as 150% of their body weight in one day. Maximum consumption occurs when water temperatures are at 78 to 90 °F and is greatly reduced below 55 °F (Colle 2009). Similarly, consumption of plants by grass carp is reduced by 45% when oxygen content in the water falls below four ppm (Colle 2009). Specific to duckweed species, Miller and Decell (1984) reported that a 35.2 gram (g) grass carp can consume 436 to 700 g of duckweed per day. Grass carp consumption rates for water chestnut have not been reported.

Piscivorous Fish: Experience in aquaculture indicates that bighead and grass carps are highly susceptible to predacious fishes, but little is known about which native predators will prey effectively on bighead, black, grass, and silver carp, at what sizes, and the effects of environmental factors or habitat types on this relationship (Conover et al. 2007). Research is needed to determine which native predator fish can effectively prey on Asian carps, the vulnerability (sizes and life stages) of Asian carps to predation, and the stocking size and density of predators required for effective population control. Bioenergetics models have shown that some predatory fish are very good at controlling prey populations. Simulations of alewife consumptions by stocked salmonids suggest that as much as 20 to 33% of the annual alewife production in Lake Michigan may be consumed annually (Stewart et al. 1981).

However, Asian carps grow very rapidly, achieving a length of almost 12 inches by the end of the first year of life (Williamson & Garvey 2005). The size of the predatory fish's mouth, also known as its gape-size, restricts the predator's ability to consume larger fish. A prey fish is too large to be consumed by a predatory fish when the width of a prey fish reaches the predator gape-size limit (Nilsson & Brönmark 2010). Stocked piscivorous fish would only have a short window when their prey would be small enough for them to consume, therefore they would have to survive on smaller native species for most of the year.

Many invasive fish species can tolerate poorer water quality and higher water temperatures (USEPA 2008); consequently, the survival requirements of stocked piscivorous fish must be considered.

Molluscivorous fish: The long-term reduction of invasive mussels by natural predators has yet to be demonstrated (Molloy et al. 1997; Molloy 1998).

Introduced Predatory Insect Species – There are no insect biological control agents currently approved for release in the U.S. for use against ANS of Concern – CAWS. Insects such as *G. birmanica*, however, are known to be important pests to cultivated water chestnut in China and India (Pemberton 1999, 2002).

Pseudomonas fluorescens CL 145A – The bacterium, *P. fluorescens* CL 145A, is effective for controlling veligers and adult life stages of zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*, respectively) and golden mussels. The product has not been tested on the three (3) invasive mollusk species identified as ANS of Concern – CAWS (greater European pea clam, European fingernail clam, and European stream valvata); it is possible, however, that these species are also sensitive to *P. fluorescens* CL 145A.

Targeted Disease Agents – Spring viremia of carp (SVC) can be highly fatal in young fish with mortality rates up to 70%. In Europe, where this disease has been endemic for at least 50 years, 10 to 15% of one-year-old carp are lost to SVC each year (U.S. Department of Agriculture, Animal and Plant Health Inspection Service 2003). Koi herpes virus (KHV) is a highly contagious disease that may cause between 80 to 100% mortality in susceptible populations, with signs of disease most commonly being expressed when water temperatures are between 72 and 81 °F (22 to 27 °C) (Ornamental Aquatic Trade Association 2001). Carp pox is closely related to KHV but is less fatal. This disease weakens the fish with infection and lesions, leaving it susceptible to secondary infections by other microorganisms.

Operating Constraints:

Introduced Predatory Fish Species – Triploid grass carp are best used in waterbodies with no outflow; this ensures fish will stay in the area where they are needed and minimizes potential impacts to downstream vegetation. To prevent loss of triploid grass carp during flooded conditions, containment devices such as mesh fence or screens are needed at all potential overflow points. Restocking may be necessary due to predation or offsite migration in unconfined systems. The use of triploid grass carp or piscivorous fish requires continuous surveillance and manipulation (restocking) to assure effectiveness and to minimize unwanted side effects (denuding the waterbody of all vegetation or native fish).

Introduced Predatory Insect Species – Once regulatory approval has been obtained for release, the success of a predatory insect species' introduction and the subsequent impact on the target or host species will depend on the establishment of a viable population. Factors that can influence successful establishment include climatic extremes, host incompatibility, predation, competition, parasites, and disease (Coombs 2004).

Pseudomonas fluorescens CL 145A – Performance of *P. fluorescens* CL 145A in flowing water systems and effects on native mussel species are unknown, however, evaluations are ongoing to determine suitability of product use as a treatment in open waters such as lakes and reservoirs (Heilman et al. 2010). Current success with this product is largely based on results of in-line pipe treatments at power generating facilities. There is some evidence that product performance can vary under certain environmental conditions, such as: soft waters with pH less than 7.4; low O_2 levels (< 2 ppm); and highly turbid waters can all reduce efficacy (Molloy & Mayer 2007). In addition, susceptibility of mussels to *P. fluorescens* CL 145A increases with water temperature (> 90% mussel mortality at 23 °C) (Molloy & Mayer 2007).

Targeted Disease Agents – The use of Targeted Disease Agents would require additional research and development prior to implementation of this technology. Unintentional consequences such as the impact of disease agents to non-target organisms, the risk of disease transfer to other waterbodies, and the environmental factors that affect disease performance and proliferation are unknown. There is some evidence that disease incidence for the koi herpes virus is best expressed when water temperatures are between 72 to 81°F (22 to 27°C) (Ornamental Aquatic Trade Association 2001).

Cost Considerations:

Introduced Predatory Fish Species – The considerations below apply to triploid grass carp and other piscivorous and molluscivorous fish.

Implementation: Implementation costs of this Control would include purchase, delivery and stocking of certified predator fish (i.e. triploid grass carp, walleye, northern pike, and redear sunfish). Stocking rates of triploid grass carp vary with density and acreage of vegetation to be controlled; however, in general terms, the stocking rates for grass carp in southeastern reservoirs ranges from 15 to 20 fish per vegetated acre. The benefits of stocking grass carp can extend more than 7 years (Sanders et al. 1991; Colle 2009). The stocking rate, stocking size, and density of piscivorous and molluscivorous fish predators required for effective population control should be modeled to determine the feasibility and the potential impacts to native species.

Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance cost considerations include an ecosystem monitoring plan and restocking.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Introduced Predatory Insect Species – The development of insect biological control is time consuming. On average, it takes 11 to 13 years of research to develop a classical biological control program for a single weed species (Andres 1977). This includes overseas surveys for agents, research on host specificity, clearance/approval of the most promising control agents, and full-scale release programs. While considerable research has been conducted to develop insect agents for water chestnut, these insects have yet to receive approval for release in the U.S. Without the availability of agents, the cost of implementing insect biological control agents against water chestnut cannot be realized.

Implementation: Implementation factors specific to this Control are unknown at this time. Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance factors are unknown at this time.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Pseudomonas fluorescens CL 145A – The cost of the product is unknown at this time; until registration of the commercial formulation is approved by the USEPA (expected in March 2012), this biopesticide is unavailable for sale.

Implementation: The implementation of this Control would include planning, design, and application of the product. Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would depend on dosage and application, and would include effectiveness monitoring.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Targeted Disease Agents – The cost of introducing a disease agent is unknown. Though certain diseases have been found in the CAWS already, the widespread introduction of an infectious disease would require careful deliberation by regulatory and public health agencies.

Implementation: Implementation factors specific to this Control are unknown at this time. Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance factors are unknown at this time.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Controlled Harvest and Overfishing

ANS Control: Controlled Harvest and Overfishing

Targeted Species: Fish and crayfish are managed through controlled harvest and overfishing. Specific ANS of Concern – CAWS[1] that may be controlled by this technology include blueback herring *(Alosa aestivalis),* skipjack herring (*A. chrysochloris),* alewife (*A. psuedoharengus),* northern snakehead (*Channa argus),* silver carp (*Hypophthalmichthys molitrix),* bighead carp (*H. nobilis),* and black carp (*Mylopharyngodon piceus)*.

Nets are commonly used to commercially harvest fish in the effort to reduce Asian carp populations in the Upper Illinois River downstream of the Electric Fish Barrier; commercial fishermen contracted by IDNR unload fish caught near Morris, IL.

Selectivity: This Control was designed to control fish and crustaceans and is non-selective.

Developer/Manufacturer/Researcher: There are various state and Federal natural resource agencies, as well as private entities, developing and researching the effectiveness of this Control.

Brief Description: Controlled harvest involves the removal of an organism to a level where it can no longer maintain a viable population. Controlled harvest implies that the captured organisms are consumed or used for some purpose other than disposal. Overfishing is similar to controlled harvest; however, the captured organisms are discarded and not necessarily used beneficially. This technique requires an intense capture effort over a long period of time. A variety of nets and traps have been designed to catch targeted species in order to reduce the by-catch of non-targeted species. It is difficult to overharvest a river system because the harvested areas quickly repopulate with fish that migrate from other parts of the river.

Attraction could be used as a capture method. Target species could be lured into backwater lakes using food, pheromones, water temperature, and similar techniques, and “corralling” them by closing off the entrance pathway with a net, gate, temporary dam or levee. The backwater lake would then be pumped down to a point where fish could be efficiently harvested and native fish sorted out and released. This method would have beneficial effects on the backwater by exposing and consolidating sediments and promoting vegetative growth (habitat), which would enhance native fish populations when the backwater naturally refills post-harvest.

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Prior Applications: In an attempt to control harvest invasive species, the State of Illinois is currently working with commercial fishers and processors, under contract with a Chinese manufacturer, to catch and export 30 million processed pounds of Asian carp from Illinois waterways (Asian Carp Regional Coordinating Committee 2011). The population dynamics of Asian carp are not understood well enough to predict the required harvest to control these species and there is insufficient data to determine whether or this level of harvest will deter upstream migrations. Controlled harvest has also been used to manage invasive crayfish populations in lakes (Hein et al. 2007).

General Effectiveness: Some species have specialized life cycle requirements that make them especially susceptible to human-induced factors, such as habitat destruction and controlled harvests (Nehlsen et al. 1991); however, many invasive species have highly adaptive life cycle requirements making them far less susceptible to targeted control actions. Long-lived, late-maturing species with infrequent and specialized reproductive requirements, called *K*-selected species, are susceptible to anthropogenic impacts (including harvest), whereas short-lived, fast-maturing species with frequent and generalized reproductive requirements, called *r*-selected species, are less susceptible (MacArthur & Wilson 1967; Sakai et al. 2001). Characteristics common to successful colonists across taxa include *r*-selected life histories (use of pioneer habit, short generation time, high fecundity, and high growth rates), the ability to shift between *r*- and *K*-selected strategies, the number of released individuals, and the number of release events (Kolar & Lodge 2001). Because many ANS of Concern – CAWS are successful colonists, controlled harvest and overfishing may be useful as suppression measures but ultimately ineffective as eradication measures. Both controlled harvest and overfishing may require either continual capture over a long period of time, or intensive harvest during critical periods of concentration and reproduction (e.g., migration and spawning season).

Population models indicate that if population density is lowered by harvesting, the net effect will be to increase resources available to survivors. This can either cause no impact on net recruitment, or have the adverse effect of causing a rapid increase in recruitment, growth rate, and fecundity of the invasive species (Zipkin et al 2009). The latter can progress to a point where population recovery to pre-harvest conditions occurs rapidly despite best efforts (Smith et al. 1997), or even cause an increase in overall population abundance (Zipkin et al 2008).

For physical removal to cause a shift to a relatively stable (but probably still temporary) alternative population density, the total population would have to be harvested to a low enough level to limit the number of available reproductive adults. Where this point lies with invasive species such as the common carp is not known, but it is most likely at a value less than 10% of original biomass (Thresher 1997), however, some models suggest that carp populations respond differently as harvest increases. One study found that common carp abundance declined 28-56% at low levels of harvest (0-20%), but at high levels of harvest (90%), abundance was only reduced 49-79% due to several factors, including increased egg production in the surviving individuals (Weber et al. 2011).

Policymakers must consider whether encouraging the harvest of a harmful invasive species is wise. In the case of Asian carp, once harvesters, processors, and communities become dependent on these fish, pressure to manage a sustainable population of Asian carp may conflict with the original purpose of removing these organisms from the environment (Speir & Brozović 2006).

Operating Constraints: Controlled harvest of fish species would require the development of an infrastructure to support a large commercial fishing industry (fleet and processing plants) and the development of a market to sustain the viability of the industry over time. The effectiveness of controlled harvest decreases where there is a high probability of reintroduction. The impact of controlled harvest on non-target organisms should be evaluated prior to implementation to minimize unintended consequences.

Cost Considerations:

Implementation: Implementation costs would include the cost to harvest, or overfish and dispose of fish.

Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: The effectiveness of harvesting/overfishing can only be determined through routine monitoring of fish populations.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

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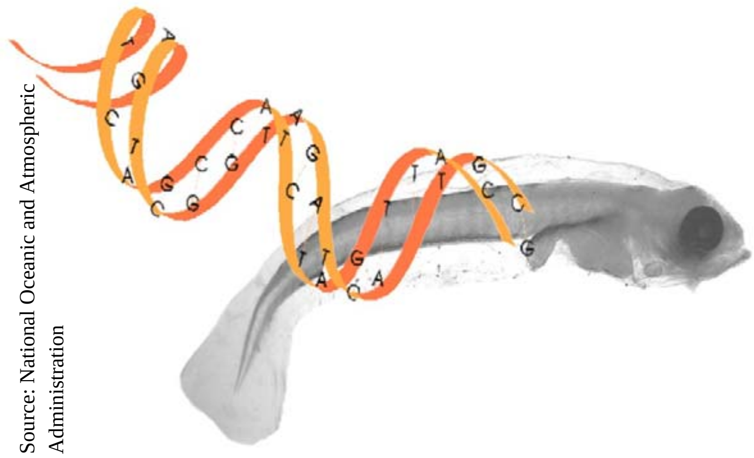
Deleterious Gene Spread

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Deleterious Gene Spread – Daughterless Gene and Trojan Y Chromosome Technologies

Targeted Species: This genetically-based technology is an effective control for fish. Specific ANS identified as ANS of Concern – CAWS [1] that may be controlled with this technology include bighead carp *(Hypophthalmichthys nobilis)*, black carp *(Mylopharyngodon piceus)*, sea lamprey *(Petromyzon marinus)* and silver carp *(H. molitrix)*.



Source: National Oceanic and Atmospheric Administration

DNA can be manipulated to produce only male offspring, leading to the eventual extinction of a species.

Selectivity: This experimental technology is under consideration for targeting bighead carp, black carp, sea lamprey and silver carp. (Teem et al. 2011).

Developer/Manufacturer/Researcher: All projects are presently in the research phase. Research organizations include the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, U.S. Fish and Wildlife Service, and the US Geological Survey's Hammond Bay Biological Station, MI.

Brief Description: There are hundreds of genetically-based strategies that have been or are currently being experimentally tested to control a target population of a non-native species (Pimentel et al. 1989; Muir & Howard 2002; Kapuscinski et al. 2003; Thresher & Kuris 2004; Kapuscinski 2005; Snow et al. 2005; Bergstedt & Twohey 2007). This fact sheet addresses only those with the highest potential to manage ANS fish species in the CAWS. These techniques involve the production and release of genetically altered fish that bear a deleterious genetic construct (transgene) designed to disrupt a specific aspect of the organism's life cycle or biology. Genetic disruption is achieved by releasing fish that produce: offspring of a single sex; sterile offspring; or non-viable embryos (Kapuscinski 2005; Kapuscinski & Patronski 2005; Grewe et al. 2005). A variety of genes could be targeted to control aspects of development, survival, or gametogenesis in offspring. Two autocidal genetic biocontrol methods have been proposed as a means to eliminate invasive fish by changing the sex ratio of the population: the daughterless gene strategy and the Trojan Y.

Daughterless Gene – Daughterless gene technology is a form of sex ratio distortion, where a transgene disrupts a key step in sexual development (i.e., expression of aromatase enzyme) to produce all-male

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

offspring (Werren et al. 1981; Thresher 2008; Thresher & Bax 2003, Kapuscinski & Patronski 2005; Thresher et al. 2002). The transgene is inheritable to future generations (Thresher & Bax 2003) and progressively skews the population sex ratio to the point where the population's reproductive output begins to decline leading to extinction (Grewe 1997; Burt 2003).

Trojan Y Chromosome – The Trojan Y chromosome strategy makes use of a genetically engineered female fish with multiple Y chromosomes. In this approach, a female fish with two Y chromosomes (Trojan Y) is added to a target population. Subsequent mating of the Trojan Y fish with males of the target population would result in the production of all male progeny, half of which are super males (males with two Y chromosomes, making them sterile) (Gutierrez & Teem 2006). Models indicate that for fish species that mature and reproduce once a year, the timeframe for extinction is about 70 years if the Trojan Y fish is stocked at 1.66% of the total population annually (Teem et al. 2011).

Prior Applications: The concept of daughterless gene technology has been around since the mid 1960s (Hamilton 1967). Models indicate that these technologies are feasible, at least under laboratory conditions, and they have been considered for experimental use in Australia, Florida, and the Great Lakes (Bergstedt & Twohey 2007). Thresher (2008) reported that the CSIRO would be ready to conduct a field test of daughterless carp technology in as little as 5 years (2013) in Australia. The Trojan Y chromosome strategy has not been attempted in wild populations.

General Effectiveness: Deleterious genes have not been field tested, but mathematical models have been developed to demonstrate their potential effect.

Daughterless Gene – Preliminary modeling done by Thresher & Bax (2003) showed that when 5% of wildtype carp recruits in a year were replaced with daughterless carriers, a common carp population would show a significant decrease in population levels by 2020 and near extinction by 2030 in Australia. Although the daughterless gene technology appears to have lab research that is the most developed of all transgenic biocontrol strategies, a vast majority of the research has been done outside of North America. Literature indicates that this technology is genetically feasible and has the potential to control aquatic nuisance species, but the potential efficacy of this technique will depend on site- and species- specific characteristics.

Trojan Y Chromosome – A model that compared daughterless gene and Trojan Y chromosome strategies showed that the Trojan Y chromosome strategy worked faster and required the introduction of fewer genetically engineered fish to the target population to achieve local extinction (Teem et al. 2011).

Operating Constraints: Manipulation of genes can manifest unforeseen and significant undesirable side effects and would require extensive research before being accepted as a Control (Liberman et al. 1996). Unintended consequences, such as the spread of genetic material to other species, should be understood before application of this Control. The ecological and economic costs of non-selective treatments will be important to weigh against the risk of spreading genetic material to other species. The subtle effects of even minor variability in some genetic parameters suggest that genetic techniques be applied in an active adaptive management framework (Bax & Thresher 2009). The Food and Drug Administration regulates genetically engineered animals through its New Animal Drug Application process under the Federal Food, Drug, and Cosmetic Act, and would be the lead Federal agency for permitting the application of this technology in the United States.

Cost Considerations:

Implementation: Implementation costs would include the cost of fish and staffing fish release activities. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include effectiveness monitoring and continued release of fish.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Dredging and Diver Dredging

ANS Control: Dredging and Diver Dredging[1]

Targeted Species: Dredging may be used to control submersed and emergent vegetation. Specific ANS of Concern – CAWS[2] that may be controlled with this technology include plants such as Cuban bulrush *(Oxycaryum cubense)*, marsh dewflower *(Murdannia keisak)*, reed sweetgrass *(Glyceria maxima)*, swamp sedge *(Carex acutiformis)*, and water chestnut *(Trapa natans)*.

Scuba diver using suction dredge to remove submersed hydrilla

Diver dredging is mainly applicable to controlling submersed aquatic vegetation (SAV), but may also have applications on emergent vegetation. This technology is designed for submersed aquatic vegetation, so it may or may not have application with the current ANS of Concern – CAWS.

Selectivity: Dredging is a non-selective means of controlling submersed and emergent vegetation and may also remove species that reside in the dredged sediment. Compared with dredging, diver dredging is a more selective method for controlling submersed aquatic plants; however, it will remove species that reside in the sediment.

Developer/Manufacturer/Researcher: Modern dredging is conducted by the U.S. Army Corps of Engineers (USACE) using both in-house and contract labor, and by other private and public agencies and entities such as port authorities.

Workers collecting hydrilla removed by diver dredging

Diver dredging is conducted specifically for invasive plant management and was developed by the British Columbia Ministry of Environment. Several state environmental agencies, such as the Washington Department of Ecology, currently use this technology to control nuisance SAV (Washington State Department of Ecology 2011).

Brief Description: The main use of dredging is to manage and relocate sediment for purposes typically related to navigation and flood control. Associated benefits of this activity related to the control of ANS include the removal of vegetation and mollusks, as well as altering the bathymetry [3] so

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[1] Dredging and diver dredging are forms of mechanical control. See fact sheet titled "Mechanical Control Methods" for more details on similar technologies.
[2] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[3] Bathymetry is topography of a water body; it is the measure of depth and contour of a water body's soil and changes in elevation.

that an area is no longer suitable for inhabitance by a variety of species (Heilfrich et al. 2009). Depending on the scope of the dredging operation, dredging may not eliminate plant ANS; instead, it will reduce the plant mass at the dredging location.

Dredging – Two main types of dredging methods exist: mechanical dredging and hydraulic dredging. Mechanical dredging removes material by scooping it from the channel bottom and placing it into a barge for transport to a disposal area (Sabbatini et al. 1994). Hydraulic dredging works like a vacuum, sucking a mixture of dredged material and water from the channel bottom and pumping it to a destination.

Mechanical dredging in Calumet River, Chicago, IL. Although this dredging was performed to maintain navigation depths, dredging for ANS control would use similar equipment and methods.

Each type of dredge equipment performs the function in a different manner, but all result in sediment being removed from one area and relocated to a temporary or permanent storage or disposal area. Dredge material management areas (DMMAs) are storage or disposal facilities that normally consist of diked areas that hold the dredged material until the material is dewatered. The material is then stored permanently or, depending on its geotechnical and environmental characteristics, may be put to use for projects such as roadbed construction. Confined disposal facilities are a type of DMMA that are used for permanent disposal of contaminated sediments. Unconfined disposal sites can include onshore, near-shore, or open water locations where material is disposed of or beneficially reused. Beneficial uses can include placing sand to encourage marsh or shoreline vegetation development, or reduce shoreline erosion.

Diver Dredging – Diver dredging is essentially a scuba diver with a vacuum hose. Currently, the technology has focused on the removal of invasive SAV. The diver is trained to identify invasive SAV; once the target species is located, the diver removes it using the hose of a small suction dredge.

Prior Applications: Dredging has been used to modify water bodies since the beginning of civilization. Diver dredging was developed more recently to perform specific work, such as aquatic plant management and underwater excavation.

Dredging – Dredging has been applied in waterways to manage water flow, volume, and direction, to alter or improve navigation of federal navigation channels for commercial navigation and recreational traffic, and to improve flood control (USACE, April 2011). Specific uses of dredging to control aquatic plants can be found in urban and agricultural landscapes worldwide (Heilfrich et al 2009). Modern practices in both areas alter water flow and nutrient levels in aquatic environments, creating a need for management. This often involves the removal of sediment to manage aquatic plant growth, restore water storage capacity, reduce downstream pollution, and/or improve navigation (Bhowmik et al. 1988).

Diver Dredging – Diver dredging technology was developed to manage SAV; it has been adapted to manage invasive SAV within stands of native SAV, as well as to prevent invasive spread by fragmentation. Eurasian watermilfoil *(Myriophyllum spicatum)* and curly-leaf pondweed *(Potamogeton crispus)* are two invasive submersed plants managed in practice using this technology (Tobiessen et al. 1992). While the technology has not been applied to mollusks to date, diver dredging may have application to control mollusks in certain environments.

General Effectiveness:

Dredging – Dredging is a highly effective method for controlling submersed and emergent aquatic vegetation. This is done through both direct removal of the vegetation and alteration of the habitat (Gettys et al. 2009).

Diver Dredging – The technology is an effective method for selectively removing submersed aquatic vegetation.

Operating Constraints: In areas where native vegetation is mixed with ANS or native species are living in the sediment, dredging cannot selectively remove the targeted ANS, and disrupts the benthic ecosystem. If sediment containing ANS is to be beneficially reused, caution must be taken to ensure that the reuse of this sediment will not cause establishment of ANS in a new location. The potential for downstream establishment of species is a risk during dredging, managing vegetative fragments generated by dredging prevents the accumulation of decaying plant material or downstream infestation of target species. In addition, special consideration should be given for disturbance of sediment and sediment management, when using this technology to control invasive vegetation.

Dredging – Dredging requires highly specialized equipment and capabilities.

Diver Dredging – Diver dredging is principally limited by underwater visibility and diver safety concerns. In principle, the technology should be applicable to any type of vegetation, as long as the suction dredge has adequate suction ability. The technology was designed for SAV and has not been utilized on emergent and/or wetland plants.

Cost Considerations:

Dredging and Diver Dredging

Implementation: Implementation costs would include sediment characterization to ensure proper handling and disposal, dredging and dewatering, transportation, and either disposal or reuse of the dredged material. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operation and Maintenance: Operation and maintenance requirements would include continued inspection and removal of ANS of Concern – CAWS.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Electron Beam Irradiation

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ANS Control: Electron Beam Irradiation

Targeted Species: Electron beam irradiation has been used to effectively control a variety of microorganisms in aquatic pathways. Specific ANS of Concern – CAWS[1] that may be controlled include bloody red shrimp (*Hemimysis anomala),* European amphipod (*Echinogammarus ischnus),* fish-hook water flea (*Cercopagis pengoi),* harpacticoid copepod (*Schizopera borutzkyi),* parasitic copepod *(Neoergasilus japonicas),* scud (*Apocorophium lacustre*), spiny water flea (*Bythotrephes longimanus),* testate amoebas *(Psammonobiotus communis, Psammonobiotus dziwnowi*, and *Psammonobiotus linearis),* and water flea (*Daphnia galeata galeata).*

Selectivity: Electron beam irradiation is designed to control microbial ANS. It is a non-selective Control.

Developer/Manufacturer/Researcher: Dr. Michael Fisch of Kent State University is a researcher and developer of this technology for aquatic pest control/aquatic species management.

Brief Description: Irradiation involves water treatment by exposing contaminated water to low doses of radiation from gamma-sterilizers or electron accelerators (Woods & Pikaev 1994). Electron beam irradiation can break down DNA in living organisms, resulting in microbial sterilization or death. Electrons penetrate through the cell wall and cytoplasmic membrane, causing a molecular rearrangement of the microorganism's DNA, which prevents it from reproducing. Electrons are an effective agent for irradiation because they are not strongly scattered by turbidity, can penetrate deeply into organic materials, and are more ionizing than ultraviolet (UV)[2] light (an alternative form of irradiation) (Fisch 2010). The radiation sensitivity of a microorganism generally depends on the amount of DNA in the nucleus. The lethal dose depends on how well the organism is protected from electron penetration.

Prior Applications: Electron beam irradiation has a well-documented history of use in irradiation of food (Diehl 1990), environmental waste (Cooper et al. 1998), medical sterilization (Woods and Pikaev 1994), and water treatment (Cleland et al. 1984).

General Effectiveness: Overall, electron beam irradiation can be an effective technology to treat water for possible aquatic microbial nuisance species. It is impossible to achieve total destruction of all microorganisms in a sample via irradiation, but the number of viable organisms can be greatly reduced. The primary advantages of this technology are that it adds no chemicals to the water supply, creates no by-products, and has no specialized storage requirements.

Operating Constraints: Electron beam irradiation works in contained areas such as pipes and flowing troughs; it is ineffective in large, open, or turbid systems such as marshes, lakes, rivers, and canals. Irradiations can target specific organisms using constant water flow and varying the beam current for dose adjustment (Gehringer et al. 2003).

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] For more information on the use of this control technology, please see the fact sheet titled "Ultraviolet Light (UV)."

Irradiation is most effective after solids have been removed from untreated water. Suspended solids or particulate matter can cause shielding, which may allow microbes to pass through the filter without undergoing direct penetration by the electron beam. Current pretreatment requirements and the ability to treat only a constant-flow stream of water make using this technology to treat natural or urban water sources problematic. This Control is less effective when high concentrations of suspended solids exist, therefore it would be less effective during storm events.

Cost Considerations:

Implementation: Implementation costs may include the construction of a piping system and electron beam irradiation treatment facility. Facility construction costs would consist of the primary facility and supporting systems, such as access, equipment, and power supply infrastructure.

Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include electricity to operate the system, regular inspections, repair of mechanical parts, site safety and security, and an effective monitoring program.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed evaluations.

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Hydrologic Separation

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Hydrologic Separation—Physical Barriers

Targeted Species: Hydrologic separation may be effective at preventing the transfer, via aquatic pathways, of all ANS of Concern – CAWS, up to and including the design event. See *General Effectiveness* and *Operating Constraints* for more information.

Selectivity: Hydrologic separation may prevent the transfer of any species via aquatic pathways, under normal flow regimes and some flood conditions. This Control is non-selective.

Developer/Manufacturer/Researcher: Not applicable

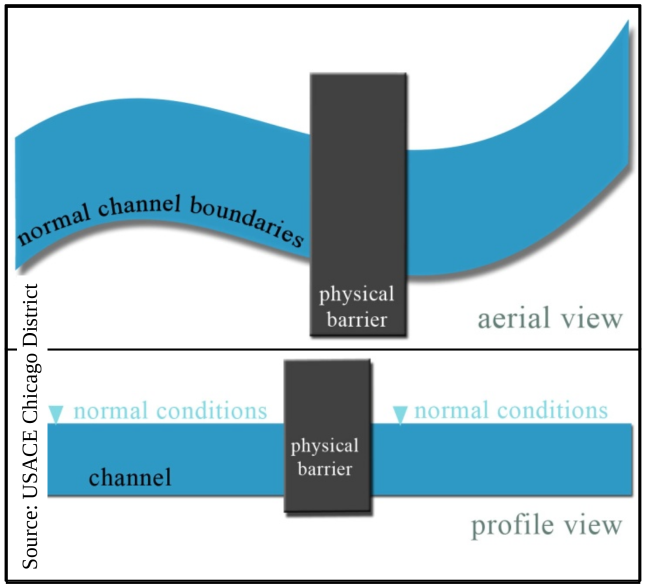

Figure 1. Hydrologic separation is the use of physical means to separate two, or more, watersheds

Brief Description: Hydrologic separation is the use of physical means to permanently separate two or more connected watersheds to prevent the mixing of all untreated surface waters between the watersheds (Figure 1). The design of the physical barrier would have to account for site-specific conditions and generally, would consist of a physical blockage constructed in a channel, river, lake, or wetland and possibly auxiliary structures outside of the water body. The structure would be designed to prevent the mixing of untreated water from disconnected watersheds.

Prior Applications: Hydrologic separation of the Great Lakes (GL) Basin from the Mississippi River (MR) Basin has been identified as a possible means to prevent the transfer of ANS through the CAWS (Aquatic Invasive Species Summit Proceedings Conference 2003, Great Lakes Commission 2011, Rasmussen 2002). Hydrologic separation has also been specifically identified as a means for preventing the transfer of Asian carp (bighead carp (*Hypophthalmichthys nobilis),* silver carp (*H. molitrix),* grass carp *(Ctenopharyngodon idella)* and black carp *(Mylopharyngodon piceus)*) into the Upper MR Basin via aquatic pathways (FishPro, 2004). USACE is evaluating hydrologic separation of the MR and GL basins as an alternative for GLMRIS.

General Effectiveness: The effectiveness of a permanent physical barrier to achieve hydrologic separation would be based on in-stream conditions and local topography. Generally, physical barriers are designed to prevent overtopping of flows created by flood events up to the design event. If the design (flood) event will flow outside the normal channel boundaries at the physical barrier location, then the physical barrier must extend past these channel boundaries and tie into high ground at the design elevation (Figure 2). If a storm produces flows that exceed the design event flows, the physical barrier will no longer act as a means of hydrologic separation. Instead, water will overtop (Figure 3a) or will flow around (bypass) the physical barrier (Figure 3b).

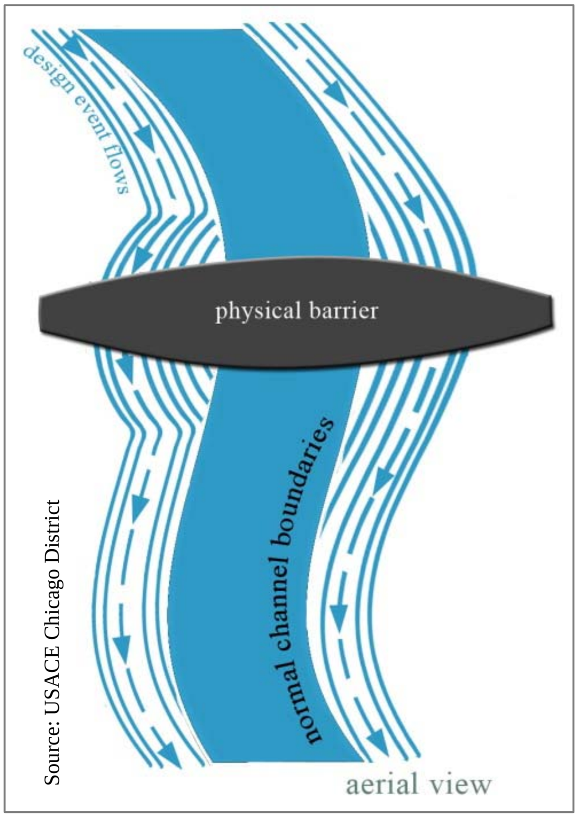

Figure 2. Barrier extends outside normal channel boundaries to separate design event flows

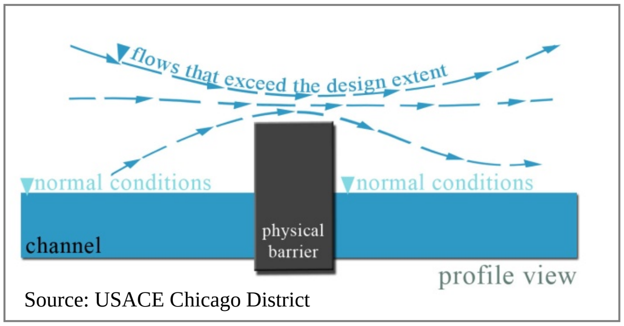

Figure 3a. Flood flows overtop physical barrier

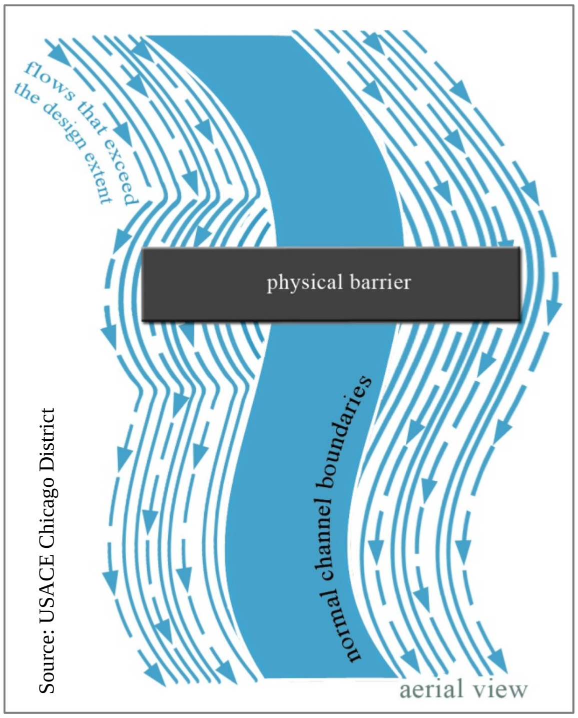

Figure 3b. Flood flows bypass physical barrier

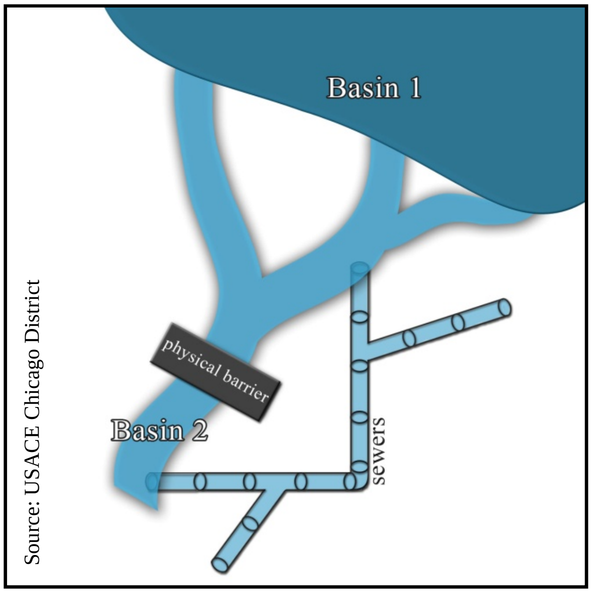

Figure 4. Water from Basin 1 could circumvent the physical barrier through the sewer system and discharge to Basin 2

Additional design considerations include an evaluation of all aquatic pathways around the proposed physical barrier site. Design engineers would consider current local drainage patterns, which may have been altered through the process of urban development. These modifications could include modified terrain, channelized rivers and streams, filled wetlands, sewer networks and flood detention/retention areas. Depending on the location of the physical barrier, untreated water from one watershed could be collected, routed, and discharged into the second watershed, inadvertently bypassing a physical barrier intended to hydrologically separate the watersheds (Figure 4) through natural or man made connections.

Operating Constraints: For hydrologic separation, a physical barrier would be designed to separate two or more watersheds up to the design event. This design would correspond to a particular elevation. To assure flows up to the design event do not overtop (Figure 3a) or flow around the physical barrier (Figure 3b), the physical barrier must terminate or tie into high ground that is at or above the design level's particular elevation (Figure 2). If water on either side of the physical barrier overtops or flows around, the physical barrier would no longer provide for hydrological separation of the watersheds.

For design events that flow outside of normal channel boundaries (Figure 2), the physical barrier's design must include structures such as flood walls, levees or berms. These structures will connect the in-channel physical barrier to high ground that is outside the normal channel boundaries and is at the design elevation. In areas where terrain is fairly flat, the length of structures (flood walls, levees or berms) outside of the channel will likely increase as the size of the design event increases.

Depending on the location of the physical barrier and the frequency of the interbasin connection - either a continuous connection or intermittent connection during flood events - various users of the connected waterways may be impacted. Waterway users include, but are not limited to: natural resources, communities that use the waterway for storm flow relief, commercial and recreational navigation, water users and dischargers, and recreational users.

Cost Considerations:

Implementation: Implementation costs may include the physical barrier design, permitting and construction of the physical barrier. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Depending on the method and frequency of interbasin connection, debris may need to be cleared from the physical barrier. A plan would need to be implemented to monitor the effectiveness of this Control and, if necessary, modify its operation.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors are based on site-specific and project-specific requirements that will be addressed in subsequent evaluations.

Citations:

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Irrigation Water Chemicals

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Irrigation Water Chemicals - Acrolein and Xylene

Targeted Species: Acrolein and xylene are currently registered for use to control nuisance algae and submersed and floating aquatic plants in irrigation canals. Specific ANS of Concern – CAWS[1] that can be controlled by acrolein and xylene include all of the algae species (*Bangia atropurpurea*, *Cyclotella cryptica*, *C. pseudostelligera*, *Stephanodiscus binderanus*, *and Enteromorpha flexuosa)*, water chestnut (*Trapa natans*), and dotted duckweed (*Landoltia* (*Spirodela*) *punctata*).

Aquatic plants and algae can be problematic in irrigation conveyance systems and can be controlled with proper application of acrolein or xylene.

Selectivity: Acrolein and xylene are non-selective toxicants and will kill most species of algae and submersed and floating aquatic plants. Acrolein and xylene will not control emergent aquatic vegetation (Senseman 2007). Both acrolein and xylene are toxic to fish and other aquatic organisms at use rates that control aquatic plants and algae (Baker Petrolite Corporation 2008; Ross & Lembi 1985; USEPA 2005; USEPA 2008).

Developer/Manufacturer/Researcher: Acrolein as the formulation Magnacide® H[2] is manufactured by Baker Petrolite Corporation, Sugar Land, Texas, and exclusively distributed by Alligare LLC, Opelika, Alabama. Xylene as the formulation Aquatic Weed Killer® is manufactured and distributed by Thatcher Company, Salt Lake City, Utah.

Pesticide Registration/Application: Pesticides, including irrigation water chemicals, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: Both acrolein and xylene are active ingredients registered by the USEPA for control of unwanted aquatic vegetation in irrigation conveyance systems, primarily in western states. Acrolein is designated as a "restricted use pesticide" by the USEPA; therefore, it can be purchased and used only by trained and certified applicators to avoid possible adverse health or environmental effects

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

(USEPA 2008; Baker Petrolite Corporation 2008). The application of xylene as the formulation Aquatic Weed Killer® is also limited and can be used only for control of submersed weeds in irrigation and drainage canals managed by the Bureau of Reclamation and cooperating water user organizations in several western states (AZ, CA, CO, ID, KS, MT, NE, NV, NM, ND, OR, SD, UT, WA, and WY), provided appropriate state registrations are also in place (USEPA 2005; USEPA 2011; Thatcher Company 2011).

Acrolein – Acrolein (acrylaldehyde or prop-2-enal) is a general cell toxicant that destroys enzymes and disrupts plant metabolism (Senseman 2007). Acrolein is readily absorbed by aquatic plants and algae, but poorly by terrestrial vegetation. Aquatic weeds become flaccid within a few hours of exposure, followed by gradual chlorosis (yellowing) and tissue disintegration (Senseman 2007). Acrolein is applied by directly injecting a liquid formulation into the water from pressurized containers; proper application can eliminate plants up to 25 miles downstream (Ross &Lembi 1985). Acrolein is not persistent in aquatic environments; primary mechanisms of degradation are volatilization and hydrolysis (Senseman 2007; Sytsma & Parker 1999).

Xylene – Xylene (1,2, 1,3, and 1,4-dimethyl benzene) is an aromatic hydrocarbon formulated as a liquid concentrate and applied with an emulsifier by directly metering or injecting the product below the water surface; submersed vegetation can be controlled for 3 to 6 miles downstream (USEPA 2005; Ross & Lembi 1985). The mechanism of action for xylene in plant cells is unknown. Xylene persistence in water is low; the predominant degradation process is volatilization (USEPA 2005; Sytsma & Parker 1999).

Prior Applications: Acrolein and xylene are currently used to control problem submersed and floating plants and algae in irrigation and drainage canals. Terrestrial and shoreline or emergent vegetation will not be affected. Both compounds are non-selective and will kill all vegetation in waters exposed to treatment. Similar to other aquatic herbicides, acrolein and xylene are not used as a "preventative" control measure and cannot be used as a permanent chemical barrier. Neither product is persistent in aquatic sediments and neither will eliminate tubers, seeds, or other plant propagules that reside in sediments.

General Effectiveness: When properly applied and in accordance with product label directions, both acrolein and xylene are effective for eliminating submersed and floating aquatic plants and algae from irrigation conveyance systems within a matter of hours. Both compounds are toxic to fish and other aquatic organisms.

The efficacy of acrolein can be impacted under certain environmental conditions. Sytsma and Parker (1999) reported that the toxicity of acrolein to plants is temperature dependent; the concentration required at 60 °F is double that required at 80 °F.

Operating Constraints: Constraints for using acrolein and xylene in aquatic environments are defined on the manufacturer product label and may include: restrictions on water use after chemical application; when, where, and how the product can be applied; frequency and maximum rate of application; conditions that can reduce product efficacy; and potential impacts to sensitive, non-target species. Acrolein and xylene are toxic to fish and other aquatic organisms and can be considered general biocides; sensitivity is dependent on dose and exposure (Sytsma & Parker 1999; Baker Petrolite Corporation 2008; Thatcher Company 2011). Acrolein cannot be used in waters that flow into potential sources of drinking water (Baker Petrolite Corporation 2008).

Cost Considerations: Cost will vary with product choice, rate of application, and the size of the treatment area.

Implementation: Implementation costs would involve the development of a management plan, purchase and application of the chemical. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include monitoring effectiveness of chemical treatment and reapplication when aquatic nuisance species begin to reappear.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Lethal Temperatures

ANS Control: Lethal Temperatures — Carbon Dioxide (CO_2) Pellet (Dry Ice) Blasting, Dessication, Freezing, Hot Water Thermal Barrier, and Pressurized Hot Water/Steam Treatments

An employee of the Tahoe Resource Conservation District uses a high pressure hot water nozzle to remove adult mussels from the hull of a boat.

Targeted Species: Lethal water temperature is an effective control method for many types of organisms, and may be effective at preventing the transfer, via aquatic pathways, of all ANS of Concern – CAWS[1].

Selectivity: This technology was designed to manage the majority of aquatic organisms and is not selective.

Developer/Manufacturer/Researcher: Thermal barriers are being studied by the University of Illinois at Urbana-Champaign HydroSystems Lab in cooperation with the Metropolitan Water Reclamation District of Greater Chicago (Asian Carp Regional Coordinating Committee 2012). Manufacturers of pressurized hot water units and dry ice are readily available throughout the United States.

Pesticide Registration/Application: Pesticides must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: The preferred, upper, and lower lethal temperature ranges for all aquatic life forms vary between and among species and are dependent on genetics, developmental stage and thermal histories (Beitinger et al. 2000). Free swimming aquatic organisms tend to gravitate to a narrow range of temperatures, referred to as a preferred temperature zone (Figure 1). In fish, avoidance will occur as water temperature exceeds the preferred temperature zone by 4 to 18 °F (1-10 °C) (Coutant 1977).

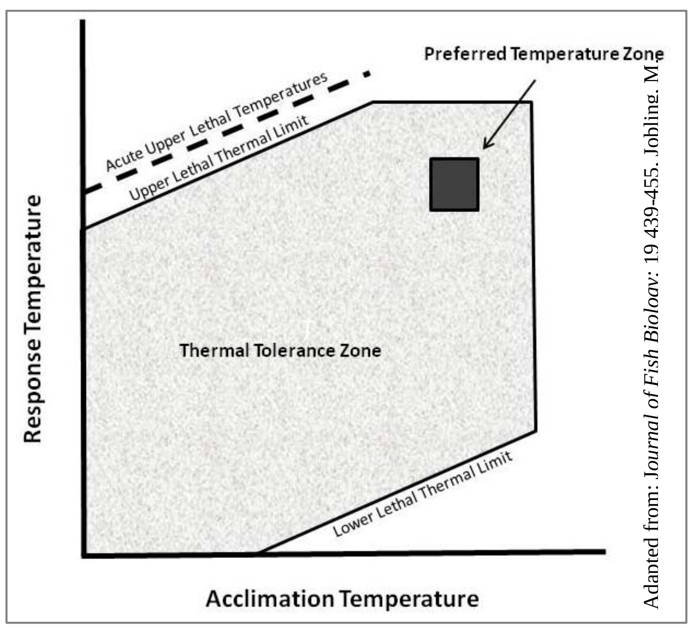

Figure 1: Diagram showing temperature relations of fish

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Aquatic nuisance species are susceptible to temperatures that exceed their thermal tolerance. Two types of upper lethal thermal limits exist: acute upper lethal temperatures, and chronic or incipient upper lethal temperatures. Acute upper lethal temperatures are the temperatures at which death occurs when water temperature is raised rapidly. Chronic or incipient upper lethal thermal limits involve continuous exposure of the target organism to constant lethal temperatures for a time period long enough to achieve significant mortality. The zone of resistance, within which there is a strong interaction between temperature and exposure time, lies outside the tolerance temperatures.

Death occurs when temperatures exceed the thermal tolerance of an organism. There are two types of upper lethal thermal limit. The first, acute upper lethal temperature, is the exposure to high temperature, beyond the tolerance of the organism. Death is relatively rapid. The second, chronic or incipient upper lethal thermal limit, involves the exposure of an organisms to a high temperature for a longer period of time. Organisms can survive thermal discomfort for a while, but cannot survive sustained exposure. Temperature tolerance is dependent upon previous thermal history (Reynolds & Casterlin 1979; Jobling 1981).

An organism that is acclimated to cold temperatures will be more susceptible to lower upper lethal temperatures than it would be if it were acclimated to a warmer temperature. Because organisms become seasonally adjusted to different water temperatures, hotter water must be applied in the summer than in the winter to achieve a lethal temperature.

Figure 2: Thermal Tolerance of Various Non-native Species in the Great Lakes and Mississippi River Basins

		Temperature			
Species	**Size or Age**	**Acute Upper Lethal**	**Upper Avoidance**	**Preferred**	**Reference**
Alewife (*Alosa psuedoharengus*)	Large	-	71.6 °F (22 °C)	-	Coutant
coho salmon (*Oncorhynchus kisutch*)	Adult	-	-	57.2 - 62.6 °F (14 - 17 °C)	Brown
common carp (*Cyprinus carpio*)	Large	-	94.1 °F (34.5 °C)	84.4 - 89.4 °F (29.1 - 31.9 °C)	Gammon
grass carp (*Ctenopharyngodon idella*)	Adult	100 °F (38 °C)	-	-	Fedorenko & Fraser
skipjack herring (*Alosa chrysochloris*)	Adult	-	84.2 °F (29 °C)	78.8 - 83.3 °F (26 - 28.5 °C)	Gammon
spiny waterflea (*Bythotrephes longimanus*)	Adult	110 °F (43 °C)	-	-	Beyer et al.
zebra mussel (*Dreissena polymorpha*)	Adult	104 °F (40 °C)	-	-	McMahon et al.

Thermal shock can occur under natural conditions, however it is most frequently observed as a result of changes in thermal effluents from power generation and production industries and at various water control projects. Thermal shock can occur when aquatic organisms are rapidly subjected to temperature changes greater than 18 °F (10 °C) of acclimation temperature (Coutant 1977; Donaldson et al. 2008). Depending upon the degree of shock, the organism may react with instantaneous or delayed mortality. Thermal shock is a potential threat only to those fish resident and acclimated to temperatures in the thermal plume, and has no effect on fish outside of the plume, including those migrating through the system (USEPA 2008).

There are a variety of thermal treatments for managing ANS:

Carbon Dioxide (CO_2) Pellet Blasting – CO_2 pellet blasting is similar to sand blasting except that frozen CO_2 pellets are used instead of sand. CO_2 pellet blasting leaves no blasting medium residue because the CO_2 pellets turn into a gas at room temperature. CO2 pellet blasting flash freezes the target organism, both killing it and making it brittle and easier to remove (Boelman et al. 1997).

Desiccation – Desiccation refers to the drying out of a living organism. In lakes and rivers, it would involve the use of water level drawdowns to expose ANS to the air and interfere with habitat utilization and reproduction. Exposure to the air quickly leads to death for active water-breathing organisms like fish, but mollusks and plants are more tolerant to desiccation and would require a long drying period and have life stages that can be highly resistant to desiccation (Boelman et al. 1997; Richards et al 2004).

Freezing - Freezing involves the lowering of temperature and the formation of ice. Most living cells can tolerate low temperatures; however the formation of ice within the cell results in injury and death. This technique is often attempted in conjunction with water level drawdowns during cold weather to freeze exposed ANS (Richards et al 2004).

Hot Water Thermal Barrier – A hot water thermal barrier is a lethal zone created in a section of the waterway by mixing heated water throughout the water column, creating a kill zone for ANS (Boelman et al. 1997)..

Pressurized Hot Water/ Steam Treatments – Pressurized hot water/steam treatment involves spraying pressurized hot water or steam to kill and remove ANS from boats, pipes and structures (Jonelle Bright, Tahoe Resource Conservation District, telephone communication, 2011) .

Prior Applications:

Lethal water temperature has varied and far reaching uses that include pressurized hot water sprays that are applied to clean boats to thermal barriers that alter the water temperature to a level that is not sustainable for viable organisms. Because of its non selectivity, it can be highly effective in targeting multiple organisms at once but can be limited by the physical or flow characteristics of the water body. Following are more specific applications of each specific method:

Carbon Dioxide (CO_2) Pellet Blasting – This method has been used extensively to remove of organics from aircraft, producing no deterioration of surfaces (Boelman et al. 1997).

Desiccation – Desiccation has been studied as a control for zebra mussels (McMahon et al. 1993). Winter drawdowns with prescribed fire have been used to reduce the invasive plant torpedograss on Lake Okeechobee, Florida (University of Florida 2012).

Freezing – Freezing has been attempted to control Asian clams in Owasco Lake, one of the Finger Lakes in New York, during the winter of 2011-12 (Bruce Natale, Cayuga County Planning , E-mail communication, 2011). Freezing has also been studied for controlling the New Zealand mudsnail (Richards et al. 2004).

Hot Water Thermal Barrier – This type of control has been proposed for the CAWs because of the availability of existing sources of heated industrial water in the vicinity. The USEPA commissioned a study of the existing conditions of water temperature in the CAWS and their effect on non-indigenous species. The report concluded that current thermal conditions in the CAWS present a very small obstacle (1 to 12%) to passage of approximately half of the non-indigenous species considered. Warm temperatures which would impede movement occur only in the summer months, leaving nine months for completely unimpeded passage. The report identified the Lockport region with the highest water temperatures and thus the greatest temperature barrier to fish movement (USEPA 2008). A hot water thermal barrier would also require downstream cooling to restrict the length of the heat zone.

Pressurized Hot Water/ Steam Treatments –This technique is commonly used to kill zebra and quagga mussels at municipal and industrial facilities. High pressure hot water spray is used to clean ANS off of recreational boats at cleaning stations by the Tahoe Resource Conservation District (Jonelle Bright, Tahoe Resource Conservation District, telephone communication, 2011). Hot water and steam are commonly used in the food and medicine industry to sterilize equipment (autoclaving), purify water (boiling), and preserve foods (pasteurization) to destroy harmful microorganisms. These methods are intended to treat small objects, equipment, and structures but are impractical for treating flowing waters.

General Effectiveness: Lethal water temperature can be 100% effective in preventing ANS transfer when ANS are exposed to the correct temperatures for the appropriate duration. Sub-lethal water temperatures are an attractant to many species, particularly in the fall, winter, and spring.

Carbon Dioxide (CO_2) Pellet Blasting – CO_2 pellet blasting is preferred over conventional sand blasting for removing encrustations of zebra mussels. CO_2 pellet blasting freezes zebra mussels, making them brittle and more easily removed, and when solid carbon dioxide converts to a gas, it penetrates voids and the area of zebra mussel attachment, lifting the organism off the surface. Unlike sandblasting, carbon dioxide pellet blasting is less likely to damage surfaces (Boelman et al. 1997).

Desiccation – This technique may be effective and managing aquatic plants and mussels. Temperature is positively related and humidity negatively related to zebra mussel mortality. To ensure 100 percent mortality, aerial exposure must last nearly a month at moderately low temperature (5ºC) and high humidity (95%) but only 2 days at moderately high temperature (25ºC) and extremely low humidity (5%). However, even at high humidity (95%), 100% mortality is expected in approximately 5 days at 25ºC (Payne 1992). Aquatic plants can be dried and burned, however rooted vegetation may resprout if the soil is not dried sufficiently.

Freezing - Zebra mussels can be effectively controlled by winter drawdown and exposure to subfreezing air temperatures. Clustered mussels are more tolerant of reduced air temperatures than are individual organisms. Exposure time for 100% mortality of individual mussels range from 15 hr at -1.5º C to less than 2 hr at -10 ºC. For clustered mussels, these times range from over 48 hours at -1.5 ºC to 2 hr at -10 C (Payne 1992).

Hot Water Thermal Barrier – This method was previously examined by a report from Midwest Generation in the CAWS (USEPA 2008). Most industrial sources would find it difficult to generate a thermal load to the receiving water that would ensure that the lethal zone would be maintained to allow sufficient exposure time. For some industrial facilities, it may be possible to establish a thermal barrier in the summer, but for most it would be impossible in the winter due to the increase in thermal load that would be necessary to result in lethal water temperatures. Where ANS are mobile and able to preferentially avoid or seek a thermal plume, hot water thermal barrier will not have the desired effect, because ANS could pass the thermal barrier in the winter months.

Beyer et al. (2011) found that a water temperature of 110 °F (43 °C) was necessary to kill the spiny waterflea (*Bythotrephes longimanus)*. Grass carp, a close relative of the silver, bighead, and black carps, cannot tolerate temperatures greater than 100 °F (38 °C) (Fedorenko & Fraser 1978). Zebra mussel mortality occurs at 104 °F (40 °C) (McMahon et al. 1995).

Pressurized Hot Water/Steam Treatments – This ANS Control is effective for treating small objects, equipment, and structures.

Operating Constraints: Below are general operating constraints associated with the Lethal Temperature ANS Controls.

Carbon Dioxide (CO_2) Pellet Blasting – CO_2 pellet blasting is limited to controlling ANS on objects that have been removed from a water body.

Desiccation – Desiccation requires the draining of a water body.

Freezing – Depending on site conditions, freezing may require winter drawdown of water in a water body. The ambient temperatures must reach the threshold temperature for a sufficient duration to be an effective ANS Control.

Hot Water Thermal Barrier – Water hot enough to create a thermal barrier must be supplied on a continuous basis and be adequately mixed throughout the water column to ensure the target temperature throughout the water column is reached. Maintaining temperature and exposure time is a significant challenge due to the following potential non-static conditions of a water body: fluctuating flow velocities driven by wet vs. dry weather, inconsistent flow direction, including reverse flows, driven by storm surges, density currents, and flat gradients; and abrupt changes in flow velocity.

The thermal tolerance of all life stages of an organism must also be considered; many aquatic plants can tolerate a wide range of temperatures, especially in the seed stage (Lacoul & Freedman 2006).

Pressurized Hot Water/Steam Treatments – Pressurized hot water/steam treatment is limited to controlling ANS on objects that have been removed from a water body.

Cost Considerations:

Implementation: Implementation costs for this Control would vary depending on the type of Lethal Temperature implemented. A very general description of implementation cost considerations follows. CO_2 pellet blasting and pressurized hot water/steam would require a land-based hand-application systems and waste collection and removal. Desiccation and freezing would require infrastructure (i.e. dams and levees) to control water levels. Hot water thermal barriers would require a means of heating water or a source of hot water, such as a neighboring industrial source. To treat a flowing system, hot water thermal barriers would require a distribution and mixing component to ensure the required temperature is reached throughout the water column.

Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would vary with the technique selected for heating and mixing water. An effectiveness monitoring program would be required.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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ANS Control: Light Attenuating Dyes

Varying concentrations of light attenuating dye in water. The product labels for Aquashade® and Admiral® recommend doses between 0.5 and 2.0 parts per million for suppressing growth of submersed aquatic plants and algae.

Targeted Species: This is an effective control method for algae and some aquatic vascular plants. ANS of Concern – CAWS[1] that may be controlled include red macro-algae (*Bangia atropupurea*), diatoms (*Cyclotella cryptica*, *C. pseudostelligera*, and *Stephanodiscus binderanus*),[2] and grass kelp (*Enteromorpha flexuosa*). The growth of water chestnut (*Trapa natans*) may be suppressed if light attenuating dyes are applied pre-emergent (prior to plant germination).

Selectivity: Light attenuating dyes were designed to control algae and some vascular plants. They can be selective or non-selective. Selectivity of algae and plants to light attenuating dyes will vary by species, rate of dye application, and timing of application.

Developer/Manufacturer/Researcher: Aquashade® is manufactured by Applied Biochemists in Germantown, Wisconsin. Admiral® is manufactured by Becker Underwood, Inc. in Ames, Iowa.[3]

Pesticide Registration/Application: Pesticides, including light attenuating dyes, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: Light attenuating dyes are concentrated synthetic colorants that can be applied to water for the purpose of reducing the growth of submersed aquatic plants and algae (Bellaud 2009; Lembi 2009; Lynch 2006, Glomski & Netherland 2005; Madsen 2000; Spencer 1984). The dyes act to reduce light penetration into the water column, thereby inhibiting the ability of submersed plants and algae from capturing the necessary light needed for photosynthesis. Light attenuating dyes do not directly kill plants or algae, but can reduce or suppress their growth.

There are only two light attenuating dyes that are currently registered by the USEPA for use in water for the purposes described above: Aquashade® (Applied Biochemists 2009) and Admiral® (Becker Underwood, Inc. 2007). Both Aquashade® and Admiral® are a blend of blue and yellow dyes (Acid Blue 9 and Acid Yellow 23), which filter out specific portions of the sunlight spectrum required for

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Cryptic algae (*Cyclotella cryptica*), cylindrical algae (*C. pseudostelligera*), and diatom (*Stephanodiscus binderanus*) are three (3) species of algae that belong to the algal subcategory of diatoms. For the purpose of this fact sheet, they will be referred to collectively as diatoms.
[3] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

photosynthesis by underwater aquatic vegetation, namely red-orange and blue-violet light. The products vary slightly in the percent concentration of each dye in their respective formulations. Water treated with these dye formulations will retain a blue tint following application. As these dyes will degrade and dilute over time, reapplication is necessary to maintain long-term effectiveness.

Light attenuating dyes are intended for use in natural and manmade contained lakes and ponds (ornamental, recreational, fish rearing and fish farming water bodies) with little or no outflow of water.

Prior Applications: The product labels for Aquashade® and Admiral® specify that dosage rates of 0.5 to 2.0 parts per million (ppm) can suppress the growth of submersed plants, such as leafy pondweed (*Potamogeton foliosus*), slender naiad (*Najas flexilis*), watermilfoil (*Myriophyllum* spp), hydrilla (*Hydrilla verticillata*), muskgrass (*Chara* spp.), filamentous green algae (*Spirogyra* spp) and many bluegreen algae species (Applied Biochemists 2009; Becker Underwood, Inc. 2007). Going and Purdue (1985) reported that the use of Aquashade® in a 215-acre lake in New York resulted in significant suppression of nuisance levels of broad-leaved pondweeds.

Laboratory studies showed that photosynthetic rates of five algae species (*Pediastrum tetras*, *Selenastrum capricornutum*, *Anabaena flos-aquae*, *A. cylindrical*, and *A. falcatus* var. *acicularis*) were reduced by at least 50% with the use of Aquashade® dye (Spencer 1984). Glomski and Netherland (2005) demonstrated in outdoor mesocosm studies that varying rates of Aquashade® (0.5 to 1.5 ppm) reduced growth (measured as shoot biomass) of sago pondweed (*Stuckenia pectinata*) by 59 to 73% over a 9-week period. In another study, hydrilla grown at two different depths (1.4 m and 3.0 m) was reduced by 50 to 84%, respectively, when exposed to 1.0 ppm Aquashade® (Glomski & Netherland 2005).

Dyes alone are seldom effective for controlling submersed aquatic vegetation, but they can be used in conjunction with an algaecide or herbicide treatment to reduce regrowth (Lembi 2009; Osborne 1979).[4] Osborne (1979) reported that the use of Aquashade® after an autumn application of the herbicide Hydrothol 191® was successful for long-term control of hydrilla in a Florida pond; the addition of dye prevented re-infestation of hydrilla from vegetative propagules (tubers and turions).

General Effectiveness: As mentioned in the prior applications section, the growth of certain algal species and submersed aquatic plants can be suppressed with light attenuating dye products. Light attenuating dyes are not effective on floating or emergent aquatic plants. While there is no published information on the use of light attenuating dyes against water chestnut, the growth of this plant may be suppressed if dyes are applied early in the growing season, before plants germinate. There are no published reports in the literature on the effectiveness of light attenuating dyes against the five algae species included in the ANS of Concern – CAWS.

Light attenuating dyes can be applied in conjunction with herbicides and algaecides to enhance plant growth suppression (Osborne 1979; Applied Biochemists 2009; Lembi 2009).

[4] For more information on algaecide and herbicide Control technologies, please see the fact sheets titled “Algaecides” and “Aquatic Herbicides.”

Operating Constraints: Aquashade® and Admiral® are for use only in natural or contained lakes and ponds with little or no outflow of water (Applied Biochemists 2009; Becker Underwood, Inc. 2007). Neither product can be applied to waters that are used for human consumption; however, there are no restrictions for animal or livestock drinking water, irrigation, swimming, or fish consumption, when recommended product rates (0.5 to 2.0 ppm) are applied.

To achieve optimal results, light attenuating dyes should be applied pre-emergent (prior to plant or algal spore germination) or before the growing season begins (March or early April) to prevent early season growth (Applied Biochemists 2009; Lynch 2006). Because these dyes photodegrade over time, reapplication throughout the growing season is necessary to maintain product effectiveness. Light attenuating dyes are not effective for suppressing growth of floating aquatic plants, floating algal mats, or emergent shoreline vegetation. Dyes have reduced effectiveness in waters less than 2 feet deep and on matured submersed aquatic plants (Applied Biochemists 2009). The color and effectiveness of these dyes will be lost in waters containing active chlorine.

Cost Considerations:

Implementation: Implementation costs will vary with the size and volume of the dye treatment area and method of application; the effective rate of application is usually in the range of 0.5 to 2.0 ppm. Product cost will vary depending on volume of purchase and distributor. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Dye degradation will occur at some rate over time. Operations and maintenance activities would include an effectiveness monitoring program and reapplication of the product as necessary for the desired effect.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Manual Harvest

ANS Control: Manual Harvest

Targeted Species: All species of aquatic and wetland plants could possibly be managed using manual harvest (commonly referred to as hand removal) techniques. Specific examples of ANS of Concern – CAWS[1] that may be controlled with this method include swamp sedge *(Carex acutiformis)*, reed sweetgrass *(Glyceria maxima)*, dotted duckweed *(Landoltia (Spirodela) punctata)*, marsh dewflower *(Murdannia keisak)*, Cuban bulrush *(Oxycaryum cubense)*, and water chestnut *(Trapa natans)*.

Selectivity: Manual harvesting can be a selective control method for plants. The overall level of selectivity depends on whether or not selective removal is required, as well as the skills and abilities of personnel performing control activities.

Developer/Manufacturer/Researcher: This Control does not require any special research or development.

Brief Description: Manual harvesting (or hand removal) includes a variety of methods, the simplest being physical removal of a plant by pulling it out of the ground or water, or more refined and site-specific methods, such as cut stump control. Cut stump control is an integrated pest management approach; workers use cutting tools to remove the top of the plant, then treat the remaining portion of the plant with herbicide[2] to prevent regrowth. The 'cut stump' method is most often utilized with woody stemmed vegetation, however, many large grass species, including bamboo, Napier grass, and phragmites, are also controlled using this method.

Cutting tools, such as hand swung machetes and axes, as well as chainsaws, can be used in conjunction with hand removal to improve removal speed and effectiveness. Additionally, rakes and

Youth Conservation Corps hires pull invasive water chestnut from a lake at Silvio O. Conte National Fish and Wildlife Refuge in Massachusetts.

Water lettuce is removed from a Florida waterway. Targeted plants are placed in blue bins and transported to a disposal site.

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] For more information on this technology, please see the fact sheet titled "Herbicides."

hoes can be used to control and/or reduce root mass. The most effective application of hand removal is in conjunction with herbicide application; combining the two techniques is effective at selectively removing vegetation from a site.

Prior Applications: Manual harvesting techniques date back to the beginning of agrarian society, and today are still widely used in agricultural practice and for the removal of unwanted vegetation. Hand removal has been used to eliminate water chestnut and Eurasian watermilfoil in New England, and remove invasive trees and other woody-stemmed vegetation in South Florida ecosystems. In South Florida, harvesting teams wear waders and walk through wooded swamps, using machetes and herbicide spray application to target individual tree species. In the Northeast United States, hand removal of Eurasian watermilfoil is completed with snorkels and wetsuits in the fall, after native vegetation has senesced for the growing season (Bailey & Calhoun 2008).

General Effectiveness: When implemented properly, manual harvesting methods provide extremely effective results. Due to the nature of the work, it can be tool for eradicating small populations, or providing a rapid response to a new infestation. Hand removal is most effective when implemented prior to seed production. Removal prior to seed set reduces the need for follow up control efforts.

Operating Constraints: The nature of hand removal lends itself to environmental and physical operating constraints. Hand removal requires more time and is more labor intensive to complete than other controls targeting the same species. It is most easily implemented in small areas, but can be utilized on larger water bodies or entire systems. A key constraint of harvesting efforts is weather, as the work can only be conducted in safe weather conditions, hospitable to the type of work performed. Site logistics, such as how effectively workers can traverse the landscape, must also be considered, due to difficulties traversing wetland and aquatic soils on foot. Habitat may be damaged when employing large parties of workers to harvest aquatic plants in shallow wetland waters or along a shoreline. The harvested ANS must be properly collected and disposed to prevent introduction of an ANS downstream or at a disposal site.

Cost Considerations:

Implementation: Implementation of this Control would include planning and execution of manual harvesting techniques. The majority of this Control's cost is labor-driven, and initial control efforts may be expensive in the United States when compared to other technologies for controlling the same species (Bailey & Calhoun 2008).

Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: If performed on a routine basis, maintenance costs may be lower than the initial treatment (Kelting & Laxon 2010). Additionally, a monitoring plan must be implemented to assess the effectiveness of this Control, and to determine the timing of maintenance efforts.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

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Mechanical Control Methods

ANS Control: Mechanical Control Methods – Harvesting, Shredding, Mowing, Rototilling, Rotovating, and Chaining[1]

Targeted Species: Mechanical control methods may be applied to emergent, floating, and submersed aquatic vegetation. Specific ANS of Concern – CAWS[2] that may be controlled by this method include swamp sedge *(Carex acutiformis)*, reed sweetgrass *(Glyceria maxima)*, dotted duckweed *(Landoltia (Spirodela) punctata)*, marsh dewflower *(Murdannia keisak)*, Cuban bulrush *(Oxycaryum cubense)*, and water chestnut *(Trapa natans)*.

Mechanical harvester removing tussock material from Lake Hicpochee, FL

Selectivity: Mechanical control methods described in this fact sheet can be applied to plant ANS and are non-selective. A trained machinery operator, carefully identifying and avoiding non-target vegetation, can achieve a minimal level of selectivity.

Developer/Manufacturer/Researcher: A variety of mechanical harvesters are currently available for specialized wetland and aquatic applications. Shredders, such as tiger cutters and cookie cutters, are generally custom-made machines tailored to specific harvesting activities. Rotovators are custom-made machines tailored to a specific activity. Mowing, rototilling and chaining activities use commercial available equipment such as mowers and tractors.

Brief Description: Mechanical control methods involve the complete or partial removal of plants by mechanical means, including: harvesting, shredding, mowing, rototilling, rotovating, and chaining. Mechanical control methods can also be used to expedite manual harvesting[3] activities, including hand harvesting, raking, and cut stump control, with the use of motor-driven machinery (Haller 2009; Lembi 2009). These management techniques for plants rarely result in localized eradication of the species, but rather, reduce target plant abundance to non-nuisance levels. A range of machinery for managing and controlling aquatic vegetation is in use today, designed for specific plant types (floating, submersed, and emergent vegetation) and for operation in specific aquatic habitats (open water, canals, shorelines, and wetlands).

Mechanical Harvesting – A mechanical aquatic harvester (harvester) is a type of barge used for a variety of tasks, including aquatic plant management and trash removal in rivers, lakes, bays, and harbors. Harvesters are designed to collect and unload vegetation and debris using a conveyor system on a boom, adjustable to the appropriate cutting height, up to 6 feet below the surface of the water. Cutter bars collect material and bring it aboard the vessel using the conveyor; when the barge has reached capacity, cut material is transported to a disposal site and offloaded using the conveyor.

[1] Another form of mechanical control, dredging, is described in the fact sheet titled "Dredging and Diver Dredging."
[2] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[3] For more information on this control technology, please see the fact sheet titled "Manual Harvest."

Harvester barges are typically driven by a diesel engine, which powers a paddle wheel for propulsion and hydraulics for operating the conveyor system and cutter bars.

Mechanical harvesting provides good control of floating vegetation, but the effort will not result in eradication of a plant species. The size and nature of the equipment does not allow operators to target individual plants or small infestations.

Shredding – Cookie cutters and Tiger cutters are small barges designed to shred aquatic weeds, equipped with engine-powered, front-mounted blades. The cookie cutter was developed in Florida to address emergent aquatic vegetation and floating islands of vegetation and sediment, and to cut openings in shoreline and wetland areas through emergent wetland plants (USACE). Tiger cutters are similar to shredding barges, with the added advantage of being generally more maneuverable.

Shredding equipment is designed to shred weeds blocking the flow of water, including floating vegetation such as tussocks, emergent vegetation in soft soil or detritus, and submersed vegetation. The equipment is able to target smaller populations of vegetation than mechanical harvesters, but it cannot achieve complete eradication of target vegetation.

Mowing – Mowers can be an effective tool for managing emergent vegetation under certain environmental conditions. The concept is the same as in turf management - to reduce weeds and promote growth of desired species. Mowing vegetation provides non-target species temporary relief from the canopy of weeds or target ANS, allowing them the opportunity to establish; mowing has the added benefit of forcing many types of mowed vegetation to use energy reserves for regrowth in the same location rather than spreading to new areas. Mowing is most effectively used in conjunction with other control methods, such as hand harvesting and/or herbicide application.[4]

Mechanical harvester removing floating and emergent vegetation from a USACE boat basin in Clewiston, FL

Rototilling – Rototilling is an effective method of managing both perennial vegetation with large rhizomes or tubers, and annual vegetation before seed production. Care should be used when implementing rototilling, as it is not selective in managing individual types of vegetation, and can cause large amounts of soil disturbance and possible ecological consequences. This method is ideal for situations where a monoculture of a plant ANS exists, or when target perennial species have an extensive rhizome system.

Rototilling as a Control is most effectively executed in combination with follow-up herbicide applications. Typical equipment used to conduct this work ranges from specialized tilling machines,

[4] For more information on Herbicides, please see the fact sheet titled "Herbicides."

which operate in the same manner as a garden tiller, or standard farm equipment, such as tractors equipped with plows or discs.

Rotovating – Rotovating is similar to rototilling, with the distinction of targeting submersed vegetation. Specialized equipment has been developed to conduct this work in shallow lakes with large infestations of submersed weeds. Rotovating work may be very intrusive to an underwater ecosystem, in the same manner as rototilling, and is only effective for dense underwater infestations.

Chaining – Chaining is a vegetation clearing method used in water supply and flood control canal systems to conduct non-selective control of submersed and emergent aquatic vegetation. A large chain is dragged across the channel bottom, guided by trucks or tractors on each side of the channel. The chain is sized so that it has sufficient weight to remain in place as it scours the channel bottom, shearing vegetation at or below the surface.

Prior Applications: Mechanical removal is used for management of aquatic vegetation in a variety of habitats including streams, rivers, lakes, and canals. The equipment is limited by the depth of water in which it can navigate.

Mechanical Harvesting – Mechanical harvesting has been used throughout the United States to manage a variety of floating, submersed and emergent vegetation problems, as well as to collect organic and inorganic flood debris.

Shredding – Shredding is used throughout the world to manage weeds that impede navigation, or for flood control functions. These tools are also common tools used to manage vegetation in lakes, rivers, and waterways. Cutters are used in Florida to manage floating mats of Cuban bulrush as well as other floating and emergent vegetation.

Chaining – Chaining has been used to non-selectively control vegetation in flood control and water supply canals throughout the United States.

General Effectiveness: Mechanical control is an effective method for managing vegetation, but this Control has limited ability to target isolated populations. This trait of non-selectivity does not allow mechanical control methods to be as effective in mixed communities of target and non-target plants, because there is limited area over which the equipment can be used without harming non-target plant communities.

Tiger cutter barge and mechanical harvester working in conjunction to control aquatic vegetation in Monkey Box Run Lake Okeechobee, FL

Proper timing of mechanical control operations can improve control and reduce the spread of propagules. Vegetative debris fragments must be contained onsite, in order to prevent plants that reproduce vegetatively from infesting downstream.

Mechanical Harvesting and Shredding – Harvesting and cutting equipment can be used together for a more effective control of floating or matted vegetation. Cutters, a type of shredder, are able to dismantle the vegetation, while mechanical harvesters collect and dispose of the materials. This system allows the mechanical harvester to operate more quickly, because it does not have to cut the vegetation it is collecting. Although this operation is more expensive, it allows the least amount of vegetative material to spread outside the targeted area.

Operating Constraints: The use of mechanical control equipment is limited by environmental and site conditions. Mechanical control activities are non-selective.

When operating mechanical control equipment near water intake structures or flood control channels, the direction and velocity of flow must be considered to prevent vegetative debris from blocking the structure or channel. In addition to potentially preventing the downstream establishment of plant ANS, collecting vegetative fragments generated by mechanical control methods prevents the accumulation of decaying plant material in the channel, which may pose water quality issues.

Mechanical Harvesting – Most harvesting equipment needs approximately 36 inches of water (for a loaded barge) to operate, and enough room to maneuver a barge 30 feet long by 10 feet wide. The control mechanism is highly effective for controlling vegetation, but cannot selectively remove target plant or animal species from weed infestations. Harvesting is traditionally used for emergent vegetation and SAV in lake or riverine systems. The equipment is not as effective at managing shoreline or marsh vegetation in shallow or seasonal water systems.

Shredding – The primary operational considerations for cookie cutters are water depth and maneuvering room. Operation of these machines requires less water and little maneuvering room relative to mechanical harvesters. The cookie cutter does not have any type of harvest capability; it only cuts mats of vegetation. As such, biomass is still present in the water system and there is often a need for a harvesting machine to support this type of operation (USACE).

Mowing and Rototilling – Mowing and rototilling require site conditions with firm enough soil to operate a rubber-tired piece of equipment; this may be possible in standing water, but water depth and soil types must be evaluated before starting work. Significant ecosystem damage may occur if the operation is not carried out properly, including soil disturbance that may allow for ANS establishment. Special consideration should be given to suspension of sediment and sediment management when using this technology to control invasive vegetation in wetland or aquatic habitats.

Rotovating – Rotovating requires enough depth to float and operate the piece of equipment (which is similar in size to a harvester), but also cannot be too deep, as the rotovating head has limited reach. Special consideration should be given for suspension of sediment, and sediment management, when using this technology to control invasive vegetation.

Chaining – Chaining requires unobstructed paths on both sides of a canal, so that trucks or tractors can be operated with minimal downtime over long distances. Chaining stirs sediment causes turbidity and disturbs aquatic species that live in the targeted area.

Cost Considerations:

Implementation: Implementation costs would include planning, equipment, and labor for initial application of mechanical control activities. Mechanical control methods for aquatic plants are usually priced per acre, based on a variety of environmental conditions and site-specific logistics, as well as equipment types and quantities required. Harvesting of floating aquatic plants is also priced per acre, based on density of vegetation and travel distance between collection and disposal sites. Other cost considerations can include decontamination of equipment to prevent spread of ANS and construction or development of an existing disposal site near the harvest area. Large volumes of harvested vegetation require significant amount of temporary storage; after the material dries, its volume is reduced and can then be left on the nearby disposal site to compost (if permitted), or hauled to a permitted compost facility or landfill. The cost of hauling material is dependent on distance, volume, and level of difficulty required to access the disposal site.

Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operation and maintenance costs would include monitoring effectiveness of the Control method, modifying application parameters if necessary, and scheduling and completing periodic reapplications.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Molluscicides

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Molluscicides (Non-oxidizing molluscicides) – Quaternary and Polyquaternary Ammonium Compounds, Aromatic Hydrocarbons, Endothall as the mono (N,N-dimethylakylamine) salt, Metals and their salts, and Niclosamide

Targeted Species: Molluscicides are used to control mollusks. Specific ANS of Concern – CAWS[1] that may be controlled with molluscicides include the greater European pea clam (*Pisidium amnicum*), the European fingernail clam (*Sphaerium corneum*), and the European stream valvata (*Valvata piscinalis*).

Application of copper sulfate pentahydrate crystals to Lake Offutt, Offutt Air Force Base, NE, for control of invasive mussels

Selectivity: Molluscicides are non-selective against mollusk species; however, activity is dependent upon proper concentration, method and timing of application, and contact time or length of exposure. Molluscicides may impact non-target aquatic organisms at use rates that control mollusks.

Developer/Manufacturer/Researcher: Molluscicides discussed in this fact sheet are proprietary formulations developed, registered, and sold by chemical manufacturers. Examples of available molluscicide products and their respective manufacturers include: Copper sulfate pentahydrate crystals and copper chelates, manufactured by Chem One LTD., Applied Biochemists, and SePRO Corporation (Natrix™); TD2335 Industrial Biocide-Molluscicide, manufactured by United Phosphorus, Inc.; Barquat Molluscicide 80, manufactured by Lonza, Inc.; Clam-Trol® (numerous formulations are available), manufactured by Betz Laboratories, Inc.; Bulab®, manufactured by Buckman Laboratories; and Bayluscide, manufactured by Bayer and Pro-Serve, Inc.[2]

Pesticide Registration/Application: Pesticides, including molluscicides, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: Molluscicides are chemical substances or biocides developed specifically for destroying mollusks (Claudi & Mackie 1994). The mode of action of many of these compounds is stress to the water balance system of mollusk species. McCullough et al. (1980) determined that stress

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

on the water balance system alone can cause death of mollusks; additionally, the reduction of normal water flow in the mollusk body results in other disturbances in metabolism or physiological function, which will often lead to organism death. Other products cause toxic reactions to occur at gill membranes (Sprecher & Getsinger 2000).

Molluscicides are typically classified as either oxidizing or non-oxidizing compounds. Oxidizing chemicals include chlorine, chlorine dioxide, chloramines, ozone, bromine, hydrogen peroxide, and potassium permanganate (Claudi &Mackie 1994, Netherland & Getsinger 1998, Sprecher & Getsinger 2000). The information presented here focuses on those molluscicides described as non-oxidizing chemicals.[3]

Non-oxidizing chemicals (including organic film-forming antifouling compounds, gill membrane toxins, and nonorganics) can be classified into several distinct groups: quanternary and polyquaternary ammonium compounds (Clam-Trol®, some formulations of Bulab®, and Barquat Molluscicide 80); aromatic hydrocarbons (some formulations of Bulab®); endothall as the mono (N,N-dimethylalkylamine) salt (TD2335 Industrial Biocide-Molluscicide); metals and their salts (copper sulfate formulations and Natrix™); and niclosamide (some formulations of Bayluscide). Bayluscide was initially developed as a sea lamprey larvicide, but has molluscicidal activity (Andrews et al. 1982; Sprecher & Getsinger 2000; Giovanelli et al. 2002).[4] Non-oxidizing molluscicides have a higher per-volume cost than oxidizing chemicals, but remain cost-effective due to lower use rates, short exposure time requirements, and rapid toxicity. Sprecher and Getsinger (2000) reported that these products often provide better control of adult mussels, due to the inability of mussels to detect them; as such, mollusk shells remain open and shorter exposures to the toxicant are required. While some of these products are biodegradable, many require detoxification or deactivation to meet state and Federal discharge requirements (McMahon et al. 1993).

Prior Applications: Most of the non-oxidizing molluscicides were originally developed for bacterial disinfection and algae control in water treatment systems (Claudi & Mackie 1994). The use of molluscicides is a recognized procedure by the World Health Organization for the treatment of waters infested with snails carrying parasites that cause schistosomiasis[5] (McCullough et al. 1980; McCullough 1992).

There is limited information published in scientific literature concerning prior application and effectiveness of molluscicides on mollusk species of the ANS of Concern – CAWS (particularly the European fingernail and pea clams and the European stream valvata); however, some information exists on other invasive mollusk species and may be applicable. Molluscicides have been utilized extensively against the invasive zebra mussel (*Dreissena polymorpha*) (McMahon et al. 1993; Waller et al. 1993; Claudi & Macki 1994; Piccirillo et al. 1997; Netherland & Getsinger 1998; Sprecher & Getsinger 2000). Most molluscicides have very restricted uses due to their toxic effects on non-target aquatic organisms, and are primarily used in closed-end industrial systems or recirculating and once-through cooling water systems (Claudi & Mackie 1994; Sprecher & Getsinger 2000). Niclosamide (as

[3] For further information on the oxidizing chemicals listed, please see the fact sheet titled "Biocides for Industrial Use."
[4] For further information on Bayluscide use to control fish, please see the fact sheet titled "Piscicides."
[5] Schistosomiasis is a parasitic disease caused by worms of the genus *Schistosoma*. It is a chronic illness that can damage internal organs in humans and impair growth and cognitive development in children. Freshwater snails serve as a host in the *Schistosoma* life cycle.

the formulation Bayluscide 70% Wettable Powder) is currently labeled by the USEPA as a molluscicide for control of snail populations in aquaculture ponds (USEPA, 2004). Niclosamide has been used to control ram's horn snail (*Helisoma* sp.) infestations in commercial channel catfish ponds (Terhune et al. 2003). The ram's horn snail was identified as the intermediate host in the life cycle of a trematode (*Bolbophorus* sp.) which caused high mortality rates and decreased production in channel catfish (Terhune et al. 2003). Niclosamide is designated as a restricted use pesticide by the USEPA; therefore it can be purchased and used only by trained and certified applicators to avoid possible adverse human health and environmental effects (USEPA 2004).

Copper and potassium salts have lethal activity against mussels and have been used primarily to control zebra mussels and snails that are hosts to parasites that cause schistosomiasis. In addition, Hosea and Finlayson (2005) reported that copper sulfate solutions containing 252 mg/L copper, were effective for controlling New Zealand mudsnails (*Potamopyrgus antipodarum*) from infested wading and angling gear. Copper products (copper sulfate and copper carbonates or chelates) can be used to control mollusks in open water systems, but require a Special Local Need Label (also known as a Section 24-c) issued by the USEPA. A lake-wide application of copper sulfate (as pentahydrate crystals) was applied to Lake Offutt, Offutt Air Force Base, Nebraska, in 2008, under a Special Local Need Label, in an attempt to eradicate zebra mussels (URS Group, Inc. 2009). Copper sulfate applied at a rate of 1 part per million (ppm) was effective for controlling zebra mussels in Lake Offutt; however, some non-target fish mortality was observed following treatment. Similarly, a Special Local Need Label is available for the use of the copper carbonate formulation, Natrix™, for control of invasive and exotic aquatic mussels, snails, oysters and clams in Idaho (SePRO Corporation 2011a), Georgia (SePRO Corporation 2011b), Missouri (SePRO Corporation 2010a), South Carolina (SePRO Corporation 2010b), and Texas (SePRO Corporation 2010c).

Laboratory and field trials conducted by Piccirillo et al. (1997) to evaluate the mollusicidal effects of TD2335 showed that an 8-hour exposure to concentrations of 2 mg/L and higher controlled zebra mussels. A 1-hour exposure to 80 mg/L endothall (as the dimethylalkylamine salt; active ingredient in TD2335 Industrial Biocide-Molluscicide) killed 100% of red-trimmed milania snails (*Melanoides tuberculata*) in studies by Mitchell et al. (2007).

General Effectiveness: When properly applied and in accordance with product label directions, molluscicides can be effective for controlling targeted mollusks. Currently, only copper sulfate and copper chelate formulations have been utilized as a viable molluscicide treatment in open water systems with proper permitting. Niclosamide may be used for controlling snail (mollusks) populations in aquaculture ponds.

Operating Constraints: Constraints for using molluscicides in aquatic environments will be defined on the manufacturer product label and may include: restrictions on water use after application; when, where, and how the product can be applied; frequency and maximum rate of application; conditions that can reduce product efficacy; and potential impacts to sensitive, non-target species. Continuous use of copper-based molluscicides may result in an accumulation of copper in sediments and, consequently, may restrict sediment reuse and disposal (Cooke et al. 1993).

Cost Considerations: The cost of this technology would depend on product choice and method and rate of application.

Implementation: Implementation costs would involve planning, purchase and application of the molluscicide. Most products are labeled for treatment of mollusk-infested waters in closed systems, and application of chemicals to treat mollusks in open water may require special labeling from the USEPA.

Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operation and maintenance costs would include monitoring effectiveness of treatment and reapplication for long-term control, and may include a water quality monitoring program. Other possible costs include "detoxification", as some molluscicides require detoxification prior to discharge of treated water, since they are harmful to fish and other aquatic organisms.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Pheromones

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Repellant and Attractant Pheromones

Targeted Species: Pheromones are a potential control method for fish. Specific ANS of Concern – CAWS[1] that are being studied include bighead carp *(H. nobilis)*, black carp *(Mylopharyngodon piceus)*,silver carp *(Hypophthalmichthys molitrix)* and sea lamprey (*Petromyzon marinus*).

Selectivity: Pheromones are designed to control or manage some species of fish, however, the effects on other organisms are not known.

Robin Calfee, a biologist with USGS, sets up an experiment to determine what scents attract Asian carp. Such knowledge may be useful in population control efforts.

Developer/Manufacturer/Researcher: The main researchers of this technology include: the U.S. Geological Survey [(USGS (Ed Little, Robin Calfee, and Holly Puglis)]; Columbia Environmental Research Center, Columbia, MO; Peter Sorensen, University of Minnesota, Minneapolis, MN; and Dean Gilligan, Industry & Investment NSW, Invasive Animals Cooperative Research Centre, Hillston, New South Wales, Australia.

Brief Description: Pheromones are secreted or excreted chemical factors that trigger a social response in members of the same species. They can be either an attractant or repellant. Three categories of pheromones can be discerned based on their function: anti-predator cues, social cues, and reproductive cues. Each of these categories comprises pheromones that can induce "primer" effects (developmental and/or endocrinological changes) and/or "releaser" effects (strong behavioral changes). Anti-predator pheromones are volatile substances released by some species when attacked that can trigger either "fight or flight" with surrounding fish of the same species. When studied, Asian carp tend to distance themselves from the area where the "alarm" chemical was released. Numerous studies show that fish exhibit evasive (alarm or fright reactions) responses to the odor of damaged conspecifics (same species), or predators that have eaten conspecifics. In many fishes, including goldfish and common carp, conspecific odor promotes aggregation and shoaling. This response is apparently not based on immediate familial relationship, although this aspect has largely been ignored. Both bile acids and L-amino acids have been implicated in species-recognition, but little research has been directed to this question (Sorensen & Stacey 2004). Pheromones are collected by filtering fish holding water or through tissue extraction. Some pheromones can be synthetically manufactured.

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Numerous species of fish, including cyprinids such as bighead and silver carp, have an alarm pheromone that is produced by cells in the outermost epidermal layer of fish skin (Pfeiffer 1977). The substance is released into the water upon damage to the layer of skin overlying the scales as would occur during attack by a predator. This substance, initially described 60 years ago, induces a fright reaction in conspecifics which may include freezing, heightened swimming, or rapid escape from the area. Some other species will also avoid areas where the alarm substance is present. In minnows, the alarm substance persists for hours in water, is not affected by freezing, and apparently is unaffected by digestion after a predator consumes fish containing the substance. In such cases, the alarm substances scent the predator and its feces (Little et al. 2011).

The USGS is conducting field studies on Asian carp (bighead and silver) to evaluate the effectiveness of hormonally-induced sex pheromone production in caged female carp, as an attractant to aid in the capture of wild carp. Initial findings indicate high sensitivity of the carp's sense of smell to sex hormone metabolites associated with sex pheromones; these metabolites result from chemical processes in the fish's body. A feeding stimulus was also developed, which was attractive to the Asian carp during field testing. Attractant pheromones may be used in practice to draw Asian carp into an area where other Controls could be applied.

Prior Applications: Pheromone deterrents are still in the research phase for a variety of species. This Control has been tested in a variety of fish, including: goldfish (Saglio & Le Martret 1982; Saglio & Blanc 1983); common carp (Industry and Investment NSW 2010); salmon (Moore & Waring 1996); eels (Sorensen 1986); sea lamprey (Sorensen et al. 2003) ; and Asian carp (Little et al. 2011).

General Effectiveness: In the past, chemical control measures have been applied to control invasive organisms, such as the lamprey in the Great Lakes. Pheromones appeal to the Great Lakes sea lamprey program because they may enhance the existing control strategies (Li et al. 2003). Sorensen et al. (2003) demonstrated that the migratory pheromone plays a key role in determining adult lamprey distribution.

Operating Constraints: If pheromones are classified as pesticides by regulatory agencies, a National Pollutant Discharge Elimination System permits would be required for application. The effects of pheromones are temporary and diminish as the target organism acclimates to constant application. Effectiveness of this Control may prove to be short-term.

Cost Considerations:

Implementation: Implementation costs would include developing and manufacturing the pheromone, developing a plan for their use, and construction of any feature required for delivery and application. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include continuous application of pheromones and an effectiveness monitoring program.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Piscicides

ANS Control: Piscicides – antimycin A, rotenone, niclosamide and 3-Trifluoromethyl-4-nitropheno (TFM)

Targeted Species: Piscicides have an affect on all fish including those specific ANS of Concern – CAWS[1]. This control may be effective on blueback herring *(Alosa aestivalis)*, skipjack herring (*A. chrysochloris)*, alewife (*A. pseudoharengus)*, northern snakehead (*Channa argus)*, threespine stickleback (*Gasterosteus aculeatus*), ruffe (*Gymnocephalus cernuus)*, silver carp (*Hypophthalmichthys molitrix)*, bighead carp (*H. nobilis)*, inland silverside (*Menidia beryllina)*, black carp (*Mylopharyngodon piceus)*, sea lamprey (*Petromyzon marinus)*, and tubenose goby (*Proterorhinus marmoratus).*

Selectivity: Piscicides were designed to manage or control fish; however, they are non selective and are known to affect macro-invertebrates. Depending on the type, concentration, method and timing of application, and length of exposure to the piscicide used, it may be toxic to other aquatic species.

Developer/ Manufacturer/ Researcher: Piscicides are manufactured by a variety of chemical companies. Federal research entities working on piscicides include scientists at the United States Geological Survey (USGS) Great Lakes Science Center (Ann Arbor, MI); the USGS Upper Midwest Environmental Science Center (La Crosse, WI); and the USGS Columbia Environmental Research Center (Columbia, MO).

Pesticide Registration/Application: Pesticides, including piscicides, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). These pesticides are restricted use pesticides – as such any user must be a certified applicator for the state in which the material is being applied. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Pump, piping, and rotenone staged for use in the CAWS

Workers placing piping to administer rotenone

Buoys mark the location of submerged pipes across the CAWS for the rotenone

December 2009 Application of Rotenone in the CAWS

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Brief Description: Piscicides are chemicals used to kill fish. They can be used in a variety of aquatic environments including lakes and rivers. There are four chemical piscicides registered for use in the United States: antimycin A, rotenone, niclosamide and TFM. The lampricides, niclosamide and TFM, are registered to control sea lamprey; niclosamide is also registered to control mollusks.

Antimycin A and rotenone –Antimycin A and rotenone are often referred to as general piscicides, meaning they are relatively indiscriminate in the fish species killed, though antimycin A is generally considered to have greater toxicity to scaled fishes. Antimycin A is product of fungal fermentation whereas rotenone is a naturally occurring plant flavonoid. Both affect gill-breathing animals by inhibiting their use of oxygen at the cellular (mitochondrial) level (Bettoli & Maceina 1996). Rotenone has impacts on terrestrial insects as well (Isman 2006).

Antimycin A is more toxic to fish than rotenone (Bettoli & Maceina 1996), yet less toxic to aquatic invertebrates in terms of long-term effects on aquatic community diversity and abundance (Lennon et al. 1971). Fish do not sense (i.e. avoid) antimycin A as they do rotenone (or the petroleum carriers used to solubilize rotenone). It also requires less contact time than rotenone to cause death and kills all life stages of fish, including eggs (Berger et al. 1969). However, one study suggests that silver and bighead carp are relatively insensitive to antimycin A (Chapman et al. 2003); whereas another refutes this finding (Rach et al. 2009). Additionally, antimycin A degrades faster than rotenone especially when exposed to air, warm temperatures, and high pH. Potassium permanganate readily detoxifies both antimycin A and rotenone (Bettoli & Maceina 1996).

Oral Delivery Systems: Researchers are exploring ways to selectively kill only invasive fish species while protecting native fish species. One technique, treating fish food pellets with rotenone, has been effective at controlling common carp in marshes (Gilligan et al. 2005; Bonneau & Scarnecchia 2001). Food pellets require far less rotenone to deliver a lethal dose than direct water application of rotenone, and can be removed from the water if not consumed; however, fish must typically be trained to consume the food pellets. Development of oral delivery techniques requires a full understanding of native and invasive species gill and gut enzyme activity and physiology, because a targeted delivery system will likely use an oral or gill adhesion delivery route. Designing the pellets to float and correctly sizing the pellets can reduce the chance of poisoning non-target fish (Gehrke 2003).

Niclosamide and TFM – Niclosamide and TFM are used for controlling sea lamprey ammocetes in the Great Lakes tributaries. Niclosamide is the active ingredient in USEPA-registered molluscicides as well. Application of these piscicides is generally limited to headwaters where the diversity and abundance of fish is not high, limiting impacts, however, they have also been applied to larger rivers, such as the St. Mary's River on the Michigan/Ontario border, when required. The lampricide TFM exhibits selectivity to lamprey because the version of the enzyme lamprey possess to eliminate TFM is less efficient than in most fishes – thus TFM accumulates in the lamprey and causes mortality during exposures that don't cause mortality in other fish species. The toxicity of these compounds is highly pH/alkalinity dependent and minor shifts in environmental conditions can result in marked shifts in the toxicity of the compounds to non-target aquatic animals. Amphibians are occasionally found dead in creeks immediately after TFM treatment in Lake Erie watersheds and elsewhere in the Great Lakes though this does not occur with regularity. TFM is degraded both by photolysis and biological pathways (aerobic and anaerobic metabolism paths) and the half life is on the order of hours. Niclosamide is often used in small amounts in large streams or fast-flowing water bodies to reduce the amount of TFM needed to kill sea lamprey larvae (Bettoli & Maceina 1996), and in lake areas where the volume of chemical would otherwise be prohibitively large (Brege et al. 2003).

Prior Applications: Piscicides have been used by fishery biologists to sample fish communities and remove undesirable fish species since the 1930s (Bettoli & Maceina 1996), and they have been a principal means for assessing fish populations in Ohio River locks for many years (Margraf & Knight 2002). Standard operating procedures have been developed for the application of antimycin A, rotenone and lampricides (Finlayson et al. 2010; Moore et al. 2008; Adair & Sullivan 2011).

The National Park Service has successfully used antimycin A to restore native fish populations (Gresswell 1991). Extracts from rotenone containing plants have been used to catch fish prior to their application for fisheries science (Krumholz 1948). Rotenone was used in the CAWS in 2009 during the maintenance of the Chicago Sanitary and Ship Canal's Electric Fish Barrier IIA and in 2010 to determine whether Asian carp were present in areas where eDNA[2] tests had indicated that bighead and silver carp may have been present (USACE 2010). In Australia, rotenone was used to eliminate carp from Tasmania in the 1970s and to eradicate non-native trout from streams (West et al. 2007). Rotenone pellets have been used experimentally in controlling common and grass carp in lakes (Fajt 1996; Gehrke 2003).

The lampricides TFM and niclosamide have been used successfully for sea lamprey control in tributaries of the Great Lakes since 1958. (Smith & Tribbles 1980)

General Effectiveness: There are a variety of factors that impact the effectiveness of piscicides, including suspended solids, temperature, pH, dissolved oxygen, and dissolved iron. Rotenone was found to be fatal to bighead and silver carp after a 4-hour exposure period (Chapman et al 2003). Rotenone was effective at killing common carp and 10 other fish species during the 2009 CAWS application and over 40 fish species during the 2010 CAWS application (USACE 2010).

The period of time it takes antimycin A to kill fish may be influenced by the surfactant used during application. One study indicated that it took 32 hours to kill Asian carp while using the most concentrated antimycin A dose permitted (Chapman et al. 2003), but antimycin A used with a different surfactant killed various cyprinid fishes after an exposure period of 12 hours (Rach et al. 2009). At the typical treatment rates used for antimycin A, all fish species would be vulnerable, though some are more sensitive. Antimycin A is relatively selective for fish with scales. It has been used to selectively remove scaled fish from catfish aquaculture facilities (Finlayson et al. 2011). Antimycin A is more

[2] eDNA (Environmental DNA) is the genetic material of an organism that is found in the environment. Organisms, like Asian carp, release DNA into the environment in the form of secretions (slime), feces, and urine. These substances and the DNA within them slowly degrade in the environment, but can be collected in water samples if caught soon enough. These water samples are filtered and the genetic material is collected and processed to identify the presence or absence of Asian carp DNA.

active in warm water than in cold, is slightly more active in soft water than hard, and is more active and persists far longer in water at pH 5 to 8 than at pH 9 or 10 (Berger et al. 1969).

Oral Delivery Systems: An oral delivery formulation for Asian carp is still in the developmental stages. The USGS is developing microparticle oral delivery systems to selectively deliver piscicides to silver and bighead carp. Their research has identified enzyme triggers to release the piscicide from the microparticle - enzymes present in bighead and silver carp that are less active or not present in native planktivores like gizzard shad and bigmouth buffalo. They are presently testing the effectiveness of the oral delivery system microparticle to deliver antimycin to bighead and silver carp but not affect bigmouth buffalo or paddlefish. The effectiveness of oral delivery systems on invasive fish species such as Asian carp has yet to be determined. Baiting fish with rotenone-treated product has had limited success in past attempts (Gehrke 2003; Boogaard 2003).

Operating Constraints: Standard operating procedures are required for piscicides, including extensive preparatory work, stringent application procedures, and follow-up (monitoring), all of which are intended to reduce effects on non-target organisms. Piscicides require application of the treatment, and collection and disposal of dead fish. Fish kills with piscicides generate large quantities of dead fish that must be collected and properly disposed. The required amount of time to apply piscicides varies greatly, depending on the selected piscicide, size of the treatment area, water temperature, target fish species, flow, mixing rate, and the detoxification protocol. Lampricides are labeled for use only by the US Department of the Interior, the US Fish and Wildlife Service, state fish and game agencies, and Fisheries and Oceans Canada and Provincial Certified Applicators trained in sea lamprey control.

Cost Considerations:

Implementation: Implementation costs would include application method planning, purchase of the piscicide, and application of the piscicide. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include routine application of the piscicide, collection and disposal of dead fish, and effectiveness monitoring. Another consideration is the deactivation of the compound to limit effects on non-target organisms.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

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Screens

ANS Control: Screens – Non-Mechanical and Mechanical, and Filters

Targeted Species: Screens are an effective control method for many types of organisms. Except for louvered screens and filters, the identified screens may be effective at controlling the fish and plant species identified as ANS of Concern – CAWS.[1] Louvered screens may be effective at controlling the fish species identified as ANS of Concern – CAWS. Filters may control all ANS of Concern – CAWS.

Fences such as this one along the Chicago Sanitary and Ship Canal are being used to prevent ANS from bypassing barriers during flood events.

Selectivity: Depending on the type, screens will manage and/or control all organisms, and this Control is non-selective.

Developer/Manufacturer/Researcher: There are many manufacturers of screens. The U.S. Army Corps of Engineers (USACE) uses a variety of screen types at dams, diversions, and intake structures.

Brief Description: A screen prevents the movement of ANS through an aquatic pathway while allowing water to continue to flow through the screen. The size and type of a screen depends upon the size of the target organism, the typical amount of debris in the waterway, and the water velocity. Screens fall into three general categories: non-mechanical screens, mechanical screens, and filters.

Non-Mechanical Screens – Non-mechanical screens consist of a variety of screen materials (e.g. woven cloth, perforated plate, or profile wire) mounted over an opening. The filtering capacity of the screen material is sized to prevent the target organism from passing through, but large enough to let water pass. Non-mechanical screens must be periodically cleaned of debris. There are several types of non-mechanical screens: fences, bar screens, trash racks, and curtains.

Mechanical Screens – Mechanical screens operate the same way as non-mechanical screens, but have an automatic cleaning mechanism to remove debris. Screens placed in a waterway are difficult to maintain in flowing environments because they intercept ice and debris, and clogged screens can cause debris jams and localized flooding. This is particularly problematic during floods when large amounts of debris naturally wash through waterways. Mechanical, self cleaning, screens reduce the need for continuous monitoring by operations and maintenance personnel. Several types of mechanical screens are available: chain bar screens, reciprocating rake bar screens, catenary bar screens, continuous belt bar screens, rotating drum screens (paddle wheel or power), wedge-wire cylinders, louvered screens, and mechanical climber screens (USACE 1994).

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Filters – A filter is a porous material through which a liquid is passed in order to separate particulate matter from the fluid. A variety of materials are used as filters including cloth, paper, porous porcelain, or a layer of charcoal, diatomaceous earth or sand. Most filters strain particulate matter, however, some remove material through adsorption.

Prior Applications: Screens are a common type of control technology used to prevent the movement of ANS (Hillyard et al 2010). Exclusion screens are used worldwide to prevent and restrict the movement of unwanted organisms or material between separated water bodies.

Non-Mechanical Screens – The most common measures employed to reduce turbine entrainment of fish consist of an angled bar trash rack with closely-spaced bars (approximately 2 cm) set at an angle to the intake flow path. Other types of fixed fish screens range from variations of conventional trash racks oriented perpendicular to flow, to more novel designs employing cylindrical, wedge-wire intake screens (Čada & Sale 1993).

Most recently, fences, a type of non-mechanical screen, have been installed to prevent the movement of adult Asian carp between the Des Plaines River and the Chicago Sanitary and Ship Canal (USACE January 2010, USACE 2012), and to divide Eagle Marsh in Indiana during flood events (USACE November 2010).

Mechanical Screens – Traveling screens are used in the gatewells of large hydroelectric projects to remove objects from the water (Čada & Sale 1993). Improved screen types are continuously being developed as new materials become available. Engineered polymer water screen technology is replacing steel in traveling screens at many hydropower facilities because it has strong impact resistance, lighter weight, and is easier to maintain than metal screens. The smooth surface of a polymer water screen is less likely to harm fish that come in contact with the screen.

Filters – Four types of filters are generally used in water treatment: slow sand filters, rapid sand filters, pressure filters, and diatomaceous earth filters. Slow sand filters are used for small groundwater systems; rapid sand filters are used for surface water treatment; pressure filters are used for iron and manganese removal in small groundwater systems; and diatomaceous earth filters are used in the food and beverage industry and for treatment of swimming pools.

General Effectiveness: Screen effectiveness is dependent on the size of the organism, and the mesh size, bar spacing, and type of filter membrane or medium. Screens are not as effective as other methods at preventing downstream movement of small organisms (e.g. fish eggs, larvae, diatoms, spores, seeds, or plant fragments). Filters are effective at removing small organisms, but are prone to clogging and require a high level of maintenance to remove solids accumulation, which reduce flow through the filter.

Operating Constraints: The optimal screen configuration depends on site conditions, desired flows, and the size of the target organism and typical debris material. Floods and ice jams should be considered in the design of a screening mechanism.

Filters would require continuous cleaning and maintenance. Filtration rates vary depending upon filter type. Filter operation is constrained by resistance through the filter membrane or medium, and filter fouling.

Cost Considerations: The costs of non-mechanical screens vary based on site-specific factors. Spacing, thickness, and screen type all have significant impacts on cost and design. As a general rule, clogging and fouling increases as the size of a screen opening decreases, increasing operation and maintenance costs.

Non-Mechanical Screens –

Implementation: Implementation costs of non-mechanical screens vary depending on the type of screen, the mesh size and material, site topography, and the amount of screen required for the project area. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Maintenance costs include repairs, trash removal, and adjustments for changing conditions. Maintenance costs of non-mechanical screens are significantly less in upland areas, where the primary maintenance cost is cleaning the screens after flood events.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed evaluations.

Mechanical Screens –

Implementation: Implementation costs of mechanical screens vary depending on the size of each screen, site topography, and total project area, as well as the complexity of the screening mechanism. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Maintenance costs include repairs, trash removal, power and adjustments for changing conditions.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Filters –

Implementation: Implementation costs would include the construction of a pipe system and filtration treatment facility. Construction of a facility and piping system would involve the facility, access, power, equipment, and associated construction costs.

Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Maintenance costs include such costs as repairs, power, filter replacement, trash removal, and adjustments for changing conditions.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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Sensory Deterrent Systems

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Sensory Deterrent Systems – Acoustic Air Bubble Curtains, Electrical Barrier, Underwater Sound, and Underwater Strobe Lights

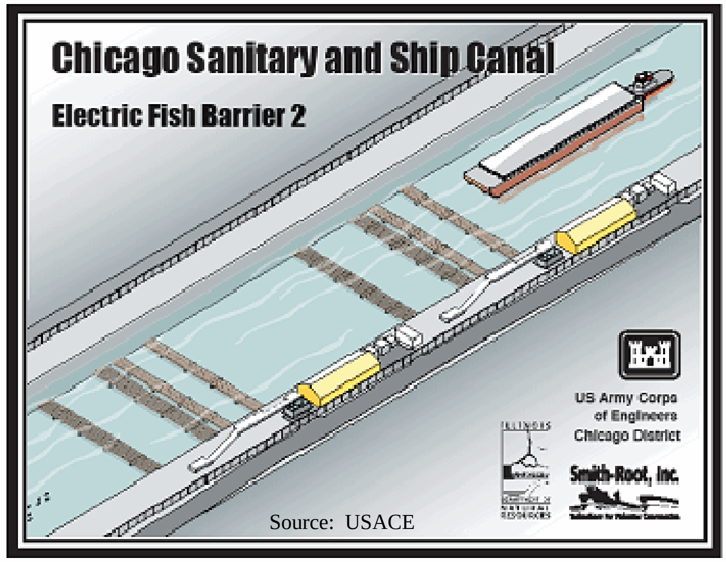

Illustration of Electrical Barriers and submerged electrical arrays within the Chicago Sanitary and Ship Canal, located in Romeoville, IL

Targeted Species: Sensory deterrent systems are used to prevent the upstream movement of fish; specific ANS of Concern – CAWS[1] that may be controlled through use of these technologies include alewife (*A. psuedoharengus*), bighead carp (*H. nobilis*), black carp (*Mylopharyngodon piceus*), blueback herring (*Alosa aestivalis*), inland silverside (*Menidia beryllina*), lamprey (*Petromyzon marinus*), ruffe (*Gymnochephalus cernnus*), northern snakehead (*Channa argus*), sea and tubenose goby (*Proterorhinus marmoratus*), silver carp (*Hypophthalmichthys molitrix*), skipjack herring (*A. chrysochloris*), and threespine stickleback (*Gasterosteus aculeatus*).

Selectivity: This technology was designed to control or manage fish. It is non–selective and cannot target specific fish ANS of Concern – CAWS.

Developer/Manufacturer/Researcher: These technologies are available through a variety of manufacturers.

Brief Description: Locating an effective and economical way to influence fish behavior and movement is one of the main challenges in fish management. Several technologies that attempt to elicit fish movement have been explored, and are collectively referred to as sensory deterrent systems.

Acoustic Air Bubble Curtains – This system can be deployed in much the same way as a standard air bubble curtain, but its effectiveness as a fish barrier is potentially enhanced by the addition of a sound signal. Bubble curtains are walls of bubbles rising from a bottom-resting bubbler manifold (perforated pipe) supplied with compressed air. Bubble curtains have been used for many years to protect fish from the effects of pressure waves created by explosions from underwater construction (Keevin & Hempen 1997). When used with sound at an effective frequency, bubble curtains can contain and amplify sounds that repel some species of fish (Kuznetsov 1971; Hocutt 1980).

Electric Barrier – Electric barriers use an electrical stimulus to alter fish behavior. There are three electrical barriers in the Chicago Sanitary and Ship Canal that span the width of the waterway with a series of electrodes. These electrodes emit pulsed DC charges into the water at a rate of up to 2.3

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

volts/inch, 30 hertz and 2.5 milliseconds. Depending upon strength of the field, electric barriers can be used to deter, stun, or kill the organism. The reactions of fish to electrical exposure is often size and species dependent (Bird & Cowx 1993). Electric barriers are most effective against actively swimming organisms rather than planktonic organisms that float in the water column. A stunning strength field would work best if the only organisms involved were swimming upstream. If the organism encountered the field and failed to turn away, it would be stunned and washed downstream, whereas a downstream moving organism would be stunned and washed through the barrier. A deterring electric field would deter fish or other actively swimming organisms from passing upstream or downstream through the field (USACE 1999).

Underwater Sound – This type of sensory deterrent system uses underwater sound (projectors powered by audio amplifiers and electronic signal generators) to create a repellent acoustic field, comprised of near- and far-field sound components. The near-field sound component is primarily caused by water particle vibration; the far-field sound component, located further from the sound source, is caused by pressure. The combination of near- and far-field sound displacement may be useful as a deterrent system because fish use sound to orient themselves in their surrounding environment. Depending on the type of sound system, frequencies range from 20 to 500 Hz, under varying amplitudes.

Underwater Strobe Lights – Strobe lights are a widely used type of lighting for fish control. Strobe lights produce flashes of light at rapid rates, depending on the target species and scale of the water body and light installation. Large scale systems commonly consist of four individual lights that flash at a rate of 450 flashes/minute, and have an approximate light intensity of 2634 lumens/flash. This type of system uses xenon gas tubes, which emit broad spectrum white light. Small scale systems can consist of an individual cylindrical strobe light (0.16 m length by 0.04 m diameter) with a flash rate of only 86 flashes/minute. Both systems have been shown to alter fish movements in both experimental and field settings for a variety of fish species.

Prior Applications: Air bubble curtains (Patrick et al. 1985; Welton et al. 2002); and combinations thereof have been successful in altering fish behavior (Amaral et al. 2001); underwater sound (Popper & Carlson 1998; Goetz et al. 2001; Mueller et al. 2001; Sand et al. 2001); underwater strobe lights (Patrick et al. 1985; Sager et al. 1987; Konigson et al. 2002; Richards et al. 2007; Hamel et al. 2008).

Acoustic Air Bubble Curtains – Ruggles (1991) reported that air bubbles are an effective control for some saltwater species, and possibly for other species in streams and small rivers. Patrick et al. (1985) reported that air bubbles produced avoidance behavior in laboratory experiments with gizzard shad *(Dorosoma cepedianum)*, alewife, and rainbow smelt, and that avoidance increased when air bubbles were combined with strobe lights. Acoustic bubble curtains have been used experimentally to guide salmon movements on the San Joaquin River (Science News 2009). While the basis for the response was not known, it may have been a visual stimulus or the sound associated with the bubbles, as suggested by Kuznetsov (1971).

Electric Barrier – Electric fields were initially applied in North America in large scale to prevent the upstream movements of sea lamprey in the Great Lakes basin in the 1950s. By 1960, electric barriers were installed in 132 tributaries of the Great Lakes. However, lamprey control measures did not become truly effective until after 1958 when a selective toxicant - the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) - was used to destroy larval lampreys in streams (Smith & Tibbles 1980). Electrical barriers have been used to protect lakes from common carp and bigmouth buffalo (Verrill & Berry, Jr. 1995). The U.S. Army Corps of Engineers operates three electrical barriers on the Chicago Sanitary and Ship Canal near Romeoville, Illinois, to prevent Asian carp species from transferring from the Mississippi River Basin into the Great Lakes Basin.

Underwater Sound – Both laboratory and field tests have been performed on acoustic systems. For example, a study was conducted to evaluate an infrasound (<35 Hz) acoustic fish fence designed to guide downstream migrating European silver eels *(Anguilla anguilla)*. The result indicated a significant shift of the migrating eels away from the infrasound source (Sand et al. 2001). In a similar study, experimental tests were conducted to evaluate behavioral responses of chinook salmon to infrasound, including both hatchery-reared and wild juvenile fish. Both wild juvenile chinook salmon (40-45 mm) and hatchery-reared chinook salmon (45-50 mm) showed avoidance responses when exposed to a 10 Hz source (Mueller et al. 2001). In addition, Gibson and Myers (2002) reported positive results for a fish diversion system that utilized high-frequency sound (122-128 kHz) at the Annapolis Royal Generating Station, upstream of Annapolis Royal, Nova Scotia, Canada. The effectiveness of the diversion system was evaluated by monitoring fish passage through the turbine and two adjacent fishways; the rates of passage of American shad *(Alosa sapidissima)* and alewife through the turbines decreased by 42% and 48% respectively.

Underwater Strobe Lights – Nemeth and Anderson (1992) evaluated the effects of strobe lights on juvenile coho salmon *(Oncorhynchus kisutch)* under controlled conditions and found that smolts[2] typically hid when subjected to lights. Similarly, Maiolie et al. (2001) reported an 80% reduction in density of kokanee *(O. nerka)* within a 30 meter radius when the fish were subjected to a field application of strobe lights. Richards et al. (2007) found largemouth bass *(Micropterus salmoides)*, chinook salmon *(O. tshawytscha)*, yellow perch *(Perca flavescens)*, and channel catfish *(Ictalurus punctatus)* all elicited an avoidance response to strobe lights in an experimental setting. Additionally, Hamel et al. (2008) reported that rainbow smelt *(Osmerus mordax)* were repelled to a horizontal distance of 15 meters when subjected to underwater strobe lights in a clear water reservoir.

General Effectiveness: Overall, the applicability of sensory deterrent systems across species or across varying environmental or physical conditions and of different ages and sizes of organisms is not well understood (Coutant 2001).

Acoustic Air Bubble Curtains – The effectiveness of an acoustic air bubble curtain depends on several factors, including flow, background noise, and source interactions. Taylor et al. (2005) reported that an acoustic air bubble curtain was 95% effective at holding back bighead carp when tested in a raceway. Overall, little work has been done with bubble barriers relative to other sensory deterrent systems. The work that has been completed does not appear to have been broadly successful in influencing fish behavior or movements.

[2] A smolt is a juvenile salmon in the stage of migrating from fresh water to the sea.

Electric Barrier – Electrical barriers have been shown to be effective for a wide range of fish species and fish sizes (Palmisano & Burger 1988; Swink 1999; Holliman 2010). However, the complexity of electrical barrier systems and the intricacies involved in operation and monitoring may always preclude absolute effectiveness (Stokstad 2003; Clarkson 2004).

Underwater Sound – Unlike underwater strobe lights, sound is a good candidate for an effective control technology because it has few limitations in water. Sound is especially effective when used over long distances, or when visibility is marginal. Sound travels at high speed through water and attenuates in all directions. The critical issue that remains to be determined is how well a particular species can detect a signal with the inner ear and/or lateral line (Popper & Carlson 1998).

Underwater Strobe Lights – The overall rate of effectiveness of underwater strobe lights depends on a number of variables, including species, age, physiological condition, and environmental conditions (Popper & Carlson 1998). The transmission of light in water is affected by water quality characteristics. Concentrations of inorganic suspended solids, chlorophyll *a*, and detritus can affect light absorption and scattering, thereby influencing light attenuation. The effectiveness of strobe lights in water also varies depending on time of day. During daytime hours, background illumination often fades out light from the stimulus, making it less effective; at night, ambient light is low and the strobe lights are more efficient (Electric Power Research Institute 1994). In addition to water clarity, the rate at which fish are deterred is dependent on the target species. Species vary in their response to a light stimulus; for some it may act as an attractant, while for others it acts as a deterrent, even if two species are found in the same habitat (Brett & McKinnon 1953; Feist & Anderson 1991). Brett and McKinnon (1953) demonstrated this behavior in an early study of sealed beam lights. When subjected to the light source, some fish species swam toward the light, while others were repelled. As Hamel et al. (2010) noted, however, this response could be due to a concentration of prey (e.g., zooplankton) and/or an increase in feeding efficiency for visual-feeding fish.

Aforementioned data indicates that it is not clear whether strobe light illumination is an effective control method for all species or all ages of a particular species (Patrick 1982). As Anderson (1988) discussed, without data on the behavioral responses of different species to strobe illumination, it will not be possible to design proper lighting systems or to ensure that the fish will be influenced.

Operating Constraints: The main operating constraints in implementing sensory deterrent systems include flow field conditions, environmental and physical conditions at study sites, cost, scale, and site-specific characteristics. Due to the varying width and depth of a natural stream or river, such a deterrent barrier would need to cover a much wider cross section than just the main river channel; otherwise, ANS may bypass the barrier during high flow conditions. Frequent repair or replacement of underwater equipment for sensory deterrent barriers in channels is anticipated, due to the harsh environment, including floating ice, debris, shifting sand and gravel banks, and boat traffic.

Cost Considerations:

Implementation: Implementation costs for each of the sensory deterrent systems will vary depending on site-specific characteristics, location, scale, and construction and equipment requirements. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: All deterrent systems require electricity and routine maintenance. A performance monitoring program would be required for each sensory deterrent system.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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ANS Control: Ultrasound

Targeted Species: Algae are affected by ultrasound. Examples of ANS of Concern – CAWS[1] controlled by this technology may include red macro-algae (*Bangia atropurpurea*), diatoms (*Cyclotella cryptica*, *C. pseudostelligera*, and *Stephanodiscus binderanus*),[2] and grass kelp (*Enteromorpha flexuosa*). See the *Prior Applications* section of this fact sheet for more details.

Sound waves are generated by a transducer placed in the water; the transducer is powered by line voltage or solar cells.

Selectivity: Sound wave frequencies emitted by the SonicSolutions[3] system and other similar devices are specific for control of algae (Taylor 2011). Selectivity will vary among algal species.

Developer/Manufacturer/Researcher: A device specifically developed for algae control is manufactured by SonicSolutions, LLC, West Hatfield, Massachusetts. Ultrasonic irradiation modules used in Lake Senba, Japan (described in the Prior Applications section) were developed by Honda Electronics Company, LTD [3] (Toyahashi, Japan) (Lee et al. 2002). Other manufacturers of similar devices may be available. To date, no commercial ultrasonic device has been developed for control of aquatic vascular plants (Wu & Wu 2007).

Brief Description: Ultrasound is a high frequency sound wave (>20,000 Hz) above the audible frequency range of humans (Wu & Wu 2007; Soar 1985). The device developed by SonicSolutions, LLC, claims to emit sound wave frequencies within a range (proprietary information) that specifically targets nuisance algal species. Complete kill of algal species can take up to 4 to 5 weeks with continuous (24-hour) application. Sound waves are generated by a transducer placed in the water, which floats on the water surface; the transducer is powered by line voltage or solar cells (SonicSolutions, LLC, 2011a).

The effects of ultrasound on plant cells and tissues can be mechanical or thermal in nature (Wu & Wu 2007; Ahn et al. 2003). When plants absorb ultrasonic waves, energy associated with the wave is converted into heat, causing a "thermal" effect. Ultrasound can also cause acoustic cavitation in plant cells. Documented biological effects of sonication on plant cells includes chromosomal anomalies, disruption or collapse of gas vesicles and subsequent loss of buoyancy, damage to or destruction of cellular organelles, cell death, changes in cellular osmotic potential, inhibition of photosynthesis and cell division, destruction of cell membranes, and formation of free radicals (Wu & Wu 2007; Zhang et al. 2006; Hao et al. 2004; Ahn et al. 2003; Lee et al. 2002; Nakano et al. 2001; Soar 1985). These effects have been reported after short exposures to ultrasonic waves, from seconds (Lee et al. 2002) to

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Cryptic algae (*Cyclotella cryptica*), cylindrical algae (*C. pseudostelligera*), and diatom (*Stephanodiscus binderanus*) are three (3) species of algae that belong to the algal subcategory of diatoms. For the purpose of this fact sheet, they will be referred to collectively as diatoms.
[3] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

minutes (Zhang et al. 2006; Hao et al. 2004; Soar 1985). Ahn et al. (2003) reported that algal cell densities and chlorophyll *a* concentrations of *Microcystis aeruginosa* were significantly decreased after 3 days of ultrasonication (20 kHz applied twice daily for 2-minute exposures).

Prior Applications: The use of ultrasound technologies has been evaluated for multiple purposes in many systems and against several species of algae, plants, and bacteria. This technology is best suited for small water bodies, including golf course and ornamental ponds, small lakes and reservoirs, lagoons, and marinas. It also has been used to reduce algal biofilms in some water treatment facilities. The application of ultrasonic irradiation to control cyanobacterial blooms in eutrophic systems (including *M. aeruginosa* and *Spirulina platensis*) has been documented by many researchers (Zhang et al. 2006; Hao et al. 2004; Ahn et al. 2003; Lee et al. 2002; Nakano et al. 2001).

Rockland Country Club (New York) before and after the addition of ultrasound treatment

Laboratory and greenhouse studies by Wu and Wu (2007) demonstrated that ultrasonic waves of 20 kHz, aimed directly at water chestnut (*Trapa natans*) stems and petioles, caused severe damage and plant death. These findings indicate that ultrasound may hold promise as a new control technique for this invasive weed species. The submersed aquatic macrophyte, Eurasian watermilfoil (*Myriophyllum spicatum*), is also susceptible to ultrasound (Soar 1985).

Phull et al. (1997) evaluated the use of ultrasound for wastewater treatment and found that ultrasound, in combination with chlorination, was more effective for reducing bacterial colonies over sonication used alone. Ultrasound also reduced the amount of chlorine required for wastewater disinfection (Phull et al. 1997). Ultrasonic technologies coupled with hydraulic flushing effectively controlled blue-green algae blooms in Lake Senba, Japan (Lee et al. 2002).

General Effectiveness: The manufacturer states that of the five algal species identified as ANS of Concern – CAWS, only diatoms can be controlled with the SonicSolutions ultrasound system. It is unlikely that the filamentous green algae, grass kelp, will be affected by ultrasound due to its plantlike characteristics. It is unknown whether unbranched red macro-algae would be affected by ultrasound; data is currently nonexistent on this species ((D. Taylor, SonicSolutions, LLC, E-mail communication, 2011). The SonicSolutions technology is not effective on vascular aquatic plants (SonicSolutions, LLC, 2011b).

Operating Constraints: Operating constraints identified with use of the SonicSolutions ultrasound system include: the transducer must be positioned in a minimum of 2 feet of water; the placement of transducers is important for maximum effectiveness, as ultrasound waves bounce off hard surroundings such as concrete, rip-rap, large rock islands, sandbars, and weirs, which can degrade signal strength; dense beds of submersed aquatic weeds can reduce signal strength; large and irregularly shaped bodies of water require installation of multiple units; the system is most effective in enclosed bodies of water (e.g., ponds, pools, lagoons, tanks, and small lakes); the system is not effective on vascular aquatic plants or plantlike, macrophytic algae (*Chara* or *Nitella* spp.); and complete kill of algae may take as long as 4 to 5 weeks (SonicSolutions, LLC, 2011b). The use of ultrasound in flowing water systems may not be practical, given the duration of exposure (4 to 5 weeks) required to destroy susceptible algal cells. Massive die-off and/or decay of algae in a short period of time may result in low dissolved oxygen levels in some systems.

According to Wu & Wu (2007), limited research has been conducted to determine the effects of ultrasound frequencies, capable of damaging plant cells (20 kHz was successful for destroying plant cells in these studies), on benthic organisms, fish, or wildlife. These researchers concluded that additional studies should be conducted to investigate the potential impacts of ultrasound on aquatic communities prior to large-scale field application of this technology.

Cost Considerations:

Implementation: Implementation costs would include purchase and placement of units, and costs related to installation of a power source in the area of treatment. Placement requires no equipment and can be accomplished quickly. The number of units required is dependent on the area of water to be treated. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: In recommended applications, little maintenance is needed. In most applications, the device must be removed from the water for minor cleaning on a monthly basis. Operations would include electricity requirements of approximately 10 watts per hour per unit. Repair and replacement costs would vary, depending on damage from impacts of ice, debris, changing channel depths, and boat traffic. Solar-powered ultrasound units are available, but may have additional maintenance considerations (battery replacement).

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

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Ultraviolet Light

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Ultraviolet (UV) Light

Ultraviolet light is used in some wastewater treatment plants for disinfection. The process breaks down microorganisms, making them unable to reproduce.

Targeted Species: Ultraviolet light can be used to effectively control a variety of microorganisms. The ANS of Concern – CAWS[1] that may be controlled by UV include bloody red shrimp (*Hemimysis anomala),* diatoms (*Cyclotella cryptic*, *C. pseudostelligera*, *Stephanodiscus binderanus*), European amphipod (*Echinogammarus ischnus),* fish-hook water flea (*Cercopagis pengoi),* grass kelp (*Entermorpha flexuosa),* harpacticoid copepod (*Schizopera borutzkyi),*.parasitic copepod *(Neoergasilus japonicas),* red macro-algae (*Bangia atropupurea),* scud (*Apocorophium lacustre),* spiny waterflea (*Bythotrephes longimanus),* testate amoebas (*Psammonobiotus* spp.*),* and water flea (*Daphnia galeata galeata).*

Selectivity: Ultraviolet light treatment is designed to control microorganisms and is not selective.

Developer/Manufacturer/Researcher: There are numerous manufacturers of UV technology. A partial list is available on the International Ultraviolet Association website (www.iuva.org).[2]

Brief Description: Ultraviolet water purifiers destroy harmful microbes, including yeast, bacteria, algae, molds, virus and oocysts near the UV light. A UV filter is an enclosed chamber containing a series of UV-emitting light bulbs. As water flows through the chamber, UV light deactivates the DNA of bacteria, viruses and other pathogens, which destroys their ability to multiply and cause disease. As UV light penetrates through the cell wall and cytoplasmic membrane, it causes a molecular rearrangement of the microorganism's DNA, which prevents it from reproducing. Specifically, UV light causes damage to the nucleic acid of microorganisms by forming covalent bonds between certain adjacent bases in the DNA. The formation of such bonds prevents the DNA from being "unzipped" for replication, and the organism is unable to reproduce.

Ultraviolet treatment involves the conversion of electrical energy in a low-pressure mercury vapor "hard glass" quartz lamp. Electrons flow through the ionized mercury vapor between the electrodes of the lamp, creating UV light that penetrates through water flowing past the light (Yanong 2009). Ultraviolet light is electromagnetic radiation with a wavelength shorter than that of visible light. The spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the color violet.

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[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

UV light affects spore germination and chloroplast function in several algae species (Agrawal 2009; Poppe et al. 2003; Cordi et al. 2001). Each organism may require a different exposure rate (or dose) to UV light in order to be killed.

Prior Applications: Ultraviolet is commonly used at fish hatcheries and water treatment facilities to prevent contamination. For many years, the medical industry has used UV light to sanitize rooms and equipment. Ultraviolet light is used for disinfection of drinking water, wastewater treatment, and disinfection of foods and beverages.

General Effectiveness: At certain wavelengths, UV is mutagenic to algae, bacteria, viruses, and other small organisms and microorganisms. Ultraviolet light is categorized by light spectrum ranges: short wave UV-C; medium wave UV-B; and long wave (black light) UV-A [US Environmental Protectin Agency (USEPA) 2006]. UV has not been specifically applied to the ANS of Concern – CAWS, but may be effective on a variety of small organisms.

Operating Constraints: Ultraviolet light is used to treat contained, flowing waters, but is ineffective in treating large, open, turbid systems, such as marshes and lakes. UV light treatment is most effective after sediment, suspended solids, iron, and manganese have been filtered from water, prior to disinfection. Suspended solids or particulate matter can cause a shielding problem in which a microbe may pass through the UV filter without receiving any direct UV penetration. Iron and manganese will cause staining on the quartz sleeve that houses the UV bulb, at levels as low as 0.3 parts per million (ppm) of iron and 0.05 ppm of manganese (USEPA 2006). Working best with filtered water that is treated at a constant flow rate, use of UV light disinfection may be limited to small-scale applications.

Cost Considerations:

Implementation: Implementation costs would include the construction of a piping system and UV treatment facility. Construction of a facility and piping system may have considerable costs, including facility, access, electricity, and equipment costs. Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would involve operating and maintaining a filtering and treatment system, regular inspections and repair of mechanical parts, and an effectiveness monitoring program.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

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Vertical Drop Barrier

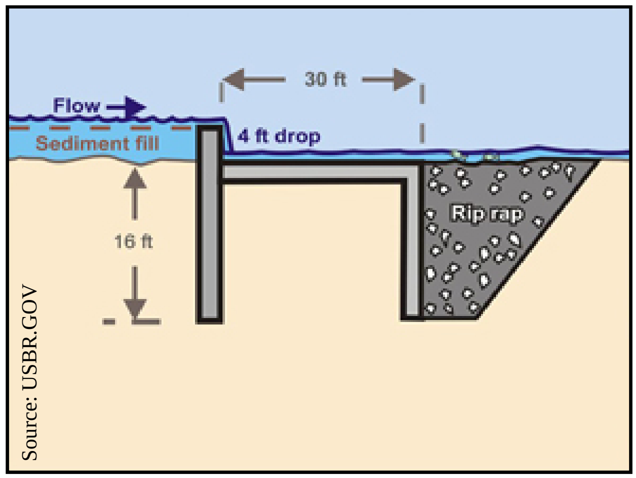
U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Vertical Drop Barrier

Targeted Species: This Control may be effective at preventing the upstream transfer via aquatic pathways of all ANS of Concern – CAWS[1]. See *General Effectiveness* and *Operating Constraints* sections for more information.

Selectivity: This Control is a unidirectional barrier, meaning that it only stops upstream movement of organisms and is non-selective.

Developer/Manufacturer/Researcher: The U.S. Bureau of Reclamation has experience in constructing vertical drop barriers.



Cross section of a vertical drop barrier

Brief Description: A basic design for a drop barrier consists of a vertical concrete wall that rises 4 to 5 feet above a concrete apron on the channel bottom. The vertical wall typically follows the configuration of the channel bottom so that a 4 to 5 feet drop extends across the entire bottom of the channel. The apron is designed to produce uniform water velocities that exceed fish swimming abilities, thereby precluding upstream passage. Jumping ability, swimming speed, and swimming endurance must all be taken into account when developing a vertical drop, as it must be designed to a height that exceeds the leaping abilities of fish when combined with the shallow, fast-flowing water over the apron. Upstream movements of fish during floods are not expected in mid-channel because of high current velocities and sediment loads, but potential movements along the edges of floodwaters will be prevented by the maintained vertical drop (Clarkson & Marsh 2010). Sediment accumulates in the pool upstream of the barrier over time.

Prior Applications: Stuart (1962) described the ability of fish to take advantage of the kinetic energy in the submerged wave at the foot of a fall to obtain a lift in jumping. Stuart's studies indicate that under favorable conditions, trout and juvenile salmon not only jump several feet from the crest of a submerged wave, but also use visual aids in orienting the height and direction of the leap. The fish may also swim for short distances vertically up a waterfall and, on occasion, successfully ascend a weir crest in this manner.

Horizontal screening racks can be added to the crest to prevent ANS from leaping over small vertical drops. These racks can be designed to be self-cleaning and alter flow conditions to hinder fish from jumping (Flick 1968).

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

General Effectiveness: Vertical drops are effective at stopping most varieties of organisms from moving upstream during normal flow conditions, but are ineffective at stopping downstream movement of organisms. Large flood events would reduce or eliminate the effectiveness of a vertical drop barrier due to the leveling of the water surface elevation above and below the barrier during high discharge. Under these high water conditions, fish could either leap or swim over and around the barrier. Silver carp are well-known for their leaping ability (Kolar et al. 2007).

Operating Constraints: A vertical drop is a unidirectional barrier, meaning that it stops upstream movement of fish only. In the construction of any vertical drop barrier, all factors contributing to the ability of a fish to jump should be taken into consideration including height of the vertical drop at all river stages including flood stage, and the velocity, hydraulic flow pattern, and depth of the tailwater. Other issues that need to be considered include; the interruption of migration patterns of native fishes and potential interference with navigation.

Cost Considerations:

Implementation: Implementation costs would include the construction of the barrier, as well as equipment access corridors and warning signage. Site conditions, such as waterway depth, subsurface soils, and accessibility, may have significant cost impacts. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would involve periodic inspection, removal of debris, and replacement of eroded materials.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

Clarkson, R.W. & P.C. Marsh. 2010. Effectiveness of the Barrier-and-Renovate Approach to Recovery of Warmwater Native Fishes in the Gila River Basin. In *Proceedings of the Colorado River Basin Science and Resource Management Symposium, November 18-20, 2008, Scottsdale, Arizona*, T.S. Mellis, J.F. Hamill, L.G. Coggins, Jr., P.E. Grams, T.A. Kennedy, D.M. Kubly, & B.E. Ralston (eds.) U.S. Geological Survey Scientific Investigations Report 2010-5135, 372 pp

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Williams' Cage

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ANS Control: Williams' Cage

Targeted Species: This method is effective in controlling the upstream movement of some fish. Specific ANS of Concern – CAWS[1] that may be controlled include the silver carp (*Hypophthalmichthys molitrix)* and the sea lamprey (*Petromyzon marinus).*

Selectivity: This Control was designed to manage some species of fish, but it is non selective. See *Brief Description* and *General Effectiveness* sections for more details.

Williams' Cage is a selective control device used to separate jumping carp from non-jumping fish.

Developer/Manufacturer/Researcher: Researchers and developers include Ivor Stuart, Alan Williams, John McKenzie, and Terry Holt of the Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria, Australia.

Brief Description: The Williams' Cage is a simple device that automatically separates jumping common carp from non-jumping fish. Its use has been experimentally tested under field conditions on common carp (*Cyprinus carpio)* in Australian waterways (Stuart et al. 2006b). According to Stuart et al. (2006a), common carp display an escape behavior of jumping out of the water, which is not exhibited by most Australian native fishes. The idea for the Williams' Cage was developed based on this observation and designed to exploit this unique behavior to aid in selective removal. Of the 3 species of Asian carp, only the silver carp demonstrates leaping behavior, however, it may be possible that attractant flow patterns could be adjusted to lure other species into a Williams' Cage.

Prior Applications: Stuart et al. (2006a) experimentally tested the Williams' Cage in a fishway in the Murray River in Australia.

General Effectiveness: Stuart et al. (2006a) found the Williams' Cage in a fishway (a fish ladder) to be effective at separating adult common carp (88% caught) from non-jumping native fish (99.9% native fish passage). Conversely, a trial of the Williams' Cage in a non-fishway setting produced opposite results, with common carp actively avoiding entering the cage (Stuart et al. 2006b). The authors noted that this avoidance behavior warrants further research for the use of Williams' Cages in riverine settings. It appears that the Williams' Cage would be most effective in a confined setting. Outlets and drains in wetland areas may be effective locations for Williams' Cages because their flows attract many fish species. This technique has not been applied outside of Australia or with species other than common carp.

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Operating Constraints: A Williams' Cage must be operated in flowing water to stop upstream moving fish. Williams' Cages are designed for use in fishways. They would only work in a natural channel or canal if a screen across the channel were used to divert fish into the cage. This screen would be an obstacle to navigation traffic and would require frequent maintenance to remove accumulated debris. A non-automated version of the Williams' Cage would require manual removal of fish from the basket and manual disposal of fish.

Cost Considerations:

Implementation: Implementation costs would include the construction of the barrier or modification of an existing dam to create a sluice for the Williams' Cage. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would involve regular inspections, removal and disposal of fish and debris, and repair of mechanical parts.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

Stuart, I. G., A. Williams, J. McKenzie, & T. Holt. 2006a. Managing a migratory pest species: a selective trap for common carp. *North American Journal of Fisheries Management*, vol. 26, pp. 888-893

Stuart, I. G., A. Williams, J. McKenzie, & T. Holt. 2006b. The Williams' Cage: a key tool for carp management in Murray-Darling Basin fishways. A Final Report on the Williams' Carp Separation Cage to the Murray-Darling Basin Commission, Australia. Project R3018SPD.