The GLMRIS Report

Appendix F - Water Quality Analyses

USACE
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CONTENTS

LIST OF ATTACHMENTS

FIGURES

TABLES

F.1 INTRODUCTION

This Appendix contains the results of two water quality modeling efforts that were conducted for GLMRIS to examine the impacts of hydrologic separation on water resources. The U.S. Army Corps of Engineers (USACE) Chicago District contracted with the United States Geological Survey (USGS) and Marquette University to model the effects of hydrologic separation on water quality in the Chicago Area Waterways System (CAWS). Dr. Charles Melching of Marquette University first developed the DUFLOW model for the CAWS in 2001 for a study led by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). DUFLOW was selected for the GLMRIS project because of its capabilities and the decade of development effort already invested into its analysis of the CAWS. The DUFLOW model simulates Current, Baseline, Future No Project, Future Lakefront Separation, and Future Mid-System Separation scenarios. GLMRIS Baseline conditions refer to 2017, when Thornton and McCook Stage I reservoirs are scheduled to be online. All references to “future” conditions represent 2029, when Thornton and McCook Stage I and II reservoirs are scheduled to be complete and operational.

The USACE Chicago District contracted with USGS and Michigan State University to model the effects of hydrologic separation on water quality in Lake Michigan. The Finite Volume Coastal Ocean Model (FVCOM) utilizes the pollutant loads to Lake Michigan generated by the DUFLOW model as water quality inputs, and subjects them to a hydrodynamic field generated using atmospheric data. The FVCOM simulates five scenarios: Baseline, Continuous release (2017), Continuous release (2029), Episodic release (2017) and Episodic release (2029). In the FVCOM report, the naming conventions differ from the rest of the GLMRIS Report: the “Baseline scenario” refers to current conditions; “Episodic release (2017)” represents the GLMRIS Baseline conditions defined above; “Episodic release (2029)” represents Future Without Project conditions; and “Continuous release (2029)” represents the Mid-System Hydrologic Separation alternative. FVCOM does not consider the Lakefront Hydrologic Separation alternative, because for this alternative, backflows to Lake Michigan would be prevented up to a 0.2% annual chance of exceedance (500-year) storm event.

The Impacts and Mitigation Summary below describes, in brief, the expected water quality impacts of each GLMRIS project alternative and suggests mitigation measures to lessen the impacts. The DUFLOW and FVCOM models were the primary tools used to estimate future water quality impacts, and their results are summarized below for each project alternative. The DUFLOW and FVCOM models simulated the GLMRIS project alternatives with no mitigation measures included. The purpose of the modeling was to approximate the impact of project measures, which would indicate the type and location of mitigation measures necessary to make the project environmentally acceptable. Therefore, the simulation outputs do not represent final conditions for alternatives where water quality mitigation is proposed. If a GLMRIS project is selected for implementation, additional modeling and analysis would be needed to refine the selection and design of measures to mitigate impacts to water quality. This additional modeling and analysis would also be required to provide a complete assessment of project water quality conditions for purposes of a complete NEPA analysis.

F.2 IMPACTS AND MITIGATION SUMMARY

The expected water quality impacts of each GLMRIS project alternative are described below. On the basis of the expected water quality impacts of each alternative, additional project measures are suggested to mitigate adverse effects on water resources. Conceptual designs of mitigation measures are described.

F.2.1 No New Federal Action

Future water quality conditions in the CAWS and Lake Michigan, assuming no GLMRIS project is implemented, are discussed in the Future Without Project Assessments found in Appendix B – the Affected Environment. No mitigation for impacts on water quality is proposed for this alternative.

F.2.2 Nonstructural Control Technologies

The Nonstructural Control Technologies alternative proposes nine approaches to reduce the risk of aquatic nuisance species (ANS) interbasin transfer, including: Education and Outreach; Monitoring; Biocides; Antifouling Materials; Biological Control; Manual/Mechanical Removal; Habitat Alteration; Ballast and Bilge Water Management; and Laws and Regulations. The majority of these approaches are expected to have negligible impact on water quality in the CAWS and Lake Michigan. The Biocides approach suggests application of lethal chemicals directly to the ANS in confined locations and for discrete time periods. The Habitat Alteration approach suggests applying chemical compounds such as carbon dioxide (CO_2), ozone, nitrogen, alum, and sodium thiosulfate to the aquatic environment to make it less hospitable to target species. These two approaches have potential to impact water quality in the areas and time periods in which they are implemented. Application of chemicals would likely impair the designated uses of the waterways (e.g., Aquatic Life, Fish Consumption, Public Food Processing Water Supplies, Primary Contact Recreation, Secondary Contact Recreation, Indigenous Aquatic Life and Aesthetic Quality) temporarily and locally, however it would not impose a structural or systemic change to the flow direction or operation of the system as a whole. The magnitude of the potential impacts on water quality would depend on the concentration, duration, extent and method of chemical application and would need to be evaluated for each specific activity.

F.2.3 Mid-System Control Technologies without a Buffer Zone

The Mid-System Control Technologies without a Buffer Zone Alternative proposes structural measures, including electric barriers, GLMRIS Locks, and ANS Treatment Plants, to create ANS control points in the Calumet-Sag Channel and the Chicago Sanitary and Ship Canal (CSSC). The normal flow of the CAWS would be diverted from the channel on the lake side of the new locks, through ANS Treatment Plants at each location, and then discharged back to the river side of the new locks. This operation is not expected to change the flow direction or other operations of the Chicago Area Waterway System. Water quantity and quality in the system are expected to be essentially equivalent for the Future With Project and Future Without Project conditions. No mitigation for impacts on water quality is proposed for this alternative.

F.2.4 Technology Alternative with a Buffer Zone

The Technology with a Buffer Zone Alternative utilizes novel technology applications such as the GLMRIS Lock and ANS Treatment Plant to prevent or reduce the risk of ANS interbasin transfer to the maximum extent possible, while still maintaining lock operations for navigation. This Alternative impacts water quality in the CAWS because it precludes the use of untreated Lake Michigan water to ameliorate water quality in the CAWS as is done currently. Absence of Lake Michigan diversion water in the CAWS system would result in low flows, stagnant zones, and low dissolved oxygen concentrations during the summer months.

In addition to their role as an ANS Control measure, proposed ANS Treatment Plants at Wilmette (Illinois), Chicago (Illinois), and T.J. O'Brien (Illinois) would also function to mitigate water quality impacts. The ANS Treatment Plants (ANSTPs) would supply ANS-treated water to the CAWS and allow the discretionary diversion of Lake Michigan water allocated to MWRDGC to continue. With this mitigation, water quantity and quality in the system are expected to be essentially equivalent for the Future With Project and Future Without Project conditions.

F.2.5 Lakefront Hydrologic Separation

F.2.5.1 Impacts on Water Quality—CAWS

The Lakefront Separation project alternative proposes four physical barriers near the lake to stop the flow of water and ANS between watersheds. Water quality modeling described in this appendix was used to evaluate the impacts of the proposed separation. Note that no modeling data are available on water quality in the Little Calumet River, although a barrier is proposed for that river. Additional modeling would be needed to determine water quality impacts related to the Little Calumet River flow changes. This discussion focuses on the Chicago River, Calumet River, and the canal system.

Water quality modeling indicates that stagnant conditions would develop near the dead-end reaches of the system if the proposed barriers were installed at the lakefront. Consequently, the number of hours in noncompliance with the candidate benchmark for dissolved oxygen (DO) in the CAWS is expected to increase above the expected Future Without Project conditions. Numeric water quality standards are either under review or are undefined for several parameters studied in the GLMRIS water quality modeling. As a result of interagency coordination, USEPA and Illinois EPA collaborated to provide candidate benchmarks against which to measure expected future water quality conditions. The suggested candidate benchmarks are provided as an attachment to this appendix.

Figure F.1 illustrates the hours per year that various reaches of the CAWS are expected to be out of compliance with the DO benchmark if no project is implemented, during characteristically dry conditions. Figure F.2 shows the expected hours of non-compliance once the Lakefront Separation barriers are installed. Similarly, Figures F.3 and F.4 illustrate levels of non-compliance with and without the Lakefront Separation barriers, but under "wet" conditions. When compared to Future Without Project conditions, the Lakefront Separation would result in more than 1000 additional hours of noncompliance with the DO benchmark in the Upper North Shore Channel, during dry and average years. In the Chicago River, the Lakefront Separation increases noncompliance by more than 1500 hours in the Chicago River main stem during dry and average years and by 900 hours on the South Branch Chicago River or SBCR (during dry and average years at the upstream end and for all years at the downstream end). Though also stagnant, the Little Calumet River North (LCRN) maintains higher levels of compliance with the DO benchmark under all project alternatives and during all years, compared to the Future Without Project conditions. While DO compliance generally improves during "wet" years, the Lakefront Separation negatively impacts compliance under wet conditions, particularly near Bubbly Creek (South Fork of the South Branch) and in the Upper North Shore Channel.

Figures F.5 and F.6 illustrate the exceedance of the fecal coliform benchmark in the CAWS with and without the Lakefront Separation project, under dry conditions. Similarly, Figures F.7 and F.8 illustrate exceedances of the fecal coliform benchmark in the CAWS with and without the Lakefront Separation, under wet conditions. The model assumes that water reclamation plant (WRP) disinfection is online at the Calumet and O'Brien WRPs and that a 2-log (99%) reduction in bacteria concentrations is achieved. Higher levels of compliance with the bacteria benchmark are achieved in the North Shore Channel and Chicago River under the No-Project alternative because of the discretionary diversion from Lake Michigan. In all other reaches, the No Project and Lakefront Separation alternatives yield similar levels of compliance, largely owing to the dominance of WRP effluent downstream of the plant outfalls.

Figures F.9 and F.10 illustrate the compliance with the chloride benchmark in the CAWS, with and without the Lakefront Separation project, under dry conditions. Figures F.11 and F.12 show the levels of compliance with the chloride benchmark in the system with and without the Lakefront Separation project, under wet conditions. Throughout the Chicago River system and downstream of Stickney WRP, compliance with the chloride benchmark is nearly identical for the No Project and Lakefront Separation alternatives during the wet year. On the Calumet system, the No Project alternative yields substantially higher levels of compliance. This indicates that discretionary diversion and other flows at the O'Brien Lock and Dam positively influence chloride concentrations in the Calumet River system. Chloride compliance is markedly worse during wet years, which is to be expected since stormwater runoff and salt application to snowy roadways are the primary sources of chloride to the system. Naturally, during all years, compliance improves on the lake side of the barriers, since there is no influence from the loads in the CAWS system.

Currently, phosphorus concentrations in the North Shore Channel are dominated by the O'Brien WRP plant effluent, except during the summer months, when the phosphorus and other contaminant loads are substantially diluted by the discretionary diversion from Lake Michigan. The Lakefront Separation scenario prevents the diversion water from entering the CAWS, and phosphorus concentrations in the waterway increase. Outside of the periods when diversions are taken at Wilmette, Chicago River Controlling Works (CRCW), and O'Brien Lock and Dam, the phosphorus concentrations throughout the system are very similar for the With and Without Project conditions, again owing to the dominance of the WRP flows in the system.

F.2.5.2 CAWS Water Quality Results Summary—Lakefront Hydrologic Separation

F.2.5.2.1 CAWS Dissolved-Oxygen Benchmark.

Proposed by Illinois EPA for all reaches except the Chicago Sanitary and Ship Canal (CSSC); the August–February standard applies to the entire year for the CSSC: March–July: 5.0 mg/L at any time; August–February: 4.0 mg/L 7-day average of the daily minima and 3.5 mg/L at any time.

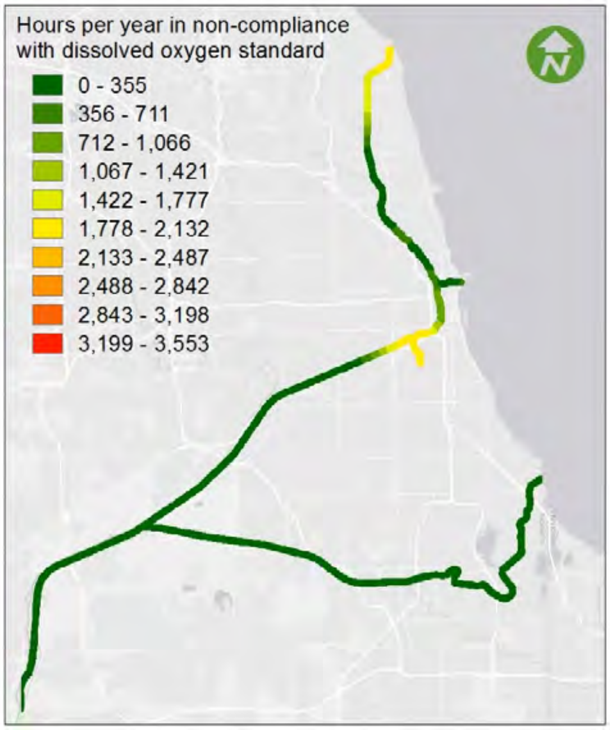

FIGURE F.1 No Project, Dry Year

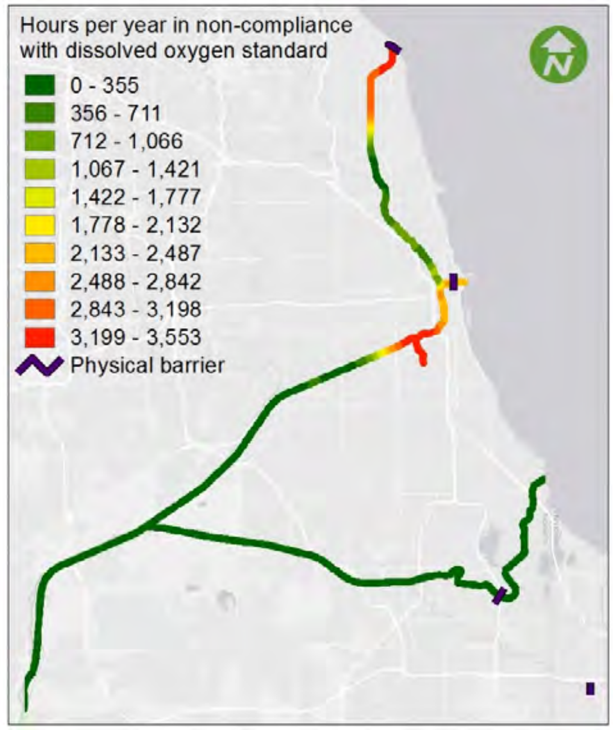

FIGURE F.2 With Project, Dry Year

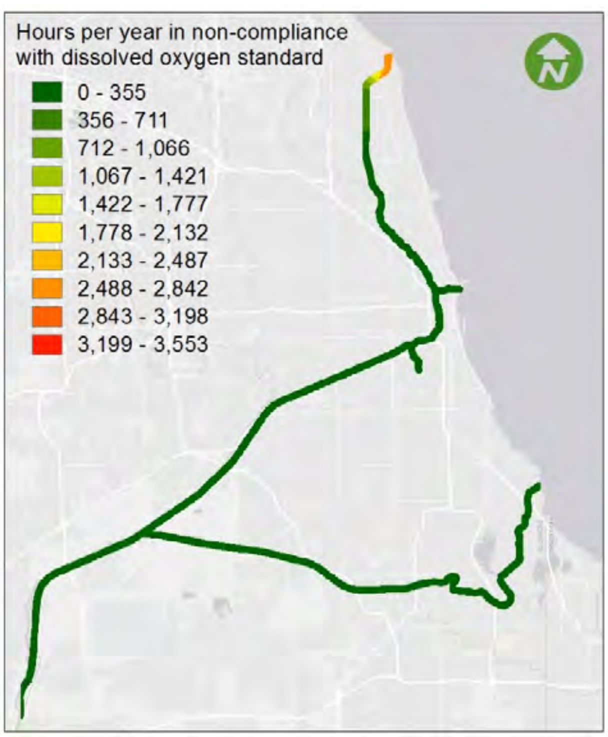

FIGURE F.3 No Project, Wet Year

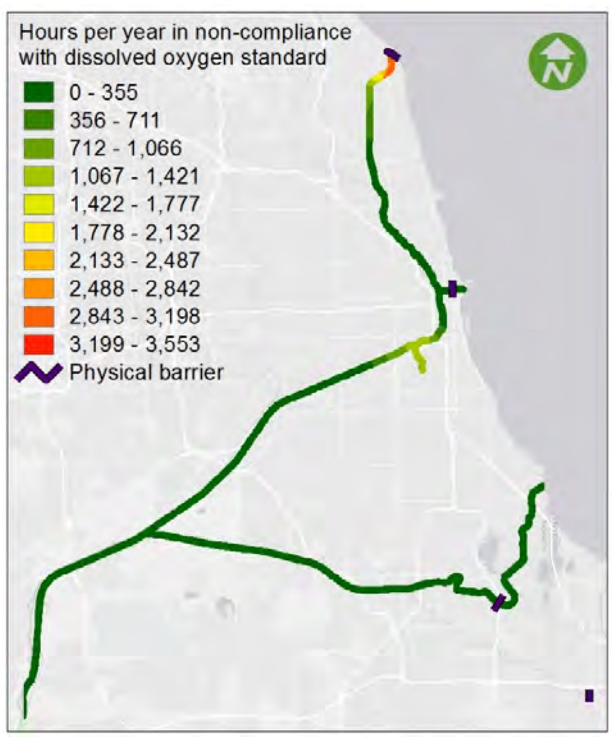

FIGURE F.4 With Project, Wet Year

F.2.5.2.2 CAWS Water Quality Benchmark for Fecal Coliform

Benchmark = 200 CFU per 100 mL (May–October)

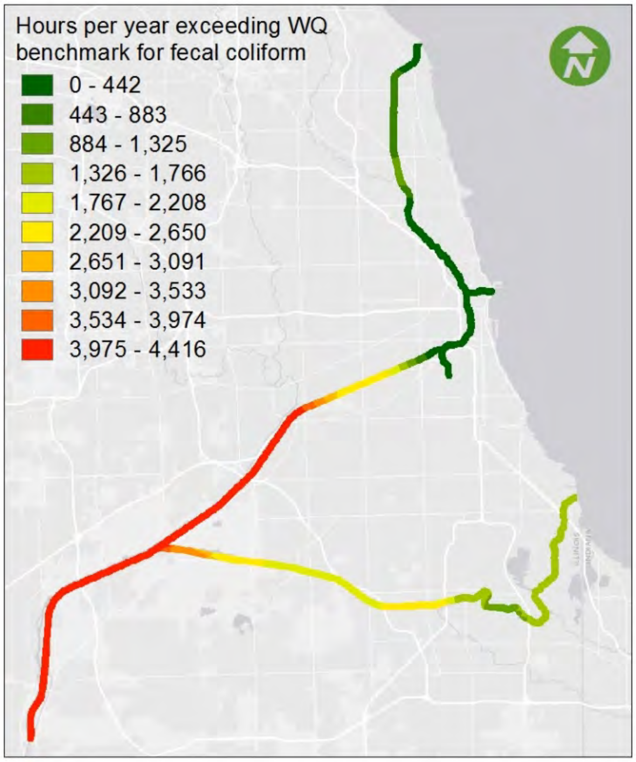

FIGURE F.5 No Project, Dry Year

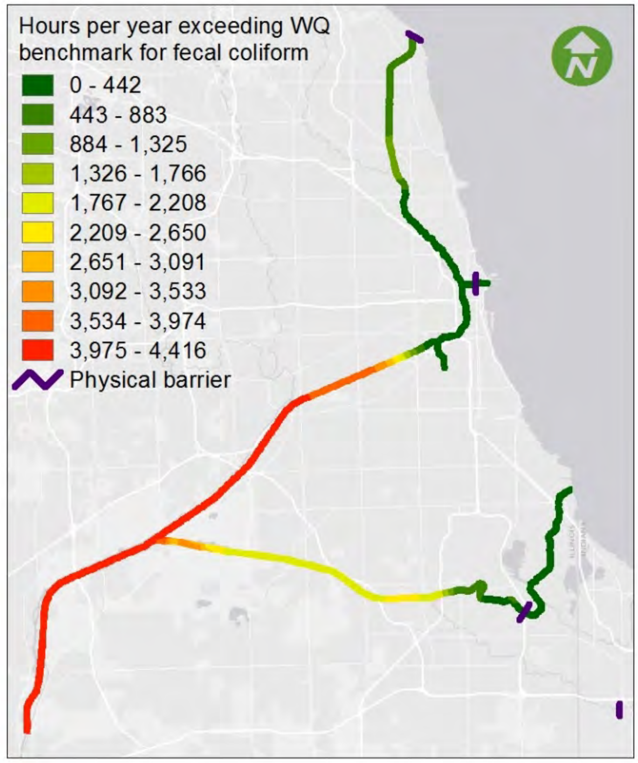

FIGURE F.6 With Project, Dry Year

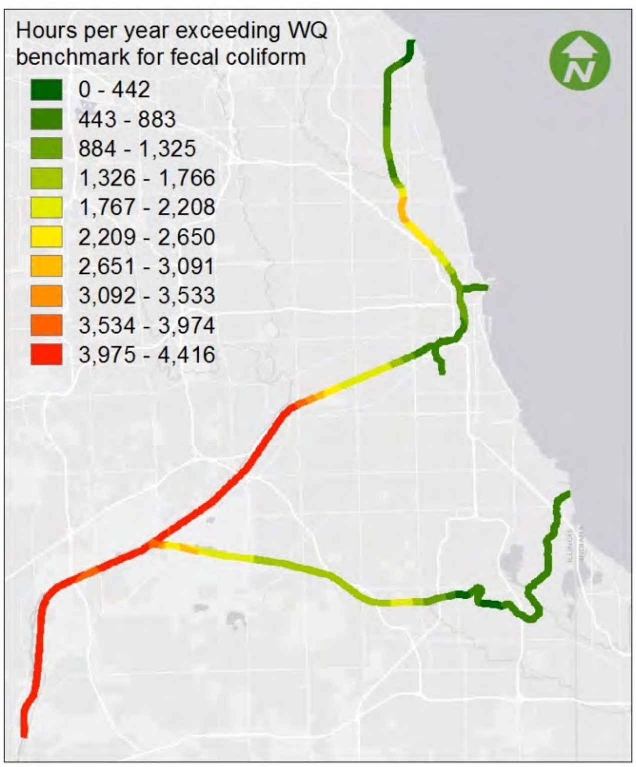

FIGURE F.7 No Project, Wet Year

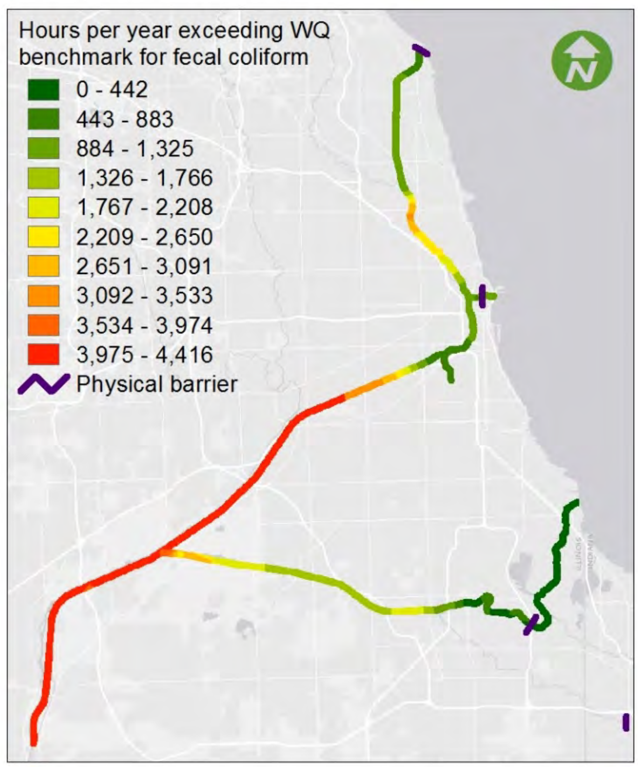

FIGURE F.8 With Project, Wet Year

F.2.5.2.3 CAWS Water Quality Benchmark for Chloride

Benchmark = 230 mg/L.
USEPA recommended Clean Water Act (CWA) 304(a) chronic criteria for aquatic life

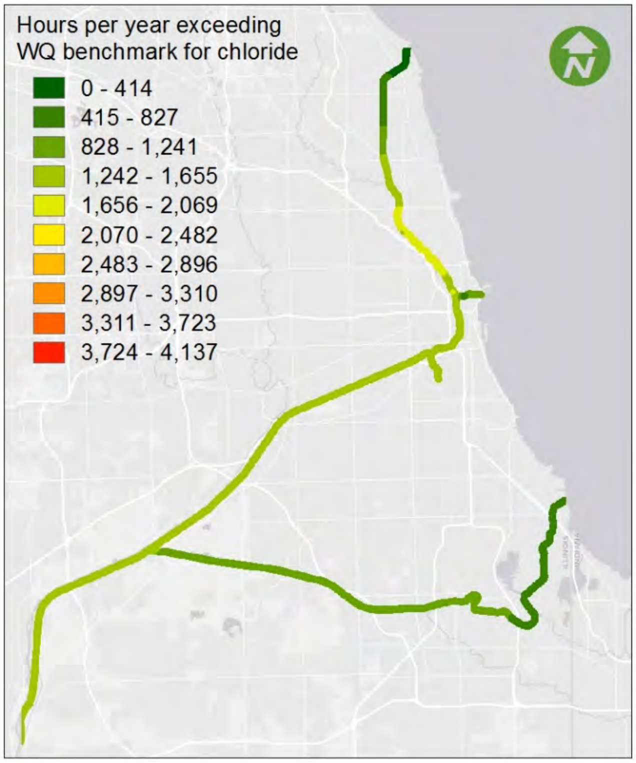

FIGURE F.9 No Project, Dry Year

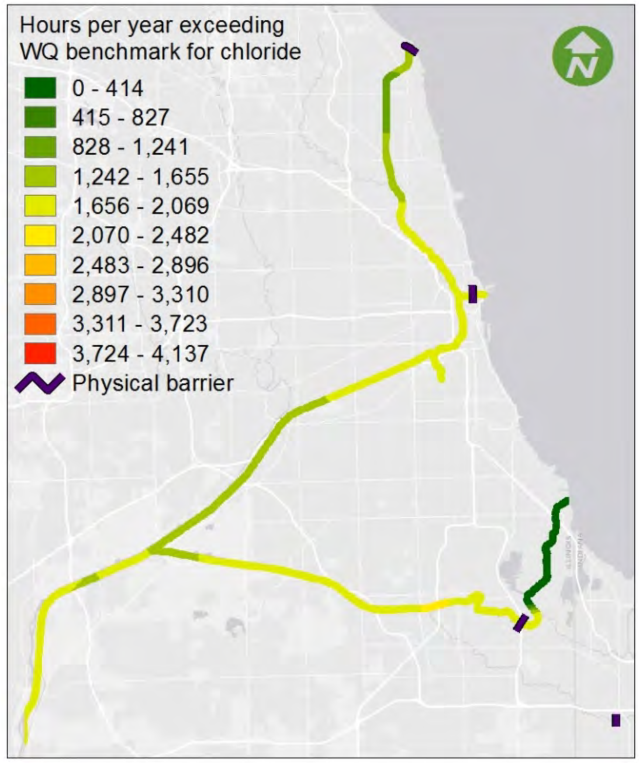

FIGURE F.10. With Project, Dry Year

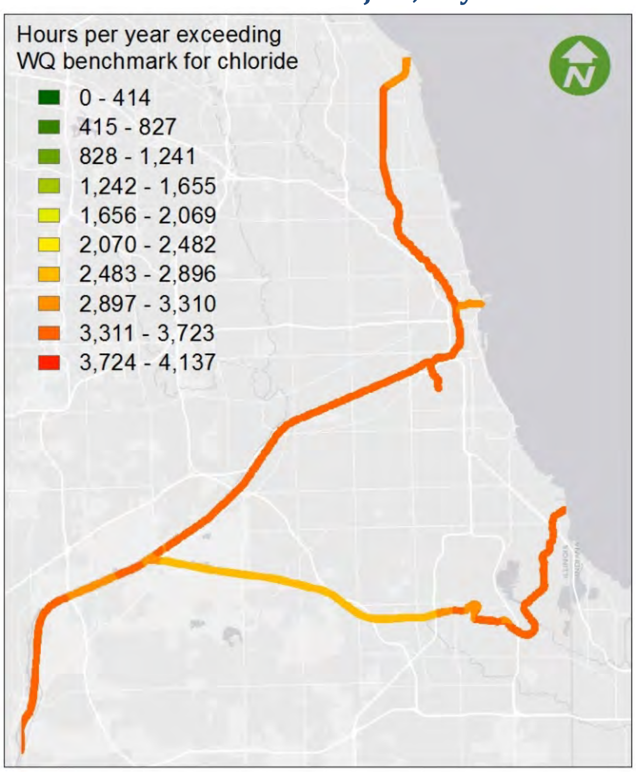

FIGURE F.11 No Project, Wet Year

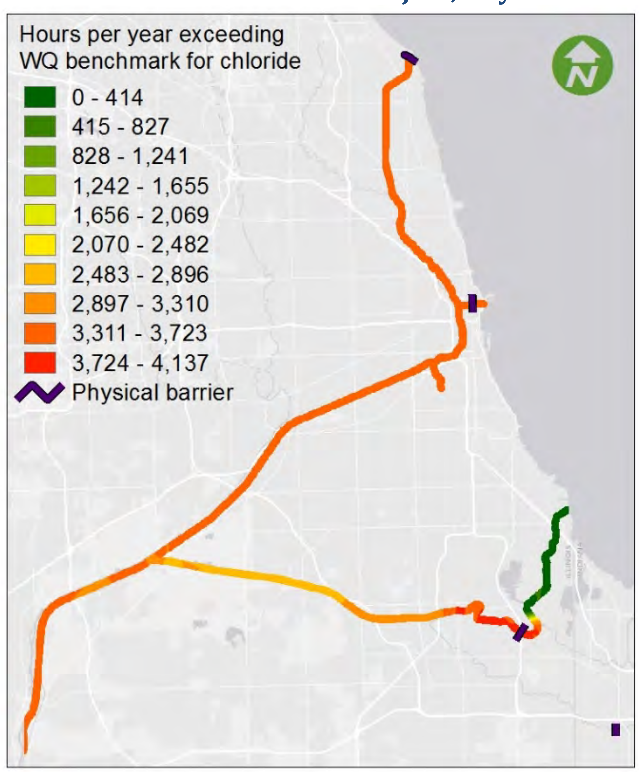

FIGURE F.12 With Project, Wet Year

F.2.5.3 Impacts on Water Quality – Lake Michigan

The Lakefront Separation alternative results in net improvements to water quality in Lake Michigan. Flood Risk Management mitigation measures would capture all backflows from the CAWS to Lake Michigan during large storms up to and including a 0.2% annual chance of exceedance (500-year) event. This mitigation would reduce combined sewage-stormwater backflows to Lake Michigan. Frequency and duration of historical backflow events are described in Appendix E – Hydraulic and Hydrologic Analyses.

F.2.5.4 Mitigation of Impacts to Water Quality

F.2.5.4.1 Flow Augmentation

Flow augmentation is proposed to mitigate conditions of stagnation and oxygen depletion generated by the Lakefront Separation alternative. The addition of highly oxygenated water would improve the low-flow and oxygen-depleted conditions near the separation barriers, and would dilute concentrations of other pollutants. Augmenting stagnant and low flows in the CAWS could be achieved by pumping water from Lake Michigan over the proposed physical barrier and through a treatment process to remove ANS before discharging it to the CAWS. Installation of ANSTPs at the Wilmette, Chicago, and T.J. O'Brien project locations would allow the discretionary diversion of Lake Michigan water currently allocated to MWRDGC to continue and the CAWS hydrology to remain very similar to current conditions. With this mitigation, water quantity and quality are expected to be essentially equivalent for the Future With Project and Future Without Project conditions.

Treatment technology included in the ANSTPs for this alternative would include screening and ultraviolet (UV) radiation to remove or deactivate high- and medium-risk GLMRIS ANS of concern and their various life stages currently found in the Great Lakes Basin. In the first treatment step, self-cleaning screens would exclude ANS and other organic matter greater than 0.75 in. (19.05 mm) in size. For proposed ANSTPs near Lake Michigan, UV treatment is the second and final recommended treatment step. UV radiation is expected to inactivate organisms entrained in Lake Michigan water that pass through the 0.75-in. screens. UV light inactivates organisms by damaging their nucleic acids, thereby preventing reproduction. The response to UV light can vary widely between organisms. The UV dose-response relationships for each of the target species would require future study in order to develop an effective design.

UV treatment performance is affected by water clarity, as suspended particles can shade and encase target species and prevent the UV light from reaching them. Transmittance of UV light can also be inhibited by some dissolved constituents, such as iron, nitrate, and natural organic matter. On the basis of water quality data collected by MWRDGC between 2007 and 2011, screening combined with UV treatment is expected to be an effective process for ANSTPs located very close to Lake Michigan, where turbidity and other possible UV interferences are minimal. UV radiation is a well-established technology for disinfecting drinking water and domestic wastewater. It effectively inactivates bacteria, viruses, protozoa and spores; however, different strains of bacteria and viruses react differently to UV because of variations in DNA content and in how that DNA absorbs UV light. Limited literature is available on the effect of UV treatment on some GLMRIS target species, as discussed in Appendix C – Risk Assessment. Site-specific dose-response tests would be required in the future to determine the UV dose necessary to inactivate target species.

The ANSTPs were sized to treat the maximum daily diversion from Lake Michigan to the CAWS. Lake Michigan Diversion Accounting (LMDA) data from 2007 to 2012 were utilized to identify the maximum diversion flows taken at Wilmette Pumping Station, Chicago Lock, and O'Brien Lock and Dam over this time period. A seven-day moving average of daily diversion volumes was calculated and the maximum daily flow was selected after the elimination of a few outlying data points. It is estimated that ANSTPs with capacities of 200 MGD, 450 MGD, and 450 MGD would be sufficient to treat the discretionary diversion from Lake Michigan at Wilmette (Illinois), Chicago (Illinois) and Calumet City (Illinois), respectively. On the basis of the size of existing facilities owned and operated by MWRDGC, these three plants would require approximately 0.7 acre, 1.5 acres, and 1.5 acres of land, respectively.

F.2.5.4.2 Additional Water Treatment

As described in Appendix D, the Lakefront Hydrologic Separation alternative is expected to result in increased flood risk to the Chicago metropolitan area. To mitigate these anticipated flood impacts and prevent backflows to Lake Michigan, new reservoirs are proposed in McCook, Illinois, and Thornton, Illinois. The new reservoirs are sized to capture and store stormwater up to a 500-year (0.2% probability) event, until it can be treated and discharged back into the CAWS. Expansion of existing wastewater treatment facilities may be necessary to treat this additional stormwater volume in a reasonable time frame. The average annual additional treatment volume is estimated below.

The average annual treatment volume was computed as follows:

0.002 * Qb500
(0.01 - 0.002) * [0.5*(Qb500 + Qb100)]
(0.02 - 0.01 -0.002) * [0.5*(Qb100 + Qb50)]
(0.04 - 0.02 - 0.01 -0.002) * [0.5*(Qb50 + Qb25)]
(0.1 - 0.04 - 0.02 - 0.01 -0.002) * [0.5*(Qb25 + Qb10)],

where Qb500 represents the backflow volume for a 500-year event, Qb10 is the backflow volume for a10-year event, etc. Since the probability is cumulative "exceedance," the probability density was computed as shown in the parentheses above.

Additional treatments required at existing treatment facilities are as follows:

Wilmette	56.8 acre-feet (to Stickney WRP)
Chicago	74.1 acre-feet (to Stickney WRP)
O'Brien	310.5 acre-feet (to Calumet WRP)
Hart Ditch	766.6 acre-feet (to Calumet WRP)
Total	1,208.0 acre-feet

The estimated additional annual treatment volume at Stickney WRP is

(56.8 + 74.1) acre-feet = 42.65 MG

The estimated additional annual treatment volume at Calumet WRP is

(766.6 + 310.5) acre-feet = 350.97 MG

F.2.5.4.3 Variations in Mitigation Strategy

In addition to flow augmentation, there are other possibilities for mitigating stagnant and low-oxygen conditions expected with this project alternative, including recirculation, aeration, or combined sewer overflow (CSO) control.

Recirculation. A 2007 study conducted for MWRDGC examined recirculating up to 450 MGD of O'Brien WRP effluent to the headwaters of the North Shore Channel to improve compliance with the DO standard. The study found that water quality standards could be achieved by aerating 100 MGD of the O'Brien WRP effluent to saturation DO and relocating the plant outfall from its current location to the headwaters of the North Shore Channel (NSC) in Wilmette (CTE/AECOM 2007). A similar approach could be used to stimulate flow near the proposed separation barrier at Wilmette, where waters are expected to be stagnant after installation of the barriers. On the Little Calumet River, effluent from the Calumet WRP could be used to stimulate flow on either or both sides of the barriers. Future analysis would be required to determine the efficacy of recirculation strategies for mitigating water quality impacts resulting from hydrologic separation at the lakefront. The scope of the MWRDGC study was limited to the North Shore Channel and did not consider hydrologic separation conditions or operation of the Tunnel and Reservoir Plan (TARP) reservoirs. Recirculation to add oxygen to the system would not address other expected water quality impacts, such as increases in chloride and bacteria concentrations.

Aeration. MWRDGC currently operates instream and sidestream elevated-pool aeration stations in the CAWS to improve compliance with DO standards. Additional studies could examine whether operating the existing aeration stations more frequently or adding additional aeration stations would be effective in lieu of or in conjunction with other mitigation measures to boost oxygen concentrations in the system. Again, aeration systems would be expected to mitigate low DO levels resulting from the separation barriers, but would not address the increased exceedances of water quality benchmarks for other parameters.

CSO Control. Water quality modeling indicates that during dry weather, the dead-end river reaches on the CAWS are stagnant. When storm events cause combined sewage-stormwater to enter these stagnant reaches, poor water quality would persist, owing to lack of flow to flush the system. Eliminating CSOs, by either expanding storage and/or treatment, may reduce the quantity of flow augmentation necessary to maintain compliance with water quality standards.

F.2.6 Mid-System Hydrologic Separation

F.2.6.1 Impacts on Water Quality—CAWS

The Mid-System Hydrologic Separation alternative proposes one physical barrier on the CSSC and another on the Cal-Sag Channel in order to stop the flow of water and ANS between watersheds. Under current conditions, the CAWS drains downstream to the Illinois River system. The Mid-System Hydrologic Separation would interrupt the current flow pattern and instead, all the discharges on the North Shore Channel, the Chicago River system, the Calumet River system and their tributaries would drain to Lake Michigan.

The Mid-System Separation also presents significant threats to water quality on the river-side of the barriers. Water quality modeling (DUFLOW) indicates that the SBCR, north end of the CSSC, and Cal-Sag Channel would become stagnant waterways owing to the physical blockage of flows by the barriers. Numeric water quality standards are either under review or are undefined for several parameters studied in the GLMRIS water quality modeling. As a result of interagency coordination, USEPA and Illinois EPA collaborated to provide candidate benchmarks against which to measure expected future water quality conditions. The suggested candidate benchmarks are provided as an attachment to this appendix.

Figure F.13 shows the hours per year that various reaches of the CAWS are out of compliance with the candidate benchmark for DO in the CAWS, during characteristically dry conditions. Figure F.14 shows the expected hours of non-compliance with the Mid-System Separation barriers installed. Similarly, Figures F.15 and F.16 illustrate levels of non-compliance with and without the Mid-System Separation barriers, but under wet conditions. When compared to Future Without Project conditions, DO compliance on the upper North Shore Channel would improve by up to 950 hours per year as a result of the Mid-System Separation barrier, because the barrier directs approximately a third of the O'Brien WRP effluent north directly toward Lake Michigan, while the remainder of the flow would follow the Chicago River south, as it does under current conditions. Small improvements in compliance would also be seen near Bubbly Creek and on the Little Calumet River. However, the Mid-System Separation would result in up to 1,000 additional hours of noncompliance with the DO benchmark in the Lower North Branch Chicago River (NBCR) and more than 1,000 additional hours on the stagnant SBCR, northern CSSC, and Cal-Sag Channel.

Figures 17 and 18 illustrate exceedance of the fecal coliform benchmark in the CAWS with and without the Mid-System Separation project, under dry conditions. Figures F.19 and F.20 show the exceedance of the fecal coliform benchmark in the CAWS with and without the Mid-System Separation, under wet conditions. The model assumes that WRP disinfection is online at the Calumet and O'Brien WRPs and that a 2-log (99%) reduction in bacteria concentrations is achieved. In the North Shore Channel and NBCR, the No Project alternative achieves higher levels of compliance with the bacteria benchmark than the Mid-System Separation scenario, because the discretionary diversion from Lake Michigan is available to dilute the WRP effluent and flush it downstream. On the CSSC, the Mid-System Separation barrier directs all Stickney WRP effluent downstream towards Lockport. This causes compliance with the fecal coliform benchmark to improve in the upper CSSC and SBCR, on the lake side of the barrier. The separation barrier on the Cal-Sag Channel creates a stagnant zone on either side of the physical barrier. On the east side of the barrier, compliance with the fecal coliform benchmark declines because the Calumet WRP effluent and CSOs are confined to this reach. At the west end of the Cal-Sag Channel, the fecal coliform concentrations are dominated by those in the CSSC. However, in the middle sections of the Cal-Sag Channel, the Mid-System Separation alternative shows higher levels of compliance with the benchmark, consistent with the low loads of fecal coliform bacteria in these reaches.

Figures F.21 and F.22 illustrate the compliance with the chloride benchmark in the CAWS with and without the Mid-System Separation project, under dry conditions. Figures F.23 and F.24 show the exceedances of the chloride benchmark in the system with and without the Mid-System Separation, under wet conditions. In the upper North Shore Channel, the Mid-System Separation alternative yields similar levels of compliance as for the other two alternatives. However, the Mid-System Separation alternative results in lower levels of compliance on the NBCR, Chicago River main stem, and the stagnant SBCR and northern CSSC. Among the three study years, the wet year yielded the lowest levels of compliance with the chloride benchmark for nearly all the alternatives and locations in the Chicago River system. On the Calumet River system, the Mid-System Separation alternative yields by far the best compliance with the chloride benchmark. For this alternative for the dry and wet years shown in Figures F.22 and F.24, respectively, but not in the average year, the entire stagnant Cal-Sag Channel fully complies with the chloride benchmark except for the far downstream end, which is influenced by conditions in the CSSC. For the Little Calumet River, substantially lower levels of noncompliance also result for the Mid-System Separation alternative compared to No Project.

In general, phosphorus concentrations in the CAWS are governed by the presence of WRP effluent and the diversion water from Lake Michigan, which dilutes it. Currently, phosphorus concentrations in the North Shore Channel are dominated by the O'Brien WRP plant effluent, except during the summer months, when the phosphorus and other contaminant loads are substantially diluted by the discretionary diversion from Lake Michigan. Under the Mid-System Separation alternative, the North Shore Channel would carry O'Brien WRP effluent to Lake Michigan and phosphorus concentrations in the Upper North Shore Channel would increase in comparison to the No Project scenario. In the Lower North Shore Channel and NBCR, south of the O'Brien WRP, the phosphorus concentrations are similar to the No

Project conditions in the months with no discretionary diversion. Similarly, on the Chicago River main stem, phosphorus concentrations are similar for the No Project and Mid-System Separation scenarios during months with no diversion. On the CSSC, downstream of the Stickney WRP, phosphorus concentrations are completely dominated by the Stickney WRP effluent, as would be expected. On the Calumet River system, the phosphorus concentrations in the Cal-Sag Channel for the Mid-System Separation reflect the phosphorus concentrations in Stony Creek and Tinley Creek, which discharge to the otherwise stagnant reaches on either side of the barrier. The phosphorus concentrations at the downstream end of the stagnant Cal-Sag Channel reflect the influence of the Stickney WRP effluent.

F.2.6.2 DUFLOW Water Quality Results Summary – Mid-System Separation

F.2.6.2.1 CAWS Dissolved-Oxygen Benchmark.

Proposed by Illinois EPA for all reaches except the CSSC; the August–February standard applies to the entire year for the CSSC: March–July: 5.0 mg/L at any time; August–February: 4.0 mg/L 7-day average of the daily minima and 3.5 mg/L at any time.

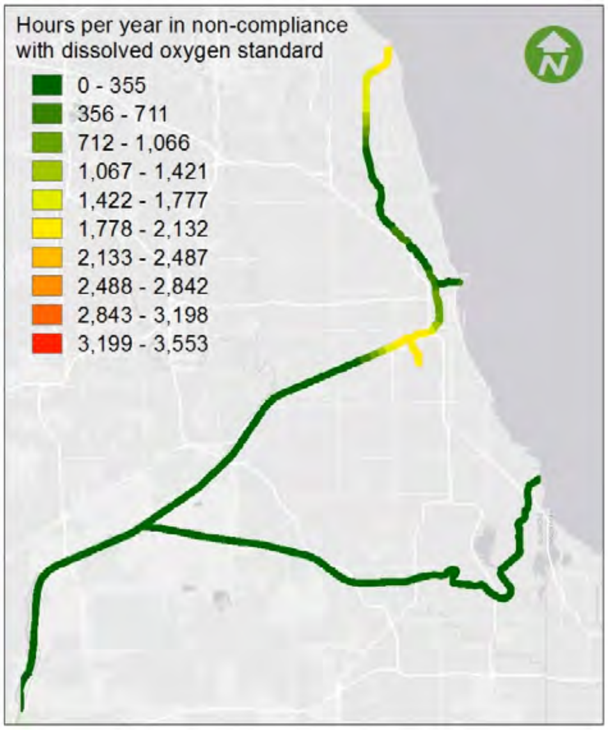

FIGURE F.13 No Project, Dry Year

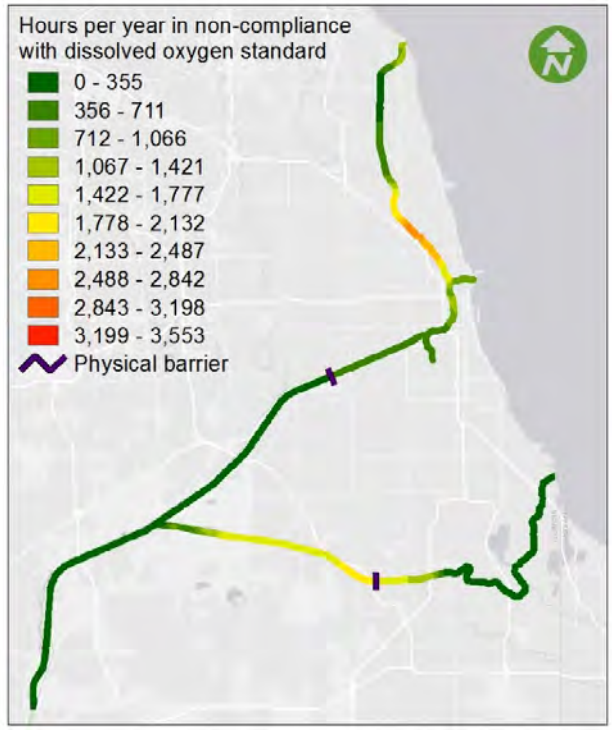

FIGURE F.14 With Project, Dry Year

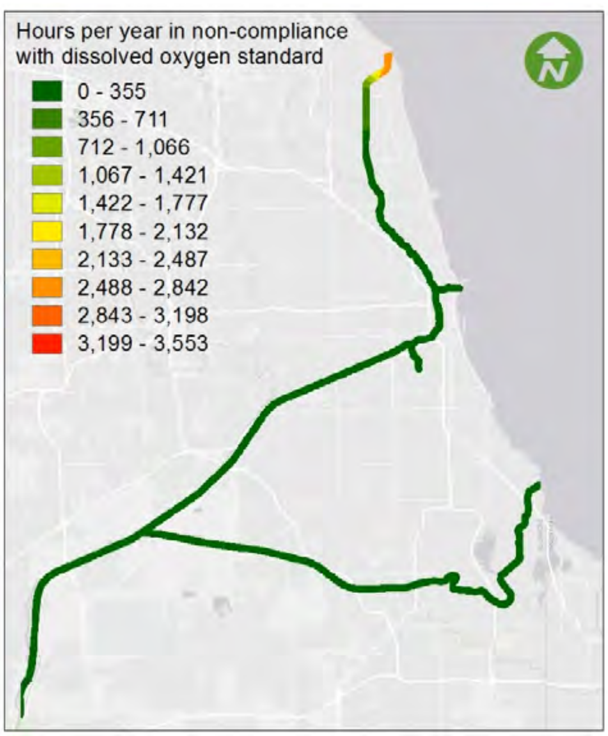

FIGURE F.15 No Project, Wet Year

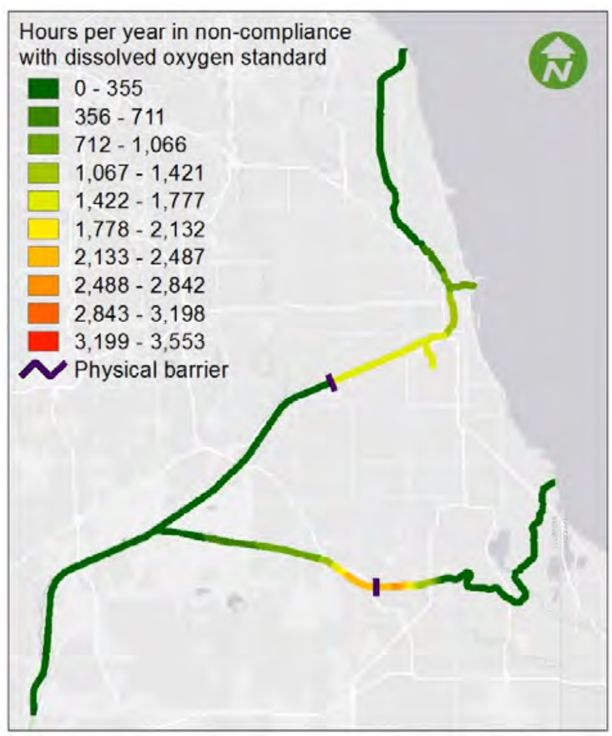

FIGURE F.16 With Project, Wet Year

2.6.2.2 CAWS Water Quality Benchmark for Fecal Coliform

Benchmark = 200 CFU per 100 mL (May–October).

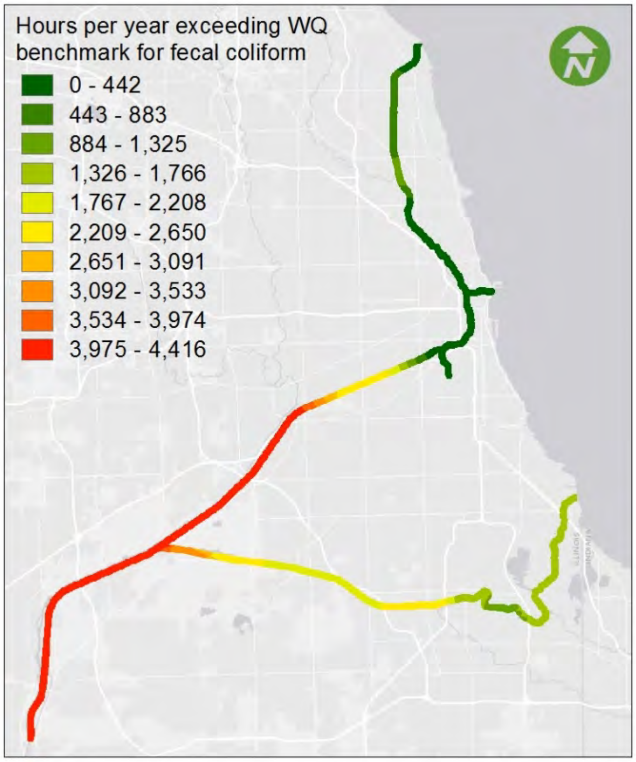

FIGURE F.17 No Project, Dry Year

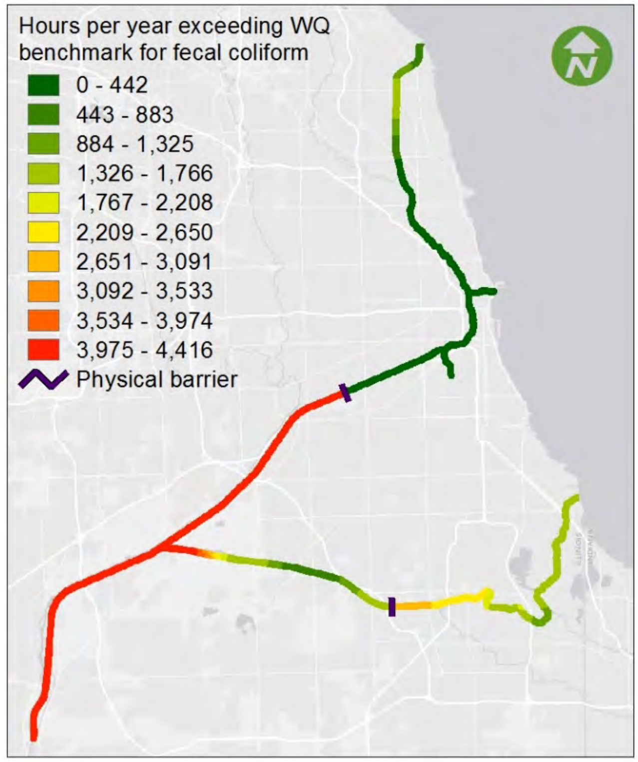

FIGURE F.18 With Project, Dry Year

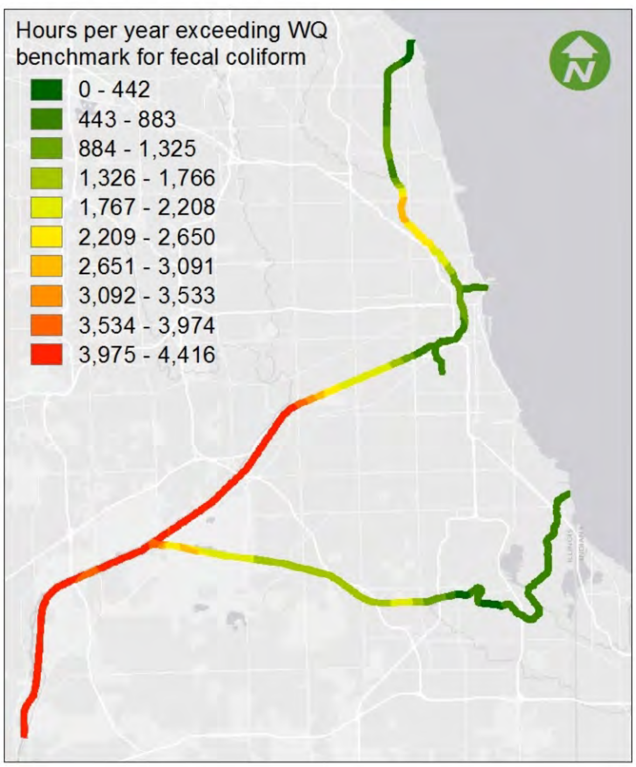

FIGURE F.19 No Project, Wet Year

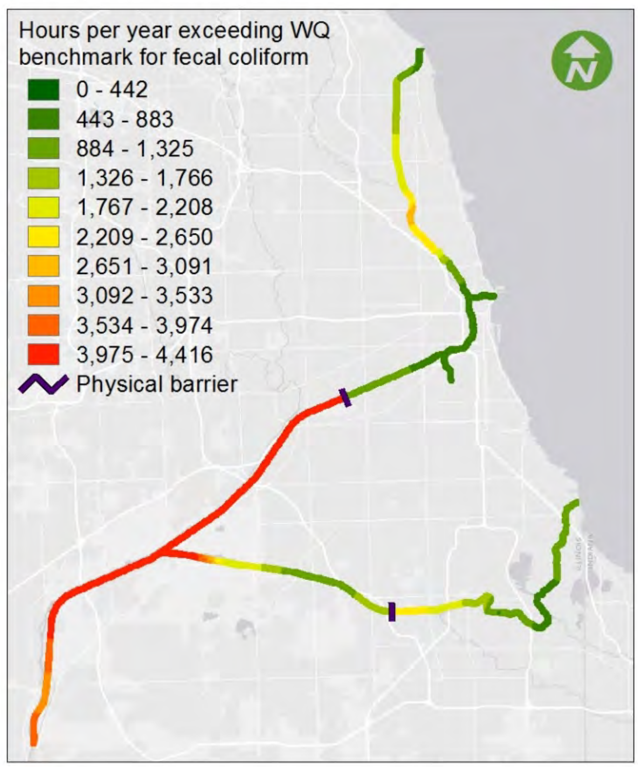

FIGURE F.20 With Project, Wet Year

F.2.6.2.3 CAWS Water Quality Benchmark for Chloride

Benchmark = 230 mg/L.
USEPA recommended CWA 304(a) chronic criteria for aquatic life.

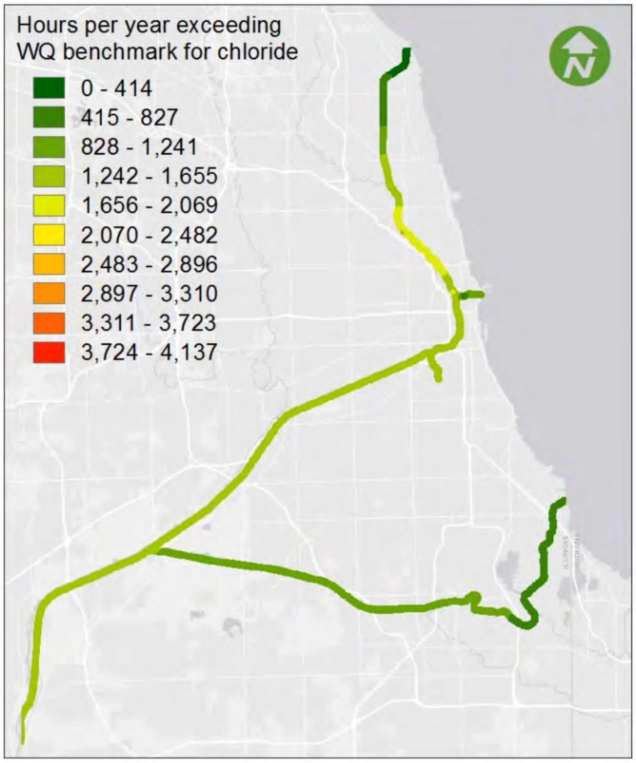

FIGURE F.21 No Project, Dry Year

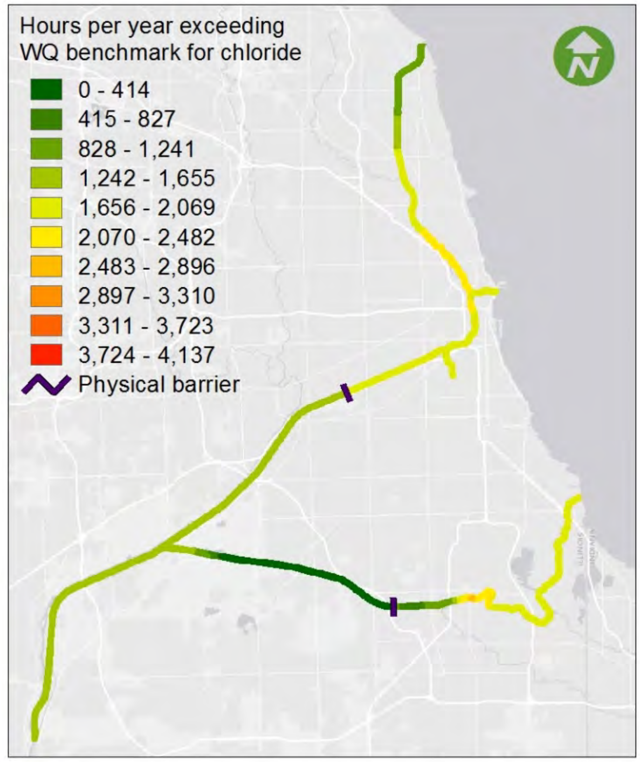

FIGURE F.22 With Project, Dry Year

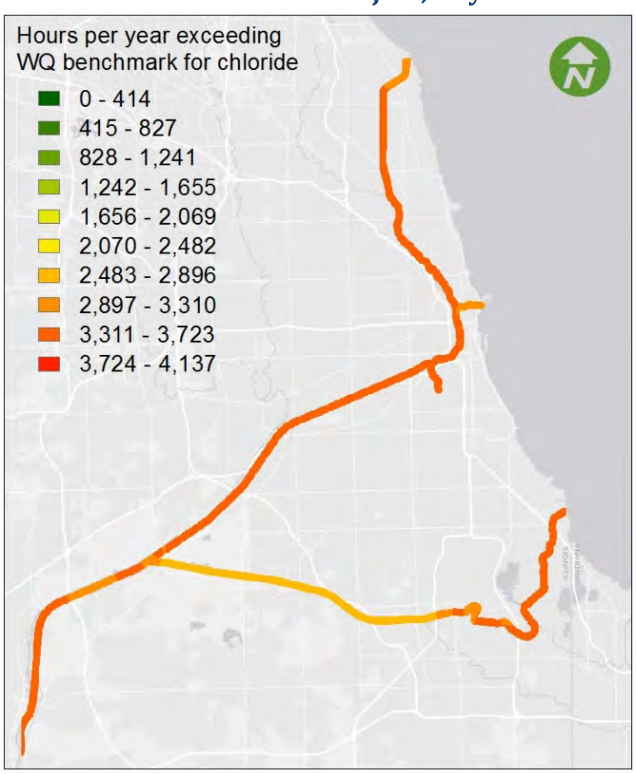

FIGURE F.23 No Project, Wet Year

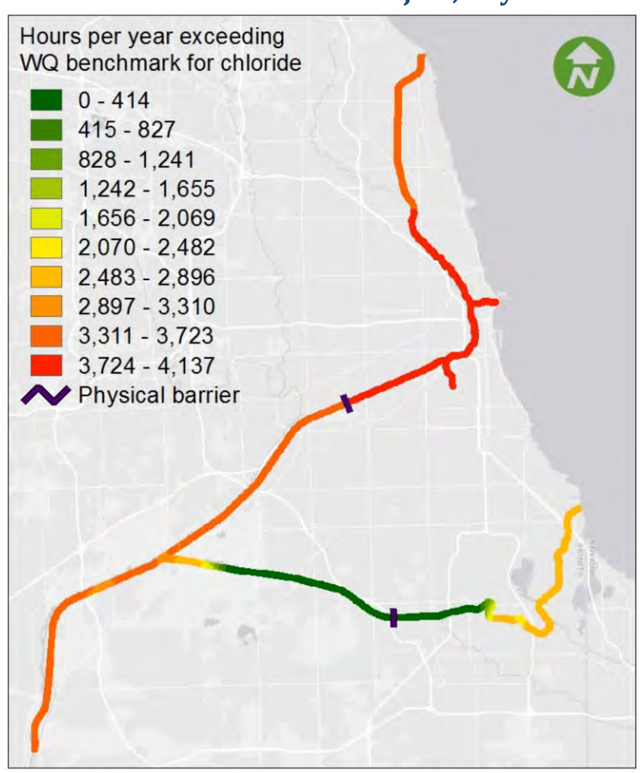

FIGURE F.24 With Project, Wet Year

F.2.6.3 Impacts on Water Quality – Lake Michigan

The most significant impacts of the Mid-System Separation alternative are the short-term and cumulative contaminant loads directed to Lake Michigan. As a result of the Mid-System Separation alternative, treated effluent from the O'Brien and Calumet WRPs, hundreds of combined sewer overflows, dozens of storm sewer flows, and effluent from five CSO pumping stations would all be directed toward Lake Michigan on a continuous basis. Urban storm runoff and contaminated sediment, while not assessed by the models, would also contribute to the water quality impacts of this project alternative on Lake Michigan.

The DUFLOW model estimated the loads of biochemical oxygen demand (CBOD), DO, organic nitrogen, ammonia nitrogen, nitrate, total phosphorus, total suspended solids, chloride, and fecal coliform bacteria discharged to Lake Michigan for the Mid-System Hydrologic Separation and No Project alternatives, summarized below in TABLE F1. If implemented, the Mid-System Separation alternative could produce nitrogen, phosphorus, and chloride loads in Lake Michigan that are, respectively, more than 8,500, 1,100, and 270,000 MTA higher than for the No Project condition. Such loads, year after year, would have substantial cumulative undesirable effects on Lake Michigan.

The degradation of nearshore environments by anthropogenic substances is already a pervasive national issue. Over-enrichment of nutrients, primarily phosphorus and nitrogen, results in planktonic nuisance algal blooms, toxic algal blooms, nuisance benthic algae, and hypoxia. These factors result in economic and social impacts on beaches, recreation, and tourism, recreational and commercial fisheries, and drinking water; and they degrade habitats and food chains. In the 1970s, significant efforts to reverse the eutrophication of the Great Lakes were undertaken and total phosphorus loading targets were developed for each of the Great Lakes as part of the Great Lakes Water Quality Agreement (GLWQA). Lake Michigan has met the phosphorus loading target of 5,600 MTA since the early 1990s (Dolan and Chapra 2012). The Mid-System Separation alternative would reverse much of the progress achieved by the GLWQA toward reducing total phosphorus loads. To illustrate the impact, FIGURE F25 shows phosphorus loads expected to result from the GLMRIS Mid-System Hydrologic Separation alternative in comparison to the loads delivered from each of the major tributaries to Lake Michigan in 2008.

Increased loads of chloride, bacteria, and other contaminants in Lake Michigan may also cause adverse impacts on aquatic life, recreation and other beneficial uses. Additional modeling was conducted to evaluate the short-term impacts of the continuous release of contaminants that would result from installation of Hydrologic Separation barriers at Stickney (Illinois) and Alsip (Illinois).

TABLE F.1 Annual Contaminant Loads to Lake Michigan – Mid-System Separation

	No project	Mid-System Separation		
Constituent	Water Year (WY) 2008	WY 2001 (avg flow)	WY 2003 (dry year)	WY 2008 (wet year)
Volume (acre-ft)	14,200	884,000	745,000	1,050,000
CBOD (MTA)	230	2,503	1,711	3,030
Total Nitrogen (MTA)	110	6,543	5,800	8,754
Total Phosphorus (MTA)	17	908	756	1,161
Total Suspended Solids (MTA)	571	10,010	6,410	15,780
Chloride (MTA)	1,719	202,300	150,800	288,900
Fecal Coliform (CFU)	2.00×10^{16}	3.84×10^{16}	0.614×10^{16}	13.1×10^{16}

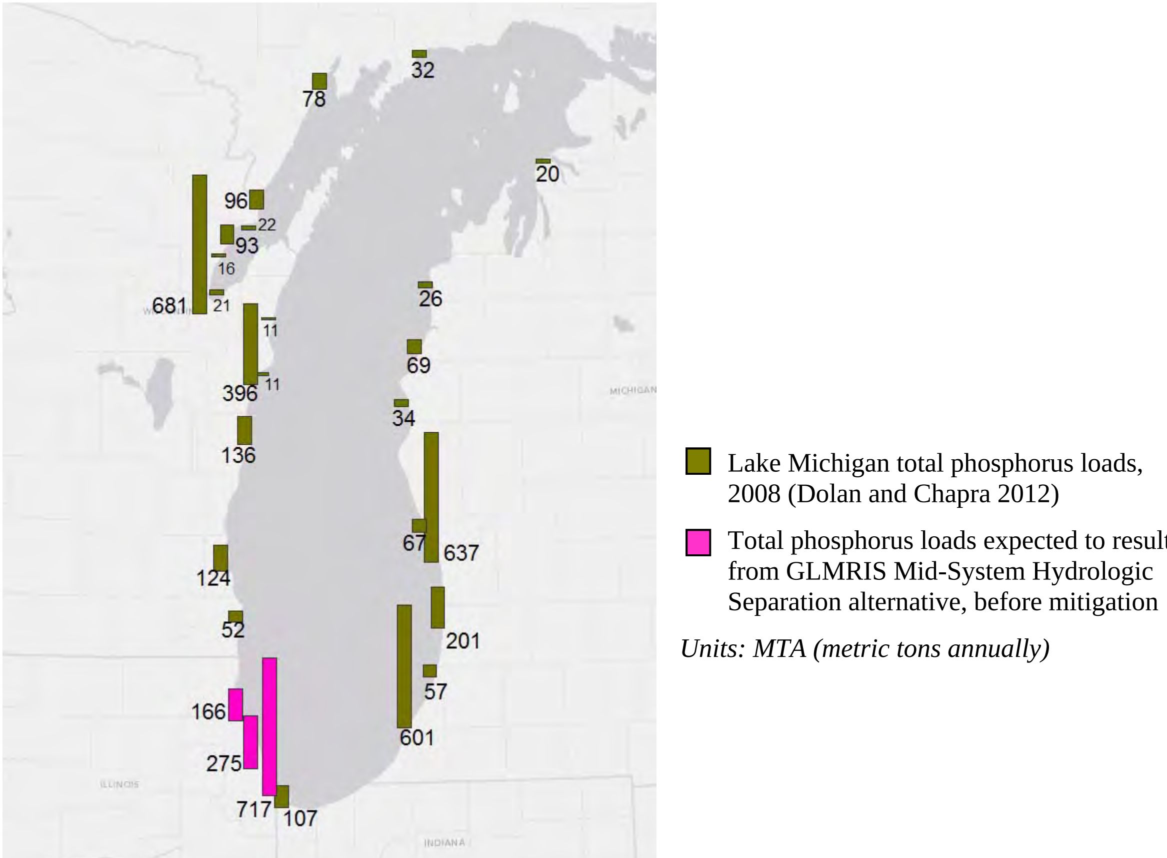

FIGURE F.25 Lake Michigan Tributary Phosphorus Loads (2008)

FVCOM was used to examine the immediate changes to water quality in the near-shore region of Lake Michigan as a result of hydrologic separation. The pollutant loads in Lake Michigan generated by the DUFLOW model were used as water quality inputs to FVCOM, where they were subjected to a hydrodynamic field generated using atmospheric data. Particular emphasis was given to the resulting concentration of water quality constituents near the drinking water intake structures in Lake Michigan. The attached FVCOM report illustrates the simulated concentrations of DO, biochemical oxygen demand, total phosphorus, nitrate, ammonia, phytoplankton, fecal coliform, and chloride near the water intakes for Future Without Project and Future With Project (Scenario 3) conditions.

The Future Without Project (Scenario 5) simulation ran from September 11 to October 11, 2008, a period during which there was a large storm event that resulted in backflows from the CAWS to Lake Michigan. This is the only episode in 2008 during which there were CAWS backflows to Lake Michigan at the lakefront control structures. Under current and expected Future Without Project conditions, backflows take place less than once per year, on average. Under the Mid-System Hydrologic Separation alternative (Scenario 3), there would be a continuous release of contaminants to Lake Michigan; therefore, the Scenario 3 simulation was run for a 9-month period using 2008 meteorological and water quality data.

Figures 3.25 through 3.74 of the attached report illustrate the pollutant concentrations at the water intakes for each of the scenarios. The Scenario 5 simulation of the September 2008 storm event indicated that candidate water quality benchmarks for total phosphorus, fecal indicator bacteria, chloride and DO were exceeded at the water intakes studied. Concentrations of chloride and phosphorus commonly exceed existing water quality benchmarks during non-backflow conditions. However, when there is loading of Lake Michigan from the CAWS, these exceedances can be quite dramatic. After an episodic release, the contaminant concentrations subsided to background levels in seven to ten days. Simulation results for Scenario 3, illustrated by Figures 3.45 through 3.54, indicated that chloride, nitrate, phosphorus, and bacteria benchmarks would regularly be exceeded if a Mid-System Hydrologic Separation alternative were implemented.

Elevated concentrations of nitrate in drinking water have been shown to cause adverse human health effects; however, the FVCOM simulations show that the nitrate concentrations at the drinking water intakes fall well below the USEPA's maximum contaminant level of 10 mg/L (U.S. EPA 2013). While risk for acute health effects appears to be low, the implications of these loads for the Great Lakes system are many. Nutrient inputs into the nearshore environment significantly increase the primary production and algal biomass production in the water column. Bacterial loads in the nearshore environment may impact swimming and other recreation at city beaches. Chloride and ammonia in high concentrations are toxic to aquatic life.

Extensive mitigation of water quality impacts would be required in order for the Mid-system Separation alternative to approach environmental acceptability and regulatory compliance. Furthermore, there may be impacts on water quality resulting from this project alternative for which there is no effective mitigation or for which effective mitigation would be prohibitively costly.

F.2.6.4 Mitigation for Impacts on Water Quality

To mitigate the water quality impacts of the Mid-System Hydrologic Separation alternative, the following measures are proposed: flow augmentation (including treatment facilities to remove ANS from Lake Michigan diversion water); tunnels to discharge wastewater treatment plant effluent to the river side of the separation barriers; tunnels and reservoirs to capture combined sewer overflows; sediment remediation; and aggressive stormwater management improvements.

F.2.6.4.1 Flow Augmentation

Flow augmentation is proposed to mitigate conditions of stagnation and oxygen depletion generated by the Mid-System Hydrologic Separation alternative. The addition of highly oxygenated water would improve the low-flow and oxygen-depleted conditions near the separation barriers, and would dilute concentrations of other pollutants. Augmenting stagnant and low flows in the CAWS could be achieved by pumping water from Lake Michigan over the proposed physical barrier and through a treatment process to remove ANS before discharging to the CAWS. Installation of ANSTPs near the Stickney, Illinois, and Alsip, Illinois, project locations would allow the discretionary diversion of Lake Michigan water currently allocated to MWRDGC to continue, and the CAWS hydrology to remain very similar to current conditions. On the Mississippi River side of the barriers, this mitigation is expected to make water quantity and quality essentially equivalent for the Future With Project and Future Without Project conditions. The continued flow of Lake Michigan water through the system would also alleviate stagnant conditions on the lake side of the proposed barriers.

ANS Treatment Plant (ANSTP). Treatment technology included in the ANSTPs for this alternative would include screening, filtration and UV radiation to remove or deactivate high- and medium-risk GLMRIS ANS of concern and their various life stages currently found in the Great Lakes Basin. In the first treatment step, self-cleaning screens would exclude ANS and other organic matter greater than 0.75 in. (19.05 mm) in size. For proposed ANSTPs at Stickney and Alsip, it is assumed for the purposes of this study that pre-filtration would be required prior to UV treatment. UV radiation is then expected to inactivate the smallest organisms entrained in Lake Michigan water that pass through the screens and filters. UV light inactivates organisms by damaging their nucleic acids, thereby preventing reproduction.

UV treatment performance is affected by water clarity, as suspended particles can shade and encase target species and prevent UV light from reaching them. Transmittance of UV light can also be inhibited by color and some dissolved constituents, such as iron, nitrate, and natural organic matter. Water quality data collected by MWRDGC suggests that interferences with UV treatment may be of concern at the Stickney and Alsip project locations. Turbidity measurements taken at Stickney between 2007 and 2011 ranged between 3.42 and 51.3 nephelometric turbidity units (NTU), with more than half of measurements greater than 10 NTU. Turbidity measurements at Alsip ranged from 1.93 NTU to 68.3 NTU during the same time period, with more than 60 percent of measurements exceeding 10 NTU. This is not a clear indication that pre-filtration would be necessary; rather, site-specific pilot studies are recommended to evaluate dose requirements, possible interferences, and other design questions. In a Disinfection Evaluation study performed by MWRDGC in 2005, the Disinfection Task Force stated that it was uncertain whether filtration would be necessary prior to UV treatment at the Stickney, Calumet and O'Brien WRPs, but cited benefits of pre-filtration, including: reduction of operations and maintenance costs; reduction in the required UV dose; and removal of UV-resistant pathogens associated with suspended solids (CTE/AECOM 2005).

UV radiation is a well-established technology for disinfecting drinking water and domestic wastewater. It effectively inactivates bacteria, viruses, protozoa and spores; however, different strains of bacteria and viruses react differently to UV because of variations in DNA content and how that DNA absorbs UV light. Limited literature is available on the effect of UV treatment on some GLMRIS target species, as discussed in Appendix C – Risk Assessment. Site-specific dose-response tests would be required in the future to determine the UV dose necessary to inactivate target species.

The ANSTPs were sized to treat the maximum daily diversion from Lake Michigan to the CAWS. LMDA data from 2007 to 2012 were utilized to identify the maximum diversion flows taken at Wilmette Pumping Station, Chicago Lock, and O'Brien Lock and Dam over this time period. A seven-day moving average of daily diversion volumes was calculated and the maximum daily flow was selected, after the elimination of a few outlying data points. It is estimated that ANSTPs with capacities of 650 MGD and 450 MGD would be sufficient to treat the discretionary diversion from Lake Michigan at Stickney (Illinois) and Alsip (Illinois), respectively. On the basis of the size of existing facilities owned and operated by MWRDGC, these three plants would require approximately 5.2 acres and 3.6 acres of land, respectively.

F.2.6.4.2 Wastewater Treatment Plant Tunnels

Construction of a Mid-System Hydrologic Separation project would direct effluent from MWRDGC's O'Brien and Calumet Water Reclamation Plants and several smaller wastewater treatment facilities that currently drain toward the Illinois Waterway, toward the Lake Michigan Basin. MWRDGC and other dischargers would be held to water quality standards in the receiving and downstream waters, including Lake Michigan. Lake Michigan Basin effluent and water quality standards are, in general, much more stringent then standards for the CAWS, as described in 35 Ill. Adm. Code 302. Additionally, the Illinois Pollution Control Board Regulation for Antidegradation prohibits actions that would result in the deterioration of water quality in high-quality waters or degradation of the existing uses of all waters (35 Ill. Adm. Code 302.105). Supplemental Antidegradation Provisions also require that, "waters within the Lake Michigan Basin must not be lowered in quality due to new or increased loading of substances defined as bioaccumulative chemicals of concern (BCCs)" (35 Ill. Adm. Code 302.521). BCCs are chemicals (such as PCBs, mercury and dioxin) that have been shown to cause adverse effects and accumulate in the tissue of aquatic organisms as a result of uptake from the environment. "Limit of Treatment Technology" nutrient removal processes are able to achieve effluent concentrations as low as 0.1 mg/L total phosphorus and 3.0 mg/L total nitrogen (Kang et al. 2008). However, even if the O'Brien and Calumet WRPs were upgraded to the limit of technology for nutrient removal, plant effluent would still likely constitute a violation of the Antidegradation standard if discharged to Lake Michigan, owing to both short-term and cumulative impacts. In addition to the added nutrient load, dissolved constituents such as chloride and BCCs present in municipal wastewater, which are not removed by conventional physical and biological wastewater treatment processes, would also violate the Antidegradation standard if discharged to the Lake Michigan Basin.

Reverse osmosis (RO) is an advanced water treatment process capable of separating monovalent species such as chloride and other dissolved solutes, including many BCCs. RO is typically used to purify drinking water in freshwater-scarce environments and to generate high-purity industrial process waters, among other applications. RO is extremely energy-intensive, and acceptable disposal of the concentrate (reject water) can be challenging. Upgrades to existing WRP facilities would effectively mitigate the water quality impacts of a Mid-System Separation if pre-filtration and reverse osmosis were implemented. However, RO has never before been implemented at the scale required. The O'Brien and Calumet WRPs have design capacities of 333 MGD and 354 MGD, respectively. The largest RO plants in the world are substantially smaller; the Ashkelon and Sorek desalination plants in Israel have design capacities of 86 MGD and 108 MGD, respectively (Camacho et al. 2013, p. 153). Larger RO facilities may indeed be designed and built in the coming years. However, this mitigation strategy was discounted owing to uncertainty whether RO facilities of the required size would be available within the required time frame for project implementation.

Preliminary cost estimates also show that a more cost-effective way to meet regulatory standards in the CAWS and Lake Michigan for the Mid-System Hydrologic Separation alternative is to relocate the WRP outfalls to the river side of the hydrologic separation barriers. On the Chicago River system, a tunnel 13 feet in diameter and 12.5 miles long is proposed to deliver the O'Brien WRP effluent to the river side of the proposed physical barrier in Stickney, Illinois. A pump station would be required at the downstream end in order to return the plant effluent to the elevation of the CSSC. On the Calumet River system, a tunnel 13 feet in diameter and 5.3 miles long would be needed to deliver the Calumet WRP effluent to the river side of the proposed physical barrier in Alsip, Illinois. A pump station would be required at the downstream end in order to return the plant effluent to the elevation of the Cal-Sag Channel. Tunnel configuration would approximately parallel waterway alignment. Additional design and engineering would be necessary to resolve conflicts with existing underground structures.

Several smaller wastewater treatment facilities currently discharge into tributaries to the CAWS, and would also be redirected to the Lake Michigan Basin as a consequence of the Mid-System Hydrologic Separation alternative. These facilities are shown in Figures F.26 and F.27, and their average and maximum flow rates are listed below in Table F.2. While the MWRDGC facilities located in the City of Chicago discharge several times as much flow as the next largest plant, these smaller plants would also likely be required to meet the more stringent water quality standards of the Lake Michigan Basin. No plant upgrades, tunnels or other mitigation have been identified for the smaller wastewater treatment facilities at this time.

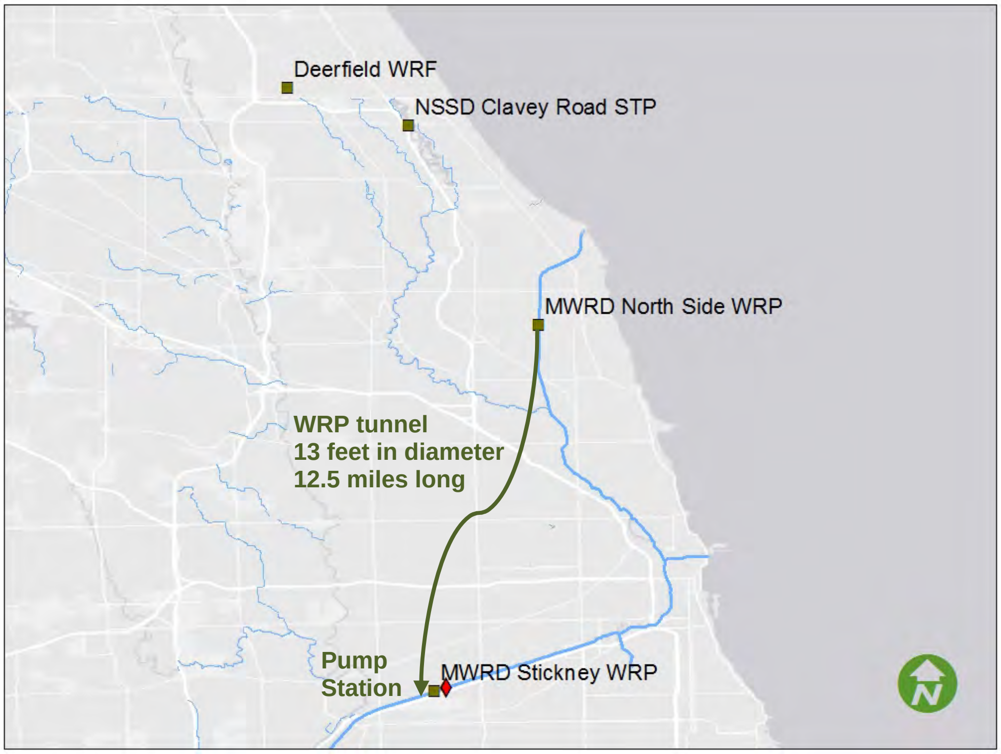

FIGURE F.26 Tunnel from O'Brien WRP to Lower CSSC

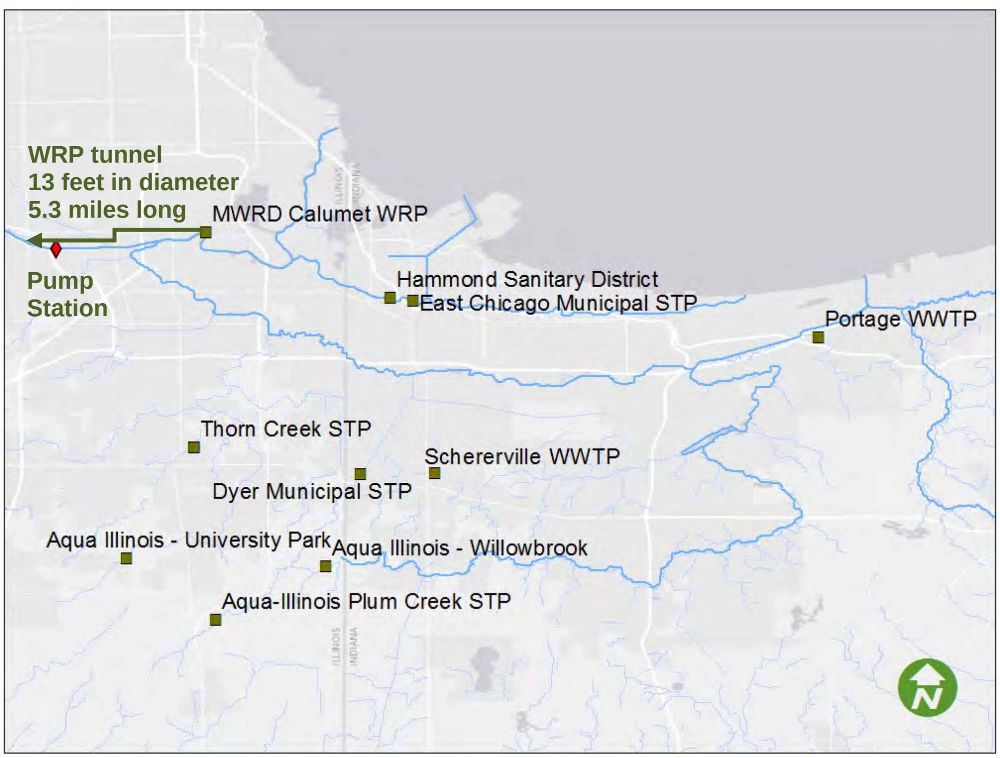

FIGURE F.27 Tunnel from Calumet WRP to Cal-Sag Channel

TABLE F.2 Wastewater Treatment Facilities that Discharge to Lake Michigan Side of Mid-System Separation Barriers

NPDES Permit Number	Facility Name	Design average flow (MGD)	Design maximum flow (MGD)
IL0024473	Aqua Illinois - University Park WWTF	2.43	6.44
IL0025755	St. Anne STP	0.15	0.51
IL0031798	Aqua Illinois - Willowbrook	0.50	2.34
IL0050202	Aqua-Illinois Plum Creek STP	0.30	0.75
IL0027723	Thorn Creek STP	15.94	40.25
IN0024457	Schererville WWTP	8.75	16.60
IN0039331	Dyer Municipal STP	2.60	7.50
IL0028061	MWRD Calumet WRP[a]	354.00	430.00
IN0023060	Hammond Wastewater Facility	37.80	68.00
IN0022829	East Chicago Municipal STP	15.00	
IN0024368	Portage Municipal STP	3.50	4.95
IL0028053	MWRD Stickney WRP[a]	1,200.00	1,440.00
IL0030171	NSSD Clavey Road STP	17.80	28.00
IL0028088	MWRD O'Brien WRP[a]	333.00	450.00
IL0028347	Deerfield WRF	3.50	8.00

[a] *Modeled in this study.*

F.2.6.4.3 Other Dischargers

The WRPs are the largest dischargers to the CAWS, by volume. During the winter months, virtually 100 percent of the flow in the system is from the Calumet, Lemont, O'Brien and Stickney WRPs and in the summer months, about 50 percent of the flow is from the WRPs (MWRDGC 2008). Other facilities, including power plants, steel plants and commercial buildings, use the CAWS for non-contact cooling water and to discharge treated process wastewaters. These withdrawals and discharges are much smaller by volume in comparison to the WRPs, but a significant number of entities may be impacted by changed water quality conditions in the CAWS. Impacts on other water users as a result of the Mid-System Hydrologic Separation alternative have not been fully evaluated at this time and would require further investigation to provide a complete assessment of with-project water quality conditions for purposes of a complete NEPA analysis. No facility upgrades or other mitigation have been identified for the cooling-water users and other dischargers at this time.

F.2.6.4.4 Combined Sewer Overflow (CSO) Control

The Mid-System Hydrologic Separation alternative would result in combined sewage-stormwater draining toward Lake Michigan during rain events. The three primary methods for controlling CSOs are: increasing CSO collection and storage capacity; increasing CSO treatment capacity; and reducing the amount of stormwater entering the combined sewer system.

The first of these strategies has been pursued in the Chicago area since 1972, when the State of Illinois, Cook County, Metropolitan Sanitary District of Greater Chicago, and the City of Chicago jointly adopted the Chicago Underflow Plan, also known as the Tunnel and Reservoir Plan (TARP). TARP's main goals are to protect Lake Michigan from raw sewage pollution; improve the water quality in area waterways; and provide an outlet for floodwaters to reduce street and basement sewage backup flooding. TARP consists of four deep tunnel systems and three reservoirs. The TARP tunnels have improved water quality in the CAWS by capturing the "first flush" of the most contaminated sewage and runoff during storms and preventing its discharge to the waterways. The McCook and Thornton reservoirs currently under construction would capture a larger portion of storm flow to ameliorate urban flooding. However, the system is not sufficiently large to capture all the CSOs during storm events. The Mid-System Separation alternative would expose Lake Michigan to the remaining CSO discharges on the lake side of the proposed barriers. Note that currently some CSO flows are released to the lake during very large events; however, under the Mid-System Separation scenario, CSO flows from much smaller storm events would be discharged to the lake on a more frequent basis.

The proposed mitigation for CSOs for the Mid-System Separation alternative is an expansion of the existing TARP system to collect the combined sewage-stormwater from the sewer systems and move it by gravity into reservoirs. Two new tunnels and two new reservoirs would be needed to accomplish this task. A 32-ft-diam tunnel, 12.5 miles long, would be constructed along the NBCR, from its confluence with the North Shore Channel to McCook, Illinois. An additional reservoir, capable of storing 25,000 acre-ft of stormwater, would be constructed in McCook, Illinois, north of the existing reservoir, to accept this flow. A second tunnel, 30 feet in diameter and 5.5 miles in length, could be constructed from Hammond, Indiana, to Thornton, Illinois. An additional reservoir capable of storing 16,000 acre-ft of stormwater, would be constructed in Thornton, Illinois, near the existing TARP reservoir. Pump stations would be needed at each of the new reservoirs in order to empty them. The reservoir water would then be pumped out to existing wastewater treatment facilities to make it suitable for discharge to the waterways. For the Mid-System Separation alternative, average additional volumes of 4,415 MG and 1,512 MG are expected for treatment at the Stickney and Calumet WRPs, respectively.

F.2.6.4.5 Variations to CSO Mitigation Strategy

At the request of the Illinois EPA, MWRDGC commissioned a study in 2006 which evaluated potential end-of-pipe treatment technologies for 170 of the CSO outfalls on the CAWS. The study considered several alternatives for each of four unit processes: screening, pumping, primary clarification, and disinfection. The recommended CSO treatment design consists of chain-driven 60° catenary bar screens, wet pit submersible pumps, vortex separators and high-intensity UV disinfection (CTE/AECOM 2006). Each facility was estimated to occupy 0.50 acre; however, the necessary footprint was not available for 65 of the 170 outfalls studied. MWRDGC concluded that even if 105 end-of-pipe CSO treatment facilities were built, bacteria standards would still be violated regularly because of the 65 untreated outfalls. While this mitigation strategy alone would not meet regulatory standards, the end-of-pipe treatment design could possibly be used in conjunction with other CSO control methods to mitigate water-quality impacts of the GLMRIS Mid-System Separation alternative.

F.2.6.4.6 Additional Water Treatment

To ensure compliance with regulatory standards, the combined sewage-stormwater captured in the new reservoirs proposed above would require treatment before it is returned to the CAWS. Expansion of existing wastewater treatment facilities may be necessary to treat this additional volume in a reasonable time frame, but capital improvements to existing treatment facilities would require future study. Average annual additional treatment volume was estimated by computing the total CSO flow from the WY 2001, 2003 and 2008 TNET model runs. A bell-shaped probability density function (20% wet year, 60% average year, and 20% dry year), was assumed to calculate the average annual volume requiring treatment.

Additional annual treatment volume at Stickney WRP: 4,415 MG
Additional annual treatment volume at Calumet WRP: 1,512 MG

F.2.6.4.7 Sediment Remediation

Under the Mid-System Hydrologic Separation alternative, contaminated sediments in the Calumet and Chicago River systems would have greater potential to impact Lake Michigan. Heavy metals and persistent organic pollutants produced throughout the region's long industrial history now reside in the rivers' bottom sediments. Under current conditions, sediment is naturally suspended and transported downstream toward the Mississippi River by fluvial processes. Hydrophobic contaminants adsorbed to sediment particles are transported and are released to the water column over time. The physical barriers proposed in this project alternative would direct much of the system's sediment and dissolved contaminants toward Lake Michigan instead of to the Mississippi River basin and would be expected to degrade water and sediment quality in the lake.

Comprehensive sediment investigation is needed to fully understand the environmental impacts of the Mid-System Separation alternative. All surficial sediments on the lake side of the proposed barriers should be systematically sampled and analyzed to determine chemical concentrations in the sediment and their potential mobility. Such an investigation would be necessary to determine the appropriate extents and methods for sediment remediation. Based on available sediment data discussed in Appendix B – Affected Environment, it is anticipated that the Chicago River system, Calumet River, and the Illinois portion of the Little Calumet River would require sediment remediation to make construction of the proposed physical barriers environmentally acceptable. To mitigate the water-quality impacts of the Mid-System Separation alternative, extensive sediment removal and capping is recommended.

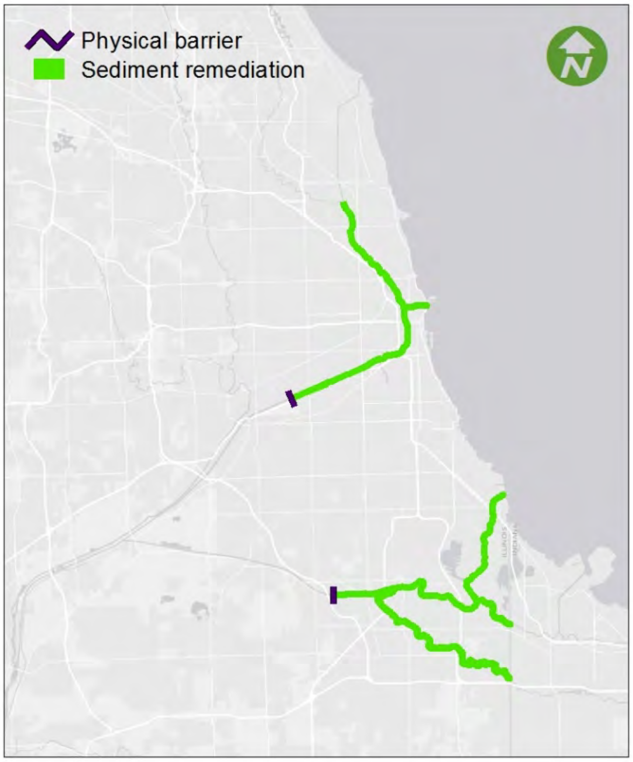

FIGURE F.28 Sediment Remediation Areas

The conceptual design for sediment remediation on the lake side of the proposed separation barriers is based on the work performed by USEPA and others on the Grand Calumet River Area of Concern. The West Branch Grand Calumet River project excavated 3–4 feet of sediment for disposal in an upland storage location. A reactive carbon mat designed to capture residual contaminants released from the underlying contaminated sediment was installed in its place and secured by a two-foot sand layer. Riprap was added for scour protection. A similar approach is assumed for remediating sediments located between the proposed GLMRIS hydro-sep barriers and Lake Michigan (shown in FIGURE F28). It is assumed that sediment in the North Shore Channel does not require remediation, on the basis of sediment data discussed in Appendix B – Affected Environment. The South Fork SBCR, also known as Bubbly Creek, is not included in the conceptual design because remediation of this tributary is already being studied by the USACE under a different project authority, which is assumed to proceed to completion. The portions of the Little and Grand Calumet Rivers located in Indiana are also excluded from the conceptual remediation plan. Environmental remediation of the Indiana portions of the Grand Calumet River by USEPA, U.S. Steel and others have been underway since 2002, and the Indiana side of the Little Calumet River drains toward the lake under current conditions. Any contamination directed toward the lake originating from the bottom sediments of the Little Calumet River does not represent a changed condition produced by the GLMRIS project alternative. Tributaries to the Chicago and Calumet River systems should be evaluated in the proposed sediment investigation for possible impacts on the lake, but are also not included in the conceptual remediation plan at this time.

For river reaches where there is no authorized federal navigation channel, the conceptual remediation strategy is to dredge two feet of surficial sediments and then install a reactive carbon mat and a two-foot sand layer. While there is no required minimum depth for reaches that are not maintained for commercial navigation, two feet of dredging would be necessary to accommodate the isolation cap without raising river stages. This strategy could apply to the Chicago River North Branch from Foster Ave. to Addison Ave, as well as the reaches of the Little and Grand Calumet Rivers that require remediation.

For river reaches where there is an authorized federal navigation project, the conceptual remediation strategy is to dredge the entire federal channel to four feet deeper than project depth. Four-to-one sideslopes would be included in the dredge volume, as shown in Figure F.29. A two-foot sand and geotextile cap would be placed to isolate contaminated sediments at depth. At the conclusion of the capping project, the top of the engineered cap would be two feet below the authorized channel depth. If and when the channel is dredged in the future, the cap would not be disturbed. It is assumed that dredged sediments would not be suitable for in-water disposal, and instead would be dewatered and transported to a RCRA Subtitle C facility.

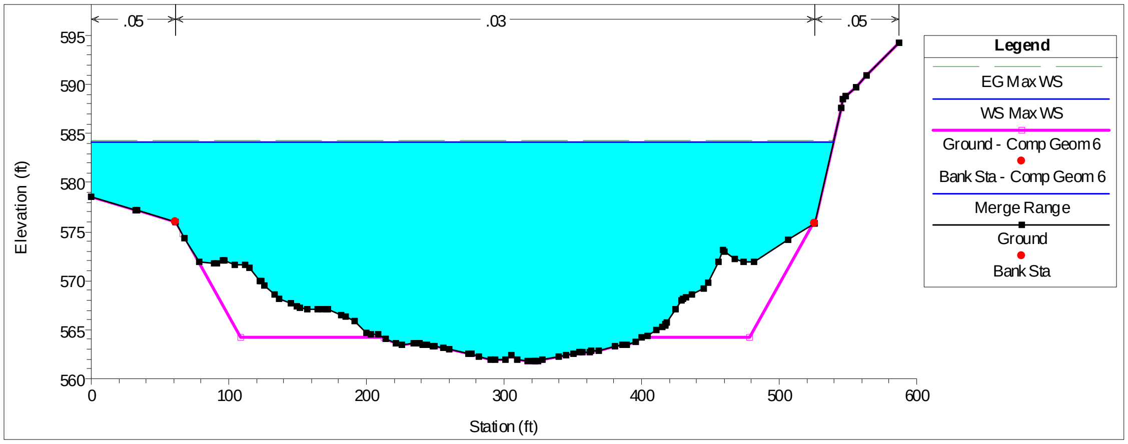

FIGURE F.29 Dredge Prism for 9-ft Authorized Navigation Channels

The Rivers and Harbor Act of 1946 authorized a 9-foot deep navigation channel in the Chicago River North Branch, from Addison Avenue to North Avenue. The authorized channel is 50 ft wide from Addison Avenue to Belmont Avenue. From Belmont Avenue to North Avenue, the channel is authorized to within 30 ft of existing bulkheads and river banks. While navigation depth in these reaches is not currently maintained, it is assumed that a permanent sediment isolation cap would be installed deeper than the authorized navigation channel to avoid disturbance by any future dredging projects. From the North Avenue turning basin south to Wolf Point and east to the Chicago Lock, the authorized navigation depth is 21 ft to within 20 ft of existing docks. The Illinois Waterway encompasses the southern half of the CAWS, including the SBCR, Bubbly Creek, CSSC, Cal-Sag Channel, LCRN, and the Calumet River. The Rock Island District of the USACE maintains a 9-ft-deep navigation channel in the Illinois Waterway.

On the basis of channel geometry data, the quantities shown in **Error! Reference source not found.**3 were estimated for dredging and capping in the CAWS. These rough, order-of-magnitude volume and area estimates were calculated using the end-area method and channel cross-section data from the HEC-

RAS hydrologic model described in Appendix E – Hydraulic &Hydrologic Analyses. For the navigable portions of the CAWS, the cross-sections were constructed using recent hydrographic survey data collected by the USACE Rock Island and Detroit Districts. Recent survey data for the upper portion of the North Branch of the Chicago River, NSC and Grand Calumet River are not available. The cross sections included in the previous UNET models were reviewed and geo-referenced before being integrated into the HEC-RAS model.

TABLE F.3 Sediment Dredging and Capping, Estimated Quantities

River	Station	Location	Dredge Volume (cu yd)	Cap Area (sq yd)
UNBCR UNBCR	333.11 327.71	Foster/Argyle North Ave.	404,297	522,676
UNBCR		North Ave Turning Basin	255,000	48,190
UNBCR UNBCR	327.44 325.54	North Ave. Wolf Point	258903	272,645
UNBCR-East UNBCR-East	327.44 326.45	North Ave. Wolf Point	66,664	99,997
Chicago Chicago	327.11 325.54	CRCW Wolf Point	258,903	315,713
SBCR SBCR	325.44 321.64	Wolf Point Bubbly Creek	361,891	542,471
SBCR		Bubbly Creek Turning Basin	113,453	66,387
CSSC CSSC	321.5 316.03	Bubbly Creek Stickney hydro-sep barrier	717,846	986,724
Calumet Calumet	333.03 325.65	Lake Michigan Confluence with Grand Cal	1,334,899	1,878,028
Calumet LCRN	325.59 319.6	Confluence with Grand Cal Confluence with LCRS, Cal-Sag	1,240,725	1,672,105
Cal_Sag Cal_Sag	319.46 315.97	Confluence with Little Cal Alsip hydro-sep barrier	451,278	599,799
Grand Cal Grand Cal	2.529 0	Illinois-Indiana State Line Confluence with LCRN	125,462	185,425
		TOTAL	**5.6 million cu yd**	**7.2 million sq yd**

F.2.6.4.8 Stormwater Best Management Practices

Water-quality data collected by MWRDGC from 2001 to 2008 indicate that the upper reaches of the NBCR contain extremely high concentrations of chloride, likely from the use of road salt. At the Albany Avenue monitoring point, chloride concentrations regularly increase to 400–500 mg/L or higher in the winter months, with the maximum recorded concentration at around 1,100 mg/L. Similarly, monitoring data from the Little Calumet River and the Grand Calumet River show elevated chloride levels in the winter months, although the concentrations are less extreme than those of the NBCR.

The proposed water-quality mitigation for the Mid-System Separation alternative, which includes CSO collection tunnels and WRP effluent tunnels to the river side of the separation barriers, would prevent much of the salty stormwater from entering the Lake Michigan basin. However, several municipalities north of Chicago have separate storm sewers that discharge to tributaries of the CAWS. These storm sewer outfalls would not be addressed by the proposed water quality mitigation and would continue to be a source of chloride for the Lake Michigan Basin. There is also an unquantified volume of water that enters the CAWS not through a pipe, but by overland flow. This storm drainage represents a non-point source of chloride and other pollutants to the waterway. Stormwater runoff also transports oil and grease, fertilizers, herbicides, and bacteria from animal feces into the waterways. Current regulations addressing pollution from nonpoint sources do not authorize any agency to restrict the use of salt, fertilizers, and other nonpoint sources. Reductions and/or restrictions on the use of road salt, fertilizers, herbicides, etc., must be voluntarily assumed by the relevant municipalities.

F.2.6.5 Unmitigated Impacts

Installation of hydrologic separation barriers on the CAWS at Alsip, Illinois, and Stickney, Illinois, are expected to produce significant impacts on water quality in both the CAWS and Lake Michigan. Many of these impacts can be mitigated by additional projects like those described above. Other impacts expected to result from the Mid-System Separation alternative would be more difficult to correct. Currently, non-point source discharges of pollutants to the waterways remain largely unregulated, and thus the Mid-System Hydrologic Separation alternative may result in unmitigated impacts to water quality in Lake Michigan resulting from stormwater runoff.

Additionally, while the proposed mitigation measures are expected to minimize any effects on the downstream Mississippi River basin outside of the CAWS, the reduction in flow was not extensively studied in GLMRIS. For additional details, see Appendix A – Effect of Mid-System Separation on Low Flows in Downstream Waterway.

F.2.7 Mid-System Separation Cal-Sag Open Control Technologies with a Buffer Zone

This hybrid project alternative was not simulated in either the DUFLOW model or FVCOM. However the water quality impacts of this alternative can be understood as a combination of the Mid-System Hydrologic Separation alternative (on the Chicago River system) and the Technology Alternative with a Buffer Zone (on the Calumet River System). Water quality conditions in the Chicago River system and Calumet River system are largely independent of one another, except at the confluence of the CSSC and the Cal-Sag Channel near Lemont, Illinois.

F.2.7.1 Impacts on Water Quality—CAWS

The “Hybrid Cal-Sag Open” alternative proposes one physical barrier on the CSSC in order to stop the flow of water and ANS between watersheds. Therefore, water quality impacts on the Chicago River system are expected to be similar to those of Alternative Plan 5, Mid-System Hydrologic Separation Alternative. DO compliance would be expected to improve in the Upper North Shore Channel as a result of the CSSC barrier at Stickney, Illinois, because this reach would receive more oxygenated flow from the O’Brien WRP. Small improvements in DO compliance would also be seen near Bubbly Creek and in the Little Calumet River. However, stagnant zones throughout the rest of the system would result in up to 1000 additional hours of noncompliance with the DO benchmark in the Lower NBCR and more than 1,000 hours in the stagnant SBCR and northern CSSC. Exceedances of the fecal coliform and chloride benchmarks would be expected to increase in the North Shore Channel and NBCR. Phosphorus concentrations would be expected to increase in the upper North Shore Channel and in the lower North Shore Channel and NBCR, and remain the same as under Future Without Project conditions during months with no discretionary diversion. The ANS control technologies proposed on the Calumet River system are not expected to substantially change the quantity or direction of flow. Therefore, water quality impacts on the Calumet River system are expected to be similar to those under the Future Without Project condition.

F.2.7.2 Impacts on Water Quality—Lake Michigan

The Hybrid Cal-Sag Open alternative is expected to contribute significant contaminant loads to Lake Michigan via the Chicago River main stem and North Shore Channel. As a result of this alternative, treated effluent from the O'Brien WRP, more than one hundred combined sewer overflows, dozens of storm sewer flows, and effluent from two CSO pumping stations would all be directed toward Lake Michigan on a continuous basis. Urban storm runoff and contaminated sediment, while not assessed by the models, would also contribute to the water quality impacts of this project alternative on Lake Michigan. If implemented, the Mid-System Separation alternative could produce nitrogen, phosphorus, and chloride loads in Lake Michigan that are, respectively, more than 3,700, 400, and 140,000 MTA higher than for the No Project condition, as shown in Table F.4. Such loads, year after year, would have substantial cumulative undesirable effects on Lake Michigan. Extensive mitigation for water quality impacts would be required in order for this alternative to approach environmental acceptability and regulatory compliance. Furthermore, there may be impacts on water quality resulting from this project alternative for which there is no effective mitigation or for which effective mitigation would be prohibitively costly.

TABLE F.4 Annual Contaminant Loads to Lake Michigan – Hybrid Cal-Sag Open Alternative

	No project	Hybrid Cal-Sag Open		
Constituent	**WY 2008**	**WY 2001 (avg flow)**	**WY 2003 (dry year)**	**WY 2008 (wet year)**
Volume (acre-ft)	5,920	421,000	330,000	442,000
CBOD (MTA)	135	1,364	759	1,456
Total Nitrogen (MTA)	56	3,471	2,670	3,769
Total Phosphorus (MTA)	7	393	297	441
Total Suspended Solids (MTA)	394	6,345	2,980	8,165
Chloride (MTA)	1,279	82,055	61,507	144,242
Fecal Coliform (CFU)	$7.48*10^{12}$	$1.64*10^{13}$	$1.27*10^{12}$	$3.33*10^{13}$

F.2.7.3 Mitigation of Impacts on Water Quality

To mitigate the water quality impacts of the Hybrid Cal-Sag Open alternative, the following measures are proposed: flow augmentation (including treatment facilities to remove ANS from Lake Michigan diversion water); tunnels to discharge wastewater treatment plant effluent to the river side of the separation barrier; tunnels and reservoirs to capture combined sewer overflows; sediment remediation; and aggressive stormwater management improvements. An abbreviated description of each is provided below. More discussion about the selection of these mitigation strategies is provided under Alternative Plan 5, Mid-System Hydrologic Separation.

F.2.7.3.1 Flow Augmentation

Flow augmentation is proposed to mitigate conditions of stagnation and oxygen depletion generated by the Hybrid Cal-Sag Open alternative. Augmentation of stagnant and low flows in the CAWS could be achieved by pumping water from Lake Michigan over the proposed physical barrier and through a treatment process to remove ANS before discharging to the CAWS. Installation of ANSTPs near the Stickney and T.J. O'Brien project locations in Illinois would allow the discretionary diversion of Lake Michigan water currently allocated to MWRDGC to continue, and the CAWS hydrology to remain very similar to current conditions. On the Mississippi River side of the barrier, this mitigation is expected to make water quantity and quality essentially equivalent for the Future With Project and Future Without

Project conditions. The continued flow of Lake Michigan water through the system would also alleviate stagnant conditions on the lake side of the proposed barrier. As described for the Lakefront Separation alternative, treatment technology included in the ANSTP at O'Brien would include screening and UV radiation to remove nine ANS that have been identified as posing a high or medium risk of interbasin transfer. As described in the Mid-System Separation alternative, screening, filtration, and UV treatment are proposed at Stickney.

The ANSTPs were sized to treat the maximum daily diversion from Lake Michigan to the CAWS. LMDA data from 2007 to 2012 were utilized to identify the maximum diversion flows taken at Wilmette Pumping Station, Chicago Lock, and O'Brien Lock and Dam over this time period. A seven-day moving average of daily diversion volumes was calculated and the maximum daily flow was selected, after the elimination of a few outlying data points. It is estimated that ANSTPs with capacities of 650 MGD and 465 MGD would be sufficient to treat the discretionary diversion from Lake Michigan at Stickney and T.J. O'Brien, respectively.

At T.J. O'Brien, additional plant capacity would be provided to supply ANS-treated water to the GLMRIS Lock. This additional daily treatment capacity was calculated by multiplying the lock volume by the maximum number of lockages in a given day during 2010–2011 (57 on July 18, 2010). It is estimated that an additional 828 MGD of treatment capacity would be sufficient to operate the GLMRIS Lock, even on the busiest days for navigation. On the basis of the size of existing facilities owned and operated by MWRDGC, plants at Stickney and T.J. O'Brien with combined capacities of 650 MGD and 1,250 MGD would require approximately 5.2 acres and 4.1 acres of land, respectively. UV plants of this size would be among the largest in the world (Greenemeier 2013).

F.2.7.3.2 Wastewater Treatment Plant Tunnels

In order for the Hybrid Cal-Sag Open alternative to meet current regulatory standards for the CAWS and Lake Michigan, the proposed mitigation strategy is to relocate the O'Brien WRP outfall to the river side of the hydrologic separation barrier. A tunnel 13 ft in diameter and 12.5 mi long would be necessary to deliver the O'Brien WRP effluent to the river side of the proposed physical barrier in Stickney, Illinois. A pump station would be required at the downstream end in order to return the plant effluent to the elevation of the CSSC.

F.2.7.3.4 Combined Sewer Overflow (CSO) Control

The Hybrid Cal-Sag Open alternative would result in combined sewage-stormwater draining toward Lake Michigan during rain events. The proposed mitigation for CSOs is an expansion of the TARP system to collect the combined sewage-stormwater from the sewer systems and move it by gravity into reservoirs. A 32-ft-diam tunnel, 12.5 mi long, would be constructed along the NBCR from its confluence with the North Shore Channel to McCook, Illinois. An additional reservoir, capable of storing 25,000 acre-feet of stormwater, would be constructed in McCook, Illinois, north of the existing reservoir, to accept this flow. A pump station would be required to pump out the new reservoir to existing wastewater treatment facilities to make it suitable for discharge to the waterways. An additional 4,415 MG annually is expected for treatment at the Stickney WRP. Capital improvements to existing treatment facilities would require future study.

F.2.7.3.5 Sediment Remediation

Under the Hybrid Cal-Sag Open alternative, contaminated sediments in the Chicago River system would have greater potential to impact Lake Michigan. The physical barrier would direct the transport of sediments and dissolved contaminants from the CAWS to Lake Michigan instead of to the Mississippi River basin and are likely to degrade water and sediment quality in the lake. Comprehensive sediment investigation is needed to fully understand the environmental impacts of the Hybrid Cal-Sag Open alternative. All surficial sediments on the lake side of the proposed barrier would need to be systematically sampled and analyzed to determine chemical concentrations in the sediment and their potential mobility. Such an investigation would be necessary to determine the appropriate extents and methods for sediment remediation. On the basis of available sediment data, it is anticipated that the Chicago River system would require substantial remediation in order to protect water quality in Lake Michigan.

For river reaches where there is no authorized federal navigation channel, the conceptual remediation strategy is to dredge 2 ft of surficial sediments and then install a reactive carbon mat and a 2-ft sand layer. While there is no required minimum depth for reaches that are not maintained for commercial navigation, 2 ft of dredging would be necessary to accommodate the isolation cap without raising river stages. For river reaches where there is an authorized federal navigation project, the conceptual remediation strategy is to dredge the entire federal channel to 4 ft deeper than project depth. A 2-ft sand and geotextile cap would be placed to isolate contaminated sediments at depth. At the conclusion of the capping project, the top of the engineered cap would be 2 ft below the authorized channel depth. If and when the channel is dredged in the future, the cap would not be disturbed. It is assumed that dredged sediments would not be suitable for in-water disposal, and instead would be dewatered and transported to a RCRA Subtitle C facility.

Table F.5 shows the volumes and areas that were estimated, on the basis of channel geometry data, for dredging and capping in the CAWS. These rough, order-of-magnitude volume and area estimates were calculated using the end-area method and channel cross-section data from the HEC-RAS hydrologic model described in Appendix E.

TABLE F.5 Sediment Dredging and Capping, Estimated Quantities

River	Station	Location	Dredge volume (cu yd)	Cap area (sq yd)
UNBCR UNBCR	333.11 327.71	Foster/Argyle North Ave.	404,297	522,676
UNBCR		North Ave Turning Basin	255,000	48,190
UNBCR UNBCR	327.44 325.54	North Ave. Wolf Point	258903	272,645
UNBCR-East UNBCR-East	327.44 326.45	North Ave. Wolf Point	66,664	99,997
Chicago Chicago	327.11 325.54	CRCW Wolf Point	258,903	315,713
SBCR SBCR	325.44 321.64	Wolf Point Bubbly Creek	361,891	542,471
SBCR		Bubbly Creek Turning Basin	113,453	66,387
CSSC CSSC	321.5 316.03	Bubbly Creek Stickney hydro-sep barrier	717,846	986,724
		TOTAL	**2.4 million cu yd**	**2.9 million sq yd**

F.2.7.3.6 Stormwater Best Management Practices

Storm runoff from separated sewers in the north suburbs of Chicago as well as from overland flow represents a non-point source of salt and other pollutants in the waterways. Stormwater runoff transports elevated concentrations of chloride, as well as oil and grease, fertilizers, herbicides, and bacteria from animal feces into the waterways. Current regulations addressing pollution from nonpoint sources do not authorize any agency to restrict the use of salt, fertilizers, and other nonpoint sources. Reductions and/or restrictions on the use of road salt, fertilizers, herbicides, etc., must be voluntarily assumed by the relevant municipalities.

F.2.7.4 Unmitigated Impacts

Installation of a hydrologic separation barrier at Stickney, Illinois, would produce significant impacts on water quality in both the CAWS and Lake Michigan. Many of the impacts can be mitigated by additional projects like those described above. Other impacts expected to result from the Mid-System Separation Cal-Sag Open Control Technologies with a Buffer Zone Alternative would be more difficult to correct. Currently, non-point-source discharges of pollutants to the waterways remain largely unregulated, and thus GLMRIS Alternatives including hydrologic separation elements may result in unmitigated impacts on water quality in Lake Michigan resulting from stormwater runoff.

Additionally, while the proposed mitigation measures are expected to minimize any effects on the downstream Mississippi River basin outside of the CAWS, the reduction in flow was not extensively studied in GLMRIS. For additional details, see Appendix A – Effect of Mid-System Separation on Low Flows in Downstream Waterway.

F.2.8 Mid-System Separation CSSC Open Control Technologies with a Buffer Zone

This hybrid project alternative was not simulated in either the DUFLOW model or FVCOM. However the water quality impacts of this alternative can be understood as a combination of the Mid-system Hydrologic Separation alternative (on the Calumet River system) and the Technology Alternative with a Buffer Zone (on the Chicago River System). Water quality conditions in the Chicago River system and Calumet River systems are largely independent of one another, except at the confluence of the CSSC and the Cal-Sag Channel near Lemont, Illinois.

F.2.8.1 Impacts on Water Quality – CAWS

The Hybrid CSSC Open alternative proposes one physical barrier on the Cal-Sag Channel in order to stop the flow of water and ANS between watersheds. Therefore, water quality impacts on the Calumet River system are expected to be similar to Alternative Plan 5, Mid-System Hydrologic Separation. The ANS control technologies proposed on the Chicago River system are not expected to substantially change the quantity or direction of flow. Therefore, water quality impacts on the Chicago River system are expected to be similar to the Future Without Project condition.

F.2.8.2 Impacts on Water Quality – Lake Michigan

The Hybrid CSSC Open alternative is expected to contribute significant contaminant loads to Lake Michigan via the Calumet River system. As a result of this alternative, treated effluent from the Calumet WRP, dozens of combined sewer overflows, and effluent from three CSO pumping stations would all be directed toward Lake Michigan on a continuous basis. Urban storm runoff and contaminated sediment, while not assessed by the models, would also contribute to the water quality impacts of this project alternative to Lake Michigan. If implemented, the Mid-System Separation could produce nitrogen, phosphorus, and chloride loads in Lake Michigan that are, respectively, more than 4,900, 700, and 144,000 MTA higher than for the No Project condition, as shown in Table F.6. Such loads, year after year, would have substantial cumulative undesirable effects on Lake Michigan. Extensive mitigation of water quality impacts would be required in order for this alternative to approach environmental acceptability and regulatory compliance. Furthermore, there may be impacts on water quality resulting from this project alternative for which there is no effective mitigation or for which effective mitigation would be prohibitively costly.

TABLE F.6 Annual Contaminant Loads to Lake Michigan – Hybrid CSSC Open Alternative

	No project	Mid-System Separation		
Constituent	WY 2008	WY 2001 (avg flow)	WY 2003 (dry year)	WY 2008 (wet year)
Volume (acre-ft)	8,270	463,000	415,000	607,000
CBOD (MTA)	93	1,139	952	1,569
Total Nitrogen (MTA)	54	3,072	3,130	4,990
Total Phosphorus (MTA)	10	515	459	717
Total Suspended Solids (MTA)	181	3,668	3,430	7,620
Chloride (MTA)	440	120,293	89,312	145,150
Fecal Coliform (CFU)	$1.50*10^{12}$	$9.75*10^{11}$	$1.64*10^{12}$	$2.63*10^{13}$

F.2.8.3 Mitigation of Impacts on Water Quality

To mitigate the water quality impacts of the Hybrid CSSC Open alternative, the following measures are proposed: flow augmentation (including treatment facilities to remove ANS from Lake Michigan diversion water); tunnels to discharge wastewater treatment plant effluent to the river side of the separation barriers; tunnels and reservoirs to capture CSOs; sediment remediation; and aggressive stormwater management improvements. An abbreviated description of each is provided below. More discussion about the selection of these mitigation strategies is provided under Alternative 5: Mid-System Hydrologic Separation.

F.2.8.3.1 Flow Augmentation

Flow augmentation is the proposed mitigation strategy for conditions of stagnation and oxygen depletion generated by the Hybrid CSSC Open alternative. Augmentation of stagnant and low flows in the CAWS would be achieved by pumping water from Lake Michigan over the proposed physical barrier and through a treatment process to remove ANS before discharging to the CAWS. Installation of ANSTPs near the Wilmette, Illinois, and Chicago, Illinois, project locations would allow the discretionary diversion of Lake Michigan water currently allocated to MWRDGC to continue, and the CAWS hydrology to remain very similar to current conditions. On the Mississippi River side of the barriers, this mitigation is expected to make water quantity and quality essentially equivalent for the Future With Project and Future Without Project conditions. The continued flow of Lake Michigan water through the system would also alleviate stagnant conditions on the lake side of the proposed barrier. As in the Lakefront Separation alternative, treatment technology included in the ANSTPs at Wilmette and Chicago would include screening and ultraviolet disinfection to remove nine ANS which have been identified to pose a high or medium risk of interbasin transfer. As described in the Mid-System Separation alternative, screening, filtration, and UV treatment are proposed at Alsip.

The ANSTPs were sized to treat the maximum daily diversion from Lake Michigan to the CAWS. LMDA data from 2007 to 2012 were utilized to identify the maximum diversion flows taken at Wilmette Pumping Station, Chicago Lock, and O'Brien Lock and Dam over this time period. A seven-day moving average of daily diversion volumes was calculated and the maximum daily flow was selected after the elimination of a few outlying data points. It is estimated that ANS Treatment Plants with capacities of 212 MGD, 438 MGD and 465 MGD would be sufficient to treat the discretionary diversion from Lake Michigan at Wilmette, Chicago and Alsip, respectively.

At the Chicago Lock, additional plant capacity would be provided to supply ANS-treated water to the GLMRIS Lock. This additional daily treatment capacity was calculated by multiplying the lock volume by the maximum number of lockages in a given day during 2010–2011 (149 on July 31, 2010). It is estimated that an additional 1,310 MGD of treatment capacity would be needed to operate the GLMRIS Lock on the busiest days for navigation. On the basis of the size of existing facilities owned and operated by MWRDGC, plants at Wilmette, Chicago and Alsip, with combined capacities of 200 MGD, 1,750 MGD and 450 MGD, would require approximately 0.7 acre, 5.7 acres, and 3.6 acres of land, respectively. UV plants of this size would be among the largest in the world (Greenemeier 2013).

F.2.8.3.2 Wastewater Treatment Plant Tunnels

In order for the Hybrid CSSC Open alternative to meet current regulatory standards for the CAWS and Lake Michigan, the proposed mitigation strategy is to relocate the Calumet WRP outfall to the river side of the hydrologic separation barrier. A tunnel 13 ft in diameter and 5.3 miles long would be necessary to deliver the O'Brien WRP effluent to the river side of the proposed physical barrier in Stickney, Illinois. A pump station would be required at the downstream end in order to return the plant effluent to the elevation of the CSSC.

F.2.8.3.3 Combined Sewer Overflow (CSO) Control

The Hybrid CSSC Open alternative would result in combined sewage-stormwater draining toward Lake Michigan during rain events. The proposed mitigation for CSOs is an expansion of the TARP system to collect the combined sewage-stormwater from the sewer systems and move it by gravity into reservoirs. A 30-ft-diam tunnel, 5.5 miles long, would be constructed along the Little Calumet River to capture sewer overflow. An additional reservoir, capable of storing 16,000 acre-ft of stormwater, would be constructed in Thornton, Illinois, near the existing reservoir, to accept this flow. A pump station would be required to pump out the new reservoir to existing wastewater treatment facilities to make it suitable for discharge to the waterways. An additional 1,512 MG annually is expected for treatment at the Stickney WRP. Capital improvements to existing treatment facilities would require future study.

F.2.8.3.4 Sediment Remediation

Under the Hybrid CSSC Open alternative, contaminated sediments in the Calumet River system would have greater potential to impact Lake Michigan. The physical barrier would direct the transport of sediments and dissolved contaminants from the CAWS to Lake Michigan instead of to the Mississippi River basin, where they are likely to degrade water and sediment quality in the lake. Comprehensive sediment investigation is needed to fully understand the environmental impacts of this alternative. All surficial sediments on the lake side of the proposed barrier would need to be systematically sampled and analyzed to determine chemical concentrations in the sediment and their potential mobility. Such an investigation would be necessary to determine the appropriate extents and methods for sediment remediation. On the basis of available sediment data, it is anticipated that the Calumet River system would require substantial remediation in order to protect water quality in Lake Michigan.

For river reaches where there is no authorized federal navigation channel, the conceptual remediation strategy is to dredge 2 ft of surficial sediments and then install a reactive carbon mat and a 2-ft sand layer. While there is no required minimum depth for reaches that are not maintained for commercial navigation, 2 ft of dredging would be necessary to accommodate the isolation cap without raising river stages. For river reaches where there is an authorized federal navigation project, the conceptual remediation strategy is to dredge the entire federal channel to 4 ft deeper than project depth. A 2-ft sand and geotextile cap would be placed to isolate contaminated sediments at depth. At the conclusion of the capping project, the top of the engineered cap would be 2 ft below the authorized channel depth. If and when the channel is dredged in the future, the cap would not be disturbed. It is assumed that dredged sediments would not be suitable for in-water disposal, and instead would be dewatered and transported to a RCRA Subtitle C facility.

On the basis of channel geometry data, the volumes and areas shown in Table F.7 were estimated for dredging and capping in the CAWS. These rough, order-of-magnitude volume and area estimates were calculated using the end-area method and channel cross-section data from the HEC-RAS hydrologic model described in Appendix E.

TABLE F.7 Sediment Dredging and Capping, Estimated Quantities

River	Station	Location	Dredge volume (cu yd)	Cap area (sq yd)
Calumet Calumet	333.03 325.65	Lake Michigan Confluence with Grand Cal	1,334,899	1,878,028
LCRN LCRN	325.59 319.6	Confluence with Grand Cal Confluence with LCRS, Cal-Sag	1,240,725	1,672,105
Cal_Sag Cal_Sag	319.46 315.97	Confluence with Little Cal Alsip hydro-sep barrier	451,278	599,799
Grand Cal Grand Cal	2.529 0	Illinois-Indiana State Line Confluence with LCRN	125,462	185,425
		TOTAL	**3.2 million cu yd**	**4.3 million sq yd**

F.2.8.3.5 Stormwater Best Management Practices

Storm runoff represents a non-point source of salt and other pollutants in the waterways. Stormwater runoff transports elevated concentrations of chloride, as well as oil and grease, fertilizers, herbicides, and bacteria from animal feces into the waterways. Illinois EPA is not empowered with the authority to regulate non-point pollutant sources. Reductions and/or restrictions on the use of road salt, fertilizers, herbicides, etc., must be voluntarily assumed by the relevant municipalities.

F.2.8.4 Unmitigated Impacts

Installation of a hydrologic separation barrier at Alsip, Illinois, would produce significant impacts on water quality in both the CAWS and Lake Michigan. Many of the impacts can be mitigated by additional projects like those described above. Other impacts expected to result from the Mid-System Separation CSSC Open Control Technologies with a Buffer Zone alternative would be more difficult to correct. Currently, non-point source discharges of pollutants to the waterways remain largely unregulated, and thus GLMRIS alternatives, including hydrologic separation elements, may result in unmitigated impacts on water quality in Lake Michigan resulting from stormwater runoff.

Additionally, while the proposed mitigation measures are expected to minimize any effects on the downstream Mississippi River basin outside of the CAWS, the reduction in flow was not extensively studied in GLMRIS. For additional details, see Appendix A – Effect of Mid-System Separation on Low Flows in Downstream Waterway.

F.3 ANS CONTROL AND MITIGATION MEASURES

F.3.1 Aquatic Nuisance Species Treatment Plant (ANSTP)

The purpose of the ANSTP is to remove ANS from Lake Michigan Basin water before discharging it to the Mississippi River Basin side of a control point. ANSTP effluent would be used to mitigate water quality impacts of GLMRIS project alternatives, such as low flows, stagnant zones, and low DO concentrations. ANSTP effluent would also supply ANS-treated water to the GLMRIS Locks.

This ANS control measure was based on water and wastewater treatment processes, which are well-established methods for separating undesirable constituents from water. The treatment technologies proposed for the ANSTP include a combination of screening, filtration and UV radiation to remove or deactivate high- and medium-risk GLMRIS ANS species of concern and their various life stages currently found in the Great Lakes Basin. In the first treatment step, self-cleaning screens would exclude ANS and other matter greater than 0.75 in. (19.05 mm) in size. Organisms passing the 0.75-in. screens would proceed to either filtration or UV treatment, depending on project location.

UV treatment performance is affected by water clarity, as suspended particles can shade and encase target species and prevent the UV light from reaching them. Transmittance of UV light can also be inhibited by some dissolved constituents, such as iron, nitrate, and natural organic matter. Water quality data collected by MWRDGC between 2007 and 2011 indicates that screening and UV treatment is likely to be an effective treatment process for ANSTPs located very close to Lake Michigan, where turbidity and other possible UV interferences are minimal. Water quality data also indicate that higher turbidity and suspended solids concentrations at the Stickney and Alsip project locations may substantially reduce the effectiveness of UV treatment. Consequently, pre-filtration is included in the ANS treatment process prior to UV treatment at Stickney and Alsip. Turbidity measurements taken at Stickney between 2007 and 2011 ranged between 3.42 NTU and 51.3 NTU, with more than half of measurements greater than 10 NTU. Turbidity measurements at Alsip ranged from 1.93 NTU to 68.3 NTU during the same time period, with more than sixty percent of measurements exceeding 10 NTU. This is not a conclusive indication that pre-filtration would be absolutely necessary; rather, site-specific pilot studies are recommended to evaluate dose requirements, possible interferences, and other design questions in the future. In a Disinfection Evaluation study performed by MWRDGC in 2005, the Disinfection Task Force concluded that it was uncertain whether filtration would be necessary prior to UV treatment at the O'Brien, Calumet and Stickney WRPs, but cited several benefits of pre-filtration, including: reduction of operations and maintenance costs; reduction in the required UV dose; and removal of UV-resistant pathogens associated with suspended solids (CTE/AECOM 2005).

UV treatment was preliminarily selected for this ANS control application because of several advantages over chlorine, ozone and other conventional water disinfection processes. UV treatment is reported to be "more effective than chlorine in inactivating most viruses, spores and cysts" (Tchobanoglous et al. 2003) and therefore is likely to be more efficacious at inactivating GLMRIS target species such as grass kelp and red algae, in all their life stages. Additionally, UV treatment produces no residual toxicity and no disinfection byproducts, and has improved safety compared to the use of chemical disinfectants. Compared to chlorination/dechlorination, UV treatment also requires far less space, which is a constraint at some proposed GLMRIS project locations. When compared to ozone facilities, UV treatment facilities were found to be significantly less costly to construct, operate and maintain, in a recent study for Chicago-area Water Reclamation Plants (CTE/AECOM 2005).

UV radiation is a well-established technology for disinfecting drinking water and domestic wastewater. While it effectively inactivates bacteria, viruses, protozoa and spores, different strains of bacteria and viruses react differently to UV because of variations in DNA content and how that DNA absorbs UV light. Limited literature is available on the effect of UV treatment on some GLMRIS target species, as discussed in Appendix C – Risk Assessment. Site-specific dose-response tests would be required in the future to determine the UV dose necessary to inactivate target species.

ANSTP sizes were determined somewhat differently for each of the GLMRIS project alternatives. Alternative Plan 3, Mid-System Control Technologies without a Buffer Zone, proposes ANSTPs in Stickney and Alsip, Illinois, to treat the normal flow in the waterway at each location. In order to size these plants, the DUFLOW model was used to generate flow hydrographs at Stickney and Alsip under future conditions and during a characteristically "wet" year. The average annual flow was found by calculating the mean of these values, as shown in FIGURE F30 and FIGURE F31. Alternative Plan 3 proposes tunnels to carry the O'Brien and Calumet WRP effluent to the downstream side of the ANSTPs; therefore, the average flows for the WRPs were deducted from the average flows in the channel. The reduced flows in the channel were then scaled up by a factor of 2 to size the plant. This factor was selected because it is the approximate relationship between the average annual flow and design maximum flow at the existing Stickney WRP. During storm events when the plant capacity is exceeded, the storm flows would be routed to a reservoir, where the water would stay until it is treated and discharged back to the waterway.

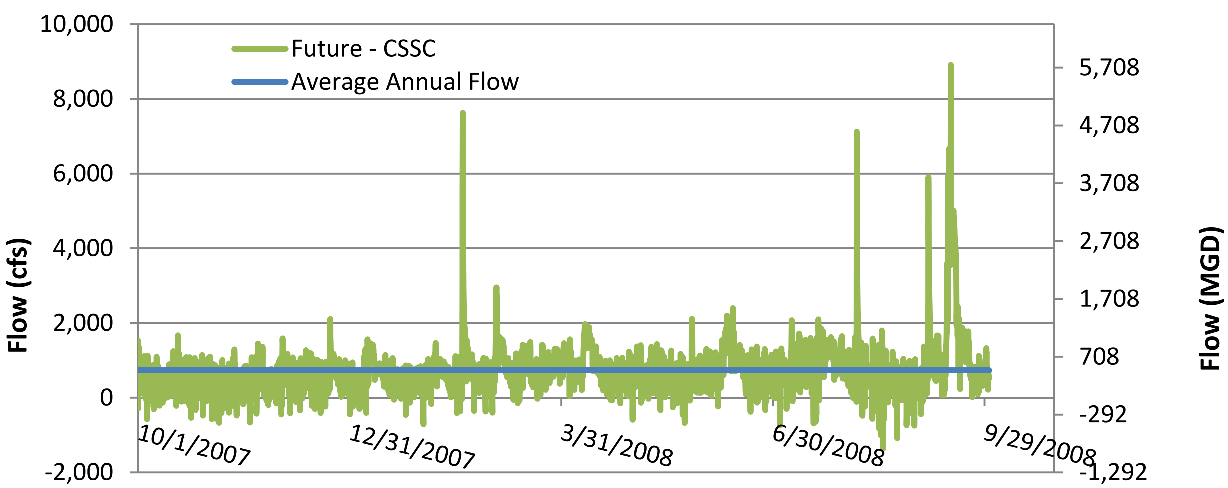

FIGURE F.30 Hydrograph at Stickney, Illinois, for Future Conditions, Wet Year

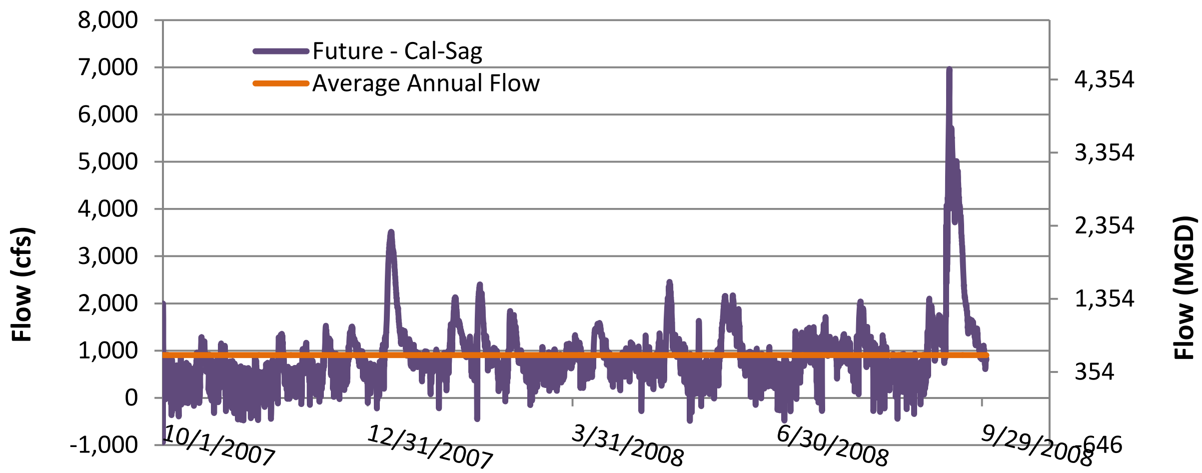

FIGURE F.31 Hydrograph at Alsip, Illinois, for Future Conditions, Wet Year

Alternative Plan 4, Technology Alternative with a Buffer Zone, proposes ANSTPs at Wilmette, Chicago Lock and O'Brien Lock and Dam. The ANSTPs are intended to remove ANS of concern from Lake Michigan water so that it may be used for flow augmentation in the CAWS to mitigate water quality impacts. The ANSTPs would also supply ANS-treated water to the GLMRIS Locks. The plants were sized to treat the maximum daily diversion from Lake Michigan to the CAWS, in addition to the total volume of water exchanged in the GLMRIS Locks on the busiest navigation day. LMDA data from 2007 to 2012 were utilized to identify the maximum diversion flows taken at each of the three locations over this time period. A seven-day moving average of daily diversion flows was calculated and the maximum daily flow was selected after the elimination of a few outlying data points. Navigation data from 2010–2011 were utilized to identify the greatest number of lockages in a day: 57 lockages on July 18, 2010 at T.J. O'Brien Lock and 149 on July 31, 2010 at Chicago Lock. The maximum number of lockages in a given day was multiplied by the lock volume to calculate the necessary treatment capacity to supply the GLMRIS Lock. As shown in Table F.8, these combined flowrates are quite large; plants large enough to meet this demand would be among the largest in the world (Greenemeier 2013). However, it is expected that operational efficiencies could be adopted to reduce the quantity of ANS-treated water needed.

Alternative Plan 5, Lakefront Hydrologic Separation, proposes ANSTPs at Wilmette, Chicago Lock, and T.J. O'Brien Lock and Dam. Alternative Plan 6, Mid-System Hydrologic Separation, proposes ANSTPs at Stickney and Alsip. The ANSTPs are intended to remove ANS of concern from Lake Michigan water so that it may be used for flow augmentation in the CAWS to mitigate water quality impacts. LMDA data from 2007 to 2012 were utilized to identify the maximum diversion flows taken at Wilmette Pumping Station, Chicago Lock, and O'Brien Lock and Dam over this time period. A seven-day moving average of daily diversion volumes was calculated and the maximum daily flow was selected after the elimination of a few outlying data points. Estimated plant capacity and required footprint for each ANSTP are provided below in Table F.8.

Alternative Plans 7 and 8 are "hybrid" alternatives. Alternative Plan 7, Mid-System Separation Cal-Sag Open Control Technologies with a Buffer Zone, is similar to Alternative Plan 4 (Technologies) on the Calumet River System and is similar to Alternative Plan 6 (Mid-System Separation) on the Chicago River system. Conversely Alternative Plan 8, Mid-System Separation CSSC Open Control Technologies with a Buffer Zone, is similar to Alternative Plan 6 (Mid-system Separation) on the Calumet River system and is similar to Alternative Plan 4 (Technologies) on the Chicago River system. Plant sizes for each were determined as described above.

TABLE F.8 ANSTP Sizes

Alt	Alt Name	ANSTP Location	Treatment volume (MGD)			Plant size (ac)
			Diversion	GLMRIS Lock	Total	
3	Mid-System Control Technologies without a Buffer Zone	Stickney	--	--	700	5.6
		Alsip	--	--	900	7.2
4	Technology Alternative with a Buffer Zone	Wilmette	200	0	200	0.7
		Chicago	450	1,300	1,750	5.7
		O'Brien	450	800	1,250	4.1
5	Lakefront Hydrosep	Wilmette	200	0	200	0.7
		Chicago	450	0	450	1.5
		Bishop Ford	450	0	450	1.5
6	Mid-System Hydrosep	Stickney	650	0	650	5.2
		Alsip	450	0	450	3.6
7	Cal-Sag Open	Stickney	650	0	650	5.2
		O'Brien	450	800	1,250	4.1
8	CSSC Open	Wilmette	200	0	200	0.7
		Chicago	450	1,300	1,750	5.7
		Alsip	450	0	450	3.6

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ATTACHMENT 1

MODELING EVALUATION OF THE WATER-QUALITY EFFECTS OF SEPARATION OF THE GREAT LAKES AND MISSISSIPPI RIVER BASINS IN THE CHICAGO AREA WATERWAYS SYSTEM

Institute for Urban Environmental Risk Management

Marquette University, Milwaukee WI 53201-1881

TECHNICAL REPORT # 21

MODELING EVALUATION OF THE WATER-QUALITY EFFECTS OF SEPARATION OF THE GREAT LAKES AND MISSISSIPPI RIVER BASINS IN THE CHICAGO AREA WATERWAYS SYSTEM

SUBMITTED TO

U.S. Army Corps of Engineers, Chicago District

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Milwaukee, Wisconsin

September 2013

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1 – INTRODUCTION

1.1 Background

1.1.1 The Chicago Area Waterways System (CAWS) and the Great Lakes and Mississippi River Interbasin Study

The City of Chicago, Illinois, is located at the southern end of Lake Michigan, the fifth largest freshwater lake in the world (by surface area) that serves as the water supply for Chicago and surrounding communities. In the 1800s, Chicago built a network of combined sewers to drain stormwater and wastewater from the city to the Chicago River and then to Lake Michigan. During large storms the polluted combined sewer flows would extend far enough into Lake Michigan that they would enter the water supply intakes for Chicago. This contributed to very high levels of death by typhoid fever in Chicago, peaking at more than 170 per 100,000 residents in 1891 (Hill, 2000).

In 1889, the Sanitary District of Chicago (now known as the Metropolitan Water Reclamation District of Greater Chicago, MWRDGC) was formed by the State of Illinois, and charged with building a canal that would carry flow from the polluted Chicago River away from Lake Michigan through the low continental divide west of Chicago to the Des Plaines River, Illinois River, and ultimately the Mississippi River (Lanyon, 2012). In 1892 construction began and in 1900 the Chicago Sanitary and Ship Canal (CSSC) was opened to reverse the flow of the Chicago River, thus, diverting the wastewater and combined sewer overflows from Chicago away from Lake Michigan and toward the Mississippi River. Two additional channels were later opened to improve water quality in the Chicago area: (1) the North Shore Channel (NSC, completed 1910) to flush water of poor quality from the North Branch Chicago River (NBCR) and (2) the Calumet-Sag Channel (completed 1922) to divert the Calumet River away from Lake Michigan. The lower portion of the NBCR, South Branch Chicago River (SBCR), Chicago River main stem, Calumet River, and Little Calumet River (north) also have been widened, deepened, and straightened to efficiently carry treated wastewater away from Lake Michigan.

The system of constructed and altered waterways described previously is known as the Chicago Area Waterway System (CAWS). In total, the CAWS is a 83.2 mi branching network of navigable waterways controlled by hydraulic structures in which the majority of flow is treated sewage effluent and there are periods of substantial combined sewer overflows (CSOs). The dominant uses of the CAWS are conveyance of treated municipal wastewater, commercial navigation, and flood control. The CAWS receives pollutant loads from 3 of the largest wastewater treatment plants in the world, nearly 240 gravity CSOs, 3 CSO pumping stations, eleven tributary streams or drainage areas, and direct diversions from Lake Michigan. The water quality in the CAWS also is affected by the operation of five Sidestream Elevated Pool Aeration (SEPA) stations and two in-stream aeration stations (IASs). The Calumet River and Chicago River systems are shown in Figure 1.1.

The operation of the CAWS has been a great public health success for the Chicago area (Hill, 2000; Lanyon, 2012), but the CAWS has created a pathway for non-indigenous aquatic species to migrate between the Great Lakes and Mississippi River basins. If invasive, non-indigenous species have the potential for populations to grow to such an extent that they are deemed undesirable, the species is known as an Aquatic Nuisance Species (ANS) (U.S. Army Corps of Engineers, 2011). The U.S. Fish and Wildlife Service (USFWS) developed a list of 21 non-indigenous aquatic species in the Mississippi River system but not yet observed in the Great Lakes, and a list of 120 non-indigenous aquatic species in the Great Lakes but not yet observed in the Mississippi River system (U.S. Army Corps of Engineers, 2010a). Among these species are the silver and big head Asian carp that have the potential to dominate a water body.

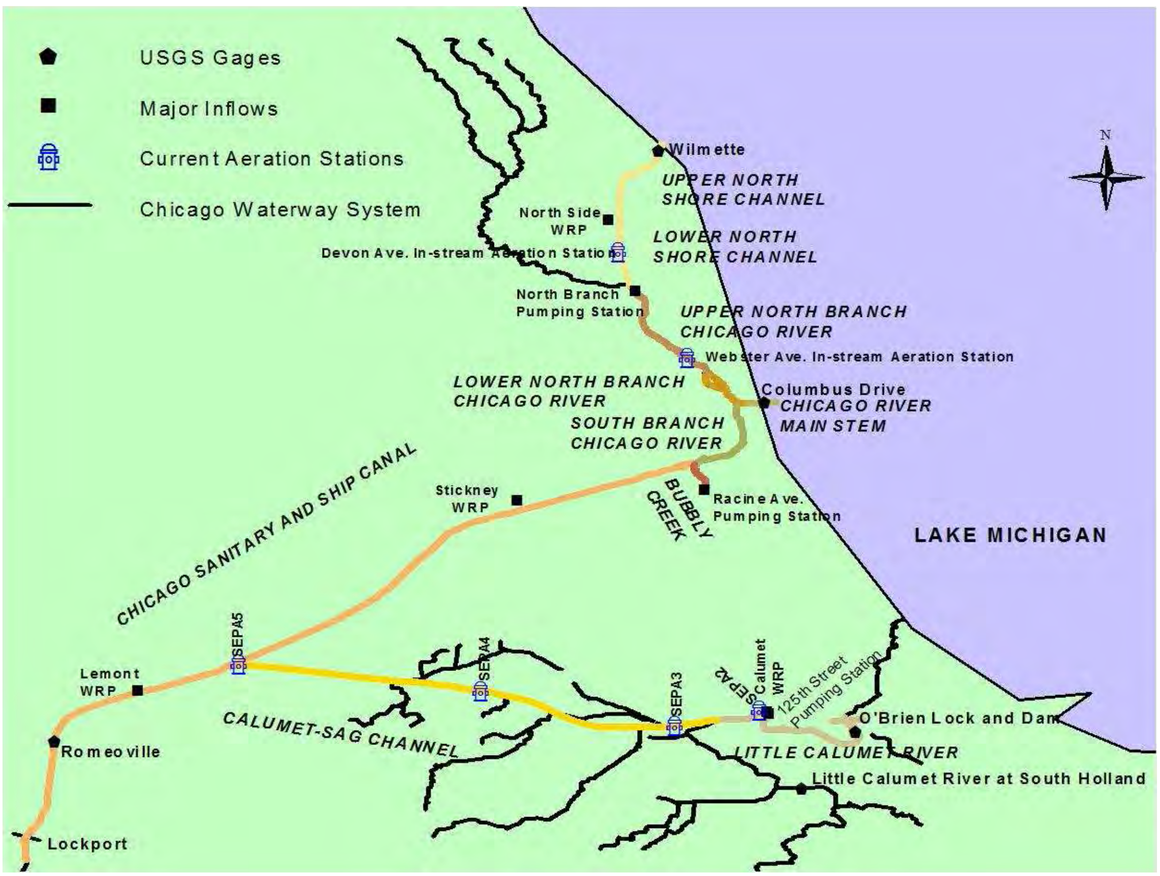

Figure 1.1. Schematic diagram of the Calumet and the Chicago River Systems (note: the upstream U.S. Geological Survey gages compose the upstream boundaries of the simulation model).

The possibility of the 141 species identified by the USFWS transferring between the basins and becoming ANSs harmful to the receiving ecosystem led the U.S. Congress to direct the U.S.

Army Corps of Engineers to initiate the Great Lakes and Mississippi River Interbasin Study (GLMRIS). The specific tasks of GLMRIS include (U.S. Army Corps of Engineers, 2010b):

- Inventory current and forecast future conditions within the study area (i.e. the Great Lakes and Mississippi River basins);
- Identify aquatic pathways that may exist between the Great Lakes and Mississippi River basins (the CAWS being the most prominent among these pathways);
- Inventory current and future potential ANS;
- Analyze possible ANS controls to prevent ANS transfer, to include hydrologic separation of the basins;
- Analyze the impacts each ANS control may have on significant natural resources and existing and forecasted uses of the lakes and waterways within the study area; and
- Recommend a plan to prevent ANS transfer between the basins. If necessary, the plan will include mitigation measures for impacted waterway uses and significant natural resources.

The project described in this report supports the fifth bullet in the foregoing list by analyzing the effects of potential hydrologic separation scenarios on the water quality in the CAWS and the pollutant loads to Lake Michigan.

1.1.2 Previous water-quality modeling studies of the CAWS

There have been several studies involving simulation of the water quality in the CAWS and the Upper Illinois River in the past. Major studies have included the study done in response to Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) by

Hydrocomp, Inc. (1979a and b) for the Northeastern Illinois Planning Commission (Hey et al., 1980) and a modeling study done by Camp, Dresser & McKee (CDM, 1992) for the MWRDGC. CDM (1992) used QUAL2EU (Brown and Barnwell, 1987) to simulate dissolved oxygen (DO) on the Chicago Waterway and Upper Illinois River. This QUAL2EU model has been used by the MWRDGC throughout the 1990s for water-quality management in the CAWS.

In 1998 the MWRDGC knew they would soon be faced with a number of difficult management issues including the impact of reduced discretionary diversions from Lake Michigan for water-quality improvement in the summer, the outcome of a use attainability analysis for the CAWS, the development total maximum daily load allocations, among other issues. Thus, in August 1998 they installed a network of 20 continuous DO and temperature measurement sondes throughout the CAWS (mainly on the Chicago River system). In July 2001 an additional 12 measurement sondes were added to the Calumet River system. From 1998 to the present the number of sondes in the network has increased and decreased such that 20 were active throughout 2008. These sondes provide hourly temperature and DO data that could be used to calibrate and verify a new water-quality model for the CAWS. Because of the dynamic nature of the CAWS the available QUAL2EU model was considered inadequate to evaluate the previously mentioned management issues and their impact on water quality in the CAWS. A model capable of simulating hydraulics and water-quality processes under unsteady-flow conditions was needed to assist the MWRDGC in water-quality management and planning decision making processes.

In 2000, a number of models were available for simulation of water quality under unsteady-flow conditions. Some models had been developed by U.S. government agencies, for example, the

Water-Quality Analysis and Simulation Program Version 5 (WASP5, Ambrose et. al., 1993), developed by the U.S. Environmental Protection Agency (USEPA) and the Branched Lagrangian Transport Model (BLTM, Jobson and Schoellhamer, 1987; Jobson, 1997), developed by the U.S. Geological Survey (USGS). The water-quality capabilities of these models are quite robust. However, the hydrodynamic portions of these models were less efficient in 2000. The hydrodynamic model suggested for coupling with WASP5 had a history of not performing well for one-dimensional unsteady flows in river systems. BLTM requires the development of a separate hydrodynamic model for the river system, and the computed stages and velocities must be transformed from the hydrodynamic-model output to the water-quality model input.

The DUFLOW Model (DUFLOW, 2000) was jointly developed in The Netherlands by the Rijkswaterstaat, International Institute for Hydraulic and Environmental Engineering of the Delft University of Technology, STOWA (Dutch acronym for the Foundation for Applied Water Management Research), and the Agricultural University of Wageningen. DUFLOW was considered a reasonable alternative to WASP (in fact, it included an option to use the WASP4 (Ambrose et al., 1988) routines to compute water-quality in the water column) and BLTM. DUFLOW has been applied with great success to several European river systems (e.g., Manache and Melching, 2004). In the study of Manache and Melching (2004), DUFLOW was found to be computationally robust with few computational failures encountered over thousands of runs. It allows several options for the simulation of water quality in stream systems, including allowing the user to add relations for the simulation of additional water-quality properties or constituents not originally included in the preprogrammed DUFLOW options. Finally, DUFLOW's compatibility with Geographical Information Systems (GIS) facilitated representation and display of the river system, its compatibility with Microsoft Windows facilitated ease of use and the import and export of input and results to and from Microsoft Excel, and its relatively low license cost made it affordable for many applications. Given these capabilities and advantages, DUFLOW was selected for modeling of the CAWS, and the MWRDGC entered into an agreement with Marquette University in 2000 to adapt the DUFLOW model for simulation of the hydraulics and water-quality processes of the CAWS. In the first several years of the adaptation of the DUFLOW model for the CAWS the MWRDGC convened an ad-hoc committee of representativeness from government agencies in Illinois—USEPA, Region 5; U.S. Army Corps of Engineers, Chicago District; USGS, Illinois District; and Illinois Environmental Protection Agency (IEPA)—to keep these agencies informed of and to get their input on the development of the model.

To simulate water quality in the CAWS the DUFLOW water-quality simulation option that adds the DiToro and Fitzpatrick (1993) sediment flux model to the WASP4 (Ambrose et al., 1988) model of constituent interactions in the water column is applied. DUFLOW distinguishes among transported material that flows with water, bottom materials that are not transported with the water flow, and pore water in bottom materials that are not transported but that can be subject to similar water-quality interactions to those for the water column. Flow movement and constituent transport and transformation are simulated within DUFLOW and constituent transport is defined by advection and dispersion. The flow simulation in DUFLOW is based on the one-dimensional (1-D) partial differential equations that describe unsteady flow in open channels (de Saint-Venant equations). These equations are the mathematical translation of the laws of conservation of mass and momentum.

Marquette University has successfully applied the DUFLOW water-quality model to the CAWS for several purposes: i) Alp and Melching (2004) used the DUFLOW model to investigate the possible effects of a change in navigational water level requirements and the navigation make-up diversion of water from Lake Michigan during storm events on water-quality in the CAWS, ii) Neugebauer and Melching (2005) developed a method to verify the calibrated DUFLOW model under uncertain storm loads, iii) Manache and Melching (2005) applied the DUFLOW model to simulate fecal coliform concentrations in the CAWS under unsteady flow conditions; iv) Alp and Melching (2006) evaluated the effectiveness of flow augmentation, supplemental aeration, and combined sewer overflow (CSO) treatment acting individually to improve dissolved oxygen (DO) conditions in the CAWS; and v) Melching et al. (2010, 2013) developed integrated strategies that combined flow augmentation and supplemental aeration in the CAWS to achieve compliance with various proposed DO standards for the CAWS.

The hydraulic component of the DUFLOW (2000) unsteady-flow model for the CAWS was calibrated and verified by Marquette University in 2003. The ability of the model to simulate unsteady flow conditions was demonstrated by comparing the simulation results to measured data for eight different periods between August 1, 1998 and July 31, 1999 (Shrestha and Melching, 2003). The DUFLOW water-quality model was calibrated and verified (Alp and Melching, 2006; Neugebauer and Melching, 2005) for the periods of July 12 to November 9, 2001 and May 1 to September 23, 2002, respectively. After these initial calibrations and verifications, the DUFLOW hydraulic and water-quality models were calibrated and verified in more detail for the full 2001 and 2003 Water Years (WYs) by Melching et al. (2010). The Water

Year begins on October 1 and ends on September 30 of the following year and is denoted by the year in which it ends.

1.2 Project Objective and Scope

The GLMRIS feasibility study is being undertaken to develop a long-term solution to prevent ANS from traveling between the Great Lakes and Mississippi River basins. One primary goal of the study is to assess the feasibility of hydrologically separating the two basins, which are currently connected through the CAWS. Re-separating the basins will radically alter the existing flow patterns in the system, and is expected to cause substantial water-quality changes. Modeling and analysis of water quality impacts to both the CAWS and Lake Michigan are needed to ensure any selected alternative will be in compliance with Illinois water-quality standards and the Clean Water Act. Thus, the objective of this project is to apply the DUFLOW model of the CAWS to simulate the water-quality response to three alternative scenarios—"No Project," "Lakefront Separation," and "Midsystem Separation." The simulation will be done for representative wet, dry, and normal years (described in Section 1.3) for baseline flow conditions that represent CSO flows with the Thornton Reservoir and McCook Reservoir Stage 1 on-line and future flow conditions that represent CSO flows with both reservoirs fully on-line. The simulation results will be analyzed to determine changes in compliance with water-quality standards for DO, fecal coliform, and chloride in the CAWS and in loads of nutrients, chloride, and fecal coliforms to Lake Michigan for the separation alternatives relative to the No Project scenario.

As a result of an Use Attainability Analysis (UAA) of the CAWS (CDM, 2007), the IEPA (2007) proposed two aquatic life use classes for the CAWS—Chicago Area Waterway System Aquatic Life Use A waters (CAWS A) and Chicago Area Waterway System and Brandon Pool Aquatic Life Use B waters (CAWS B)—to the Illinois Pollution Control Board (IPCB). For CAWS A waters the following DO concentration targets must be met or exceeded:

During the period of March through July, 5.0 mg/L at all times

During the period August through February

4.0 mg/L as a daily minimum averaged over 7 days, and

3.5 mg/L at all times

For CAWS B waters the following DO concentration targets must be met or exceeded:

4.0 mg/L as a daily minimum averaged over 7 days, and

3.5 mg/L at all times

In the original rulemaking proposal from the IEPA to the IPCB (IEPA, 2007) the lower NBCR downstream from Division Street, the Chicago River main stem, SBCR, and CSSC were proposed as CAWS B waters and all others were proposed as CAWS A waters. However, in recent negotiations between the IEPA and MWRDGC on the aquatic life uses and appropriate DO standards for the CAWS only the CSSC is considered a CAWS B water with the remainder of the waterways being CAWS A waters (i.e. subject to the 5 mg/L limit in spring and early summer). This designation of the waterways is applied when evaluating the compliance with DO standards for the various alternatives considered in this study. However, it should be noted that the designation of the CSSC as a CAWS B water and the all other waterways in the CAWS as CAWS A waters is not yet final and still subject to ongoing discussions among the IEPA and MWRDGC and a final rule making by the IPCB. Finally, modeling trials done by Melching et al. (2010) found that 3.5 mg/L at all times was more restrictive than 4.0 mg/L as a daily minimum averaged over 7 days, and, thus, only the absolute minimum DO standards were used for calculating percentage compliance with the DO standards in this study.

For fecal coliform, the General Use water-quality standard in Illinois is as follows: During the months of May through October, based on a minimum of five samples taken over not more than a 30-day period, fecal coliform shall not exceed a geometric mean of 200 coliform forming units (CFU) per 100 mL, nor shall more than 10% of the samples during any 30 day period exceed 400 CFU per 100 mL. These criteria are not easily evaluated for the case of the hourly output from the DUFLOW model as opposed to a much smaller number of field samples. Thus, to conservatively evaluate the compliance with fecal coliform standards any hourly value greater than 200 CFU per 100 mL in the months of May through October was considered an hour of non-compliance in the scenario evaluations done in this study.

For chloride, the USEPA (1986) recommended criteria for aquatic life are for acute toxicity the dissolved chloride concentration should not exceed 860 mg/L more than once every three years on the average, and for chronic toxicity the 4-day average concentration of dissolved chloride should not exceed 230 mg/L more than once every three years on the average. The simulation results indicated that concentrations greater than 860 mg/L occurred for a limited number of hours within much longer periods during which the chronic toxicity standard was exceeded. Thus, evaluation of the chronic toxicity standard provides a stringent evaluation of chloride problems without omitting any instance of an exceedance of the acute toxicity standard. Thus, no evaluation of acute toxicity was done in this study. In this study, non-compliance of chronic chloride toxicity standards was evaluated by determining the number of hours for which the 4-day moving average of the chloride concentration is greater than 230 mg/L for the various scenarios for each year and hydrologic condition.

1.3 Selection of Representative Wet, Dry, and Normal Years

Representative “wet”, “dry”, and “normal” years were selected in order to be sure that the water-quality effects of the hydrological separation of the Great Lakes and Mississippi River basins in the CAWS could be determined over a reasonable range of hydrologic conditions. These years must be selected from the Water Years between 1997 and 2010 because hourly water reclamation plant (WRP) flows are no longer available prior to the 1997 WY. Also, the continuous temperature and DO monitors on the CAWS first began collecting data in August 1998. Thus, in order to verify the model performance for the selected years and make adjustments, if necessary, Water Years 1999 to 2010 are potential candidate years.

Normally, representative “wet”, “dry”, and “normal” years should be selected on the basis of flow. However, the discharge on the Chicago Sanitary and Ship Canal at Romeoville through 2005 and at Lemont between 2005 and 2010 is greatly affected by water use in the Chicago area and seepage at the Lakefront structures separating the CAWS from Lake Michigan. This discharge is, therefore, not a good measure of runoff, which composes about 25% of the flow at Romeoville/Lemont, to the CAWS. The main gaged tributaries to the CAWS—Little Calumet River at South Holland and North Branch Chicago River at Albany Avenue at Chicago—represent conditions to the south and north, respectively, of the CSO drainage areas tributary to the CAWS. Thus, annual flows at these locations may not be representative of conditions in the main CSO areas draining to the CAWS.

Given the lack of representative flow data for the CSO drainage area to the CAWS, precipitation data and CSO pump station operation data were used to select the representative “wet”, “dry”, and “normal” years. To give a long-term perspective, precipitation data from the National Weather Service for O’Hare Airport (since WY 1963) and Midway Airport (since WY 1951) were considered through WY 2012 (Figure 1.2). To give an area-wide perspective the average precipitation measured at the 25 precipitation gages spread over the CSO drainage area in Cook County established by the U.S. Army Corps of Engineers and operated by the Illinois State Water Survey (ISWS) for use in the Lake Michigan Diversion Accounting (since WY 1990) were also considered through WY 2012 (also in Figure 1.2). Table 1.1 lists the total annual precipitation at O’Hare Airport, Midway Airport, and for the ISWS network average and the ranking from the highest annual rainfall over the period of record for each Water Year between 1997 and 2010. The long term average annual precipitation is 35.28, 36.20, and 36.77 in. and the long term median annual precipitation is 35.28, 37.11, and 36.33 in. at O’Hare Airport, Midway Airport, and for the 25 gage ISWS network, respectively. Seven of the fourteen years (WYs 1997 to 2010) had above average precipitation at O’Hare Airport, six of the fourteen years had above average precipitation at Midway Airport, and five of the fourteen years had above average precipitation for the 25 gage ISWS network.

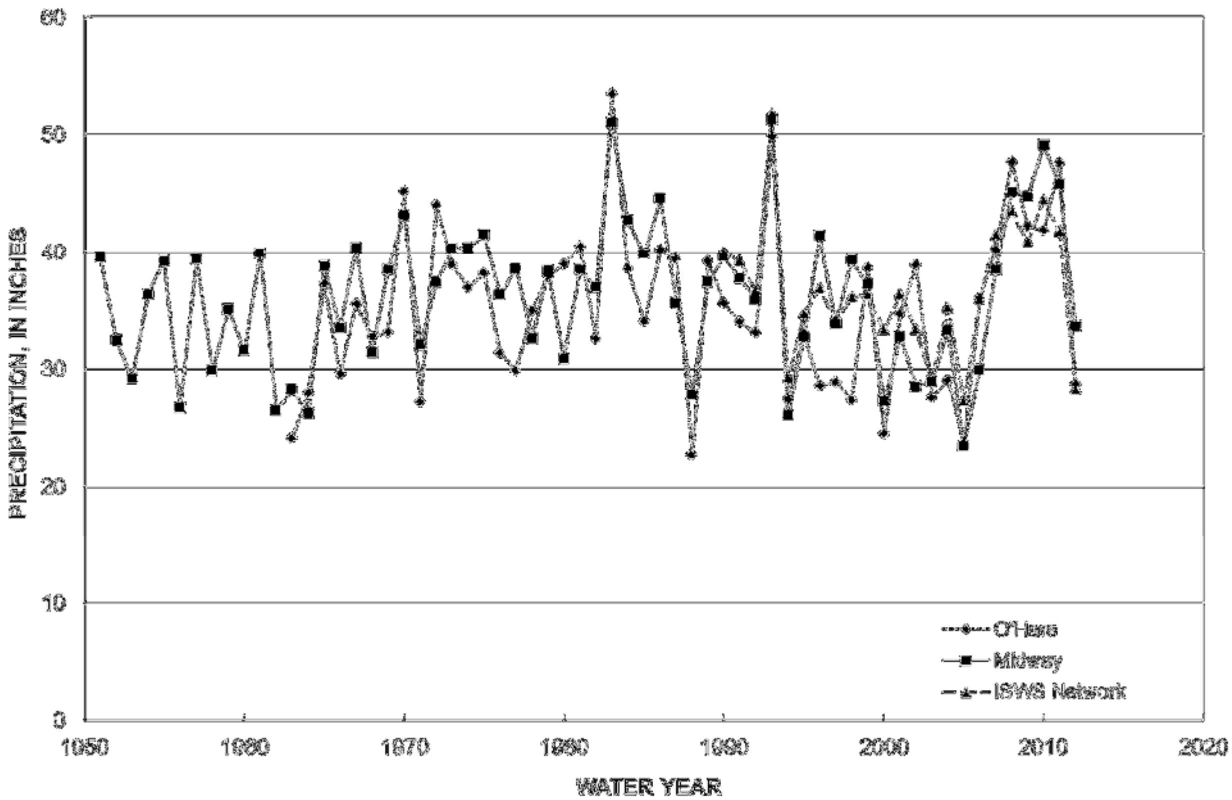

Figure 1.2. Annual Precipitation by Water Year at O'Hare Airport, Midway Airport, and for the Illinois State Water Survey (ISWS) 25 gage network in Cook County, IL.

On the basis of precipitation WYs 2008 or 2010 would appear to be an excellent representative "wet" year. WY 2010 ranks third at Midway Airport (over 62 years) and the second among 23 years for the ISWS Network, but only eighth at O'Hare Airport (over 50 years). WY 2008 ranks fifth at Midway Airport (over 62 years), third second among 23 years for the ISWS Network, and third at O'Hare Airport (over 50 years). The goal of representative is to be in the top (or bottom) quartile of years, but not being the wettest or driest year. If the volume of CSO flow at the pumping stations is considered, WY 2010 ranks fifth and WY 2008 ranks only seventh among the 20 years beginning in WY 1993 (Figure 1.3). These lower rankings in terms of CSO flow compared to precipitation reflect the fact that the Tunnel and Reservoir Plan (TARP) tunnels were completed in 2006. Thus, earlier years only had a portion of the TARP tunnel storage available beginning in 2006. Even though WY 2010 is slightly wetter than WY 2008 in terms of precipitation and CSO flow, WY 2008 was selected as the representative "wet" year because the storm of September 13-14, 2008 resulted in the largest flow reversal to Lake Michigan since the TARP tunnels started to capture combined sewer flows in 1985. The flow reversal of September 13-14, 2008 was 11049.1 million gallons (mgal) nearly double that of July 23-24, 2010 (6534.9 mgal) and this event will present an interesting example of the flow and water-quality challenges the basin hydrologic separation scenarios could face.

WY 2001 ranked 27th of 50 years and 11th of 23 years in the rankings of annual precipitation for O'Hare Airport and the ISWS Network, respectively. Further, the annual precipitation for WY 2001 was within 1% of the mean and median annual precipitation values for the ISWS network and within 2% of the mean and median annual precipitation values at O'Hare Airport. In terms of CSO flow volume at the pumping stations, WY 2001 ranked 12th of 20 years with the volume within 7.5% of the mean and median annual pump station CSO flows. Only for the precipitation at Midway Airport WY 2001 is not a typical "normal" year. At Midway Airport the precipitation for WY 2001 is in the lower third of years and the annual precipitation for WY 2001 in 9.6% lower than the mean and 11.8% lower than the median at Midway Airport. WY 1999 is near the mean and median precipitation for the ISWS network (12th of 23 years) and Midway Airport (31st of 62 years), but it falls near the upper third at O'Hare Airport (17th of 50 years). WY 1999 would also pose a substantial practical problem for the water-quality modeling because during that year no DO and temperature monitors were in the Little Calumet River (north) – Calumet-Sag Channel (Calumet system) reaches of the CWS. Thus, it would be difficult to have accurate temperature values for these reaches in the model. Therefore, WY 2001 was selected as the representative “normal” year for the evaluation of water-quality effects of hydrologic separation of the Great Lakes and Mississippi River basins in the CAWS.

Table 1.1. Annual precipitation depth and rank from the highest among the recorded years for O’Hare Airport, Midway Airport, and the Illinois State Water Survey (ISWS) 25 gage network in Cook County, IL for Water Years 1997-2010.

Water Year	O’Hare Airport		Midway Airport		ISWS Network	
	Depth	Rank among 50	Depth	Rank among 62	Depth	Rank among 23
2008	47.68	3	45.21	5	43.44	3
2010	41.87	8	49.11	3	44.46	2
2009	42.24	7	44.76	6	40.85	6
2007	40.23	10	38.47	26	41.47	5
2001	34.71	27	32.74	42	36.39	11
1999	38.60	17	37.23	31	36.33	12
1998	27.35	45	39.30	20	36.12	13
2006	36.07	23	29.96	45	35.89	14
2004	29.05	38	33.23	41	35.24	15
1997	28.89	39	33.90	38	34.09	17
2002	38.86	16	28.53	54	33.37	18
2000	24.47	47	27.28	57	33.33	19
2003	27.58	43	28.97	53	29.03	21
2005	23.68	49	23.45	62	27.29	23

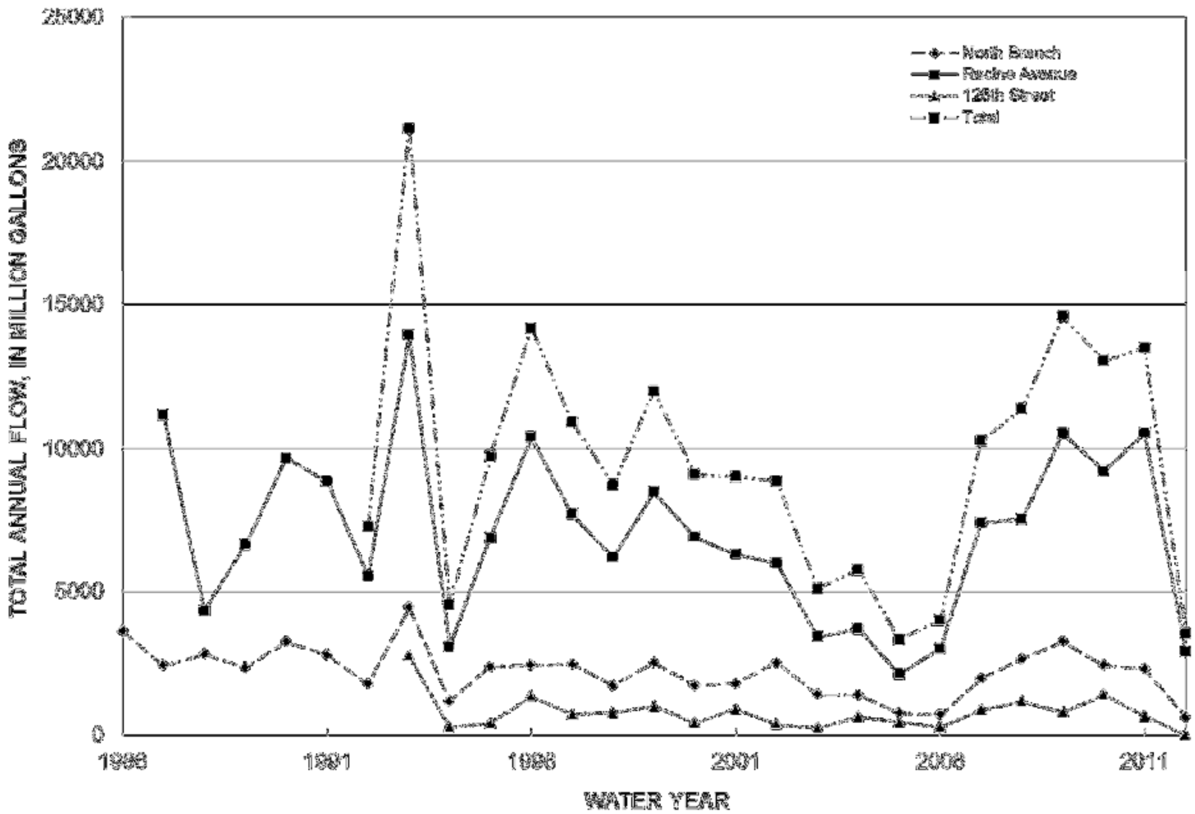

Figure 1.3. Volume of annual combined sewer overflow at the North Branch, Racine Avenue, and 125th Street Pumping Stations.

The selection of the representative "dry" year was much easier. WY 2005 probably is the driest year in the last 60 years as it ranks last in annual rainfall at Midway (over 62 years), second to last at O'Hare Airport over 50 years, and last for the ISWS network over 23 years. Further, it yielded the smallest volume of CSO flow at the pumping stations among the 20 years beginning from WY 1993. However, the representative "dry" year should not be the driest year. WY 2003 ranks as the fifth smallest CSO volume at the pumping stations among 20 years (lower 25% with two of the lowest years reflecting completed TARP tunnels—2006 and 2012) and it ranks in the lower 16% of years in terms of precipitation at O'Hare Airport and Midway Airport and the lower 10% for the ISWS network (i.e. third smallest). Given these facts, WY 2003 was selected as the representative “dry” year for the evaluation of water-quality effects of hydrologic separation of the Great Lakes and Mississippi River basins in the CAWS.

1.4 Key Geographic Locations in the CAWS

The DUFLOW model yields computed values of any of the simulated water-quality constituents and properties at any the computational points in the CAWS (more than 100 points). Thus, to keep the comparison manageable it is focused on the measurement points for the various water quality constituents and properties monitored by the MWRDGC and used to calibrate and verify the model. These measurement locations are the key geographic locations for demonstration of model accuracy and for comparison of the results of the hydrological separation alternatives. These locations are identified in two ways in this report, i.e. by their place names (i.e. name of a nearby street, railroad, or other physical location) and by the River Mile measured from the confluence of the Illinois River and Mississippi River. The U.S. Army Corps of Engineers, Chicago District, understands locations in the CAWS on the basis of river miles, whereas people at the MWRDGC and the local population of the Chicago area think in terms of place names. Thus, to serve the broader range project stakeholders both locational designations are used in the report. To clarify the relation between river miles and place names Figure 1.4 shows a map of the CAWS where place names, waterway reaches, and river miles are related, and Tables 1.2 and 1.3 list the place names, waterway reaches, and river miles of the key geographical locations referred to in this report. The river miles listed in Tables 1.2 and 1.3 (and used in the spatial plots of results in later chapters) were obtained from the USGS (Healy, 1979) whereas the river miles shown in Figure 1.4 are those determined by the U.S. Army Corps of Engineers. At many locations the USGS and U.S. Army Corps of Engineers river mile designations are the same, but at many other locations there is a 0.1 mile (or at most 0.2 mile) difference between the two designations.

Table 1.2. River mile designations for the various locations along the Chicago River system where model was calibrated and/or verified for at least one constituent or property and at which the various alternatives are compared. (River Miles are as determined by the U.S. Geological Survey as listed in Healy(1979)).

Location	Waterway	River Mile
Central Street	North Shore Channel	340.2
Simpson Street	North Shore Channel	339.5
Main Street	North Shore Channel	337.5
Oakton Street	North Shore Channel	337.0
Touhy Avenue	North Shore Channel	336.0
Foster Avenue	North Shore Channel	333.4
Wilson Avenue	North Branch Chicago River	332.6
Addison Street	North Branch Chicago River	331.3
Diversey Parkway	North Branch Chicago River	330.1
Fullerton Avenue	North Branch Chicago River	329.4
Division Street	North Branch Chicago River	327.3
Grand Avenue	North Branch Chicago River	326.0
Kinzie Street	North Branch Chicago River	325.8
Clark Street	Chicago River main stem	325.9
Wells Street	Chicago River main stem	325.8
Madison Street	South Branch Chicago River	325.3
Jackson Boulevard	South Branch Chicago River	325.0
Loomis Street	South Branch Chicago River	321.9
Damen Avenue	Chicago Sanitary and Ship Canal	321.1
Western Avenue	Chicago Sanitary and Ship Canal	320.6
Cicero Avenue	Chicago Sanitary and Ship Canal	317.3
Harlem Avenue	Chicago Sanitary and Ship Canal	314.0
Baltimore & Ohio Railroad	Chicago Sanitary and Ship Canal	312.3
Route 83	Chicago Sanitary and Ship Canal	304.1
Stephen Street	Chicago Sanitary and Ship Canal	300.5
Romeoville Road	Chicago Sanitary and Ship Canal	296.2
Lockport Controlling Works	Chicago Sanitary and Ship Canal	293.2

Figure 1.4. Waterway reaches, river miles (RM), and key geographical locations in the Chicago Area Waterways System (figure provided by the U.S. Army Corps of Engineers, Chicago District).

Table 1.3. River mile designations for the various locations along the Calumet River system where model was calibrated and/or verified for at least one constituent or property and at which the various alternatives are compared. (River Miles are as determined by the U.S. Geological Survey as listed in Healy (1979)).

Location	Waterway	River Mile
130th Street	Calumet River	327.0
Conrail Railroad	Little Calumet River (north)	325.4
Central & Wisconsin Railroad	Little Calumet River (north)	322.6
Indiana Avenue	Little Calumet River (north)	322.4
Halsted Street	Little Calumet River (north)	320.1
Ashland Avenue	Calumet-Sag Channel	319.1
Division Street	Calumet-Sag Channel	318.6
Kedzie Street	Calumet-Sag Channel	317.1
Cicero Avenue	Calumet-Sag Channel	315.0
Harlem Avenue	Calumet-Sag Channel	311.7
Southwest Highway	Calumet-Sag Channel	310.7
104th Avenue	Calumet-Sag Channel	307.5
Route 83	Calumet-Sag Channel	304.3

1.5 Report Organization

Modifications and upgrades to the DUFLOW model of the CAWS are presented in Chapter 2. Hydraulic verification for WY 2008 of the previously calibrated DUFLOW model is presented in Chapter 3. Verification of the water quality-model for WY 2008 for all constituents and for WY 2001 for DO is detailed in Chapter 4. The flow and temperature changes for the scenarios evaluated are summarized in Chapter 5. The comparison of simulated concentrations of DO, fecal coliform, chloride, and total phosphorus, the compliance of the first three of these with water-quality standards, and the loads to Lake Michigan for the “No Project,” “Lakefront Separation,” and “Midsystem Separation” scenarios are presented for WYs 2001, 2003, and 2008 in Chapters 6, 7, and 8, respectively. Chapter 9 presents the summary and conclusions of this study.

1.6 Acknowledgement

The project described in this report was supported by Grant/Cooperative Agreement Number G11AP20226 from the U.S. Geological Survey (USGS) and Contract Number W912P6-12-0047 from the U.S. Army Corps of Engineers (USACE). The contents of this report are solely the responsibility of the authors and do not necessarily represent the official views of the USGS or USACE. Mention of trade names or commercial products in this report does not constitute their endorsement by the U.S. Government.

Chapter 2 – MODIFICATIONS AND UPGRADES TO THE DUFLOW MODEL

2.1 New Water-Quality Constituents and Properties Simulated

For the GLMRIS project values of the following water quality parameters are required to get a clear picture of the effects of ecological/hydrological separation of the watersheds on the CAWS and on Lake Michigan.

- DO
- Ammonium
- Nitrate/Nitrite
- Carbonaceous Biochemical Oxygen Demand (CBOD)
- Total Suspended Solids (TSS)
- Total Phosphorus
- Temperature*
- Fecal Coliform*
- pH*
- Chloride*

The equations used in the DUFLOW model to simulate DO, ammonia, nitrate/nitrite, CBOD, TSS, and total phosphorus (as well as related parameters such as organic nitrogen, chlorophyll a, among others) are given in DUFLOW (2000). The assumptions regarding the concentrations of these constituents in the inflows to the CAWS from Lake Michigan, tributary streams and rivers, and combined sewer overflows are described in Melching et al. (2010) and Neugebauer and

Melching (2005). The assumptions regarding the DO loads from the IASs and SEPA stations are described in Melching et al. (2010) and Alp and Melching (2004). The calibration and verification quality of the DUFLOW model in the simulation of DO, CBOD, ammonium, nitrate/nitrite, chlorophyll a, and sediment oxygen demand for WYs 2001 and 2003 are presented in Melching et al. (2010). The verification quality for these constituents plus total phosphorus and TSS for WY 2008 is presented in Chapter 4.

If the DUFLOW model did not originally include a constituent or property, it is indicated with a * in the foregoing list. The capability of modeling these parameters was added to the DUFLOW model during this study, and the details of how these parameters are simulated in the DUFLOW model and the quality of the simulation are summarized in this chapter.

A version of the DUFLOW model that simulates fecal coliform concentrations (Manache and Melching, 2005; Manache et al., 2007) did exist at the start of this project, but it needed to be updated to consider the extension of the downstream boundary from Romeoville to the Lockport Controlling Works, the increase in representative combined sewer overflow (CSO) locations from 28 to 43, and the new fecal coliform data for CSOs collected by the MWRDGC in 2007.

2.1.1 Temperature

Background

Temperature has important effects on simulation of water quality constituents related to DO. The rate coefficients that describe the relations between various constituents are affected by temperature, and the saturation concentration of DO in water is affected by temperature. The DUFLOW (2000) model does not include routines for simulating the heat balance and temperature of a river system. Thus, in the original DUFLOW model of the CAWS (Alp and Melching, 2006; Melching et al., 2010) measured hourly temperatures were input at 27 locations throughout the CAWS listed in Table 2.1. These locations were selected on the basis of stations operational throughout the majority of the time periods that were the focus of the earlier studies (Alp and Melching, 2006; Melching et al., 2010): WYs 2001 and 2003 and May 1 to September 23, 2002. Thus, the Devon Avenue monitor that was discontinued in January 2001 and the Loomis Street monitor that was discontinued in January 2001 and re-activated in April 2003 were not included in the model.

The missing temperature records for WYs 2001 and 2003 were estimated by linear interpolation in time for shorter periods of missing record and by linear interpolation between neighboring monitors for longer periods of missing record. Since nearly all the monitors on the Calumet-Sag Channel and the Little Calumet River (north) were installed in July 2001, monthly average temperatures from later years were used for October 2000 through the monitor's installation date in July 2001.

Being able to use measured hourly temperatures at so many locations throughout the CAWS has contributed substantially to the reliability of the DUFLOW model of the CAWS in simulating DO and related constituents. However, measured temperature data will not be available to reflect temperature conditions in the CAWS for the various ecological/hydrological separation scenarios to be considered. Temperatures in the CAWS will change substantially at certain times of the year as the discretionary diversion of cooler Lake Michigan water into the CAWS will stop after ecological/hydrological separation is imposed. Even the baseline conditions reflecting flows in 2017 after the Thornton Reservoir and the first stage of the McCook Reservoir are on line will be different because of the closure of the Fisk and Crawford power plants in September 2012, and the retirement of the Will County Power Plant units 1 and 2 at the end of 2010 (Julia Wozniak, Midwest Generation, written communication to Dave Wethington, U.S. Army Corps of Engineers, May 30, 2012). Therefore, a model must be developed to estimate temperatures in the CAWS that reflect the baseline conditions and the conditions after various ecological/ hydrological separation scenarios are applied.

The University of Iowa developed a detailed, physics-based model, called the CHARIMA model, of the thermal regime of a portion of the CAWS for Commonwealth Edison. The model domain included 55 miles of waterway from Roosevelt Road on the South Branch Chicago River (River Mile, RM, 324.3) to Dresden Island Dam on the Illinois River (Figure 2.1). Short segments of the Bubbly Creek, Calumet-Sag Channel, Des Plaines River, Hickory Creek, DuPage River, and Kankakee River are included where they flow into the main waterway being simulated (Mohammad and Holly, 1994). The hydraulics of the waterway were simulated using the de Saint Venant Equations (the same as in the DUFLOW model) solved on a one-mile spatial grid at a 30 min time step. The thermal/temperature regime of the waterway was simulated using an Advection-Diffusion-Source equation for unsteady transport of a fully mixed, dissolved constituent.

Table 2.1. Locations of the continuous temperature monitoring stations of the Metropolitan Water Reclamation District of Greater Chicago in the modeled portion of the Chicago Area Waterways System used for specification of temperature in the DUFLOW model.

Station Location	Waterway	River Mile*	Period of Record**
Linden Avenue	North Shore Channel	340.8	August 1998 – March 2004
Simpson Street	North Shore Channel	339.5	August 1998 – March 2004
Main Street	North Shore Channel	337.7	August 1998 – Dec. 2010
Addison Street	North Branch Chicago River	331.4	August 1998 – Present
Fullerton Avenue	North Branch Chicago River	329.5	August 1998 – Dec. 2010
Division Street	North Branch Chicago River	327.4	August 1998 – March 2004
Kinzie Street	North Branch Chicago River	325.8	August 1998 – Present
Chicago River Controlling Works	Chicago River main stem	327.1	March 2000 – March 2004
Clark Street	Chicago River main stem	325.9	August 1998 – Dec. 2010
Jackson Boulevard	South Branch Chicago River	325	August 1998 – March 2004
Cicero Avenue	Chicago Sanitary and Ship Canal	317.2	August 1998 – Present
Baltimore and Ohio Railroad	Chicago Sanitary and Ship Canal	312.3	August 1998 – Present
Route 83	Chicago Sanitary and Ship Canal	304.1	August 1998 – Dec. 2010
Mile 302.6	Chicago Sanitary and Ship Canal	302.6	August 1998 – March 2004
Romeoville	Chicago Sanitary and Ship Canal	296.1	August 1998 – March 2004
Lockport Powerhouse	Chicago Sanitary and Ship Canal	291	August 1998 – Present
130th Street	Calumet River	327	July 2001 – March 2004
Conrail Railroad	Little Calumet River (north)	325.4	July 2001 – March 2004
Central and Wisconsin Railroad	Little Calumet River (north)	322.6	July 2001 – Present
Halsted Street	Little Calumet River (north)	320.1	July 2001 – Present
Ashland Avenue	Little Calumet River (south)	321.3	July 2001 – Present
Division Street	Calumet-Sag Channel	318.6	July 2001 – March 2004
Kedzie Avenue	Calumet-Sag Channel	317.1	July 2001 – March 2004
Cicero Avenue	Calumet-Sag Channel	315	July 2001 – December 2010
Harlem Avenue	Calumet-Sag Channel	311.7	July 2001 – November 2004
Southwest Highway	Calumet-Sag Channel	310.7	July 2001 – March 2004
Route 83	Calumet-Sag Channel	304.3	August 1998 - Present

* River miles for the Chicago Waterway System are given relative to the confluence of the Illinois River with the Mississippi River at Grafton, Ill.

** Present refers to June 2011 when Jennifer Wassik, MWRDGC, provided a table on the sampling history and status at each monitoring location.

The CHARIMA model of the thermal regime of the waterway system reflects complex interactions among wastewater return flows, lake diversions, heat rejection from 6 fossil-fuel power plants using once through cooling, atmospheric heat exchange, and unsteady flow (Wright and Holly, 1996). A key component of the CHARIMA model is the source/sink term for heat exchange between water and the atmosphere. This term comprises detailed expressions for the physical processes of water heating due to incoming short-wave and long-wave radiation and condensation, water cooling due to outgoing long-wave radiation and evaporation, and water heating due to conduction (Wright and Holly, 1996). Time-dependent discharges and water temperatures were specified at the primary model inflow point and all tributary inflows, including the Stickney Water Reclamation Plant (WRP). The 6 power generating stations are modeled as links that withdraw the condenser flow rate from the main channel, heat it by an amount proportional to the temperature rise at full load using the specified time-dependent power generation schedule, and return it to the channel (Wright and Holly, 1996). Overall, the calibrated CHARIMA model was considered to be accurate within about 1°F (0.556°C) for cross-sectional average conditions (Wright and Holly, 1996).

Extension of the CHARIMA model to the entire CAWS and recalibrating it to simulate conditions in the selected test water years (WYs 2001, 2003, and 2008) was impractical given the tight time frame for completing the GLMRIS study. Further, experience with filling in missing temperature data indicated that there was a strong correlation between measured temperatures at adjacent monitoring sites (see Figure 2.2 for an example of this correlation). Thus, it was thought that a simple model could be derived using linear regression between adjacent monitoring sites and adjusting for the temperature mass balance when two flow streams come together (e.g., locations where the WRPs discharge to the CAWS between monitoring sites) that could yield similar accuracy to that from the physics-based CHARIMA model. Figure 2.3 shows the mass balance principle as the temperature at Jackson Boulevard on the South

Branch Chicago River falls in between the temperatures at Kinzie Street on the NBCR and Clark Street on the Chicago River main stem which merge and flow into the SBCR.

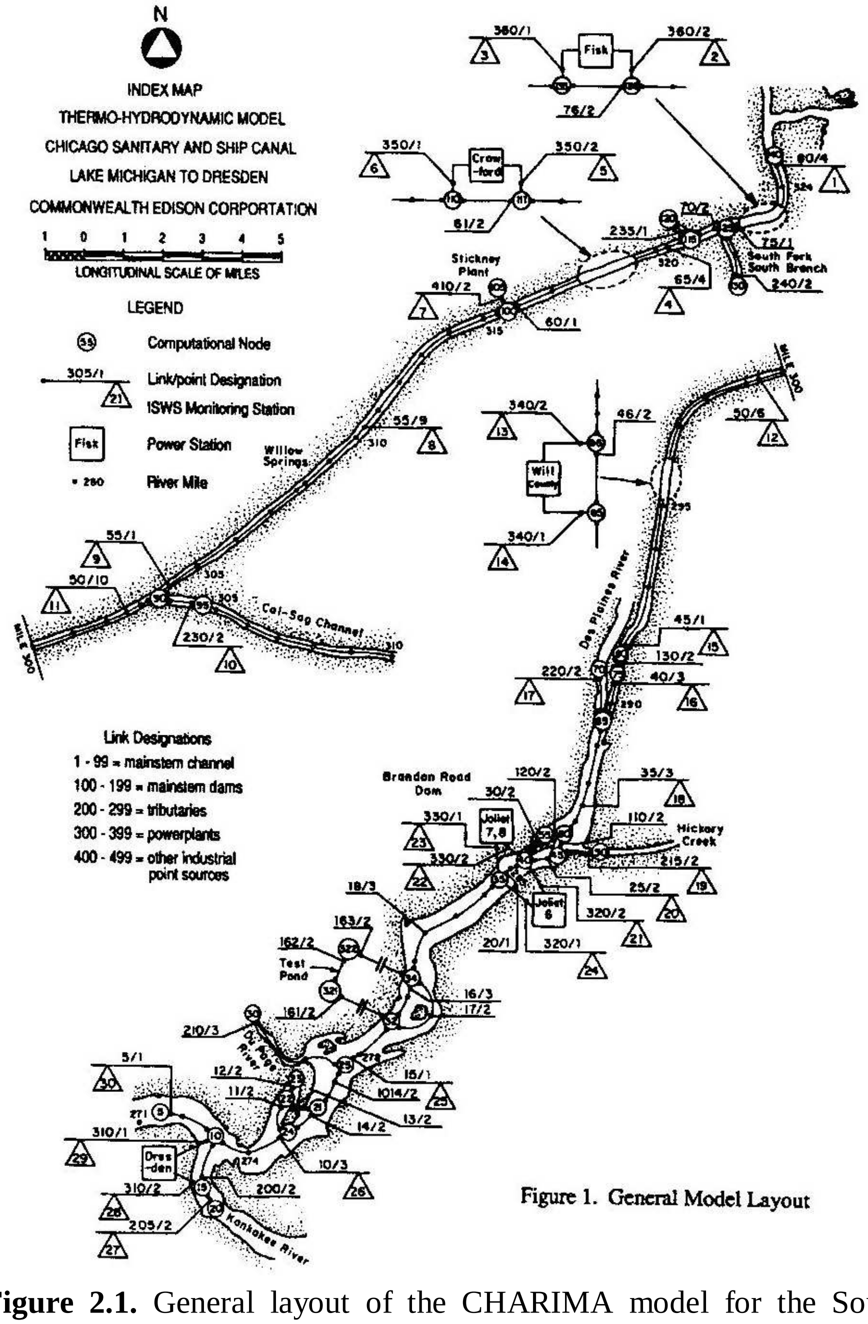

Figure 2.1. General layout of the CHARIMA model for the South Branch Chicago River, Chicago Sanitary and Ship Canal, Des Plaines River, and Illinois River (after Mohammad and Holly, 1994).

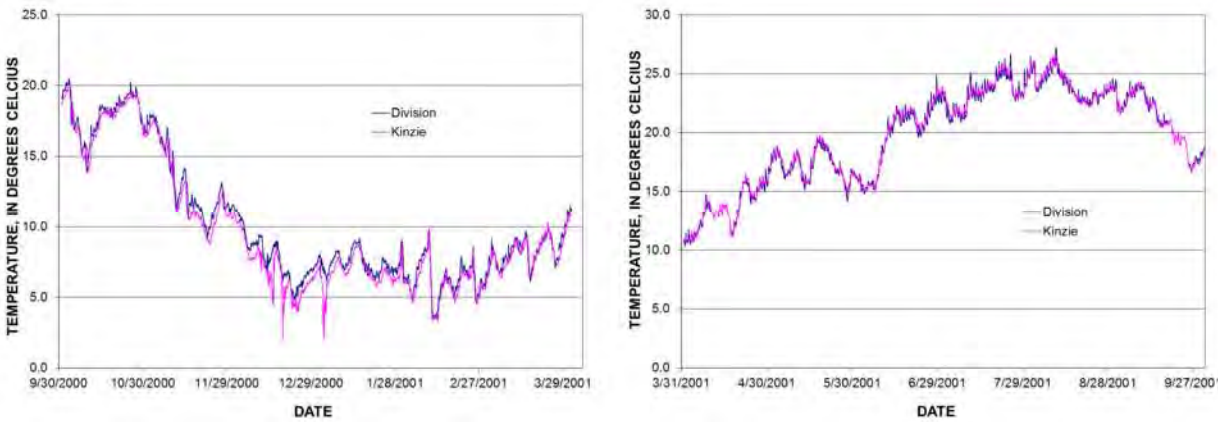

Figure 2.2. Measured hourly temperatures at Division Street (upstream) and Kinzie Street (downstream) on the North Branch Chicago River for WY 2001.

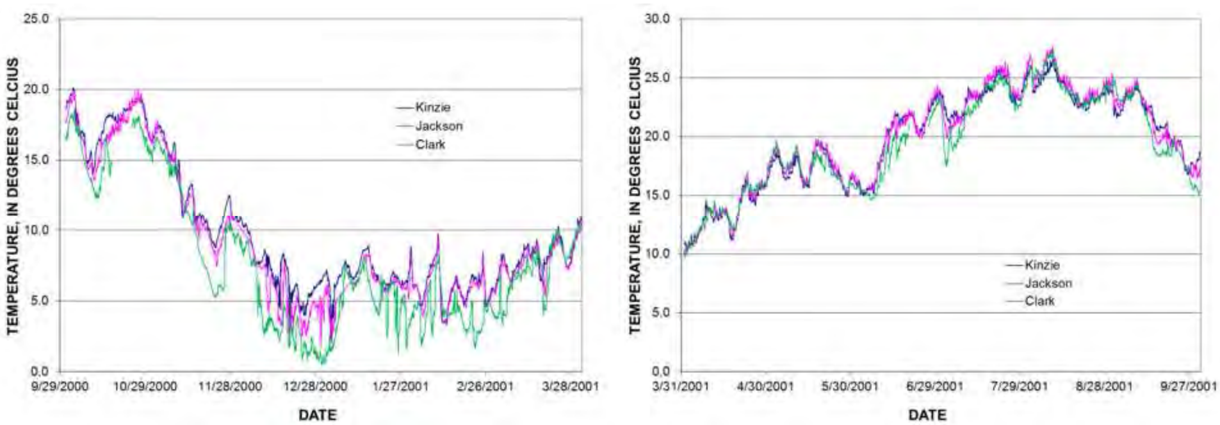

Figure 2.3. Measured hourly temperatures at Kinzie Street on the North Branch Chicago River and Clark Street on the Chicago River main stem (both upstream) and at Jackson Boulevard on the South Branch Chicago River (downstream) for WY 2001.

Thus, linear regression and mass balance models were derived to estimate temperatures at 26 of the locations listed in Table 2.1 (note: Ashland Avenue represents the upstream boundary on the Little Calumet River (south) that will not be affected by the ecological/hydrological separation scenarios). In addition to the 26 locations from Table 2.1 used in the DUFLOW model, regression and mass balance models are derived for 6 other locations in the CAWS that are not included in the DUFLOW model as follows:

- Devon Avenue on the NSC (RM = 335) is used to help estimate the DO loads from the Devon Avenue Instream Aeration Station and to better estimate the temperatures at Addison Street rather than trying to estimate temperatures at Addison Street directly from temperatures at Main Street and the O'Brien (formerly North Side) WRP.
- Foster Avenue (RM 333.4) on the NSC is used to better estimate the temperatures at Addison Street rather than trying to estimate temperatures at Addison Street directly from temperatures at Main Street and the O'Brien WRP.
- Lawrence Avenue (RM 332.9) on the NBCR is used to better estimate the temperatures at Addison Street rather than trying to estimate temperatures at Addison Street directly from temperatures at Main Street and the O'Brien WRP.
- Michigan Avenue (RM 316.4) on the Chicago River main stem is used to better estimate the temperatures at Clark Street rather than trying estimate temperatures at Clark Street directly from temperatures at the Chicago River Controlling Works (CRCW) or temperatures at CRCW directly from Clark Street.
- Loomis Street (RM 321.9) on the SBCR is used to characterize the effects of the Fisk and Crawford power plant operations on the temperature in the CAWS.
- 104^{th} Avenue (RM 307.5) on the Calumet-Sag Channel is used to better estimate the temperatures at Route 83 rather than trying to estimate temperatures at Route 83 directly from temperatures at Southwest Highway.

Linear Regression and Mass Balance Models

The derivation of the linear regression equations proceeded as follows.

The hourly data at each site was screened to determine possibly erroneous data. The raw data obtained from the MWRDGC had already been screened by the MWRDGC's quality assurance procedure to determine erroneous DO data. For any period with erroneous DO data, the temperature data also were deleted by the MWRDGC. However, the temperature data still included some erroneous data, typically (a) single hour spikes of unusually high or low temperatures relative to the other hours in the day (spikes of around 2°C or more were deleted), or (b) periods of a week or so where the temperatures abruptly jumped up or down 1.5°C or more over the entire period. These week long jumps typically began when a temperature probe was replaced and ended when the new probe was removed a week later. These erroneous data were deleted from consideration.

The time periods for which measured temperature data were available at both upstream and downstream sites were identified, and hourly regressions were developed. These regressions yielded standard errors less than 0.556°C at many locations (i.e. regression model yielded similar quality to the CHARIMA model). However, because of the traveltime between the sites the comparison of temperatures at the same time was considered inappropriate. Further, for many sites where mass balance methods need to be applied or power plant operations affect temperatures, the analysis needs to be done on a daily basis (e.g., WRP effluent temperatures are only available as daily averages). Thus, daily mean temperatures were computed for each location. A day needed to have at least 18 measured temperature values to yield a reliable daily mean. A linear regression then was applied between the upstream and downstream daily mean temperatures.

For locations where a mass balance was applied only measured daily mean flows at the main U.S. Geological Survey (USGS) gauging stations (05536101 North Shore Channel at Wilmette, IL; 05536105 North Branch Chicago River at Albany Avenue at Chicago, IL; 05536118 North Branch Chicago River at Grand Avenue at Chicago, IL; 05536123 Chicago River at Columbus Drive at Chicago, IL; 05536290 Little Calumet River at South Holland, IL; and 05536358 Calumet River below O'Brien Lock and Dam at Chicago, IL) and the daily mean flows from the three large WRPs were considered. Combined sewer overflows were not considered in the mass balance except those measured at the Grand Avenue gage. Minor tributary flows also were not considered in the mass balance. Once a temperature downstream of the confluence of the two flows was computed via a mass balance, a linear regression was applied between this mass balance temperature and the temperature at the downstream monitoring point.

The Fisk Power Plant withdrew water from the South Branch Chicago River and returns heated water to it between Jackson Boulevard and Loomis Street. The Crawford Power Plant withdrew water from the Chicago Sanitary and Ship Canal (CSSC) and returns heated water to it between Loomis Street and Cicero Avenue. Thus, as shown in Figure 2.4 the operations of these plants can have substantial effects on the downstream temperatures. Thus, operational information on whether the various power generation units at the plants were "on" or "off" were obtained from Midwest Generation. For calendar years 2005 to 2010, Midwest Generation provided a list of the periods of major outages (4 days or more) for the various power plant units at the Fisk, Crawford, and Will County power plants, thus, it was easy to separate the days with the plant fully on from those with the plant shut down when doing the regression analysis. For calendar years 1999 to 2004, Midwest Generation provided a list of the operational hours for each power plant unit for each month. Thus, the number of days with the power units turned off was determined for each month and the increase in daily mean temperature from the upstream to the downstream station was evaluated to identify the periods of power off.

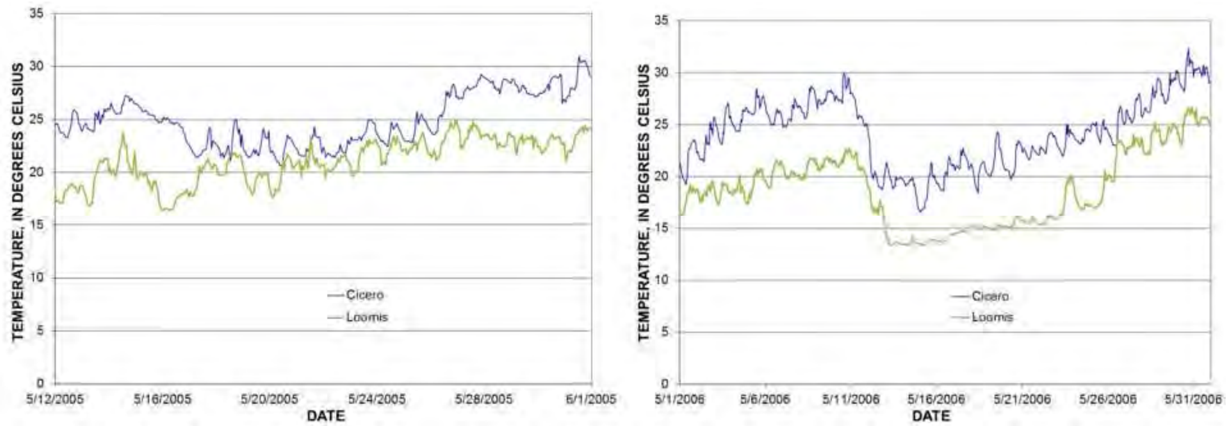

Figure 2.4. Examples of the effects of power unit outages at the Crawford and Fisk power plants: (left) Crawford unit 8 shut down May 16-26, 2005, and the downstream temperature at Cicero Avenue moves close to the upstream temperature at Loomis Street, (right) Fisk Power Plant shut down May 12-23, 2006, both downstream temperatures show a sudden decrease on the 12^{th} and a sudden increase on the 23^{rd}.

For the study of the effects of the Crawford Power Plant on temperature, temperature data are available from 1998 through 2010 minus the period from January 2001 to April 2003 when the Loomis Street monitor was not in service. Thus, the two means of identifying periods of units "on" and "off" could be compared. Considering only calendar years 2005 to 2010 (for which specific dates of units "off" are given) the linear regression equations for daily mean temperature at Cicero are

Cicero = 1.03033 Loomis + 0.51847 (power off)

Cicero = 0.91440 Loomis + 5.76101 (power on)

Whereas considering calendar years 1999 to 2010 the linear regression equations for daily mean temperature at Cicero are

Cicero = 1.07090 Loomis – 0.60431 (power off)

Cicero = 0.91476 Loomis + 5.81795 (power on)

From the foregoing equations it is clear that the periods of power “on” yield nearly identical equations, and, thus, the means of identifying these periods are consistent. The equations for the periods of power “off” are significantly different statistically (i.e. the coefficient and intercept for 2005 to 2010 is outside the 95% confidence limits for those values for 1999 to 2010). However, for the temperature range of 22 to 37°C the difference between the results of the two equations is 1% or less, from 19 to 22°C the difference is between 1 and 2%, from 13 to 18°C the difference is between 2 and 5%, and from 8 to 12°C the difference is between 5 and 10%. Thus, there is no practical difference between the results of the two equations for more than 95% of the period of record. Because temperature data are not available at the nearest upstream and downstream points for the Fisk and Will County power plants in 2005 to 2010, it is good to know the procedure for identifying “on” and “off” periods from 1999 to 2004 is sufficiently reliable when applied to these power plants.

As noted earlier units 1 and 2 at the Will County Power Plant were retired at the end of 2010, thus, for the baseline and future conditions for this study only the operations of units 3 and 4 at the Will County Power Plant need to be considered. In calendar years 2003 and 2004, April 1999, and November and December 2000, units 1 and 2 at the Will County Power Plant were out of service. Thus, these periods are studied as they reflect the baseline and future conditions, and the “on” and “off” conditions of units 3 and 4 are evaluated.

Table 2.2 lists the linear regression equations for daily mean temperatures and their coefficients of determination (R^2), standard errors, and numbers of days of observations used to derive these equations for locations along the NSC, NBCR, Chicago River main stem, SBCR, Bubbly Creek, and CSSC. Table 2.3 lists the linear regression equations for daily mean temperatures and their coefficients of determination (R^2), and standard errors and number of days of observations used to derive these equations for locations along the Calumet River, Little Calumet River (north), and Calumet-Sag Channel.

Performance of Linear Regression and Mass Balance Models

For 16 of the 32 temperature monitoring locations listed in Tables 2.2 and 2.3 the standard error is less than 0.556°C, i.e. the regression model yielded similar quality to the CHARIMA model. Whereas for 16 of the 32 temperature monitoring locations listed in Tables 2.2 and 2.3 the standard error is greater than 0.556°C (marked in red in the tables), i.e. the regression model yields lower accuracy than the CHARIMA model, however, only 5 of these locations are in the domain of the CHARIMA model. In the following paragraphs the reasons for the poorer model performance at these locations are described.

Table 2.2. Linear regression equations for the estimation of daily mean temperatures in degrees Celsius in the North Shore Channel, North Branch Chicago River, Chicago River main stem, South Branch Chicago River, Bubbly Creek, and Chicago Sanitary and Ship Canal.

Equation	R^2	Standard Error, °C	Observations	Notes
Linden = 0.97838 Simpson + 0.04537	0.97330	0.7967	537	Q≥ 20 cfs
Linden = 0.87642 Simpson +1.33644	0.96728	0.8801	474	0≤ Q < 20
Linden = 0.86540 Simpson + 1.28194	0.95486	0.9719	110	Q < 0 cfs
Simpson = 0.99481 Linden + 0.39999	0.97330	0.8033	537	Q≥ 20 cfs
Simpson = 1.10368 Linden – 1.18649	0.96728	0.9876	474	0≤ Q < 20
Simpson = 1.10336 Linden – 0.97391	0.95486	1.0974	110	Q < 0 cfs
Simpson = 0.96077 Main – 0.03624	0.96963	0.9344	519	Q≥ 20 cfs
Simpson = 0.89320 Main + 0.30409	0.93932	1.3066	539	0≤ Q < 20
Simpson = 0.94073 Main – 0.24558	0.93938	1.3367	147	Q < 0 cfs
Main = 1.00922 Simpson + 0.55590	0.96963	0.9576	519	Q≥ 20 cfs
Main = 1.05163 Simpson + 0.20621	0.93932	1.4178	539	0≤ Q < 20
Main = 0.99856 Simpson + 0.78212	0.93938	1.3772	147	Q < 0 cfs
Devon = 1.0836 MBNB + 0.60559	0.98774	0.5185	605	
Foster = 1.06165 MBNB – 1.81028	0.96721	0.8827	1832	
Lawrence = 1.13909 Devon – 3.28662	0.98133	0.7339	758	
Addison = 1.01072 Lawrence – 0.2532	0.99794	0.2404	844	
Addison = 1.01464 MBNB1 – 0.27780	0.99479	0.4254	1698	
Fullerton = 1.04520 Addison – 0.83186	0.99483	0.4262	4016	
Division = 1.05098 Fullerton – 1.03697	0.99467	0.4488	1848	
Kinzie = 1.03958 Division – 0.80339	0.99602	0.3991	1916	
CRCW = 1.02729 Michigan – 1.41955	0.98675	0.8530	1111	
Michigan = 0.96054 CRCW + 1.52963	0.98675	0.8248	1111	
Michigan = 1.04479 Clark – 1.28601	0.98966	0.7332	1149	
Clark = 0.94723 Michigan +1.35366	0.98966	0.6981	1149	
Jackson = 1.05057 MBMS – 0.76151	0.99395	0.5513	582	
Loomis = 0.91179 Jackson + 5.48385	0.95054	1.4255	752	Power on
Loomis = 1.03773 Jackson – 0.61924	0.98350	0.7232	208	Power off
Cicero = 0.91476 Loomis + 5.81795	0.90282	2.1754	2450	Power on
Cicero = 1.07090 Loomis - 0.60431	0.92949	1.4387	578	Power off
B&O = 0.99092 MBST – 0.77847	0.94496	1.4161	1285	
Route 83 = 1.03427 B&O – 0.72886	0.99128	0.7784	3099	
RM 302.6 = 1.01137 MBCS – 0.34646	0.99804	0.2884	257	
Romeo = 1.01567 RM 302.6 – 0.38954	0.99694	0.3872	1754	
Lockport = 0.91825 Romeo + 4.01442	0.98265	0.9224	299	Power on
Lockport = 0.98837 Romeo + 1.25938	0.98397	0.6439	184	Power off

MBNB = Mass balance of Main Street and O'Brien WRP temperatures
MBNB1 = Mass balance of Foster Avenue and Central Park Avenue on the upper NBCR temperatures
MBMS = Mass balance of Kinzie Street and Clark Street temperatures
MBST = Mass balance of Cicero Avenue and Stickney WRP temperatures
MBCS = Mass balance of Route 83 (CSSC) and Route 83 (Calumet-Sag) temperatures
Q = Discharge at the Wilmette Pumping Station

Table 2.3. Linear regression equations for the estimation of daily mean temperatures in degrees Celsius in the Calumet River, Little Calumet River (north), and Calumet-Sag Channel.

Equation	R^2	Standard Error, °C	Observations	Notes
130th = 0.96455 Conrail + 0.38251	0.98310	0.6327	242	Q≥ 100 cfs
130th = 0.95713 Conrail + 0.15972	0.98681	0.9398	215	0≤ Q < 100
130th = 0.93566 Conrail + 0.04900	0.98044	1.0168	117	Q < 0 cfs
Conrail = 1.01923 130th – 0.01973	0.98310	0.6504	242	Q≥ 100 cfs
Conrail = 1.03101 130th – 0.03251	0.98681	0.9754	215	0≤ Q <100
Conrail = 1.04786 130th + 0.11398	0.98044	1.0761	117	Q < 0 cfs
C & W = 0.98829 Conrail + 0.50781	0.99643	0.5357	815	
Halsted = 1.14607 MBC – 1.68826	0.92991	1.6528	719	
Division = 1.04464 MBLC – 0.97083	0.99546	0.4761	693	
Kedzie = 1.03254 Division – 0.54087	0.99841	0.2923	907	
Cicero = 1.03337 Kedzie – 0.68359	0.99807	0.3321	869	
Harlem = 1.04796 Cicero – 0.95849	0.99755	0.3850	884	
Southwest = 1.01748 Harlem –0.29975	0.99946	0.1812	823	
104th = 1.02941 Southwest – 0.73114	0.99839	0.3315	655	
Route 83 = 1.02158 104th – 0.26259	0.99781	0.3647	1952	

MBC = Mass balance of Central and Wisconsin (C&W) Railroad and Calumet WRP temperatures
MBLC = Mass balance of Halsted and Ashland temperatures, O'Brien Lock and Dam flows considered
Q = Discharge at O'Brien Lock and Dam

The flow in the reaches upstream of the three major WRPs and in the Chicago River main stem is typically very small from mid-October to the end of May and the cause-effect relationship between upstream and downstream locations, or even the definition of upstream and downstream, is weak and uncertain at times. The upstream to downstream correlation is stronger during periods when discretionary diversion or navigation make-up flow is taken at the lakefront structures, but even subdividing the analysis to consider the flow regime yielded only minor improvements in the estimates at Linden Avenue, Simpson Street, Main Street, 130th Street, and Conrail. Thus, the estimation of temperature at Linden Avenue from Simpson Street, temperature at Simpson Street from temperature at Linden Street or Main Street, and temperature at Main Street from temperature at Simpson Street yield less accurate results than achieved by the CHARIMA model. The case of the estimation of temperature at Conrail from the temperature at 130th Street and temperature at 130th Street from temperature at Conrail is further affected by the fact that 130th Street is on the Lake Michigan side of the Calumet River and only approximates the temperature on the canal side of the O'Brien Lock and Dam. Finally, the Chicago River main stem is more prone to flow reversals and bi-directional flow than the other locations, which yields the poorer regression results obtained at CRCW, Michigan Avenue, and Clark Street.

For the reaches that include a power plant discharge two factors affect the quality of the regression models. First, for Loomis Avenue, Lockport, and Cicero Avenue (between 1999 and 2004), the identification of the "on" and "off" days is approximated from the number of "off" hours and the days with smaller temperature differences between upstream and downstream, and even for Cicero Avenue between 2005 and 2010 the exact time of day of shut down and restart of the unit is not known, and, thus, some days may be improperly placed in the "off" category. Second, Julia Wozniak of Midwest Generation pointed out (written communication to Dave Wethington, U.S. Army Corps of Engineers, May 30, 2012):

> "While the data may indicate that a unit is operating, it is not necessarily operating at or close to its design capacity. Megawatt loading varies considerably over each day, as well as seasonally, and is entirely dependent upon power demand and pricing."

Thus, the periods when units are "on" do not necessarily reflect the same conditions at all times, and in the case of the Crawford and Will County power plants the periods when one unit is shut down may represent different conditions depending on whether the operation of the second unit is brought to a higher level to compensate for the other unit being shut down. Thus, the poorer estimation performance downstream from the power plants was expected.

At Lawrence Avenue the poorer performance of the regression equation is because the temperature at Lawrence Avenue is affected by the temperature of flows coming from the upper North Branch Chicago River (UNBCR), but no temperature data were available for the UNBCR during the period of operation of the Lawrence Avenue gage. The importance of the UNBCR temperature can be seen in the fact that Addison Street temperatures can be reliably estimated (standard error $< 0.556°C$) from the mass balance of temperatures at Foster Avenue on the NSC and Central Park Avenue on the UNBCR.

At Foster Avenue the poorer performance of the regression equation is because the flow for the NSC is taken as the MWRDGC estimate of daily flows at Wilmette adjusted to approximate the mean daily flows at the USGS gage 05536101 North Shore Channel at Wilmette, IL via the regression equation reported in Duncker et al. (2006):

$$Q_{USGS} = 0.9596\ Q_{MWRDGC} + 0.5914$$

These estimated flows are not as accurate as the measured daily flows available from the USGS for September 7, 1999 to September 30, 2003. The use of the MWRDGC estimates of flow may have contributed to the estimation of temperature at Foster Avenue having a standard error greater than 0.556°C, while the estimation of temperature at Devon Avenue using a similar mass balance with USGS flows has a standard error less than 0.556°C.

At the Baltimore & Ohio (B&O) Railroad on the CSSC the mass balance considers the temperature at Cicero Avenue on the CSSC for which the flows are estimated as the sum of the flow at the USGS gauges on the NBCR at Grand Avenue and on the Chicago River Main Stem at Columbus Drive, and the flow and temperature of the effluent from the Stickney WRP. These locations are, on average, more than three days travel time upstream from Cicero Avenue due to the fact that the discharge from the Stickney WRP acts as a hydraulic dam to flows coming from upstream on the CSSC (see Manache and Melching (2005)). Thus, the estimated flow on the CSSC at Cicero Avenue has higher uncertainty because of traveltime issues resulting in the poorer quality of the linear regression equation for estimation of the daily mean temperatures at the B&O Railroad.

The poorer results from the mass balance at Halsted Street on the Little Calumet River (north) may be caused by the uncertainty in the daily flows from the USGS gauge at O'Brien Lock and Dam.

Thus, among the 16 locations with standard errors greater than 0.556°C (1°F) only the poorer results at Route 83 on the CSSC cannot be explained by other physical factors that affect the mass balance and/or linear regression. Therefore, with the linear regression equations yielding standard errors less than 0.556°C at 16 locations, and other factors causing the linear regression equations to yield poorer results (standard errors greater than 0.556°C) at 14 locations, the linear regression model is sufficiently accurate to estimate temperatures reflecting future conditions resulting from the various ecological/hydrological separation scenarios.

It might be thought that the daily mean temperatures at the three lakefront locations—Linden Avenue, CRCW, and 130th Street—could be more reliably estimated from the temperature of Lake Michigan than from a reverse regression from the closest downstream location. Thus, regression relations were derived for estimating the daily mean temperatures at the lakefront locations from the Lake Michigan temperatures measured at the Jardine Water Treatment Plant shore and crib monitoring locations. These regression eqautions and their coefficients of determination (R^2), standard errors, and numbers of days of observations used to derive these equations are listed in Table 2.4. Comparison of the standard errors in Tables 2.2-2.4 indicate that the daily mean temperatures at the lakefront locations can be more reliably estimated from reverse regression from the closest downstream location.

Table 2.4. Linear regression equations for the estimation of daily mean temperatures in degrees Celsius at the Lake Michigan boundary locations on the basis of Lake Michigan temperatures measured at the Jardine Water Treatment Plant Shore and Crib monitoring locations.

Equation	R^2	Standard Error, °C	Observations
130th = 1.09523 Shore + 0.94105	0.96244	1.7504	545
130th = 1.16575 Crib + 0.91683	0.91512	2.7773	653
Linden = 0.86190 Shore + 2.18008	0.94483	1.5492	794
Linden = 0.87732 Crib + 2.73022	0.89374	2.1714	898
CRCW = 0.93492 Shore + 2.12607	0.97766	1.1110	920
CRCW = 0.99307 Crib + 2.07315	0.93377	1.9506	1041

Validation of Linear Regression and Mass Balance Models

Because of the limited amount of temperature data available at many locations, especially for the cases of the various power plants shut down, all the available temperature data were used to derive the regression equations listed in Tables 2.2 and 2.3. However, when estimating the temperature for downstream locations on the CSSC for WY 2008 for the Baseline and Future "No Project" scenario a validation of some of the regression and mass balance models could be done because Crawford Power Plant Unit 7 was shut down from September 29 to December 11, 2007. Therefore, the estimates of temperatures with the Fisk and Crawford power plants shut down is similar to the actual operating conditions from October to December 2007. Figure 2.5 shows the measured and estimated temperatures at the Baltimore & Ohio Railroad, Route 83, and Lockport Controlling Works for October to December 2007. The close agreement between the measured and estimated temperatures for the case of a power plant shut down at several locations along the CSSC indicates the general reliability/usefulness of the regression and mass balance temperature models used in this study.

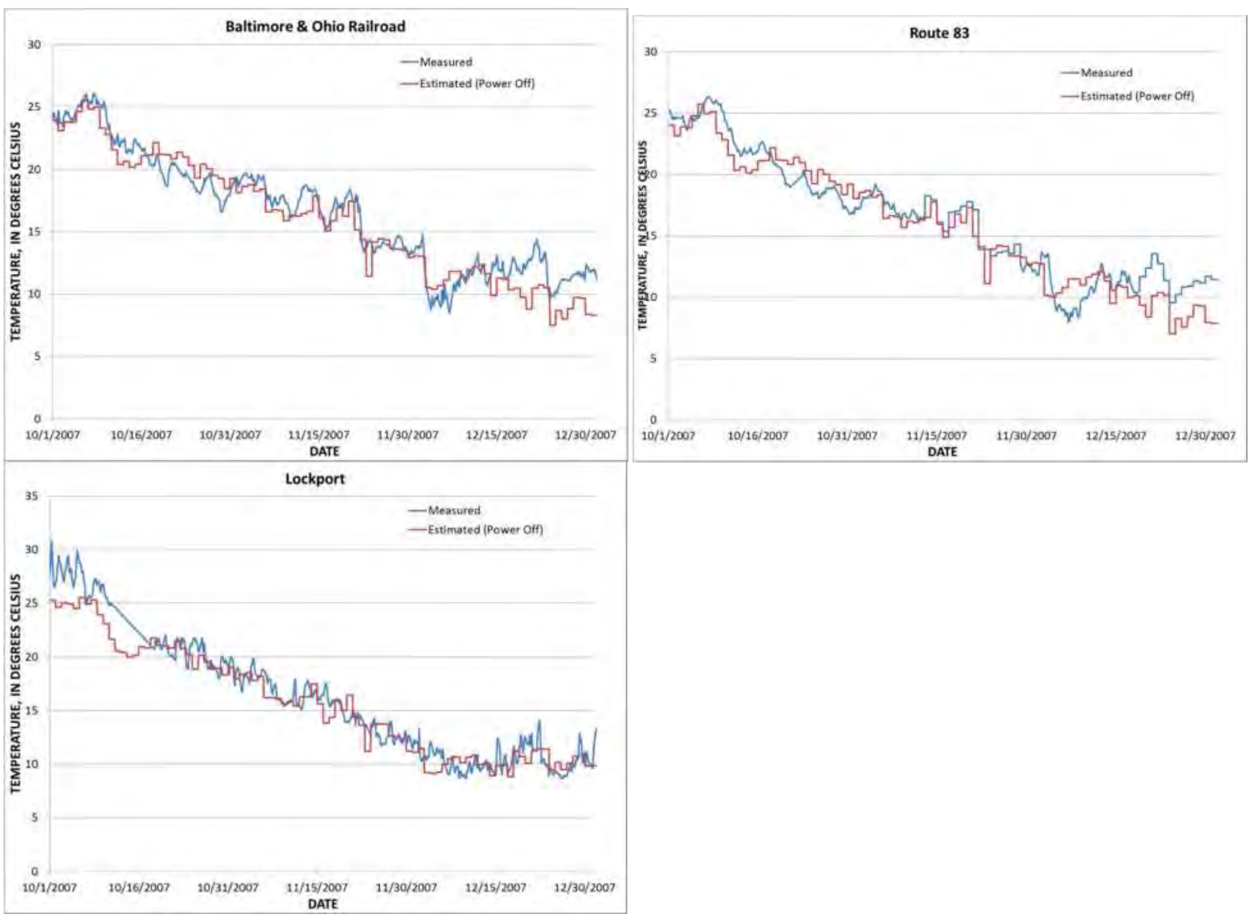

Figure 2.5. Comparison of measured and estimated (assuming Fisk and Crawford power plants shut down) water temperature at the Baltimore & Ohio Railroad, Route 83, and the Lockport Controlling Works on the Chicago Sanitary and Ship Canal for October to December 2007.

2.1.2 Fecal Coliform

A first-order decay model for simulation of fecal coliform concentrations in the CAWS was developed by Manache and Melching (2005) and Manache et al. (2007). This model was calibrated on the basis of 14 years (1990-2003) of historical monthly fecal coliform samples rather than the limited number of monthly samples to which process-based, continuous simulation models are commonly applied as detailed in Manache et al. (2007). In the calibration method applied, nonexceedance probability distributions were derived for the measured fecal coliform concentrations at adjacent sampling sites. The average travel time between each site was determined using the hydraulic model in DUFLOW. Then for many quantiles of the nonexceedance probability distribution the value of the fecal coliform decay rate, *k*, was computed as follows

$$k = \frac{\ln(\frac{C_0}{C_t})}{t}$$

where C_t and C_0 are the fecal coliform concentrations having the same probability of occurrence (quantile) at the downstream and upstream locations, respectively; and t is the mean travel time between upstream and downstream locations. The mean and median decay rates were found on the basis of many quantiles of the nonexceedance probability distributions. For the CAWS, similar mean k values were obtained when the foregoing equation was applied on paired fecal coliform concentration data collected at two successive sample locations on the same date. In the final modeling the median value of k was applied to most reaches in the CAWS as detailed in the Manache and Melching (2005) and Manache et al. (2007). The selection of the median k value and the k values for reaches including WRP inputs was made considering the comparison of measured and simulated fecal coliform concentrations for the period of July 12-September 15,

2001. The model was verified for the periods of September 11-December 30, 1998; February 5-May 24, 1999; September 2-November 11, 2001; and May 5-September 29, 2002.

In the previous calibration and verification of the fecal coliform model a single value of *k* was applied throughout the entire year and adequate results were obtained for all time periods. The use of a single *k* value throughout the year is not unique as Elshorbagy and Ormsbee (2006) also found the use of a single *k* value gave adequate results for streams in southeastern Kentucky. However, the decay rate is a function of temperature and solar radiation, which vary throughout the year. Thus, one might expect a seasonal or temperature-adjusted *k* value to yield better results. Conversely, in their laboratory experiments to estimate the total decay rate as the sum of the dark decay rate (including the effects of temperature, salinity, and predation), solar radiation decay rate, and loss due to settling, Auer and Niehaus (1993) could not find a consistent relation between the dark decay rate and temperature. They reviewed the literature on temperature effects and concluded: "it is difficult to justify the application of a temperature adjustment function." Thus, considering the previous verification results, the verification results shown in this report, and the Auer and Niehaus' conclusion on temperature adjustment functions, the use of a single *k* value throughout the year in this study is justified.

In the original fecal coliform modeling of the CAWS (Manache and Melching, 2005; Manache et al., 2007) 28 representative CSO locations were used to represent the more than 200 CSOs that discharge by gravity to the CAWS. In the development of the integrated strategy to mitigate DO problems in the CAWS, Melching et al. (2010, 2013) expanded the number of representative CSO locations from 28 to 43 to get a more accurate assessment of the low DO problems along the upper NSC. Also, in the original fecal coliform model of the CAWS, the downstream boundary of the DUFLOW model was the USGS flow measurement gage at Romeoville Road on the CSSC. In the integrated strategy study, the downstream boundary was moved to the Lockport Controlling Works on the CSSC. Therefore, in this study, the fecal coliform model was upgraded to consider the 43 representative CSO locations and the Lockport Controlling Works downstream boundary.

The change in the dispersion coefficient (D) in the DUFLOW model made between the development of the original fecal coliform model of Manache and Melching (2005) and the final DO (and related pollutants) model of Melching et al. (2010) was not applied when revising DUFLOW fecal coliform simulation for this study. The dispersion coefficients used by Manache and Melching (2005) generally were small throughout the system and followed the initial calibration of D for low flow periods in the CAWS done by Alp and Melching (2004). The calibrated dispersion coefficients were later increased throughout most of the CAWS in the more complete calibration of the DO model in Alp and Melching (2006) and Melching et al. (2010). Table 2.5 lists the dispersion coefficient values used to simulate fecal coliform bacteria and the dispersion coefficient values used to simulate DO and related constituent (as well as chloride, total suspended solids, and pH) throughout the CAWS and Figure 3.10 in Melching et al. (2010) shows the reaches to which these dispersion coefficients apply. Because Manache and Melching (2005) and Manache et al. (2007) determined the fecal coliform decay rate directly from the decrease in fecal coliform concentrations between adjacent measurement locations the effect of dispersion on fecal coliform concentrations is already included in the decay rate. Thus, the use of smaller dispersion coefficients in the DUFLOW fecal coliform model than for the DUFLOW DO model is reasonable.

In the original fecal coliform modeling of the CAWS (Manache and Melching, 2005; Manache et al., 2007) no fecal coliform data were available for post-TARP tunnel operation CSOs in the Chicago region. Thus, Milwaukee data for fecal coliform concentrations in CSOs were applied because Milwaukee also has a deep tunnel system. Two representative values were considered in the simulations done by Manache and Melching (2005):

Table 2.5. Dispersion coefficients in meters squared per second used in the DUFLOW fecal coliform (FC) and dissolved oxygen (DO) models of the Chicago Area Waterways System.

Reach Name	Waterway	River Mile	FC model	DO model
C1	North Shore Channel	341-337	15	25
C2.1	North Shore Channel	337-333.6	15	50
C2.2	North Branch Chicago River	333.6-328	15	60
C3	North Branch Chicago River	328-326.5	15	60
C4	North Branch Chicago River	326.5-325.5	15	60
C5	Chicago River main stem	327-325.5	10*	10
C6	South Branch Chicago River	325.5-322	15	60
C7	Chicago Sanitary and Ship Canal	322-316	15	1000
C8	Chicago Sanitary and Ship Canal	316-308	60	60
C9	Chicago Sanitary and Ship Canal	308-303.5	15**	60
C15	Chicago Sanitary and Ship Canal	303.5-299	50	50
C16	Chicago Sanitary and Ship Canal	299-293.2	50	50
C11	Calumet River and Little Calumet River (north)	326.5-321.5	15	15
C12	Little Calumet River (north)	321.5-319.5	15	15
C13	Calumet-Sag Channel	319.5-310	15	15
C14	Calumet-Sag Channel	310-303.5	10	10
C17	Bubbly Creek		15***	150
C18	Little Calumet River (south)		15	15

*For this reach D = 1 m^2/s in Manache and Melching (2005), but it was increased to 10 m^2/s in this study.
**For this reach D = 60 m^2/s in Manache and Melching (2005), but it was decreased to 15 m^2/s in this study.
***Bubbly Creek was not included in the portion of the Chicago Area Waterways System simulated in Manache and Melching (2005), thus, this value was determined from those of the nearby waterways—C6 and C7.

- The median value for grab samples in Milwaukee of 170,000 CFU/ 100 mL, and
- For storms resulting in flow reversals to Lake Michigan the MWRDGC takes intensive bacteria measurements near the lakefront structures. For these events in 2001 and 2002, a fecal coliform concentration of 1,100,000 CFU/100 mL (about the 90th percentile for the Milwaukee data) yielded good agreement between simulated and measured values.

In 2007, the MWRDGC took a large number of fecal coliform measurements in the flows at the North Branch (70 measurements) and Racine Avenue (119 measurements) pumping stations. Table 2.6 lists the statistics of these measurements. In this study, the median concentration for the North Branch Pumping Station was applied to all events at the North Branch and 125th Street pumping stations and gravity CSOs discharging to the NSC, NBCR, Little Calumet River, and Calumet-Sag Channel. The median concentration for the Racine Avenue Pumping Station was applied to all events at the Racine Avenue Pumping Station and the gravity CSOs discharging to the Chicago River main stem, SBCR, and CSSC. The fact that these median values lie within the range of values used by Manache and Melching (2005) supports the reliability of the original model.

Table 2.6. Minimum, maximum, mean, and median of the fecal coliform concentrations measured by the Metropolitan Water Reclamation District of Greater Chicago in the combined sewer flows at the North Branch and Racine Avenue pumping stations in 2007.

Pumping Station	Minimum	Maximum	Mean	Median
North Branch	160,000	4,700,000	862,000	485,000
Racine Avenue	38,000	18,000,000	1,696,000	810,000

As noted earlier, the original fecal coliform model for the CAWS was only tested and verified for periods of three to five months. In this study, the upgraded fecal coliform model is verified for entire water years. The fecal coliform simulation results are shown here for WY 2008 as an example in Figures 2.6-2.9. The fecal coliform simulation results for WYs 2001 and 2003 are shown in Addendum A.

A statistical analysis of the comparison between simulated and measured concentrations is not presented because even compiling the three water years in the model verification the comparison of measured and simulated concentrations can only be done for at most 36 dates. With such a small sample size, it is difficult to compute meaningful statistics because even one day of poor agreement between measured and simulated values can distort an overall fit statistic, such as the coefficient of model-fit efficiency (Nash and Sutcliffe, 1970). For example, the model achieved fit efficiencies greater than 80% over the three years at Wells Street on the Chicago River main stem and Harlem Avenue on the CSSC, indicating good performance by the model, but at other locations the model had large negative efficiencies primarily resulting from a few bad days whose influence could not be negated because of the small sample size. Poor model performance on a few days could be a function of the use of weekly measurements of fecal coliform concentration in the WRP effluent. Thus, with such a small sample for consideration visual comparison of simulated and measured concentrations is the only reliable way to evaluate the model. Canale et al. (1993) also used visual comparisons to evaluate the quality of their fecal coliform model of Onondage Lake. They noted that a statistical approach to evaluating the goodness of model fit serves poorly in their study because of the inherent uncertainty in the measurement of fecal coliform concentrations.

Examples of such fecal coliform measurement errors are the low concentrations (less than 100 CFU/100 mL) measured on the Calumet-Sag Channel at Route 83 in Figure 2.9. These low concentrations seem unreasonable given that undisinfected effluent from the Calumet WRP has been discharged to the CAWS upstream of this location whereas the simulated concentrations at this location reflect the upstream input of undisintected Calumet WRP effluent. The low concentrations measured on the NSC at Oakton Street and on the Little Calumet River (north) at Indiana Avenue reflect the influence of flows from Lake Michigan affecting fecal coliform concentrations at these locations. The discrepancy between the simulated and measured values at these locations is because of the difficulty in properly characterizing in the DUFLOW model the low flows (inflows from Lake Michigan and backflows from the WRPs) in these regions prone to flow stagnation.

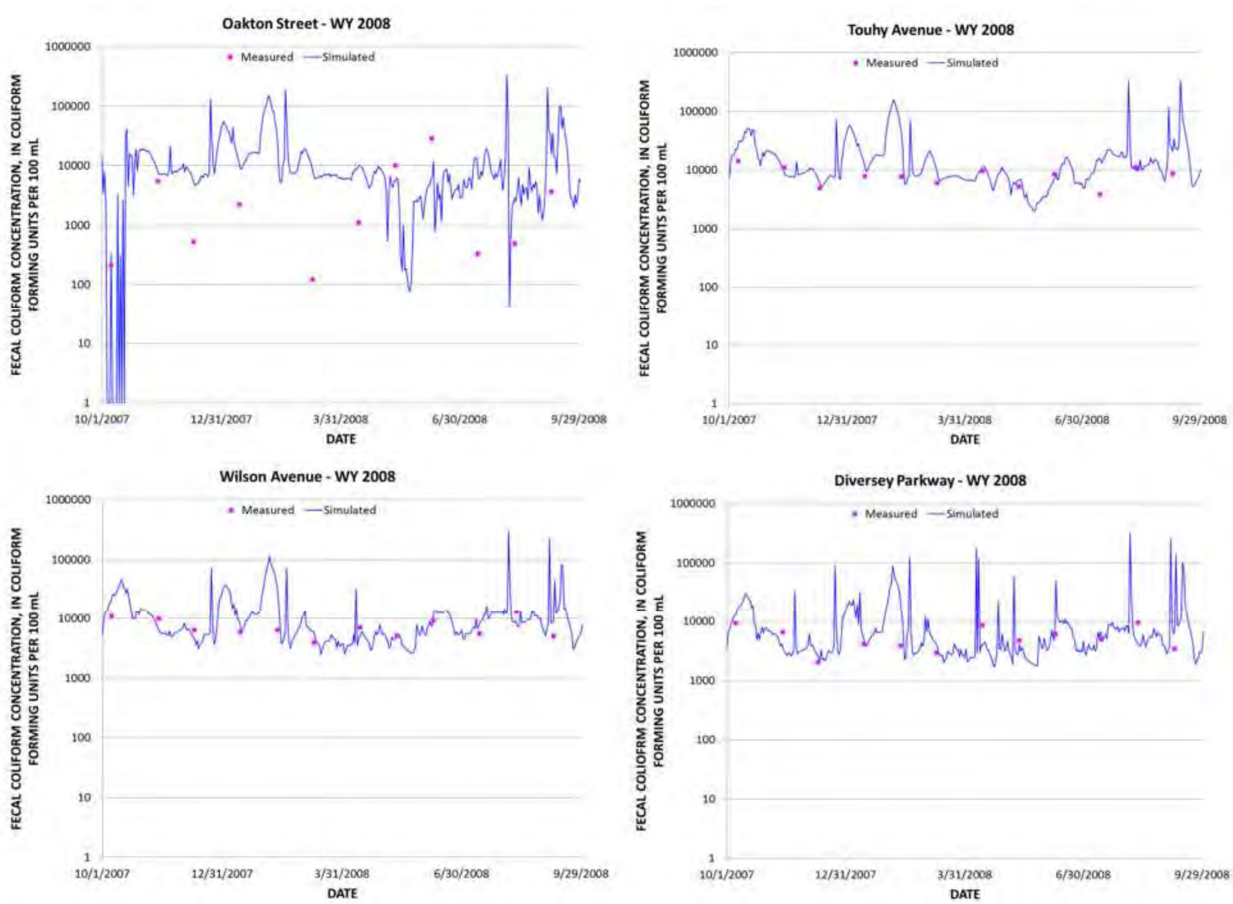

Figure 2.6. Measured and simulated fecal coliform concentration on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2008.

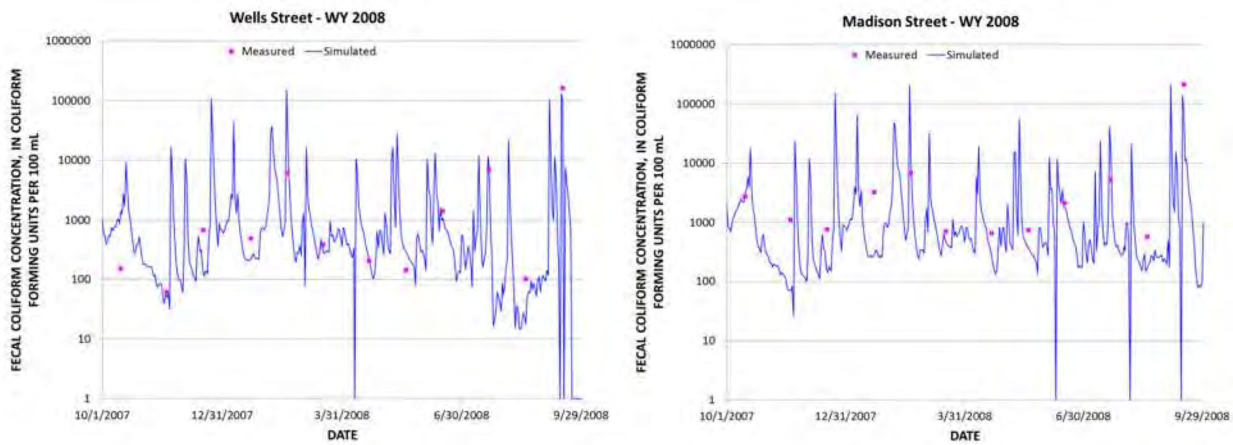

Figure 2.7. Measured and simulated fecal coliform concentration on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2008.

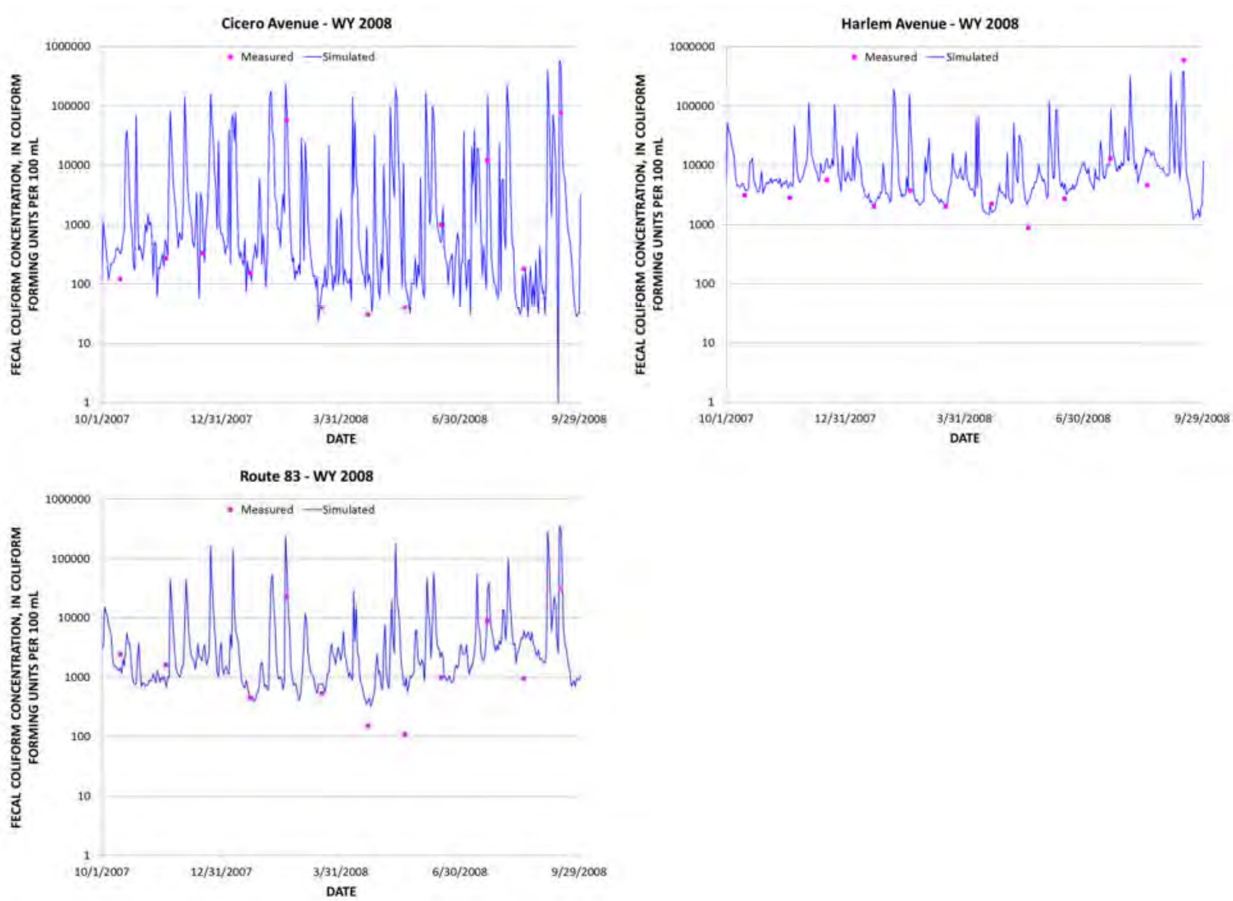

Figure 2.8. Measured and simulated fecal coliform concentration on the Chicago Sanitary and Ship Canal at Cicero Avenue, Harlem Avenue, and Route 83 for Water Year 2008.

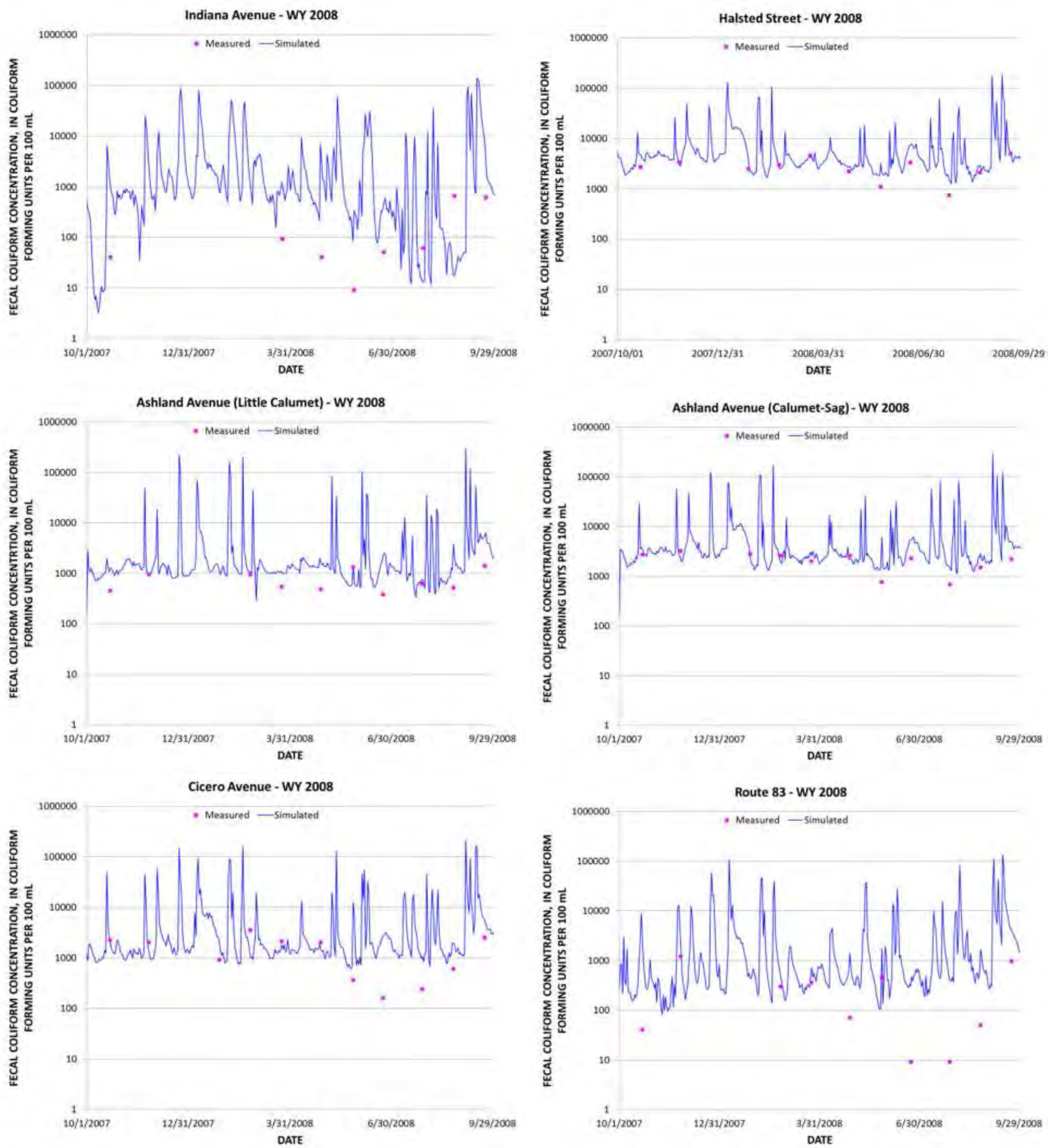

Figure 2.9. Measured and simulated fecal coliform concentration on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2008.

2.1.3 Chloride

Chloride is a conservative constituent whose value only changes along the course of a river because of dilution. Thus, chloride was added to the DUFLOW model of the CAWS as a conservative constituent. Chloride concentrations are available for the effluent for the O'Brien and Stickney WRPs and the chloride concentration for inflows from Lake Michigan is assumed to be 0. However, the simulation of the chloride concentration in the CAWS was complicated by the following issues:

- Only weekly measured values of chloride concentrations were available in the effluent from the O'Brien and Stickney WRPs,
- No chloride data were available for the effluent from the Calumet WRP,
- No chloride data were available for the CSOs, and
- Only monthly chloride data were available for the tributaries of the CAWS.

In the following subsections, the assumptions made to overcome these issues are described followed by an evaluation of the accuracy of the chloride simulation for the CAWS.

<u>Chloride Concentrations for the Water Reclamation Plants</u>—Hem (1985) reported that conductivity typically has a strong relation with chloride and conductivity has a strong relation with Total Dissolved Solids (TDS). Conductivity data are not available for any WRP, but TDS may be determined for the Stickney and Calumet WRPs as the difference between Total Solids (TS) and Total Suspended Solids (TSS) concentrations. Thus, a relation between chloride and TDS was derived for the Stickney WRP and applied to yield daily chloride concentrations at the Calumet WRP. It was also considered to apply this relation to yield daily chloride

concentrations at the Stickney WRP, but good simulations of chloride concentrations in the CAWS were achieved using the weekly chloride data at Stickney and it was decided not to generate daily chloride concentrations at the Stickney WRP.

The measurement data for the Stickney WRP effluent between 1990 and 2009 were used to determine the relation between TDS and chloride. Initially, all the data points (791 measurements) were used to construct a plot of chloride vs. TDS. Good linearity was observed in the plot, however, there were 10 outliers that markedly deviated from the rest of the sample (781 measurements). Figure 2.10 shows the linear relation between the TDS and chloride concentrations for the Stickney WRP for the edited sample of 781 paired measurements. The resulting linear regression equation for the estimation of chloride concentrations is

$$chloride = 0.56251\, TDS - 200.57$$

The coefficient of determination (R^2) for this equation is 0.95116 and the standard error for this equation is 31.99 mg/L. This equation was directly applied to the TDS values computed for the Calumet WRP effluent as the difference between TS and TSS to determine daily chloride concentrations.

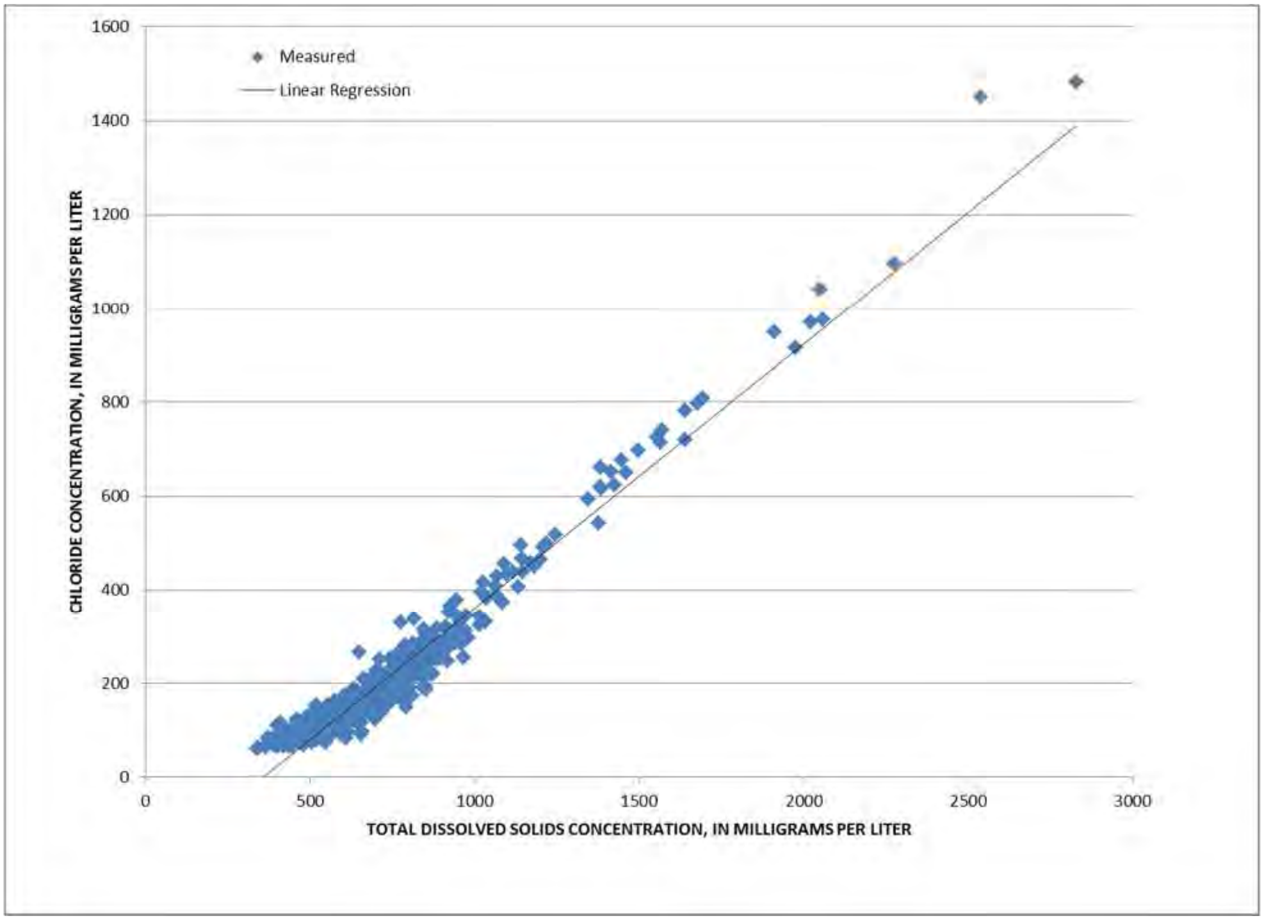

Figure 2.10. Relation between measured chloride and estimated total dissolved solids concentrations in the effluent from the Stickney Water Reclamation Plant from 1990 to 2009 with 10 outliers removed from the database.

Chloride Concentrations for the Combined Sewer Overflows—Limited conductivity data are available from the MWRDGC for the CSO pumping stations. However, a method is needed to convert between conductivity values and chloride concentrations for CSO flows. Some storm runoff data are available from the MWRDGC that include conductivity and chloride concentrations: (1) Zhang et al. (2003) collected water quality data for storm sewers in Evanston and Crestwood, Illinois, that included chloride and conductivity data, and (2) Zhang et al. (2004) collected water-quality data for storm runoff from highways at 3 Illinois Department of Transportation pumping stations that included chloride and conductivity data. The data for the storm sewers were more representative of CSO flows and were used to estimate chloride concentrations in the CSO flows via linear regression. The data available at Evanston included winter periods during which snowfall and, thus, the use of road salt was likely. These data were used to estimate chloride concentrations during winter periods involving snow and the use of road salt. No data were available during the winter at Crestwood, thus, the linear regression for Crestwood and that for Evanston for the periods with no snow were averaged to estimate chloride concentrations in non-snow periods. Table 2.7 lists the linear regression equations and their fit statistics between chloride concentrations and conductivity for storm sewer data for Evanston and Crestwood, Illinois.

Table 2.7. Linear regression relations and fit statistics between chloride (Chl) concentrations and conductivity (Cond) for storm sewers in Evanston and Crestwood, Illinois.

Location/Condition	Equation	R^2	Standard Error (mg/L)	Observations
Evanston/All Data	Chl = 0.3179 Cond – 47.73	0.94976	70.9	136
Evanston/No Snow	Chl = 0.3263 Cond – 56.47	0.95537	31.0	92
Evanston/Snow	Chl = 0.2995 Cond + 0.16	0.84283	116.6	44
Crestwood/All Data	Chl = 0.2584 Cond – 18.24	0.93119	15.9	140

For the North Branch Pumping Station (whose values also apply to gravity CSOs to the NSC and NBCR) measured arithmetic event mean values of conductivity were available for eight events and from these event mean concentrations of chloride were computed as the average of the results of the Crestwood (All Data) and Evanston (No Snow) equations in Table 2.7 as follows:

August 2, 2001	170 mg/L	August 9, 2001	286 mg/L
Sept. 19, 2001	61 mg/L	Sept. 20, 2001	159 mg/L
Sept. 21, 2001	62 mg/L	Sept. 23, 2001	153 mg/L
Oct. 14, 2001	212 mg/L	Oct. 23, 2001	159 mg/L

The values above were applied to each of the specific events, and the average of these EMCs for chloride of 158 mg/L was applied to all other events from late April to November for each of WYs 2001, 2003, and 2008. For winter events subject to snowfall (December to early April) the mean of the conductivity values for grab samples (1091 µmho/cm) of CSOs from the North Branch Pumping Station collected during winter from 2002-2010 was used to estimate the chloride concentration during the winter using the Evanston (Snow) equation in Table 2.7. The resulting chloride concentration of 327 mg/L was applied to all events from December to early April for WYs 2001, 2003, and 2008.

For the 125th Street Pumping Station (whose values also apply to gravity CSOs draining to the Little Calumet River and Calumet-Sag Channel) measured arithmetic event mean values of conductivity were available for three events and from these event mean concentrations of chloride were computed as the average of the results of the Crestwood (All Data) and Evanston (No Snow) equations in Table 2.7 as follows:

August 2, 2001	192 mg/L	August 25-26, 2001	179 mg/L
Oct. 14, 2001	137 mg/L		

The values above were applied to each of the specific events, and the average of these EMCs for chloride of 169 mg/L was applied to all other events from late April to November for each of WYs 2001, 2003, and 2008. For winter events subject to snowfall (December to early April) the mean of grab samples of conductivity (1137 µmho/cm) in CSOs from the 125th Street Pumping Station collected during winter from 2002-2010 was used to estimate the chloride concentration during the winter using the Evanston (Snow) equation in Table 2.7. The resulting chloride concentration of 341 mg/L was applied to all events from December to early April for WYs 2001, 2003, and 2008.

For the Racine Avenue Pumping Station no event mean concentration data are available for conductivity, and so the grab sample data collected from 2002 to 2010 had to be used for both winter and non-winter CSO chloride concentrations. Using the mean conductivity value for the grab samples collected in spring, summer, and fall from 2002 to 2010 (574.5 µmho/cm), a chloride concentration for CSOs of 131 mg/L was computed and applied to all events from late April to November for each of WYs 2001, 2003, and 2008. For winter events subject to snowfall (December to early April) the mean of grab samples of conductivity (1243 µmho/cm) in CSOs from the Racine Avenue Pumping Station collected during winter from 2002-2010 was used to estimate the chloride concentration during the winter using the Evanston (Snow) equation in Table 2.7. The resulting chloride concentration of 372 mg/L was applied to all events from December to early April for WYs 2001, 2003, and 2008.

For winter events, chloride concentrations also were computed corresponding to the 75th and 90th percentiles of winter conductivity values and the model results were compared among the three cases for winter CSO chloride concentrations. Using the mean value of conductivity to estimate the chloride concentrations yielded equal quality simulations of chloride concentrations throughout the CAWS as for the 75th and 90th percentiles. Thus, the chloride concentration obtained using the mean conductivity value was utilized in this study to yield a conservative (low effect) estimate of the chloride load to Lake Michigan during winter for the Midsystem Separation alternative.

Chloride Concentrations for the Tributary Streams—For the North Branch Chicago River the monthly measurement of the chloride concentration at Albany Avenue was directly input for each of WYs 2001, 2003, and 2008 with 15-min values of chloride concentrations linearly interpolated between the measurement dates. For the Grand Calumet River the monthly measurement of the chloride concentration at Burham Avenue was directly input for each of WYs 2001, 2003, and 2008 with 15 min values of chloride concentrations linearly interpolated between the measurement dates. For the Little Calumet River at South Holland, monthly values of the chloride concentration were calculated using a mass balance approach applied to data from the Little Calumet River at Wentworth Avenue and Thorn Creek at Joe Orr Road (both upstream from the South Holland gage). Again, 15 min values were calculated applying a linear interpolation between measurement dates. For all the gaged and ungaged tributaries to the Little Calumet River and Calumet-Sag Channel, the monthly median value of chloride concentrations for Thorn Creek at Joe Orr Road was computed for the data from 1970 to 2009 and applied to that month at each of the tributaries.

Performance of Chloride Simulation—The accuracy of the DUFLOW simulation of chloride concentrations in the CAWS are shown for WY 2008 as an example in Figures 2.11-2.14. Similar chloride simulation results were obtained in the simulations for WYs 2001 and 2003 as shown in Addendum B. Table 2.8 lists the average percentage error over the entire year and for the winter (December to early April) for all chloride measurement locations in the CAWS in total over all three years—WYs 2001, 2003, and 2008. Over the entire year 6 of the 16 locations have errors less than 10%, 7 locations have errors between 10 and 25%, and only 3 locations have errors greater than 40%. Considering winter only the errors are similar with 8 of the 16 locations having errors less than 10%, 6 locations having errors between 10 and 20%, and only 2 locations having errors greater than 40%. The highest errors both year round and in winter occur at Oakton Street and Indiana Avenue. These locations are upstream of the WRPs in the zones with generally stagnant flows and poorly defined flow directions, and poor simulations of other water-quality constituents have been observed in these regions (see Melching et al., 2010). Considering the limitations of the input data described earlier in this section, the results listed in Table 2.8 and shown in Figures 2.11-2.14 are quite good.

2.1.4. pH

pH represents the negative base 10 logarithm of the hydrogen-ion activity in moles per liter. The notation "pH" is now generally taken to mean hydrogen-ion activity rather than concentration, although the distinction between these concepts was not understood at the time Sorenson proposed the use of pH notation in 1909 (Hem, 1985). The pH of many natural waters is dominated by the carbonate buffering system of the water (Chapra, 1997, p. 683). In many freshwater systems, much of this buffering is a function of the presence of dissolved organic carbon species: carbon dioxide, bicarbonate ion, and carbonate ion. Because no data on the presence of these carbon species are available for the CAWS, the changes in pH in the CAWS because of buffering cannot be simulated in DUFLOW. Thus, in this study pH is treated as a conservative property of the water just as chloride was.

Table 2.8. Average percentage error between simulated and measured chloride concentrations for winter (December to early April) and full year comparisons for the sum of Water Years 2001, 2003, and 2008.

Location	Waterway	Winter	Full Year
Oakton Street	North Shore Channel	84.18	214.22
Touhy Avenue	North Shore Channel	15.85	20.40
Wilson Avenue	North Branch Chicago River	2.60	6.08
Diversey Parkway	North Branch Chicago River	5.11	3.75
Wells Street	Chicago River main stem	-1.99	48.96
Madison Street	South Branch Chicago River	18.53	13.48
Western Avenue	Chicago Sanitary and Ship Canal	-18.27	19.47
Cicero Avenue	Chicago Sanitary and Ship Canal	11.35	22.17
Harlem Avenue	Chicago Sanitary and Ship Canal	-3.71	8.11
Route 83	Chicago Sanitary and Ship Canal	-17.79	0.35
Indiana Avenue	Little Calumet River (north)	77.32	86.00
Halsted Street	Little Calumet River (north)	4.36	15.08
Ashland Avenue	Little Calumet River (south)	-17.90	-5.19
Ashland Avenue	Calumet-Sag Channel	-4.59	9.35
Cicero Avenue	Calumet-Sag Channel	-3.65	14.73
Route 83	Calumet-Sag Channel	-9.55	14.44

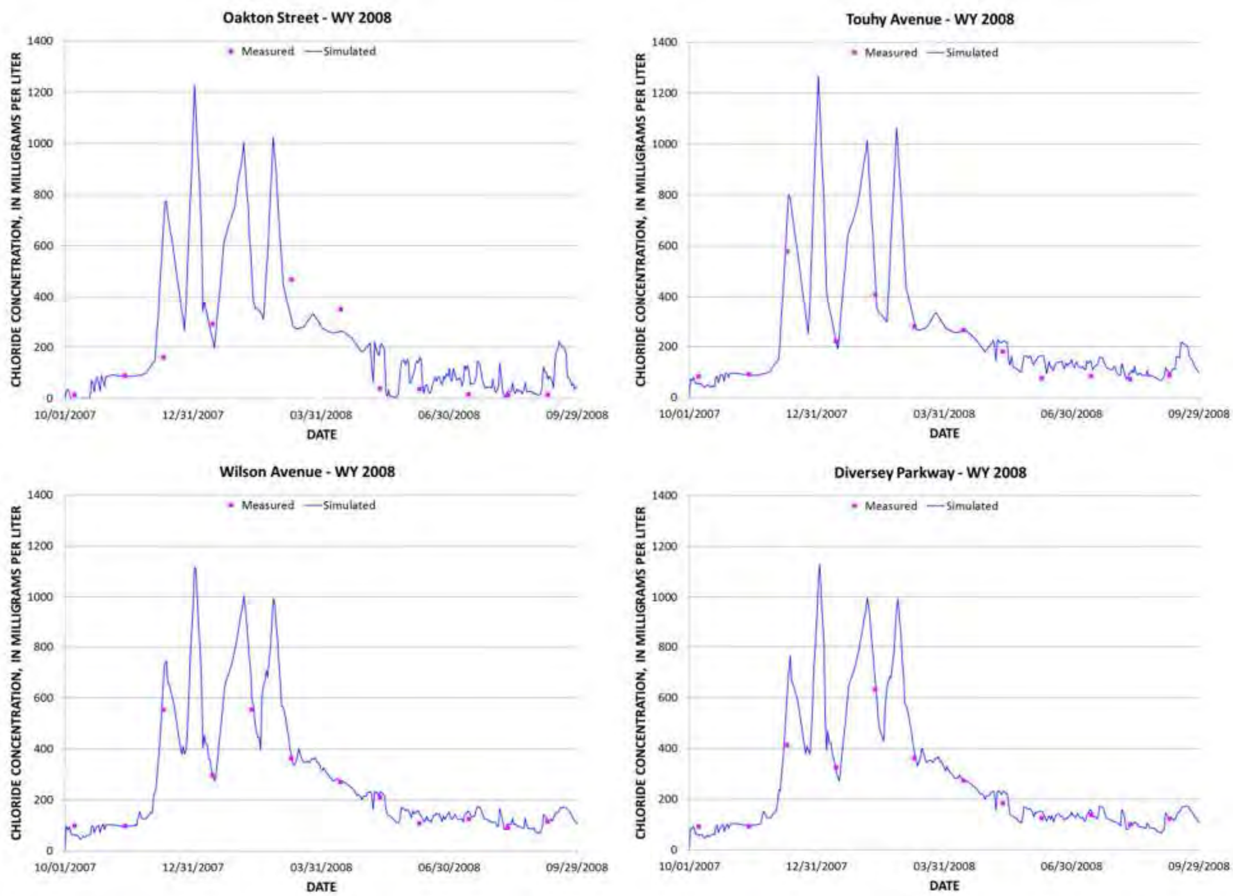

Figure 2.11. Measured and simulated chloride concentration on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2008.

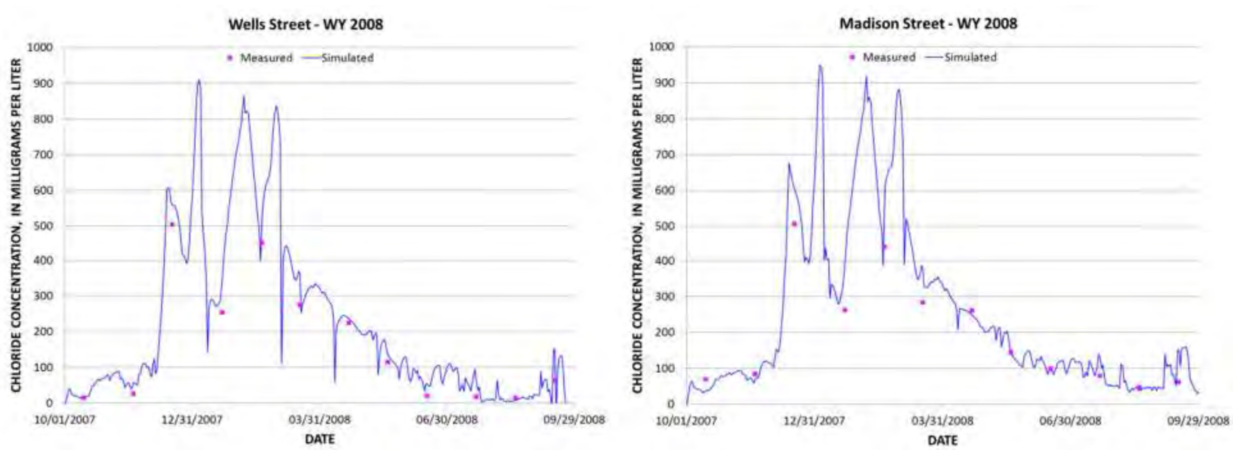

Figure 2.12. Measured and simulated chloride concentration on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2008.

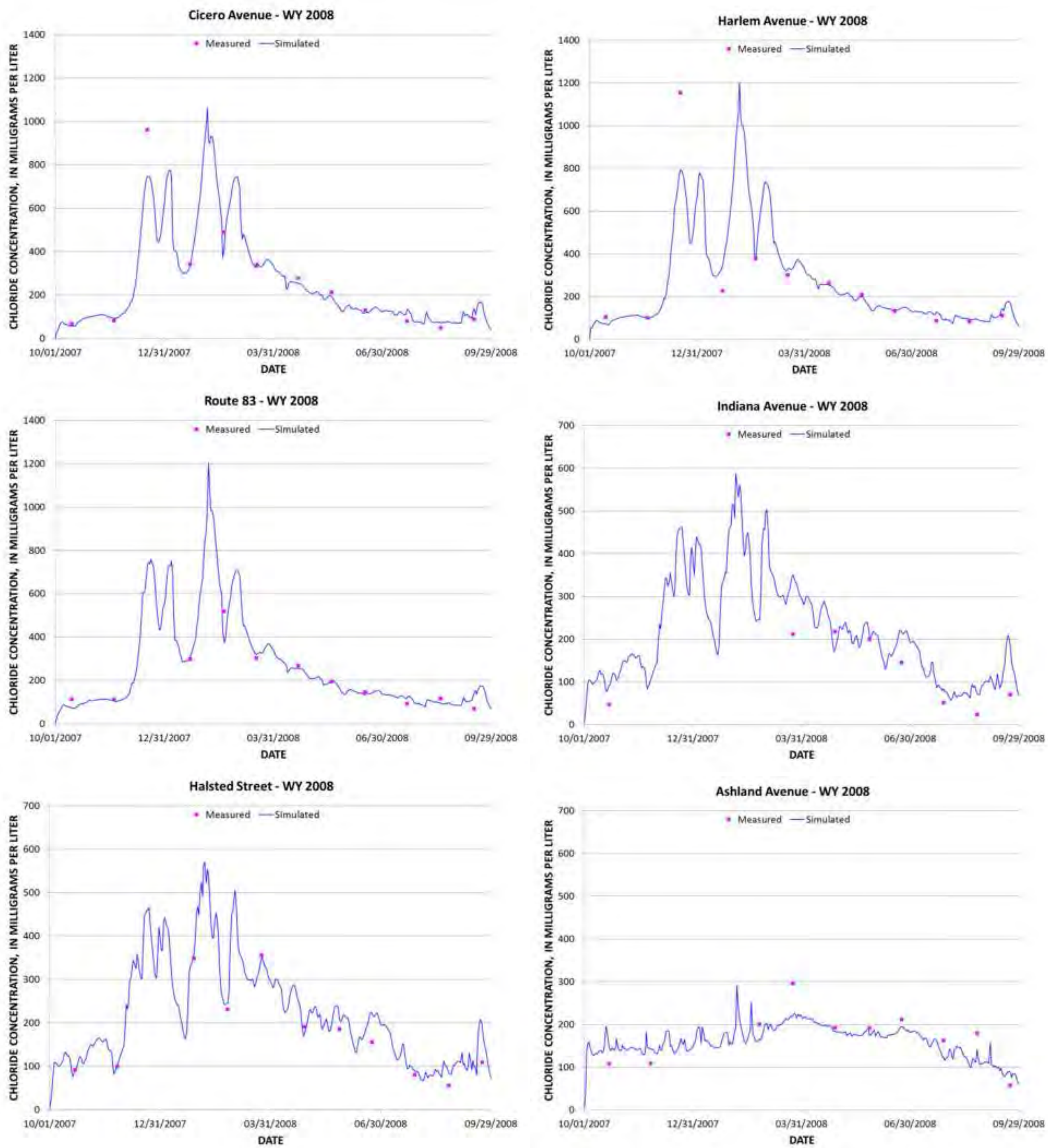

Figure 2.13. Measured and simulated chloride concentration on the Chicago Sanitary and Ship Canal at Cicero Avenue, Harlem Avenue, and Route 83 and on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue for Water Year 2008.

Daily pH values are available for the effluent for each of the WRPs. However, limited pH value data are available for the CSOs, tributaries, and Lake Michigan. In the following subsections, the assumptions made to overcome these data limitations are described followed by an evaluation of the accuracy of the chloride simulation for the CAWS.

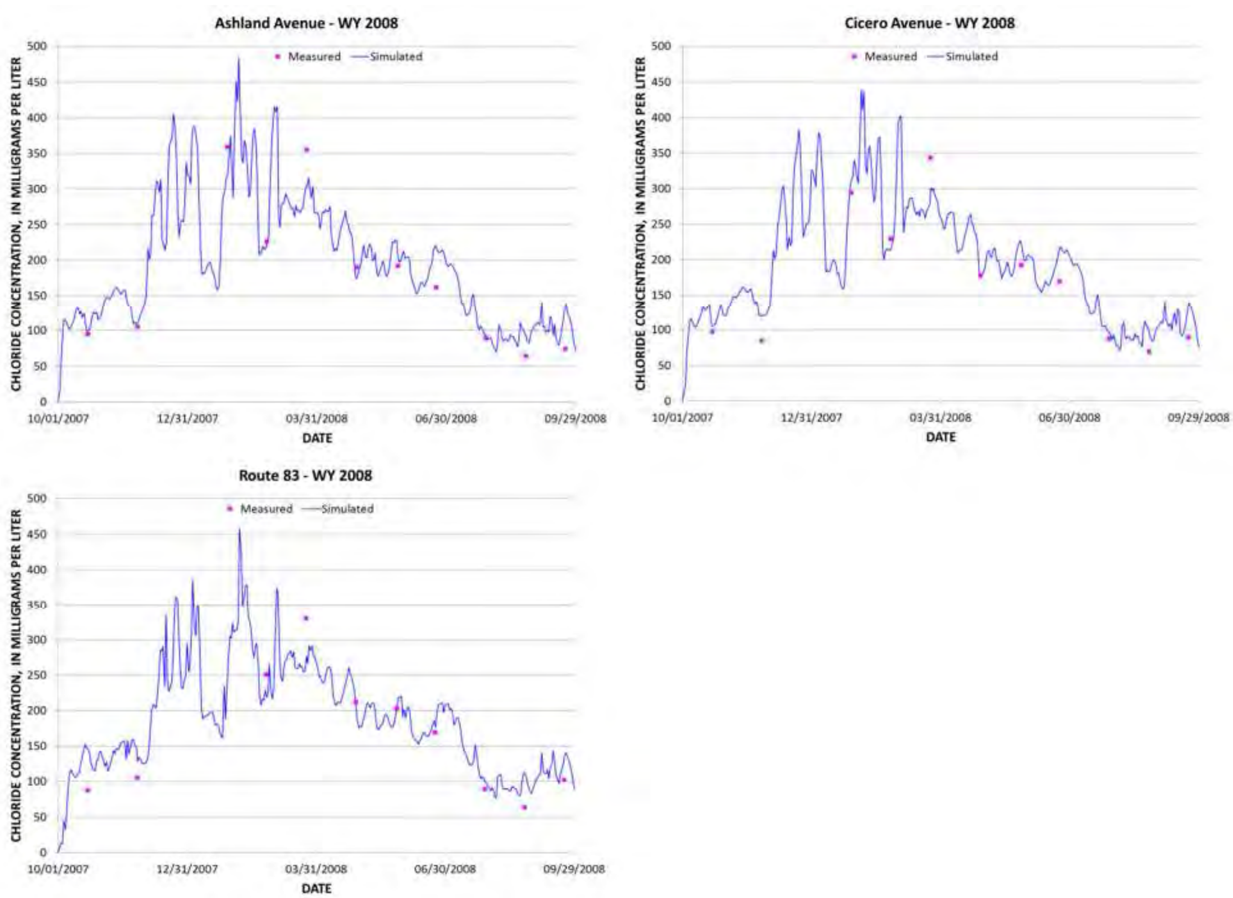

Figure 2.14. Measured and simulated chloride concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2008.

<u>pH for the Combined Sewer Overflows</u>—The MWRDGC took grab samples of CSO flows at TARP drop shafts and CSO locations in Evanston, Riverside, and Chicago (near the Racine Avenue Pumping Station) that included pH measurements in 1996 to 1999. The mean and median pH values and number of observations for these measurement locations are listed in Table 2.9. The mean of the pH values at Evanston (7.4) is applied to CSOs from the North Branch Pumping Station and for gravity CSOs discharging to the NSC and NBCR. The mean of

the pH values at Drop Shaft (DS) 28 (7.2) is applied to CSOs from the Racine Avenue Pumping Station and for gravity CSOs discharging to the Chicago River main stem, SBCR, and CSSC. Finally the mean of the pH values at Riverside (7.3) is applied to CSOs from the 125th Street Pumping Station and for gravity CSOs discharging to the Little Calumet River and Calumet-Sag Channel. Riverside is actually in the Des Plaines River basin, but it is a suburban area similar in land use composition to the areas draining to the Little Calumet River and Calumet-Sag Channel.

Table 2.9. Mean and median pH values for combined sewer flows for TARP Drop Shafts (DS) and Combined Sewer (CS) Overflows in the Chicago area for 1996 to 1999.

Location	Facility	Mean	Median	Number of Observations
Evanston	DS 106	7.4	7.4	208
Evanston	CS 106A	7.4	7.4	107
Evanston	CS 106B	7.4	7.3	122
Chicago (near Racine Avenue Pumping Station)	DS 28	7.2	7.3	163
Riverside	CS 44	7.4	7.5	136
Riverside	DS 45	7.2	7.3	60

pH for the Tributary Streams—For the North Branch Chicago River the monthly measurement of the pH at Albany Avenue was directly input for each of WYs 2001, 2003, and 2008 with 15-min values of pH linearly interpolated between the measurement dates. For the Grand Calumet River the monthly measurement of the pH at Burham Avenue was directly input for each of WYs 2001, 2003, and 2008 with 15 min values of pH linearly interpolated between the measurement dates. For the Little Calumet River at South Holland, monthly values of the pH were calculated using a mass balance approach applied to data from the Little Calumet River at Wentworth Avenue and Thorn Creek at Joe Orr Road (both upstream from the South Holland gage). Again, 15 min values were calculated applying a linear interpolation between measurement dates. For all the gaged and ungaged tributaries to the Little Calumet River and Calumet-Sag Channel, the monthly median value of pH for Thorn Creek at Joe Orr Road was computed for the data from 1970 to 2009 and applied to that month at each of the tributaries.

pH for Inflow from Lake Michigan—The Chicago Department of Water Management (CDWM) makes daily pH measurements near the shore and at the intake crib for both the Jardine Water Purification Plant (JWPP) and the South Water Purification Plant (SWPP). Unfortunately, it was not possible to access this daily data for all three water years of interest. The CDWM provided the daily pH data for the SWPP for calendar years 1998, 1999, and 2007 to 2011 and for the JWPP for calendar years 2005 to 2011. Thus, pH can be simulated using actual daily values for Lake Michigan for WY 2008, but for WYs 2001 and 2003 the daily time series from another year must be used to approximate the pH of Lake Michigan water for the year of interest. Table 2.10 lists the mean absolute error in percent for WY 2008 simulated using different time series of daily Lake Michigan pH. From Table 2.10 it can be seen that using the daily time series of Lake Michigan pH for the SWPP shore or crib yields for WY 1999 nearly identical error results as obtained would be obtained using the daily time series at the shore or crib at the SWPP or JWPP for WY 2008 when simulating WY 2008. Thus, the application of daily time series for other years was expected to (and did) yield similarly small errors in the pH simulation for WYs 2001 and 2003.

Performance of pH Simulation—The simulation of pH in the CAWS for all three waters years then was done using the daily time series of pH for WY 2008 at the Shore for the JWPP. The accuracy of the DUFLOW simulation of pH in the CAWS is shown for WY 2008 as an example in Figures 2.15-2.18. The pH simulation results for WYs 2001 and 2003 are shown in

Addendum C. Using the JWPP Shore pH time series results in 33 of the annual mean absolute errors being less than 5% out of 45 possible location-year combinations (15 locations for 3 years), and the maximum annual mean absolute error was 8.07% at Route 83 on the Calumet-Sag Channel for WY 2001. These results clearly indicate that pH can be reliably simulated as a conservative property of water in the CAWS.

Table 2.10. Mean absolute error in percent for Water Year 2008 simulated using different time series of daily Lake Michigan pH [note: SWPP = South Water Purification Plant, JWPP = Jardine Water Purification Plant].

Location	Crib			Shore		
	SWPP 1999	JWPP 2008	SWPP 2008	SWPP 1999	JWPP 2008	SWPP 2008
Oakton Street	5.49	6.13	5.54	5.51	5.18	5.59
Touhy Avenue	2.25	2.43	2.26	2.26	2.22	2.29
Wilson Avenue	2.22	2.25	2.22	2.22	1.94	2.24
Diversey Parkway	4.25	4.30	4.25	4.25	3.94	4.27
Wells Street	2.87	4.14	2.75	2.91	3.20	2.72
Madison Street	3.11	2.67	3.09	3.13	2.79	3.06
Cicero Avenue (CSSC)	3.42	3.65	3.39	3.42	3.11	3.38
Harlem Avenue	3.53	3.70	3.51	3.53	3.38	3.51
Route 83 (CSSC)	3.39	3.16	3.36	3.38	3.04	3.40
Indiana Avenue	6.08	6.08	6.08	6.08	6.08	6.08
Halsted Street	3.27	3.27	3.27	3.27	3.27	3.27
Ashland Avenue (Cal-Sag)	2.87	2.87	2.87	2.87	2.87	2.87
Cicero Avenue (Cal-Sag)	1.67	1.67	1.67	1.67	1.67	1.67
Route 83 (Cal-Sag)	4.03	4.11	4.04	4.04	4.08	4.04

2.2 Extension of DUFLOW Model to the Calumet River

The Midsystem Separation alternative involves connecting a portion of the Calumet-Sag Channel drainage area and reconnecting the Little Calumet River and Grand Calumet River to Lake Michigan through the Calumet River. Therefore, the DUFLOW model needed to be extended to simulate flow and water quality through the 6 mi length of the Calumet River. Direct surface runoff to the Calumet River is limited, primarily consisting of rainfall on Lake Calumet and CSOs from the 95th Street and 122nd Street pumping stations, which operate infrequently during the study WYs 2001, 2003, and 2008.

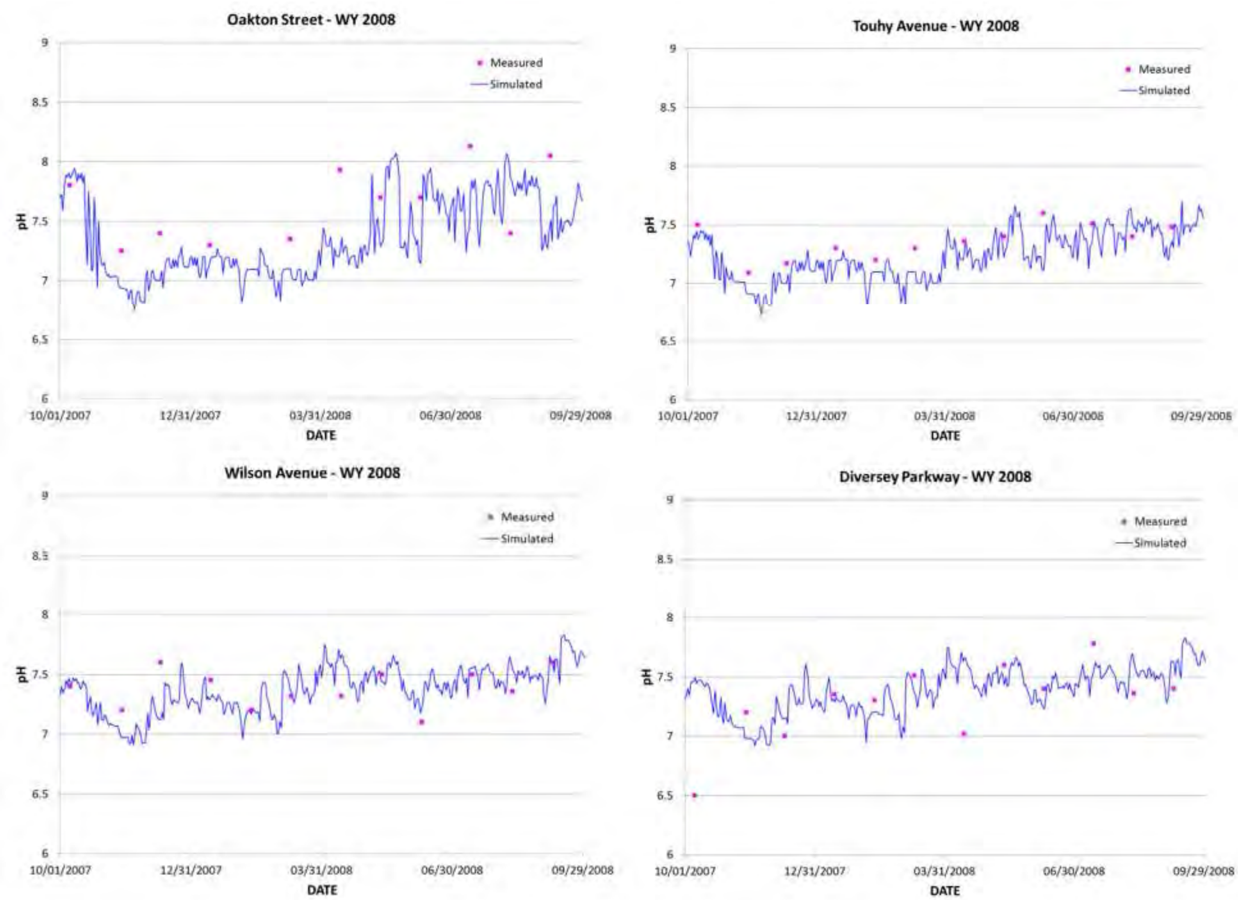

Figure 2.15. Measured and simulated pH on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2008.

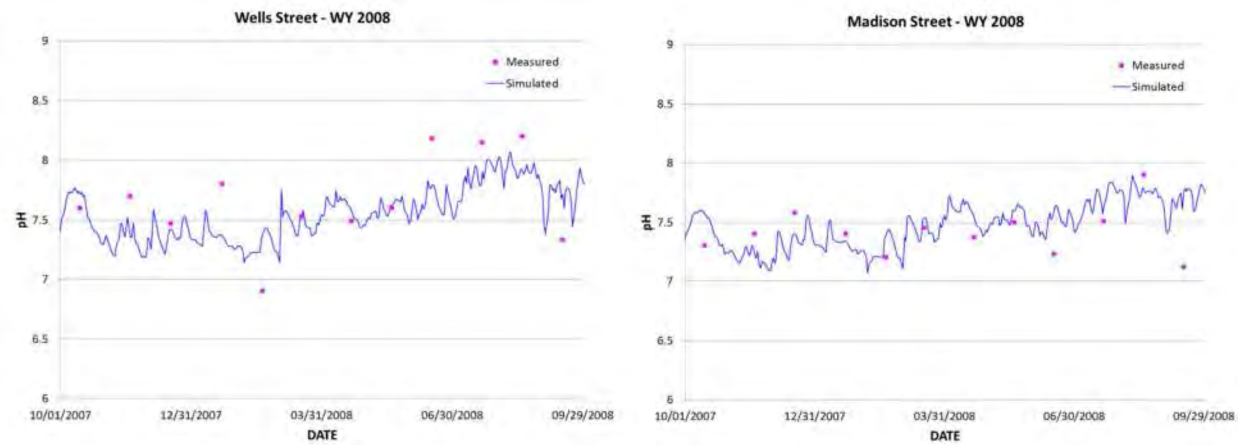

Figure 2.16. Measured and simulated pH on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2008.

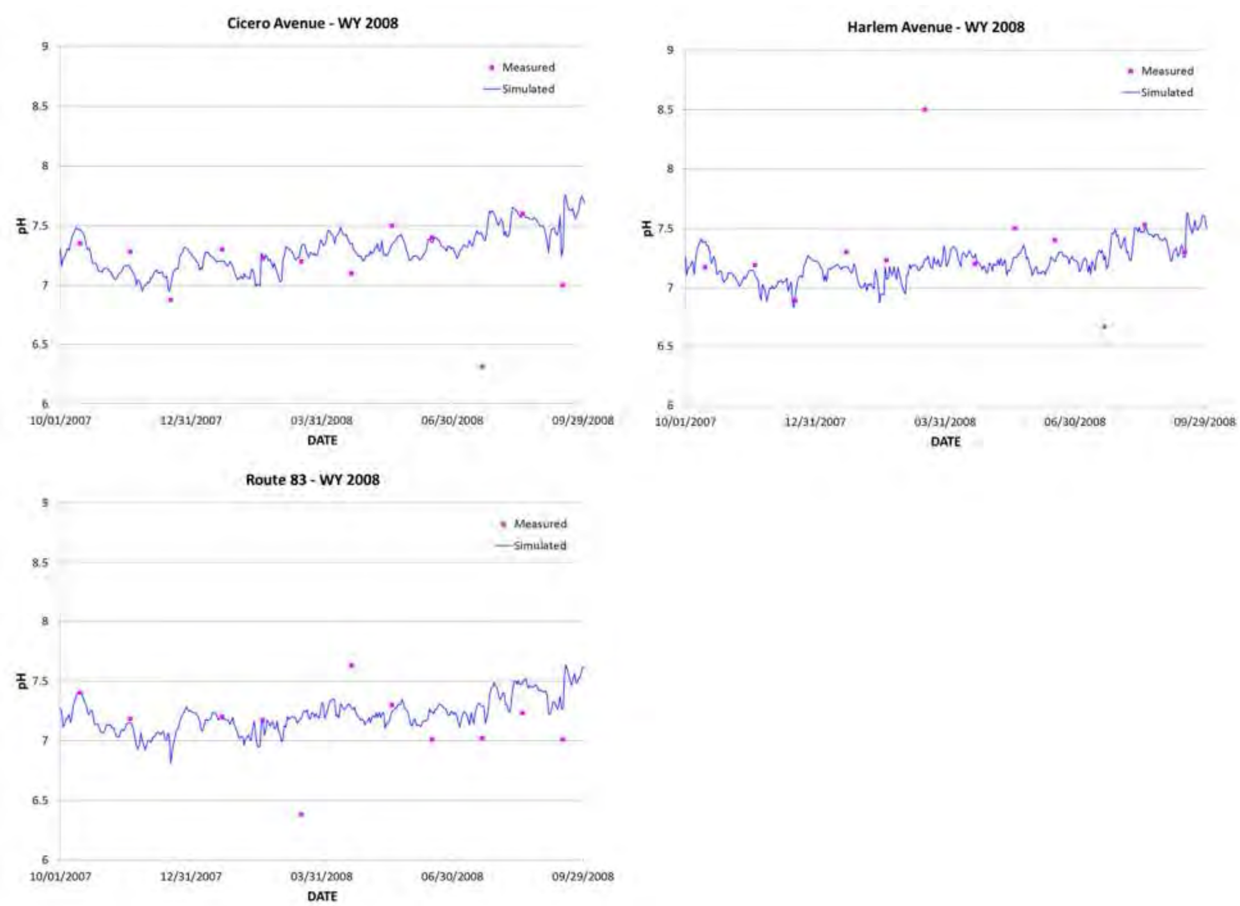

Figure 2.17. Measured and simulated pH on the Chicago Sanitary and Ship Canal at Cicero Avenue, Harlem Avenue, and Route 83.

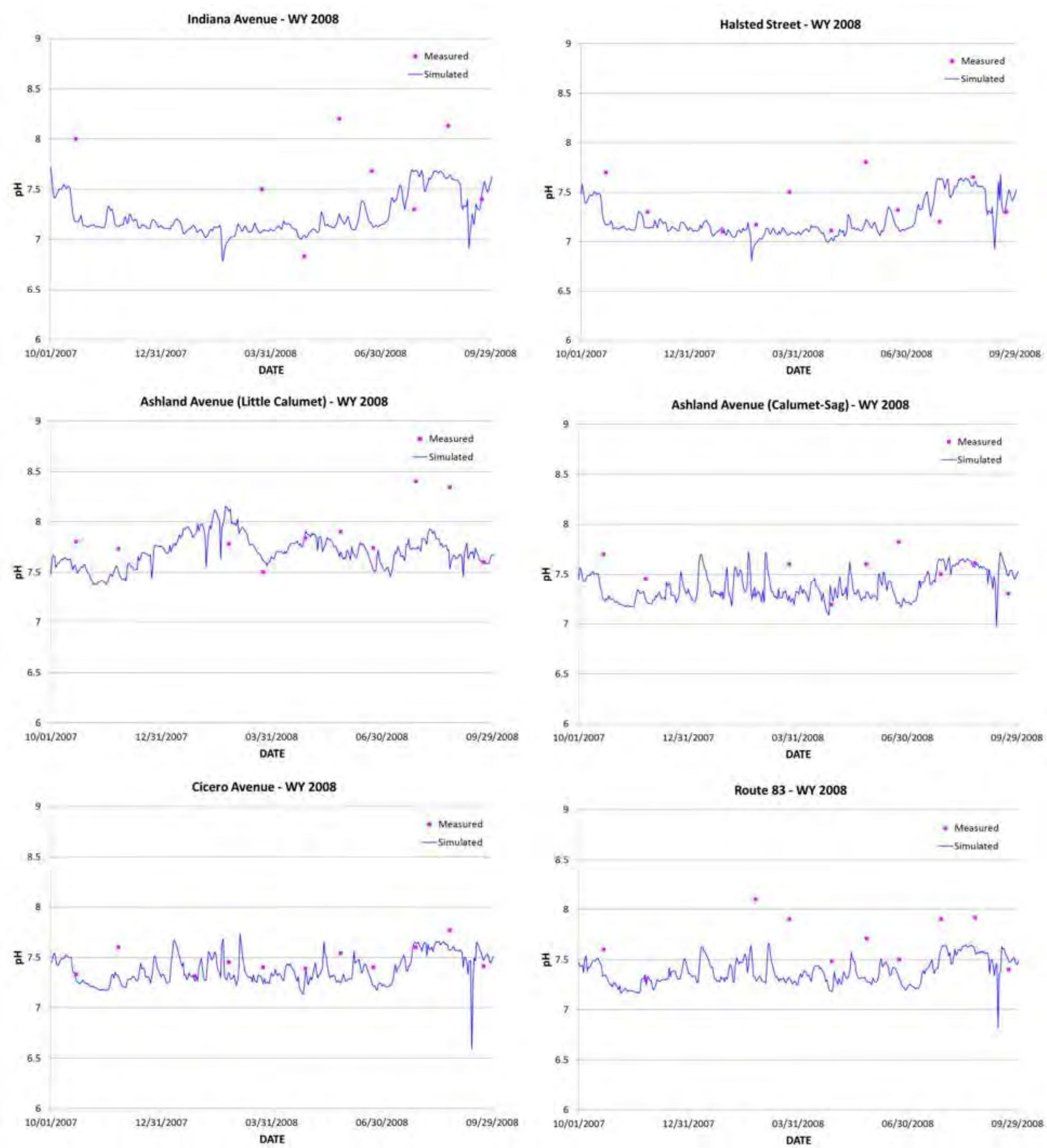

Figure 2.18. Measured and simulated pH on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2008.

Hydraulic modeling of the Calumet River between Calumet Harbor at Lake Michigan and O'Brien Lock and Dam was added to the DUFLOW model of the CAWS as follows. Cross-sectional data measured at 151 locations on Calumet River was applied to build the channel network of the Calumet River. The data were produced using HEC-GeoRAS by the U.S. Army Corps of Engineers (USACE), Chicago District. The cross-sectional data include the channel cross sectional geometry expressed as X-Y coordinates. The distances between cross sections are mostly less than 330 ft. It is noted that 2 out of the 151 cross sections, those at RM 332.15 and RM 332.14 were deleted because the cross-sectional data indicated subsurface ridges in the channel that were considered to be unreliable data. The two pumping stations (95th Street Pumping Station and 122nd Street Pumping Station) also were added to the network since they contribute flow during large rainfall events. These flows were estimated from the operational records and capacities of the pumps. In the modeling, no explicit representation of Lake Calumet—the storage in and the runoff from Lake Calumet—was included in the model.

The National Oceanic and Atmospheric Administration (NOAA) operates an hourly water level gage at Calumet Harbor, which could serve as the Lake Michigan boundary condition for the DUFLOW model of the Calumet River (in the final modeling of the Midsystem Separation alternative an average of several Lake Michigan water level gages was used to represent Lake Michigan as detailed in Chapter 5). The USACE, Rock Island District, monitored the water-surface elevation on the Lake Michigan side of the O'Brien Lock and Dam at 30 min intervals during each of WYs 2001, 2003, and 2008. The MWRDGC monitored the water-surface elevation on the Lake Michigan side of the O'Brien Lock and Dam at 1 hr intervals during each of WYs 2001, 2003, and 2008. Finally, the USGS operated an Acoustic Velocity Meter flow measurement gage on the river side of the O'Brien Lock and Dam during WYs 2001 and 2003. This gage provides flow estimates at a 15 min time step. The 15 min record was, however, subject to high variability because of the operational aspects of the O'Brien Lock and the channel configuration of the Little Calumet River (north) downstream from the O'Brien Lock and Dam, and daily flows at this site are considered more reliable than 15-min flows.

Given that measured water levels are available at each end of the Calumet River and measured flows are available at the O'Brien Lock and Dam, one might think that calibration and verification of the DUFLOW hydraulic model of the Calumet River could be easily accomplished. However, even during periods when discretionary diversion is taken at the O'Brien Lock and Dam, the flow is so low in the Calumet River, relative to the size of the cross section, that computational instabilities often result due to fluctuations and errors in the boundary conditions.

For example, the flow and water level data in WY 2001 were used to perform preliminary hydraulic simulations. The average daily water level at Calumet Harbor was used as the upstream boundary condition to try to smooth some of the hourly water level fluctuations, while the 15 min or daily flow data below O'Brien Lock and Dam was used as the downstream boundary condition. The resistance to flow was estimated using a Chezy's coefficient value of 44, which is equivalent to 0.033 for Manning's n (this assumes the Calumet River has similar hydraulic characteristics to those for the Chicago River main stem). When running the hydraulic model, computational instabilities always resulted and the simulations crashed after several time steps. Simulations using the daily or 15 min flow data as the downstream boundary condition were performed starting at 00:00:00 on 10-01-2000 (daily mean flow = 113 cfs) and at 15:00:00 on 03-08-2001 (daily mean flow = 56 cfs), respectively. The calculations at the cross section about 4.85 mi downstream from Calumet Harbor became unstable and the DUFLOW model stopped computations. When evaluating the 15 min or daily flows at the O'Brien Lock and Dam, abrupt fluctuations and reverse flows are observed at the O'Brien Lock and Dam. It is believed that the high variability of the flow boundary conditions led to the numerical instability problems found in the DUFLOW model of the CAWS when applied to days with low flows.

Thus, the only test to verify the computations made by the DUFLOW model of the Calumet River that could be made was to simulate the period of September 13-30, 2008. During this period from 17:00 on the 13th to 15:00 on the 16th the lock and/or sluice gates at the O'Brien Lock and Dam were opened to let flows pass to Lake Michigan with the estimated peak flows in the neighborhood of 5600 cfs. In the days after this flow reversal the MWRDGC took large amounts of discretionary diversion at the O'Brien Lock and Dam, such that the estimated daily mean flows between the 21st and 30th ranged between 346 and 954 cfs. Thus, during this period (13th to 30th) the flows in the Calumet River were high enough to avoid computational instabilities.

The flow boundary condition was determined as follows. A simulation of the DUFLOW hydraulic model of the CAWS system on the river side of the O'Brien Lock and Dam was made using the measured water-surface elevations at O'Brien Lock and Dam (river side), CRCW, Wilmette, and the Lockport Controlling Works as the boundaries. As discussed in Chapter 3, this all stage boundary condition run for WY 2008 yielded substantial underestimations of storm flows passing the USGS gage at Lemont and the final runs for WY 2008 were made using daily flow estimates from the MWRDGC for all days, but September 13-16. However, as noted in

Chapter 3, the simulations using the all stage boundary conditions yielded total flow volumes to Lake Michigan that are very close to the MWRDGC's estimates of the flows through the controlling structures (e.g., the DUFLOW estimate of the volume of flow to Lake Michigan at the O'Brien Lock and Dam was 13% higher than the MWRDGC estimate), and, thus, the DUFLOW estimated flows to Lake Michigan were utilized in the boundary conditions for the simulation of WY 2008 under current hydrologic conditions. Therefore, the hourly flows on the 13^{th} to the 16^{th} from the DUFLOW model were combined with the MWRDGC daily mean flow estimates for the 17^{th} to 30^{th} to compose the boundary condition at the O'Brien Lock and Dam. The hourly Lake Michigan water level boundary was taken as the average of the NOAA measurement at Calumet Harbor, the USGS measurement at CRCW, and the MWRDGC measurement at Wilmette. As mentioned earlier, the Calumet River was considered similar to the Chicago River main stem, and, thus, the hydraulic and water quality parameters calibrated for the Chicago River main stem were applied to the Calumet River.

No flow data were available to verify the DUFLOW hydraulic model of the Calumet River, and the available stage data were considered inadequate to verify the DUFLOW hydraulic model of the Calumet River. Thus, the only checks that could be made for the DUFLOW model of the Calumet River were comparisons with water-quality measurements made at 130^{th} Street, Ewing Avenue, and 95^{th} Street. During flow reversals to Lake Michigan the MWRDGC is required to intensively sample fecal coliform concentrations in flows going toward the lake at 95^{th} Street and Ewing Street. Figure 2.19 shows the measured and simulated fecal coliform concentrations in the flows to Lake Michigan at Ewing Avenue and 95^{th} Street. The results at Ewing Avenue are quite reasonable with the low concentrations representative of the Lake Michigan water at Ewing

Avenue before the CSO flows released from the 95th Street Pumping Station arrive at Ewing Avenue. Then the DUFLOW model yields good agreement with the measured data on the rise and fall of fecal coliform concentrations because of the CSOs released by the 95th Street Pumping Station. The agreement between measured and simulated fecal coliform concentrations is less good at the 95th Street sampling site and this is probably due to the characteristics of how the effluent from the 95th Street Pumping Station mixes into the Calumet River and reaches the sampling location. Note that the flow released from the O'Brien Lock and Dam takes until the 17th to have its maximum impact on these sampling locations.

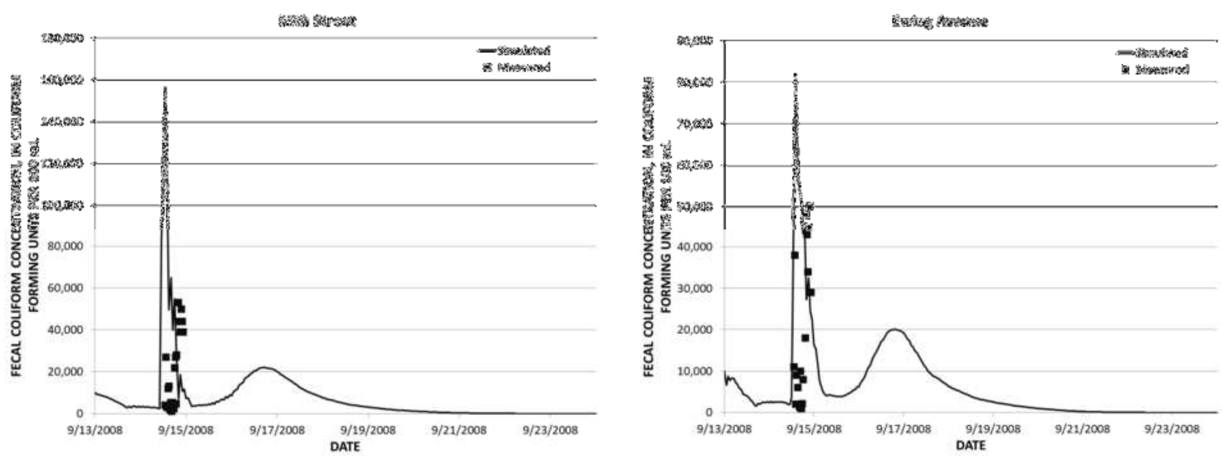

Figure 2.19. Measured and simulated fecal coliform concentrations in the Calumet River at 95th Street and Ewing Avenue during September 13 to 30, 2008.

Ewing Avenue and 130th Street are locations in the MWRDGC's Ambient Monthly Water Quality Network. Thus, for these locations the model simulated DO and ammonia concentrations can be compared with the measured values at these locations as shown in Figure 2.20. To facilitate the comparison between the hourly model output and the single measurement in the simulated period, the single measurement is linearly connected with the measured values in the neighboring months (August and October) in Figure 2.20 so that the general trends in water quality at these sites can be evaluated. At Ewing Avenue the simulated and observed concentrations agree reasonably well. At 130th Street the agreement between simulated and observed concentrations is not so close, however, in the long run, the simulated ammonia and DO concentrations approach reasonable values reflective of Lake Michigan water at these locations by October 1st.

These limited tests of the water-quality simulation for the Calumet River indicate that the DUFLOW model yields reasonable estimates of the water quality in the Calumet River. Further, in order for the water-quality simulation to yield reasonable results the hydraulic portion of the DUFLOW model also must be providing a reasonable simulation of flow in the Calumet River.

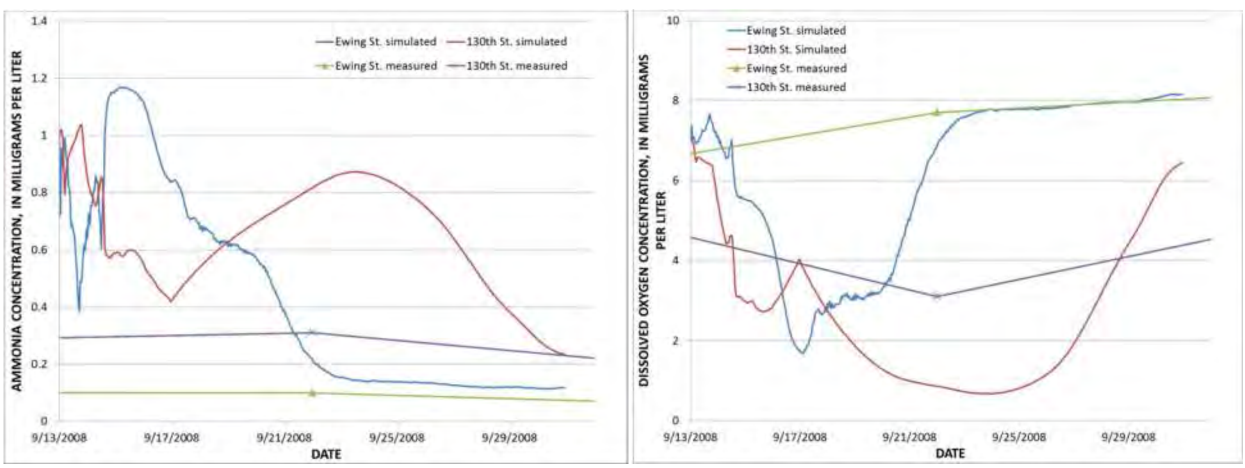

Figure 2.20. Measured and simulated ammonia and dissolved oxygen concentrations in the Calumet River at 130th Street and Ewing Avenue during September 13 to 30, 2008.

Chapter 3 - HYDRAULIC MODEL VERIFICATION

3.1 Introduction

The unsteady-flow model for the CAWS was calibrated and verified by the Institute for Urban Environmental Risk Management, Marquette University in 2003. The ability of the model to simulate unsteady flow conditions was demonstrated by comparing the simulation results to measured data for eight different periods between August 1, 1998 and July 31, 1999 (Shrestha and Melching, 2003). The model was calibrated using hourly water-surface elevation (stage) data at three gages operated by the MWRDGC along the CSSC and at the downstream boundary at Romeoville Road (in the original DUFLOW model of the CAWS) operated by the USGS, and using daily flow data collected by the USGS near the CRCW and O'Brien Lock and Dam upstream boundaries. Alp and Melching (2006) used data from the period between July 12 and November 9, 2001, and Neugebauer and Melching (2005) used data from the period between May 1 and September 24, 2002 to verify the previously calibrated hydraulic model (Shrestha and Melching, 2003).

Melching et al. (2010) updated, improved, re-calibrated, and verified the previouly calibrated DUFLOW hydraulic and water quality model for the CAWS of Alp and Melching (2006) for the representive "wet" year of WY 2001 and "dry" year of WY 2003. Three major improvements or changes in hydraulic modeling were made by Melching et al. (2010) to the previous DUFLOW model reported in Alp and Melching

(2006). First, new CSO locations on the NSC were added. Second, the CSO discharges simulated by the U.S. Army Corps of Engineers (USACE), Chicago District were used. Third, the downstream boundary was moved from Romeoville Road to the Lockport Controlling Works on the CSSC.

As in the most recent CAWS DUFLOW model (Melching et al., 2010), the simulated gravity CSO flows obtained from the USACE models are used in the CAWS DUFLOW modeling in this study to improve the temporal and spatial distribution of CSO inflows for WY 2008. For the purposes of the design of the Tunnel and Reservoir Plan (TARP) the USACE developed a series of models to simulate the surface and subsurface runoff in the TARP drainage area (which includes the CAWS watershed); the flows in the major interceptors; the distribution of the flows to the WRPs or potentially to gravity CSO outfalls or TARP drop shafts; and the flows in the TARtunnels. These models also are run for each water year using precipitation input from a network of 25 gages operated by the Illinois State Water Survey as part of the Lake Michigan diversion accounting. Detailed discussions of the USACE models (a combination of the Hydrological Simulation Program-Fortran, Special Contributing Area Loading Program, and Tunnel Network Model) is given Section 5.1.1 and in Espey et al. (2004).

As in the most recent CAWS DUFLOW model (Melching et al., 2010), 43 representative CSO locations are used as CSO inflow points in the model to represent nearly 240 CSOs throughout the CAWS watershed. In the NSC area of the CAWS where the CSO flows are dominant, 19 gravity CSO locations are included to represent 24 TARP drop shaft overflow locations. In the Calumet-Sag Channel and Little Calumet River portion of the CAWS watershed, 10 gravity CSO locations are used in the modeling. Finally, 14 gravity CSO locations are used to represent the gravity CSO inflows to the NBCR, SBCR, Chicago River main stem, and CSSC.

In addition to the features previously mentioned, the upstream boundary at O'Brien Lock and Dam was moved as necessary to the Calumet Harbor at Lake Michigan in order to simulate the loads to Lake Michigan on Calumet River side for the case of simulating the effects of the "Midsystem Separation" alternative and the flows to Lake Michigan in September 2008. Details of the DUFLOW model extension to the Calumet River are given in Section 2.2.

In the following sections, improvements to the previous model and inputs and the results of the hydraulic verification for WY 2008 are presented.

3.2 Hydraulic Data used for the Model Input

Since all data needed for input to the model are not available, some assumptions were made to estimate missing data and flow from ungaged tributaries and ungaged watersheds. In the following subsections the hydraulic data used in the model are explained.

3.2.1 Measured Inflows, Outflows, and Water-Surface Elevations

A total of three sets of upstream boundary conditions at three near lake locations have been examined to find the best available upstream boundary condition for the DUFLOW model applied to WY 2008. Initally, water-surface elevation upstream boundary conditions were used for the model because the water-surface elevation measurements are more accurate that the daily flow estimates available from the MWRDGC computed on the basis of lake and river water-surface elevations, gate settings, and numbers of lockages. The simulated flows on the NBCR at Grand Avenue and the CSSC at Lemont Avenue were compared to the flows measured by the USGS as shown in Figure 3.1. It can be seen that the simulation result of the flows at Lemont Avenue was not good. In particular, the peak flows for the storm events were substantially underestimated implying that unrealistic flows to Lake Michigan were computed at the near lake boundaries of the model when water-surface elevation boundary conditions were used for WY 2008. Thus, it was decided to apply the daily flow estimates made by the MWRDGC as the boundary conditions for the DUFLOW model.

One exception to generally poor quality of the flows estimated using the water-surface elevation boundary conditions at the near lake boundaries was the simulation of the flow reversals during the September 13^{th} to 16^{th} storms. At CRCW the sluice gates were open from 10:00 am on the 13^{th} to 11:30 am on the 15^{th} and the lock was open from 12:58 to 5:00 pm on the 14^{th}. The MWRDGC estimated the total flow to Lake Michigan during this period as 5438.2 million gallons (mgal), whereas using the water-surface elevation boundary conditions the DUFLOW estimate of the total flow to Lake Michigan during this period was 4957.7 mgal (a 8.84% underestimate). At Wilmette the sluice gate was open from 6:18 am on the 13th to 7:30 am on the 16th. The MWRDGC estimated the total flow to Lake Michigan during this period as 2941.7 mgal, whereas using the water-surface elevation boundary conditions the DUFLOW estimate of the total flow to Lake Michigan during this period was 2937.2 mgal (a 0.15% underestimate). At O'Brien Lock and Dam the sluice gates were open from 5:30 pm on the 13th to 2:35 pm on the 16th and the lock was open from 2:35 to 7:55 pm on the 14th. The MWRDGC estimated the total flow to Lake Michigan during this period as 2669.2 mgal, whereas using the water-surface elevation boundary conditions the DUFLOW estimate of the total flow to Lake Michigan during this period was 3016.0 mgal (a 12.99% overestimate). Summing the three locations, the MWRDGC estimate of the total flow to Lake Michigan was 11049.1 mgal, whereas the DUFLOW estimate was 10910.9 mgal (a 1.25% underestimate). Thus, the simulated hourly flows obtained from the DUFLOW model during the days of flow reversals (13th to 16th) were combined with the daily flow estimates at each near lake boundary to compose a flow boundary condition at these locations.

The daily mean flows estimated by the MWRDGC were used as one set of upstream boundary conditions at each near lake boundary. An alternative set of upstream flow boundary conditions were computed using regression equations developed by the USGS to provide backup flow estimates for the streamflow gages at Maple Avenue on the NSC (0.2 mi downstream from Wilmette), Columbus Drive on the Chicago River main stem (0.5 mi downstream from CRCW), and O'Brien Lock and Dam on the Calumet River.

Daily mean flows at Wilmette were estimated from the MWRDGC estimate (Q_{MWRDGC}) as follows (Duncker et al., 2006):

$$Q_{USGS} = 0.9596\ Q_{MWRDGC} + 0.5914$$

Daily mean flows at O'Brien Lock and Dam were estimated from the MWRDGC estimate as follows (Duncker et al. 2006):

$Q_{USGS} = 0.822\ Q_{MWRDGC} + 149.2$ (for periods with discretionary diversion)

$Q_{USGS} = Q_{MWRDGC}$ (for periods without discretionary diversion)

Daily mean flows at CRCW were estimated from the MWRDGC estimate as follows (James Duncker, USGS, written commun., June 6, 2012, these equations are based on the station analysis for WY 2006, the last year that the Columbus Drive gage was fully active):

$Q_{USGS} = 0.8257\ Q_{MWRDGC} + 10.422$ (for periods with discretionary diversion)

$Q_{USGS} = 0.733\ Q_{MWRDGC} + 8.5486$ (for periods without discretionary diversion)

Tables 3.1 and 3.2 show the Nash and Sutcliffe (1970) coefficient of model-fit efficiency and average error of the simulation of the flow at Lemont Avenue on the CSSC and Grand Avenue on the NBCR, respectively. According to the statistics, the daily flows computed using the MWRDGC flow estimates as the upstream boundary condtions at the three near-lake locations produced the best simulation results at Lemont Avenue and nearly the best results at Grand Avenue. Therefore, the estimated daily flows from the MWRDGC were used as the upstream boundary conditions for WY 2008 in the DUFLOW model. The comparison of simulated and measured flows at Lemont Avenue on the CSSC for the MWRDGC flow upstream boundary conditions is shown in Figure 3.6 at the end of this chapter.

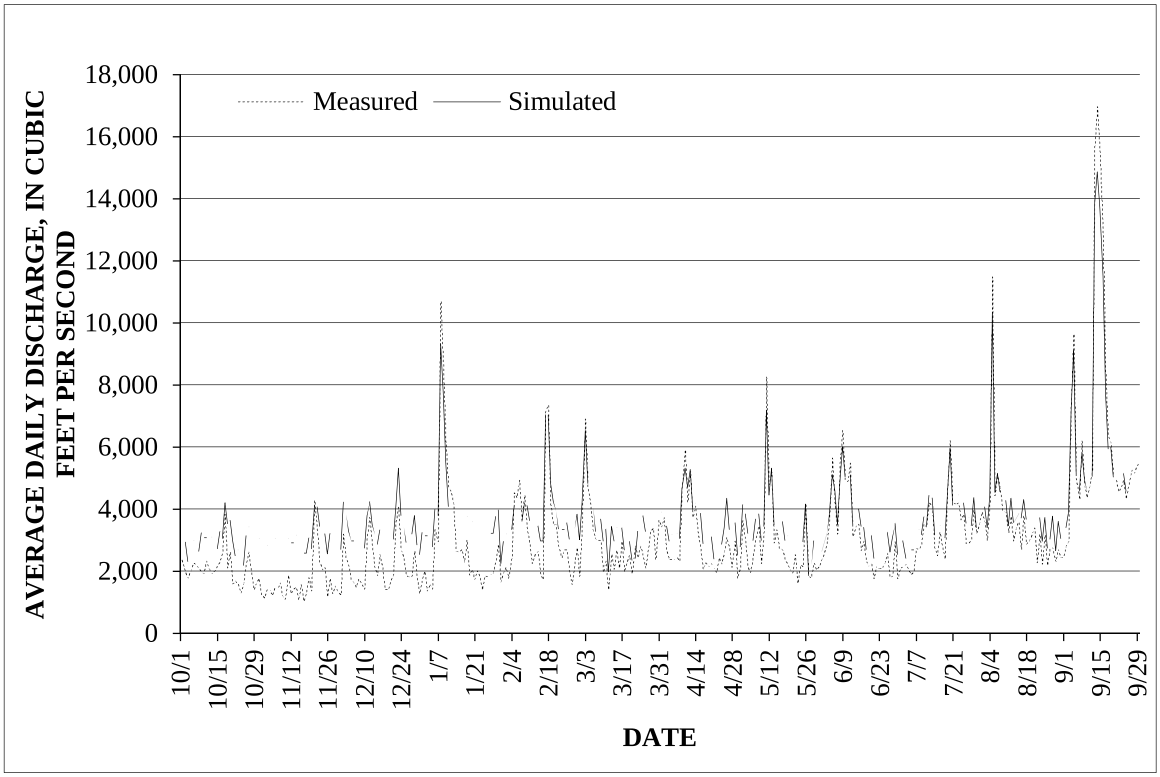

Figure 3.1. Comparison of measured and simulated flows at Lemont Avenue on the Chicago Sanitary and Ship Canal for Water Year 2008.

Table 3.1. Model-fit efficiency and average errors for the simulated flow at Lemont Avenue on the Chicago Sanitary and Ship Canal for Water Year 2008.

Upstream Boundary Condition	Efficiency	Average Error (%)	Average Absolute Error (%)	Average Error (cfs)	Average Absolute Error (cfs)
MWRDGC Flow	0.8689	7.4	45.7	77.7	593.3
USGS Flow	0.8670	7.9	46.5	84.7	596.8
MWRDGC Stage	0.7521	42.7	94.1	628.6	932.3

Table 3.2. Model-fit efficiency and average errors for the simulated flow at Grand Avenue on the North Branch Chicago River for Water Year 2008.

Upstream Boundary Condition	Efficiency	Average Error (%)	Average Absolute Error (%)	Average Error (cfs)	Average Absolute Error (cfs)
MWRDGC Flow	0.7714	8.1	19.0	53.0	109.5
USGS Flow	0.7718	7.8	19.0	53.0	109.5
MWRDGC Stage	0.7568	23.7	24.0	134.2	137.7

Water-surface elevation versus time data (on an hourly basis) from the MWRDGC gage on the CSSC at the Lockport Controlling Works are used as the downstream boundary condition for the model. The flow data from the USGS gage on the Little Calumet River (south) at South Holland provide a flow versus time upstream boundary condition at a 15-min time step for the model. Two tributaries to the Calumet-Sag Channel are gaged by the USGS, Tinley Creek near Palos Park and Midlothian Creek at Oak Forest, and their flows are input to the model at a 15-min time step. The USGS gage on the Grand Calumet River at Hohman Avenue at Hammond, Ind. is used to obtain the flow from the Grand Calumet River on an hourly time step, which is a tributary to the Little Calumet River (north). Flow on the NBCR is measured at a 15-min time step just upstream of its confluence with the NSC at the USGS gage at Albany Avenue.

There are also inflows coming from MWRDGC facilities. Hourly flow data are available from the MWRDGC for the treated effluent discharged to the CAWS by each of the four WRPs—O'Brien, Stickney, Calumet, and Lemont. Hourly flows were input to the model for the first three WRPs; whereas daily flows were used at Lemont. In addition, hourly flows discharged to the CAWS at three CSO pumping stations—North Branch, Racine Avenue, and 125th Street—were estimated from operating logs of these stations (as described in Section 2.1.1 of Melching et al., 2010). The boundary conditions and tributary inflows for the DUFLOW model of the CAWS are summarized in Section 3.2.3.

3.2.2 Estimation of flow for ungaged tributaries and combined sewer overflows

It is necessary to estimate the inflows from ungaged tributary watersheds. The same procedure was followed as applied in the original hydraulic calibration of the model (Shrestha and Melching, 2003). In the original hydraulic calibration, flows on Midlothian Creek were used to estimate flows on ungaged tributaries on an area-ratio basis. The drainage area ratios for the ungaged tributaries compared to the Midlothian Creek drainage area are listed in Table 3.3. The U.S. Army Corps of Engineers (2001) has estimated the land cover distribution in percent for the "ungaged" Calumet-Sag (including Midlothian and Tinley Creeks) and lower Des Plaines watersheds as follows.

Watershed	Impervious	Grassland	Forest
Ungaged Calumet-Sag	35.8	58.7	5.5
Ungaged lower Des Plaines	30.1	40.3	29.6

Because of the relatively small variation in the distribution of pervious and impervious land cover in the ungaged watersheds the area-ratio method results in estimates with sufficient accuracy for the purposes of this study.

Table 3.3. Calculation of ungaged tributaries and watersheds.

Stream Ungaged	Ratio with Midlothian*
Mill Creek West	0.55
Stony Creek West	1.086
Cal-Sag Watershed East	0.246
Navajo Creek	0.137
Stony Creek East	0.486
Ungaged Des Plaines Watershed	0.703
Calumet Union Drainage Ditch	1.168
Cal-Sag Watershed West	0.991

*The gaged Midlothian Creek drainage area is 12.6 mi^2, but these ratios are computed to the total Midlothian Creek drainage area of 20 mi^2. The total flow for both Midlothian and Tinley Creeks was determined by area ratio of the total drainage area to the gaged drainage area, 12.6 mi^2 and 11.2 mi^2 for Midlothian and Tinley Creeks, respectively.

Hourly flows from all 3 pumping stations were estimated from pump operation records of on and off times and the rated capacity of the various pumps and then input to the model. Daily average discharges from the 3 pumping stations are shown in Figure 3.2 for WY 2008.

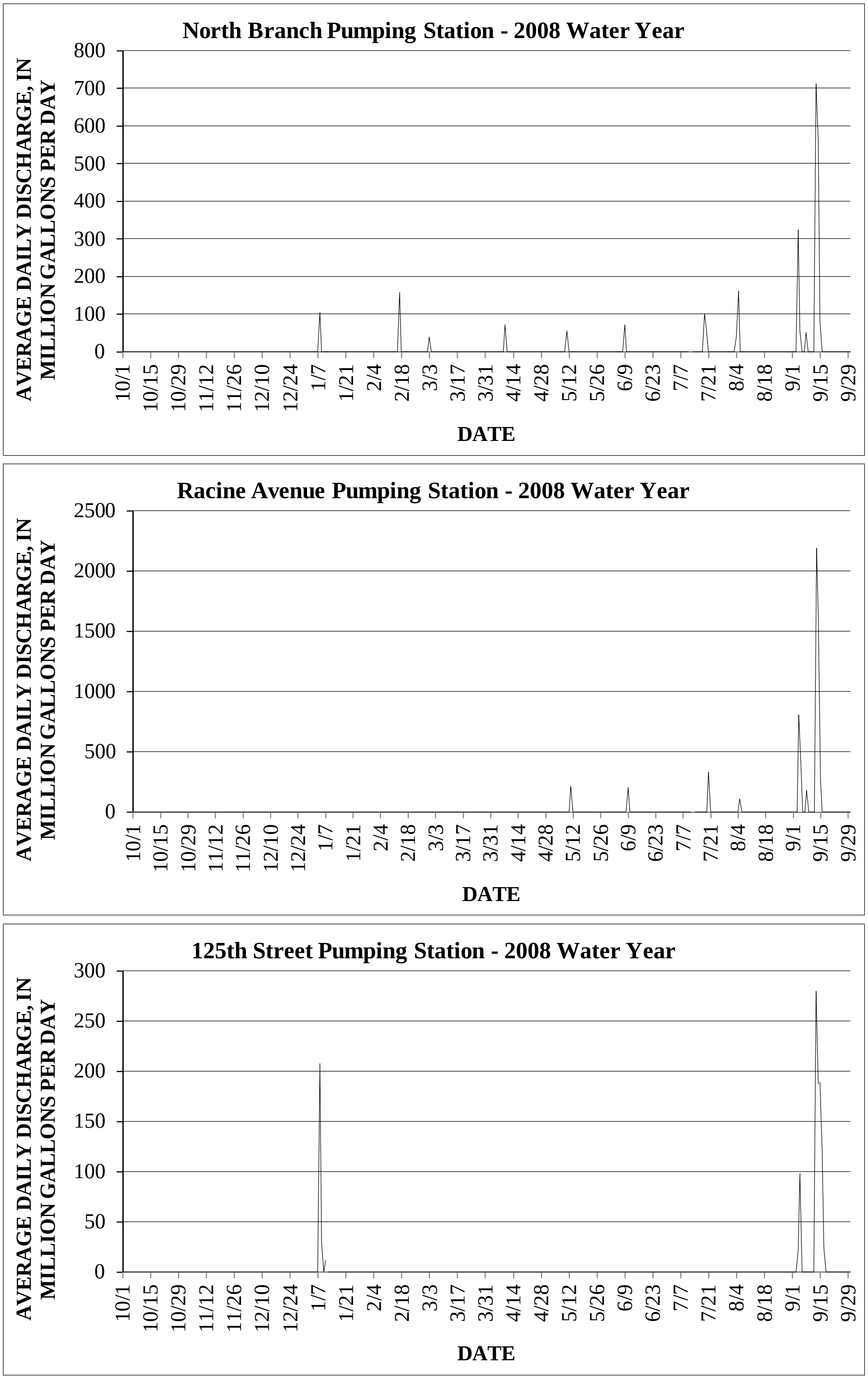

Figure 3.2. Daily average discharges from the North Branch, Racine Avenue, and 125th Street Pumping Stations for Water Year 2008.

3.2.3 Summary of Boundary Conditions and Tributary Inflows

Boundary and initial conditions for WY 2008 were set by data collected by the USGS and the MWRDGC at the three lake front control structures, by the MWRDGC data at the Lockport Controlling Works, and by the USGS for the tributary flows. Data collected by the MWRDGC for the discharges from different WRPs also were used.

Boundary Locations:

- Chicago River at Columbus Drive (near CRCW)
- North Shore Channel at Wilmette (Maple Avenue)
- Calumet River at O'Brien Lock and Dam
- Little Calumet River (south) at South Holland (Cottage Grove Avenue)
- CSSC at the Lockport Controlling Works (downstream boundary)

The major flows into the CAWS have been identified as follows:

- O'Brien Water Reclamation Plant
- Stickney Water Reclamation Plant
- Calumet Water Reclamation Plant

and the minor flows into the CAWS are from:

- North Branch Chicago River at Albany Avenue
- Racine Avenue Pumping Station
- North Branch Pumping Station
- 125^{th} Street Pumping Station
- 95^{th} Street Pumping Station
- 122^{nd} Street Pumping Station

- Lemont Water Reclamation Plant
- Tinley Creek+Navajo Creek (i.e. Navajo Creek estimated based on area ratio with Midlothian Creek and added with nearby Tinley Creek)
- Midlothian Creek
- Grand Calumet River
- Mill+Stony Creek (West)*
- Stony Creek (East)*
- Des Plaines River Basin*
- Calumet Union Drainage Ditch*
- Calumet-Sag Watershed West*
- 43 representative CSO locations

* These flows were estimated based on Midlothian Creek flows

3.3 Channel Geometry and Roughness Coefficient

The channel geometry is represented as a series of 197 (UPDATE THIS TO INCLUDE THE NEW CALUMET RIVER MODEL0 measured cross sections in the calibrated hydraulic model. The DUFLOW model uses Chezy's roughness coefficient, C, to calculate hydraulic resistance. The calibrated C values, which vary between 6 and 60 were used in this study, and the equivalent Manning's n values range from 0.022 to 0.165. Complete details on the calibrated values of Chezy's C and the equivalent Manning's n values are listed in Table 4.2 of Shrestha and Melching (2003).

3.4 Model Verification Locations

Because flow in the various branches of the CAWS are not measured, water-surface elevation recorded at different locations was used for the verification of the model. The water-surface elevations recorded on the NBCR at Lawrence Avenue; on the CSSC at Western Avenue, Willow Springs Road, and Sag Junction by the MWRDGC and at Lemont Avenue by the USGS; and on the Calumet-Sag Channel at Southwest Highway were used for model verification. Daily flows recorded or estimated by the USGS for the CSSC at Lemont Avenue and the NBCR at Grand Avenue also were used for model verification (as detailed in Tables 3.1 and 3.2.

3.5 Flow Balance

The inflow to the CAWS is comprised of flows from tributaries, WRPs, pumping stations, gravity CSOs, and from Lake Michigan at the controlling structures. All the inflows to the system are measured as flow at the USGS gage at Lemont Avenue. During the calculation of the flow balance, it is assumed that the difference in the water balance due to the travel time and change in storage are negligible. Daily average simulated gravity CSO flows obtained from the USACE for WY 2008 as explained in Section 3.1 are shown in Figure 3.3. Comparison of the summation of all inflows to the system and outflow at Lemont is shown in Figure 3.4. All inflows to the system and flow at Lemont for WY 2008 are listed in Table 3.4. Over WY 2008 the inflows were 3.8% higher than the flow at Lemont.

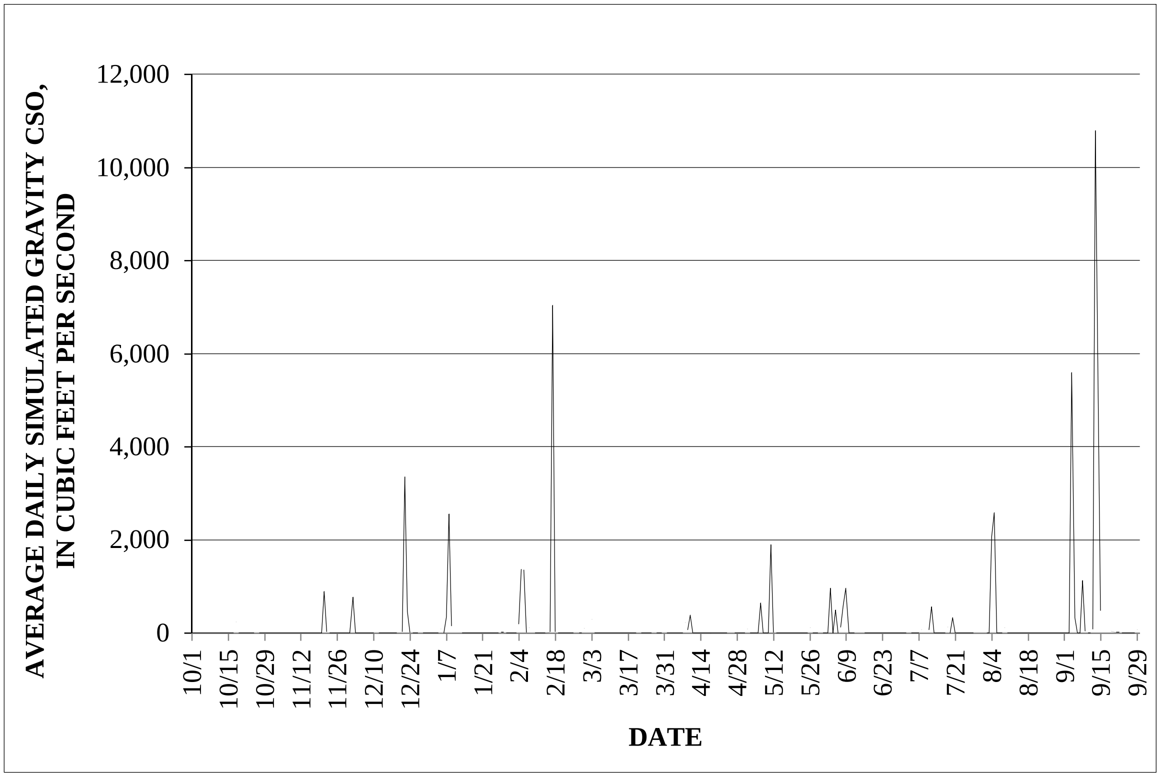

Figure 3.3. Daily average simulated gravity combined sewer overflow (CSO) flows obtained from the U.S. Army Corps of Engineers models for Water Year 2008.

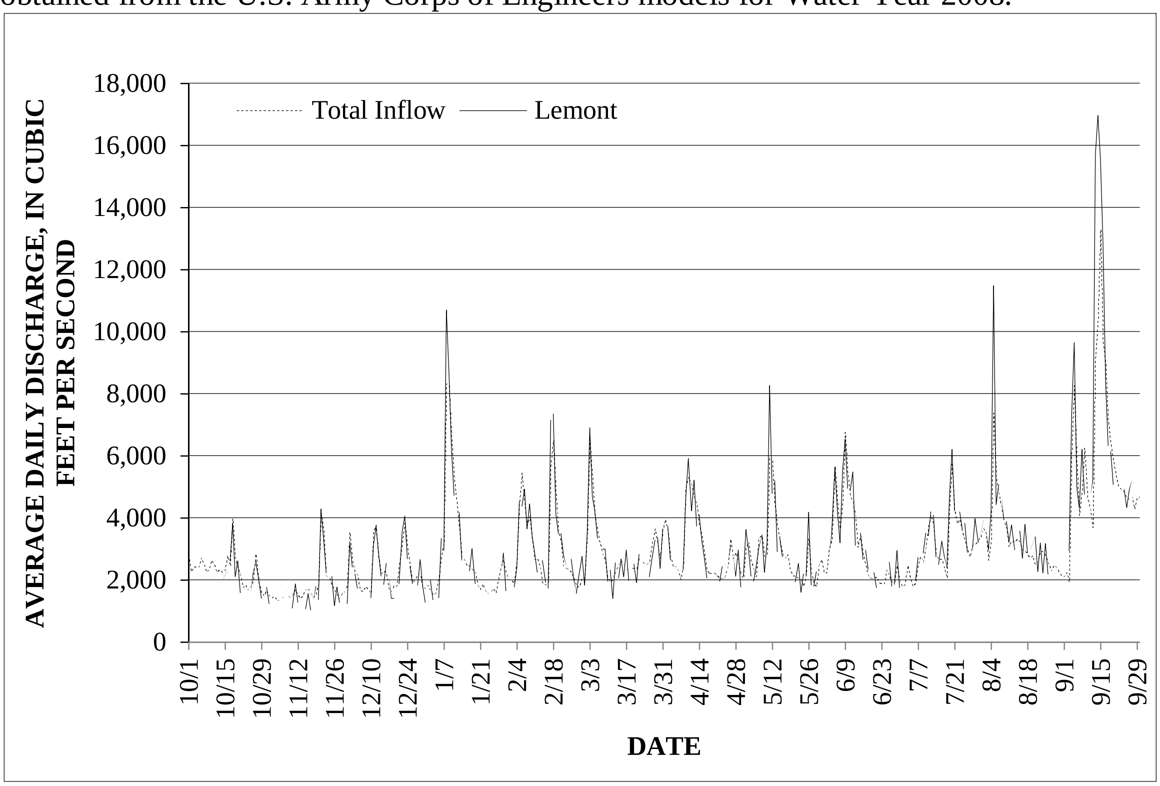

Figure 3.4. Comparison of the summation of all measured or estimated (except gravity combined sewer overflows) inflows (Total Inflow) and the measured outflow at Lemont Avenue on the Chicago Sanitary and Ship Canal for Water Year 2008.

Table 3.4. Balance of average daily flows for the Chicago Area Waterway System for Water Year 2008.

Inflows (2008 WY)	Flow (cfs)
Mill Creek + Stoney Creek (W)*	59.2
Narajo Creek*	4.9
Calumet Union Drainage Ditch*	42.1
Stoney Creek (E) *	17.5
Calumet-Sag End Watershed*	8.9
Lower Des Plaines basin*	25.4
Midlothian Creek	36.1
Grand Calumet River	10.2
Tinley Creek	21.0
Chicago River at Columbus Drive	175.5
O'Brien Lock and Dam	135.9
North Shore Channel at Wilmette	53.3
Little Calumet River at South Holland	244.1
North Branch Chicago River at Albany Avenue	202.9
125th Street Pump Station	4.9
North Branch Pump Station	11.3
Racine Avenue Pump Station	27.0
Lemont Water Reclamation Plant	3.8
Calumet Water Reclamation Plant	430.7
Northside Water Reclamation Plant	377.0
Stickney Water Reclamation Plant	1162.6
Total simulated gravity combined sewer overflows*	159.3
Lemont (Outflow)	3096.4
Total Inflow (except CSOs)	3213.6
Difference (cfs)	117.2
% Difference	3.8

*Estimated flows

3.6 Results of the Hydraulic Verification

The comparison of measured and simulated water-surface elevations at various locations used in the model verification is shown in Figure 3.5 for WY 2008. The statistical analysis listed in Table 3.5 shows that the difference between the measured and simulated stages are below 5% relative to the depth (where depth is measured relative to the thalweg of the channel) of the water for at least 99% of the simulation periods for all locations except for Lawrence Avenue and Southwest Highway. As listed in Table 3.5, the high percentages of small errors and the high correlation coefficients (0.74-0.86) indicate a good hydraulic verification of the model.

Table 3.5. Correlation coefficient and percentage of the hourly water-surface elevations for which the error in simulated versus measured water-surface elevations relative to the depth (D) of flow (measured from the thalweg of the channel) is less than the specified percentage for Water Year 2008.

		Percentage		
Location	**Correlation Coefficient**	**<±2% of D**	**<±5% of D**	**<±10% of D**
Lawrence Avenue (NBCR)	0.78	18	50	77
Grand Avenue (NBCR)	0.86	94	99	100
Western Avenue (CSSC)	0.79	94	99	100
Willow Springs (CSSC)	0.81	95	99	100
Southwest Highway (Cal-Sag Channel)	0.74	18	83	97
Calumet-Sag Junction	0.79	94	99	100
Lemont (CSSC)	0.85	98	100	100

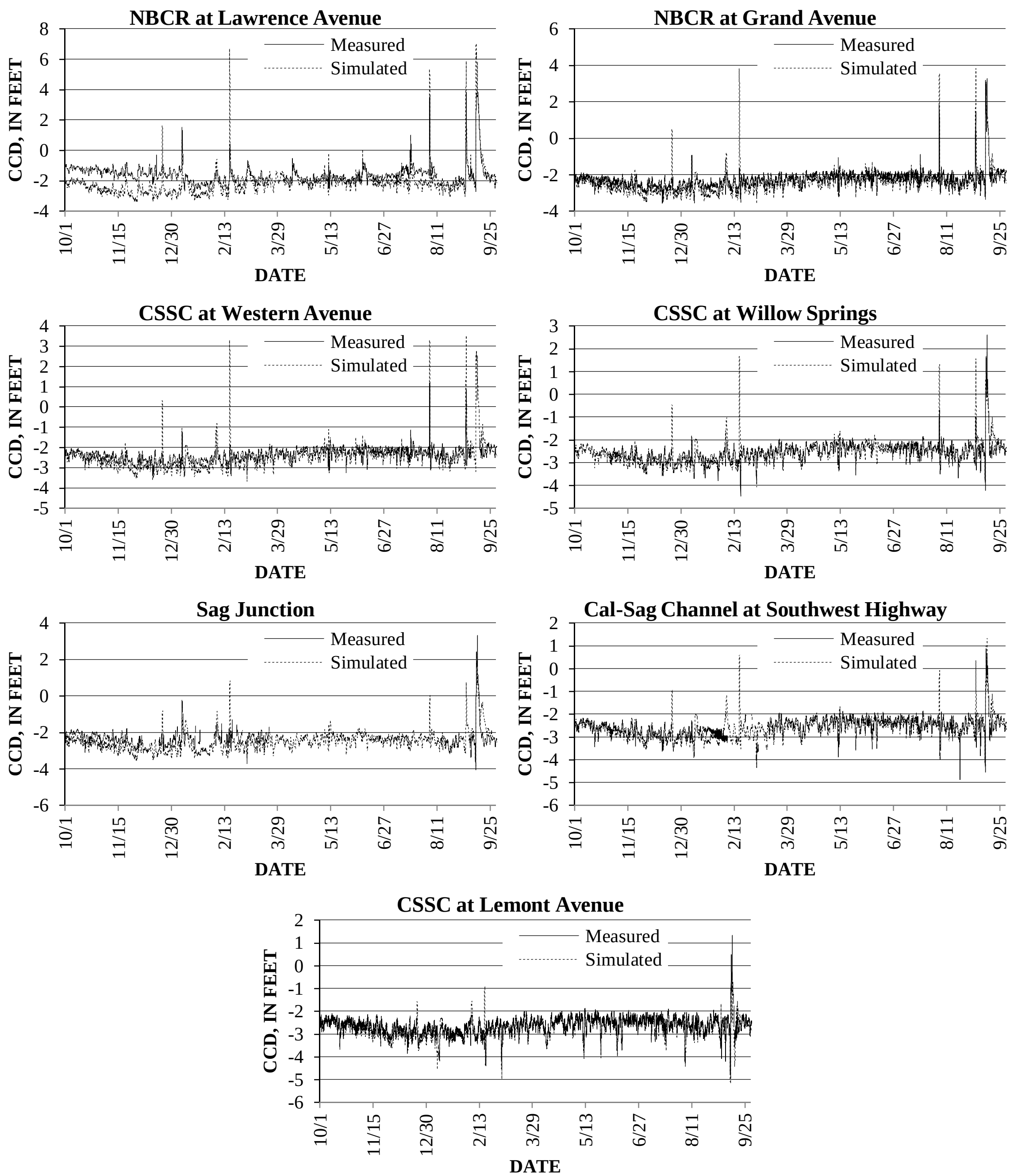

Figure 3.5. Measured and simulated water-surface elevations relative to the Chicago City Datum (CCD) at different locations along the Chicago Area Waterway System for Water Year 2008.

The comparison of measured and simulated average daily flows on the CSSC at Lemont Avenue is shown in Figure 3.6. The simulated average flow rate at Lemont Avenue is 3175.1 cfs for WY 2008. The measured and simulated flows show very close agreement and the overall difference between the simulated and measured daily discharges at Lemont Avenue is 2.5% for WY 2008.

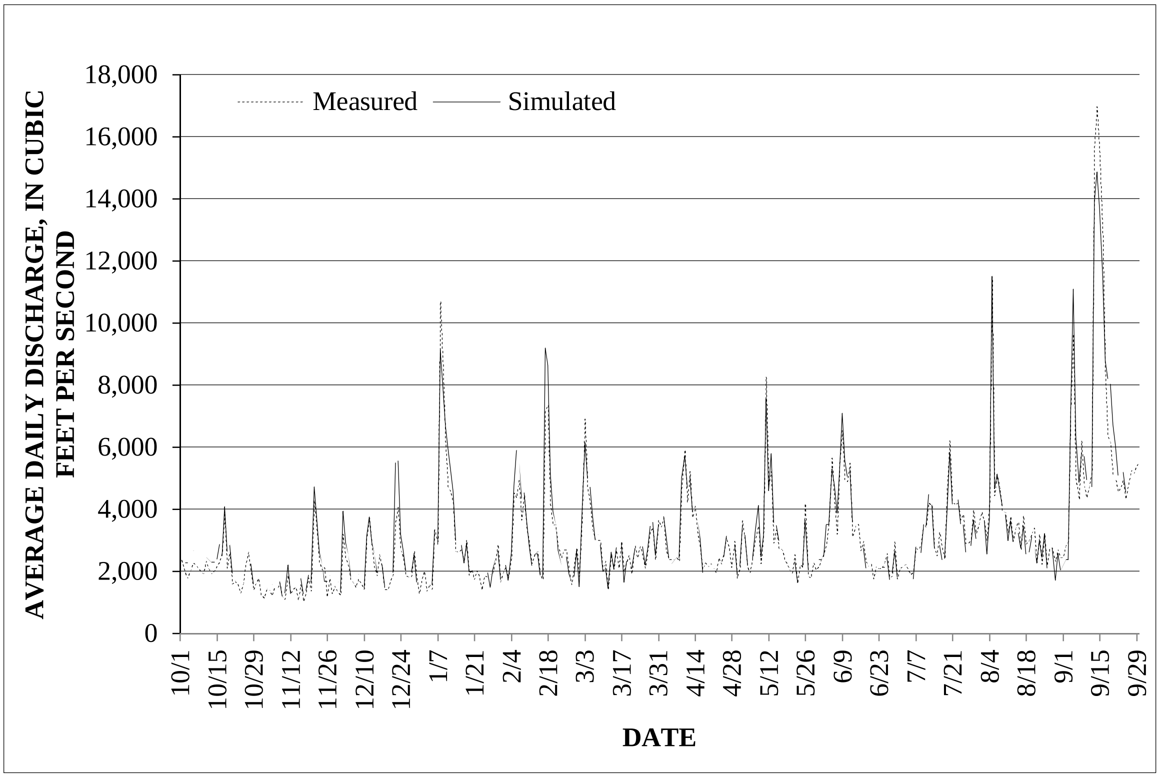

Figure 3.6. Measured and simulated average daily flows on the Chicago Sanitary and Ship Canal at Lemont Avenue for Water Year 2008.

Chapter 4 – VERIFICATION OF THE WATER QUALITY MODEL

4.1 DUFLOW Water-Quality Model

The DUFLOW modeling system (DUFLOW, 2000) provides a water manager with a set of integrated tools, to quickly perform simple analyses. But the system is equally suitable for conducting extensive, integral studies. It enables water managers to calculate unsteady flows in networks of canals, rivers, and channels. It also is useful for simulating the transport of substances in free-surface flow. More complex water-quality processes can be simulated as well.

The DUFLOW modeling system allows for a number of processes affecting water quality to be simulated, such as algal blooms, contaminated silts, salt intrusions, etc., to describe the water quality and it is able to model the interactions between these constituents. Two water-quality models are included in the DUFLOW modeling system as EUTROF1 and EUTROF2. EUTROF1 calculates the cycling of nitrogen, phosphorus, and DO using the same formulations as applied in the U.S. Environmental Protection Agency WASP version 4 (Ambrose et al., 1988). EUTROF1 is particularly suitable to study the short-term behavior of systems. If the long-term functioning of a system is of interest the other eutrophication model, EUTROF2, is more appropriate (DUFLOW, 2000). In this study, EUTROF2 was selected as the appropriate unsteady-flow water-quality model for the CAWS. Details of the EUTROF2 model can be found in Alp and Melching (2004) and Neugebauer and Melching (2005). The complete EUTROF2 model was given in Appendix A in Melching et al. (2010).

4.2 Water Quality Input Data

The water quality in the modeled portion of the CAWS is affected by the operation of five SEPA stations and two IASs. The CAWS receives pollutant loads from four WRPs, nearly 240 CSOs (condensed to 43 representative locations to facilitate the modeling), direct diversions from Lake Michigan, and eleven tributary streams or drainage areas. The effects of nonpoint source pollution are included in the CSO and tributary flow pollutant loads.

In the current model for WY 2008, SEPA stations, IASs, WRPs, Tributaries, CSOs, Boundaries, and Initial Conditions are handled in the same way as in the most recent DUFLOW model of the CAWS (Melching et al., 2010). Initial conditions, calculation nodes, and sections are provided in Addendum D. In the following sections, the up-to-date information and data on the consituent concentrations from the various inflows to the CAWS are provided as appropriate for the application of the DUFLOW model to WY 2008. No new data of the quality of CSOs has become available since Melching et al. (2010) was completed. Thus, the concentrations of pollutants for the CSOs are the same as reported in Melching et al. (2010).

4.2.1 SEPA stations

There are five SEPA stations along the Calumet-Sag Channel, Little Calumet River (north), and Calumet River. All of these SEPA stations are within the water-quality model study area. SEPA station 1 is included in the extension of the DUFLOW model to the Calumet River. The locations of the SEPA stations are listed in Table 4.1.

The details of the estimation of the DO loads from the IASs and SEPA stations are given in Alp and Melching (2004) except for SEPA stations 1 and 2. SEPA station 1 has four pumps each with a capacity of 100 cfs, and SEPA station 2 has two pumps each with a capacity of 45.5 cfs. On the basis of information in Butts et al. (1999) SEPA stations 1 and 2 bring water to 102% and 99% of saturation, respectively. These pump capacities and saturation percentages are used to compute the DO loads from SEPA stations 1 and 2 as per the method described in Alp and Melching (2004).

Table 4.1. Locations of Sidestream Elevated Pool Aeration (SEPA) stations.

SEPA STATION #	**Location**	**River Mile***
1	Calumet River	328.09
2	127th Street	321.3
3	Blue Island	318
4	Worth (Harlem Avenue)	311.7
5	Sag Junction	303.3

*River miles for the Chicago Waterway System are given relative to the confluence of the Illinois River with the Mississippi River at Grafton, Ill.

4.2.2 Corrected Ammonia Concentration for Water Year 2001 from the O'Brien Water Reclamation Plant

The measured effluent ammonia as nitrogen concentration in the O'Brien WRP between January 1 and April 30 in WY 2001 was not available in the MWRDGC online database of daily WRP effluent quality at the beginning of the Use Attainability Analysis study of Melching et al. (2010), and a long term average ammonia as nitrogen concentration of 0.4 mg/L during this period was used in the calibration of the most recent DUFLOW model of the CAWS (Melching et al., 2010). In the current model for WY 2001, the corrected ammonia as nitrogen daily composite concentrations from the O'Brien WRP are used, as shown in Figure 4.1. It can be seen that the ammonia as nitrogen concentrations that were discharged in the O'Brien WRP effluent during the winter were greater than the assumed long-term average. The simulation results of the water quality parameters (ammonia, nitrate, and DO) affected by this correction in the O'Brien WRP effluent discharge for WY 2001 can be found in Addendum E.

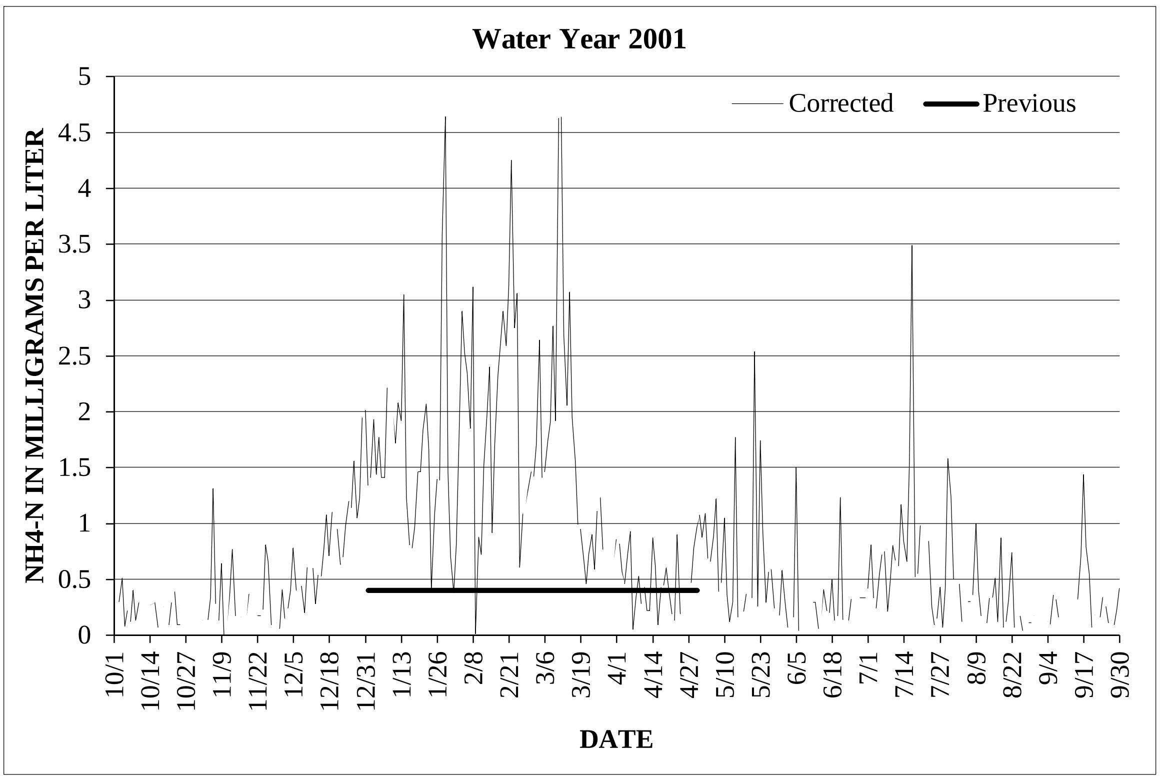

Figure 4.1. Corrected Ammonia as Nitrogen Concentration for Water Year 2001 from the O'Brien Water Reclamation Plant.

4.2.3 Water Reclamation Plants

Four point sources potentially affect the water quality in the CAWS: the O'Brien WRP, Stickney WRP, Calumet WRP, and Lemont WRP. Measured daily composite concentrations are used in the model for the four WRPs. The summation of the discharges from the O'Brien, Stickney, and Calumet WRPs has the greatest contribution of loads to the CAWS. Daily measured concentration from these three WRPs are shown in Figures 4.2-4.4, respectively. In these figures and throughout the report the constituent abbreviations are as follows: DO = dissolved oxygen, CBOD5 (figures) $CBOD_5$ (text) = 5-day carbonaceous biochemical oxygen demand, TSS = total suspended solids, TKN = total Kjeldahl nitrogen as nitrogen, NH4-N (figures) NH_4-N (text) = ammonia as nitrogen, Org-N = organic nitrogen as nitrogen, NO3-N (figures) NO_3-N (text) = nitrate as nitrogen, NO2+NO3 = nitrite plus nitrate as nitrogen, P-Tot = total phosphorus, Sol-P = soluble phosphorus, Org-P = organic phosphorus, In-P = inorganic phosphorus, and Chll-a = chlorophyll a. The load from the Citgo Petroleum outfall was not considered in this study because of lack of water-quality data on this discharge and the insignificant amount of flow and pollutant load contributed by this discharger.

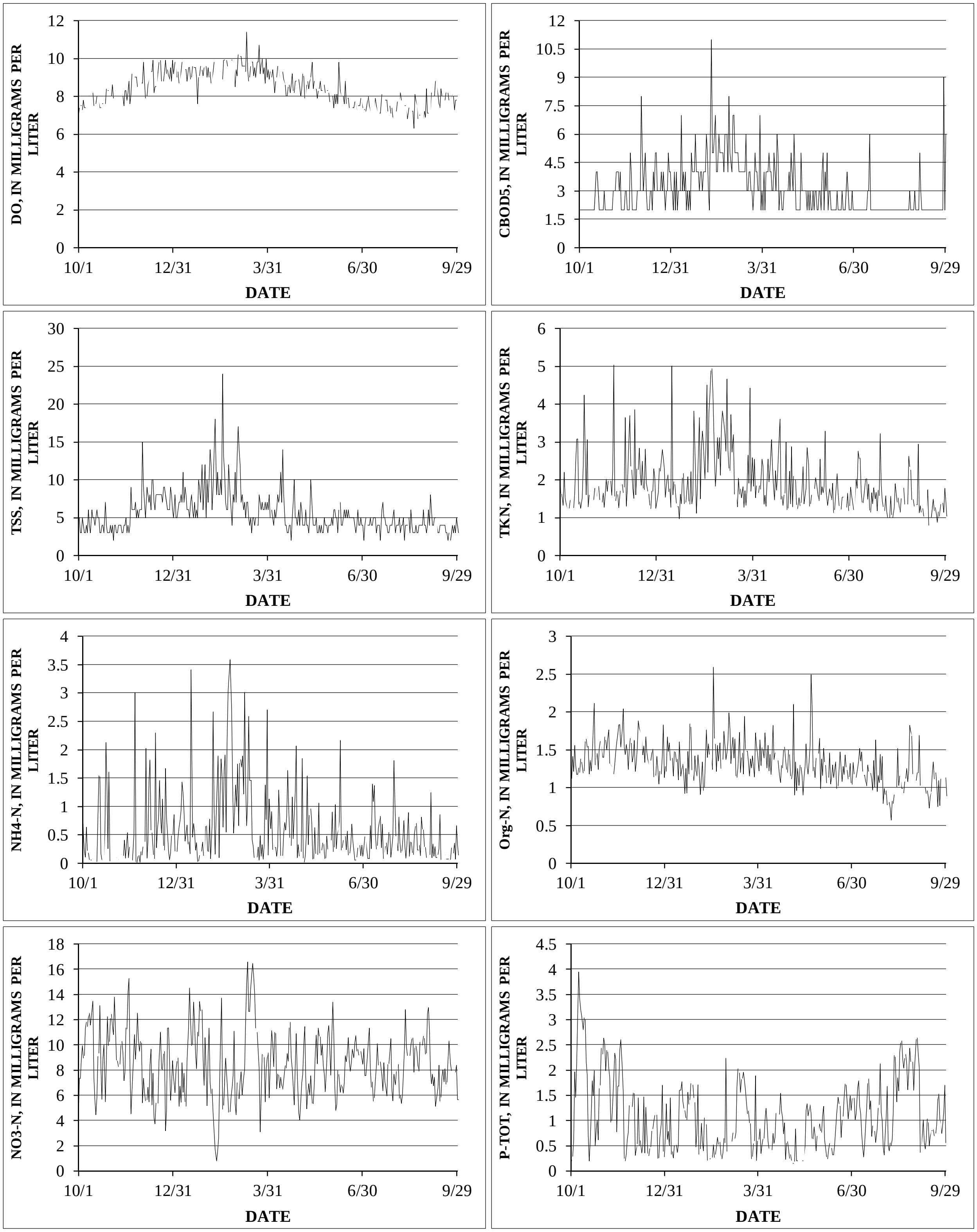

Figure 4.2. Stickney Water Reclamation Plant daily effluent concentrations for Water Year 2008.

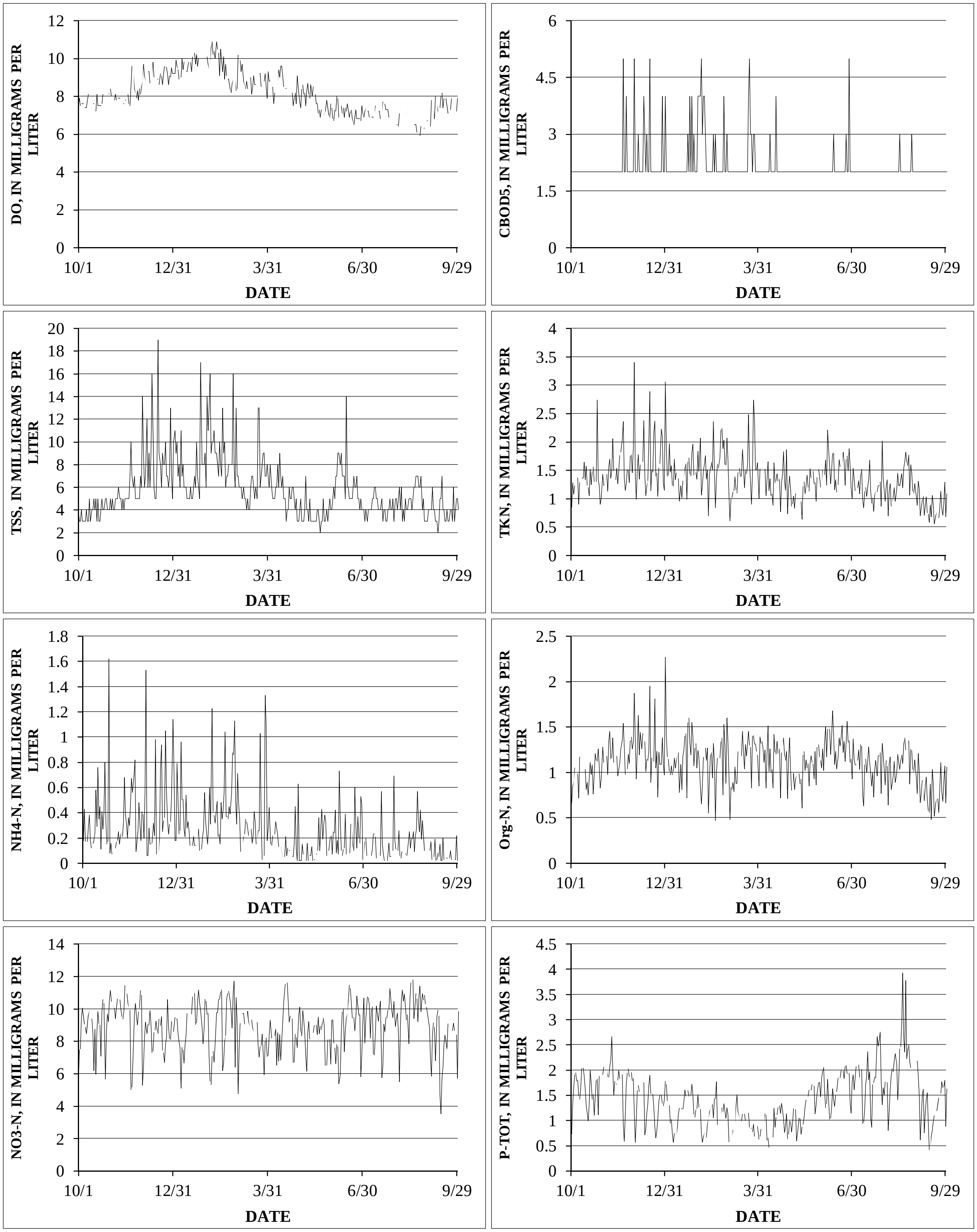

Figure 4.3. O’Brien Water Reclamation Plant daily effluent concentrations for Water Year 2008.

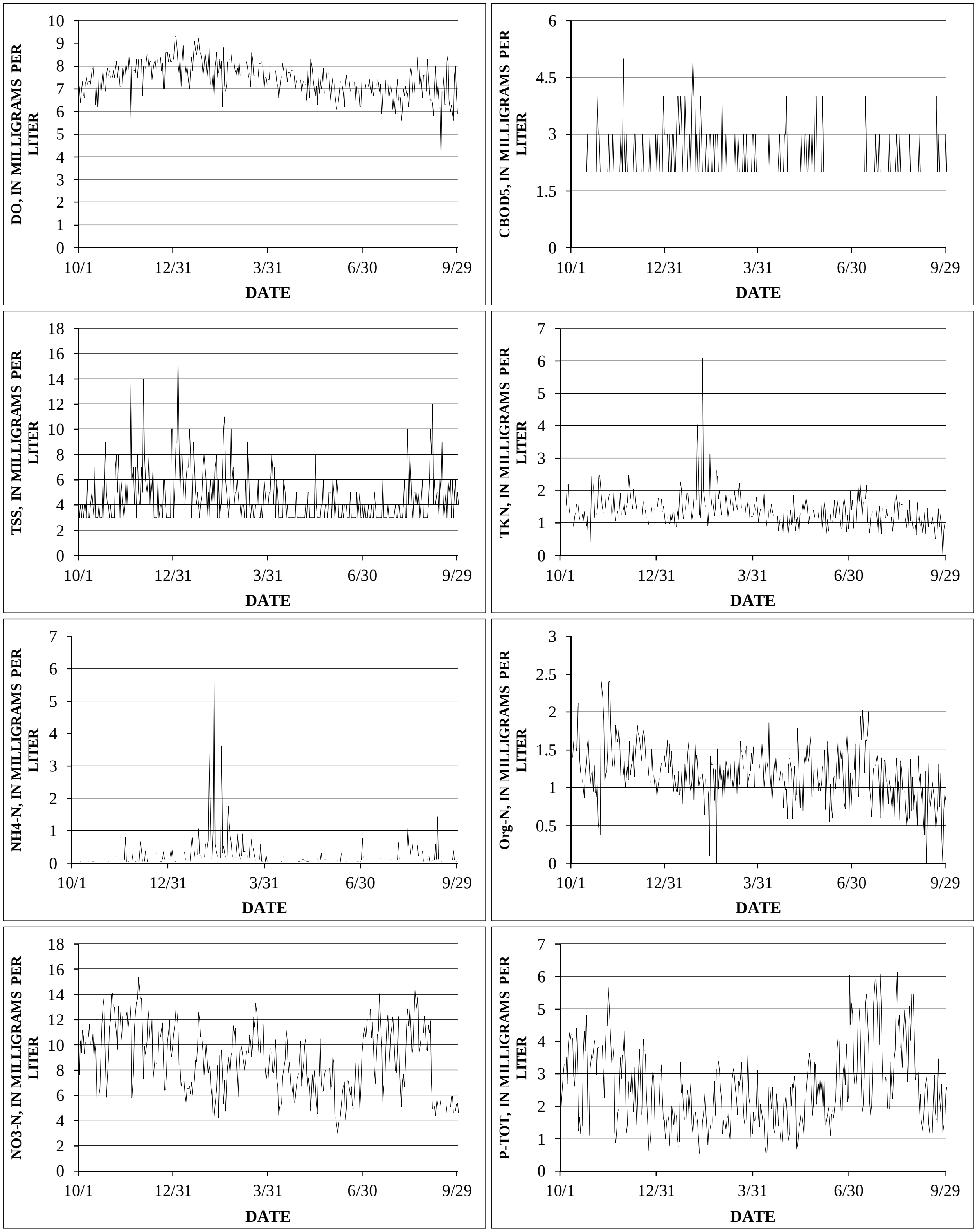

Figure 4.4. Calumet Water Reclamation Plant daily effluent concentrations for Water Year 2008.

4.2.4 Tributaries

Constituent concentrations on the Little Calumet River at South Holland for Calendar Years 2001-2011 were calculated using a mass balance approach with the data from the Little Calumet River at Wentworth Avenue (upstream from the South Holland gage) and at Ashland Avenue (downstream from the South Holland gage) and Thorn Creek at 170th Street (upstream from the South Holland gage). In the most recent DUFLOW model of the CAWS (Melching et al., 2010), the mass balance was performed for the available water quality data between 2000 and 2004. The average concentrations listed in Table 4.2 were used as model input for WY 2008.

Table 4.2. Little Calumet River at South Holland concentrations.

$CBOD_5$ (mg/L)	TSS (mg/L)	DO (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	Org-N (mg/L)	P-Tot (mg/L)	NO_2+NO_3 (mg/L)	Sol-P (mg/L)
1.3	47.0	*	1.39	0.26	1.14	1.04	4.78	0.97

* Monthly average DO concentrations measured between 2001-2011 are used as model input

Monthly constituent concentrations at the Grand Calumet River at Burnham Avenue measured between 1990 and 2011 were directly used as the concentration inputs at the Grand Calumet River at Hohman Avenue gage. The mean concentrations are listed in Table 4.3.

Table 4.3. Grand Calumet River at Hohman Avenue concentrations.

$CBOD_5$ (mg/L)	TSS (mg/L)	DO (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	Org-N (mg/L)	P-Tot (mg/L)	NO_2+NO_3 (mg/L)	Sol-P (mg/L)
6.62	32.84	**	4.29	2.03	2.27	0.75	6.41	0.22

** For DO measured hourly concentrations from the Grand Calumet River at Torrence Avenue station were assigned to the inflows on the Grand Calumet River at Hohman Avenue

The average concentrations of the monthly measurements between 2000 and 2011 for the North Branch Chicago River at Albany Avenue are listed in Table 4.4 and are used as model input for WY 2008.

Table 4.4. North Branch Chicago River at Albany Avenue concentrations.

$CBOD_5$ (mg/L)	**TSS (mg/L)**	**DO (mg/L)**	**TKN (mg/L)**	**NH_4-N (mg/L)**	**Org-N (mg/L)**	**P-Tot (mg/L)**	**NO_2+NO_3 (mg/L)**	**Sol-P (mg/L)**
2.13	21.23	***	1.20	0.18	1.01	0.79	4.04	0.81

*** Monthly average DO concentrations measured between 2000-2011 are used as model input

Average monthly chlorophyll-a concentrations were calculated for the Little Calumet River at South Holland, while measured concentrations were used at the North Branch Chicago River at Albany Avenue and Grand Calumet River at Burnham Avenue. The chlorophyll-a concentration, in micrograms per liter (μg/L), for the Little Calumet River at South Holland was computed using the same mass balance approach applied for the other constituents. The average monthly chlorophyll-a concentrations for all three locations are listed in Table 4.5 and these are used as model input for WY 2008. Concentrations for the other tributaries to the CAWS are based on the Little Calumet River concentrations because all of the other gaged and ungaged tributaries are on the southern portion of the Chicago metropolitan area and were assumed to be similar to the Little Calumet River drainage basin.

Table 4.5. North Branch Chicago River at Albany Avenue, Little Calumet River at South Holland, and Grand Calumet River at Burnham Avenue chlorophyll-a concentrations based on data from 2001-2011.

	North Branch Chicago River at Albany Avenue (µg/L)	**Little Calumet at South Holland (µg/L)**	**Grand Calumet River at Burnham Avenue (µg/L)**
October	7	4	24
November	9	6	106
December	9	3	5
January	6	7	30
February	9	7	35
March	17	13	168
April	33	15	4
May	23	6	36
June	13	6	11
July	13	13	28
August	21	10	25
September	8	7	121

4.2.5 Boundaries

Three of the upstream boundaries for the water-quality model are near Lake Michigan: near the CRCW at the Chicago River at Columbus Drive, near the Wilmette Pumping Station at the North Shore Channel at Maple Avenue, and near O'Brien Lock and Dam on the Calumet River. In the most recent DUFLOW model of the CAWS (Melching et al., 2010), seasonal and monthly average concentrations of water quality parameters were based on the data collected from 1990 to 2004 for the simulations of WYs 2001 and 2003. In the current model, the seasonal and monthly average concentrations of water quality parameters are based on data collected from 1990 to 2011 for the WY 2008 simulations.

Mean concentrations at the three boundaries near Lake Michigan for 1990-2011 are listed in Table 4.6. Monthly mean concentrations for the Chicago River Main Stem at Lake Shore Drive, North Shore Channel at Central Avenue, and the Calumet River at 130th Street taken as representative of the boundary conditions for 1990-2011 are shown in Figures 4.5-4.7. The seasonal variations are related to the use of discretionary diversion during the late spring, summer, and early fall at CRCW and the Wilmette Pumping Station.

Table 4.6. Mean concentrations at the water-quality model boundaries near Lake Michigan for 1990-2011 (note: all constituents are in milligrams per liter except chlorophyll-a which is in micrograms per liter).

CRCW	$CBOD_5$	Chll-a	NH_4-N	NO_3-N	In-P	Org-N	Org-P	TSS
Fall	1.11	1.9	0.09	0.77	0.05	0.30	0.06	6.27
Winter	3.23	1.5	0.40	1.93	0.20	0.55	0.09	10.05
Spring	2.11	4.4	0.30	1.39	0.16	0.46	0.05	7.11
Summer	0.94	1.2	0.05	0.22	0.03	0.25	0.04	7.34
Wilmette	$CBOD_5$	Chll-a	NH_4-N	NO_3-N	TIP	TON	TOP	TSS
Fall	0.78	2.4	0.14	0.31	0.05	0.37	0.05	8.85
Winter	3.10	7.1	0.82	0.48	0.29	0.71	0.01	18.21
Spring	3.56	29.6	0.30	0.48	0.07	0.78	0.08	18.89
Summer	0.67	1.7	0.09	0.22	0.04	0.30	0.02	11.45
O'Brien Lock and Dam	$CBOD_5$	Chll-a	NH_4-N	NO_3-N	TIP	TON	TOP	TSS
October	0.8	2.9	0.1	0.3	0.0	0.3	0.0	11.3
November	1.7	2.6	0.1	0.4	0.0	0.4	0.1	11.0
December	2.8	5.3	0.2	0.5	0.1	0.4	0.1	11.1
January	3.7	4.6	0.3	0.6	0.0	0.5	0.0	9.6
February	2.8	6.7	0.4	0.7	0.0	0.7	0.1	17.2
March	3.0	9.1	0.4	0.8	0.1	0.7	0.0	12.6
April	1.7	6.2	0.3	1.0	0.2	0.8	0.0	12.3
May	2.5	4.5	0.2	0.9	0.3	0.6	0.0	10.1
June	0.5	4.4	0.1	0.5	0.6	0.4	0.0	8.3
July	0.8	6.0	0.1	0.3	0.0	0.3	0.0	8.1
August	0.7	5.8	0.1	0.3	0.0	0.3	0.0	9.3
September	1.0	3.4	0.1	0.3	0.0	0.3	0.0	8.4

* Mean concentrations for nitrogen compounds were calculated for the period of 1997-2011

** Estimation of daily DO concentrations to be applied to each hour of the day at 130^{th} Street, Linden Street, and Columbus Drive (CRCW) is described in Section 4.2.6.

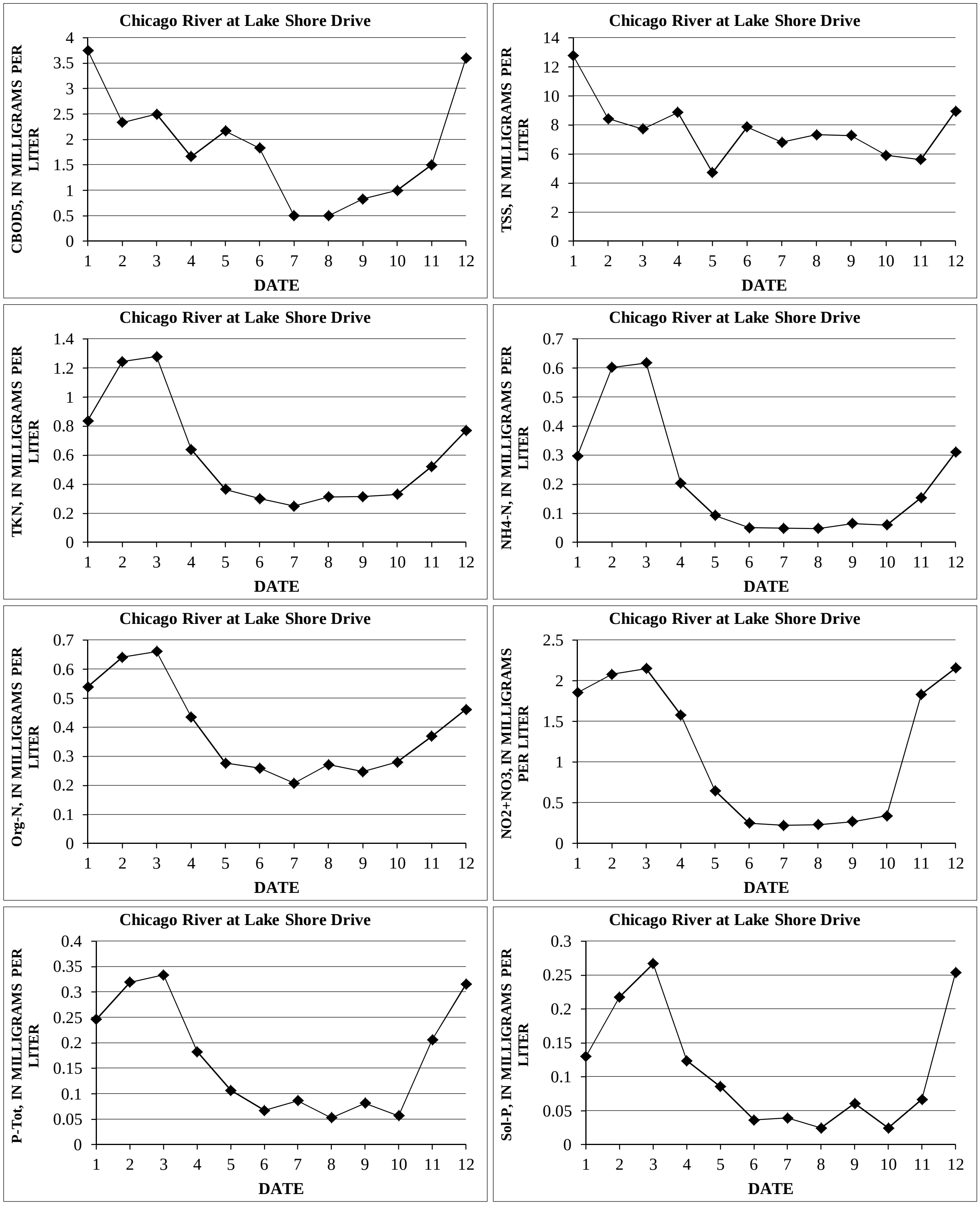

Figure 4.5. Monthly mean concentrations for the Chicago River Main Stem at Lake Shore Drive for 1997-2011 taken as representative of the boundary condition at Columbus Drive 0.3 mi downstream.

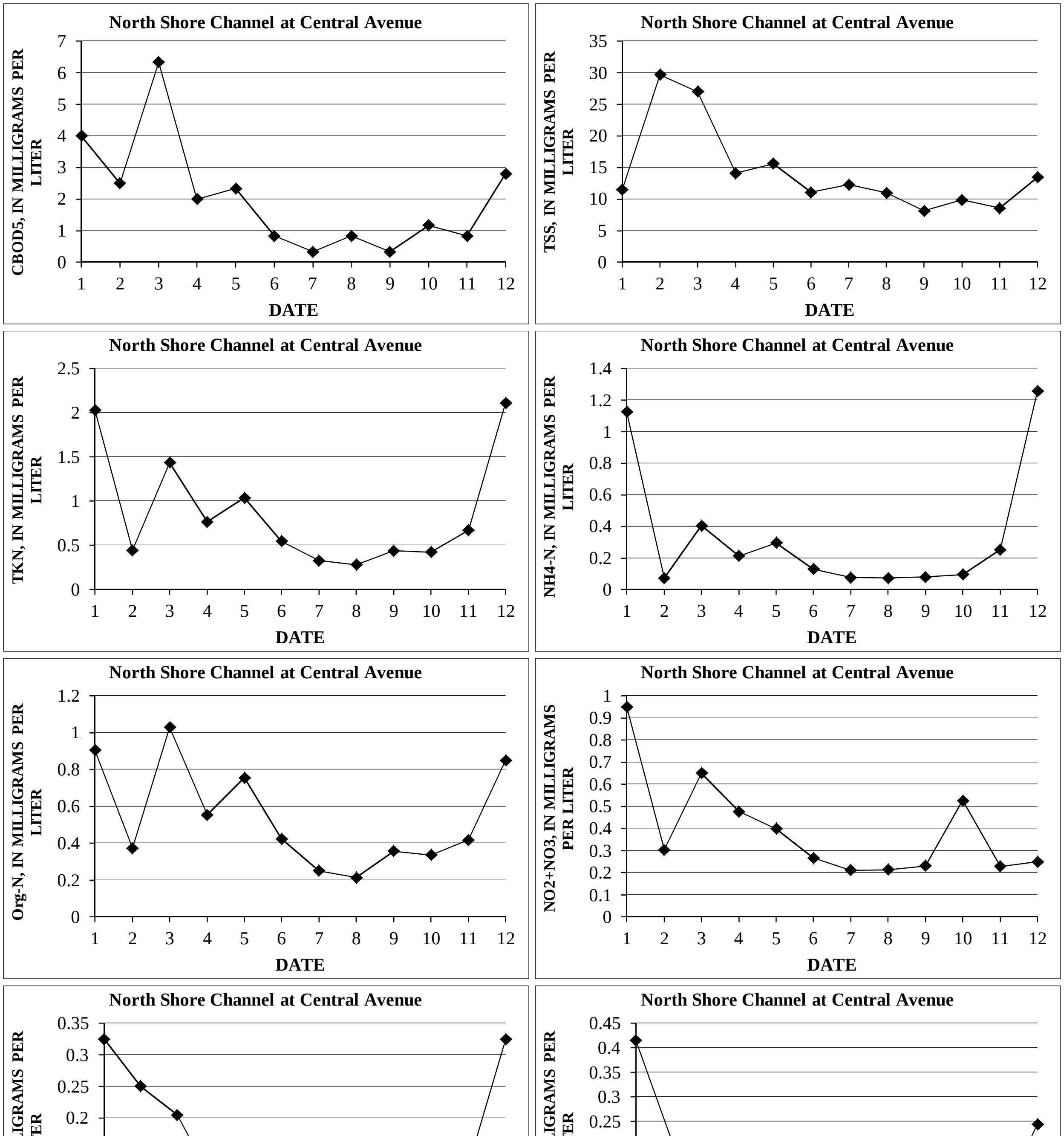

Figure 4.6. Monthly mean concentrations for the North Shore Channel at Central Avenue for 1997-2011 taken as representative of the boundary conditions at Maple Avenue 0.4 mi upstream.

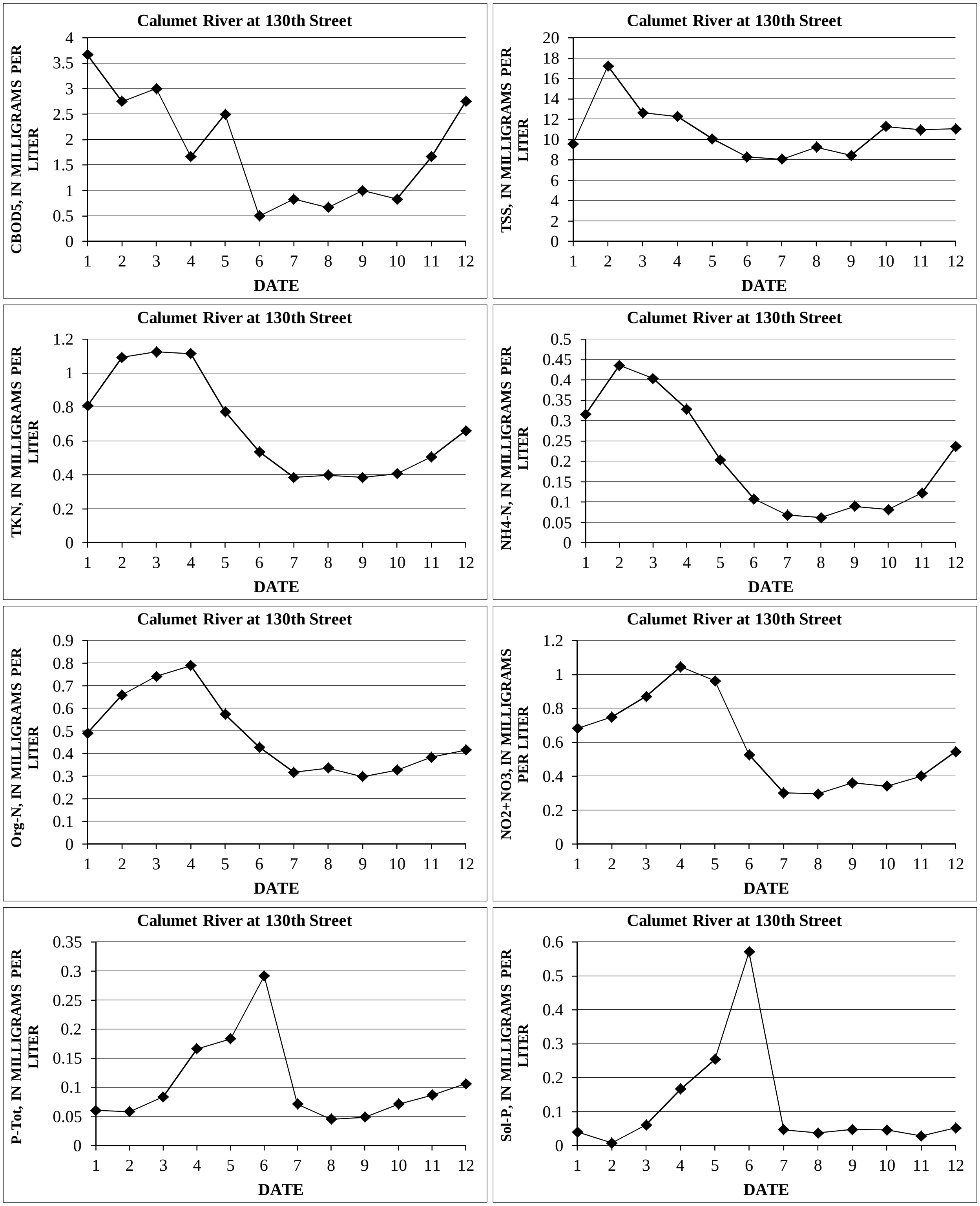

Figure 4.7. Monthly mean concentrations for the Calumet River at 130th Street for 1997-2011 taken as representative of the boundary condition at the O'Brien Lock and Dam 0.5 mi downstream.

4.2.6 Dissolved Oxygen Concentration at the Upstream Boundaries

The MWRDGC discontinued DO monitoring at Linden Street (just downstream from the Wilmette Pumping Station), CRCW, and 130th Street (0.5 mi upstream of the O'Brien Lock and Dam and taken as representative of conditions at O'Brien Lock and Dam) in March 2004, thus, the time series of DO concentrations at these locations had to be estimated for WY 2008 to define the boundary conditions for DO at these model inflow points. In order to estimate the DO concentrations at Wilmette and 130th Street, the available measured DO concentrations at each site were reviewed to determine relations between the appropriate fractions of the saturation concentrations of DO at these locations throughout the year. Thus, the daily mean temperatures at each of the boundary locations could be estimated using the equations listed in Tables 2.2 and 2.3. Then the saturation concentrations of DO (C_s) could be estimated as a function of temperature at each location using the following equation ("Solubility", 1960):

$$C_s = 14.652 - 0.41022T + 0.007991T^2 - 0.000077774T^3 \qquad (1)$$

where T is water temperature in degrees Celsius. The fractions of the saturation concentration of DO could then be used to estimate the daily mean DO concentration that was then applied to each hour in the day in the DUFLOW simulations.

The distance from CRCW to Clark Street is 1.2 mi with no substantial inflows between these two points. Further the hourly DO and temperature monitor at Clark Street was still operational in WY 2008. Thus, linear regression models were developed to estimate the DO concentration at CRCW on the basis of the measured DO concentration at Clark Street. The following subsections describe the assumptions used to estimate the DO concentrations for each boundary location.

Wilmette Pumping Station

A review of measured DO concentrations at Linden Street was done for days when discretionary diversion or navigation make-up water was taken, i.e. conditions at Linden Street were dominated by Lake Michigan water. Typically, when the conditions at the Linden Street Continuous DO Monitoring (CDOM) station were dominated by Lake Michigan water, the DO concentrations ranged from about 85% of saturation to a little above saturation. Figure 4.8 compares measured DO concentrations at Linden Street with 90% and 95% of the DO concentration at saturation for May and September 2001. On the days with discretionary diversion (i.e. all days except May 27 and September 1, 20, 24, and 25), 95% saturation seems to give reasonable agreement with the measured DO concentrations. In other months slightly higher and lower values relative to the 95% line were observed in the measured concentrations on days with discretionary diversion, but overall 95% of saturation seemed to give the best estimate of DO concentrations on days with discretionary diversion. Thus, for WY 2008 the DO concentration boundary condition was set to 95% of the saturation concentration of DO for days when discretionary diversion was taken at Wilmette.

The amount of leakage through the Wilmette Pumping Station and Sluice Gate is small. Thus, during periods without discretionary diversion at Wilmette the DO concentration measured at Linden Street reflects the stagnant conditions and the back-up of O’Brien WRP effluent and CSOs in the upper NSC. Thus, on days when discretionary diversion was not taken at Wilmette the DO concentration at Wilmette was set to the average fraction of saturation for days without discretionary diversion at Wilmette for that month determined from the historic data collected between August 1998 and March 2004. These average fractions of saturation are listed in Table 4.7. The value listed for May was considered to be too small as a result of a large amount of missing data and much of the available data being for storm periods. Thus, a fraction of 0.55 was applied to make the DO estimates for May 2008 similar to those for June 2008.

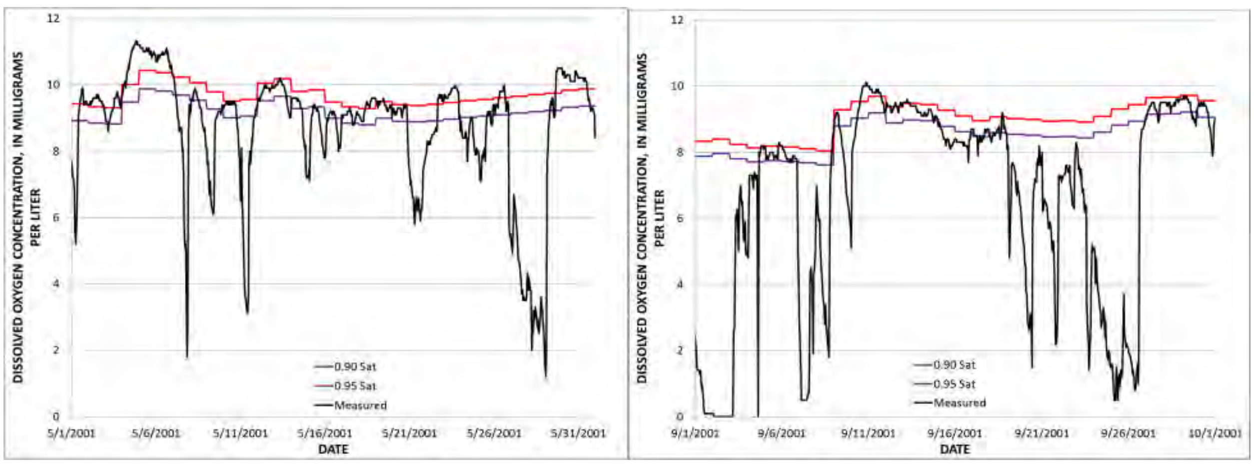

Figure 4.8. Comparison of measured dissolved oxygen (DO) concentrations and 90% and 95% of the DO concentration at saturation at Linden Street for May (left) and September (right) 2001.

Chicago River Controlling Works

In developing the regression equations for estimating the hourly DO concentration at CRCW from the measured hourly DO concentration at Clark Street, the period of measured data at each location was subdivided into periods with discretionary diversion and navigation make-up flows (i.e. period dominated by Lake Michigan water) and periods without these flows. For periods with discretionary diversion and/or navigation make-up flows the DO concentration at CRCW could be estimated as follows:

$$CRCW = 0.795232\ Clark + 2.174604 \quad (2)$$

Table 4.7. Average fraction of the saturation concentration of dissolved oxygen by month for periods with no discretionary diversion at the Wilmette Pumping Station based on hourly data collected at Linden Street for August 4, 1998 to March 24, 2004.

Month	Fraction
October	0.44703
November	0.30484
December	0.30338
January	0.22466
February	0.44974
March	0.41294
April	0.31911
May	0.09366*
June	0.56766
July	0.71005
August	0.26029
September	0.52935

*A value of 0.55 was applied to periods without discretionary diversion in May 2008.

This equation has a coefficient of determination (R^2) of 0.56397 and a standard error of estimate of 0.81836 mg/L on the basis of 14,202 simultaneous hourly DO observations at CRCW and Clark Street. For periods without discretionary diversion or navigation make-up flows the DO concentration at CRCW could be estimated as follows:

$$\text{CRCW} = 0.646834\ \text{Clark} + 4.717329 \qquad (3)$$

This equation has a R^2 of 0.50036 and a standard error of estimate of 1.16424 mg/L on the basis of 18,683 simultaneous hourly DO observations at CRCW and Clark Street.

130th Street

Because the DO and temperature monitor at 130th Street is on the Calumet River on the lake side of the O'Brien Lock and Dam, the DO concentration at this location is not influenced by whether or not discretionary diversion flows are taken on a given day. Therefore, monthly mean fractions of the saturation concentration of DO were computed for 130th Street on the basis of the hourly

DO concentration data collected by the MWRDGC between May 1, 2001, and March 24, 2004, as listed in Table 4.8. The mean monthly fractions range between 0.80 and 0.95. The mean monthly standard deviations of the fractions range between 0.030 and 0.105 indicating a fairly tight spread among the values, thus, implying this approach will yield reasonable values of the DO concentrations at the O'Brien Lock and Dam boundary.

Table 4.8. Mean and standard deviation of the fraction of the saturation concentration of dissolved oxygen by month and the number of observations used to compute these statistics at 130th Street based on hourly data collected for May 1, 2001 to March 24, 2004.

Month	Fraction	Standard deviation	Number of observations
October	0.84942	0.03017	1487
November	0.86883	0.04032	1271
December	0.88833	0.04068	1955
January	0.92385	0.09516	2111
February	0.94596*	0.08516	1964
March	0.94596*	0.08516	1705
April	0.90868	0.05430	1437
May	0.85603	0.09124	1423
June	0.80419*	0.09392	1162
July	0.80419*	0.09392	1474
August	0.83959	0.08523	1894
September	0.80444	0.05107	2049

*The values for these paired months were so close that they were analyzed together when estimating the missing dissolved oxygen concentration values.

4.3 Verification Results of the Water-Quality Model

The current Duflow water quality model of the CAWS has been calibrated for WY 2001 and verified for WY 2003, and is further verified for WY 2008 in this report. The same set of calibrated model coefficients for each of 18 CAWS reaches are applied as those listed in Table

3.10 in Melching et al. (2010), and the reliability of the model in simulation of sediment oxygen demand also is presented in Melching et al. (2010).

The water-quality model for WY 2008 was verified using monthly grab sample data at 22 locations and hourly DO concentration data at 18 locations in the CAWS collected by the MWRDGC. Verification results for WY 2008 of the DUFLOW water quality model are presented in the following two sections. First, the simulated ammonia as nitrogen, nitrate as nitrogen, total phosphorus, total suspended solids, and chlorophyll-a concentrations are compared with the data collected in WY 2008 and with ranges of historic measurements. Then, simulated and measured hourly DO concentrations are compared at the 18 DO measurement locations. The previous results of the calibration and verification of the water quality model for WYs 2001 and 2003 for DO concentrations are also shown as appropriate in parallel with those for WY 2008 in order to understand the overall quality of the current model for WY 2008.

4.3.1 Ammonia, Nitrate, Total Phosphorus, Total Suspended Solids, and Chlorophyll-a

When calculating the processes that affect DO in a stream system, DUFLOW also computes the concentration changes in space and time of $CBOD_5$, organic nitrogen, ammonia as nitrogen, nitrate as nitrogen, total inorganic phosphorus, total organic phosphorus, total suspended solids, and algal biomass species. The transformation of nitrite as nitrogen to nitrate as nitrogen is assumed to happen rapidly, and, thus, nitrite nitrogen is not explicitly simulated in DUFLOW. The MWRDGC collects monthly samples of $CBOD_5$, total Kjeldahl nitrogen, organic nitrogen, ammonium as nitrogen, nitrite plus nitrate as nitrogen, chlorophyll-a, total phosphorus, soluble phosphorus (only through WY 2001), and total suspended solids among many other constituents (see for example, Abedin et al., 1999) at 24 locations in the simulated portion of the CAWS (limited results for the two locations on the Calumet River—130th Street and Ewing Avenue—are shown in Section 2.2). To evaluate the fully simulation of the phosphorus cycle comparison of measured soluble phosphorus to simulated inorganic phosphorus and of measured and simulated total phosphorus for WY 2001 are presented in Addendum F. The MWRDGC did not collect $CBOD_5$ data during WY 2008 so no verification of the simulation of $CBOD_5$ is presented here, but the calibration and verification for $CBOD_5$ is presented in Melching et al. (2010) for WYs 2001 and 2003, respectively.

In the verification process, the simulated values of each constituent at each location were compared to the mean and one standard deviation confidence bounds determined from the measured values for 1997-2011. The graphic comparisons for ammonium as nitrogen, nitrate as nitrogen, total phosphorus, total suspended solids, and Chlorophyll-a are shown in Figures 4.9-4.13, respectively. It should be noted that for the case of Lockport measured concentrations at the Powerhouse are compared with simulated concentrations at the Controlling Works. It can be seen that the model predicted most of the measured concentrations with reasonable accuracy for WY 2008.

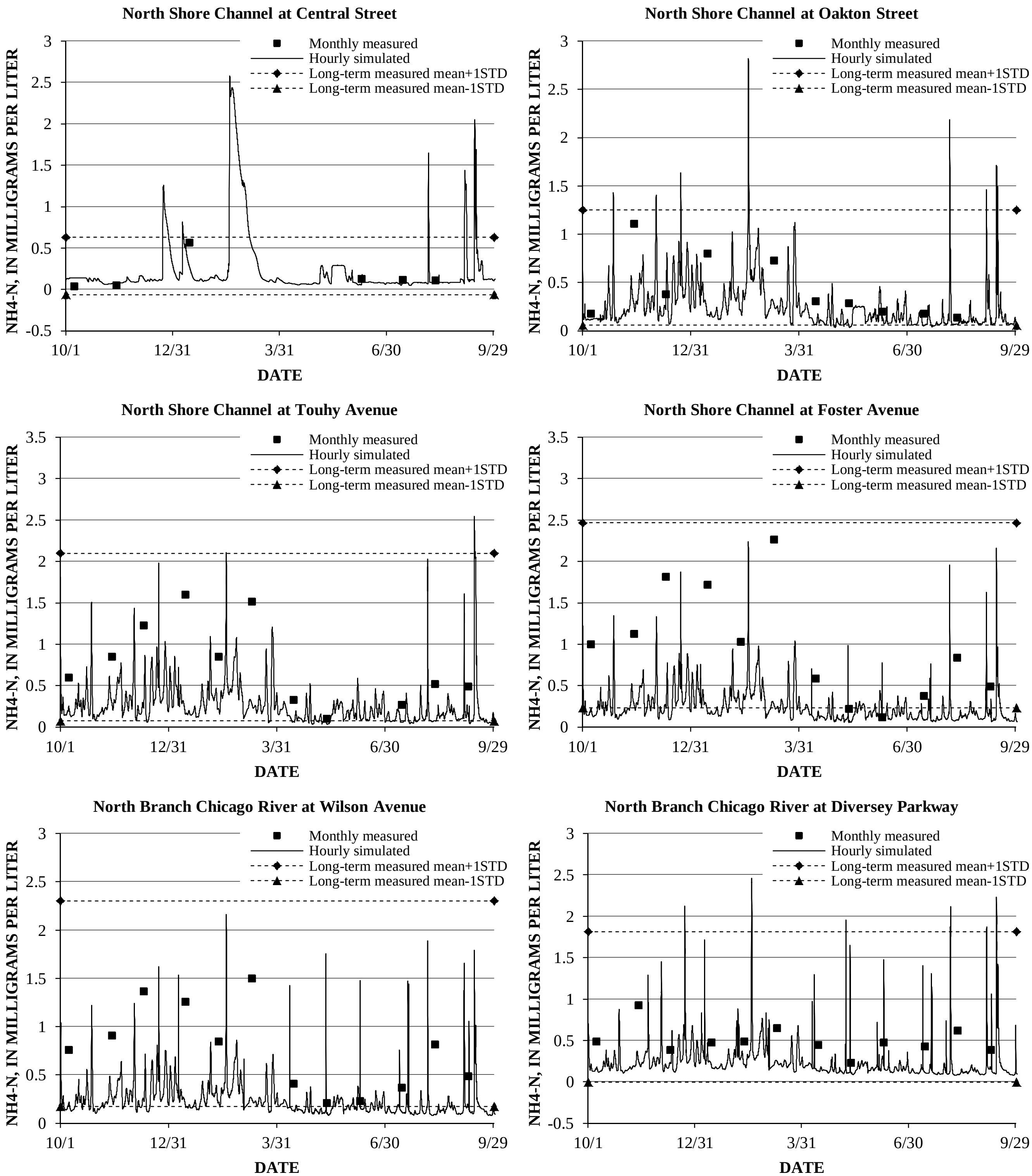

Figure 4.9. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonia as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008.

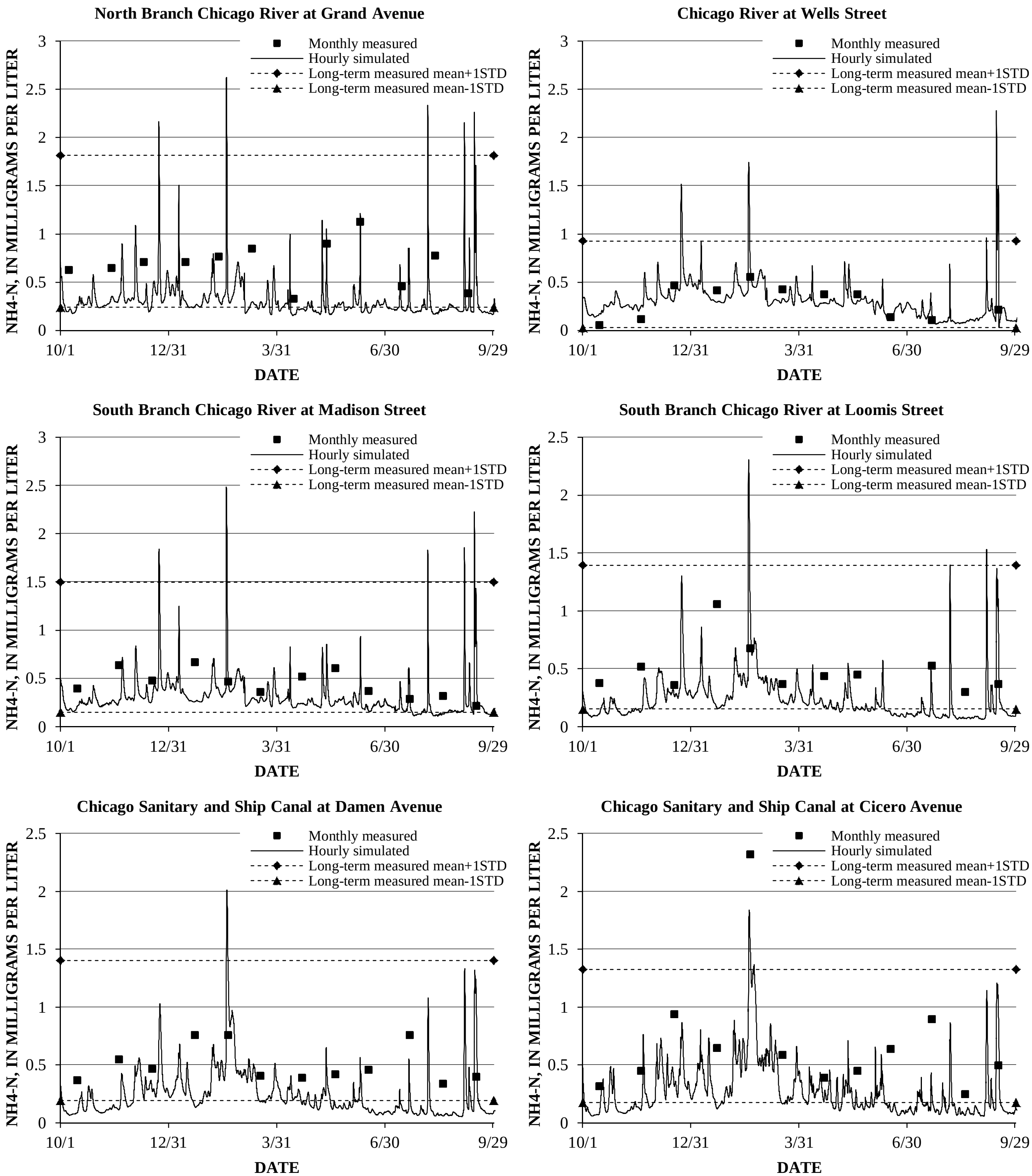

Figure 4.9 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonia as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

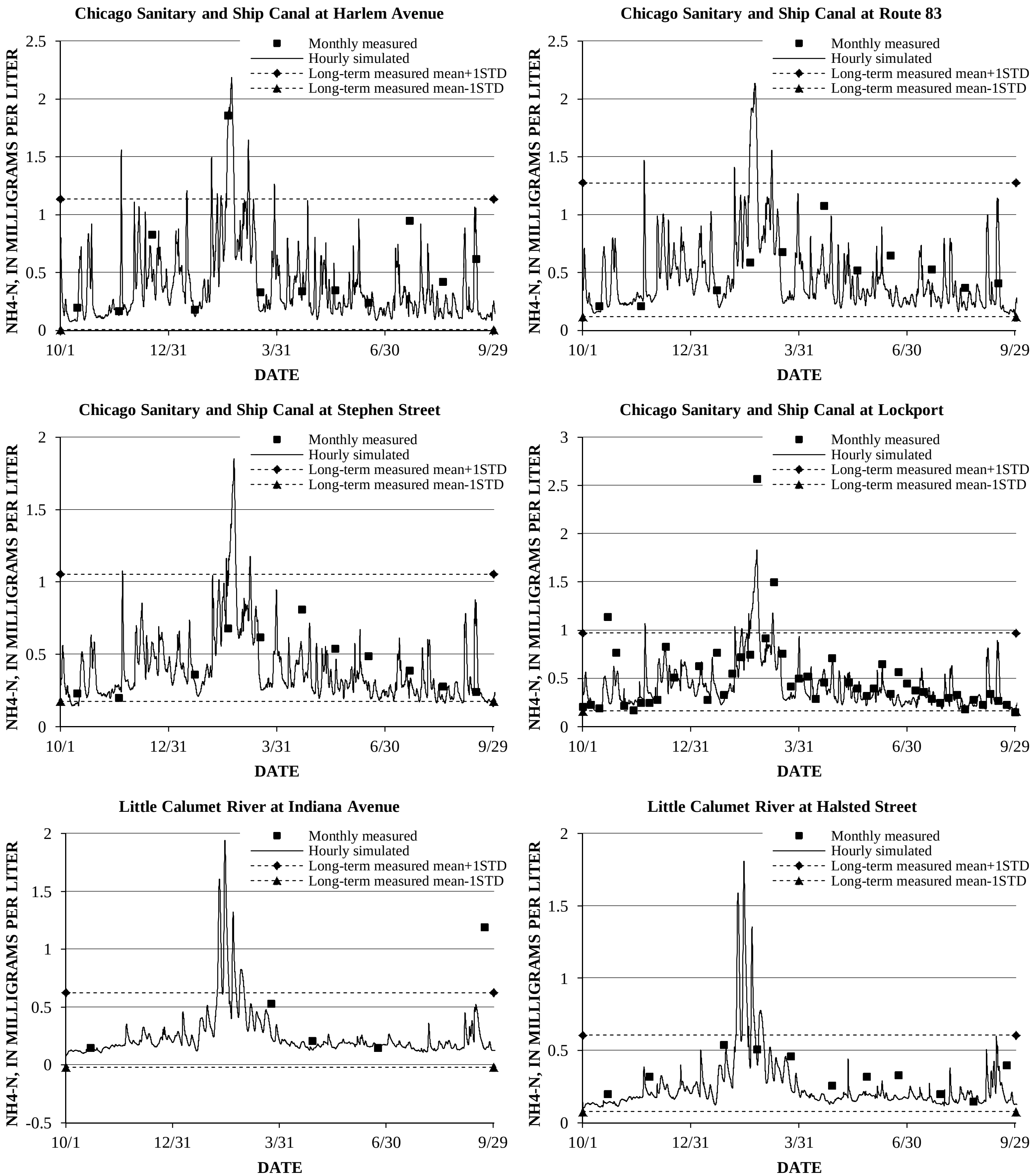

Figure 4.9 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonia as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

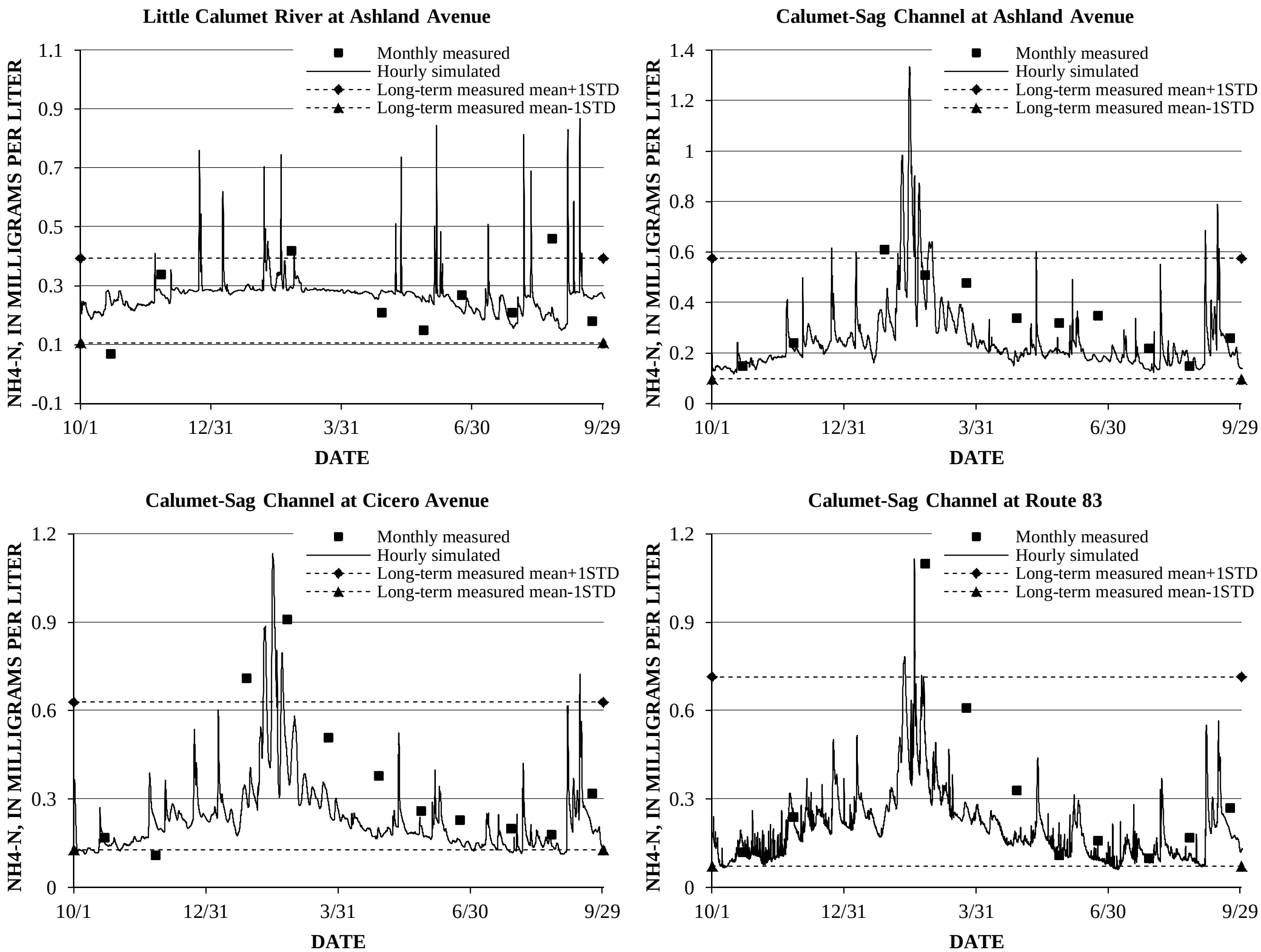

Figure 4.9 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonia as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

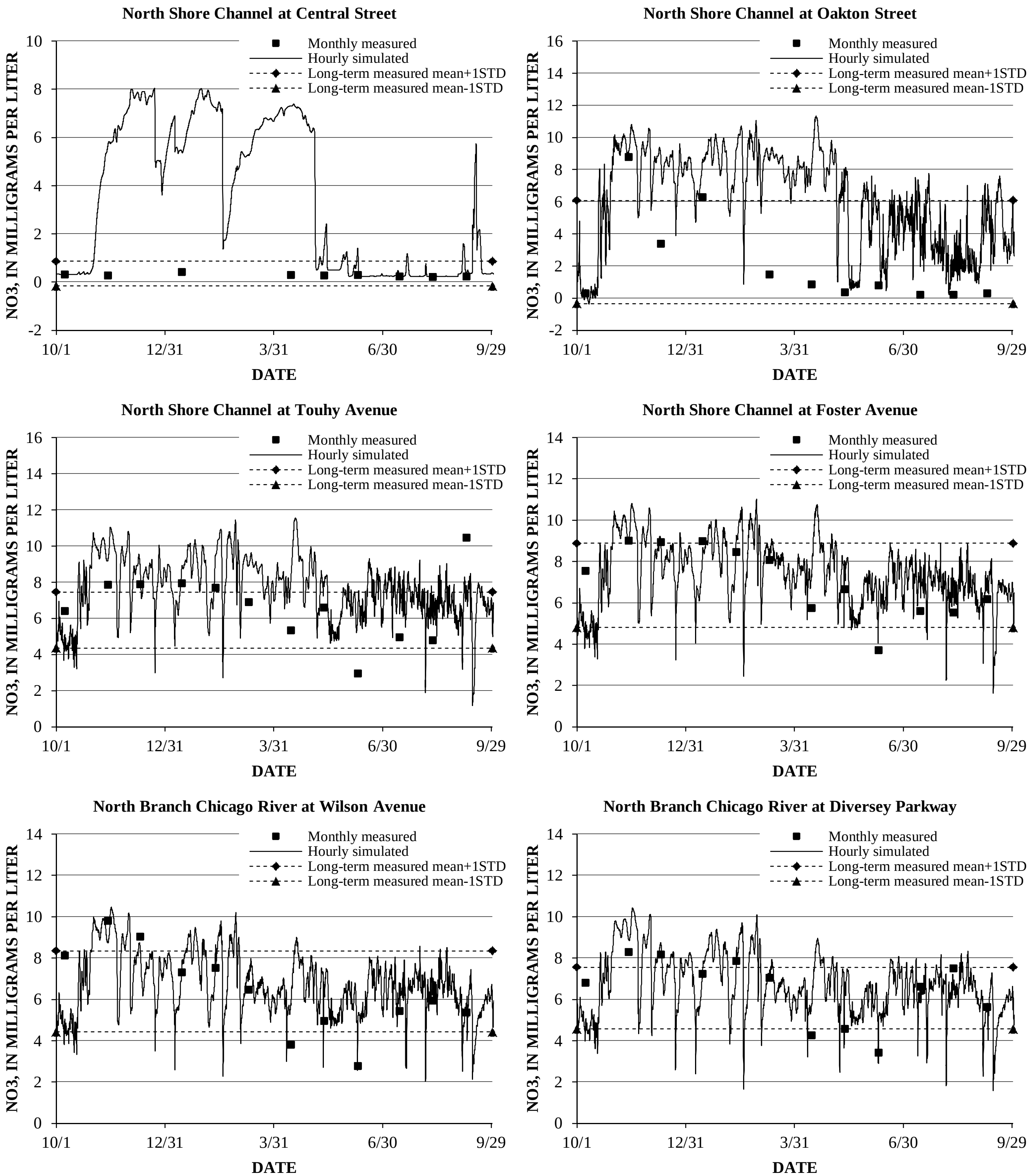

Figure 4.10. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008.

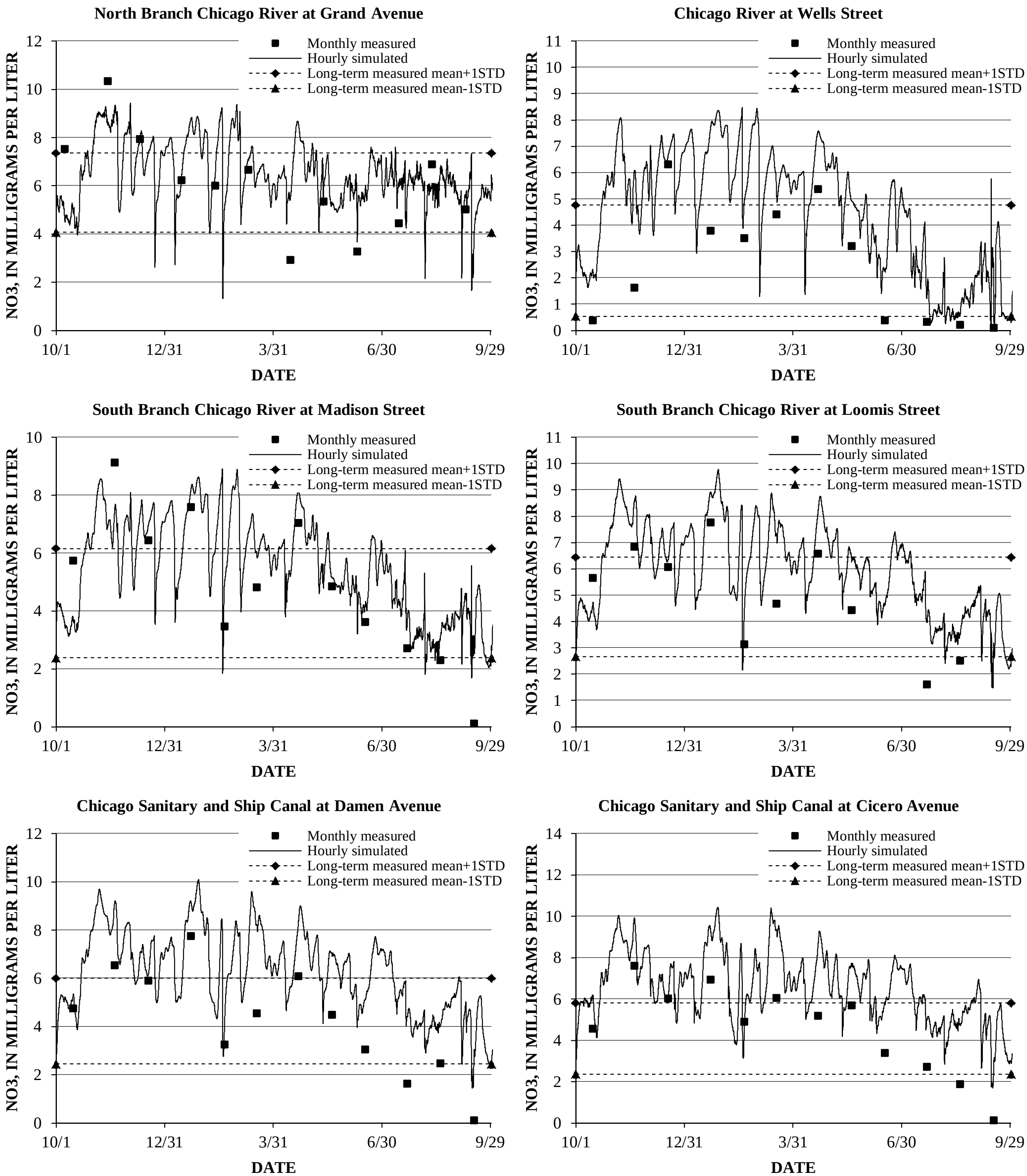

Figure 4.10 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

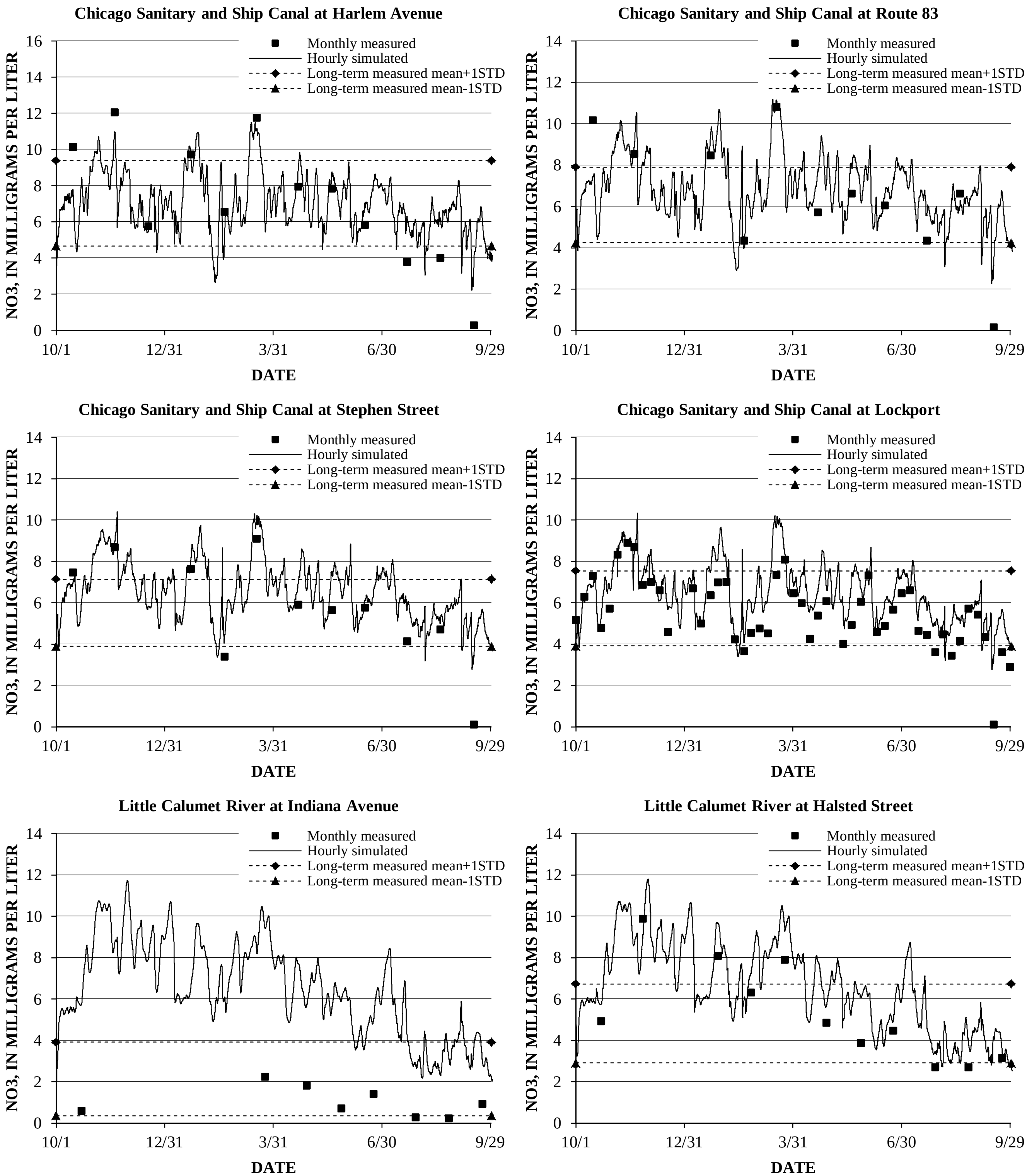

Figure 4.10 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

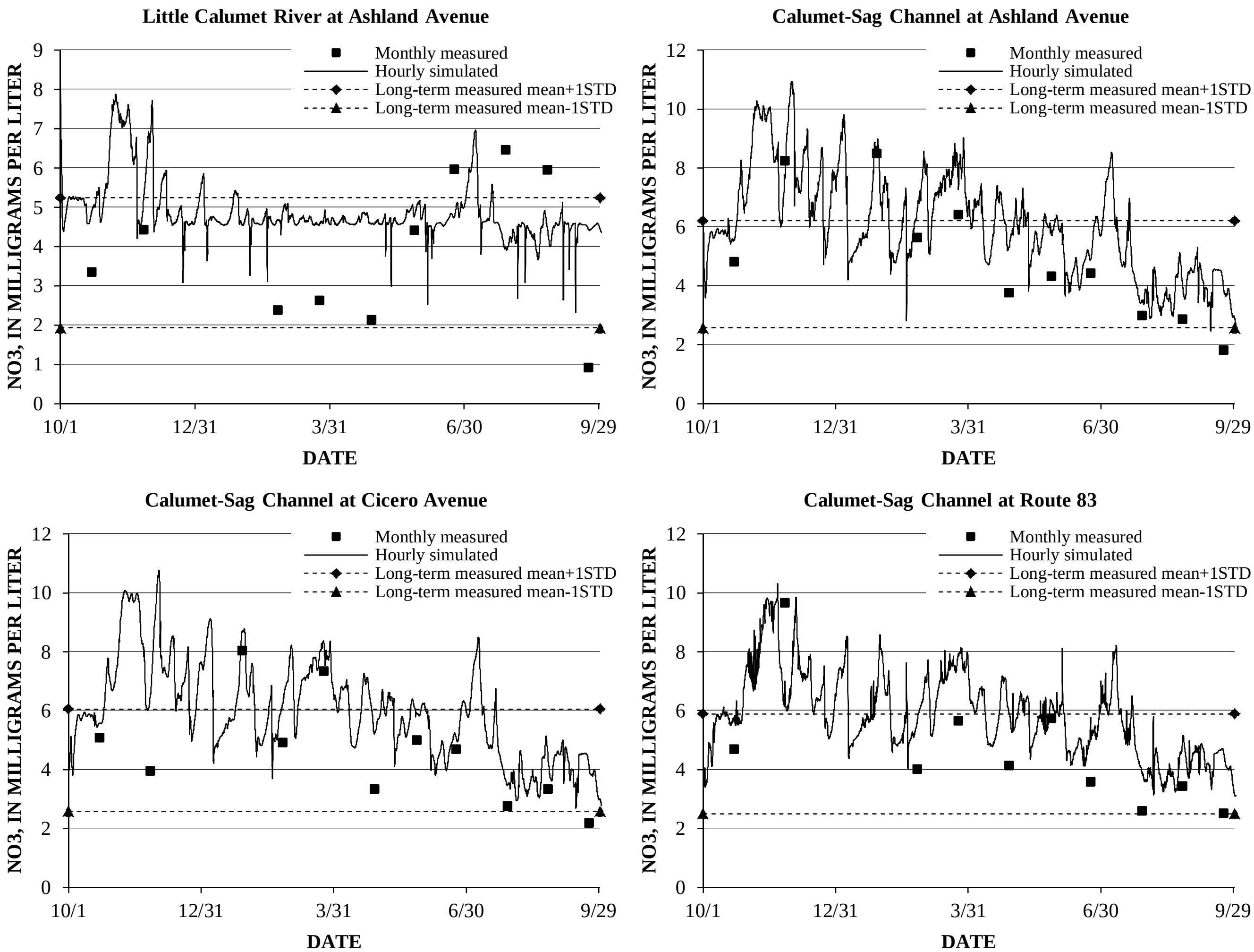

Figure 4.10 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

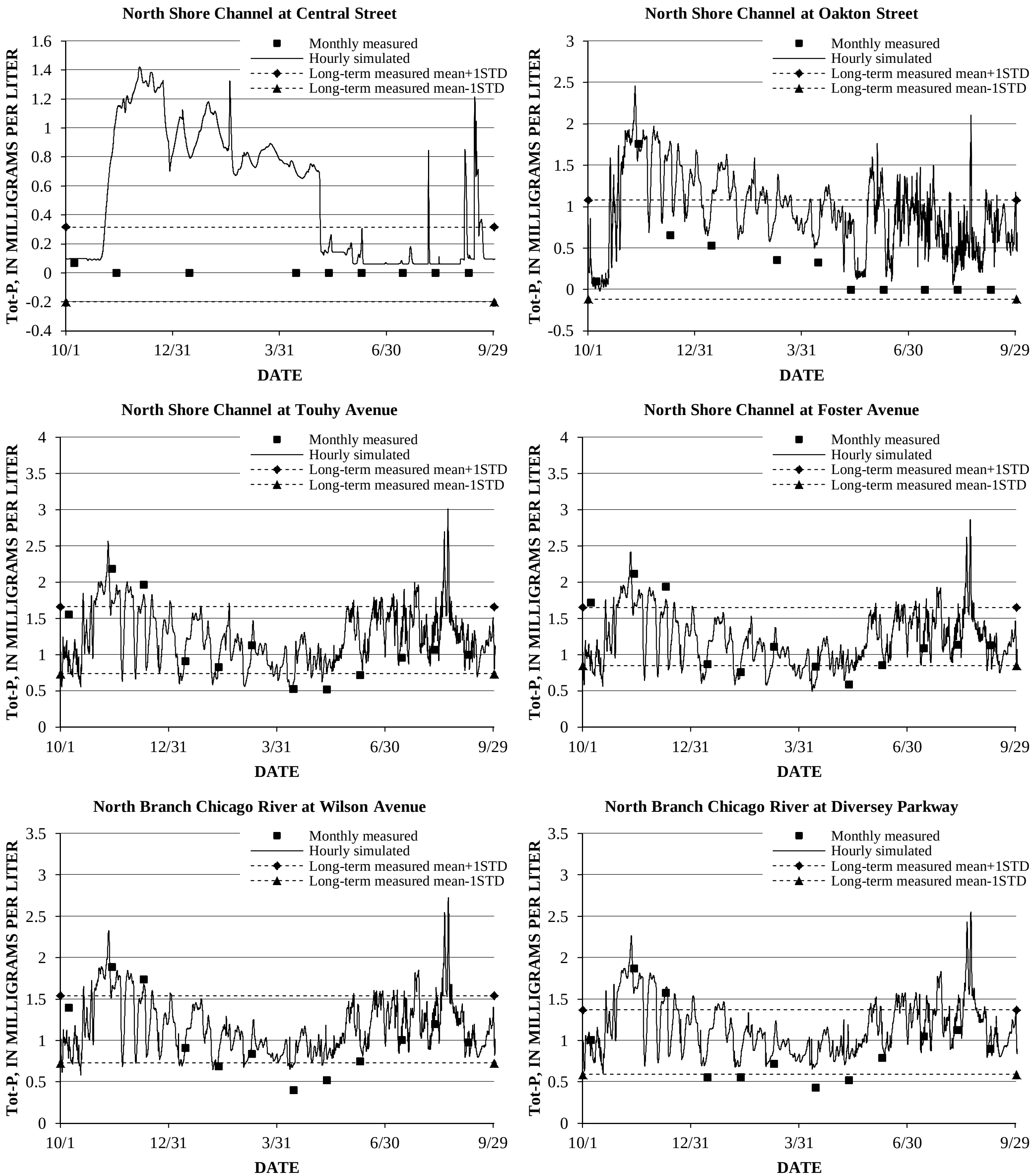

Figure 4.11. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008.

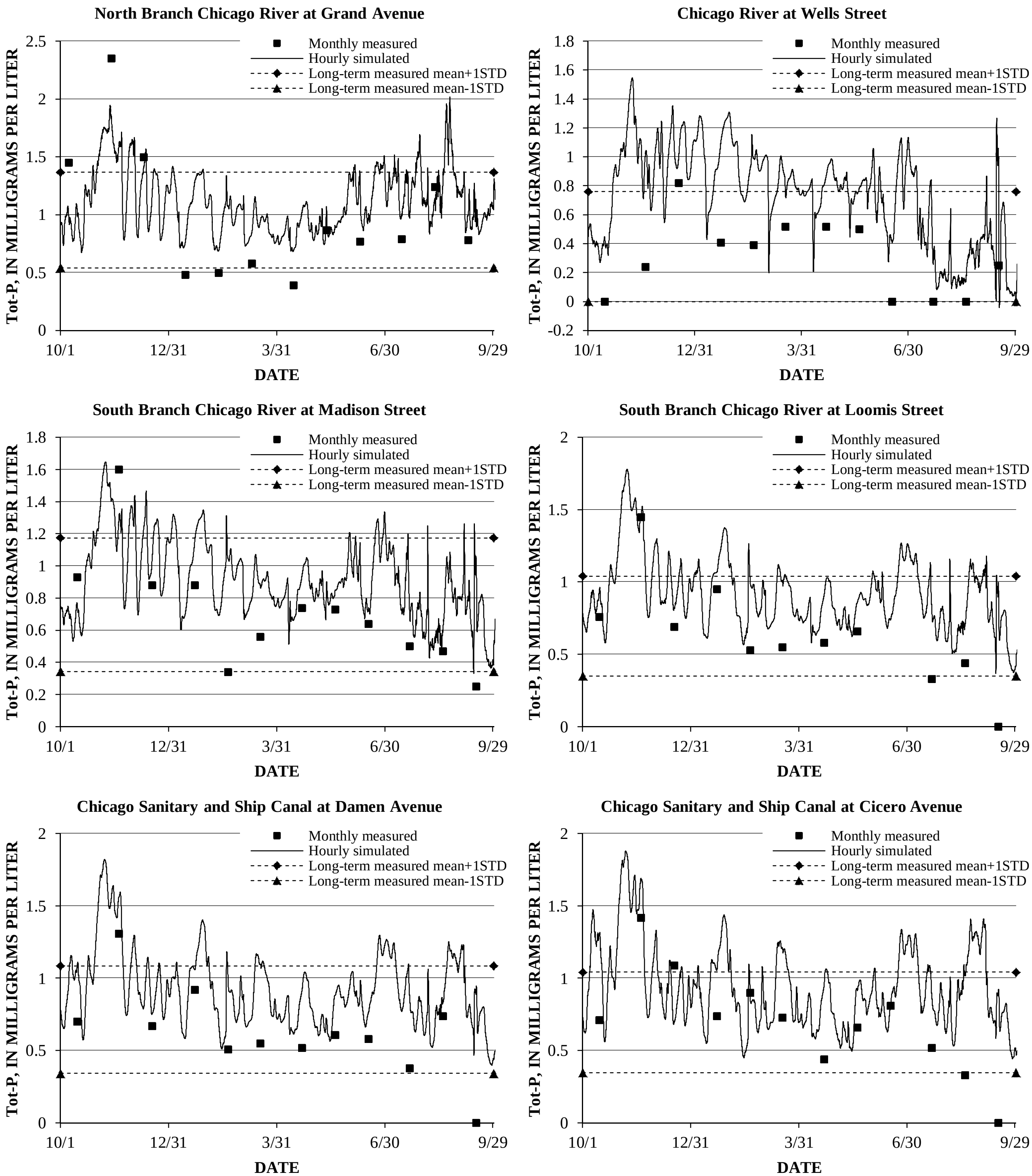

Figure 4.11 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

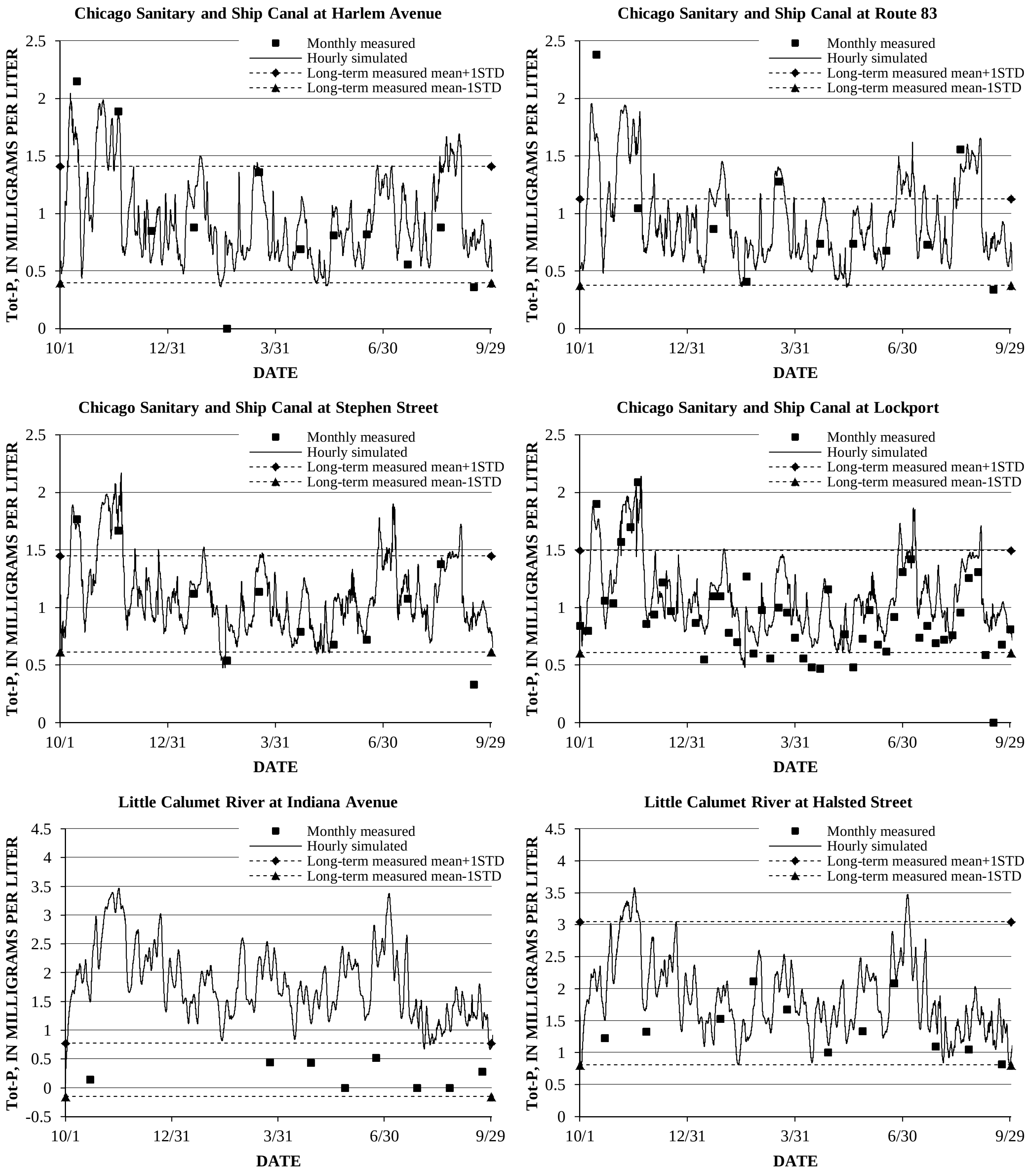

Figure 4.11 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

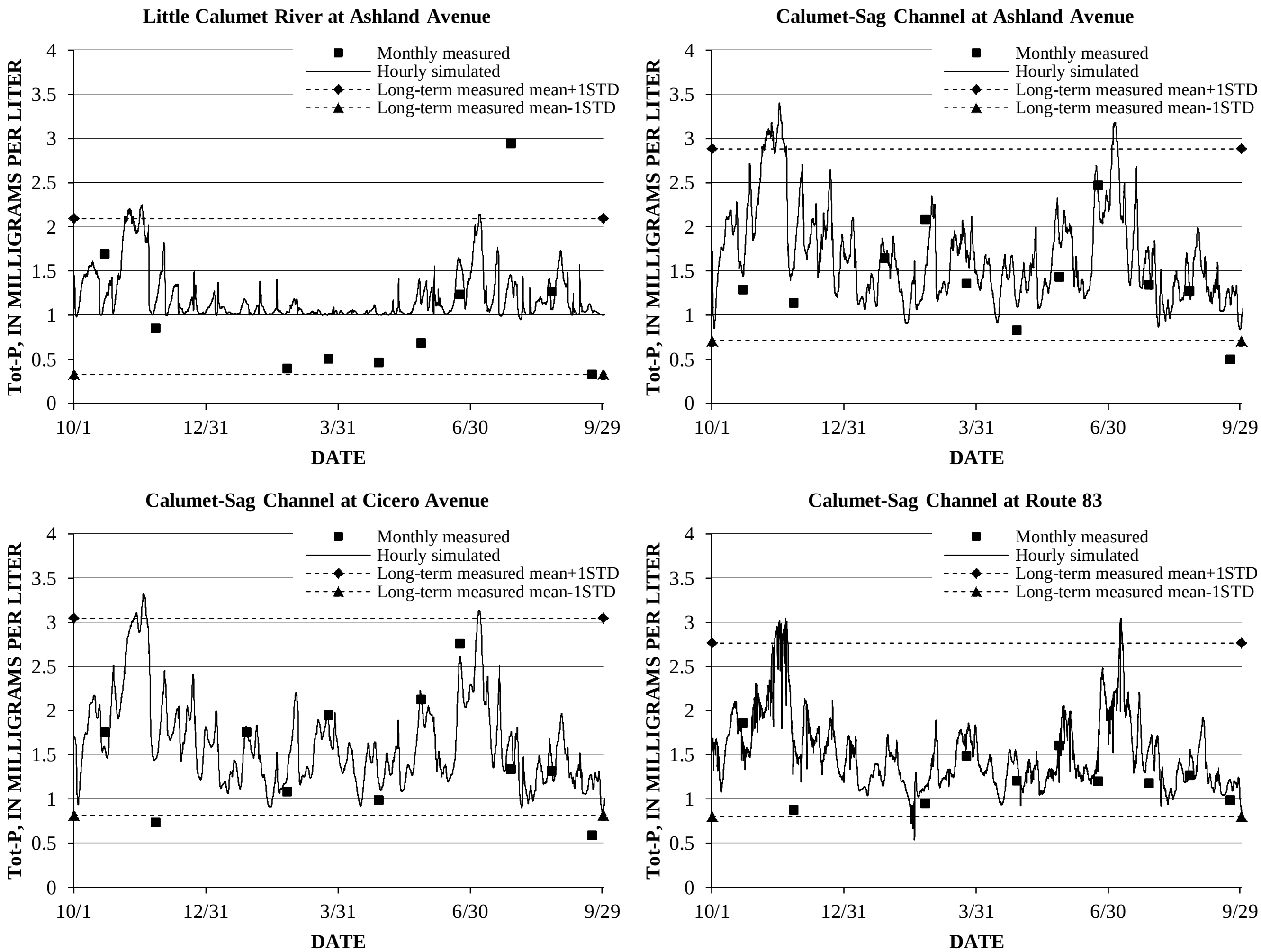

Figure 4.11 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

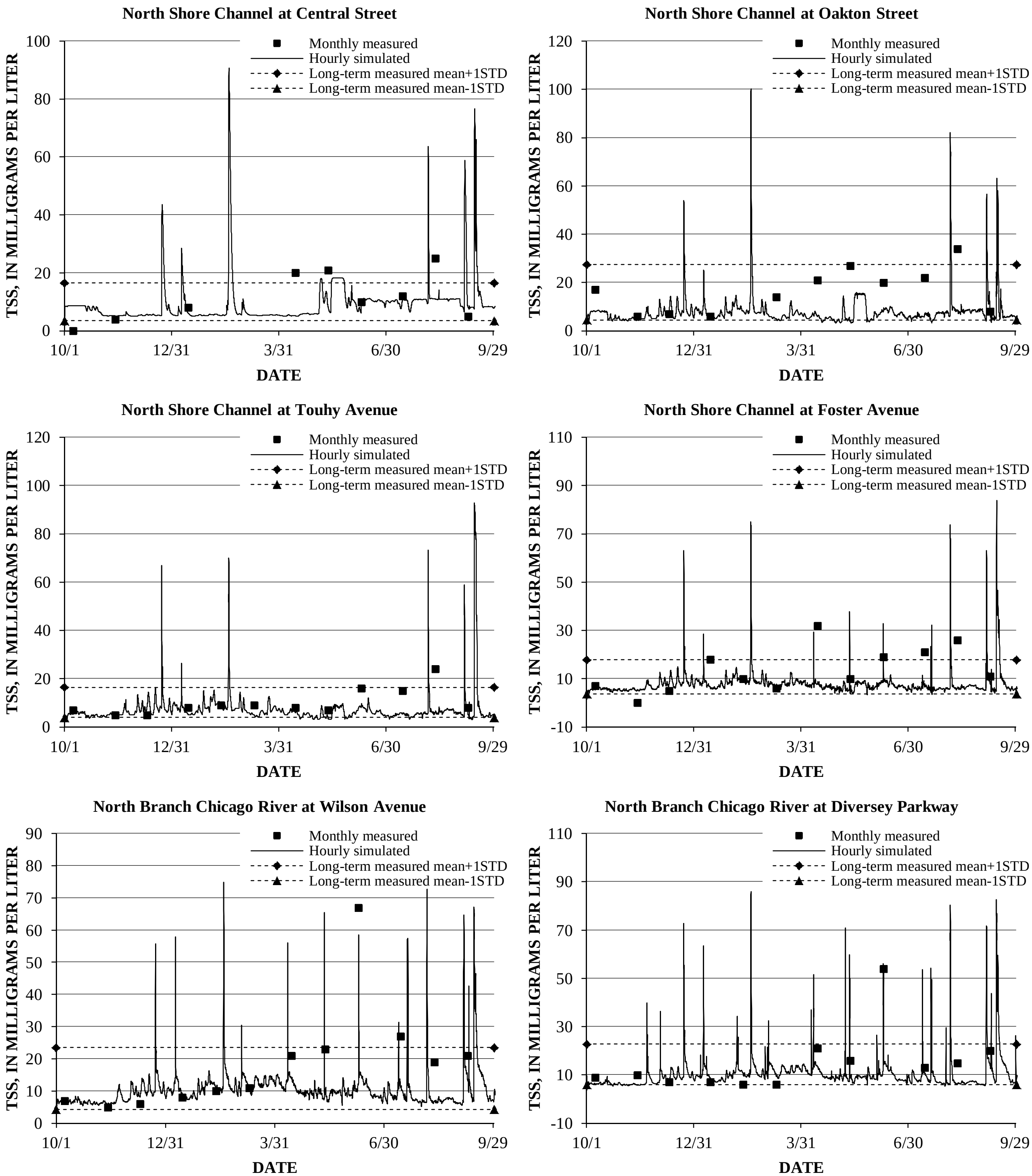

Figure 4.12. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total suspended solids (TSS) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008.

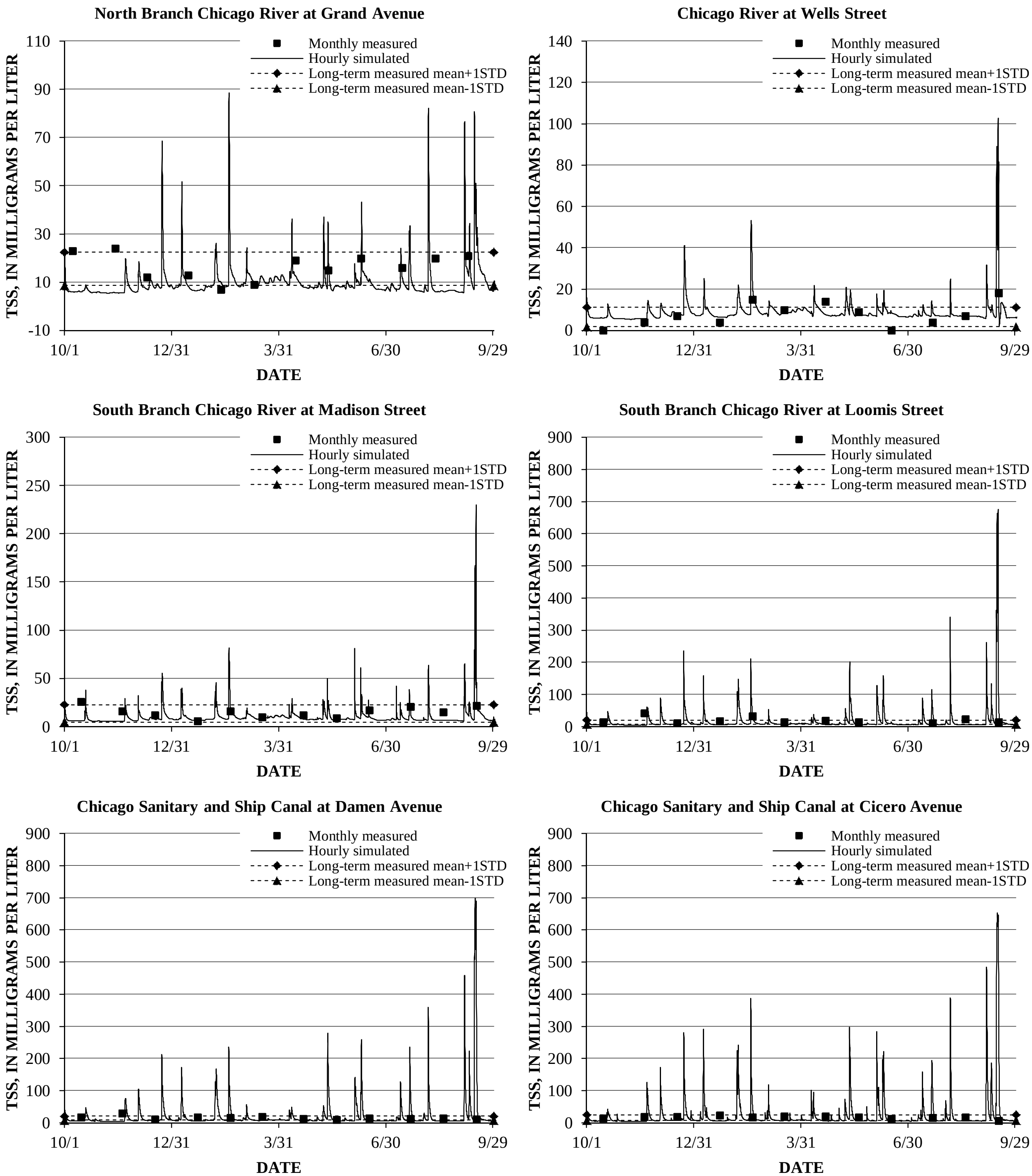

Figure 4.12 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total suspended solids (TSS) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

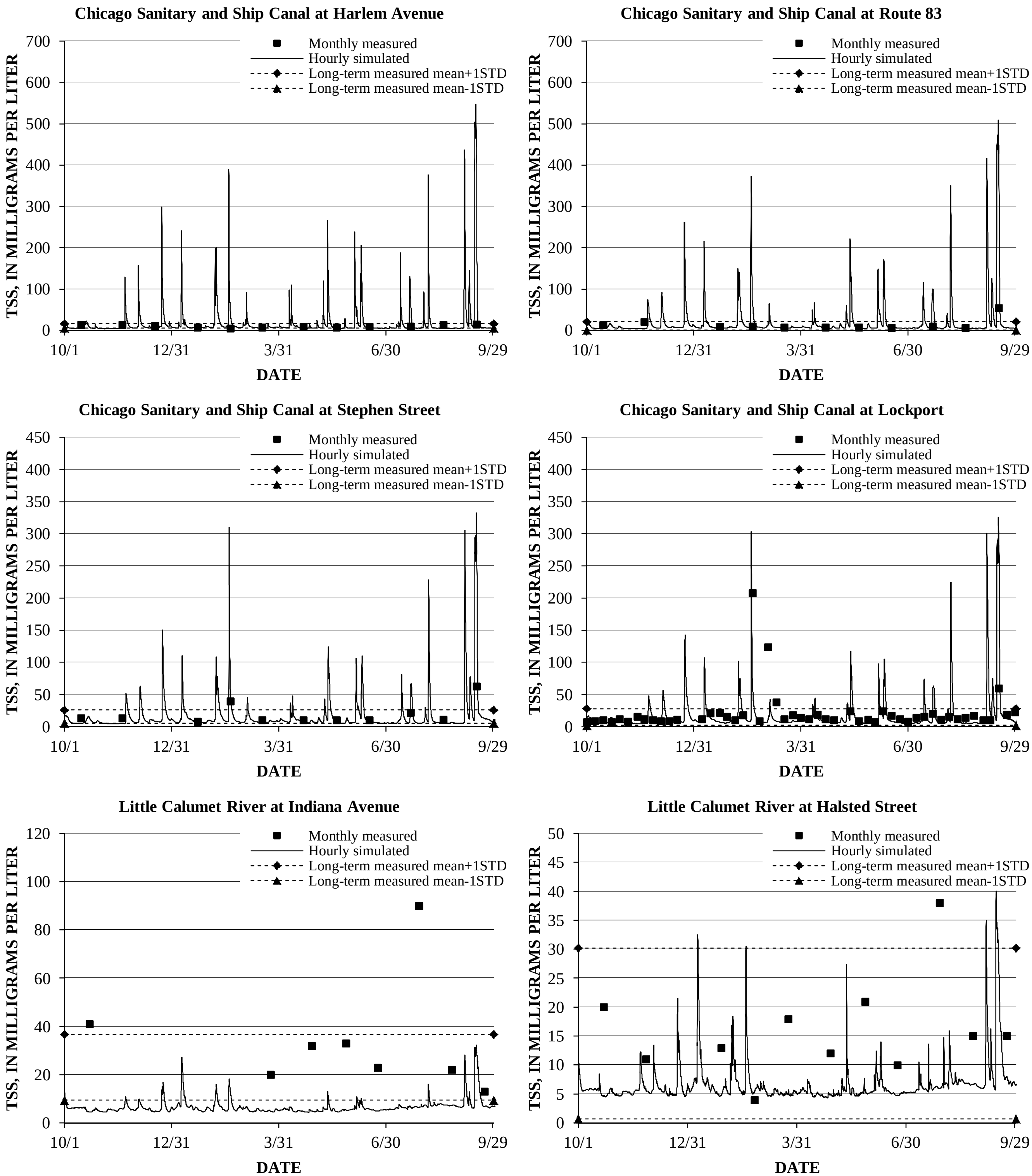

Figure 4.12 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total suspended solids (TSS) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

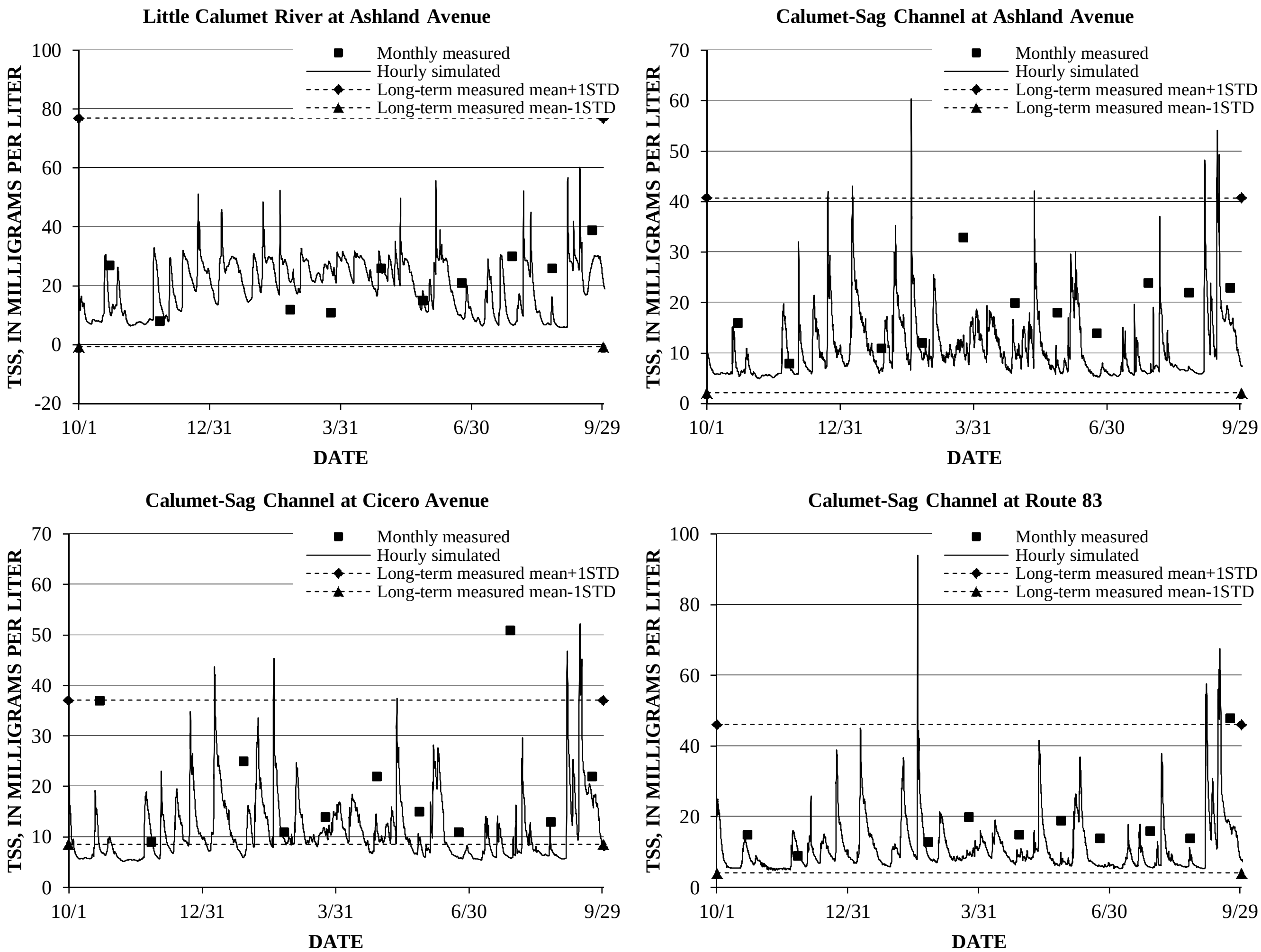

Figure 4.12 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total suspended solids (TSS) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

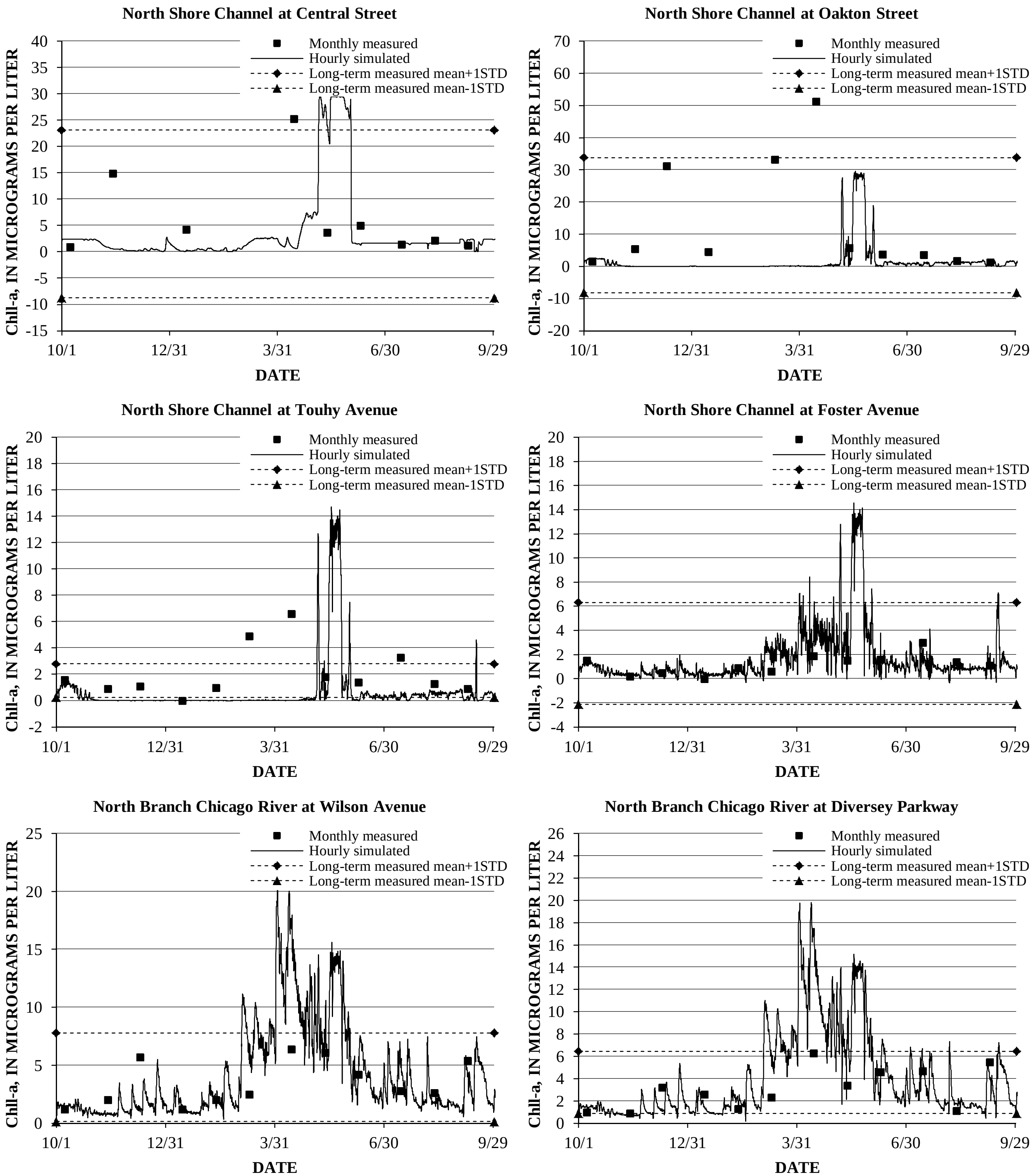

Figure 4.13. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly chlorophyll-a (Chll-a) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008.

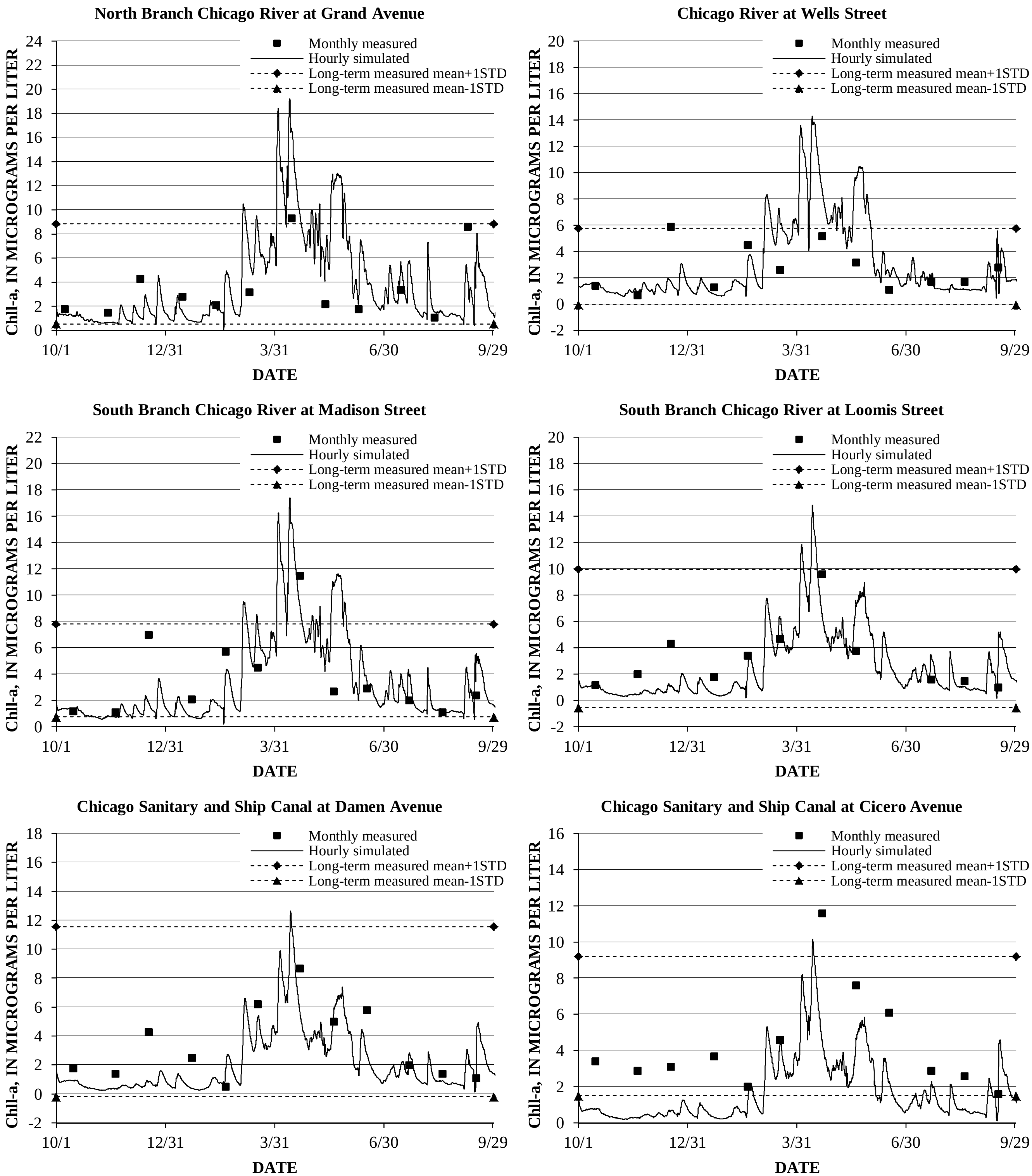

Figure 4.13 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly chlorophyll-a (Chll-a) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

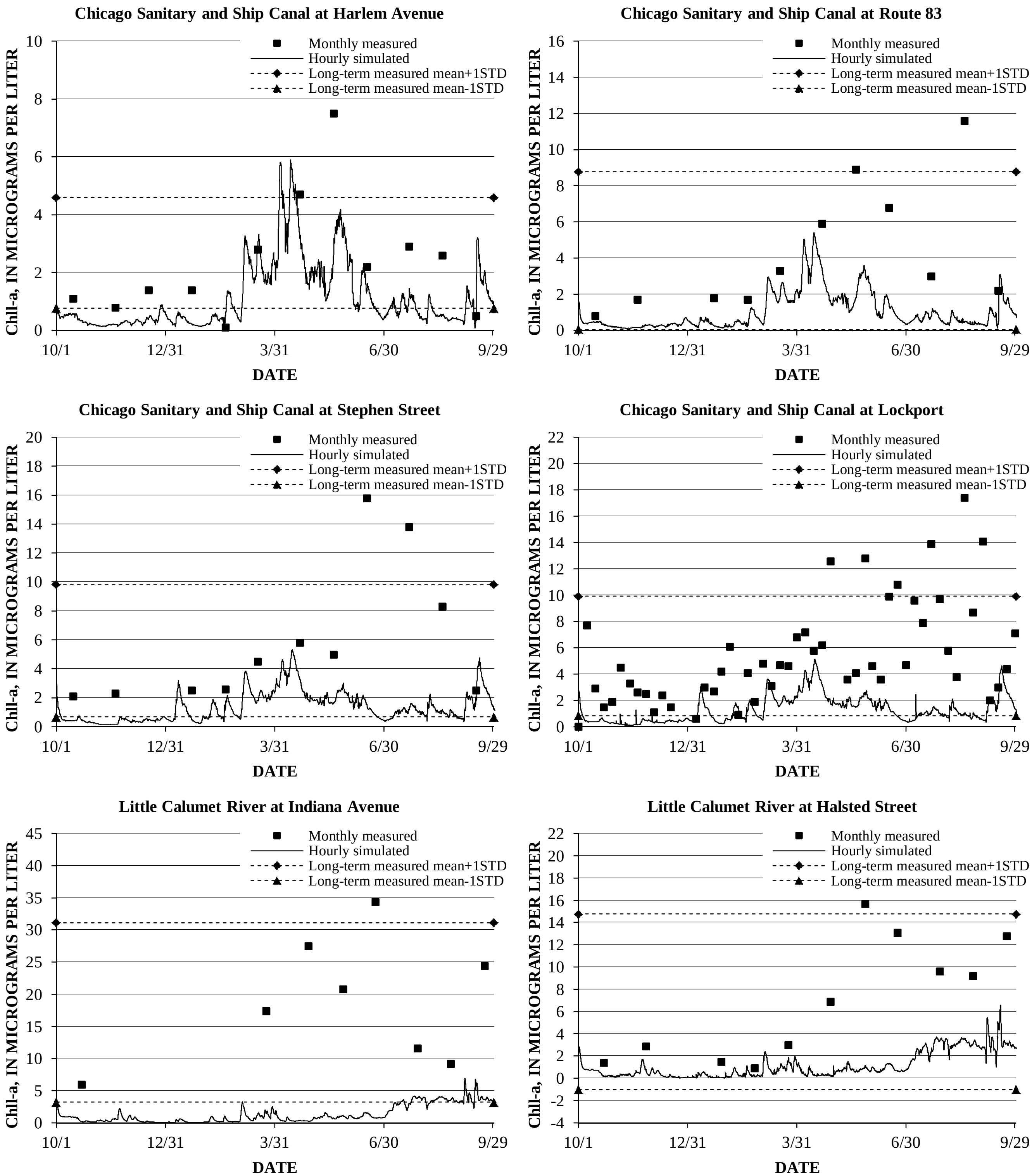

Figure 4.13 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly chlorophyll-a (Chll-a) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

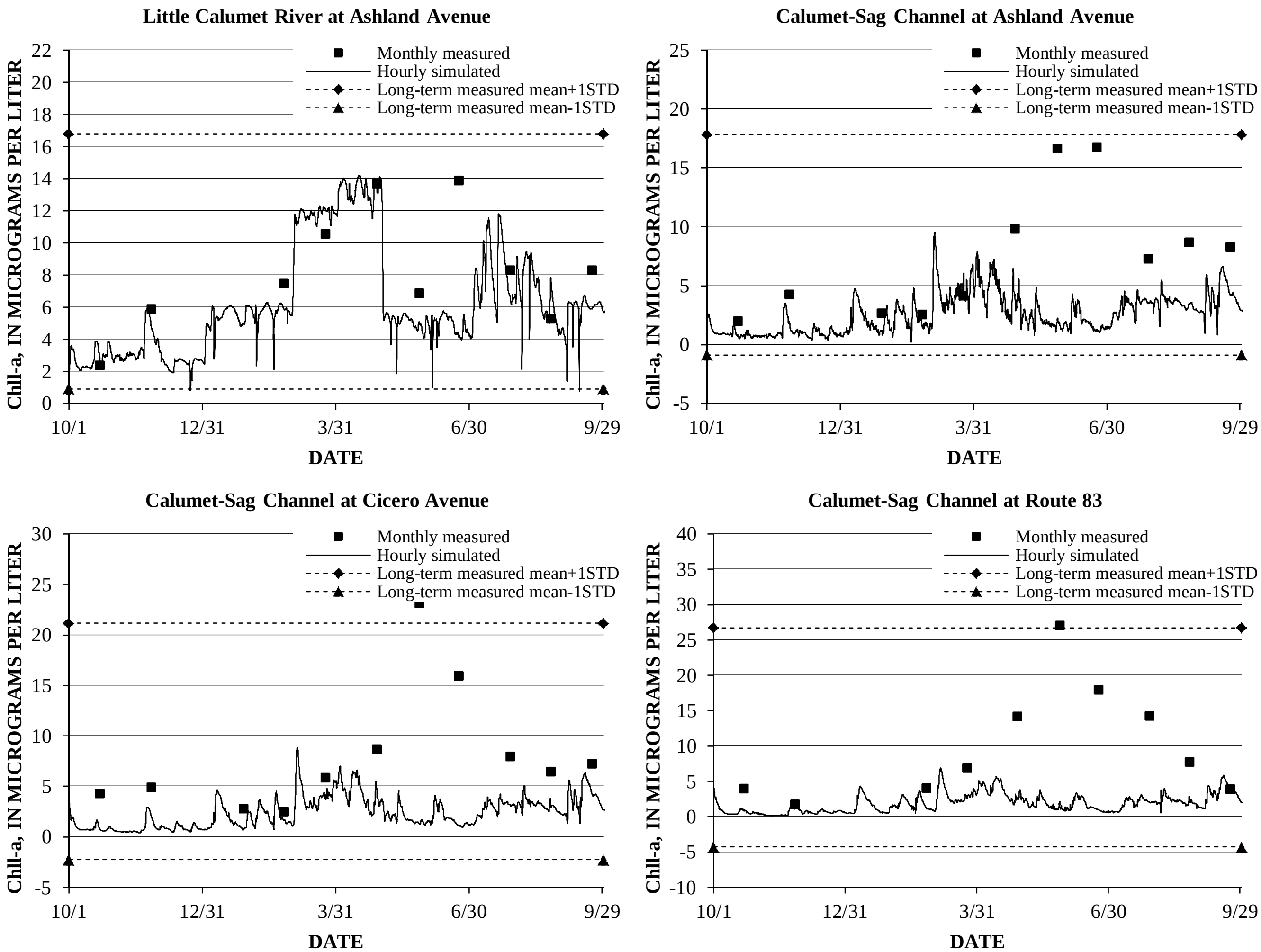

Figure 4.13 (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly chlorophyll-a (Chll-a) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2008

Figures 4.14-4.18 compare the mean of the simulated concentrations with the mean and one standard deviation confidence bounds of the measured historic data for ammonia as nitrogen, nitrate as nitrogen, total phosphorus, total suspended solids, and chlorophyll-a, respectively. The comparison is shown for trajectories along the (a) NSC, NBCR, SBCR, and CSSC [the Chicago River System], and (b) the Calumet River, Little Calumet River (north), and Calumet-Sag Channel [the Calumet River System].

In summary, the comparisons of the simulated constituent concentrations with long-term mean measured concentrations and one standard deviation confidence bounds did not indicate anything unusual with nearly all the simulated mean concentrations passing through the one standard deviation confidence bounds of the measurements. Thus, the DUFLOW simulation of these constituents was considered acceptable.

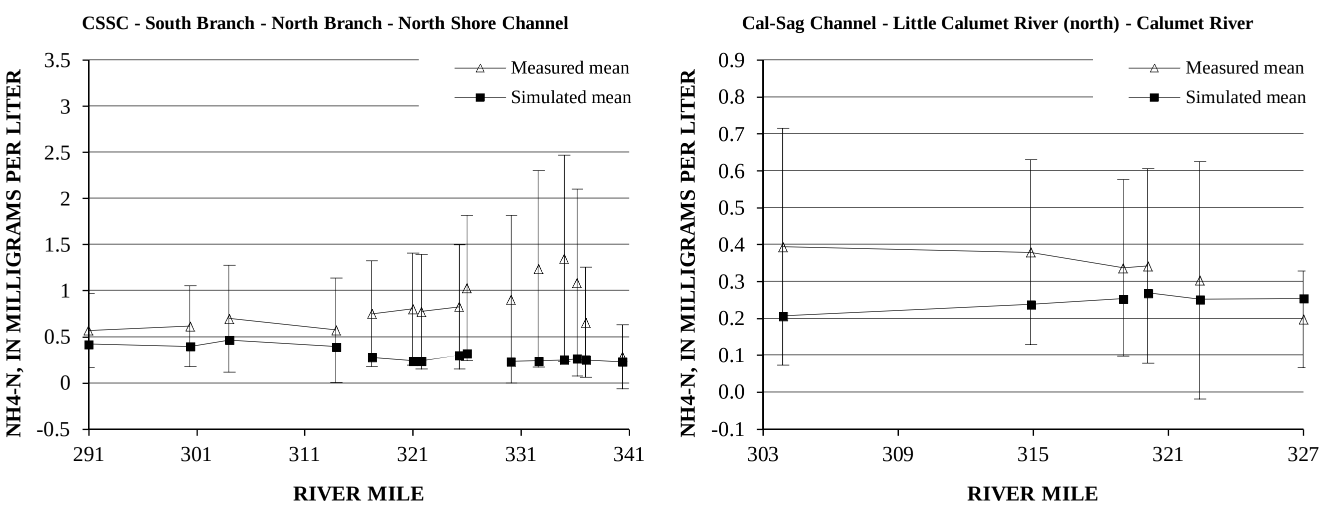

Figure 4.14. Comparison of long-term (1997-2011) measured mean (plus or minus one standard deviation) and simulated mean ammonia as nitrogen (NH4-N) concentrations in the Chicago Area Waterways System for Water Year 2008.

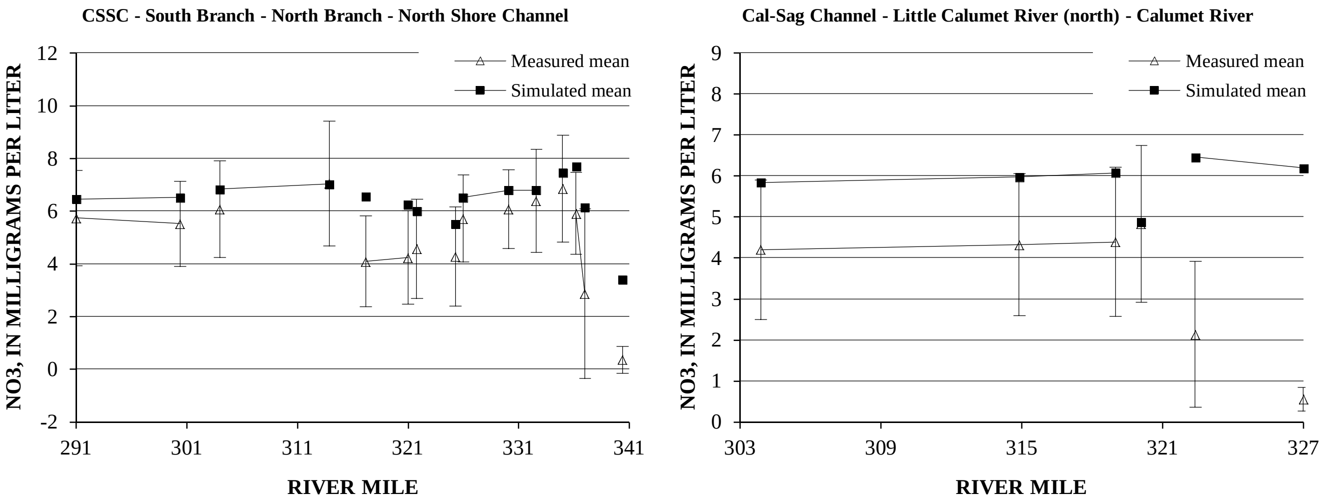

Figure 4.15. Comparison of long-term (1997-2011) measured mean (plus or minus one standard deviation) and simulated mean nitrate as nitrogen (NO3-N) concentrations in the Chicago Area Waterways System for Water Year 2008.

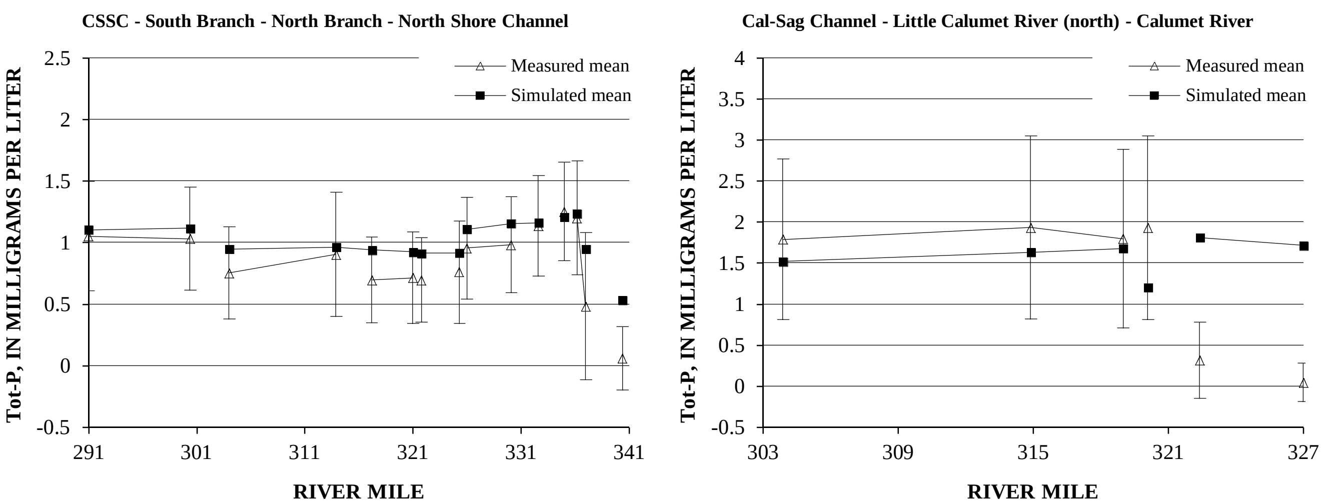

Figure 4.16. Comparison of long-term (1997-2011) measured mean (plus or minus one standard deviation) and simulated mean total phosphorus (Tot-P) concentrations in the Chicago Area Waterways System for Water Year 2008.

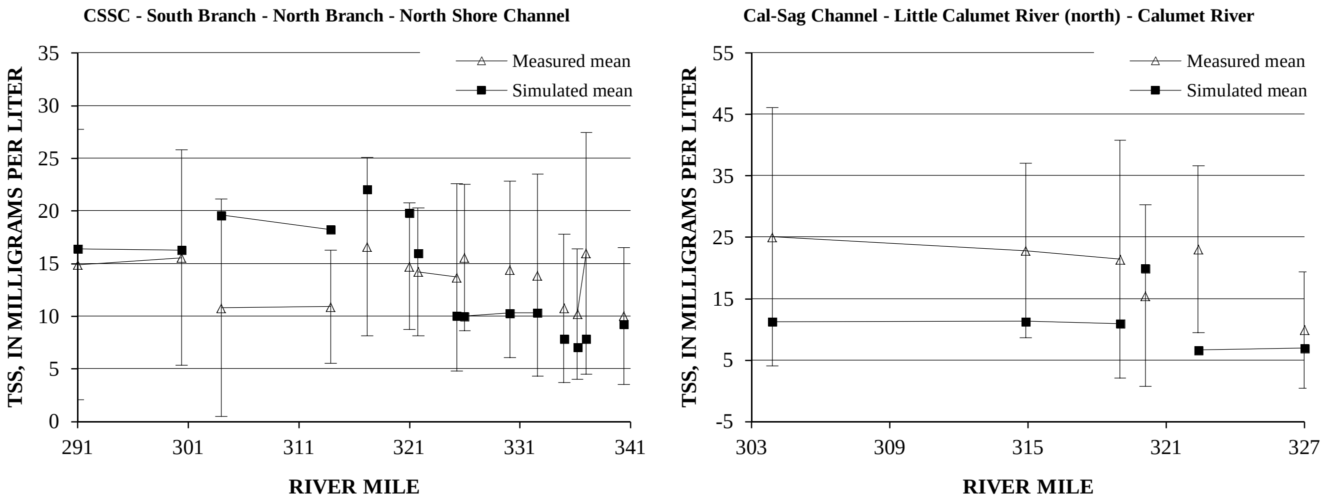

Figure 4.17. Comparison of long-term (1997-2011) measured mean (plus or minus one standard deviation) and simulated mean total suspended solids (TSS) concentrations in the Chicago Area Waterways System for Water Year 2008.

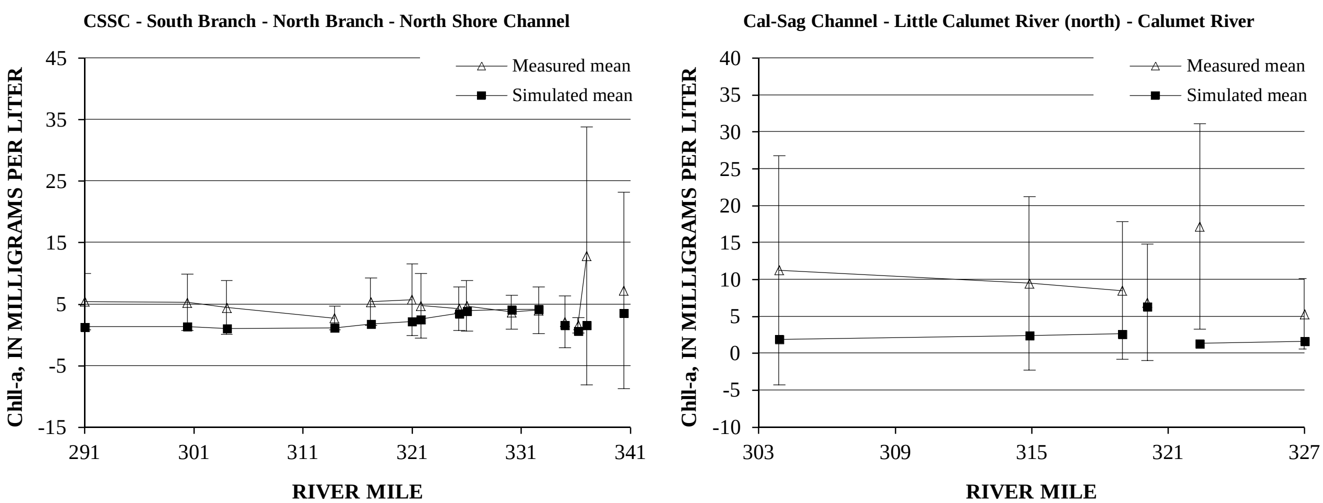

Figure 4.18. Comparison of long-term (1997-2011) measured mean (plus or minus one standard deviation) and simulated mean chlorophyll-a (Chll-a) concentrations in the Chicago Area Waterways System for Water Year 2008.

4.3.2 Dissolved Oxygen Concentration

Simulated DO concentrations were compared with hourly measured DO concentrations at 18 locations for WY 2008. Results are presented in 4 categories: lower NSC and NBCR, SBCR and CSSC, Calumet-Sag Channel, and boundaries (this includes DO monitoring sites on the upper NSC, Chicago River main stem, Bubby Creek, and Little Calumet River (north) upstream of the Calumet WRP).

In the following subsections, the quality of the DO simulation for WY 2008 is listed by season and over the entire year. The statistical and graphic comparisons between simulated and measured DO concentrations at all available monitoring locations are presented.

<u>Lower North Shore Channel and North Branch Chicago River</u>

This section of the CAWS is divided into 3 reaches and the following continuous DO monitoring stations represent each reach: i) Foster Avenue, ii) Addison Street and Fullerton Avenue, and iii) Kinzie Street. A statistical comparison between seasonally averaged hourly simulated and measured DO concentrations for WYs 2001 and 2008 is listed in Tables 4.9 and 4.10, respectively, where fall is defined as September-November, winter is defined as December-February, spring is defined as March-May, and summer is defined as June-August. Details of WY 2001 are included here to indicate the quality of the simulation results after the ammonia as nitrogen concentrations in the effluent from the O'Brien WRP were corrected as described in Section 4.2.2. In all cases, the average percentage error is less than 8 % indicating unbiased estimates of DO concentrations are obtained throughout these reache

Figure 4.19 shows the comparison of measured and simulated DO concentrations at Foster Avenue on the NSC and Addison Street, Fullerton Avenue, and Kinzie Street on the NBCR for WY 2008. It can be seen that there is good agreement between simulated and measured DO concentrations especially at Foster Avenue, Addison Street, and Fullerton Avenue. The results for WY 2001 are shown in Addendum E.

Table 4.9. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Branch Chicago River, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Addison Street			Fullerton Avenue			Division Street			Kinzie Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	Error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	6.4	6.5	0.1	5.7	6.4	0.7	6.2	6.7	0.5	6.0	6.6	0.6
Winter	7.9	6.7	-1.2	7.3	6.0	-1.3	7.4	5.8	-1.6	7.0	5.7	-1.3
Spring	7.0	6.9	-0.1	6.1	6.3	0.2	6.2	6.5	0.2	6.2	6.2	0.1
Summer	5.9	5.6	-0.3	4.7	5.2	0.6	5.7	5.6	-0.1	5.2	5.4	0.2
Overall Average	6.8	6.4		6.0	6.0		6.4	6.1		6.1	6.0	
Error	-0.4			0.0			-0.2			-0.1		
% Error	-5.3			0.6			-3.8			-1.5		

Table 4.10. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Branch Chicago River, Water Year 2008 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Foster Avenue			Addison Street			Fullerton Avenue			Kinzie Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. Mg/L	Sim. mg/L	Error mg/L
Fall	7.0	7.3	0.3	6.6	7.0	0.3	6.2	6.7	0.4	5.7	6.7	1.0
Winter	8.7	9.1	0.4	9.5	9.0	-0.5	8.9	8.6	-0.3	9.0	8.2	-0.8
Spring	8.2	8.4	0.2	8.9	8.6	-0.3	8.7	8.4	-0.3	7.8	8.1	0.4
Summer	7.0	7.1	0.1	6.4	6.7	0.3	5.6	6.6	1.0	5.3	7.0	1.8
Overall Average	7.7	8.0		7.9	7.8		7.4	7.6		7.0	7.5	
Error	0.3			0.0			0.2			0.6		
% Error	3.5			-0.6			2.7			7.9		

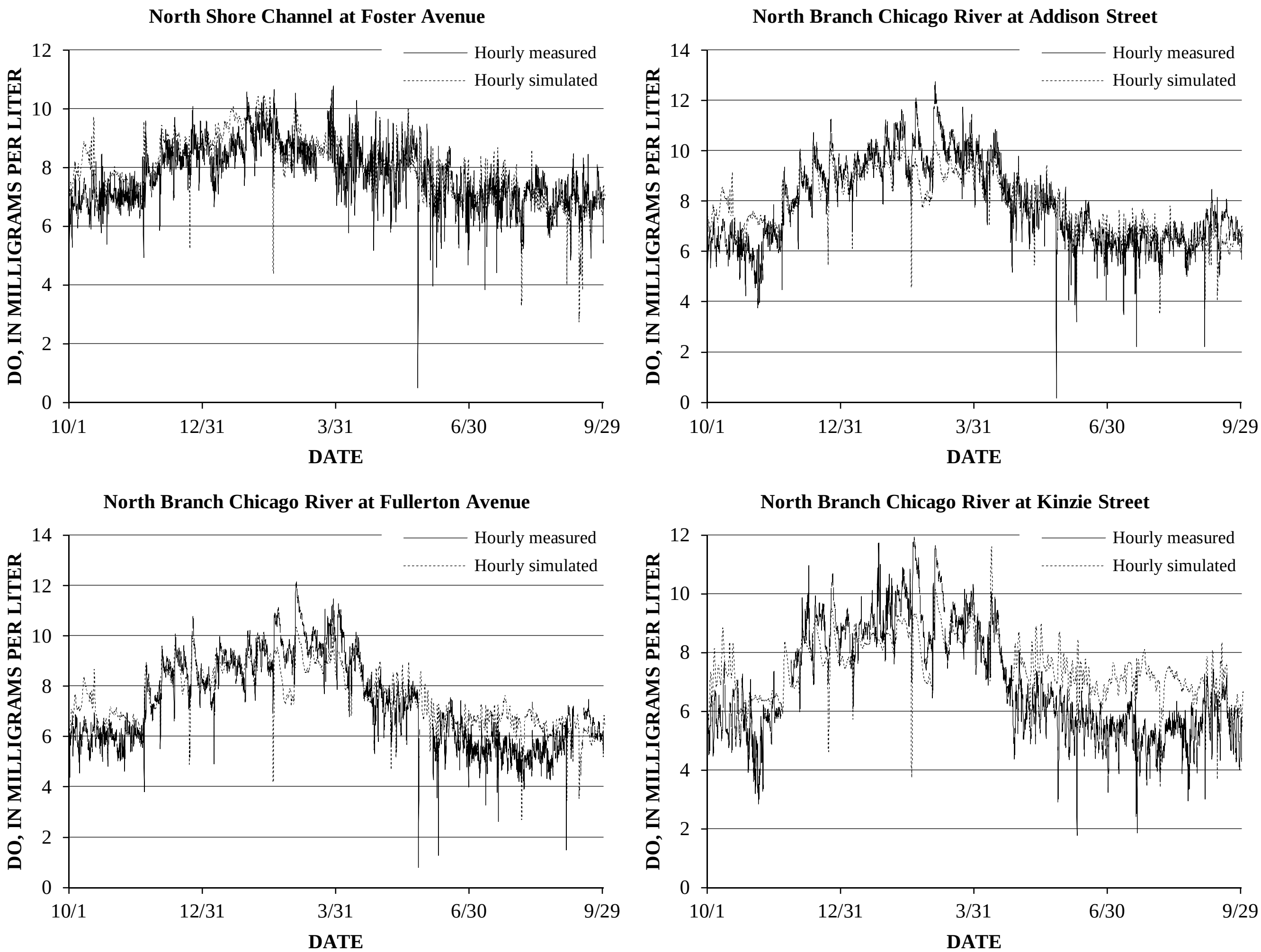

Figure 4.19. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Foster Avenue on the North Shore Channel and Addison Street, Fullerton Avenue, and Kinzie Street on the North Branch Chicago River for Water Year 2008.

South Branch Chicago River and Chicago Sanitary and Ship Canal

This section is divided into five reaches and the following DO stations represent each reach: i) Loomis Street (Jackson Boulevard for WY 2001), ii) Cicero Avenue, iii) Baltimore and Ohio Railroad, iv) Route 83, v) Lockport (where simulated concentrations at the Controlling Works are compared with measured concentrations at the Powerhouse). A statistical comparison between seasonally averaged simulated and measured hourly DO concentrations for WYs 2001 and 2008 is listed in Tables 4.11 and 4.12 (because the comparison at Lockport is not for the same location only a visual comparison is done for this location). In all but one case the average percentage error is less than 9 % indicating unbiased estimates of DO concentrations are obtained throughout these reaches.

Figure 4.20 shows the comparison of measured and simulated DO concentrations at Loomis Street on the SBCR and Cicero Avenue, B&O Railroad, Route 83, and Lockport on the CSSC for WY 2008. The large differences between measured and simulated DO concentrations from November through March at Loomis Street and Cicero Avenue are attributed to the presence of density currents in the CAWS (particularly the lower NBCR, SBCR, and Chicago River main stem) in the winter. When the density currents are present, the surface layer in which DO is measured has a higher DO concentration than the overall water column. Melching et al. (2010) and references therein discuss the density currents in detail.

Table 4.11. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the South Branch Chicago River and Chicago Sanitary and Ship Canal, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Jackson Boulevard			**Cicero Avenue**			**Baltimore and Ohio RR**			**Route 83**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	Error mg/L
Fall	6.0	6.4	0.3	4.9	5.1	0.3	6.5	6.1	-0.4	5.4	5.8	0.4
Winter	7.1	5.2	-1.9	7.2	5.0	-2.1	8.3	6.5	-1.7	7.7	6.5	-1.2
Spring	5.4	5.6	0.2	5.0	4.7	-0.3	6.7	6.2	-0.5	5.5	6.1	0.6
Summer	5.3	5.6	0.3	3.8	4.2	0.4	5.1	5.4	0.3	4.1	5.2	1.1
Overall Average	5.9	5.7		5.2	4.8		6.6	6.0		5.7	5.9	
Error	-0.2			-0.4			-0.6			0.2		
% Error	-3.8			-8.4			-8.9			4.1		

Table 4.12. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the South Branch Chicago River and Chicago Sanitary and Ship Canal, Water Year 2008 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Loomis Street			**Cicero Avenue**			**Baltimore and Ohio RR**			**Route 83**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	6.4	5.6	-0.8	4.9	5.5	0.6	6.2	6.2	0.0	5.5	6.1	0.5
Winter	9.4	6.3	-3.1	8.4	6.2	-2.1	8.8	7.2	-1.6	8.0	7.1	-0.9
Spring	8.0	6.6	-1.3	7.1	6.4	-0.6	7.9	7.3	-0.6	6.7	7.2	0.5
Summer	5.9	5.8	-0.1	4.7	5.3	0.6	5.8	6.0	0.2	4.6	5.9	1.2
Overall Average	7.5	6.1		6.2	5.9		7.1	6.7		6.6	6.5	
Error	-1.4			-0.3			-0.5			-0.1		
% Error	-19.1			-5.5			-6.7			-1.1		

Little Calumet River (north) and Calumet-Sag Channel

In this section simulation results for locations between the Calumet WRP and the junction of the Calumet-Sag Channel with the CSSC are presented. This section is divided into 3 reaches and the following DO stations represent each reach: i) Halsted Street, ii) Cicero Avenue, and iii) 104th Avenue and Route 83. A statistical comparison between seasonally averaged simulated and measured hourly DO concentrations for WY 2008 is listed in Table 4.13. For WY 2008 the overall percentage errors in simulated hourly DO concentrations at Halsted Street, Cicero Avenue, 104th Avenue, and Route 83 are less than 6 %. These results indicate that unbiased estimates of DO concentrations are obtained throughout these reaches.

Figure 4.21 shows the comparison of measured and simulated DO concentrations at Halsted Street on the Little Calumet River, and Cicero Avenue, 104th Street, Route 83 on the Calumet-Sag Channel for WY 2008. Close agreement is shown between measured and simulated DO concentrations at all locations in Figure 4.21.

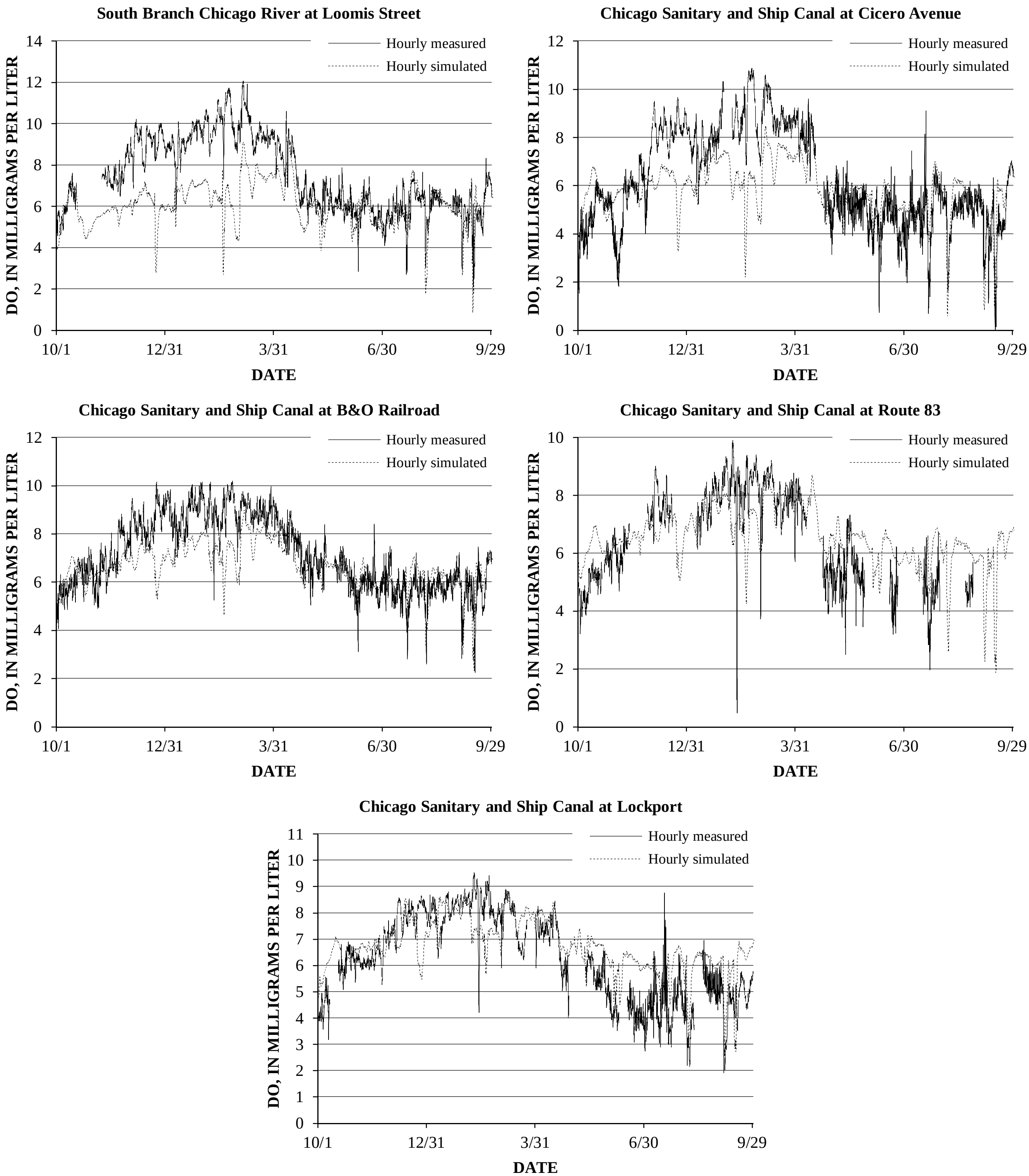

Figure 4.20. Comparison of measured and simulated dissolved oxygen (DO) concentrations at five locations on the South Branch Chicago River and Chicago Sanitary and Ship Canal for Water Year 2008.

Table 4.13. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Calumet-Sag Channel and Little Calumet River (North) downstream from the Calumet WRP, Water Year 2008 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Halsted Street			**Cicero Avenue**			**104th Avenue**			**Route 83**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	6.3	6.8	0.5	6.1	6.9	0.8	7.0	7.0	0.0	6.0	6.9	0.9
Winter	7.6	7.2	-0.4	8.8	8.4	-0.3	9.4	8.7	-0.7	9.3	8.7	-0.6
Spring	6.9	7.1	0.2	7.7	7.8	0.1	8.0	7.9	-0.1	7.9	7.9	-0.1
Summer	6.5	6.2	-0.3	6.2	6.4	0.2	7.1	6.5	-0.6	5.8	6.4	0.5
Overall Average	6.8	6.8		7.3	7.4		8.0	7.5		7.3	7.4	
Error	0.0			0.1			-0.5			0.1		
% Error	-0.1			1.8			-6.0			1.8		

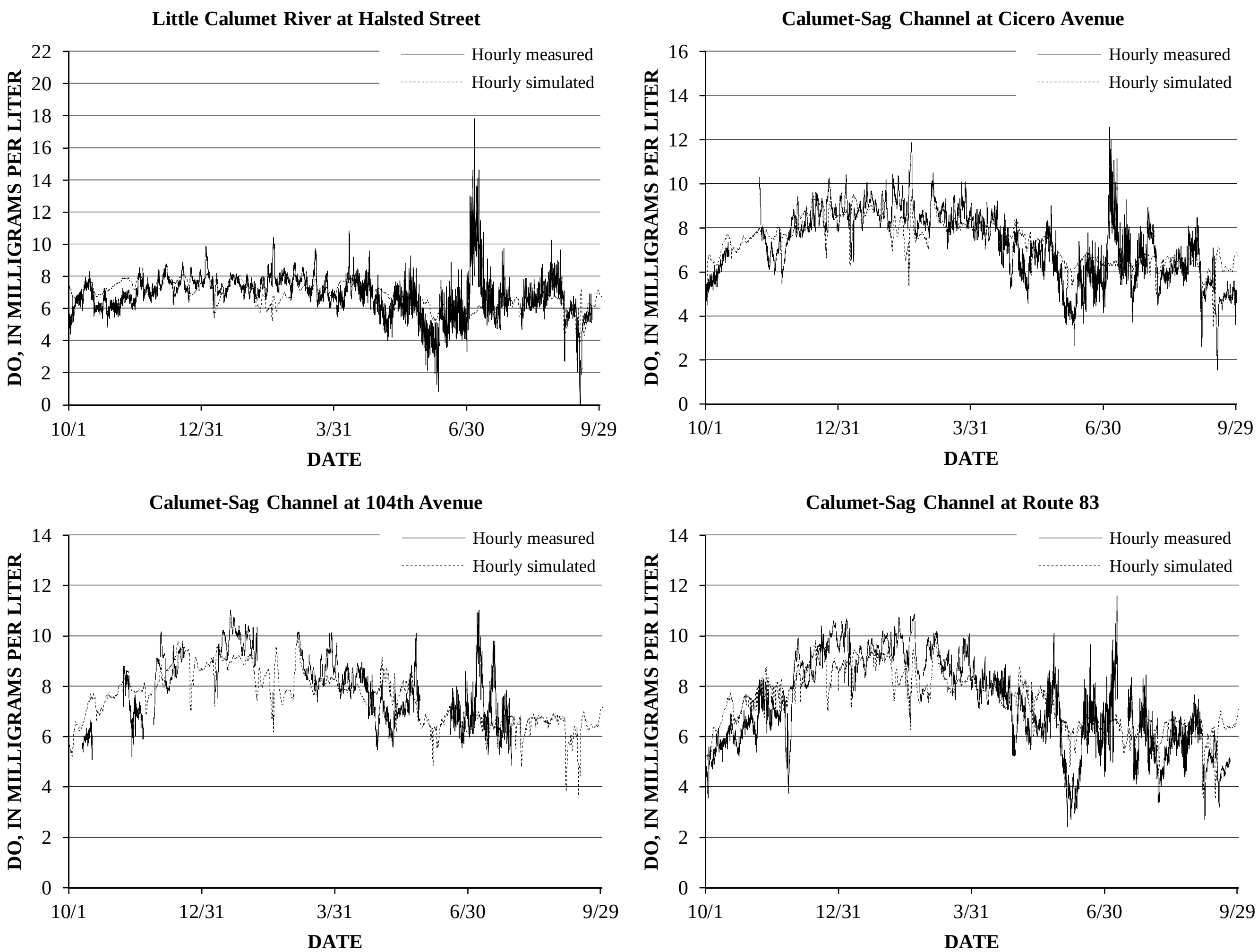

Figure 4.21. Comparison of measured and simulated dissolved oxygen (DO) concentrations at different locations on the Little Calumet River (north) and Calumet-Sag Channel for Water Year 2008.

Boundaries (North Shore Channel, Chicago River main stem, Little Calumet River (north))

A statistical comparison between seasonally averaged simulated and measured hourly DO concentrations for WYs 2001 and 2008 is listed in Tables 4.14-4.19. The average percentage errors at these locations is higher (in the 10-17% range) than for the other locations in the CAWS. The reason for the lower quality results at these locations is related to the difficulty in correctly simulating the flows in these generally stagnant reaches. A detailed discussion of these reaches is given in Melching et al. (2010).

For WY 2008 the comparison of measured and simulated DO concentrations at Main Street on the NSC, Clark Street on the Chicago River, Central & Wisconsin (C&W) Railroad on the Little Calumet River (north) is shown in Figure 4.22, and that for I-55 and 36th Street on the Bubbly Creek is shown in Figure 4.23. The DO comparison at Clark Street shows the effect of the density current in the Chicago River main stem (Figure 4.22). At each of the other locations the measured and simulated DO concentrations agree very well at some times but differ greatly at others. This type of result is common in water-quality modeling as Harremoes et al. (1996) note it is almost impossible to match all the hourly data if there are a large number of data to be fitted to.

Table 4.14. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Shore Channel, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Simpson Street			Main Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	5.5	5.1	-0.4	5.0	5.2	0.2
Winter	1.2	3.1	1.9	4.5	4.9	0.3
Spring	6.6	5.4	-1.2	7.7	5.4	-2.3
Summer	4.5	5.2	0.6	2.8	4.4	1.6
Overall Average	4.5	4.7		5.1	5.0	
Error	0.2			-0.1		
% Error	5.5			-2.2		

Table 4.15. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Shore Channel, Water Year 2008 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Main Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L
Fall	7.0	6.1	-0.9
Winter	5.6	6.7	1.1
Spring	10.1	6.8	-3.4
Summer	7.9	7.8	-0.1
Overall Average	7.7	6.9	
Error	-0.9		
% Error	-11.1		

Table 4.16. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Chicago River Main Stem, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Michigan Avenue			Clark Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	8.8	7.6	-1.2	7.9	7.1	-0.8
Winter	9.1	6.3	-2.8	8.7	5.8	-2.9
Spring	7.2	6.3	-0.9	6.7	6.0	-0.7
Summer	8.1	7.5	-0.6	7.6	7.0	-0.6
Overall Average	8.4	6.9		7.7	6.5	
Error	-1.4			-1.2		
% Error	-17.2			-15.9		

Table 4.17. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Chicago River Main Stem, Water Year 2008 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Clark Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L
Fall	7.9	7.2	-0.7
Winter	10.0	7.8	-2.2
Spring	8.5	8.0	-0.5
Summer	8.1	8.1	0.0
Overall Average	8.6	7.8	
Error	-0.8		
% Error	-9.8		

Table 4.18. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Little Calumet River (North) for Water Year 2008 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	Central and Wisconsin Railroad		
Season	Meas. mg/L	Sim. mg/L	error mg/L
Fall	7.5	6.6	-0.9
Winter	11.6	7.2	-4.4
Spring	11.0	6.9	-4.2
Summer	6.1	6.0	-0.1
Overall Average	9.1	6.7	
Error	-2.4		
% Error	-26.7		

Table 4.19. Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on Bubbly Creek at I-55, for Water Year 2008 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100].

	36th Street			I-55		
Season	Meas. Mg/L	Sim. mg/L	error mg/L	Meas. Mg/L	Sim. mg/L	error mg/L
Fall	5.0	5.2	0.2	4.9	5.4	0.5
Winter	5.2	5.7	0.6	8.1	6.0	-2.2
Spring	7.5	6.1	-1.5	6.6	6.3	-0.3
Summer	1.9	5.1	3.2	4.1	5.4	1.3
Overall Average	4.9	5.5		5.9	5.8	
Error	0.6			-0.2		
% Error	12.9			-2.9		

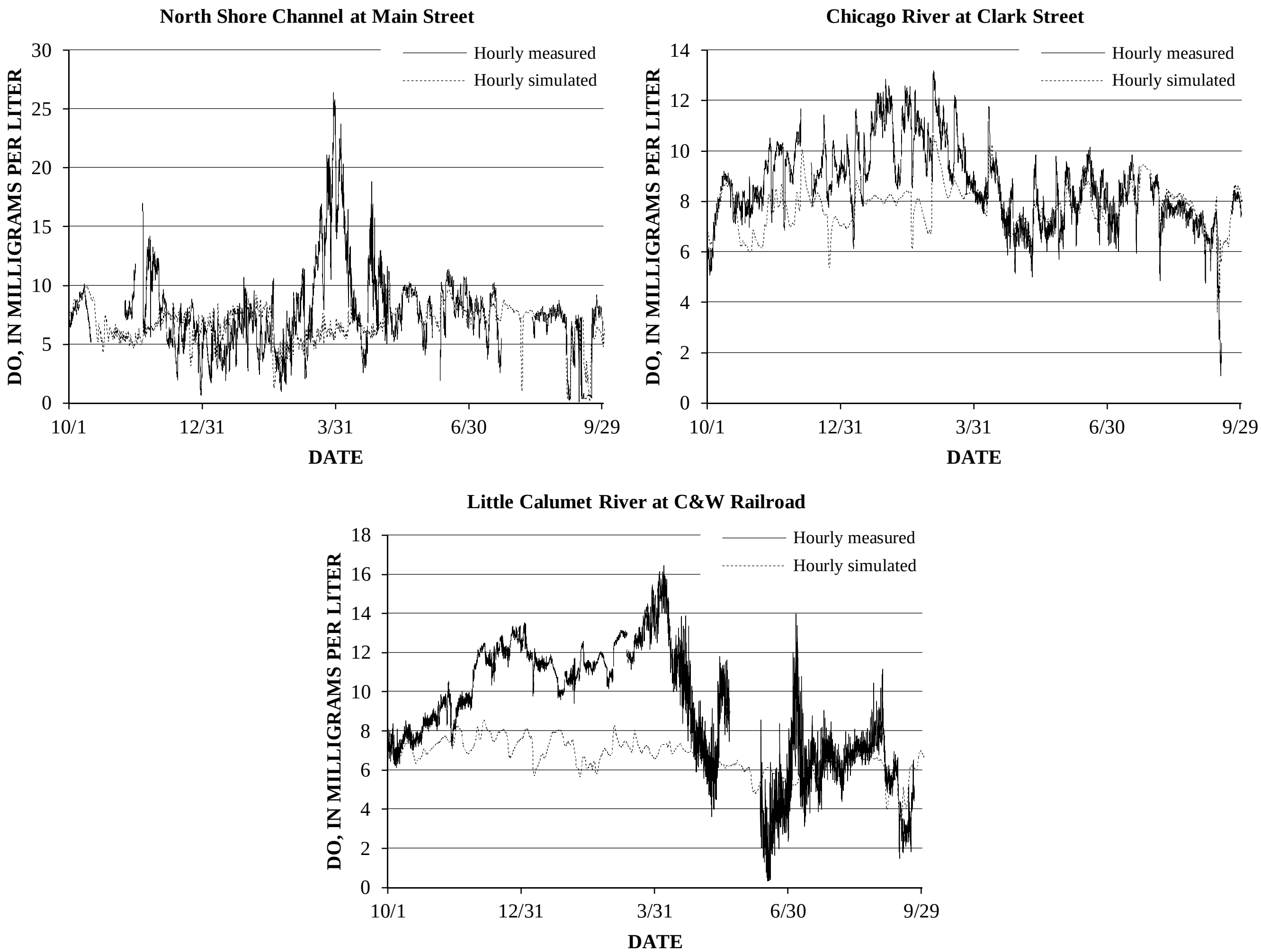

Figure 4.22. Comparison of measured and simulated dissolved oxygen (DO) concentrations at different locations near the boundaries of the Chicago Area Waterways System for Water Year 2008.

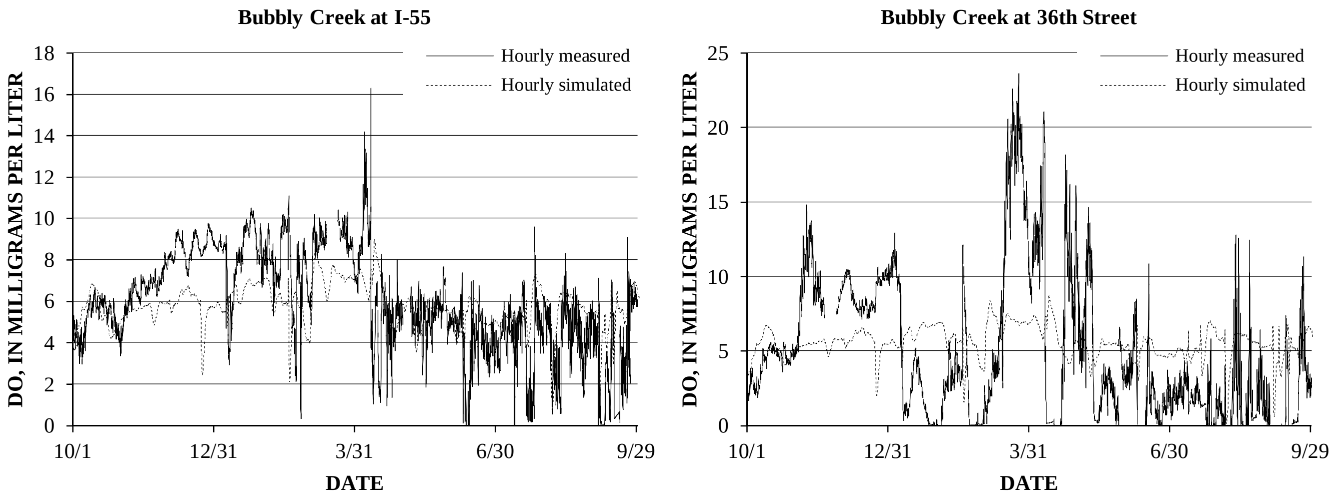

Figure 4.23. Comparison of measured and simulated dissolved oxygen (DO) concentrations at I-55 and 36th Street on the Bubbly Creek for Water Year 2008.

Overall Performance of the Dissolved Oxygen Model

Table 4.20 lists the average annual errors in percent for the simulated DO concentrations compared to the measured DO locations for the 14 locations in the CAWS for which measured data are available in each of WYs 2001, 2003, and 2008. Only 10 out of the 42 (23.8%) annual errors are greater than 10% in Table 4.20. If the near boundary locations (Main Street, Clark Street, and C&W Railroad) are ignored, only 3 out of the 33 annual errors are greater than 10%. Thus, for the free flowing portions of the CAWS more than 90% of the annual errors are less than 10%.

Table 4.20. Average annual percentage error in the simulated dissolved oxygen concentrations for each of Water Years 2001, 2003, and 2008.

Location	Waterway	WY 2001	WY 2003	WY 2008
Main Street	NSC	-2.2	-35.2	-11.1
Addison Street	NBCR	-5.3	-7.8	-0.6
Fullerton Avenue	NBCR	0.6	-0.9	2.7
Kinzie Street	NBCR	-1.5	-3.1	7.9
Clark Street	Chicago River	-15.9	-16.7	-9.8
Cicero Avenue	CSSC	-8.4	-7.6	-5.5
B&O Railroad	CSSC	-8.9	-10.7	-6.7
Route 83	CSSC	4.1	7.3	-1.1
Lockport	CSSC	5.1	6.1	7.7
C&W Railroad	Little Calumet River (north)	-19.4*	-26.2	-26.7
Halsted Street	Little Calumet River (north)	-7.3*	-3.3	-0.1
Cicero Avenue	Calumet-Sag Channel	0.2*	-6.8	1.8
104th Avenue	Calumet-Sag Channel	2.7*	-12.5	-6.0
Route 83	Calumet-Sag Channel	-0.3	-11.9	1.8

*For these locations the DO probe was installed in July 2001, thus, this is only a partial year statistic.

For 6 of the 14 locations, the annual errors are both positive and negative indicating that if the model parameters are changed to improve the fit quality for one year the fit quality for another year would be reduced. Addison Street on the NBCR and Halsted Street on the Little Calumet River (north) is consistently low, but for one of the years the error is so small (less than 1%) that it would be unwise to change parameter values. The consistently low simulations for Clark Street on the Chicago River main stem are the result of the large differences in November to March because of the density current. The consistent low simulations at the Central & Wisconsin Railroad on the Little Calumet River (north) are the result of the unusually high (at or above saturation) DO concentrations measured each year in the winter and early spring (see Figure 4.22) the cause of these high DO concentrations cannot be explained, and, thus, cannot be simulated by the DUFLOW model. Cicero Avenue and the Baltimore & Ohio (B&O) Railroad on the CSSC are consistently low, whereas Lockport on the CSSC is consistently high. Thus, efforts to improve conditions at one location might hurt the others, and it was decided to not change the calibration since all but one of the annual errors at these locations was less than 10%.

4.4 Summary of Verification

In the previous sections, comparisons were shown of the simulated constituent concentrations ($CBOD_5$, nitrogen compounds, total phosphorus, TSS, and chlorophyll-a) with long-term mean measured concentrations, one standard deviation confidence bounds, and concentrations measured in WY 2008. It can be seen that especially for the lower DO concentrations, the CAWS DUFLOW water-quality model predicted DO concentrations with relatively high accuracy (less than 10% error on average in most locations and years). It can be concluded that, in general, the DUFLOW model represents water-quality processes in the CAWS well enough to be a useful tool for evaluating water-quality planning and management problems of interest to the GLMRIS study.

Chapter 5 – FLOW AND TEMPERATURE CHANGES FOR THE ALTERNATIVES EVALUATED

Whereas the DUFLOW model of the CAWS was tested and verified for the actual flow, treatment plant effluent load, and temperature conditions in WYs 2001, 2003, and 2008 in Chapters 2, 3, and 4 and previous studies (e.g., Melching et al., 2010), the evaluation of the GLMRIS project alternatives must reflect expected future conditions. These conditions are dictated by already agreed to changes in WRP effluent permit limits (i.e. the requirement of a maximum total phosphorus concentration of 1 mg/L) and planned upgrades to the WRPs (i.e. institution of disinfection at the O'Brien and Calumet WRPs). Also, the changes in thermal power plant operations (i.e. the closure of the Fisk and Crawford power plants in 2012) will affect water quality in the CAWS resulting from the GLMRIS project alternatives. The reduction in the discretionary diversion from Lake Michigan for water-quality improvement purposes from 270 cfs to 101 cfs scheduled for WY 2015 will affect the "No Project" alternative. Finally, the phased completion of the TARP Reservoirs—Thornton Reservoir in 2015, McCook Reservoir Stage 1 in 2017, and McCook Reservoir Stage 2 in 2029—will greatly affect the flows in the CAWS and the evaluation of the GLMRIS project alternatives.

Some of the changes in the DUFLOW model inputs required to reflect changed conditions during the period of GLMRIS project operation are easy to implement. For the case of the effluent limit for total phosphorus, the actual effluent total phosphorus concentrations were adjusted such that the concentrations less than 1 mg/L remained in the input unchanged and the concentrations greater than 1 mg/L were changed to 1 mg/L. For the case of the disinfection at the O'Brien and Calumet WRPs, Dr. Catherine O'Connor (personal communication, January 10, 2013), MWRDGC Director of Engineering, reported that "we are expecting at least a 2 log reduction" in fecal coliform concentrations in the effluent from the WRPs after disinfection. Thus, the measured effluent concentrations for the O'Brien and Calumet WRPs were reduced by 99% in the GLMRIS project alternative evaluations reported here.

The changes in CSO inflows to the system and the resulting changes in the downstream water level boundary condition are more complex as are the changes in water temperature resulting from the new flow patterns resulting from the various GLMRIS project alternatives. Thus, the following sections of this chapter describe in detail how the flow, boundary condition, and temperature changes necessary to reflect the GLMRIS project alternatives were implemented in the DUFLOW simulations.

5.1 Combined Sewer Overflow and Water Reclamation Plant Flow Changes

Two CSO inflow conditions are considered in the evaluation of the GLMRIS project alternatives: the Baseline and Future Conditions. It is anticipated that the earliest any of the GLMRIS project alternatives could be implemented is 2017. Thus, the Baseline conditions were composed to reflect the CSO inflow conditions in 2017 with the Thornton Reservoir completed and the McCook Reservoir partially completed (i.e. Stage 1 completed). The Future conditions reflect the completion of both reservoirs in 2029.

5.1.1 Baseline Conditions

For the actual inflow conditions for WYs 2001, 2003, and 2008, estimates of the gravity CSO flows to the modeled portion of the CAWS were obtained from the series of models developed by the USACE, Chicago District, to simulate the flows in the TARP system. The Hydrological Simulation Program—Fortran (HSPF) is used to simulate surface and subsurface runoff from the drainage basin on the basis of precipitation measured by the network of 25 precipitation gages maintained by the Illinois State Water Survey as part of the accounting of flows diverted from the Lake Michigan watershed by the State of Illinois (see, for example, Westcott, 2002). The output flows from HSPF are input to the Special Contributing Area Loading Program (SCALP) which simulates the flows in the major interceptor sewers in the Chicago area. The output from the SCALP program is then input to the Tunnel Network (TNET) model, which determines which potential CSOs can enter the TARP system via the drop shafts and which will go directly to the CAWS as CSOs. A detailed discussion of the USACE models is given in Espey et al. (2004). The simulated CSO flows obtained from the USACE models then were aggregated to determine the total inflow to the CAWS from each of the 43 representative CSO locations (see Chapter 3).

For the Baseline conditions the USACE models were run again for each of WYs 2001, 2003, and 2008 for the case of the Thornton Reservoir and the McCook Reservoir Stage 1 in operation. The simulated CSO flows obtained from the USACE models for the case of the reservoirs in operation then were aggregated to determine the total inflow to the CAWS from each of the 43 representative CSO locations. These CSO inflows then were input to the DUFLOW model at each of the representative CSO locations. The difference in CSO inflows with and without reservoirs then was summed to determine a portion of the inflow to the Thornton and McCook Stage 1 reservoirs. This stored water is assumed to be pumped out from the reservoirs as capacity is available at the Stickney WRP for McCook or Calumet WRPs for Thornton. Typically the pump out of the reservoir is started after the tunnels have been pumped out. The pump out of the tunnels is indicated in the flow record from the WRPs by the periods when the WRP is discharging at or above its capacity (430 million gallons per day [mgd] for the Calumet WRP and 1200 mgd for the Stickney WRP). In actual operations flows above the capacity of the plants occur when the tunnels are being drained, but in this study the rate at which the reservoirs are drained is the difference between the actual inflows to the WRP and its capacity. Also, it is assumed that the increased effluent flow has the same quality (i.e. constituent concentrations) as for the actual effluent on that day. That is, the WRP performance is assumed to be unaffected by the increased flow. Similarly, the concentrations of pollutants in the CSOs are considered the same as for the actual conditions in WYs 2001, 2003, and 2008 (see Chapter 4 and Melching et al. (2010)). Thus, it is assumed that the reduction in "first flush effects" and subsequent reduction in the concentration of pollutants in the CSOs accomplished by the TARP tunnels adequately describes the capture of pollutants by the reservoirs.

For most locations and events the CSO flows after the reservoirs were operational were lower than for the case without reservoirs. However, for some events and locations (particularly the upstream locations along the NSC and NBCR) the CSO flows increased after the reservoirs were operational compared to the case without reservoirs. One cause of these increases, is that when only the TARP tunnels are storing water they are drained more quickly than when both the tunnels and reservoirs must be drained. Thus, if two events occur closely in time, without a reservoir to drain the tunnels may be empty when the second event occurs and the CSOs are reduced as the tunnels fill; conversely, if the tunnels and associated reservoir must be drained there may be no space in the tunnels and the combined sewer flows from the second event overflow to the CAWS. A second cause of these increases in post-reservoir CSOs, is that the larger available storage may change the sequence of allowing downstream combined sewer flows to enter the tunnels. With limited storage space available (i.e. no reservoir), the drop shafts for the downstream locations may have been closed earlier in the simulations to reserve some storage space for upstream locations. With more storage space available, larger amounts of downstream flows are allowed to enter the tunnels leading to some blockage to upstream flows (that occur later because of the southwest to northeast storm movement) entering the tunnels as the water flows to the reservoirs. Whereas all decreases in CSO flows are assumed to be stored in the appropriate reservoir, the increases in flows are not considered subtractions from the flows going to the reservoirs. Thus, the volume pumped out of the reservoirs and subsequent increase in WRP flows is higher than might truly be the case. This is done in order to have a conservative (slightly high) estimate of the flows in the CAWS for the post-reservoir case.

Several CSOs are present on the North Branch Chicago River upstream of Albany Avenue and the Little Calumet River upstream of the USGS gage at South Holland whose flows will be affected by the operation of the McCook Reservoir Stage 1 and Thornton Reservoir, respectively. For these locations the difference in the CSO flows from the USACE model runs with and without the reservoirs was determined and summed for the CSO locations upstream of each USGS streamflow gage—Albany Avenue and South Holland. If the difference was less than the measured flow, it was subtracted from the 1 hr flows measured by the USGS and the difference was considered an inflow to the appropriate reservoir. If the difference was greater that the measured flow at the Albany Avenue or South Holland gages, as appropriate, the inflow was set to zero, and the streamflow value was considered an inflow to the appropriate reservoir. Again, for certain locations and events the CSO flows were greater for the with reservoir case than for the without reservoir case. In this case, the difference was added to the measured streamflow entering the CAWS, but the difference was not considered a subtraction from the inflow to the appropriate reservoir for the reasons previously described.

Finally, the flows from the CSO pumping stations are affected by the operation of the TARP reservoirs. For the North Branch, Racine Avenue, and 125th Street pumping stations the percentage decrease in CSO flows for the areas tributary to these pumping stations were determined from the USACE models for the case of the reservoirs in operation relative to the case without reservoirs. The percentage reductions then were applied to the CSO flows for these pumping stations estimated from pump capacity and operations. The flow reductions at these pumping stations were considered inflows to the appropriate reservoir.

For the 95th Street and 122nd Street pumping stations (discharging to the Calumet River), comparison of simulated flows with and without the Thornton Reservoir in operation are not available. Thus, other assumptions were made regarding the effects of the Thornton Reservoir on the operation of these pumping stations. For WYs 2001 and 2003, the 95th Street and 122nd Street pumping stations were operated less often than the 125th Street Pumping Station, but when they were turned on, they operated earlier than the 125th Street Pumping Station. Thus, it was assumed that the effluent from the 95th Street and 122nd Street pumping stations would completely enter the Calumet TARP system before that from the 125th Street Pumping Station. Thus, for WYs 2001 and 2003 the flows from the 95th Street and 122nd Street pumping stations were set to zero, and the flows were added to the inflow to the Thornton Reservoir. For WY 2008, however, the 95th Street and 122nd Street pumping stations were turned on (in actual practice) after the simulations indicated that the Thornton Reservoir was full. Thus, because the reservoir is full the effluent from these pumping stations was assumed to flow directly into the Calumet River unaltered by the operation of the Thornton Reservoir.

Water Year 2001—Tables 5.1 and 5.2 list the percentage of CSO flows captured by the McCook Reservoir Stage 1 and Thornton Reservoir, respectively. On average, well above 90% of the total without reservoir CSO flows for WY 2001 are captured and stored by the reservoirs, especially for the Calumet TARP system which captures more the 99.8% of the without reservoir CSO flows.

Figure 5.1 shows the sum of the gravity CSOs to the Chicago River system for the current (no reservoir) and the Baseline (with reservoir) conditions. With the McCook Reservoir Stage 1 in operation, only August 2nd, experiences substantial CSO flows and very small CSOs occur on July 25th, August 30th, and September 18th. Figure 5.1 and Table 5.1 clearly show the effectiveness of the McCook Reservoir Stage 1.

Table 5.1. Percentage of combined sewer overflows (CSOs) captured by the McCook Reservoir Stage 1 for Water Years 2001, 2003, and 2008.

Water Year	Gravity CSOs	Racine Avenue	North Branch
2001	90.0	98.3	99.5
2003	83.6	95.7	84.4
2008	60.2	85.4	77.1

Table 5.2. Percentage of combined sewer overflows (CSOs) captured by the Thornton Reservoir for Water Years 2001, 2003, and 2008.

Water Year	Gravity CSOs	125th Street	95th Street	122nd Street
2001	99.8	100.0	100.0	100.0
2003	95.7	96.8	100.0	100.0
2008	49.9	76.5	0.0	0.0

Figure 5.2 shows the simulated storage in the McCook Reservoir Stage 1 for Baseline conditions and the flows from the Stickney WRP under current (actual) and Baseline conditions (reflecting the pumping out of the reservoir). It should be noted that there is still water in the reservoir at the end of the year that will affect the flow balance when comparing current and Baseline conditions.

Figure 5.3 shows the sum of the gravity CSOs to the Calumet River system for the current (no reservoir) and the Baseline (with reservoir) conditions. With the Thornton Reservoir in operation, only very small CSOs occur on August 2nd and 25th. Figure 5.3 and Table 5.2 clearly show the effectiveness of the Thornton Reservoir. Figure 5.4 shows the simulated storage in the Thornton Reservoir for Baseline conditions and the flows from the Calumet WRP under current (actual) and Baseline conditions (reflecting the pumping out of the reservoir).

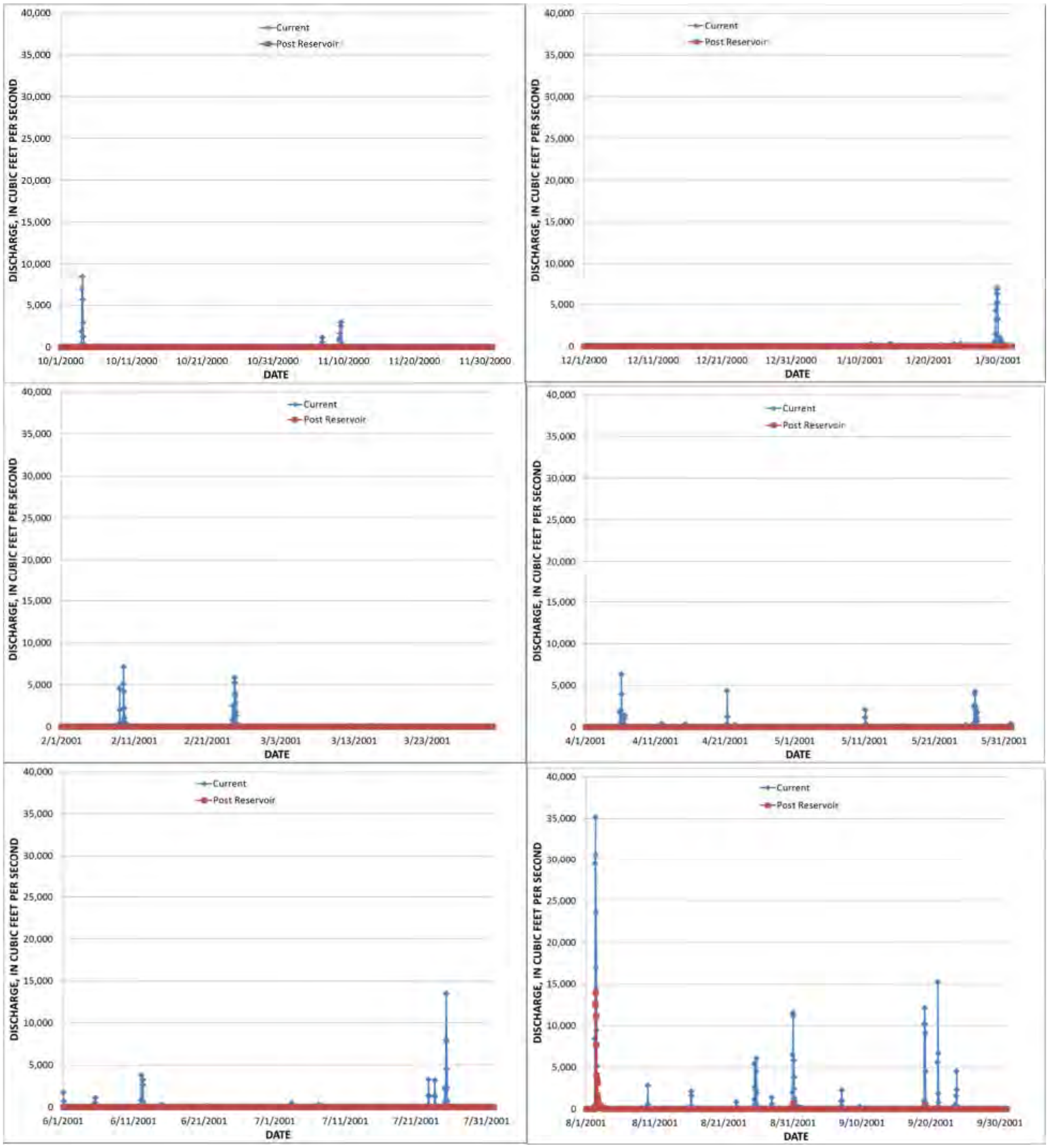

Figure 5.1. Sum of combined sewer overflows to the Chicago River system under current (no reservoir) conditions and Baseline (McCook Reservoir Stage 1 operational, i.e. post reservoir) conditions for Water Year 2001.

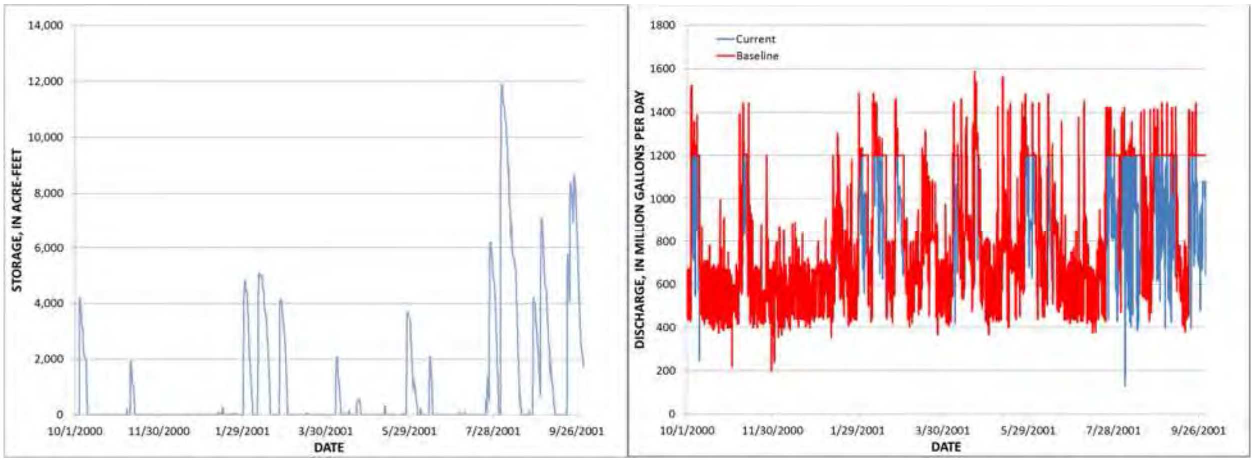

Figure 5.2. Storage in the McCook Reservoir Stage 1 for Baseline conditions (left) and effluent from the Stickney Water Reclamation Plant for current (no reservoir) and Baseline conditions for Water Year 2001.

<u>Water Year 2003</u>—Tables 5.1 and 5.2 list the percentage of CSO flows captured by the McCook Reservoir Stage 1 and Thornton Reservoir, respectively. On average, well above 83% of the total without reservoir CSO flows for WY 2003 are captured and stored by the reservoirs, especially for the Calumet TARP system which captures more the 95% of the without reservoir CSO flows. It may seem odd that the reservoirs capture higher percentages of CSO flows for the representative "normal" year (WY 2001) that for the representative "wet" year (WY 2003). Whereas WY 2003 is substantially drier than WY 2001, early May 2003 experienced a series of storms that filled the Mainstream tunnels and McCook Reservoir Stage 1 and late July experienced a series of several storms that filled the Calumet tunnels and Thornton Reservoir such that, in each case, only small portions of the combined sewer flows from the later storms can be captured as can be seen in Figures 5.5-5.8.

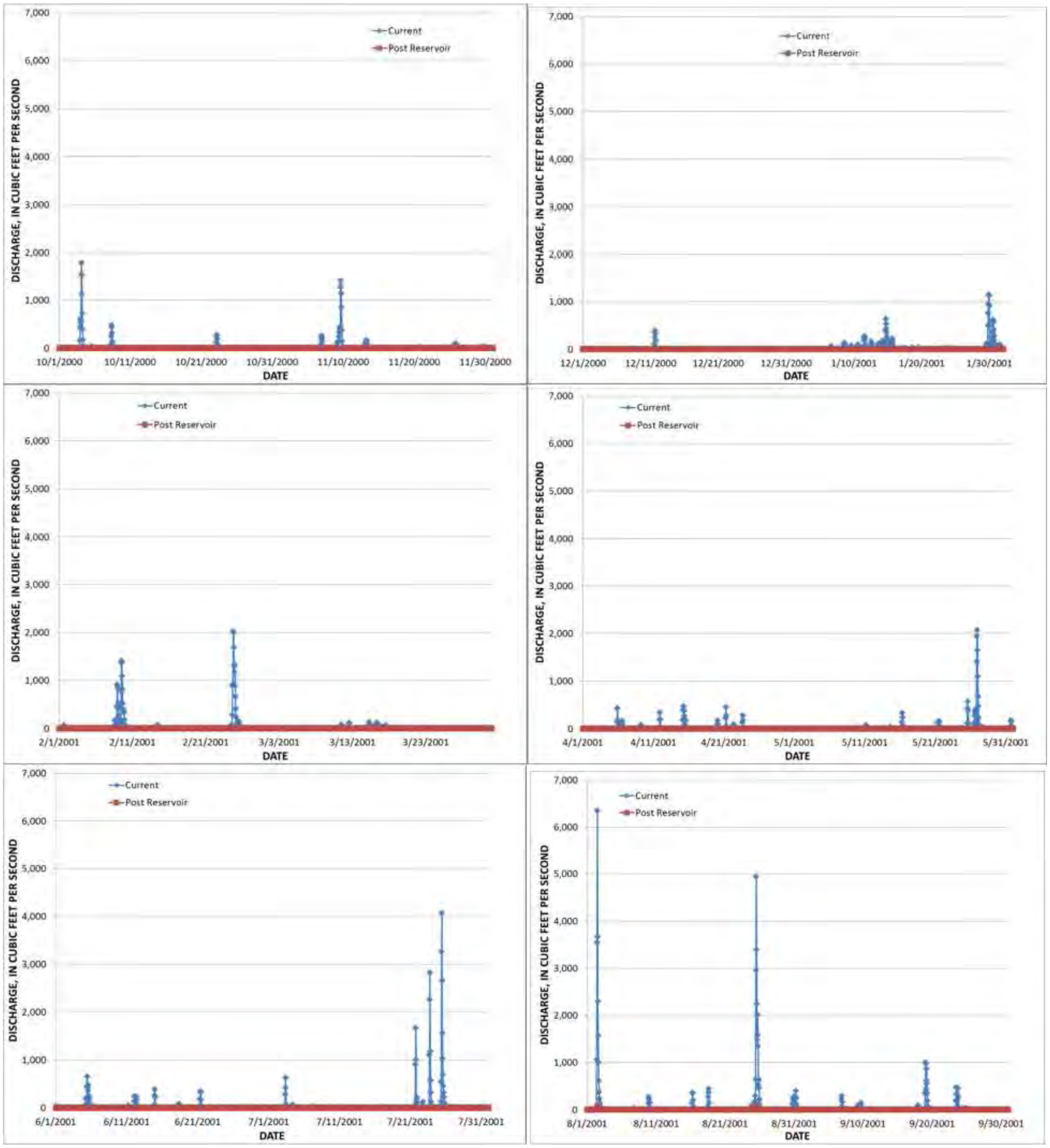

Figure 5.3. Sum of combined sewer overflows to the Calumet River system under current (no reservoir) conditions and Baseline (Thornton Reservoir operational, i.e. post reservoir) conditions for Water Year 2001.

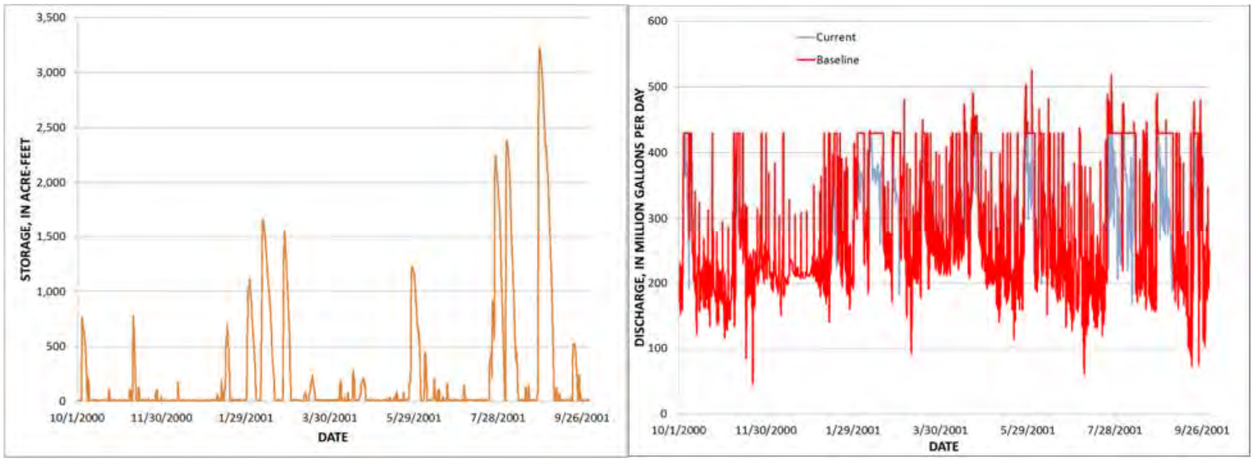

Figure 5.4. Storage in the Thornton Reservoir for Baseline conditions (left) and effluent from the Calumet Water Reclamation Plant for current (no reservoir) and Baseline conditions for Water Year 2001.

Figure 5.5 shows the sum of the gravity CSOs to the Chicago River system for the current (no reservoir) and the Baseline (with reservoir) conditions. With the McCook Reservoir Stage 1 in operation, May 5th, 9th, and 11th experience substantial CSO flows, and very small CSOs occur on May 1st and 10th. Outside of May no CSOs occur with the McCook Reservoir Stage 1 in operation. Figure 5.5 and Table 5.1 clearly show the effectiveness of the McCook Reservoir Stage 1. Figure 5.6 shows the simulated storage in the McCook Reservoir Stage 1 for Baseline conditions and the flows from the Stickney WRP under current (actual) and Baseline conditions (reflecting the pumping out of the reservoir).

Figure 5.7 shows the sum of the gravity CSOs to the Calumet River system for the current (no reservoir) and the Baseline (with reservoir) conditions. With the Thornton Reservoir in operation, substantial CSOs occur on July 17th and 27th and only very small CSOs occur on August 11th. Figure 5.7 and Table 5.2 clearly show the effectiveness of the Thornton Reservoir. Figure 5.8 shows the simulated storage in the Thornton Reservoir for Baseline conditions and the flows from the Calumet WRP under current (actual) and Baseline conditions (reflecting the pumping out of the reservoir).

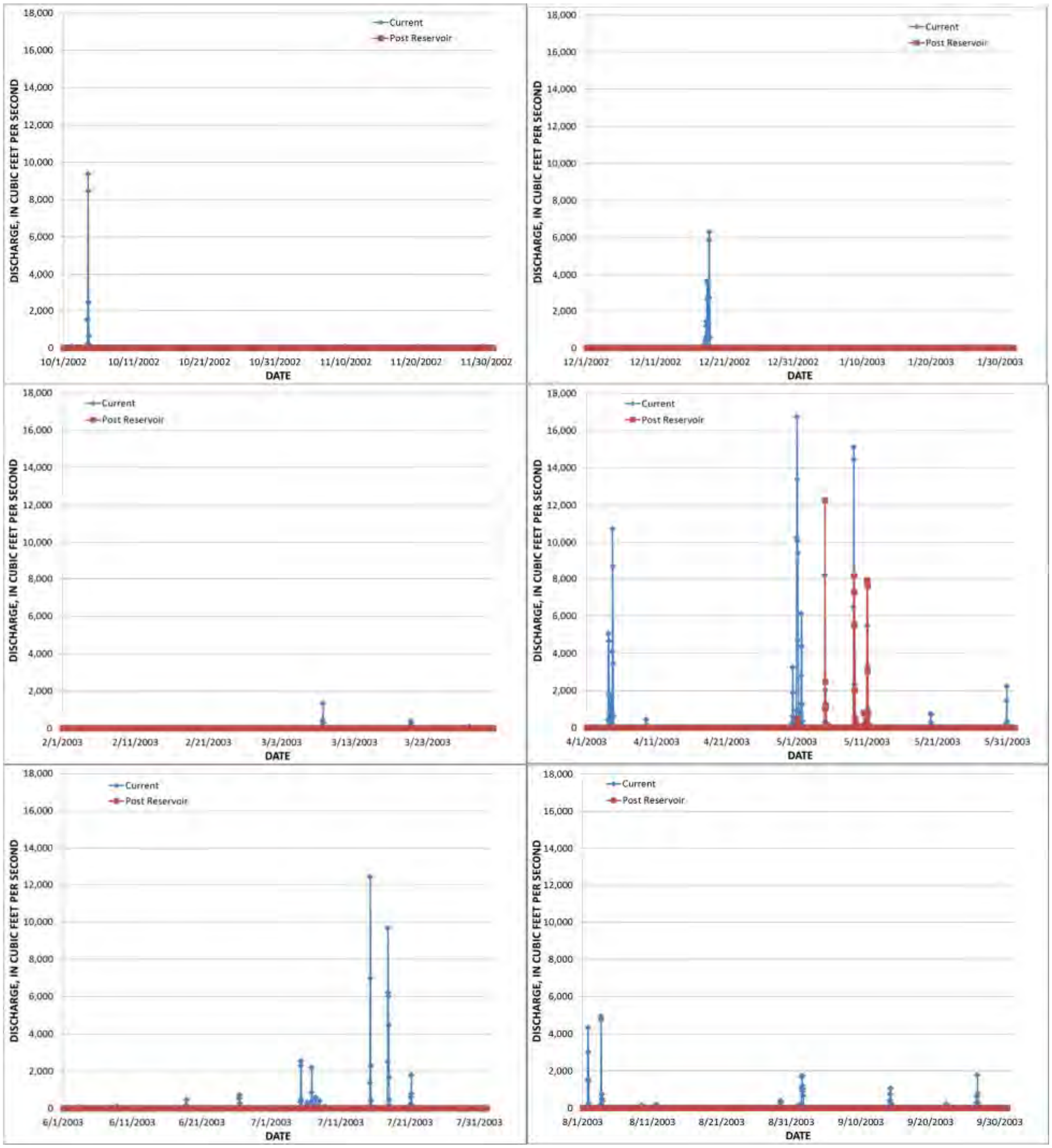

Figure 5.5. Sum of combined sewer overflows to the Chicago River system under current (no reservoir) conditions and Baseline (McCook Reservoir Stage 1 operational, i.e. post reservoir) conditions for Water Year 2003.

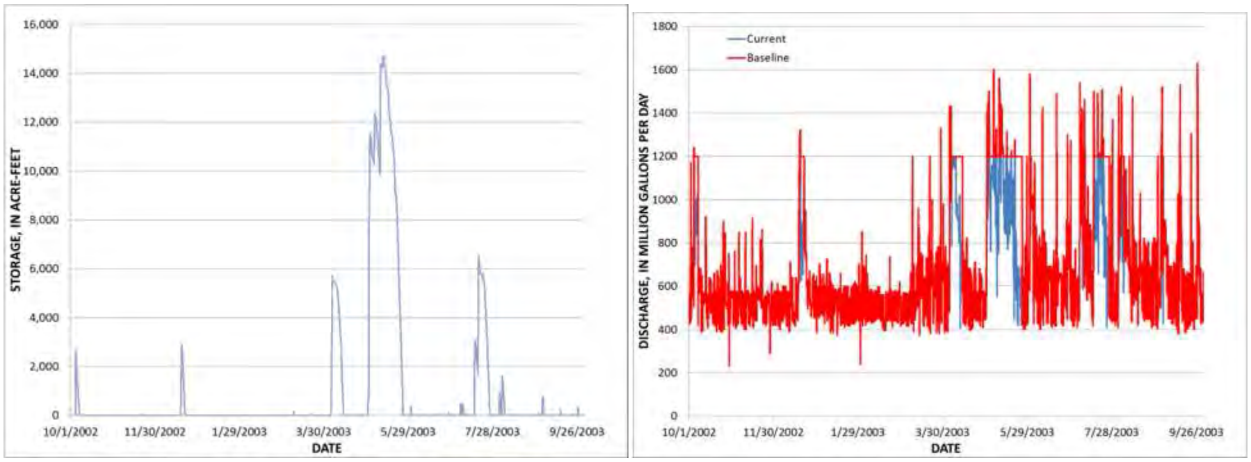

Figure 5.6. Storage in the McCook Reservoir Stage 1 for Baseline conditions (left) and effluent from the Stickney Water Reclamation Plant for current (no reservoir) and Baseline conditions for Water Year 2003.

<u>Water Year 2008</u>—Tables 5.1 and 5.2 list the percentage of CSO flows captured by the McCook Reservoir Stage 1 and Thornton Reservoir, respectively. On average, above 50% of the total without reservoir CSO flows for WY 2008 are captured and stored by the reservoirs. The percentage captured for WY 2008 is far smaller than for WYs 2001 and 2003 because of the unique sequence of storms in early to mid-September 2008. The storms of September 4th and 8th fill the reservoirs and tunnels, such that very little of the combined sewer flows from the storms of September 13th to 16th are captured in reservoirs and the CSOs discharge to the CAWS almost the same as they did for the no reservoir case for this the largest storm in the three year study period as can be seen in Figures 5.9-5.12.

Figure 5.9 shows the sum of the gravity CSOs to the Chicago River system for the current (no reservoir) and the Baseline (with reservoir) conditions. With the McCook Reservoir Stage 1 in operation, February 17th, August 5th, and September 4th and 8th experience substantial CSO

flows, and September 13th to 16th experience massive CSO flows. Consideration of the conditions in WY 2008 clearly shows the need for Stage 2 of the McCook Reservoir.

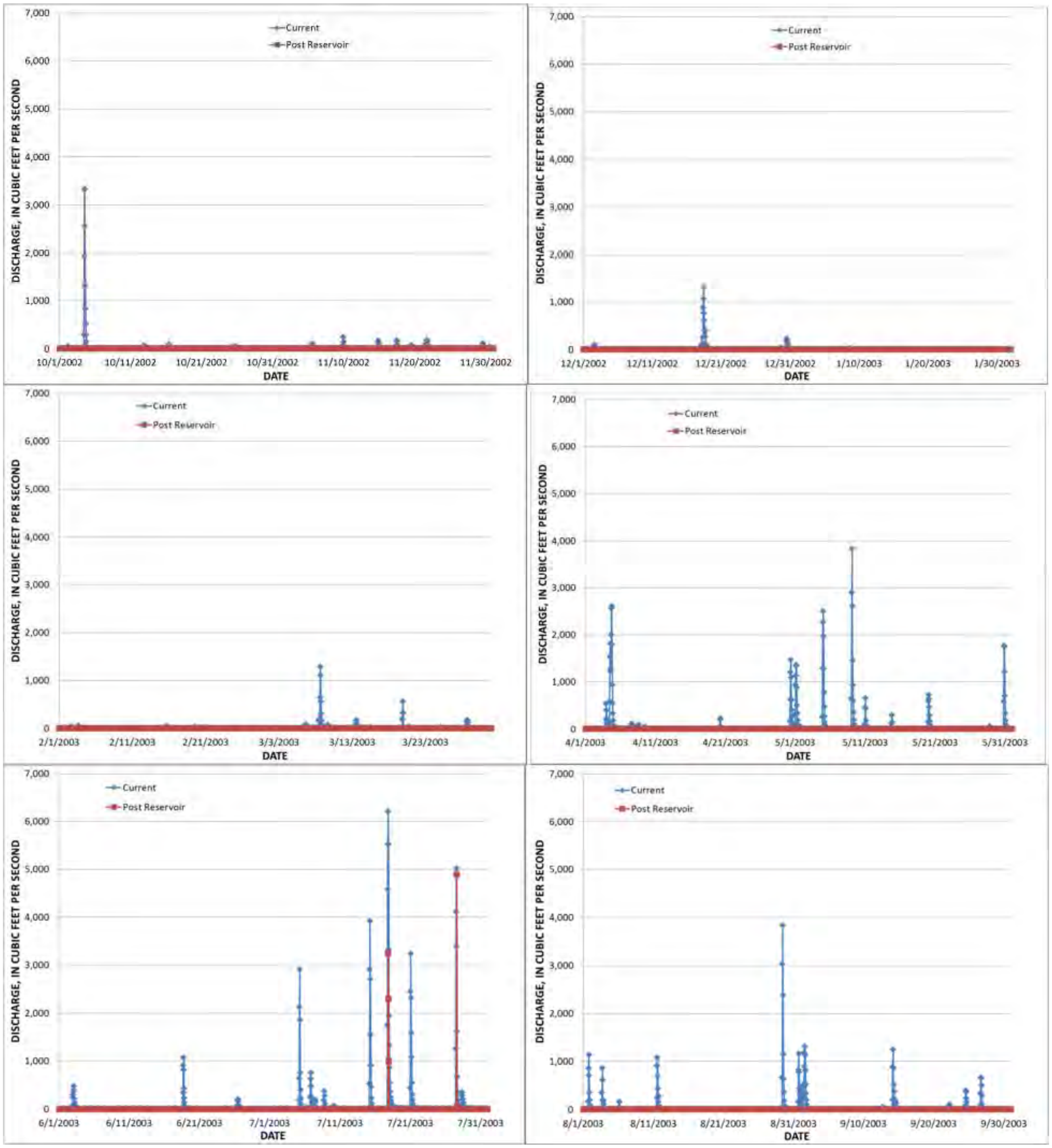

Figure 5.7. Sum of combined sewer overflows to the Calumet River system under current (no reservoir) conditions and Baseline (Thornton Reservoir operational, i.e. post reservoir) conditions for Water Year 2003.

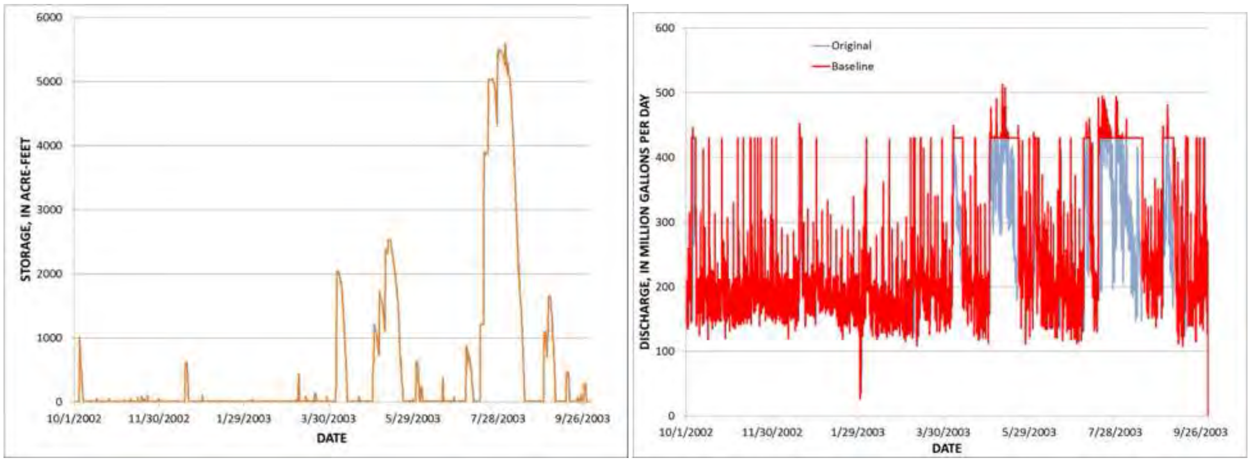

Figure 5.8. Storage in the Thornton Reservoir for Baseline conditions (left) and effluent from the Calumet Water Reclamation Plant for current (no reservoir) and Baseline conditions for Water Year 2003.

Figure 5.10 shows the simulated storage in the McCook Reservoir Stage 1 for Baseline conditions and the flows from the Stickney WRP under current (actual) and Baseline conditions (reflecting the pumping out of the reservoir). It should be noted that there is still water in the reservoir at the end of the year that will affect the flow balance when comparing current and Baseline conditions.

Figure 5.11 shows the sum of the gravity CSOs to the Calumet River system for the current (no reservoir) and the Baseline (with reservoir) conditions. With the Thornton Reservoir in operation, very small CSOs occur on January 7th, February 17th, May 11th, August 4th, and September 4th, and then September 13th to 16th experience massive CSO flows. Figure 5.11 and Table 5.2 clearly show the limitations in effectiveness of the Thornton Reservoir.

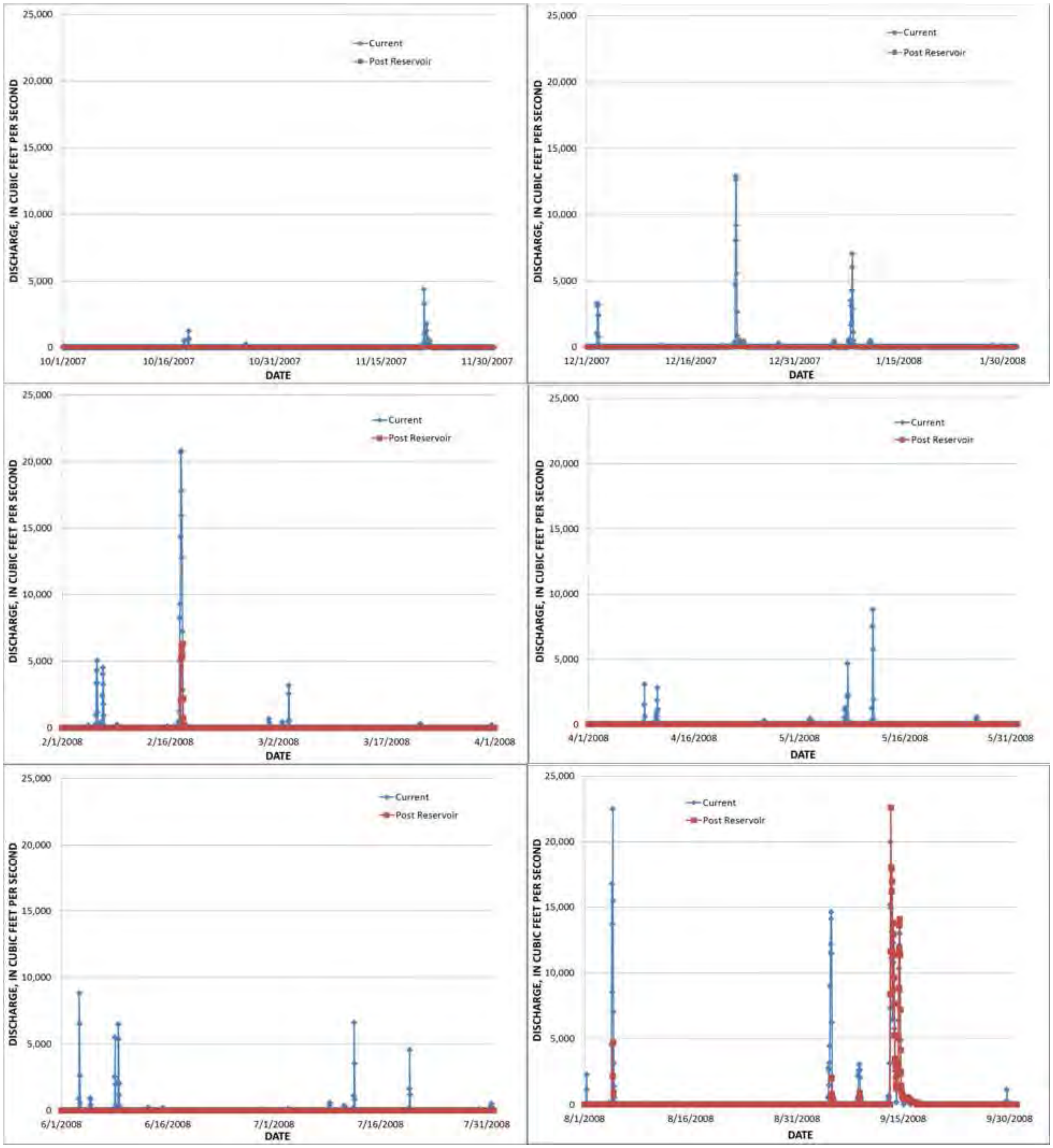

Figure 5.9. Sum of combined sewer overflows to the Chicago River system under current (no reservoir) conditions and Baseline (McCook Reservoir Stage 1 operational, i.e. post reservoir) conditions for Water Year 2008.

Figure 5.12 shows the simulated storage in the Thornton Reservoir for Baseline conditions and the flows from the Calumet WRP under current (actual) and Baseline conditions (reflecting the pumping out of the reservoir). It should be noted that there is still water in the reservoir at the end of the year that will affect the flow balance when comparing current and Baseline conditions.

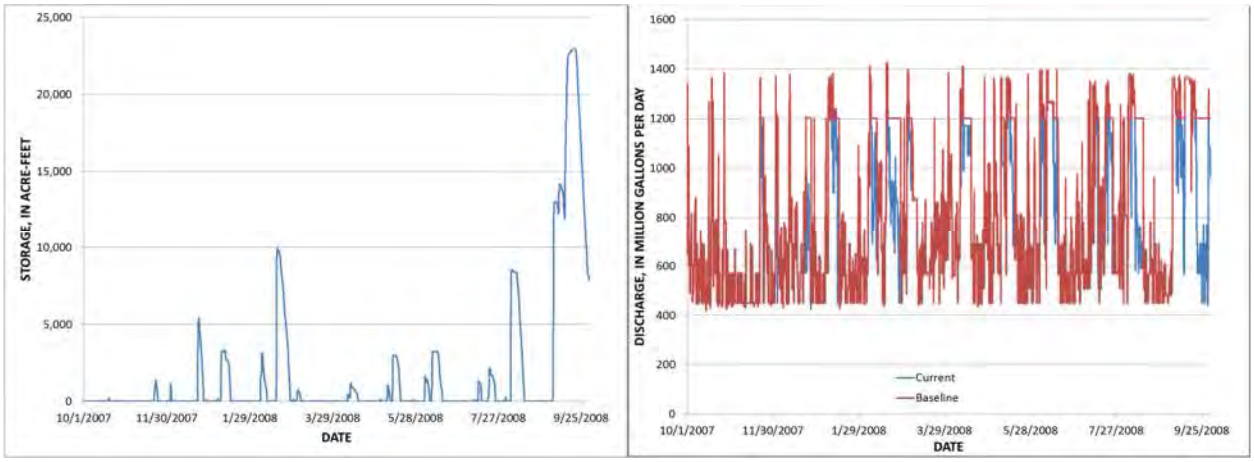

Figure 5.10. Storage in the McCook Reservoir Stage 1 for Baseline conditions (left) and effluent from the Stickney Water Reclamation Plant for current (no reservoir) and Baseline conditions for Water Year 2008.

5.1.2 Future Conditions

For the Future conditions the USACE models were run again for each of WYs 2001, 2003, and 2008 for the case of the McCook Reservoir Stages 1 and 2 in operation. The simulated CSO flows obtained from the USACE models for the case of the reservoir in operation then were aggregated to determine the total inflow to the CAWS from each of the 43 representative CSO locations. These CSO inflows then were input to the DUFLOW model at each of the representative CSO locations. The difference in CSO inflows with and without reservoirs then was summed to determine a portion of the inflow to the McCook Reservoirs. This stored water is assumed to be pumped out from the reservoirs as capacity is available at the Stickney WRP in the same way as was done for the Baseline conditions. The performance of the Thornton

Reservoir is identical for the Baseline and Future conditions because the Thornton Reservoir will be fully completed in 2015.

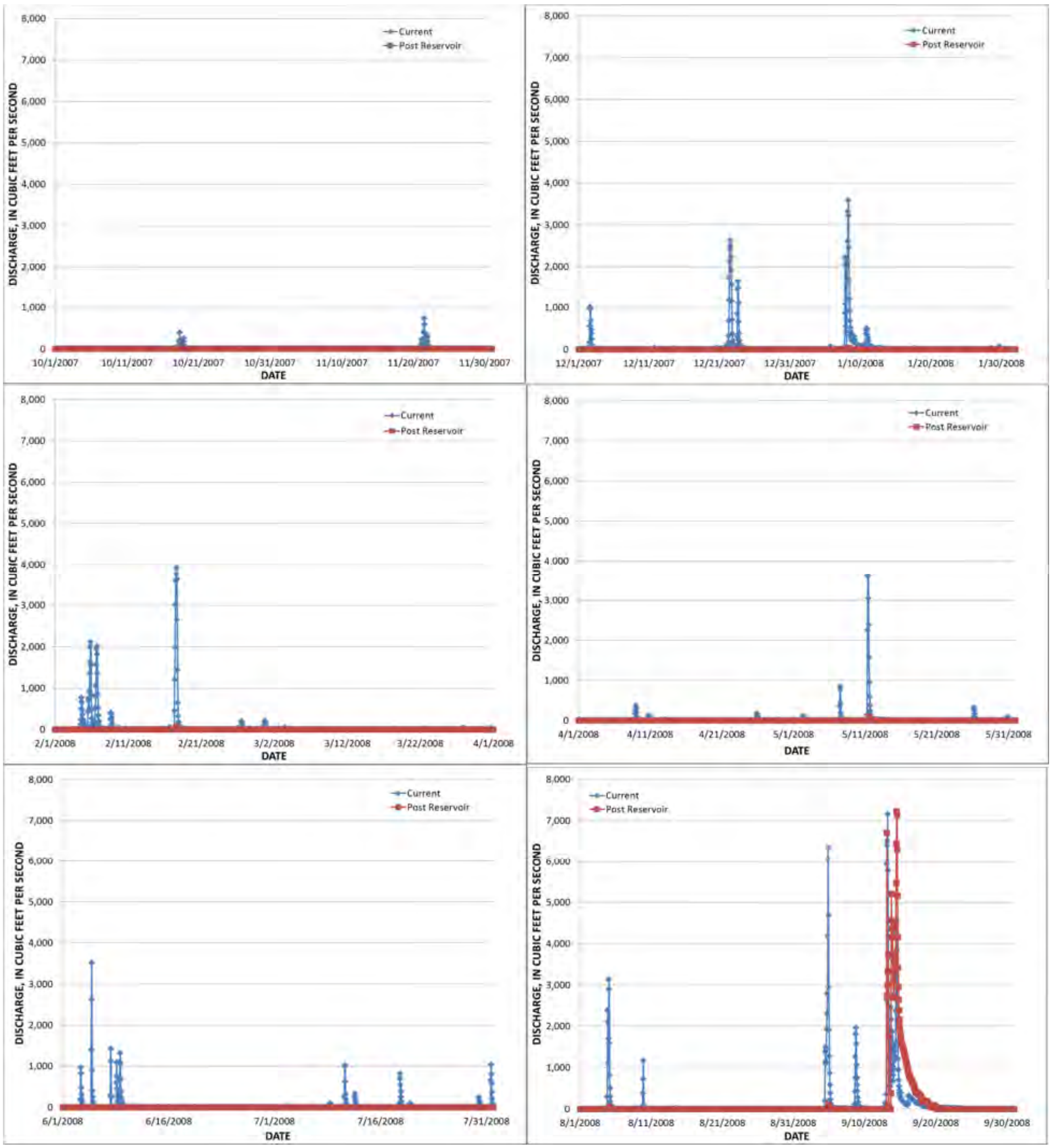

Figure 5.11. Sum of combined sewer overflows to the Calumet River system under current (no reservoir) conditions and Baseline (Thornton Reservoir operational, i.e. post reservoir) conditions for Water Year 2008.

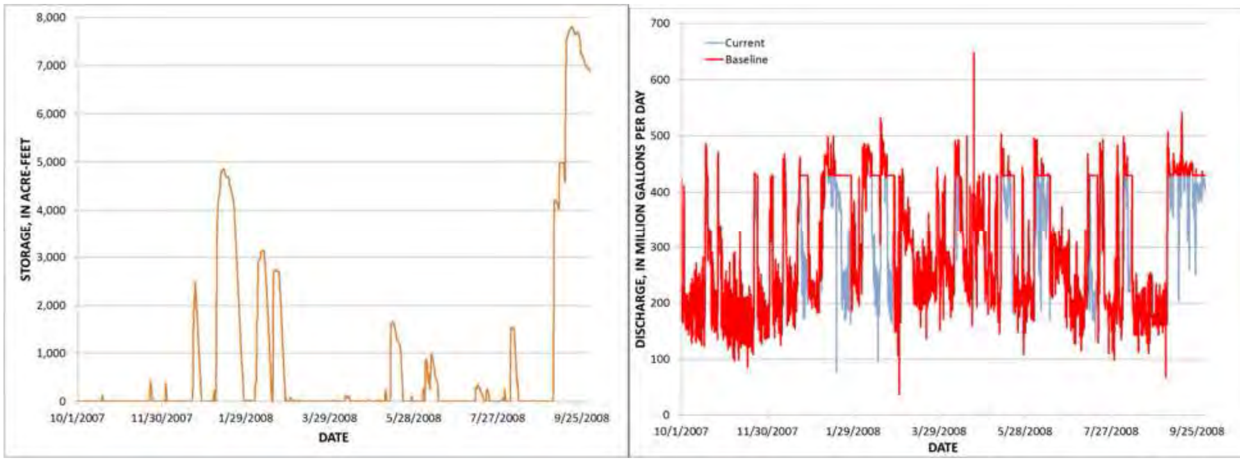

Figure 5.12. Storage in the Thornton Reservoir for Baseline conditions (left) and effluent from the Calumet Water Reclamation Plant for current (no reservoir) and Baseline conditions for Water Year 2008.

As was the case for the Baseline conditions, for most locations and events the CSO flows after the McCook Reservoir Stage 2 becomes operational were lower than for the case without reservoirs. However, for some events and locations (particularly the upstream locations along the NSC and NBCR) the CSO flows increased after the reservoirs were operational compared to the case without reservoirs and/or compared to the case of only McCook Reservoir Stage 1 being operational. The causes of these unexpected flow increases are the same as for the unexpected flow increases obtained when comparing the no reservoir case to the McCook Reservoir Stage 1 case. The changes in flows on the North Branch Chicago River above Albany Avenue for the Future conditions were handled in the same way as for the Baseline conditions. Finally, the changes in flows at the Racine Avenue and North Branch pumping stations for the Future conditions were handled in the same way as for the Baseline conditions.

Water Year 2001—Table 5.3 lists the percentage of CSO flows captured by the McCook Reservoir Stages 1 and 2. On average, well above 94% of the total without reservoir CSO flows for WY 2001 are captured and stored by the McCook Reservoir Stages 1 and 2.

Figure 5.13 shows the sum of the gravity CSOs to the Chicago River system for the current (no reservoir), Baseline (McCook Reservoir Stage 1), and Future (McCook Reservoir Stages 1 and 2) conditions. The results of the Baseline and Future conditions differ substantially only for August, thus, only the results for August are shown in Figure 5.13. For the storm of August 2, 2001, the peak discharge of CSOs is nearly the same for the Baseline and Future conditions, but over the entire event a substantially smaller total CSO volume occurs for the Future condition with the full McCook Reservoir operational.

Figure 5.14 shows the simulated storage in the McCook Reservoir Stages 1 and 2 for Future conditions and the flows from the Stickney WRP under current (actual) and Future conditions (reflecting the pumping out of the reservoir). It should be noted that there is still water in the reservoir at the end of the year that will affect the flow balance when comparing current and Baseline conditions.

Table 5.3. Percentage of combined sewer overflows (CSOs) captured by the McCook Reservoir Stages 1 and 2 for Water Years 2001, 2003, and 2008.

Water Year	Gravity CSOs	Racine Avenue	North Branch
2001	94.0	99.3	99.7
2003	96.4	100.0	97.5
2008	73.2	95.0	89.0

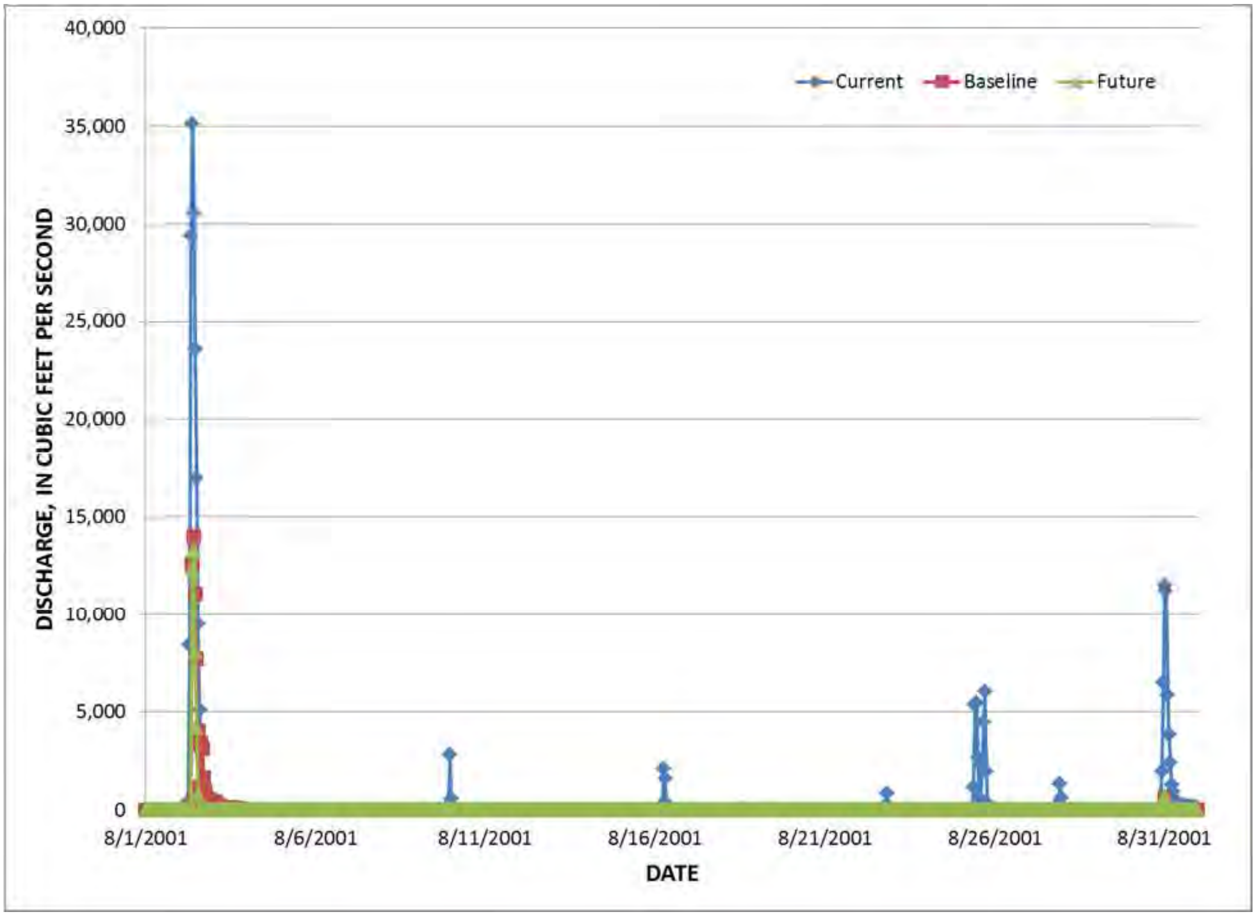

Figure 5.13. Sum of combined sewer overflows to the Chicago River system under current (no reservoir) conditions, Baseline (McCook Reservoir Stage 1 operational), and Future (McCook Reservoir Stages 1 and 2 operational) conditions for August 2001.

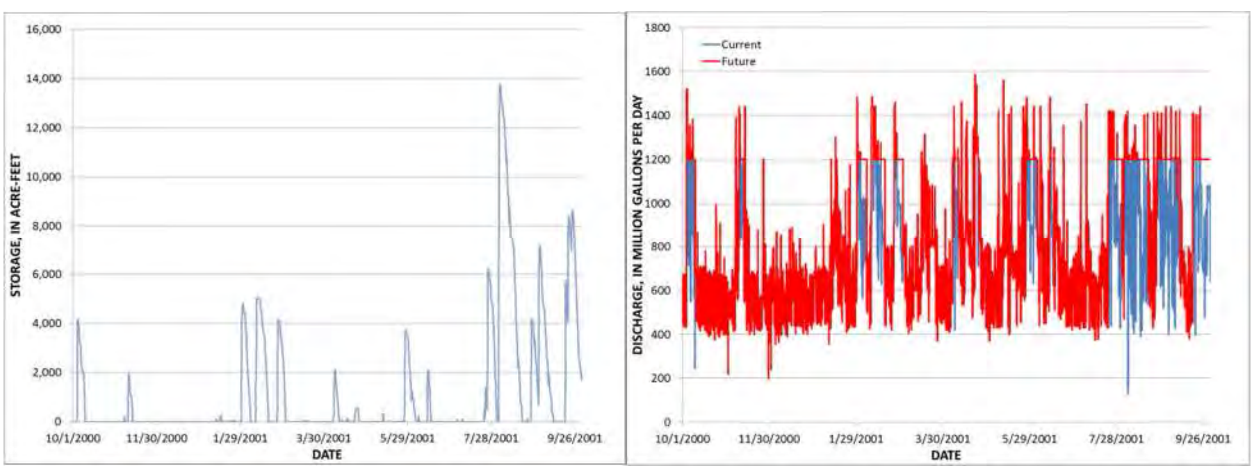

Figure 5.14. Storage in the McCook Reservoir Stages 1 and 2 for Future conditions (left) and effluent from the Stickney Water Reclamation Plant for current (no reservoir) and Future conditions for Water Year 2001.

Water Year 2003—Table 5.3 lists the percentage of CSO flows captured by the McCook Reservoir Stages 1 and 2. On average, well above 96% of the total without reservoir CSO flows for WY 2003 are captured and stored by the reservoir. The addition of McCook Reservoir Stage 2 improves the CSO capture 12.8, 4.3, and 13.1 percentage points for gravity, Racine Avenue Pumping Station, and North Branch Pumping Station CSOs, respectively, for the Future conditions compared to the Baseline conditions.

Figure 5.15 shows the sum of the gravity CSOs to the Chicago River system portion of the CAWS for the current (no reservoir), Baseline (McCook Reservoir Stage 1), and Future (McCook Reservoir Stages 1 and 2) conditions. The results of the Baseline and Future conditions differ substantially only for early May, thus, only the results for April 30th to May 12th are shown in Fig. 5.13. For the storm of April 30th to May 1st, the sum of CSOs is larger for the Future conditions than for the Baseline conditions although still far less than for the no reservoir (current) conditions. However, for the storms of May 5th, 9th, and 11th the Future condition yields greatly reduced CSOs compared to the Baseline condition leading to the great improvement in CSO capture previously discussed. The results shown in Table 5.3 and Figure 5.15 clearly show the value of Stage 2 of the McCook Reservoir. Figure 5.16 shows the simulated storage in the McCook Reservoir Stages 1 and 2 for Future conditions and the flows from the Stickney WRP under current (actual) and Future conditions (reflecting the pumping out of the reservoir).

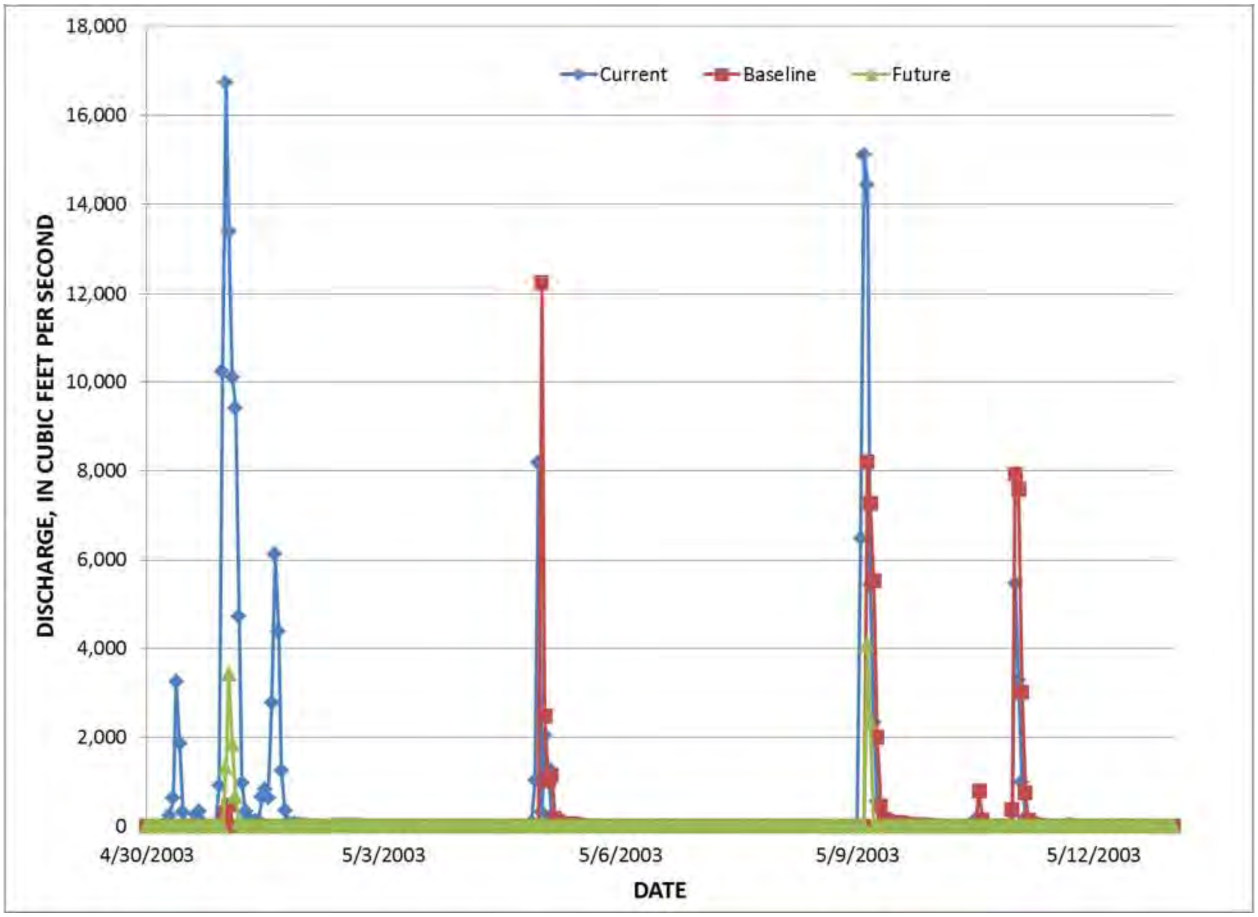

Figure 5.15. Sum of combined sewer overflows to the Chicago River system under current (no reservoir) conditions, Baseline (McCook Reservoir Stage 1 operational), and Future (McCook Reservoir Stages 1 and 2 operational) conditions for April 30 to May 12, 2003.

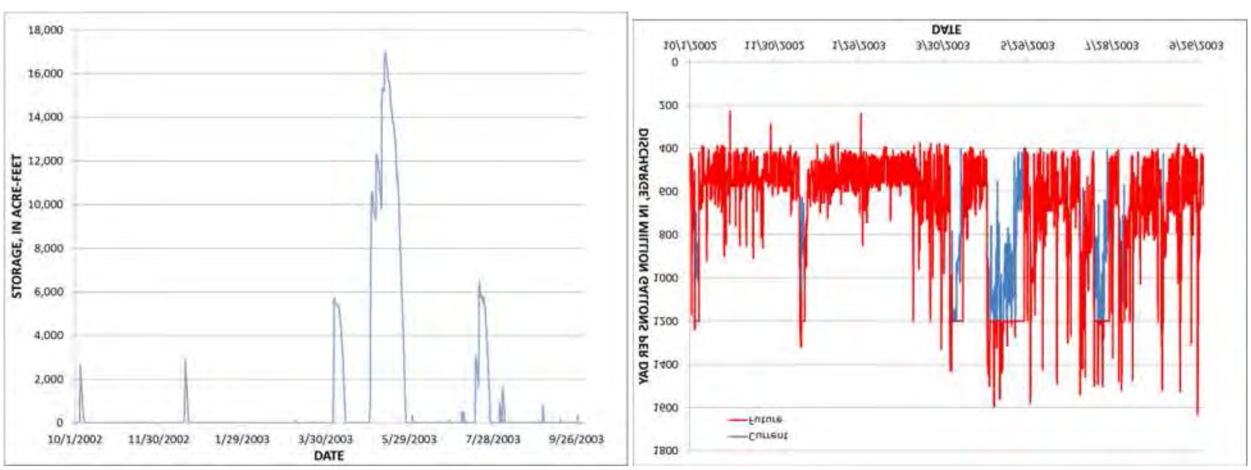

Figure 5.16. Storage in the McCook Reservoir Stages 1 and 2 for Future conditions (left) and effluent from the Stickney Water Reclamation Plant for current (no reservoir) and Future conditions for Water Year 2003.

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Water Year 2008—Table 5.3 lists the percentage of CSO flows captured by the McCook Reservoir Stages 1 and 2. On average, above 73% of the total without reservoir CSO flows for WY 2008 are captured and stored by the reservoir. The addition of McCook Reservoir Stage 2 improves the CSO capture 13.0, 9.6, and 11.9 percentage points for gravity, Racine Avenue Pumping Station, and North Branch Pumping Station CSOs, respectively, for the Future conditions compared to the Baseline Conditions.

Figure 5.17 shows the sum of the gravity CSOs to the Chicago River system portion of the CAWS for the current (no reservoir), Baseline (McCook Reservoir Stage 1), and Future (McCook Reservoir Stages 1 and 2) conditions. The results of the Baseline and Future conditions differ substantially only for December 2007, February 2008, August 2008, and September 2008, thus, only the results for these months are shown in Fig. 5.17. For the storms of December 22nd, February 17th, August 5th, and September 4th, the sum of CSOs is larger for the Future conditions than for the Baseline conditions although still far less than for the no reservoir (current) conditions. However, for the storm of September 13th the Future condition yields greatly reduced CSOs compared to the Baseline condition leading to the great improvement in CSO capture previously described. The results shown in Table 5.3 and Figure 5.17 clearly show the value of Stage 2 of the McCook Reservoir.

Figure 5.18 shows the simulated storage in the McCook Reservoir Stages 1 and 2 for Future conditions and the flows from the Stickney WRP under current (actual) and Future conditions (reflecting the pumping out of the reservoir). It should be noted that there is still water in the reservoir at the end of the year that will affect the flow balance when comparing current and Baseline conditions.

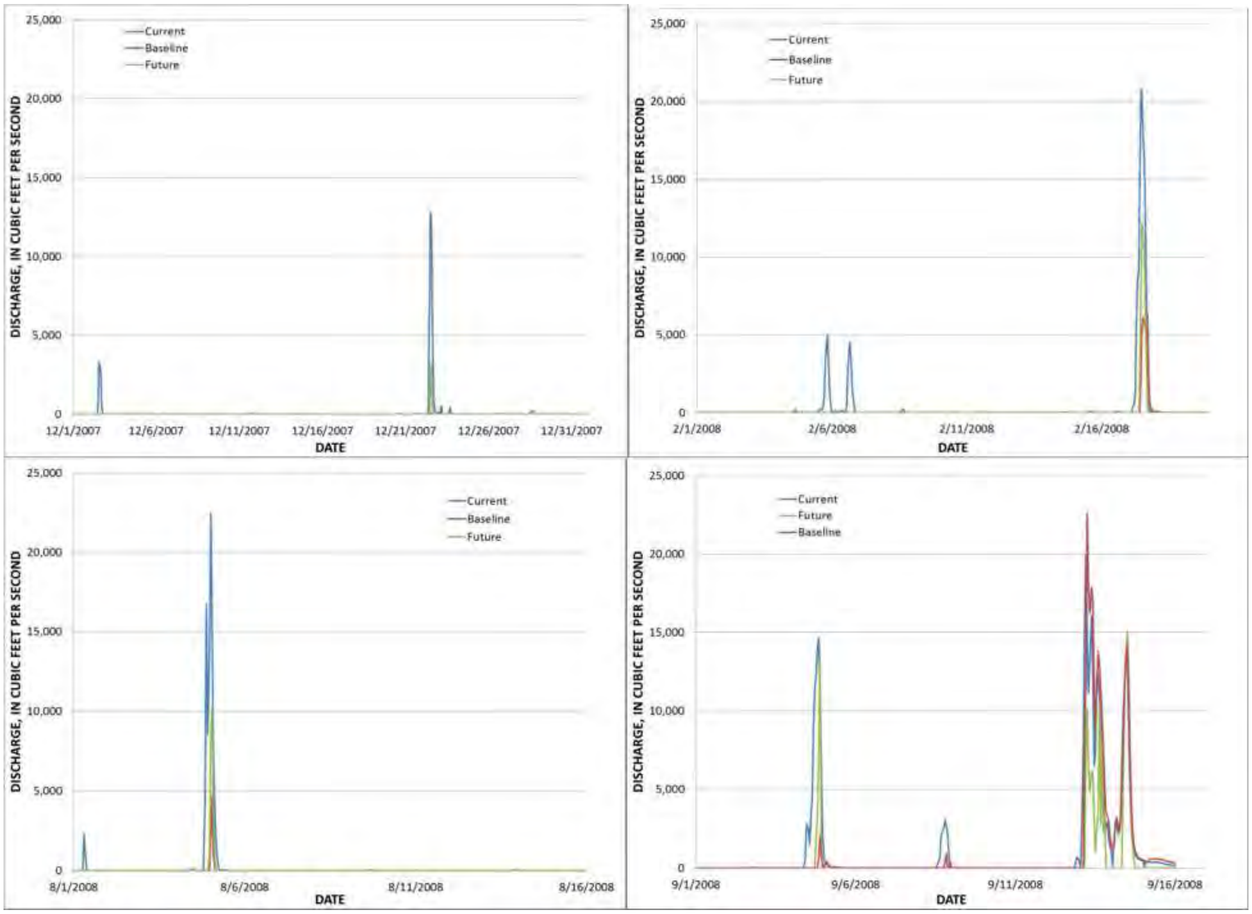


Figure 5.17. Sum of combined sewer overflows to the Chicago River system under current (no reservoir) conditions, Baseline (McCook Reservoir Stage 1 operational), and Future (McCook Reservoir Stages 1 and 2 operational) conditions for December 2007, February 2008, August 2008, and September 2008.

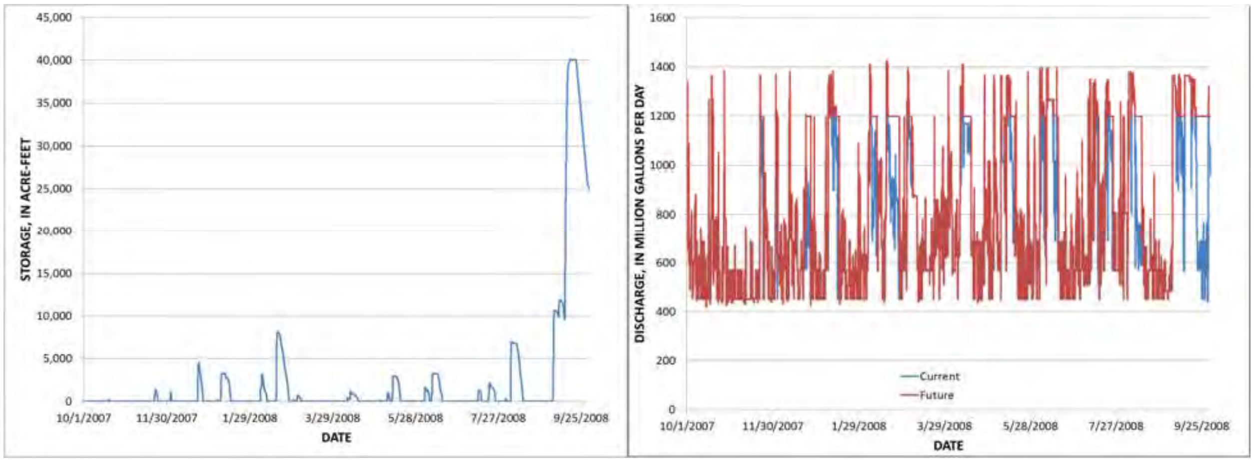


Figure 5.18. Storage in the McCook Reservoir Stages 1 and 2 for Future conditions (left) and effluent from the Stickney Water Reclamation Plant for current (no reservoir) and Future conditions for Water Year 2008.

5.2 No Project Alternative

5.2.1 Change in Upstream Boundary Flows

Beginning in WY 2015 the discretionary diversion allowed to the MWRDGC to improve water-quality conditions in the CAWS will be reduced from an annual average of 270 cfs to an annual average of 101 cfs. Therefore, the flows at the Wilmette Pumping Station, CRCW, and O'Brien Lock and Dam had to be reduced from the actual inflows for these years to values that meet the 101 cfs requirement. Typically, the withdrawal of water from Lake Michigan for discretionary diversion purposes is concentrated in the months of May to October, and low DO concentrations are most frequently encountered in the warm weather months of June to August. Thus, to make effective use of the 101 cfs of discretionary diversion it was decided to maintain the actual discretionary diversion flows for June and July and to apply the remainder of the 101 cfs to the month of August as a constant percentage of the true discretionary diversion on each day in

August. June and July were kept at their actual levels because the IEPA proposed DO standards set a 5 mg/L standard for these months and a lower 3.5 mg/L standard for August.

For WYs 2001, 2003, and 2008, annual average discretionary diversion was 255.15, 290.84, and 268.74 cfs, respectively. Thus, for the "No Project" alternative the total flow at the lakefront boundaries was reduced by 154.15, 189.84, and 167.74 cfs for WYs 2001, 2003, and 2008, respectively. Figure 5.19 shows the actual and adjusted total (sum of the three diversion locations) monthly discretionary diversion for each of the WYs. To adjust the boundary flows the daily discretionary diversion flows estimated by the MWRDGC were subtracted from each 15-min flow value estimated by the USGS for WYs 2001 and 2003 and from the daily flows (entered at a 15-min time step) estimated by the MWRDGC for WY 2008 for October to May and September with a fractional reduction in August as shown in Figure 5.19.

In WYs 2001 and 2008, flow reversals occurred from the CAWS to Lake Michigan during the storms of August 2 and August 31 in 2001 and the storm of September 13-16, 2008. With the reservoirs in operation the amount of these reversals will be decreased. For the storm of August 2^{nd} the sluice gate at Wilmette was opened from 9:00 am to 5:02 pm, the lock at CRCW was opened from 10:35 am to 12:30 pm, and the gates at CRCW were opened from 11:07 am to 2:05 pm. On August 31^{st} the sluice gate at Wilmette was opened from 12:26 to 4:00 am. During these periods the USGS measured negative flows (i.e. flows to Lake Michigan) at their near lake acoustic velocity meter streamflow gages. Because of the operation of the McCook Reservoir in the Baseline and Future conditions flow reversals to Lake Michigan are no longer needed during these periods. Thus, the flow at CRCW and Wilmette were set to zero during these periods.

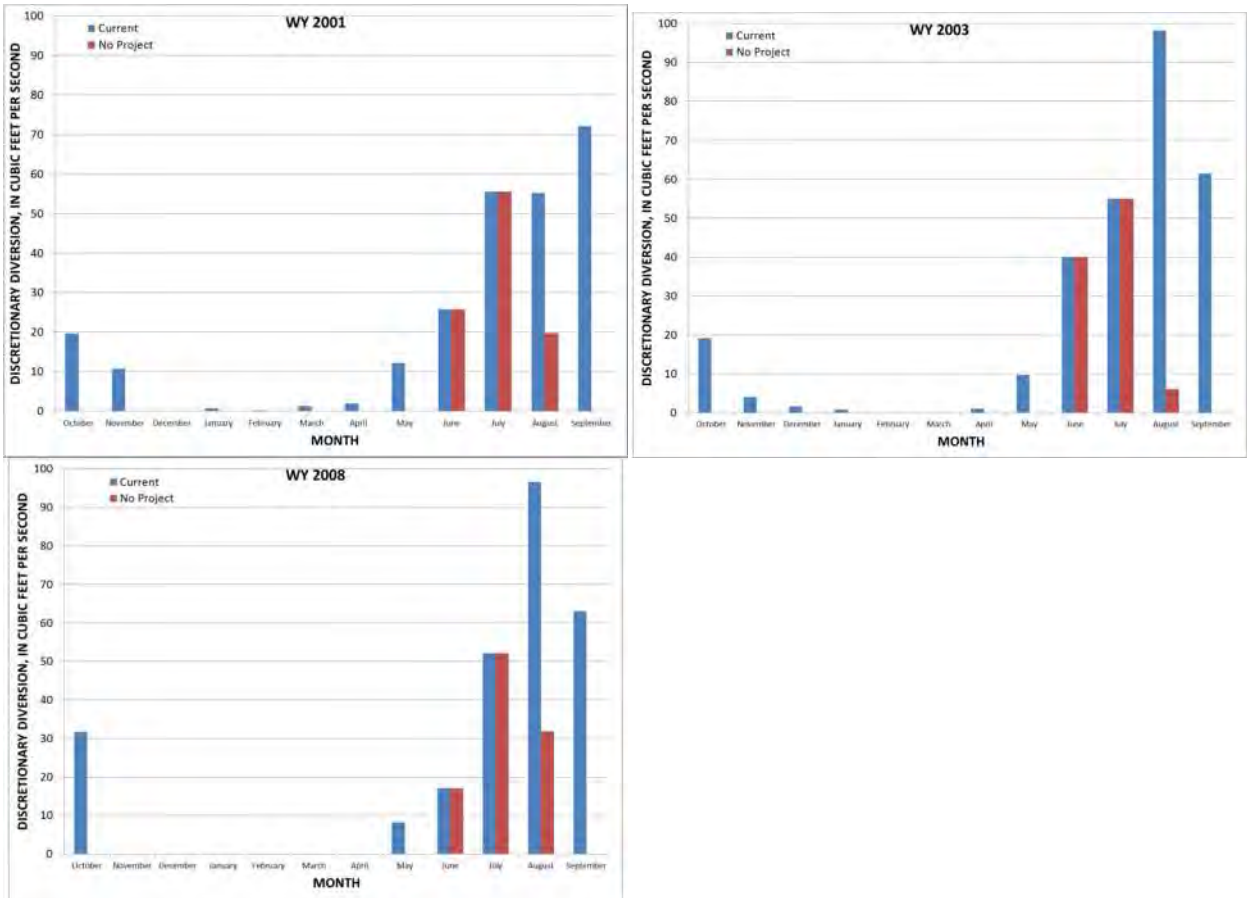


Figure 5.19. Sum of discretionary diversion to the Chicago Area Waterways System at the lakefront structures for the current (actual) conditions and the "No Project" Alternative for Water Years (WYs) 2001, 2003, and 2008.

The sluice gate at Wilmette was opened from 6:18 am on September 13th to 7:30 am on September 16th, the gates at CRCW were opened from 10:00 am on September 13th to 11:30 am on September 15th, the lock at CRCW was opened from 12:58 to 5:00 pm on September 14th, the gates were at O'Brien Lock and Dam were opened from 5:30 pm on September 13th to 2:35 pm on September 16th, and the lock at O'Brien Lock and Dam was opened from 2:35 to 7:55 pm on September 14th. Because the Thornton Reservoir and McCook Reservoir Stage 1 were filled by the combined sewer flows from the storms of September 4th and 8th no storage was available for the combined sewer flows on September 13th to 16th for the Baseline conditions and the flow reversal to Lake Michigan was the same as for current conditions. Addition of the McCook Reservoir Stage 2 provides storage for the combined sewer flows originating from the Mainstream TARP system for the storms of September 13th to 16th. Thus, for the Future conditions the flow to Lake Michigan was set to zero at CRCW. Figure 5.20 shows the current and Future conditions flows at CRCW and the measured and simulated for Future conditions water levels at CRCW. The MWRDGC typically opens the gates at CRCW when the river-side water level reaches 2.5 to 3 ft CCD. In Figure 5.20 it can be seen that when the flow is set to zero for Future conditions the water level remains well below the levels at which the gates would be opened. For Wilmette the flows could not be set to zero for the entire storm period, but they were partially reduced while maintaining the simulated water levels similar to the measured values as shown in Figure 5.21. The result for the Future conditions that no flow reversal occurs at CRCW while a flow reversal occurs at Wilmette makes the Future post-reservoir flows in the CAWS like many of the historic events for which flow reversals occur at Wilmette, but not at CRCW (e.g., the storm of August 31, 2001).

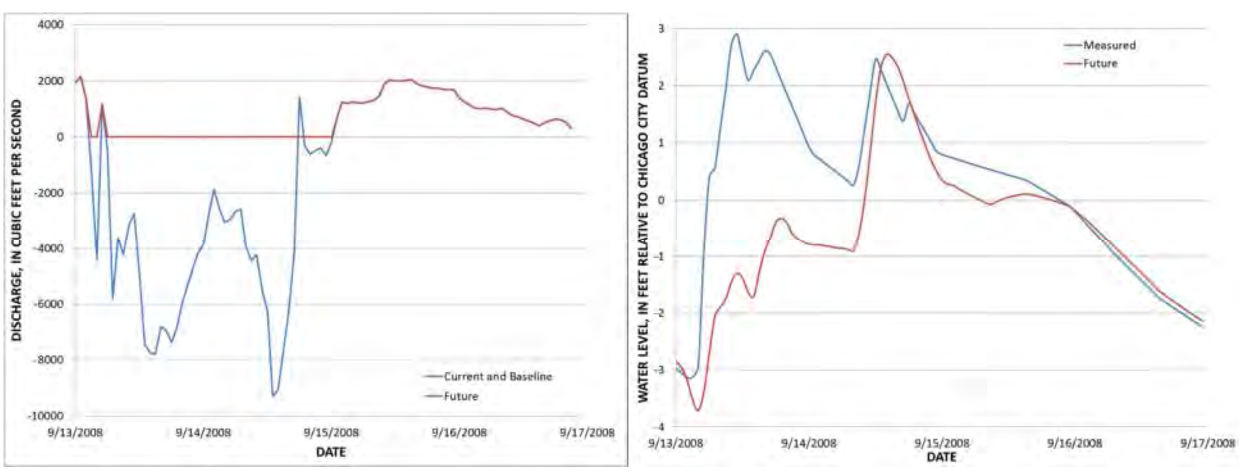


Figure 5.20. Hydraulic variables at the Chicago River Controlling Works for the storms of September 13-16, 2008: [left] flows (negative means to Lake Michigan) for Current, Baseline, and Future conditions, and [right] water levels for current (measured) and simulated Future conditions.

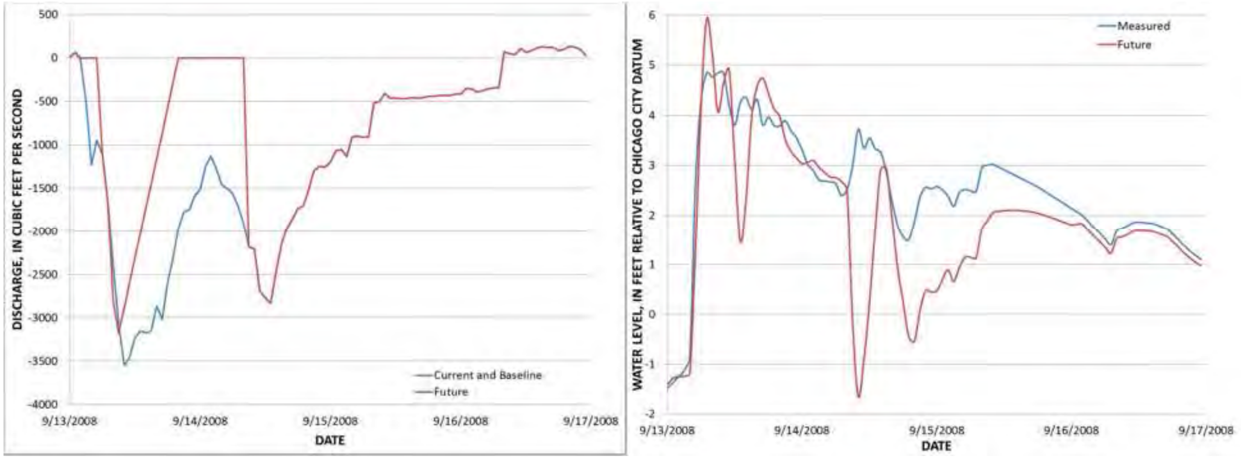


Figure 5.21. Hydraulic variables at the Wilmette Pumping Station for the storms of September 13-16, 2008: [left] flows (negative means to Lake Michigan) for Current, Baseline, and Future conditions, and [right] water levels for current (measured) and simulated Future conditions.

5.2.2. Change in Downstream Boundary Water Levels

The downstream boundary condition for the calibrated and verified DUFLOW hydraulic model is the measured hourly water level at the Lockport Controlling Works. The changes in flows coming into the system for the "No Project" Alternative for Baseline and Future hydrologic conditions will affect the downstream water levels. Thus, an approach must be determined to appropriately modify the downstream water levels in response to the reduction in flows in the CAWS. Changes in low flows occur because of the changes in discretionary diversion described in the Section 5.2.1 and changes in high flows occur because of the large changes in CSO flows described in Section 5.1. This section describes how these two changes were accounted for in the DUFLOW modeling of the "No Project" Alternative.

In order to understand the relation between flow and water level (stage) at the downstream end of the CSSC, hourly flow data at the Romeoville and Lemont gages were obtained from the USGS and hourly water level (stage) data at the Lockport Controlling Works were obtained from the MWRDGC. Finally, operational data for the Lockport Powerhouse (number of turbines on and number of sluice gates open) and Lockport Controlling Works (number of gates open) were obtained from the MWRDGC. Flow and stage then were compared for the wide range of turbine, sluice gate, and controlling works gate operations. Low (dry weather) flows typically only pass through the turbines at the Lockport Powerhouse. Figure 5.22 shows the relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of one and two turbines on at the Lockport Powerhouse and no sluice gates or controlling works gates open. From Figure 5.22 it is clear when only the turbines are operating a wide range of flows can pass through the lower reaches of the CSSC for the same water level (stage). Thus, the relatively small reductions (compared to the sum of the flows from the WRPs and tributary streams) in the dry weather flow resulting from the decrease in discretionary diversion were assumed to not substantially affect the stages at the Lockport Controlling Works and the measured stages were used as the downstream boundary condition for the dry weather periods that experienced a reduction in discretionary diversion.

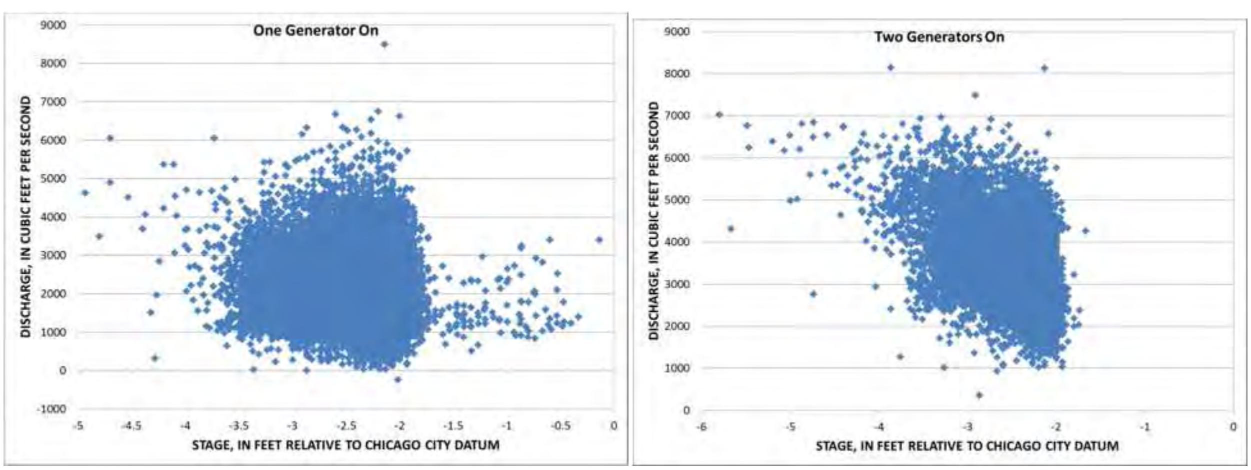


Figure 5.22. Relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of one generator (left) and two generators (right) on at the Lockport Powerhouse and no sluice gates or controlling works gates open.

Properly characterizing the changes in stage at the downstream boundary resulting from the large reductions in storm flows reported in Section 5.1 is more complex. Figure 5.23 shows the relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of one turbine on at the Lockport Powerhouse and various combinations of sluice gates and/or controlling works gates open (similar figures for two turbines on are shown in Addendum G). For the figures within Figure 5.23 it is clear that the flows passing through the lower CSSC are strongly related to the number of gates open. That is, a relatively narrow range of flows (range around 2000 to 3000 cfs) for a wide range in stages (range around 4 to 7 ft) for the different combinations of gate openings. Thus, flow through the lower CSSC is primarily a function the number of gates open and is less dependent on the downstream stage. Thus, if the change in the number of gates open resulting from the decrease in CSO flows because of the presence of the reservoirs can be reasonably determined a good approximation of the change in the stage at the Lockport Controlling Works can be made and used for the revised downstream boundary condition.

Figure 5.24 shows the sum of all inflows to the CAWS for WY 2008 for the Current (no reservoirs), Baseline, and Future Conditions [similar figures for WYs 2001 and 2003 are shown in Addendum H]. It should be noted for the majority of the time the Baseline and Future conditions yield identical total inflow values. In October, August, and September it is easy to see the effects of the reduction in the discretionary diversion in the dry weather flows.

The procedure for adjusting the stage at Lockport is as follows. It is assumed that a similar number of gates would need to be opened for a period with reduced CSO flows as for the case of a current flow with the same peak inflow. For example, for the Baseline conditions the peak inflow for the storm of February 17, 2008, is reduced to 13,760 cfs from 30,670 cfs. For the current inflows three storms had similar peak inflows to that for the Baseline conditions for February 17, 2008: June 9, 2008 with a peak inflow of 14,490 cfs, July 20, 2008 with a peak inflow of 13,940 cfs, and September 8, 2008 with a peak inflow of 12,880 cfs. For the actual operations on June 9th and September 8th a maximum of 6 sluice gates were opened to manage the inflows to the CAWS, which is the same maximum number of gates as for the actual February 17th operations. Thus, the storm July 20th for which only 4 sluice gates were opened is a more appropriate prediction of the operation of the sluice gates at the Lockport Powerhouse in response to the reduced inflows for the Baseline conditions of the storm of February 17th. For July 20th when 4 sluice gates were opened the stage ranged from -4.5 to -5.5 ft City of Chicago Datum (CCD). Thus, it was decided to hold the lowest stage around -4.8 ft CCD in the DUFLOW simulations for the Baseline conditions. Figure 5.25 shows the measured and adjusted stages at the Lockport Controlling Works for the storm of February 17, 2008. Similar adjustments were applied to all storm events for the Baseline and Future Conditions for each of WYs 2001, 2003, and 2008. The current and adjusted stages for the Baseline and Future Conditions for WY 2008 are shown in Figure 5.26 (note: when Future, Baseline, and/or current stages are identical only the Future value is seen in the figure). Figure 5.27 shows the simulated flows at the Lockport Controlling Works for the Current versus Baseline and Future Conditions for the “No Project” alternative, respectively, for WY 2008 (note: when Future, Baseline, and/or current flows are identical only the Future value is seen in the figure). The smoothness of the computed outflows in Figure 5.27 shows the reasonableness of the approximated downstream boundary conditions for the Baseline and Future conditions. For the “No Project” alternative the stage adjustments for WYs 2001 and 2003 are shown in Addendum I and the simulated flows for WYs 2001 and 2003 are shown in Addendum J.

Figure 5.23. Relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of one generator on at the Lockport Powerhouse and various numbers of powerhouse sluice gates and/or controlling works gates open.

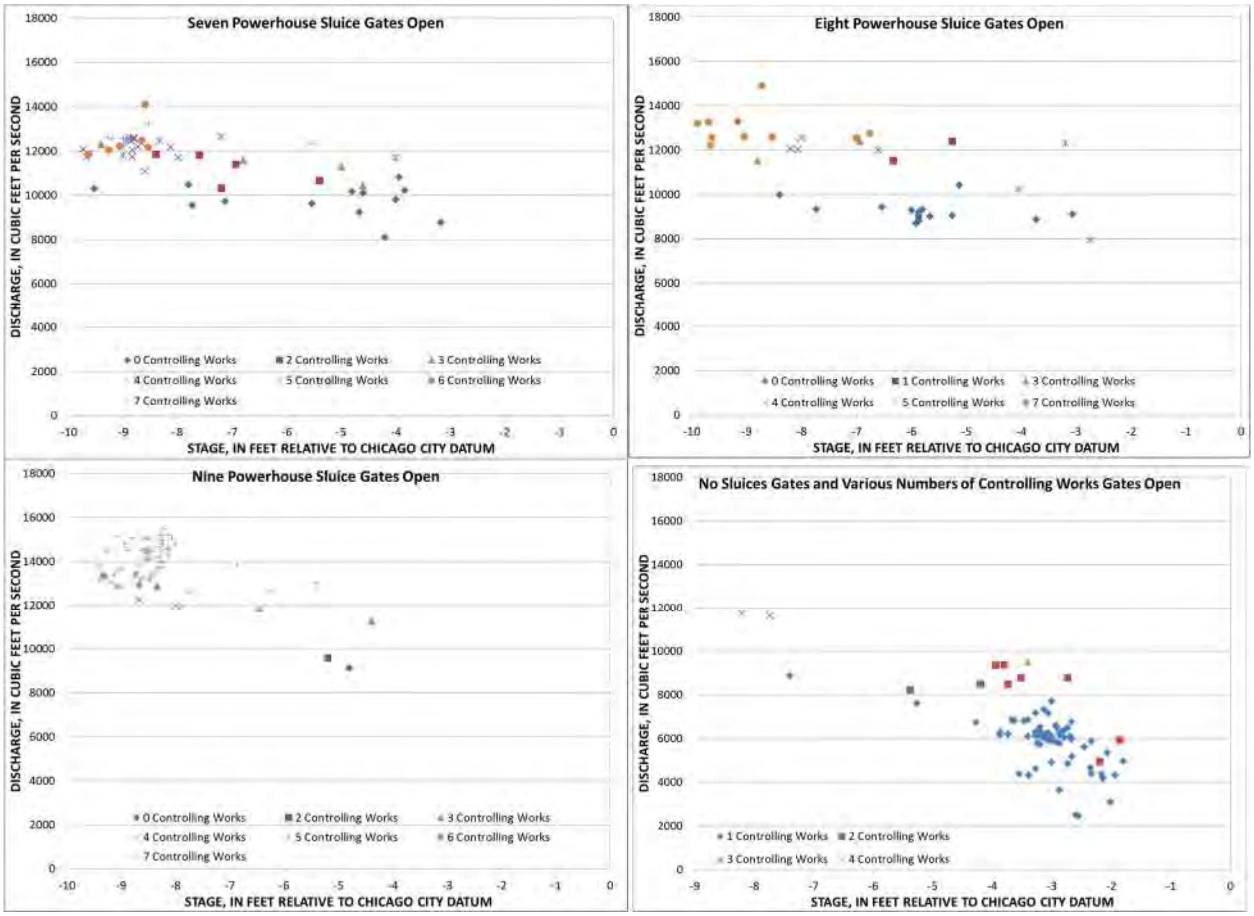


Figure 5.23 (cont.) Relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of one generator on at the Lockport Powerhouse and various numbers of powerhouse sluice gates and/or controlling works gates open.

Under Current conditions for WY 2008 the average flow in the CSSC at the Lockport Controlling Works is 3176 cfs, whereas for the Baseline and Future conditions for the “No Project” alternative the average flow is 3022 and 3017 cfs, respectively. The flow balance for the Baseline condition is as follows:

Simulated Average Flow:	3022.38 cfs
Decrease in Discretionary Diversion:	167.74 cfs
Water Stored in Reservoirs:	22.67 cfs
Total:	3212.79 cfs

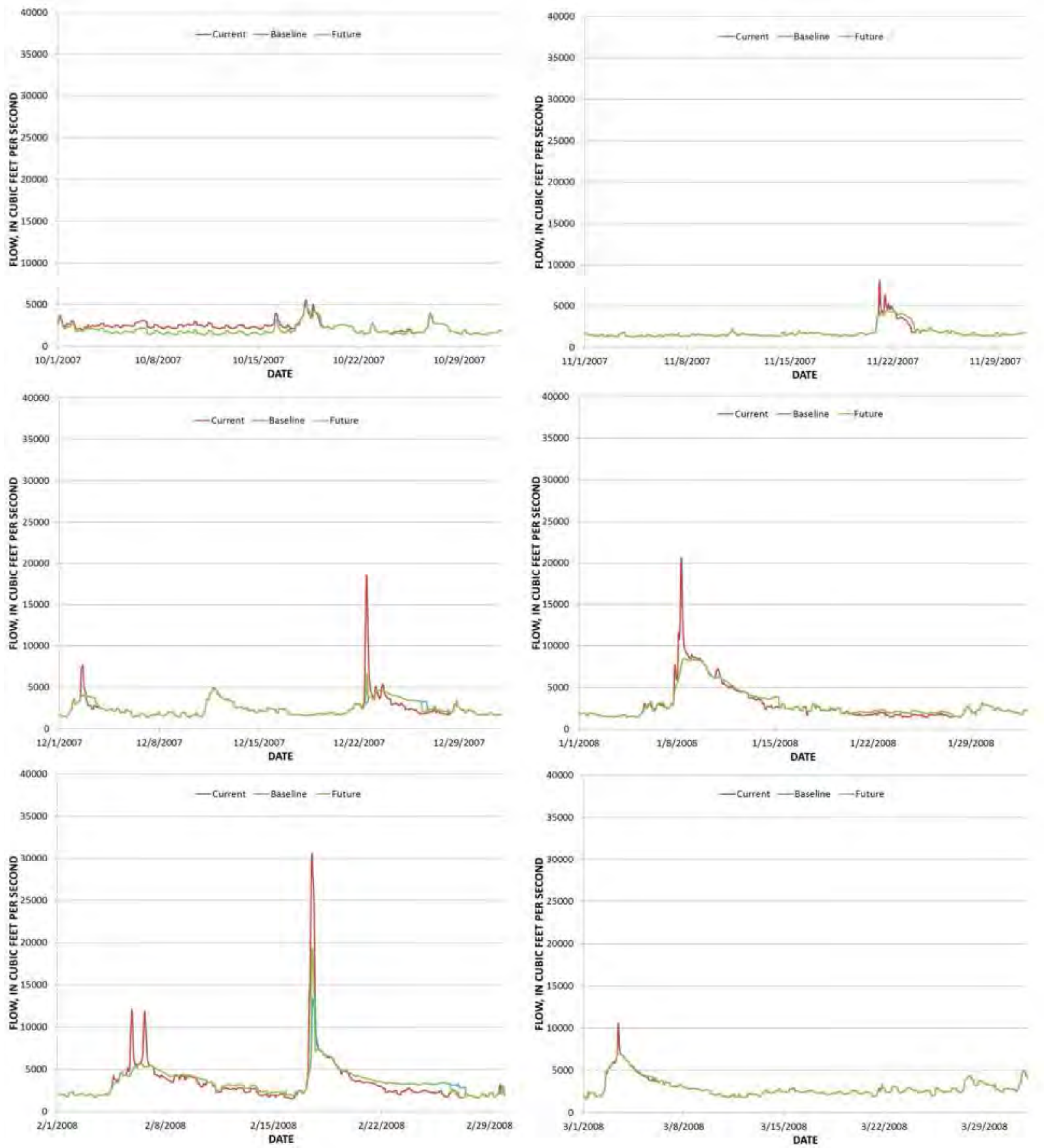


Figure 5.24. Comparison of the sum of inflows to the Chicago Area Waterway System for the Current, Baseline, and Future conditions for Water Year 2008.

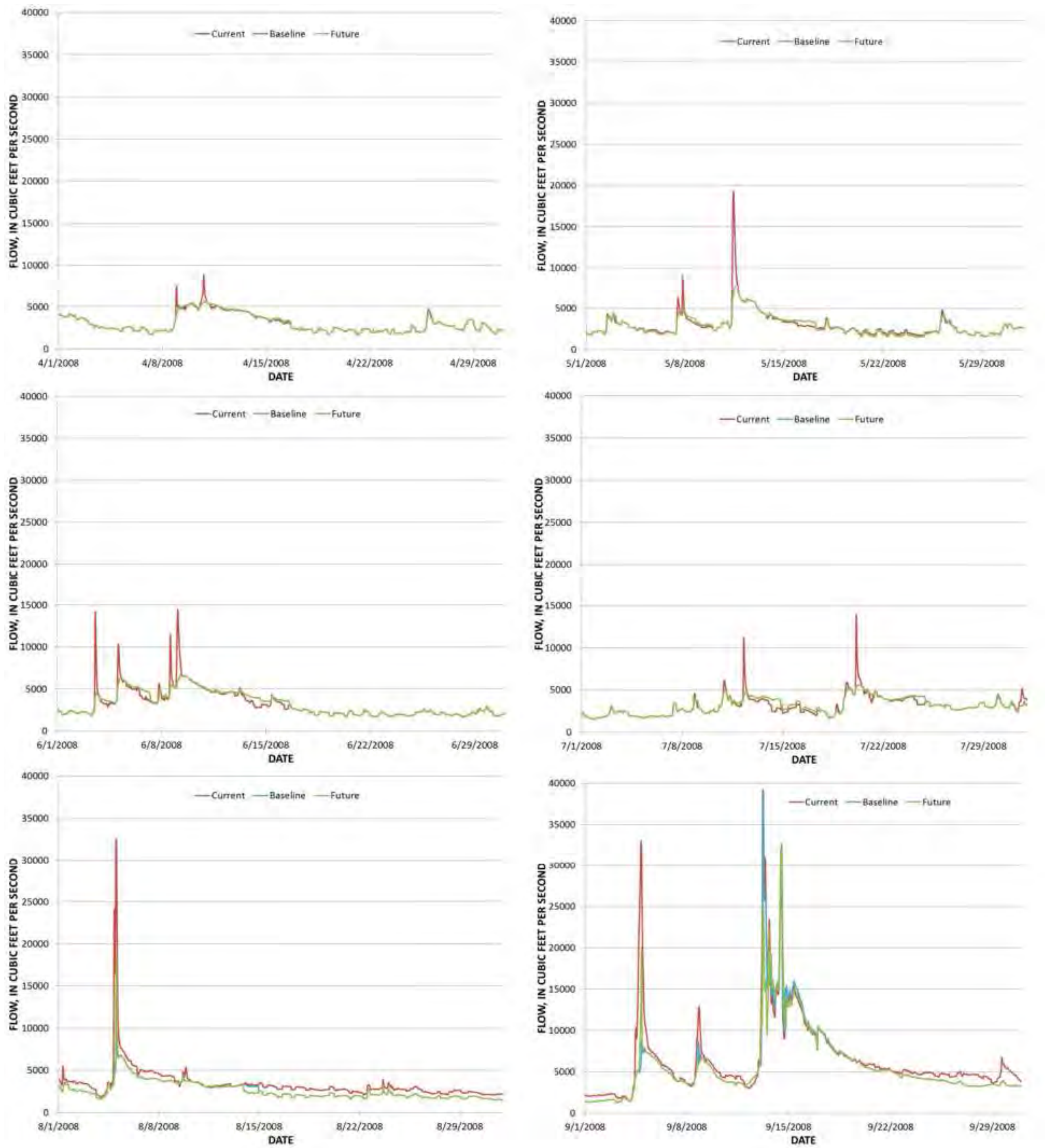


Figure 5.24 (cont.) Comparison of the sum of inflows to the Chicago Area Waterway System for the Current, Baseline, and Future conditions for Water Year 2008.

This total is 1.16% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Baseline condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases. The flow balance for the Future condition is as follows:

Simulated Average Flow:	3016.85 cfs
Decrease in Discretionary Diversion:	167.74 cfs
Water Stored in Reservoirs:	46.27 cfs
Change in flows to the Lake:	-24.99 cfs
Total:	3205.87 cfs

Figure 5.25. Measured stage and stage adjusted to account for the reduction in combined sewer overflows to the Chicago Area Waterway System for the Baseline conditions for the storm of February 17, 2008.

This total is 0.94% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Future condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases.

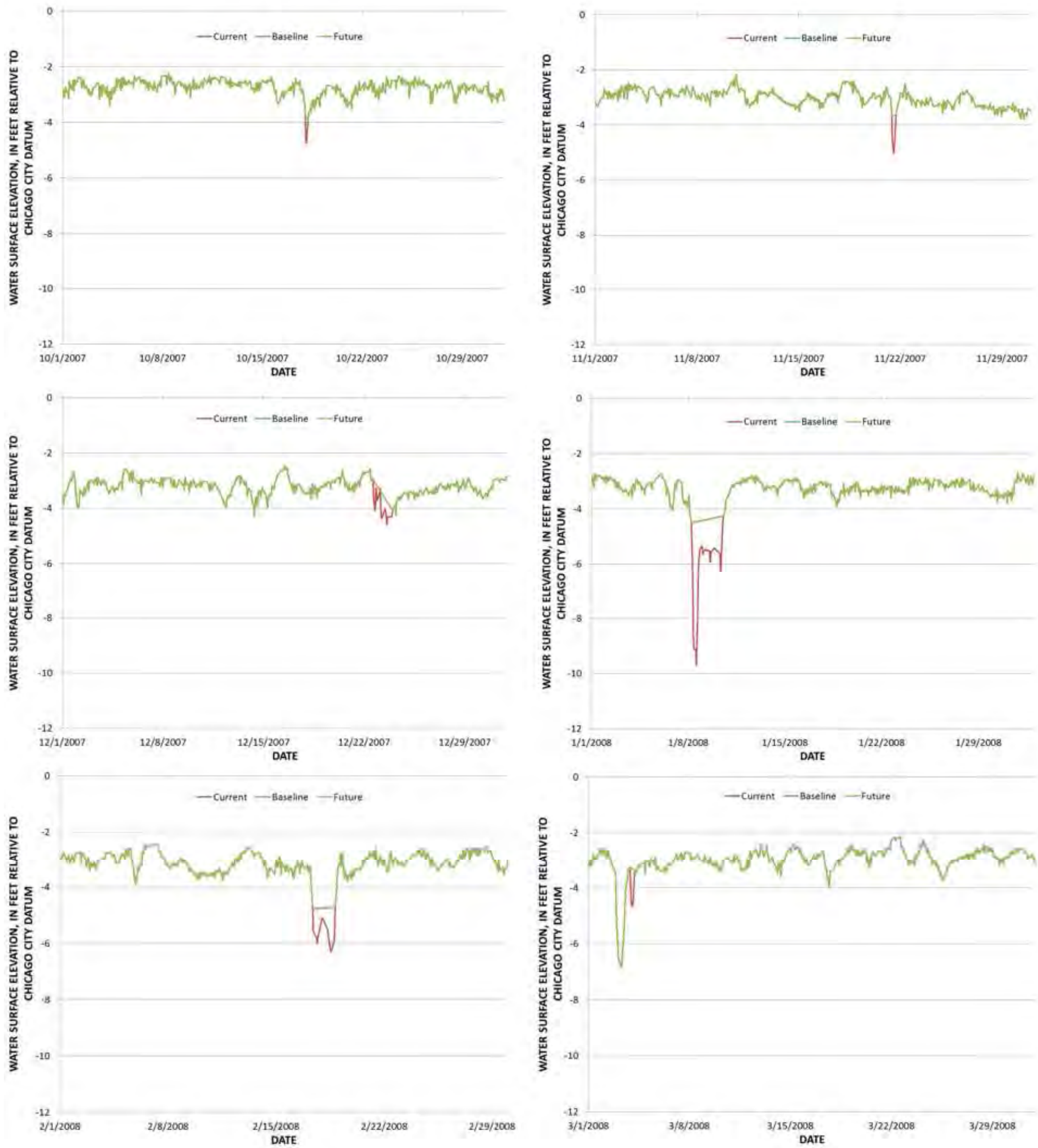


Figure 5.26. Lockport Controlling Works downstream boundary for Water Year 2008: measured (Current) water-surface elevations and water-surface elevations adjusted to reflect the reduction in combined sewer overflows to the Chicago Area Waterway System for Baseline and Future conditions.

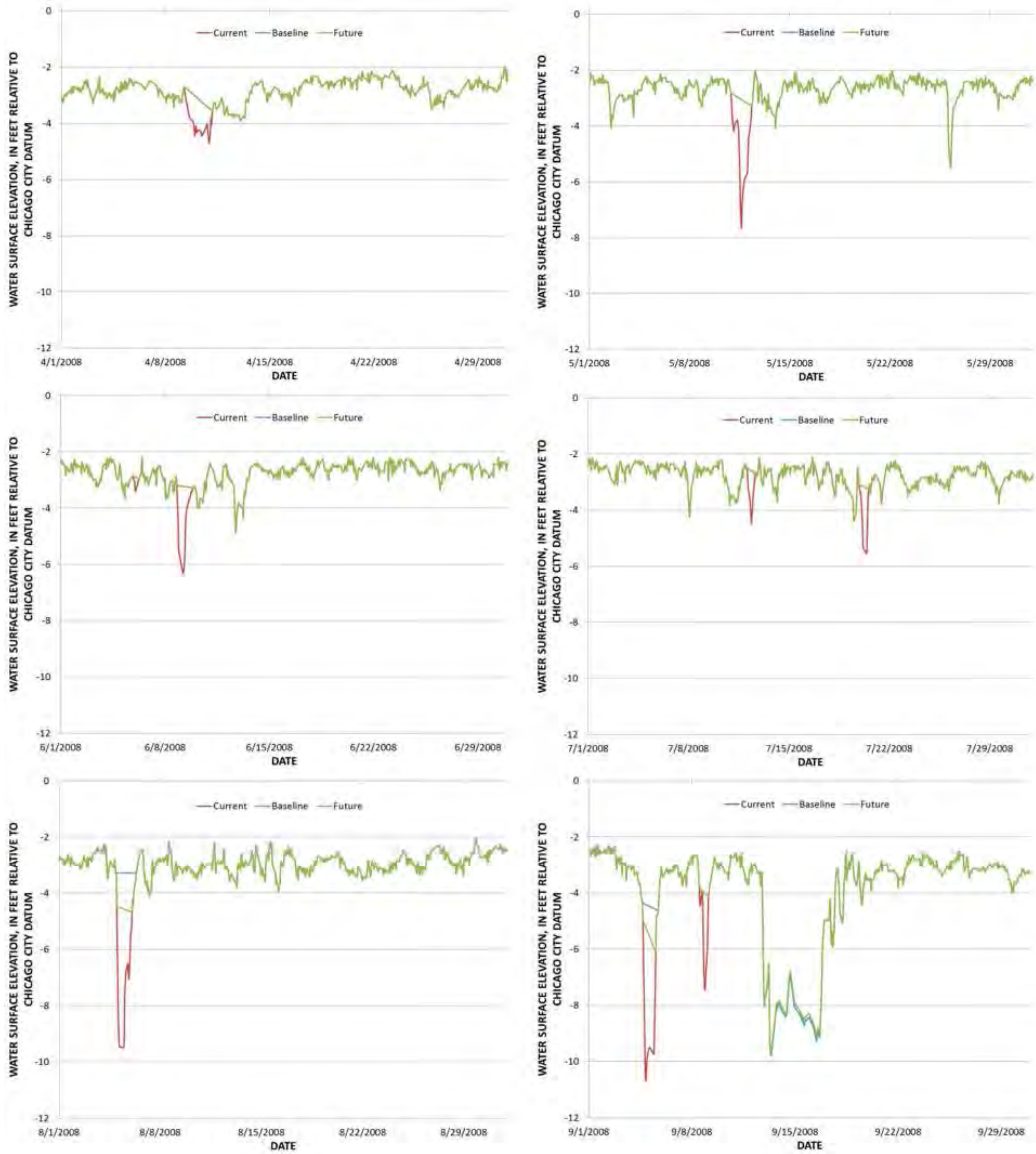


Figure 5.26 (cont.) Lockport Controlling Works downstream boundary for Water Year 2008: measured (Current) water-surface elevations and water-surface elevations adjusted to reflect the reduction in combined sewer overflows to the Chicago Area Waterway System for Baseline and Future conditions.

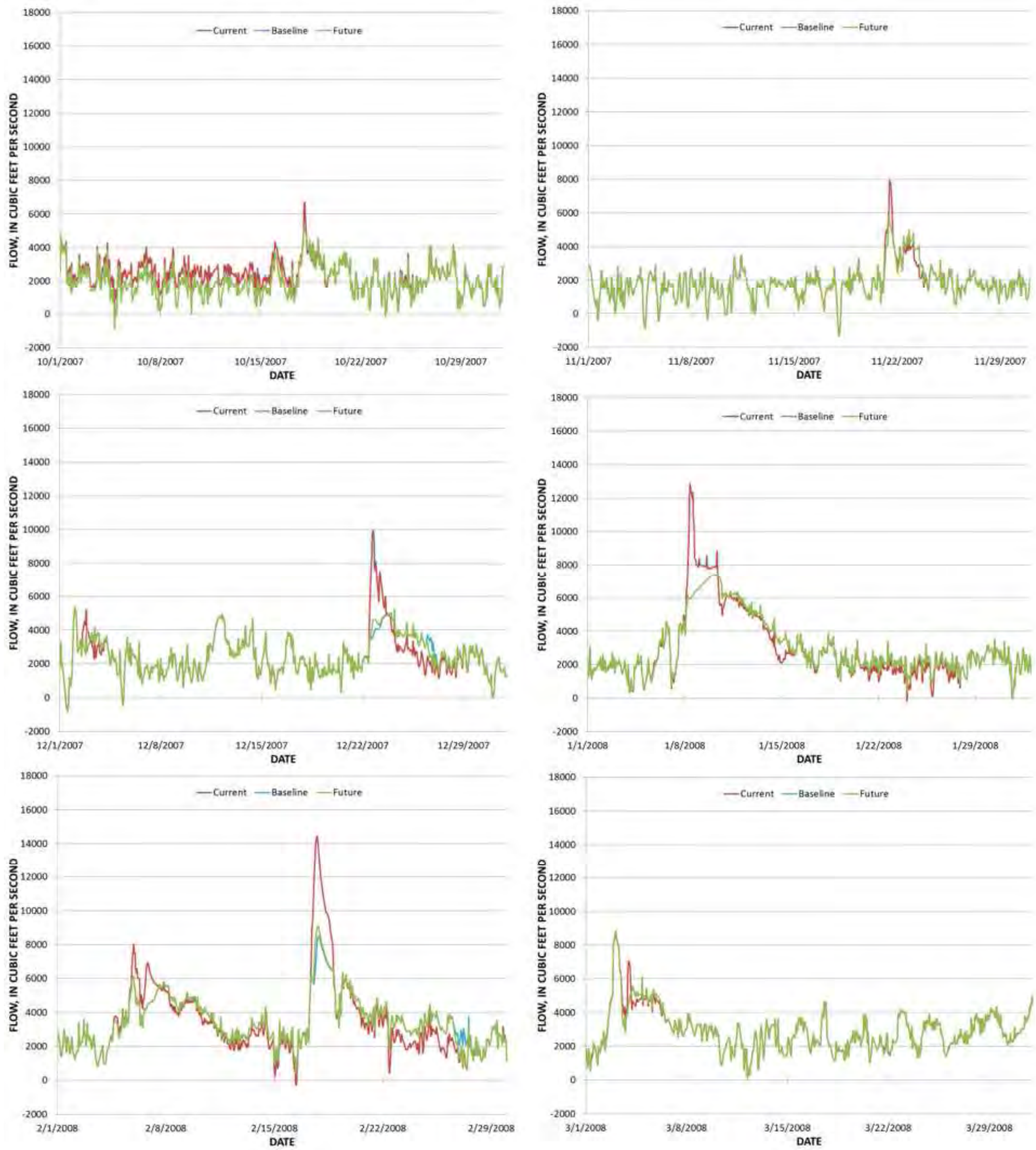


Figure 5.27. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "No Project" alternative for Water Year 2008.

Figure 5.27 (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "No Project" alternative for Water Year 2008.

Under Current conditions for WY 2003 the average flow in the CSSC at the Lockport Controlling Works is 2440 cfs, whereas for the Baseline and Future conditions for the "No

Project" alternative the average flow is 2270 and 2265 cfs, respectively. The flow balance for the Baseline condition is as follows:

Simulated Average Flow:	2269.83 cfs
Decrease in Discretionary Diversion:	189.84 cfs
Total:	2459.67 cfs

This total is 0.81% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Baseline condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases. The flow balance for the Future condition is as follows:

Simulated Average Flow:	2264.76 cfs
Decrease in Discretionary Diversion:	189.84 cfs
Total:	2454.60 cfs

This total is 0.61% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Future condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases.

Under Current conditions for WY 2001 the average flow in the CSSC at the Lockport Controlling Works is 2871 cfs, whereas for the Baseline and Future conditions for the "No Project" alternative the average flow is 2723 and 2730 cfs, respectively. The flow balance for the Baseline condition is as follows:

Simulated Average Flow:	2723.36 cfs
Decrease in Discretionary Diversion:	167.74 cfs
Water Stored in Reservoirs:	2.34 cfs
Change in flows to the Lake:	-0.87 cfs
Total:	2892.57 cfs

This total is 0.76% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Baseline condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases. The flow balance for the Future condition is as follows:

Simulated Average Flow:	2729.53 cfs
Decrease in Discretionary Diversion:	167.74 cfs
Water Stored in Reservoirs:	2.34 cfs
Change in flows to the Lake:	-0.87 cfs
Total:	2898.74 cfs

This total is 0.98% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Future condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases.

5.2.3 Change in Temperature and Other Water Quality Loads

The changes in discretionary diversion and the closure of the Fisk and Crawford power plants will change the temperatures in the CAWS for the "No Project" alternative under Baseline and Future conditions. For WYs 2001 and 2003 the measured daily mean temperatures at Linden Street, CRCW, and O'Brien Lock and Dam (approximated by 130th Street) are used to initiate the estimation of temperatures throughout the CAWS for the "No Project" alternative. At 130th Street the temperature probe was installed in May 2001 and operated from 17:01 on May 1st to 15:01 on May 8th before being continuously operated beginning 12:01 on July 11th. Average monthly temperatures determined from the period of record of the 130th Street temperature monitor were assigned to the periods in WY 2001 when the temperature monitor was not in operation. For WY 2008 the mean daily temperatures estimated at—(1) Linden Street from the measurements at Main Street through the equations in Table 2.2, (2) CRCW from the measurements at Clark Street through the equations in Table 2.2, and (3) O'Brien Lock and Dam

(130th Street) estimated from the measurement at the Central and Wisconsin Railroad through the equations in Table 3.3—are used to initiate the estimation of temperatures throughout the CAWS for the "No Project" alternative.

Beginning with the temperatures at the Linden Street, CRCW, and O'Brien Lock and Dam boundaries the regression and mass balance equations in Tables 2.2 and 2.3 were used to compute the daily mean temperatures at each monitoring point in the CAWS through a location-by-location stepwise approach in the downstream direction with the flows reflecting the changed hydraulic conditions for the Baseline or Future conditions as appropriate. The equations for the power plants turned off in Table 2.2 were used to estimate the temperatures at Loomis Street on the SBCR and Cicero Avenue on the CSSC. Figures K.1 to K.6 in Addendum K show the measured or estimated temperatures for the current conditions and estimated temperatures for the "No Project" alternative for Baseline and Future conditions. As can be seen in these figures, the temperatures at all locations upstream of the power plants on the Chicago River system and at all locations on the Calumet River system for the "No Project" alternative both for Baseline and Future conditions are very similar to the temperatures under the current conditions. Therefore, the reduction in boundary flows to meet the new discretionary diversion allocation does not substantially affect temperatures. The closure of the power plants does have a substantial impact on downstream temperatures in the CAWS.

In the simulations done in this study, the operation hours of the Devon Avenue and Webster Avenue IASs on the NSC and NBCR, respectively, and of the five SEPA stations on the Calumet River system were assumed to be the same as for actual operations in each of WYs 2001, 2003, and 2008. The DO loads yielded by each aeration station are a function of the DO concentration upstream from the station. Thus, because the DO concentrations change for the "No Project" alternative from the current conditions, the DO load from each station is different from that for the current conditions. The revised aeration station loads are computed sequentially so the effect of the upstream stations on the downstream stations is accounted for in the simulations.

5.3 Lakefront Separation Alternative

5.3.1 Change in Upstream Boundary Flows

In the "Lakefront Separation" alternative, it is assumed that impermeable barriers will be built at the Wilmette Pumping Station and the CRCW. Therefore, the flows at these locations were set to zero at all times. On the Little Calumet River (north) it is assumed that an impermeable barrier will be built at RM 324.5 (2 mi from the O'Brien Lock and Dam at RM 326.5). Thus a zero flow boundary was added to the DUFLOW model at RM 324.5. The placement of the barrier at this location not only removes discretionary and other flows at the O'Brien Lock and Dam from the CAWS, but it also removes the flows from the Grand Calumet River from the CAWS.

Also, in the "Lakefront Separation" alternative a barrier will be built on the Little Calumet River (south) near the Illinois-Indiana border about 1000 ft west of the Hart Ditch confluence with the Little Calumet River. Thus, flows from Indiana will no longer enter the CAWS through the Little Calumet River. In order to account for this reduction in flows the flow measured at USGS gage no. 05536195 Little Calumet River at Munster, IN, were subtracted from the flows at the Little Calumet River at South Holland, IL, boundary flows. If the flow at Munster was greater than the flow at South Holland, the boundary flow was set to zero.

5.3.2 Change in Downstream Boundary Water Levels

For the "Lakefront Separation" alternative the changes in the inflows to the CAWS compared to the current conditions and the "No Project" alternative are most substantial for dry weather periods. Thus, the new flows for high flows are similar to those for the "No Project" alternative, and for low flows they are within the range of stage and discharge combinations shown in Figure 5.22 and Addendum G. Therefore, the same downstream water levels were used for the "Lakefront Separation" and "No Project" Alternatives.

Figure 5.28 shows the simulated flows at the Lockport Controlling Works for the Current versus Baseline and Future Conditions for the "Lakeside Separation" alternative, respectively, for WY 2008 (note: when the Future, Baseline, and/or current flows are identical only the Future value is seen in the figure). The smoothness of the computed outflows in Figure 5.28 shows the reasonableness of the approximated downstream boundary conditions for the Baseline and Future conditions. The huge increase in flow at the Lockport Controlling Works for September 13-16, 2008, for the Baseline conditions compared to current conditions reflects the fact that in the "Lakefront Separation" alternative water can no longer escape the CAWS at the Lake Michigan boundaries during large storms. The smaller increase in flow for September 13-16, 2008, for the Future conditions reflects the storage in Stage 2 of the McCook Reservoir. The simulated flows for WYs 2001 and 2003 for the "Lakefront Separation" alternative are shown in Addendum J.

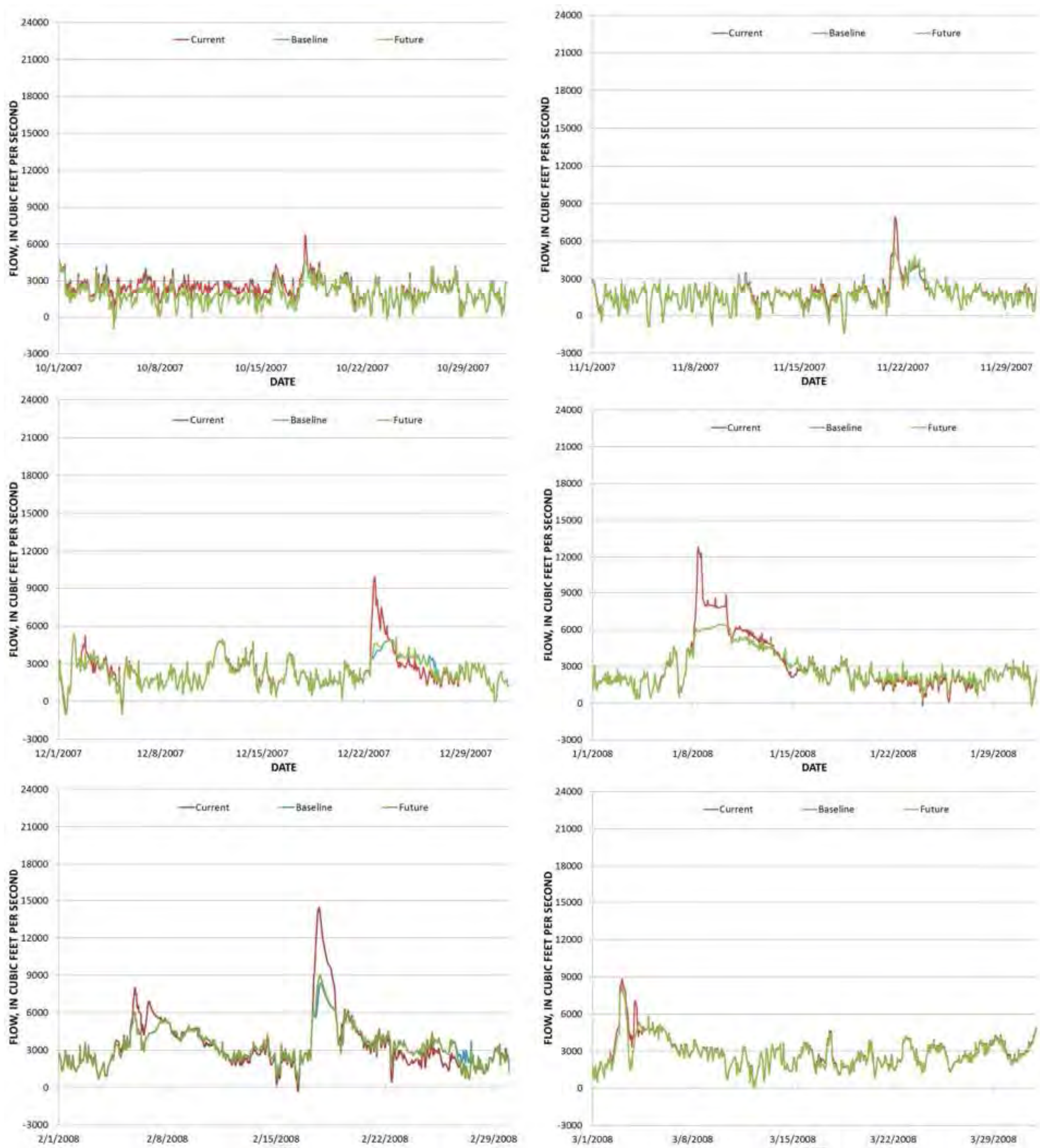


Figure 5.28. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Lakefront Separation" alternative for Water Year 2008.

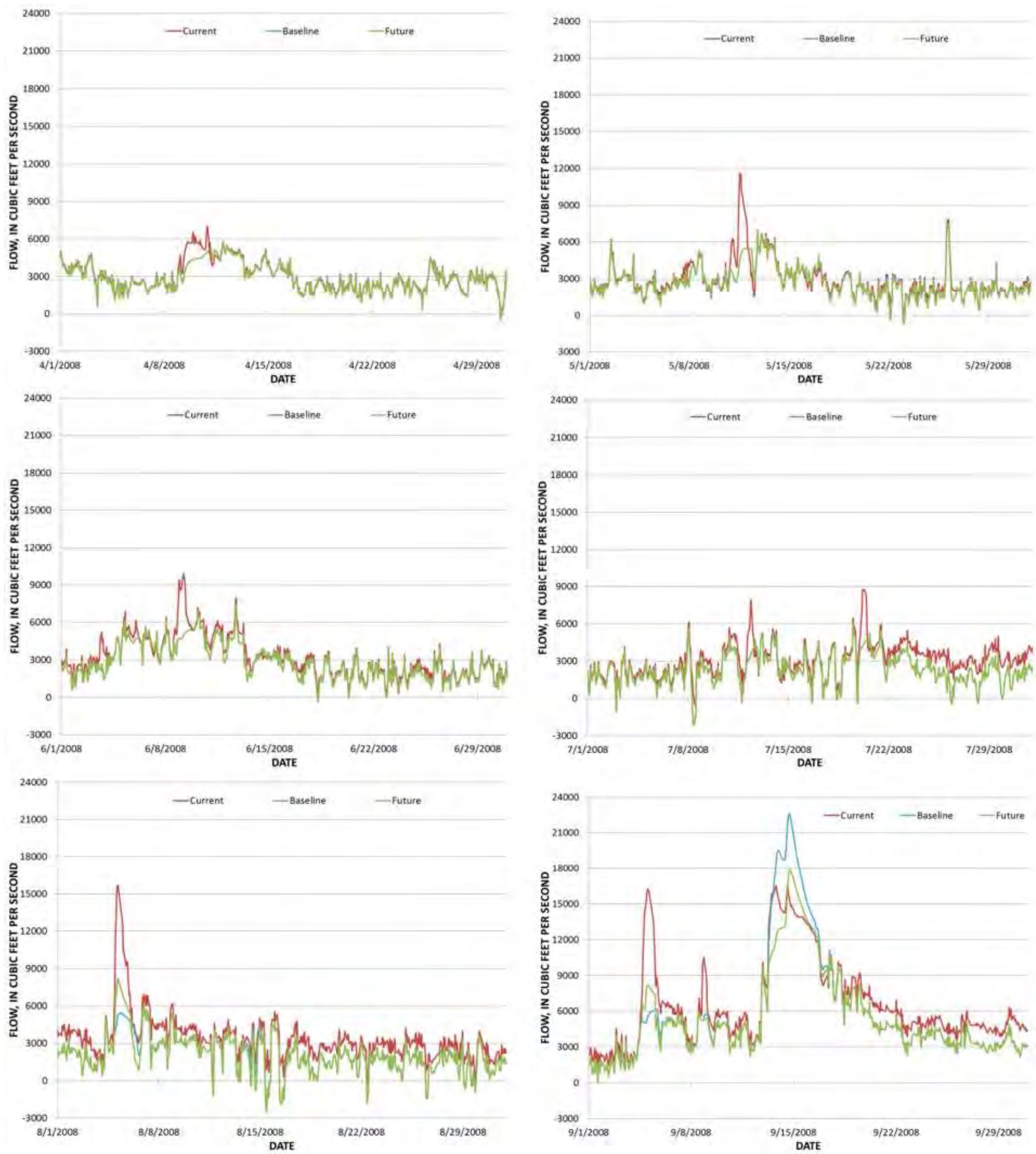


Figure 5.28 (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Lakefront Separation" alternative for Water Year 2008.

Under Current conditions for WY 2008 the average flow in the CSSC at the Lockport Controlling Works is 3176 cfs, whereas for the Baseline and Future conditions for the "Lakefront

Separation" alternative the average flow is 2773 and 2740 cfs, respectively. The flow balance for the Baseline condition is as follows:

Simulated Average Flow:	2772.86 cfs
Decrease in Lake Boundary Flows:	320.15 cfs
Decrease in Flow from Little Calumet and Grand Calumet:	90.29 cfs
Water Stored in Reservoirs:	22.67 cfs
Total:	3205.97 cfs

This total is 0.94% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Baseline condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases. The flow balance for the Future condition is as follows:

Simulated Average Flow:	2740.86 cfs
Decrease in Lake Boundary Flows:	345.14 cfs
Decrease in Flow from Little Calumet and Grand Calumet:	90.29 cfs
Water Stored in Reservoirs:	46.27 cfs
Total:	3222.56 cfs

This total is 1.47% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Future condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases.

Under Current conditions for WY 2003 the average flow in the CSSC at the Lockport Controlling Works is 2440 cfs, whereas for the "Lakefront Separation" alternative for Baseline and Future conditions the average flow is 2123 and 2118 cfs, respectively. The flow balance for the Baseline condition is as follows:

Simulated Average Flow:	2123.17 cfs
Decrease in Lake Boundary Flows:	285.30 cfs
Decrease in Flow from Little Calumet and Grand Calumet:	49.74 cfs
Total:	2458.21 cfs

This total is 0.75% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Baseline condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases. The flow balance for the Future condition is as follows:

Simulated Average Flow:	2118.02 cfs
Decrease in Lake Boundary Flows:	285.30 cfs
Decrease in Flow from Little Calumet and Grand Calumet:	49.74 cfs
Total:	2453.06 cfs

This total is 0.54% higher than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Future condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases.

Under Current conditions for WY 2001 the average flow in the CSSC at the Lockport Controlling Works is 2871 cfs, whereas for the "Lakefront Separation" alternative for Baseline and Future conditions the average flow is 2543 and 2449 cfs, respectively. The flow balance for the Baseline condition is as follows:

Simulated Average Flow:	2542.54 cfs
Decrease in Lake Boundary Flows:	258.10 cfs
Decrease in Flow from Little Calumet and Grand Calumet:	60.62 cfs
Water Stored in Reservoirs:	2.34 cfs
Total:	2863.60 cfs

This total is 0.25% lower than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Baseline condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases. The flow balance for the Future condition is as follows:

Simulated Average Flow:	2548.70 cfs
Decrease in Lake Boundary Flows:	258.10 cfs
Decrease in Flow from Little Calumet and Grand Calumet:	60.62 cfs

Water Stored in Reservoirs:	2.34 cfs
Total:	2869.76 cfs

This total is 0.03% lower than the computed flow for the Current condition and may be attributed to the CSO flow increases for the Future condition compared to the Current condition discussed in Section 5.1 and to changes in storage in the CAWS between the two different cases.

5.3.3 Change in Temperature and Other Water Quality Loads

The changes in flows from/to Lake Michigan and the closure of the Fisk and Crawford power plants will change the temperatures in the CAWS for the "Lakefront Separation" alternative under Baseline and Future conditions. As for the "No Project" alternative, for WYs 2001 and 2003 the measured daily mean temperatures and for WY 2008 the estimated daily mean temperatures at Linden Street, CRCW, and O'Brien Lock and Dam (approximated by 130th Street) are used to initiate the estimation of temperatures throughout the CAWS for the "Lakefront Separation" alternative. Beginning with the temperatures at the Linden Street, CRCW, and O'Brien Lock and Dam boundaries the regression and mass balance equations in Tables 2.2 and 2.3 were used to compute the daily mean temperatures at each monitoring point in the CAWS through a location-by-location stepwise approach in the downstream direction with the flows reflecting the changed hydraulic conditions for the Baseline or Future conditions as appropriate. The equations for the power plants turned off in Table 2.2 were used to estimate the temperatures at Loomis Street on the SBCR and Cicero Avenue on the CSSC. Figures K.7 to K.12 in Addendum K show the estimated temperatures for the "No Project" and "Lakefront Separation" alternatives for Baseline and Future conditions. As can be seen in these figures, the temperatures at all locations, except Clark Street on the Chicago River main stem, are very similar for the “No Project” and “Lakefront Separation” alternatives. Therefore, the reduction in boundary flows because of the separation from Lake Michigan does not substantially affect temperatures. The Chicago River main stem is as changing from some flow from the lake to no flow affects the temperature at Clark Street (i.e. for the “No Project” alternative different regression equations are use depending on flow, whereas for the “Lakefront Separation” alternative only the equation for zero flow is applied). The closure of the power plants also has a substantial impact on downstream temperatures in the CAWS as shown in Figures K.1 to K.6.

In the simulations done in this study, the operation hours of the Devon Avenue and Webster Avenue IASs on the NSC and NBCR, respectively, and of the five SEPA stations on the Calumet River system were assumed to be the same as for actual operations in each of WYs 2001, 2003, and 2008. The DO loads yielded by each aeration station are a function of the DO concentration upstream from the station. Thus, because the DO concentrations change for the “Lakefront Separation” alternative from the current conditions and “No Project” alternative, the DO load from each station is different from that for the previously evaluated cases. The revised aeration station loads are computed sequentially so the effect of the upstream stations on the downstream stations is accounted for in the simulations.

5.4 Midsystem Separation Alternative

5.4.1 Change in Upstream Boundary Conditions

In the “Midsystem Separation” alternative, barriers will be added to the CSSC at RM 316.01 and the Calumet-Sag Channel at RM 315.89. Thus, essentially the original DUFLOW model of the CAWS will be subdivided into three models. The first is a Northside model in which the NSC is opened to Lake Michigan at the Wilmette Pumping Station and the Chicago River main stem is opened to Lake Michigan at the CRCW. Flows from the NSC, NBCR, Chicago River main stem, SBCR, Bubbly Creek, and the northern part of the CSSC (above RM 316.01) will drain to Lake Michigan through the CRCW and Wilmette Pumping Station. The second is a Calumet River model in which the O’Brien Lock and Dam is opened and flows from the Calumet River, Little Calumet River (north and south), Grand Calumet River, and the upper portion of the Calumet-Sag Channel (above RM 315.89) drain to Lake Michigan at Calumet Harbor. The third is a CSSC and Calumet-Sag Channel model in which flows from the lower CSSC (below RM 316.01) and lower Calumet-Sag Channel (below RM 315.89) drain to Lockport. The inflows to this third model include the Stickney and Lemont WRPs, two of the representative CSO locations (numbers 17 and 18 in Table 2.2 of Alp and Melching (2004)), and four tributary streams to the Calumet-Sag Channel (Tinley Creek, Navajo Creek, Mill Creek, and Stoney Creek (west)).

The upstream boundary for the Northside model is the barrier at RM 316.01 on the CSSC, which is assigned a zero flow boundary. The upstream boundaries for the Calumet River model are the

Little Calumet River at South Holland, which is a flow boundary unchanged from the "No Project" alternative for Baseline and Future conditions, and the barrier at RM 315.89 on the Calumet-Sag Channel, which is assigned a zero flow boundary. The upstream boundaries for the CSSC and Calumet-Sag Channel model are the barrier on the CSSC at RM 316.01 and on the Calumet-Sag Channel at RM 315.89, which are each assigned a zero flow boundary.

5.4.2 Change in Downstream Boundaries

Northside and Calumet River boundaries

For both of these models the downstream boundary is Lake Michigan. Therefore, the downstream boundary condition for each of these models is the hourly water level of Lake Michigan. During the study period four gages were measuring hourly water-surface elevation data in the Chicago area: the MWRDGC gages at the CRCW and Wilmette Pumping Station; the National Oceanic and Atmospheric Administration lake level gage no. 9087044 at Calumet Harbor, IL; and the USGS gage no. 04087440 Lake Michigan at Chicago Lock at Chicago, IL. The data from these gages were all converted to the North American Vertical Datum of 1988 and then to the Chicago City Datum. The data from these gages were evaluated to determine the average water-surface elevation to be used as the downstream boundary condition for both the Northside and Calumet River models.

Figures L.1 and L.2 in Addendum L show the measured water-surface elevations from the four gages for WYs 2001 and 2003, respectively. For WY 2001 the USGS gage is consistently low from October 1, 2000 to March 18, 2001 (Figure L.1). James Duncker (USGS, written commun., July 2, 2013) indicated that the USGS gage was at an exposed location from August

1997 to July 2001. It was then moved to more sheltered location between the CRCW gates and Chicago Lock in July 2001. Finally, the gage was discontinued in September 2003 and re-established in August 2007. Review of Figure L.1 clearly shows the inconsistent water-surface elevation data prior to July 2001 at the original measurement location. Therefore, the USGS data were omitted in the computation of the average water-surface elevation for Lake Michigan for WY 2001. For WY 2003, the USGS gage at the CRCW is consistently low compared to the other gages (Figure L.2), and, thus it was again omitted in the computation of the average water-surface elevation for Lake Michigan for WY 2003. Figures 5.29 and 30 show the average water-surface elevation for Lake Michigan used as the downstream boundary condition for the Northside and Calumet River models for WYs 2001 and 2003, respectively.

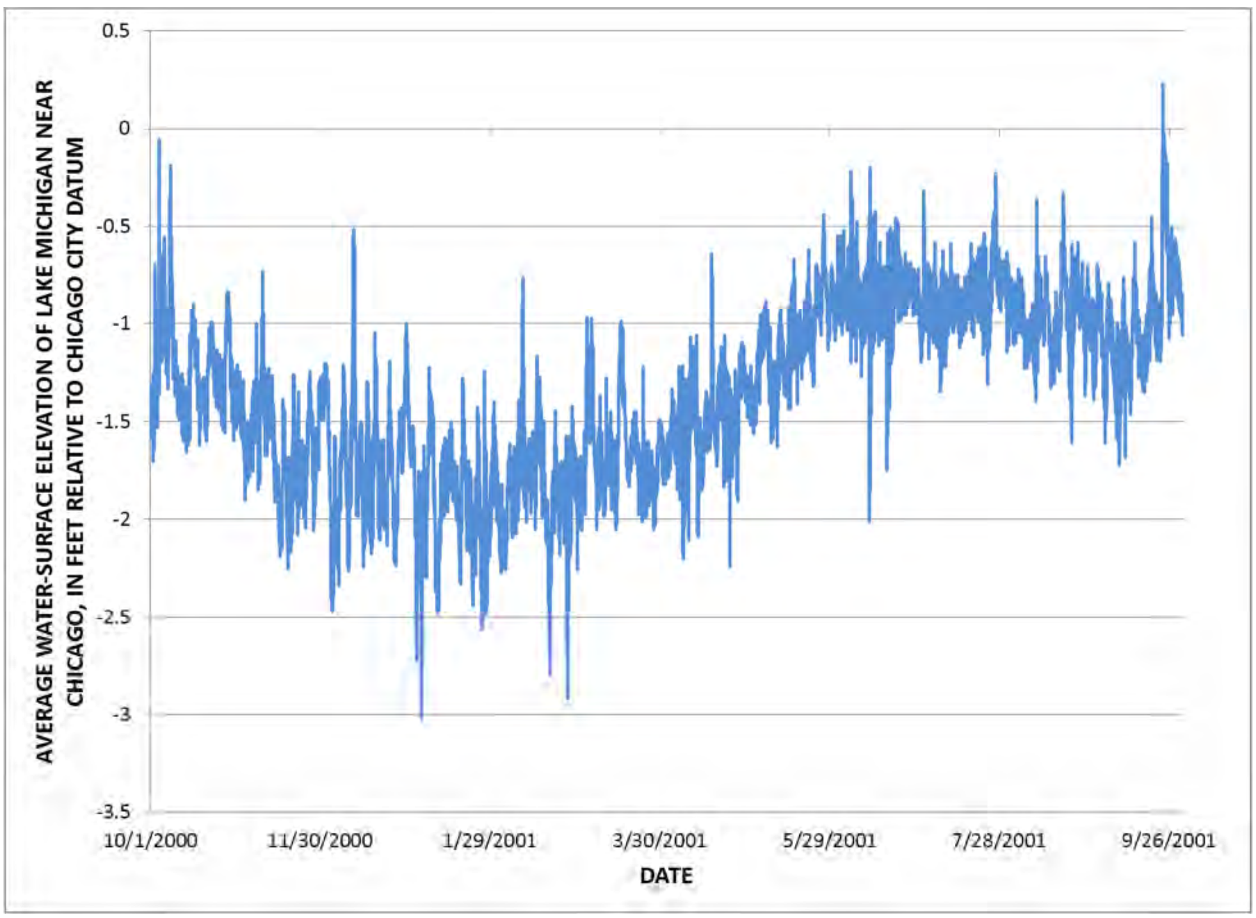


Figure 5.29. Average water-surface elevation of Lake Michigan near Chicago for Water Year 2001.

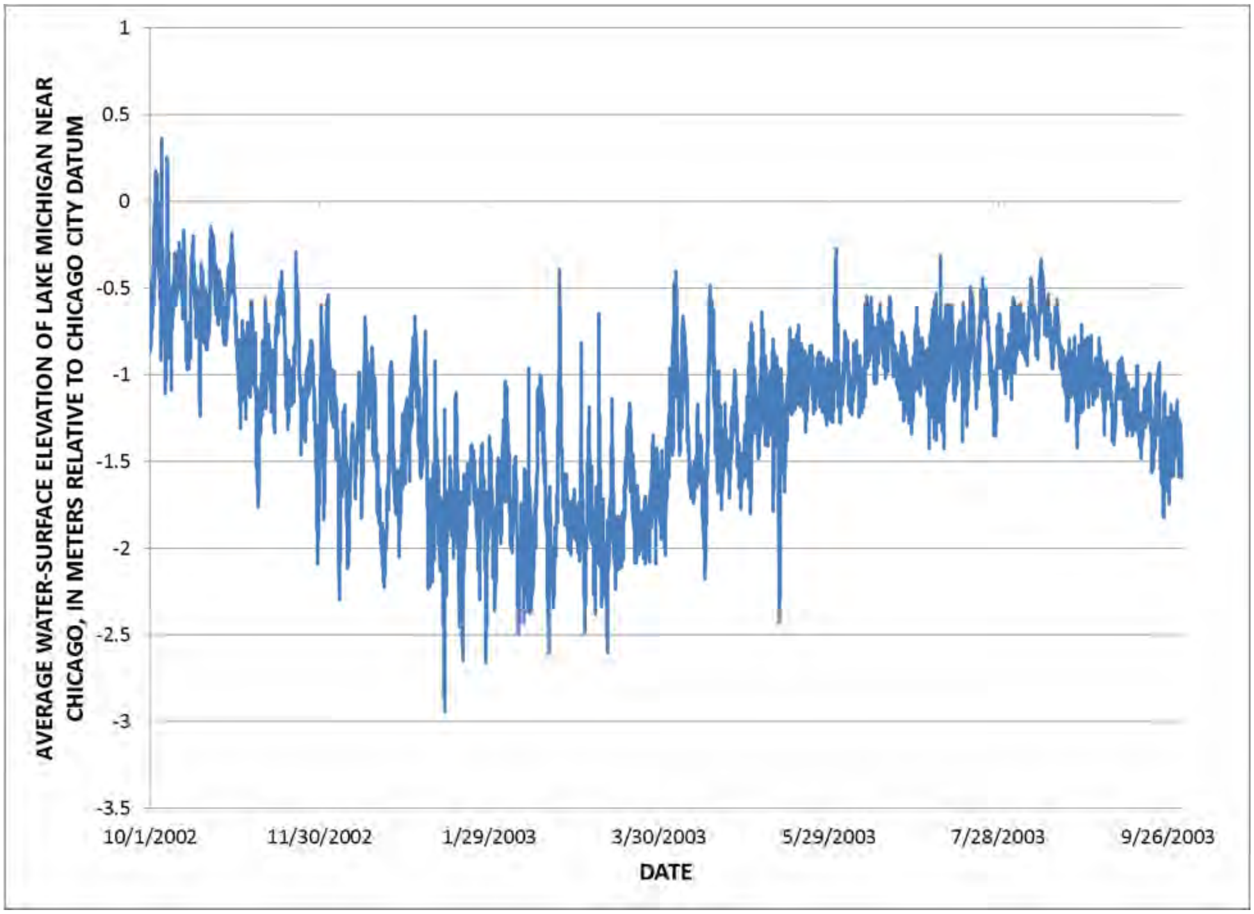


Figure 5.30. Average water-surface elevation of Lake Michigan near Chicago for Water Year 2003.

Figure L.3 in Addendum L shows the measured water-surface elevations from the four gages for WY 2008. From Figure L.3 it can be seen that the MWRDGC gage at Wilmette is consistently low compared to the other gages. Thus, the MWRDGC data for Wilmette was not included when determining the average Lake Michigan water-surface elevation for WY 2008. Figure 5.31 shows the average water-surface elevation for Lake Michigan used as the downstream boundary condition for the Northside and Calumet River models for WY 2008.

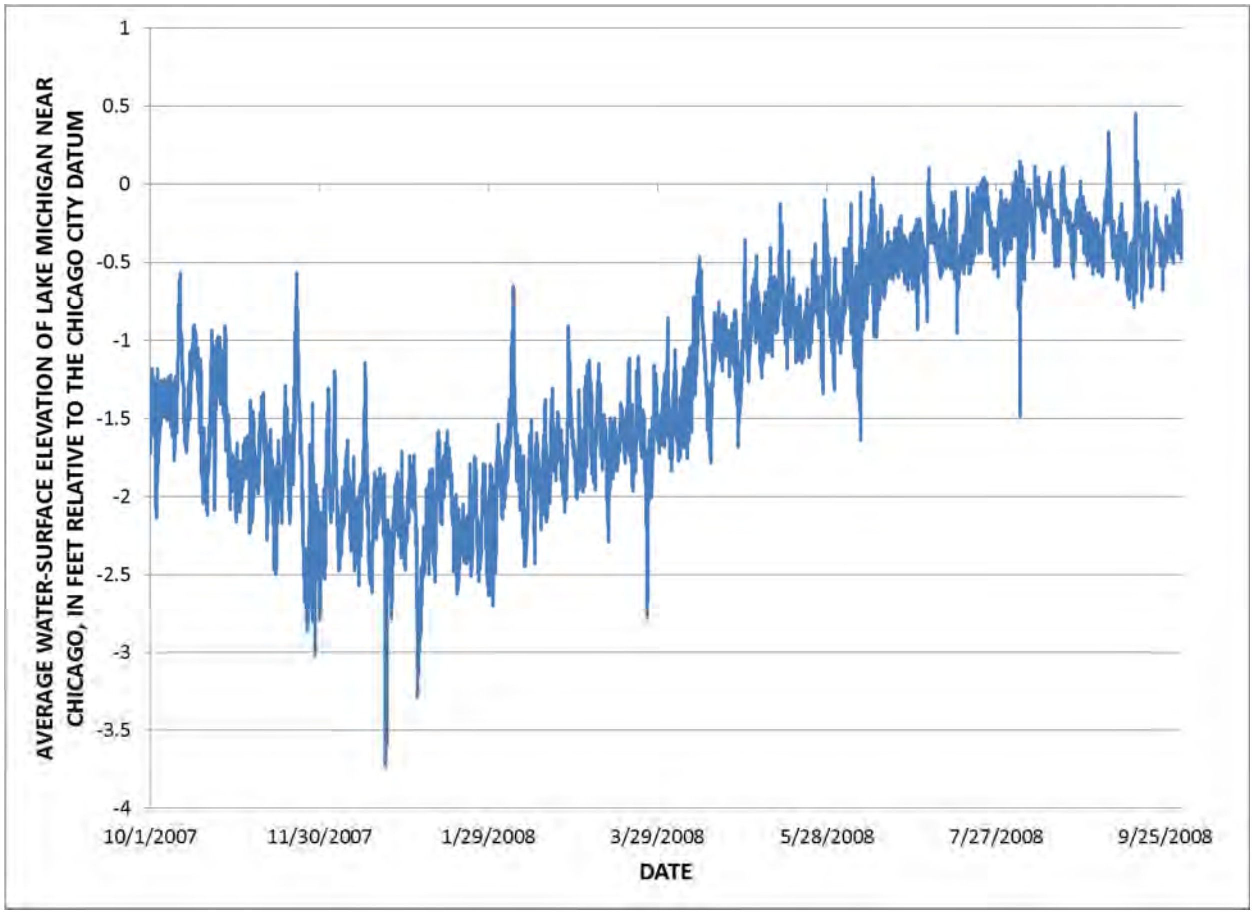


Figure 5.31. Average water-surface elevation of Lake Michigan near Chicago for Water Year 2008.

Downstream Boundary at the Lockport Controlling Works

Figures 5.32 to 5.34 show sum of the inflows for the "No Project" alternative for Future conditions compared with the sum of the inflows for the "Midsystem Separation" alternative—CSSC and Calumet-Sag Channel model—for Baseline and Future conditions for WYs 2001, 2003, and 2008, respectively. These figures clearly show the large shift in flows away from passing through the CSSC to Lockport and toward Lake Michigan. Also, these figures show that the range of inflows going to Lockport for the "Midsystem Separation" alternative is between 350 and 8100 cfs. Thus, nearly all the inflows for the "Midsystem Separation" alternative are in the range of the flow-stage combinations shown in Figure 5.22, so it was initially attempted to retain the measured water-surface elevations at the Lockport Controlling Works during dry weather and approximating the water levels during storm periods with appropriate linear water-surface elevations as was done for the "No Project" and "Lakefront Separation" alternatives. The large reductions in storm flows passing through the CSSC means that for the "Midsystem Separation" alternative the controlling works gates and powerhouse sluice gates would not be needed to pass storm flows. However, using the measured water-surface elevations resulted in highly unstable computed flows making it necessary to find an alternate way to define the downstream boundary condition for the "Midsystem Separation" alternative.

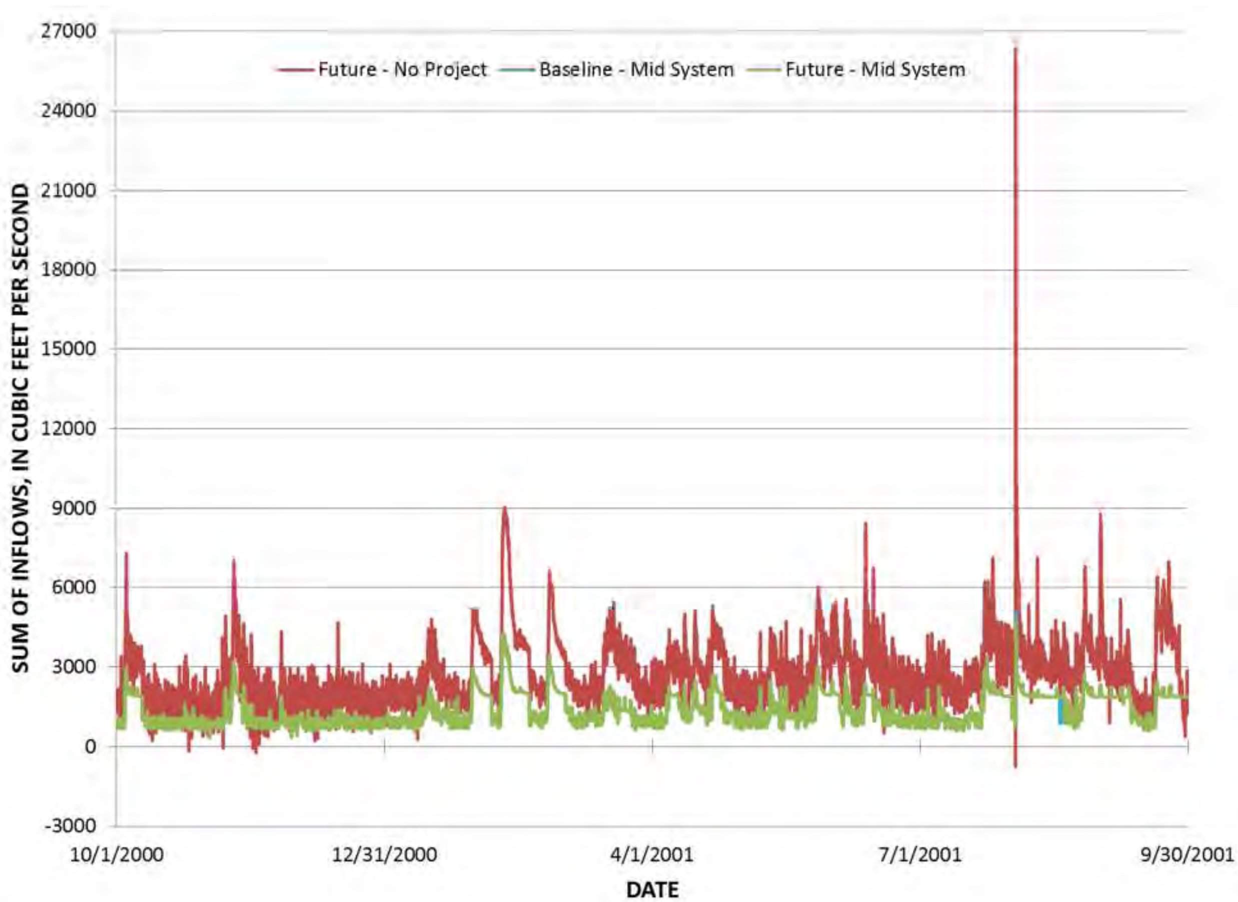


Figure 5.32. Sum of the inflows going to the Lockport Controlling Works on the Chicago Sanitary and Ship Canal for the "No Project" alternative under Future conditions and the "Midsystem Separation" alternative under Baseline and Future conditions for Water Year 2001.

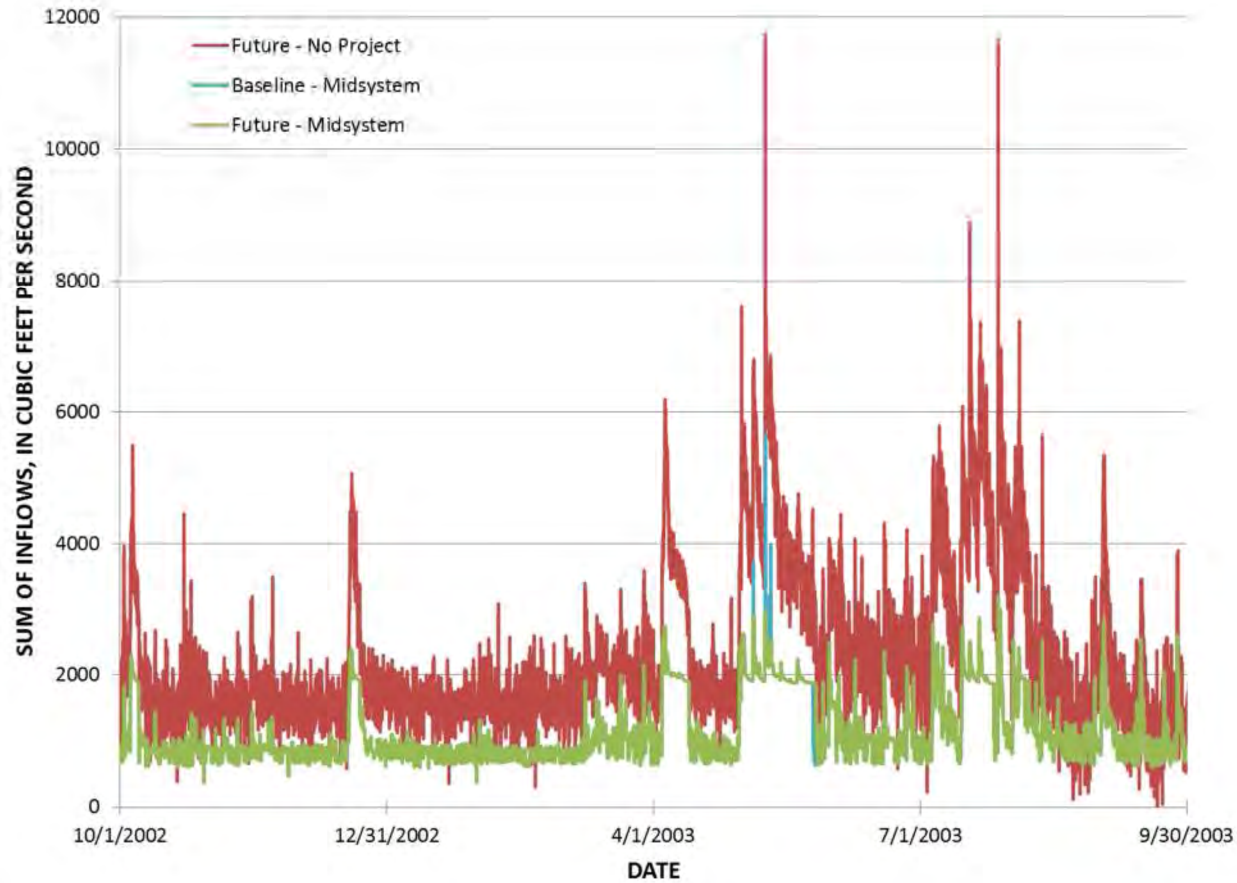


Figure 5.33. Sum of the inflows going to the Lockport Controlling Works on the Chicago Sanitary and Ship Canal for the "No Project" alternative under Future conditions and the "Midsystem Separation" alternative under Baseline and Future conditions for Water Year 2003.

The USACE has developed a HEC-RAS model of the CAWS that includes (T. Y. Su, USACE, written commun., April 8, 2013):

> "custom rules (programmed by using the built-in user interface) for the boundary condition at Lockport. That is, in anticipation of storm runoff to the waterway sluice gates at Lockport will open until the stage at the Cal-Sag Junction falls to -4.0 CCD; at this point the sluice gates will close one by one (if more than one is opened). The flow at Lockport is computed by the discharge equation of the sluice gates."

The USACE, Chicago District, provided the flow versus water-surface elevation results of the HEC-RAS model for the Lockport Controlling Works on the CSSC for a series of design events. For the "Midsystem Separation" alternative nearly all the sum of inflows values are less than 3530 cfs (100 m^3/s) (for Baseline conditions 43, 6, and 63 sums were greater than 3530 cfs for WYs 2001, 2003, and 2008, respectively; for Future conditions 42, 0, and 61 sums were greater than 3530 cfs for WYs 2001, 2003, and 2008, respectively). Thus, the analysis of the HEC-RAS "rating" at the Lockport Controlling Works focused on flows less than 3530 cfs as shown in Figure 5.35 (derived from the results of the 1% probability of exceedance flood). For flows less than 3530 cfs a relatively narrow range of water-surface elevations are shown in Figure 5.35. Thus, the average water-surface elevation for flows less than 3530 cfs of -4.00 ft was applied as a constant downstream boundary condition at the Lockport Controlling Works for the "Midsystem Separation" alternative.

Figure 5.36 shows the computed flows on the CSSC at the Lockport Controlling Works for the initial simulation applying the measured and the second simulation using the constant downstream boundary condition for the case of Baseline conditions for WY 2008. The smoothness of the results for the case of the constant downstream boundary condition indicates the reasonableness of using this simple downstream boundary condition. Also, for the storm periods when the water-surface elevations were adjusted to near constant values the flow results of the two simulations are nearly identical in Figure 5.36 indicating the relative insensitivity of the computed flows to the assumed downstream boundary condition. That is, a downstream boundary water-surface elevation within a reasonable range can yield reliable flow results.

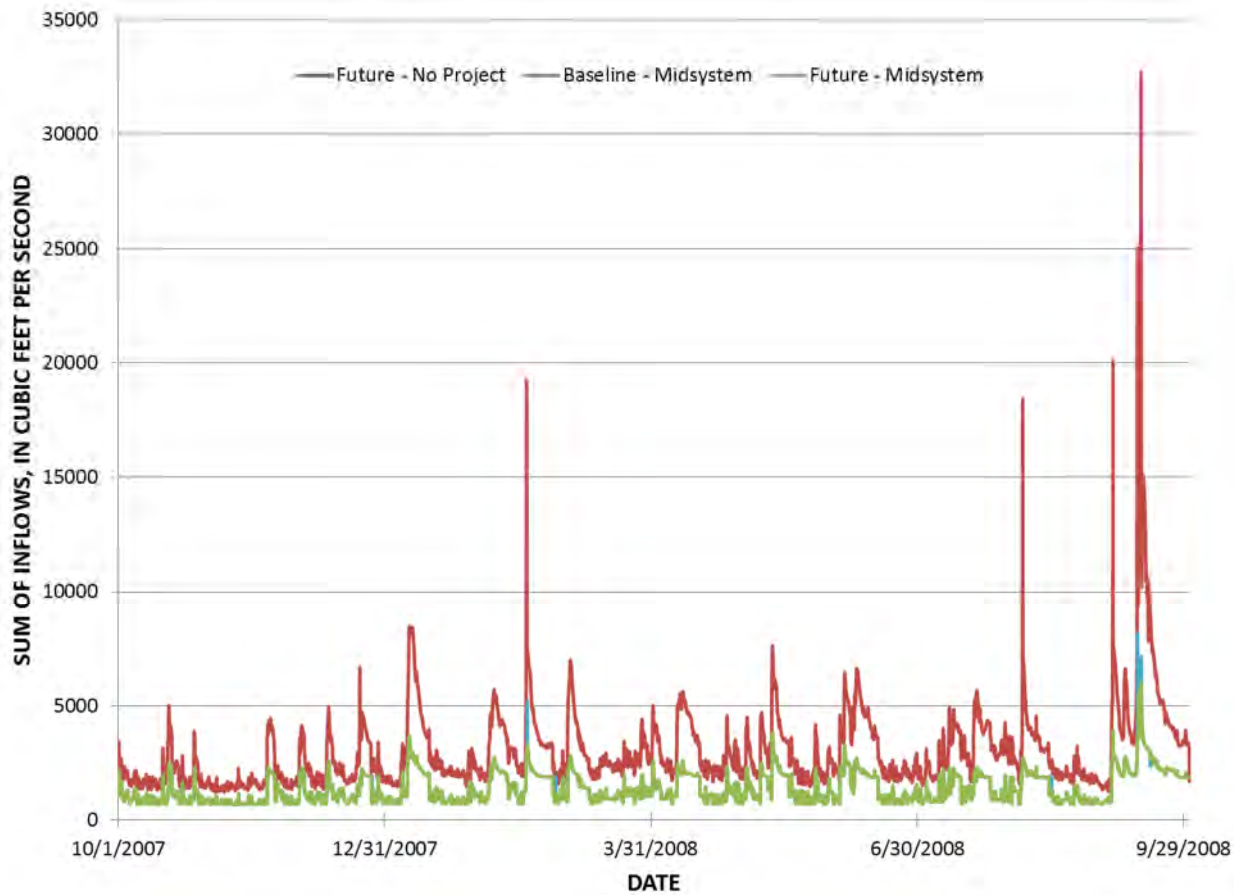


Figure 5.34. Sum of the inflows going to the Lockport Controlling Works on the Chicago Sanitary and Ship Canal for the "No Project" alternative under Future conditions and the "Midsystem Separation" alternative under Baseline and Future conditions for Water Year 2008.

5.4.3 Change in Temperature and Other Water Quality Loads

The "Midsystem Separation" alternative much more substantial changes in temperatures are expected because of the changes in flow directions and the separation of the watersheds. Thus, in the following subsections the temperature models for the Northside, Calumet River, and CSSC and Calumet-Sag Channel models are described and examples of the computed temperatures are presented.

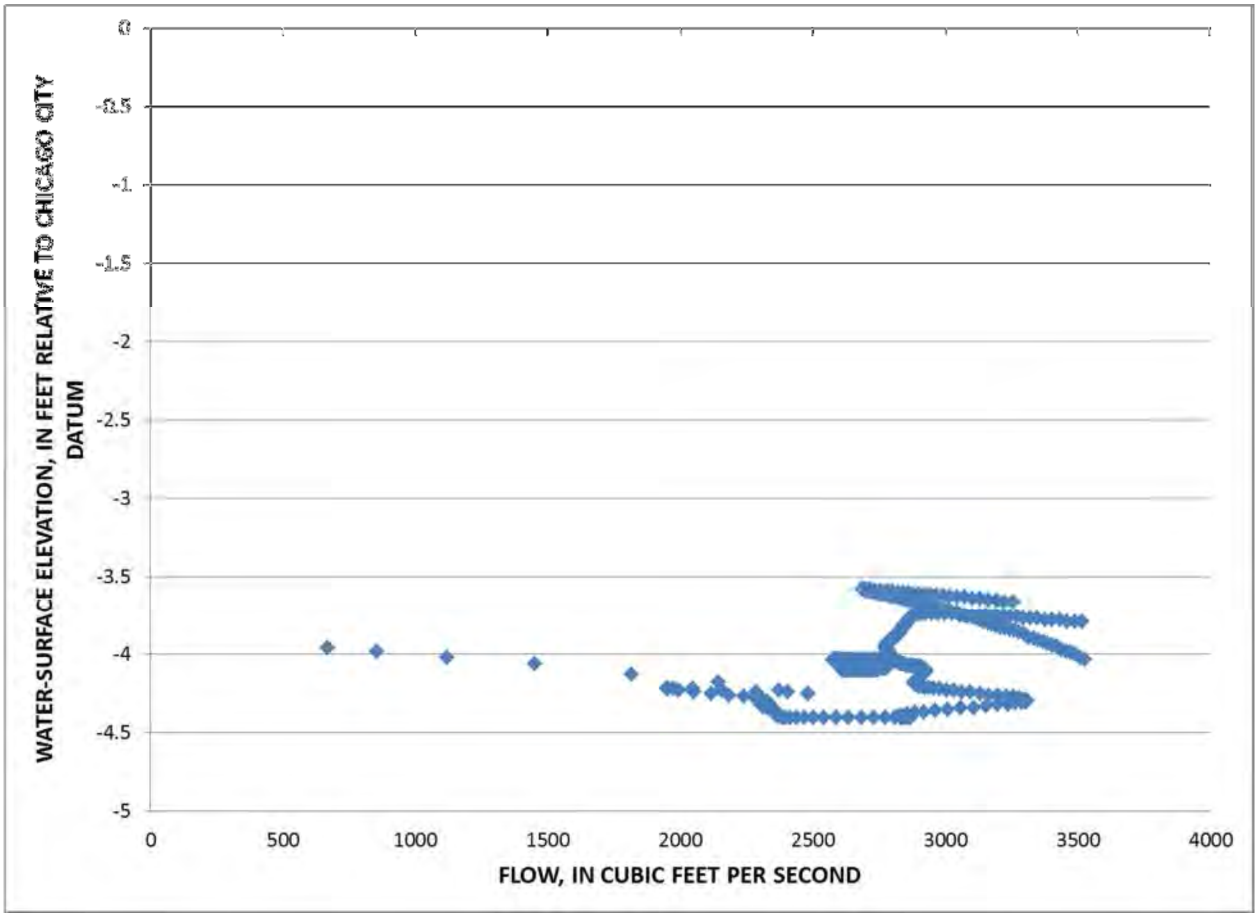


Figure 5.35. Relation between flow and water-surface elevation at the Lockport Controlling Works determined by the U.S. Army Corps of Engineers HEC-RAS model of the Chicago Area Waterways System.

Northside Model

For the Northside model the temperatures are estimated/computed as follows:

- Temperature at Main Street is set equal to that of the effluent from the O'Brien WRP.
- Temperature at Simpson Street is computed from that at Main Street using the regression equation in Table 2.2 for negative flows at Wilmette.

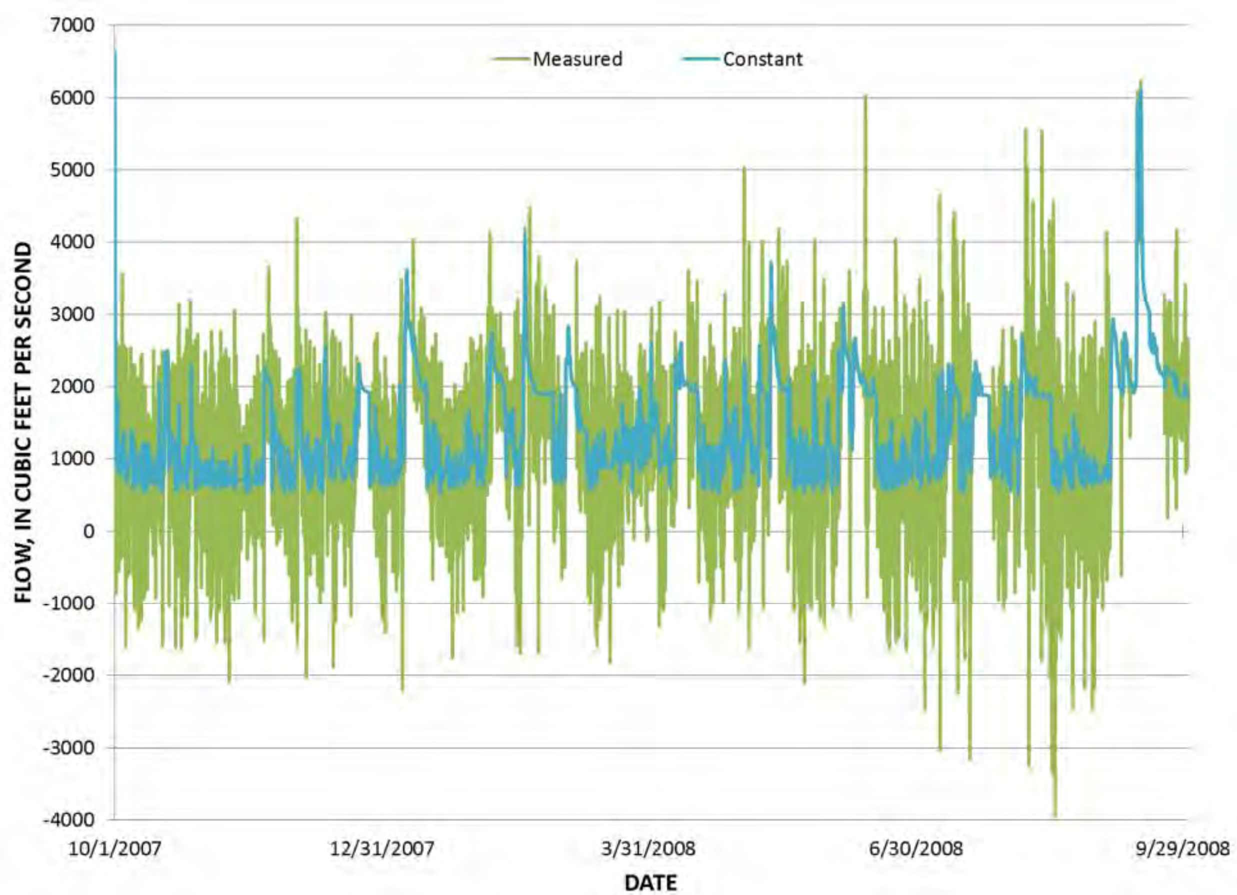


Figure 5.36. Computed flows on the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the "Midsystem Separation" alternative for Baseline conditions for Water Year 2008 obtained by using the measured water-surface elevations adjusted for reduced storm runoff (measured) and by using a constant downstream water-surface elevation.

- Temperature at Linden Street is maintained the same as for the other alternatives because Linden Street represents the temperature of the near shore Lake Michigan.
- Temperature at Devon Avenue is computed as per Table 2.2 with the O'Brien WRP effluent temperature replacing MBNB (for WYs 2001 and 2003).
- Temperature at Foster Avenue is computed as per Table 2.2 with the O'Brien WRP effluent temperature replacing MBNB (for WY 2008).

- Temperature at Lawrence Avenue, Addison Street, Fullerton Avenue, Division Street, and Kinzie Street then are computed location-by-location as per the regression equations in Table 2.2.
- Temperature at Clark Street is set equal to that at Kinzie Street.
- Temperature at the CRCW is maintained the same as for the other alternatives because the CRCW represents the temperature of the near shore Lake Michigan.
- Temperature at Jackson Boulevard is set equal to that at Kinzie Street.
- Temperature at Loomis Street and Cicero Avenue then are computed location-by-location as per the regression equations for "power off" in Table 2.2.

Figure 5.37 shows the computed temperatures for the Northside model domain for the "No Project" and "Midsystem Separation" alternatives for Future Conditions for WY 2008. The results for Baseline conditions for WY 2008 and for Baseline and Future conditions for WYs 2001 and 2003 are shown in Addendum K.

Figure 5.37 shows the continuous flow of O'Brien WRP effluent for the "Midsystem Separation" alternative will substantially raise temperature on the NSC compared to the "No Project" alternative. It also shows that the reduction in the O'Brien WRP effluent passing through the NBCR does not substantially affect temperatures on the NBCR. Similarly, the temperatures for the "Midsystem Separation" alternative are not substantially different than for the "No Project" alternative at Clark Street on the Chicago River main stem, Jackson Boulevard on the SBCR, and Cicero Avenue on the CSSC. These results imply that WRP effluent temperatures and climatic factors dominate the temperature regime in this portion of the CAWS.

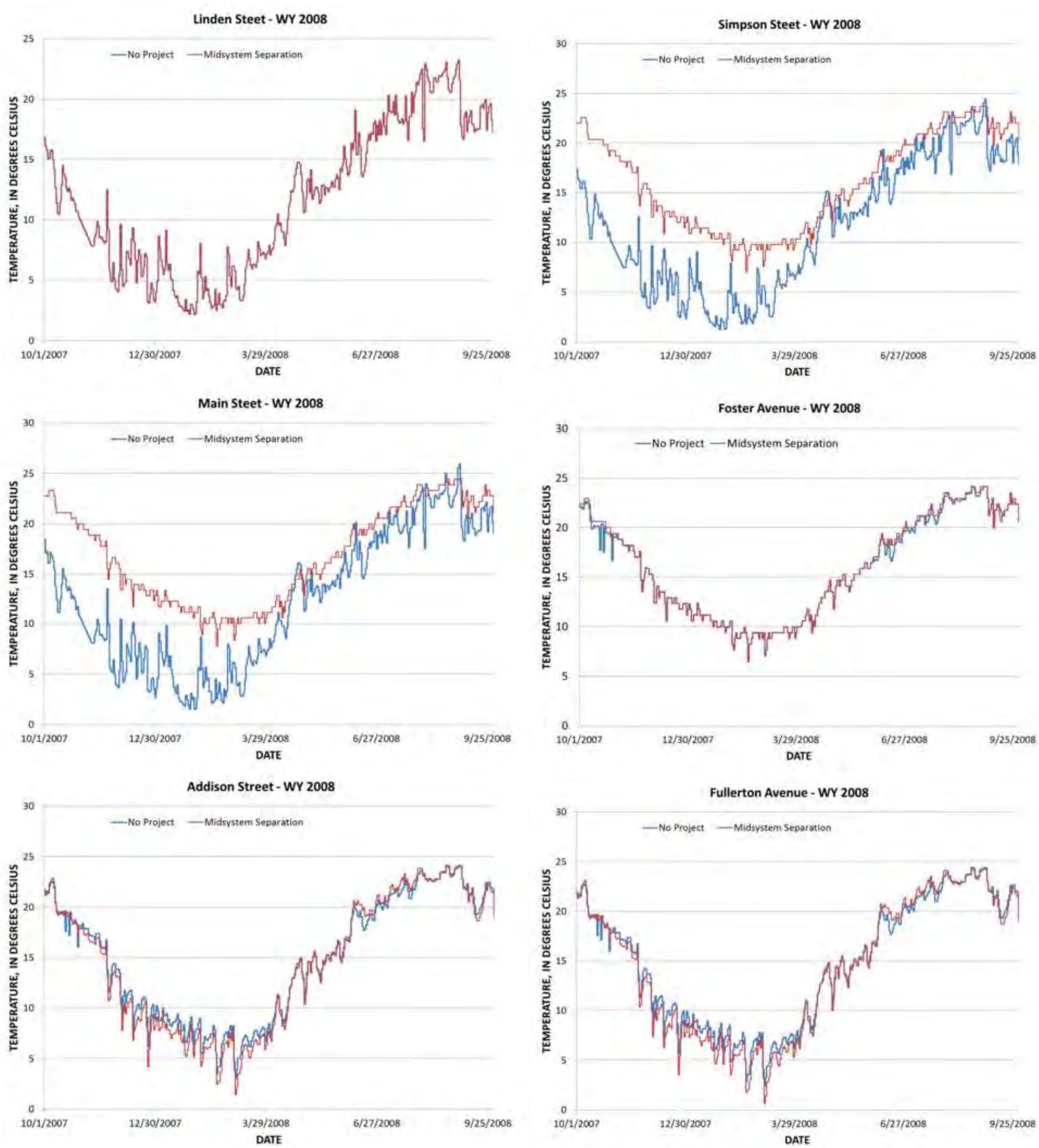


Figure 5.37. Comparison of Temperatures in the Northside model domain for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2008.

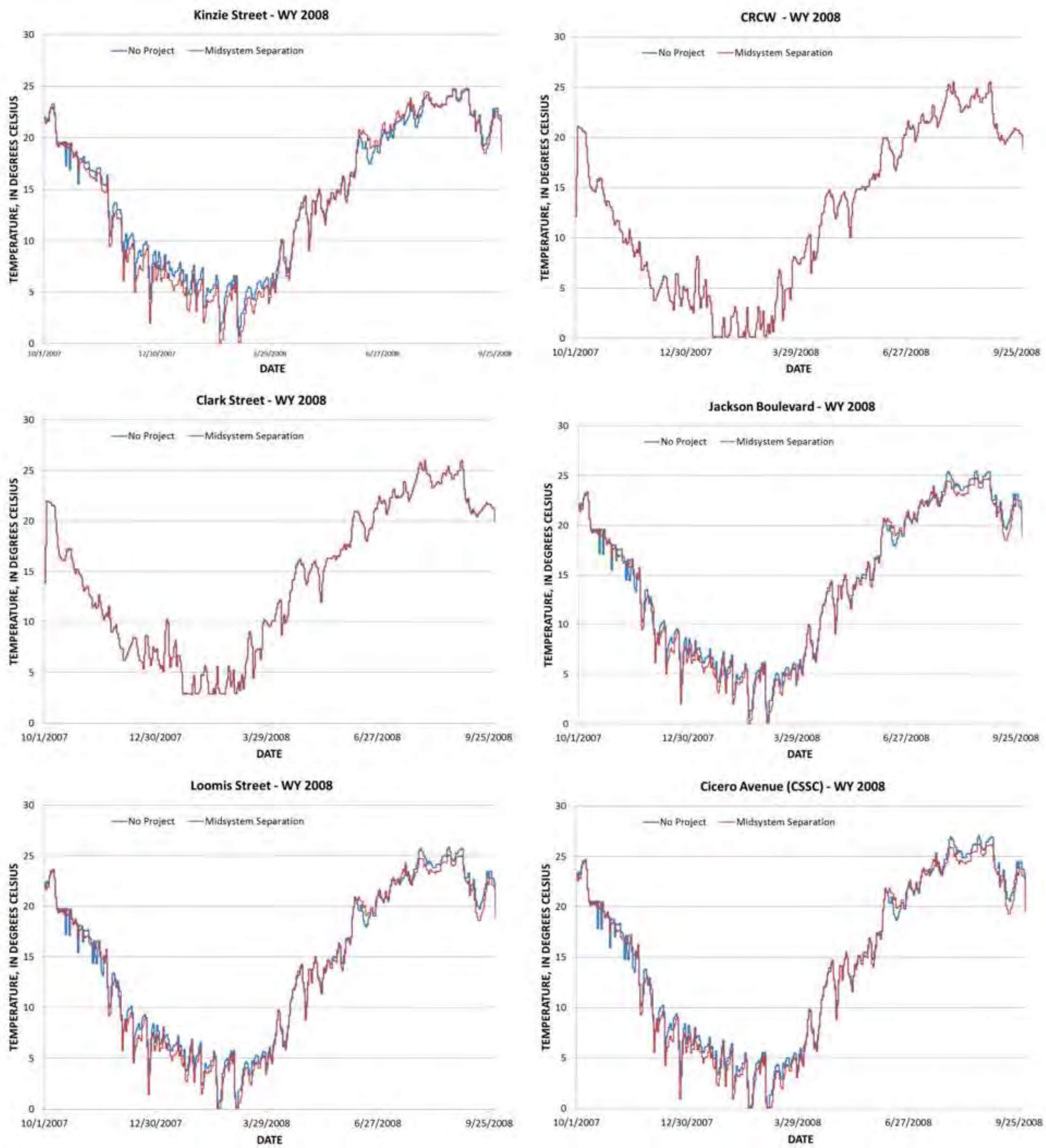


Figure 5.37 (cont.) Comparison of Temperatures in the Northside model domain for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2008.

Calumet River Model

For the Calumet River model the temperatures are estimated/computed as follows:

- Temperature at Ashland Avenue on the Little Calumet River (south) is taken the measured values at this location.
- Temperature at Halsted Street is set equal to that at Ashland Avenue on the Little Calumet River (south).
- Temperature just upstream of the Calumet WRP is estimated as follows

  Just Upstream of Calumet WRP = 0.81139 Halsted + 2.44414 (determined by reverse regression of MBC in Table 2.3).
- Temperature at Central & Wisconsin Railroad is taken as the mass balance of the temperature just upstream of the Calumet WRP and the temperature of the Calumet WRP effluent.
- Temperature at Conrail Railroad is computed from that at Central & Wisconsin Railroad using the regression equation in Table 2.3 for negative flows at the O'Brien Lock and Dam.
- Temperature at 130th Street is computed from that at Conrail Railroad using the regression equation in Table 2.3 for negative flows at the O'Brien Lock and Dam.
- Temperature at Lake Michigan is taken as the daily shore measurement at the Jardine Water Treatment Plant for WYs 2001 and 2003 and at the South Water Treatment Plant for WY 2008.
- Temperature at Division Street is set equal to that at Ashland Avenue on the Little Calumet River (south).

- Temperature at Kedzie Avenue is computed from that at Division Street using the regression equation in Table 2.3.

Figure 5.38 shows the computed temperatures for the Calumet River model domain for the "No Project" and "Midsystem Separation" alternatives for Future Conditions for WY 2008. The results for Baseline conditions for WY 2008 and for Baseline and Future conditions for WYs 2001 and 2003 are shown in Addendum K.

Figure 5.38 clearly shows as upstream and downstream directions switch between the "No Project" and "Midsystem Separation" alternatives the temperature regimes also reverse. For the "No Project" alternative 130th Street, Conrail Railroad, and Central & Wisconsin Railroad were upstream of the Calumet WRP and prone to low temperatures, but for the "Midsystem Separation" alternative they are downstream of the Calumet WRP and, thus, experiences much higher temperatures. Conversely, for the "No Project" alternative Halsted Street, Division Street, and Kedzie Avenue were downstream of the Calumet WRP and prone to higher temperatures, but for the "Midsystem Separation" alternative they are upstream of the Calumet WRP and, thus, experiences much lower temperatures.

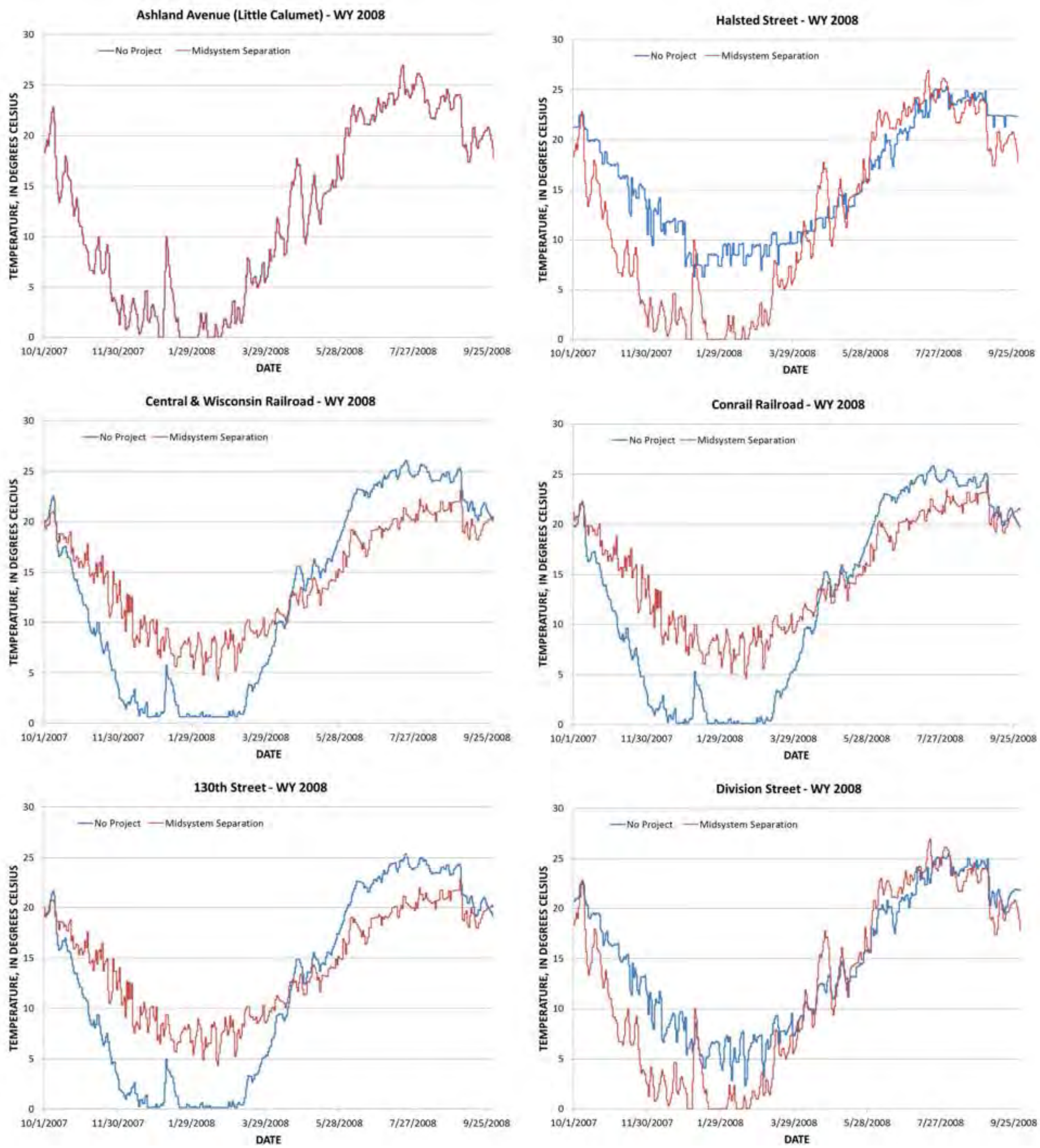


Figure 5.38. Comparison of Temperatures in the Calumet River model domain for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2008.

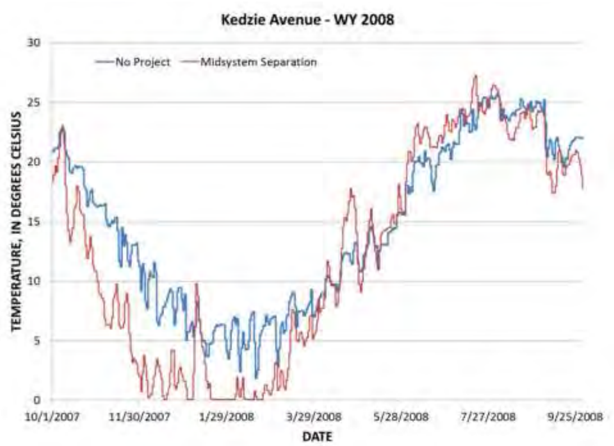


Figure 5.38 (cont.) Comparison of Temperatures in the Calumet River model domain for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2008.

CSSC and Calumet-Sag Channel Model

For the CSSC and Calumet-Sag Channel model the temperatures are estimated/computed as follows:

- Temperature at Cicero Avenue on the Calumet-Sag Channel is set equal to that at Ashland Avenue on the Little Calumet River (south).
- Temperature at the Baltimore & Ohio Railroad is computed as per Table 2.2 with the Stickney WRP effluent temperature replacing MBST.
- Temperature at all other locations is computed as per the regression equations in Tables 2.2 and 2.3.

Figure 5.39 shows the measured hourly temperatures at 130th Street on the Calumet River and the Little Calumet River (south) at Ashland Avenue for WY 2003. The temperatures at these locations are primarily driven by climatic factors just as will be the case for the Calumet-Sag channel on the Mississippi River side of the barrier installed for the "Midsystem Separation" alternative. Given that the climatic forcing results in similar temperatures at 130th Street and Ashland Avenue in Figure 5.39, it is reasonable to apply the measured temperature at Ashland

Avenue to the Cicero Avenue at the upstream end of the Calumet-Sag Channel in the "Midsystem Separation" alternative. Figure 5.40 shows the computed temperatures for the CSSC and Calumet-Sag Channel model domain for the "No Project" and "Midsystem Separation" alternatives for Future Conditions for WY 2008. The results for Baseline conditions for WY 2008 and for Baseline and Future conditions for WYs 2001 and 2003 are shown in Addendum K.

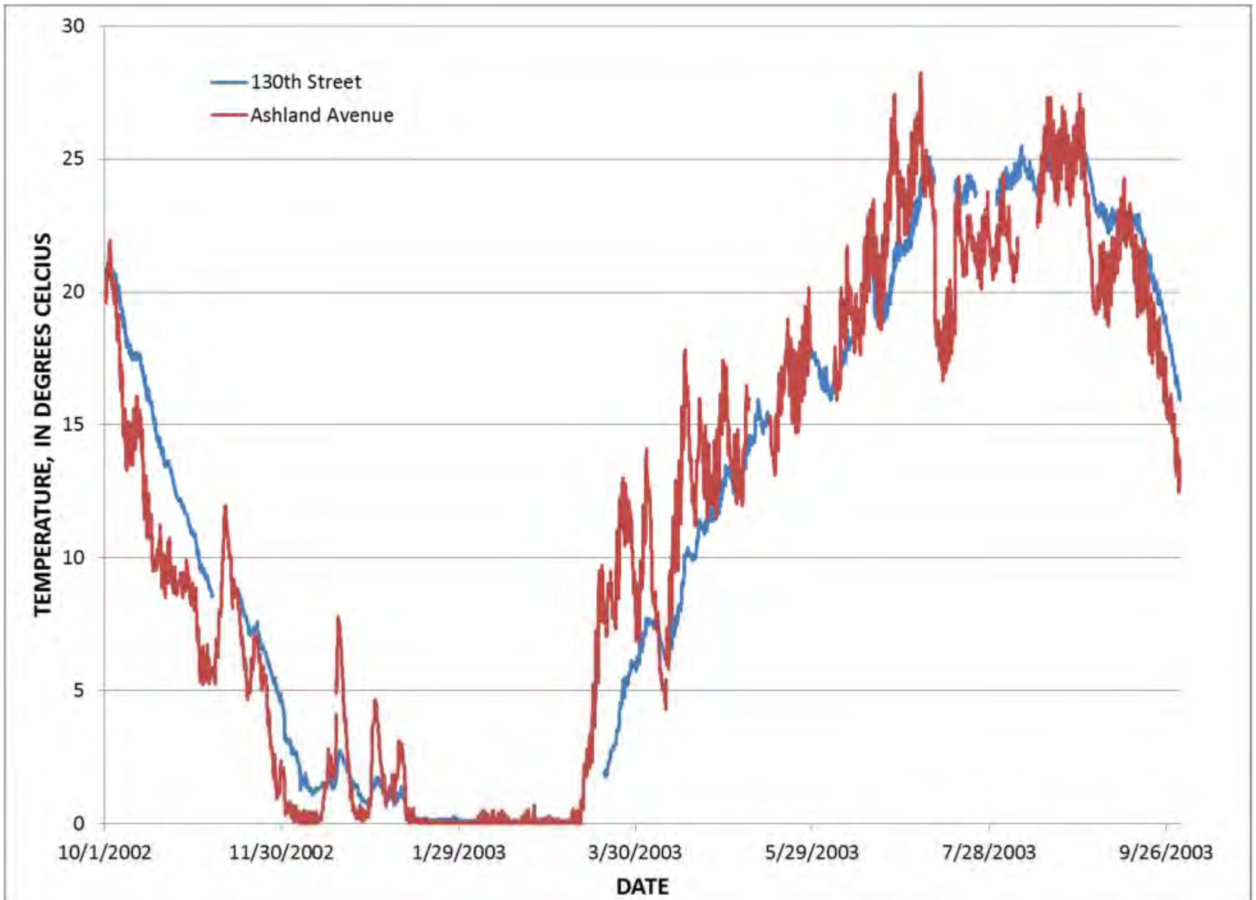


Figure 5.39. Measured hourly temperatures at 130th Street on the Calumet River and Ashland Avenue on the Little Calumet River (south) for Water Year 2003.

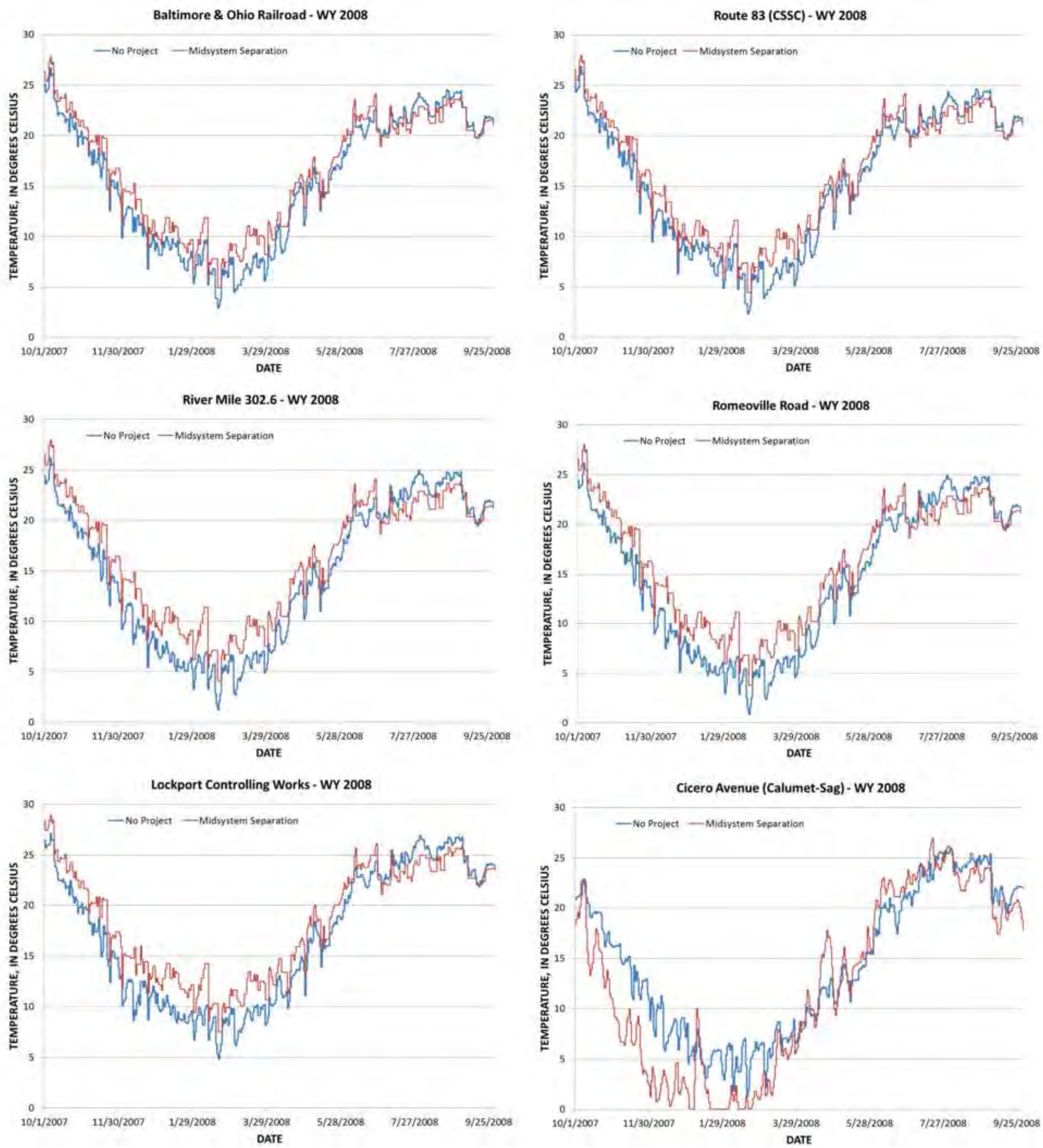


Figure 5.40. Comparison of Temperatures in the CSSC and Calumet-Sag Channel model domain for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2008.

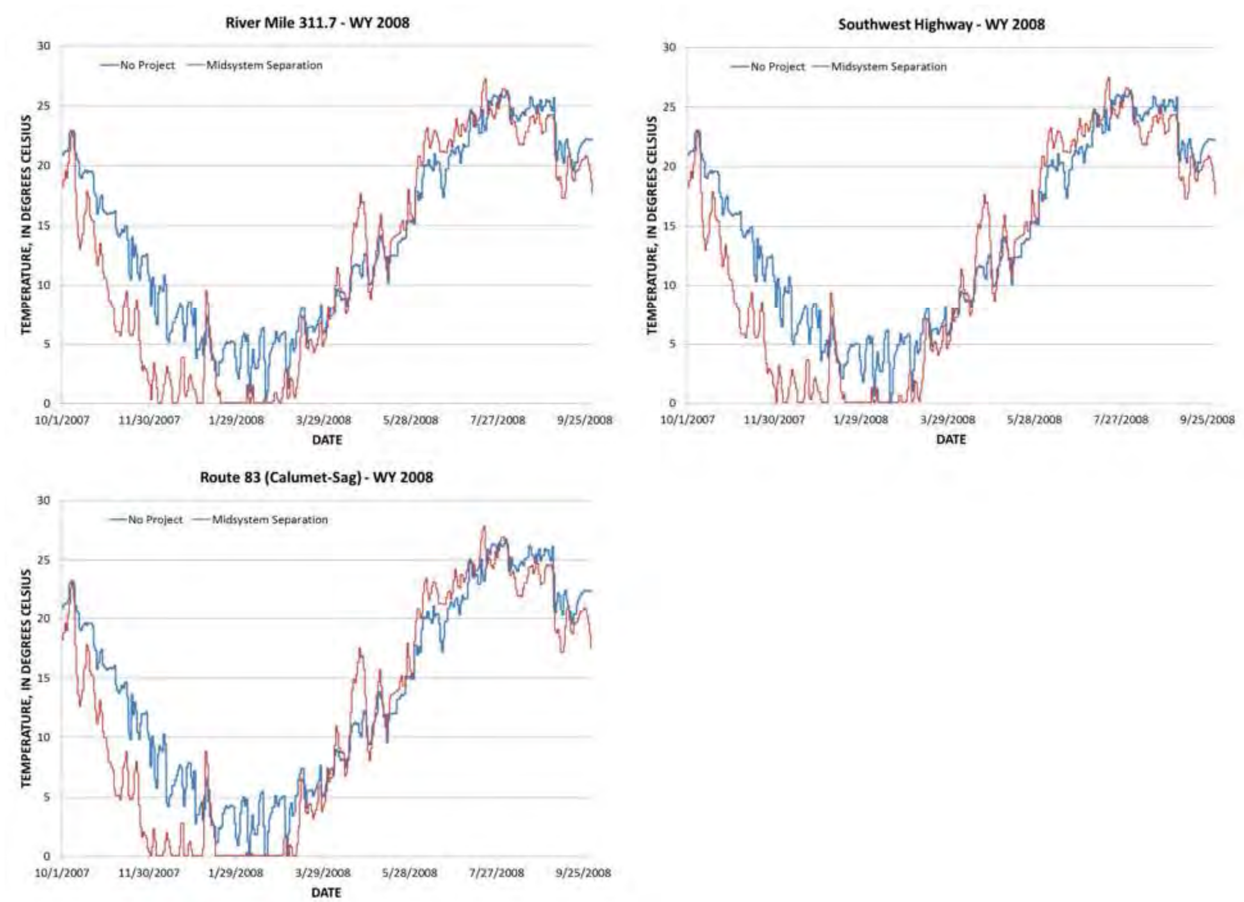


Figure 5.40 (cont.) Comparison of Temperatures in the CSSC and Calumet-Sag Channel model domain for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2008.

For the CSSC, the "Midsystem Separation" alternative consistently shows higher temperatures than the "No Project" alternative in Figure 5.40 indicating that the upstream flows tend to cool the effluent from the Stickney WRP. For the Calumet-Sag Channel, the "Midsystem Separation" alternative consistently shows lower temperatures than the "No Project" alternative from October through March, but then in April through September the "Midsystem Separation" and "No Project" alternatives yield similar temperatures.

Changes in Aeration Station Operations

In the simulations done for the "Midsystem Separation" alternative, the operation hours of the Devon Avenue and Webster Avenue IASs on the NSC and NBCR, respectively, and of SEPA station 1 on the Calumet River, SEPA station 2 on the Little Calumet River (north), and SEPA station 5 at Sag Junction were assumed to be the same as for actual operations in each of WYs 2001, 2003, and 2008. It should be noted that this assumes that the intakes for these SEPA stations will be relocated to be upstream of the station now that the flow in the receiving stream is reversed, and for the case of SEPA station 5 the intake would need to be moved to the CSSC. The DO loads yielded by each aeration station are a function of the DO concentration upstream from the station. Thus, because the DO concentrations change for the "Midsystem Separation" alternative from the current conditions and "No Project" and "Lakefront Separation" alternatives, the DO load from each station is different from that for the previously evaluated cases. The revised aeration station loads are computed sequentially so the effect of the upstream stations on the downstream stations is accounted for in the simulations.

For the SEPA stations to effectively deliver oxygen to the receiving body there needs to be flow in the receiving body to distribute the oxygen. SEPA stations 3 and 4 discharge to the Calumet-Sag Channel that becomes stagnant for the "Midsystem Separation" alternative. Thus, because these stations would not be effective for the "Midsystem Separation" alternative they were considered to be shut down with no oxygen loads in the simulation of conditions resulting for the "Midsystem Separation" alternative.

Chapter 6 – ALTERNATIVE COMPARISON FOR THE REPRESENTATIVE "NORMAL" YEAR (WY 2001)

The DUFLOW model yields simulated values of carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia, nitrate, organic phosphorus, inorganic phosphorus, algae as chlorophyll a, dissolved oxygen (DO), total suspended solids, chloride, pH, and fecal coliform bacteria. It was decided to report the variations in concentrations of DO, fecal coliform bacteria, chloride, and total phosphorus throughout the CAWS to compare among the three alternatives—"No Project," "Lakefront Separation," and "Midsystem Separation." Also important are the loads of the various constituents to Lake Michigan for the different alternatives. Obviously, there are no loads to Lake Michigan for the "Lakefront Separation" alternative. For the representative "normal" year (WY 2001), reported in this chapter, under actual operational conditions there were flow reversals to Lake Michigan on August 2nd at the CRCW and Wilmette and August 31st at Wilmette. However, with the McCook Reservoir Stage 1 operational enough of the combined sewer flows were captured such that no flow reversals to Lake Michigan are needed under the Baseline or Future conditions for the "No Project" alternative.

This chapter presents the comparison of the different alternatives in terms of concentrations throughout the CAWS and compliance with water-quality standards for DO, fecal coliform bacteria, and chloride, concentrations throughout the CAWS for total phosphorus, and loads to Lake Michigan for CBOD, total nitrogen, total phosphorus, total suspended solids, chloride, and fecal coliform bacteria. These results are reported only for the Future conditions to give a picture of the ultimate performance for any of these alternatives.

6.1 Comparison of Simulated Dissolved Oxygen Concentrations

6.1.1 Concentration vs. Time

The DUFLOW model yields computed values of any of the simulated water-quality constituents and properties at any the computational points in the CAWS (more than 100 points). Thus, to keep the comparison manageable it is focused on the DO measurement points monitored by the MWRDGC and used to calibrate and verify the model. In this report the results are presented for the various waterway reaches of the CAWS: the upper NSC; the lower NSC and NBCR (downstream of the O'Brien WRP); Chicago River main stem, SBCR, and upper CSSC (above the Stickney WRP); lower CSSC; Calumet River and Little Calumet River (north); and the Calumet-Sag Channel.

Figure 6.1 shows the computed DO concentrations on the upper NSC at Simpson Street and Main Street. The "Midsystem Separation" alternative yields high DO concentrations throughout most of the year. This is because the opening of the NSC to Lake Michigan yields a constant flow from the O'Brien WRP through the NSC resulting in better DO concentrations than those for the stagnant flow conditions that are present in the upper NSC throughout much of the year for the "No Project" and "Lakefront Separation" alternatives. This can be best seen in the computed DO concentrations at Main Street. The "No Project" alternative yields higher DO concentrations than the other two alternatives for the months of June through August reflecting the high quality Lake Michigan water released into the upper NSC as discretionary diversion during these months. At Simpson Street, the "No Project" alternative also yields the highest DO concentrations from late March through the end of May because at these times small non-discretionary flows from Lake Michigan at Wilmette improve DO conditions up to Simpson Street (1.3 mi downstream). However, by the time the flows reach Main Street (2 mi downstream from Simpson Street) much of the beneficial effects of these small flows have dissipated and the "No Project" and "Lakefront Separation" alternatives yield very similar DO concentrations reflecting the fact that the "No Project" alternative has nearly zero flow at Wilmette outside of June through August. Finally, at both locations the "Lakefront Separation" alternative yields the lowest DO concentrations throughout the year because of the totally stagnant flows in this reach. In particular, at both locations the CSOs resulting from the storms of August 2nd and September 19th drop a lot of organic load into the upper NSC that takes a long time to dissipate resulting long periods of very low DO concentrations throughout August and September.

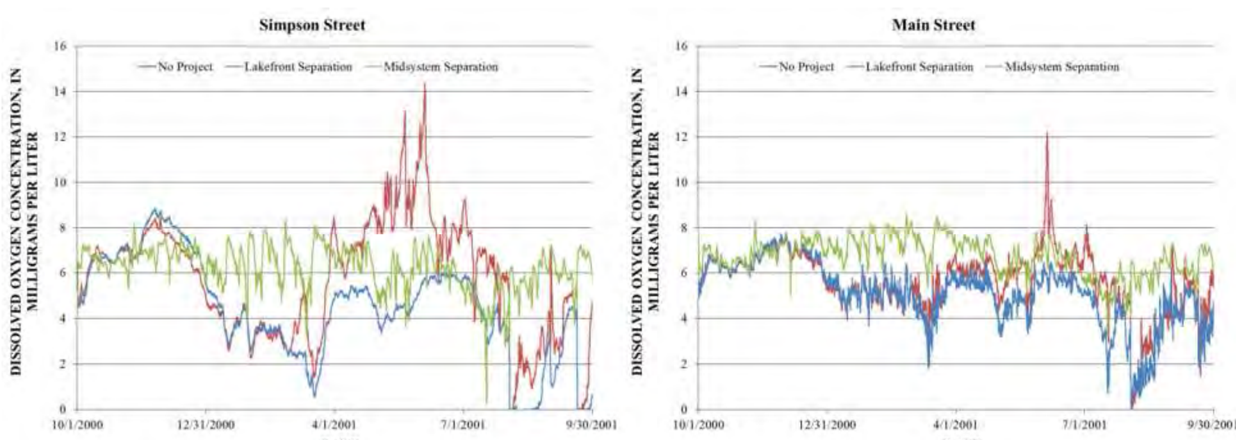


Figure 6.1. Simulated dissolved oxygen concentration on the upper North Shore Channel for the three alternatives under future conditions for Water Year 2001.

Figure 6.2 shows the computed DO concentrations on the lower NSC at Foster Avenue and on the NBCR at Addison Street, Fullerton Avenue, Division Street, and Kinzie Street. Generally, the “Midsystem Separation” alternative yields lower DO concentrations than the other two alternatives because a smaller portion of the O’Brien WRP effluent passes through these waterways for this alternative. The DO concentrations for the “No Project” and “Lakefront Separation” alternatives are nearly identical at all locations for October through May and September reflecting that these two alternatives have similar flows (or rather lack of flows) at Wilmette during these months. Even during the period of discretionary diversion at Wilmette (June through August) the “No Project” and “Lakefront Separation” alternatives yield very similar DO concentrations indicating that the discretionary diversion at Wilmette has limited benefits in these reaches for WY 2001. For June through August the “No Project” alternative yields the highest DO concentrations because of the discretionary diversion at Wilmette during these months, but the increase compared to the “Lakefront Separation” alternative is very small.

Figure 6.3 shows the computed DO concentrations at Clark Street on the Chicago River main stem, Jackson Boulevard and Loomis Street on the SBCR, and Cicero Avenue on the CSSC. Cicero Avenue is included in this grouping instead of with the other locations on the CSSC because in the “Midsystem Separation” alternative Cicero Avenue is on the lake side of the separation barrier, and, thus, reflects the water quality in the stagnant SBCR and upper CSSC resulting from the hydrological/ecological separation.

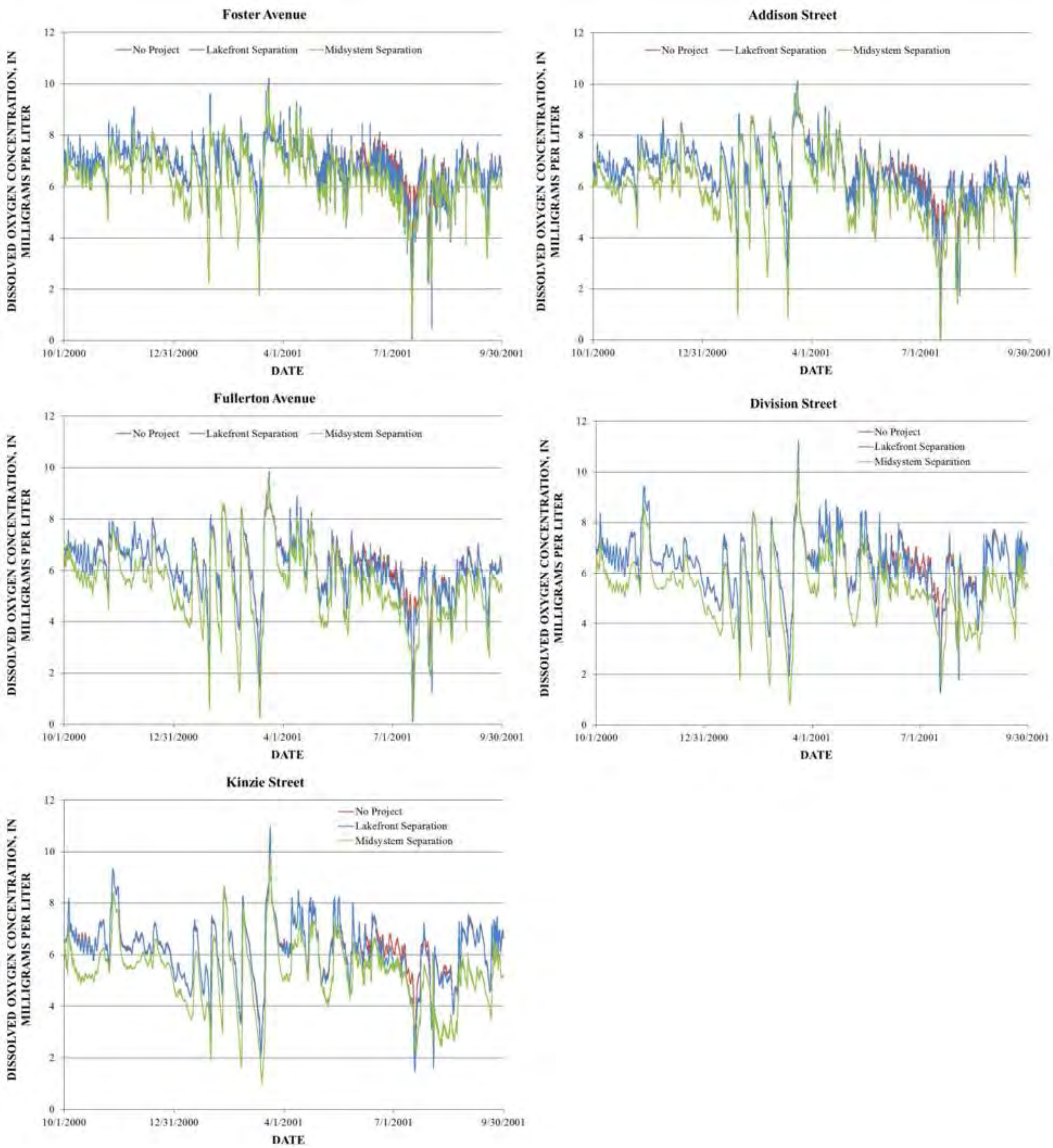


Figure 6.2. Simulated dissolved oxygen concentration on the lower North Shore Channel at Foster Avenue and the North Branch Chicago River at Addison Street, Fullerton Avenue, Division Street, and Kinzie Street for the three alternatives under future conditions for Water Year 2001.

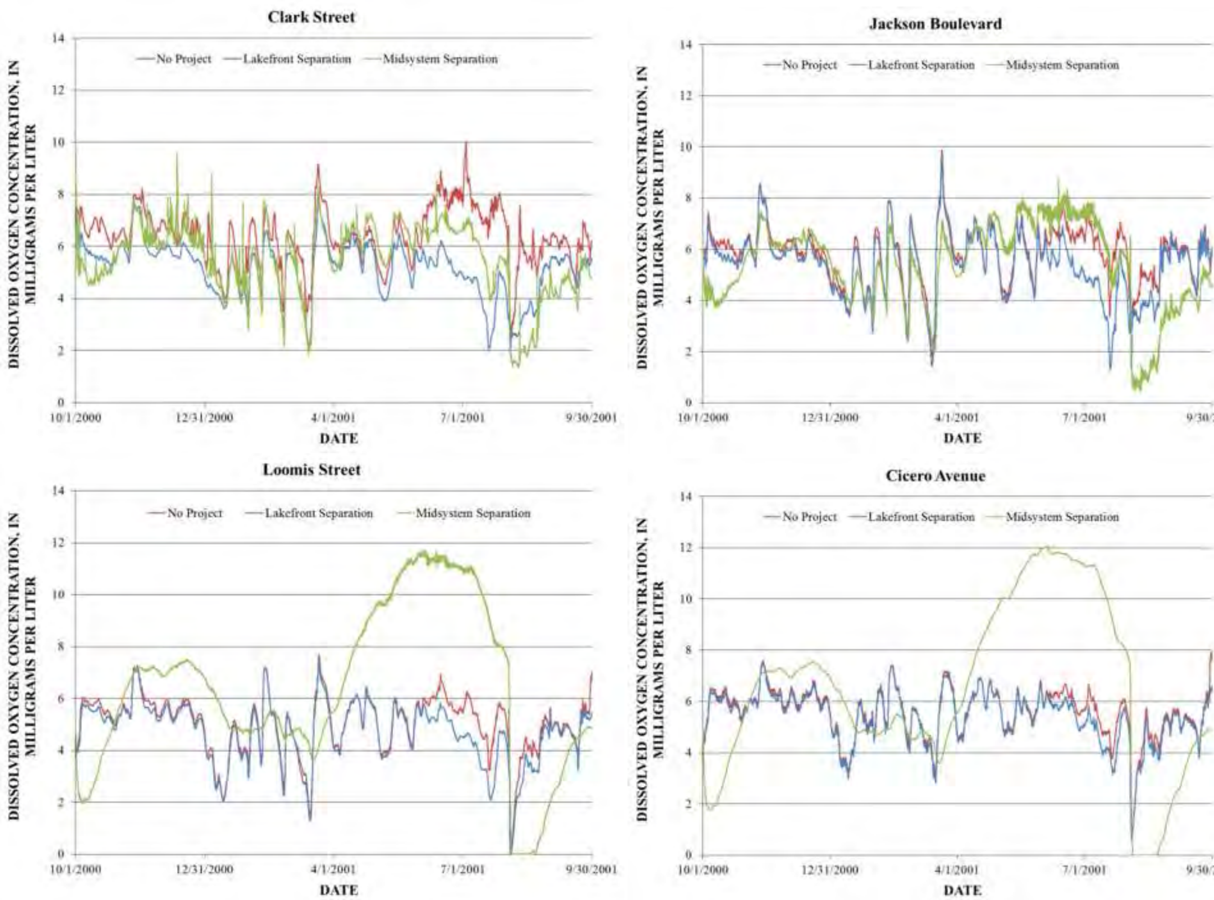


Figure 6.3. Simulated dissolved oxygen concentration on the Chicago River main stem at Clark Street, the South Branch Chicago River at Jackson Boulevard and Loomis Street, and the Chicago Sanitary and Ship Canal at Cicero Avenue for the three alternatives under future conditions for Water Year 2001.

At Clark Street, the “No Project” alternative yields the highest DO concentrations and at Jackson Boulevard it yields high DO concentrations throughout the majority of the year (Figure 6.3). Discretionary diversion flows result in higher DO concentrations for the “No Project” alternative in June through August, and non-discretionary diversion flows, especially at CRCW, result in higher DO concentrations in other months. The “Lakefront Separation” alternative consistently has the lowest DO concentration at Clark Street (except for October, August, and September in which the “Midsystem Separation” alternative yields the lowest DO concentrations) reflecting the stagnant conditions in the Chicago River main stem. The “Midsystem Separation” alternative at times yields the highest DO concentrations and other times it yields the lowest DO concentrations and at still other times it yields very similar DO concentrations to the other alternatives at both Clark Street and Jackson Boulevard. At Jackson Boulevard, Loomis Street, and Cicero Avenue, the “Midsystem Separation” alternative shows the substantial decrease in DO in the stagnant SBCR as a result of CSOs and this low DO propagates to Clark Street on the Chicago River main stem. The computed DO concentrations are very similar at Clark Street and Jackson Boulevard for both the “Lakefront Separation” and “Midsystem Separation” alternatives, this shows the interaction of the main stem and nearby points on the SBCR (Jackson Boulevard is 0.6 mi from the junction of the NBCR, SBCR, and main stem).

The “No Project” and “Lakefront Separation” alternatives yield very similar results at Loomis Street and Cicero Avenue for all months except (June through August, i.e. the period of discretionary diversion) because of the similar flows (or rather lack of flows) at Wilmette and CRCW during these months (Figure 6.3).

The results at Loomis Street and Cicero Avenue for the “Midsytem Separation” alterative show extremely high, sometimes supersaturated, DO concentrations (Figure 6.3). This is the result of algal growth in the stagnant waters in these reaches under the “Midsystem Separation” alternative. The upper NBCR delivers high concentrations of algae as chlorophyll-a in April 2001 (58.8 µg/L of algae as chlorophyll-a as discussed in Table 3.5 and related text in Melching et al. (2010)) that “seeded” the NBCR with algae. A portion of these algae was transported into the stagnant SBCR where it was able to grow and establish and maintain relatively high concentrations as shown in Figure 6.4. The pattern of high DO concentrations at Loomis Street and Cicero Avenue in Figure 6.3 is strongly correlated with the pattern of high chlorophyll a concentrations in Figure 6.4 for the “Midsystem Separation” alternative.

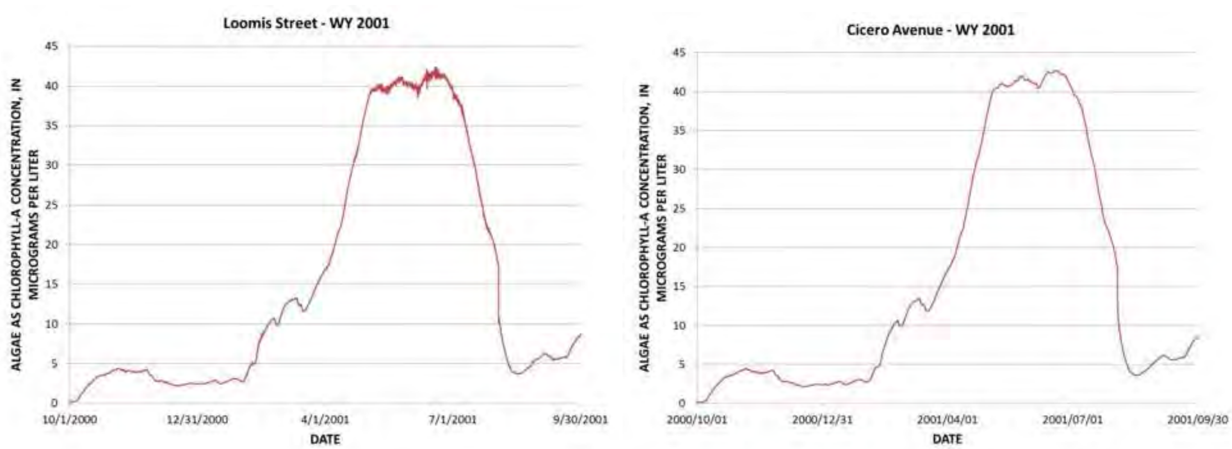


Figure 6.4. Simulated algae as chlorophyll-a concentrations on the South Branch Chicago River at Loomis Street and on the Chicago Sanitary and Ship Canal at Cicero Avenue for the “Midsystem Separation” alternative for Future conditions for Water Year 2001.

Figure 6.5 shows the computed DO concentrations along the CSSC downstream from the Stickney WRP. Through RM 302.6 the “Midsystem Separation” alternative yields higher DO concentrations than the other alternatives because the effluent from the Stickney WRP, which is nearly the only flow in this alternative, has higher DO concentrations than the upstream flows in the SBCR and upper CSSC in the other alternatives. Once the flows reach Romeoville Road the consumption of the oxygen demanding substances in the Stickney WRP effluent bring the DO concentrations for the “Midsystem Separation” alternative to values similar to those for the other alternatives. The “No Project” and “Lakefront Separation” alternatives yield nearly identical results throughout the year except for small differences in the discretionary diversion period of June through August. Overall, for all three alternatives relatively high DO concentrations far above the DO standard of 3.5 mg/L are achieved throughout the entire year except for immediately after the storm of August 2nd.

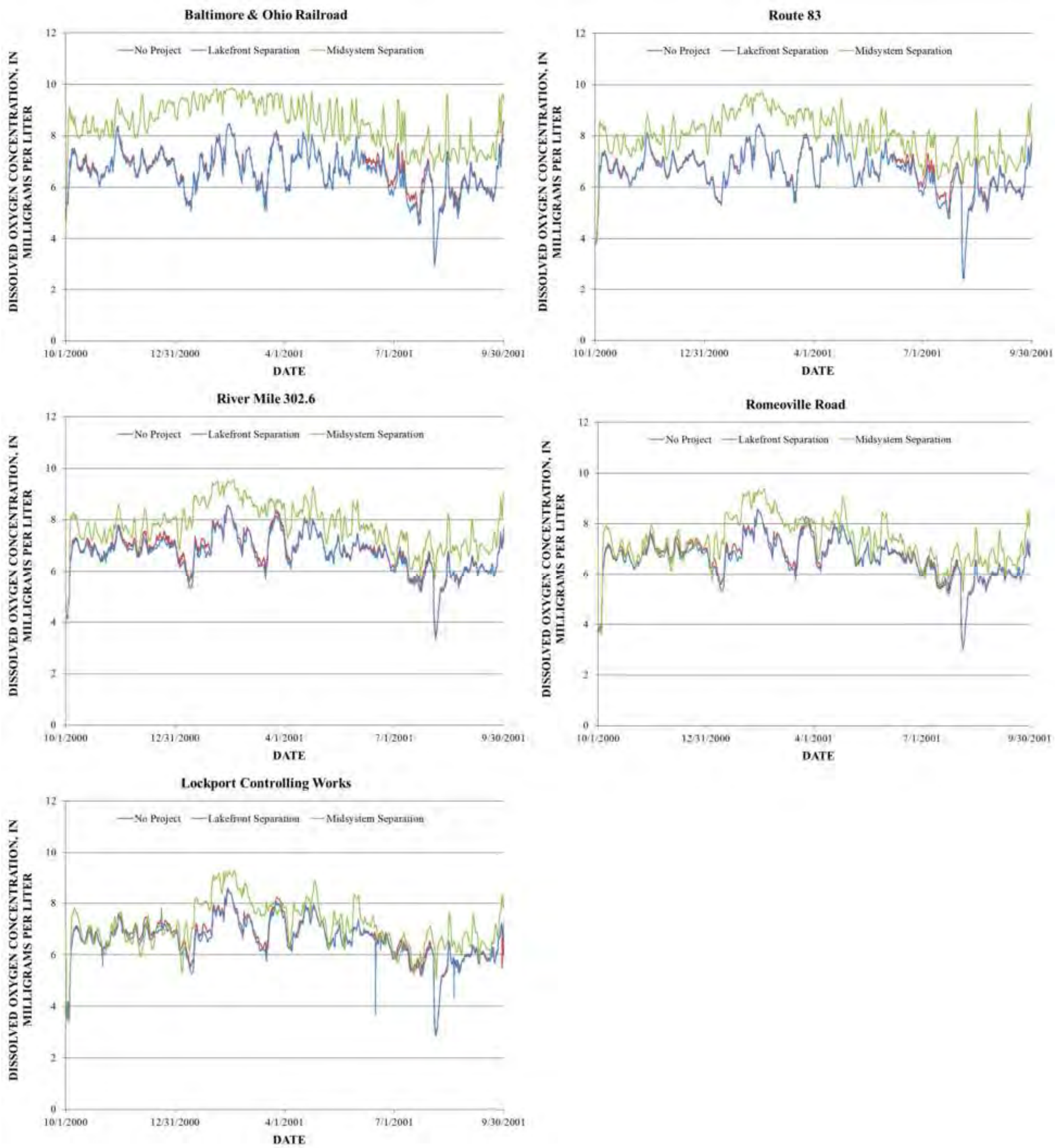


Figure 6.5. Simulated dissolved oxygen concentration on the Chicago Sanitary and Ship Canal for the three alternatives under future conditions for Water Year 2001.

Figure 6.6 shows the computed DO concentrations at 130th Street on the Calumet River and at Conrail Railroad and Central & Wisconsin Railroad on the Little Calumet River (north). In fact the figure for 130th Street shows the conditions at 130th Street for the "Midsystem Separation" alternative and on the river side of the O'Brien Lock and Dam (0.5 mi south of 130th Street) for the "No Project" alternative. No result is shown for the "Lakefront Separation" alternative because the separation barrier is placed at RM 324.5 (2 mi downstream from the O'Brien Lock and Dam).

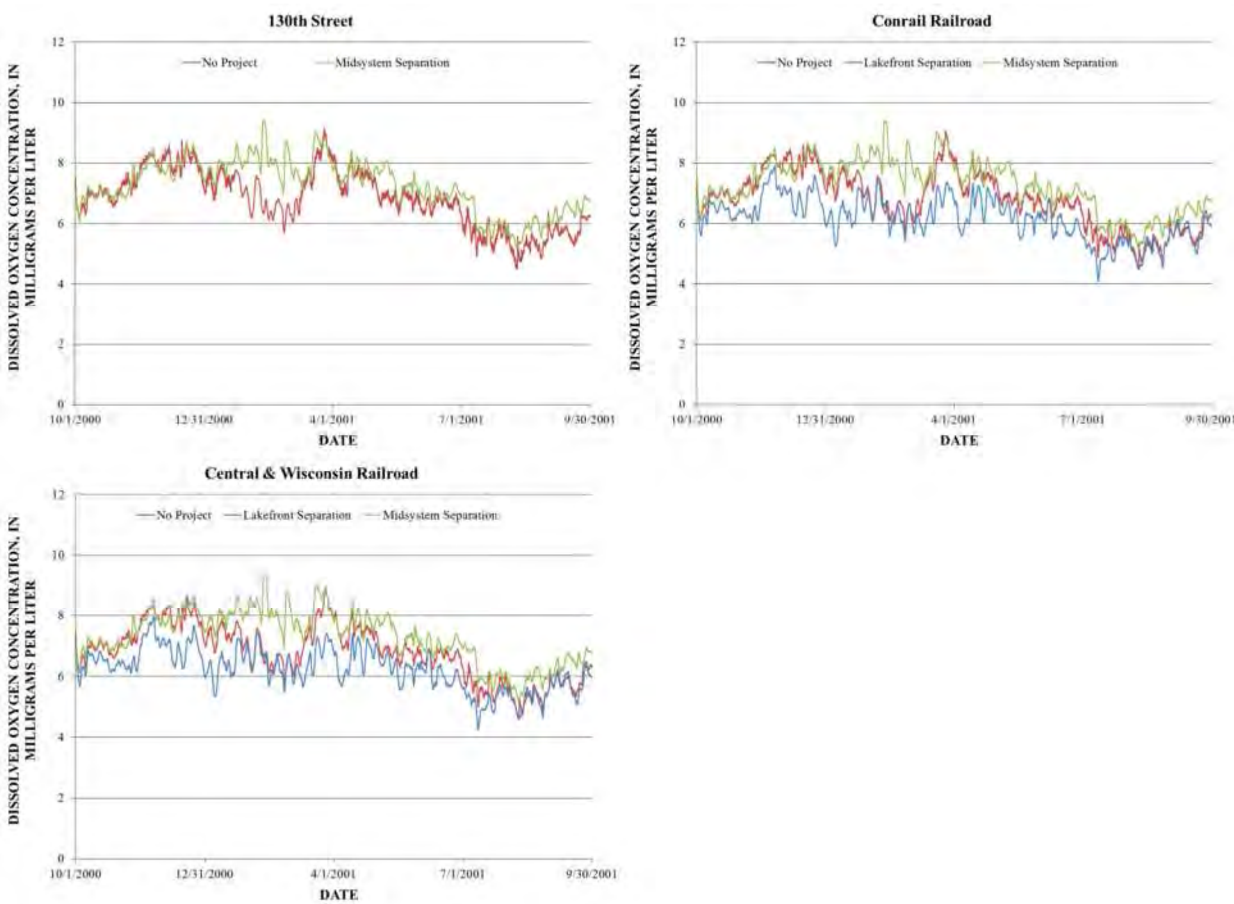


Figure 6.6. Simulated dissolved oxygen concentration on the Calumet River at 130th Street and the Little Calumet River (north) at Conrail Railroad and Central & Wisconsin Railroad for the three alternatives under future conditions for Water Year 2001.

The “Midsystem Separation” alternative yields high DO concentrations at all the locations shown in Figure 6.6 because under this alternative continuous flows pass each of these locations whereas in the other alternatives these locations generally experience stagnant flows. The “No Project” alternative also yields high DO concentrations at all the locations shown in Figure 6.6 throughout the year. The “Lakefront Separation” alternative consistently yielded the lowest DO concentrations at the locations in Figure 6.6, but even for this alternative the DO concentrations are generally above the DO standards for most of the year.

Figure 6.7 shows the computed DO concentrations at Halsted Street on the Little Calumet River (north) and at seven locations along the Calumet-Sag Channel. The simulation results at Halsted Street show that for the “Midsystem Separation” alternative DO concentrations are dictated by those at Ashland Avenue on the Little Calumet River (south), which is the source of flow to Halsted Street for this alternative. The DO concentrations along the Calumet-Sag Channel for the “Midsystem Separation” alternative show the clear effects of algal growth, particularly at Cicero Avenue, Harlem Avenue, and Southwest Highway because of flow stagnation once the watersheds are separated at RM 315.89. The Little Calumet River (south) and the tributaries to the Calumet-Sag Channel bring in medium concentrations of algae as chlorophyll-a of 18.9 and 16.1 µg/L in March and April (see Table 3.5 in Melching et al. (2010)), which seed the stagnant Calumet-Sag Channel for algal growth. Figure 6.8 shows the computed algae as chlorophyll-a concentrations in the Little Calumet River (north) at Halsted Street and along the Calumet-Sag Channel for the “Midsystem Separation” alternative. It is clear that the DO concentrations shown in Figure 6.7 are strongly correlated with the algae as chlorophyll-a concentrations in Figure 6.8. However, at Route 83 for the “Midsystem Separation” alternative on the Calumet-

Sag Channel DO concentrations are strongly influenced by those on the CSSC whose waters flow into the stagnant Calumet-Sag Channel.

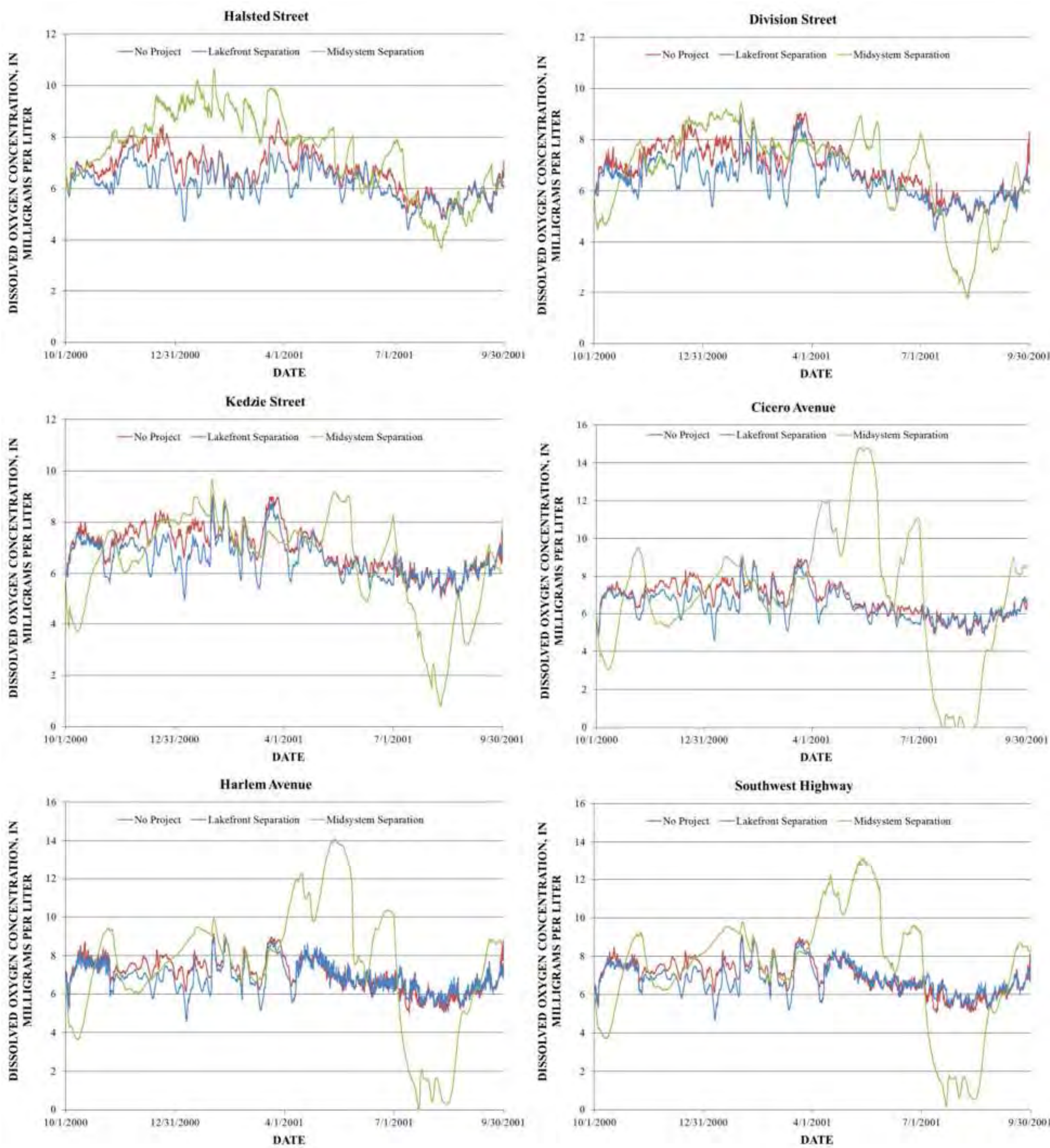


Figure 6.7. Simulated dissolved oxygen concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104^{th} Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2001.

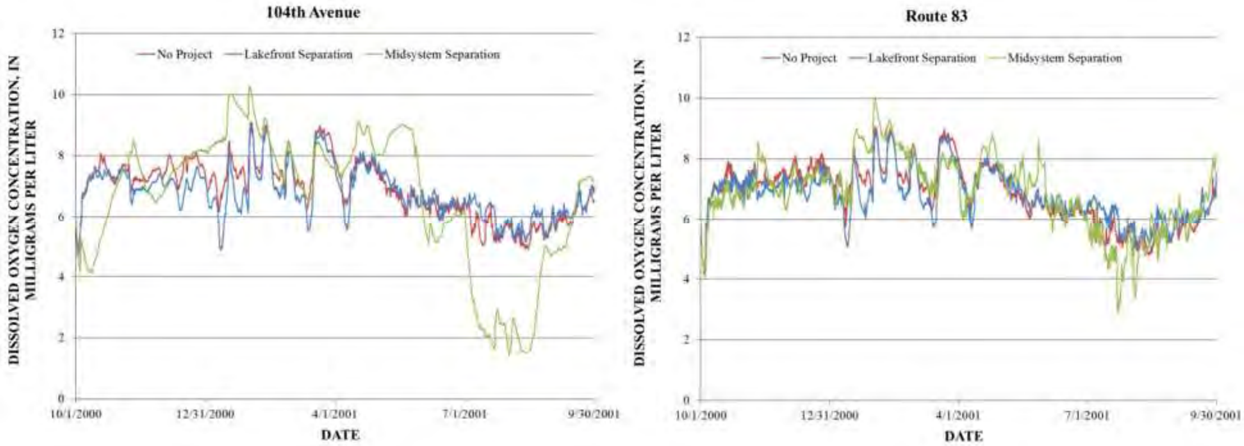


Figure 6.7 (cont.) Simulated dissolved oxygen concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2001.

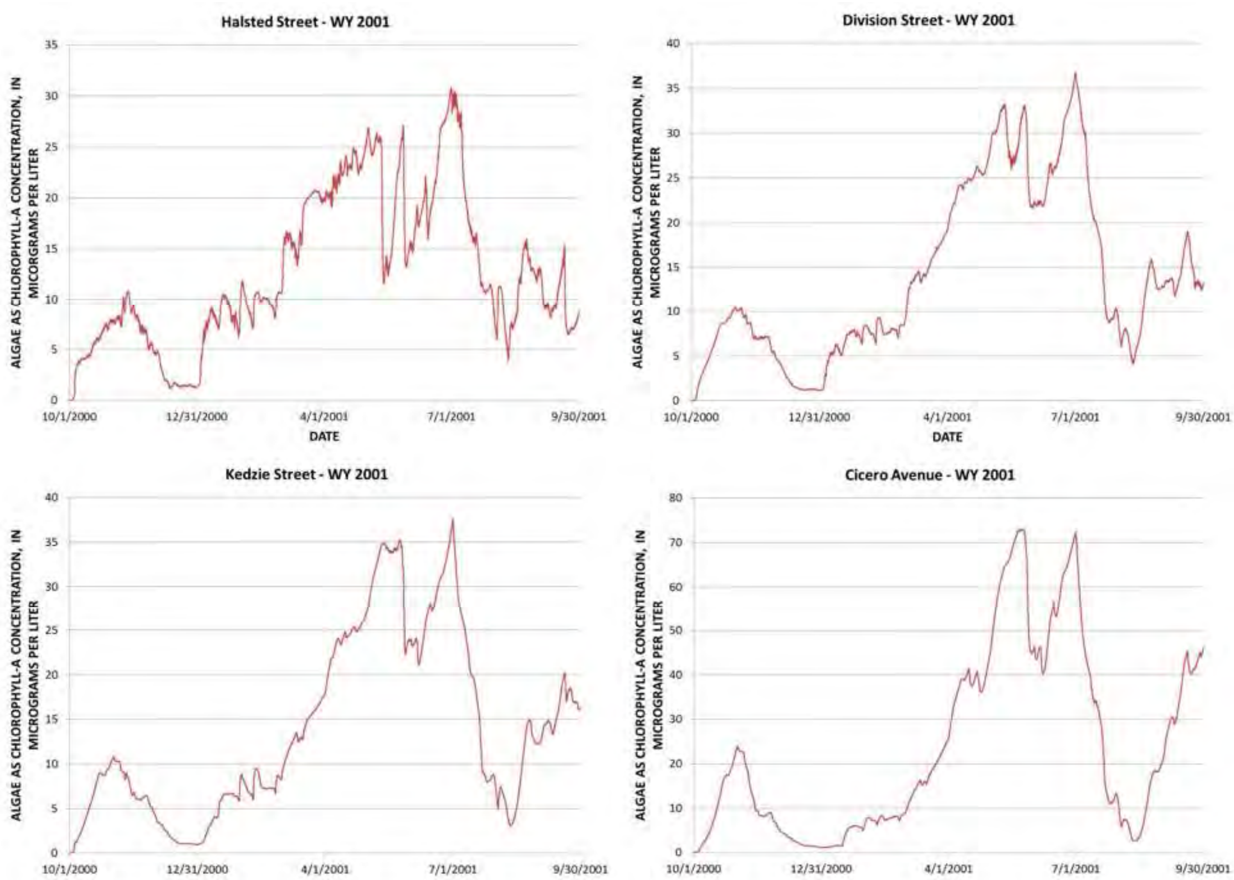


Figure 6.8. Simulated algae as chlorophyll-a concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the "Midsystem Separation" alternative under future conditions for Water Year 2001.

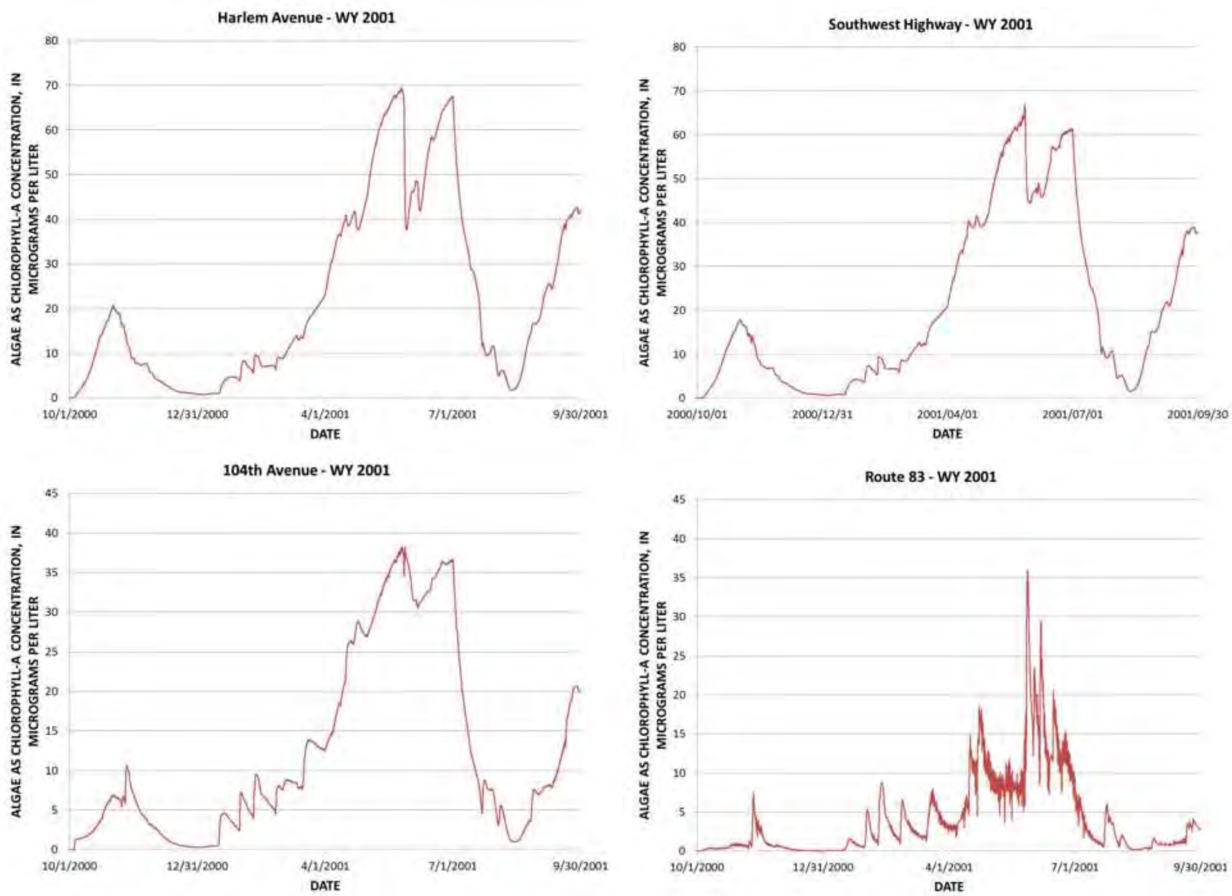


Figure 6.8 (cont.) Simulated algae as chlorophyll-a concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the "Midsystem Separation" alternative under future conditions for Water Year 2001.

The "No Project" and "Lakefront Separation" alternatives yield similar patterns of DO concentration at each location in the Calumet-Sag Channel. However, the "No Project" alternative yields higher DO concentrations that the "Lakefront Separation" for nearly all the year. However, during the period of discretionary diversion (June through August) the two results are closer together than for other months. Thus, the discretionary diversion taken in the "No Project" alternative does not substantially affect DO concentrations in this reach for WY 2001.

6.1.2 Compliance with Dissolved Oxygen Standards

Figures 6.9 and 6.10 show the number of hours not in compliance with the DO standards along the Chicago River and Calumet River systems, respectively. It is clearly seen that stagnant reaches yield high levels of noncompliance with the DO standards. These include the upper NSC (RMs 336.9 to 340.8 in Figure 6.9) and the upper Little Calumet River (north) and Calumet River (RMs 321.4 to 327 in Figure 6.10) for the "No Project" and "Lakefront Separation" alternatives, the Chicago River main stem for the "Lakefront Separation" alternative (Clark Street on the main stem is shown at RM 325.9 in Figure 6.9), and the SBCR and CSSC up to the Stickney WRP (RMs 315.5 to 325.6 in Figure 6.9) and the Calumet-Sag Channel (RMs 303.4 to 319.6 in Figure 6.10) for the "Midsystem Separation" alternative. For whatever alternative is enacted, mitigation is needed to eliminate stagnant zones if high levels of compliance with the DO standards are to be achieved. Also, high levels of noncompliance result around Loomis Street (RM 321.9) on the SBCR for the "No Project" and "Lakefront Separation" alternatives and Jackson Boulevard for the "Lakefront Separation" alternative that would require mitigation if high levels of compliance with the DO standards are to be achieved.

All three alternatives show very low levels of noncompliance (i.e. high levels of compliance) on the CSSC downstream from the Stickney WRP (RM 315.5) (Figure 6.9). The "No Project" and "Lakefront Separation" alternatives show very low levels of noncompliance on the Little Calumet River (north) and Calumet-Sag Channel which are downstream from the Calumet WRP in these alternatives (Figure 6.10). Conversely, the "Midsystem Separation" alternative shows very low levels of noncompliance on the Little Calumet River (north) and Calumet River (Figure

6.10), which are downstream from the Calumet WRP in this alternative. Finally, the upper NSC is downstream from the O'Brien WRP for the "Midsystem Separation" alternative and this reach shows improved compliance compared to the other alternatives for which the upper NSC mainly is stagnant (Figure 6.9). On the other hand, the noncompliance increases on the lower NSC and NBCR for the "Midsystem Separation" alternative because about one third of the O'Brien WRP effluent now passes through the upper NSC and not through these reaches.

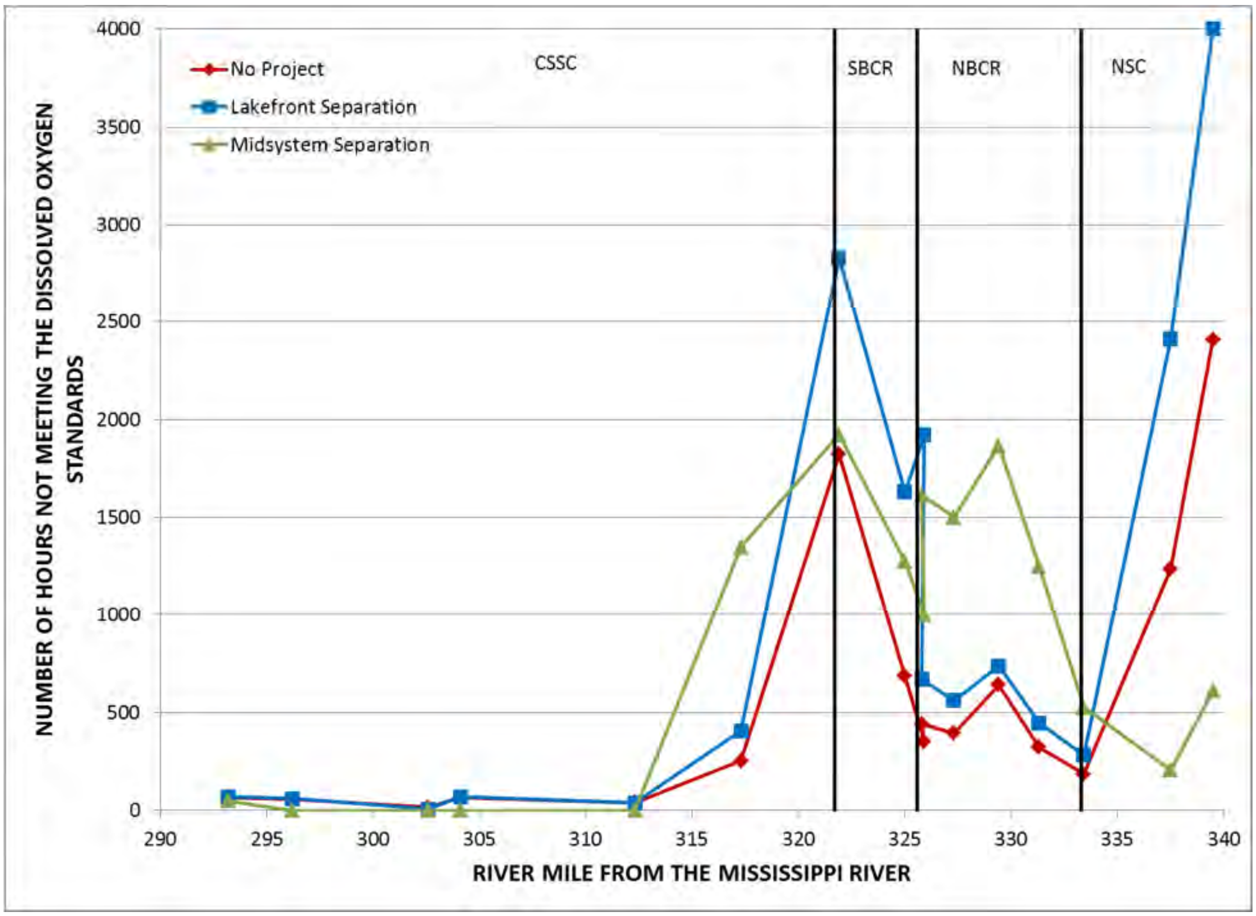


Figure 6.9. Number of hours not in compliance with the dissolved oxygen standards along the Chicago River system for Water Year 2001.

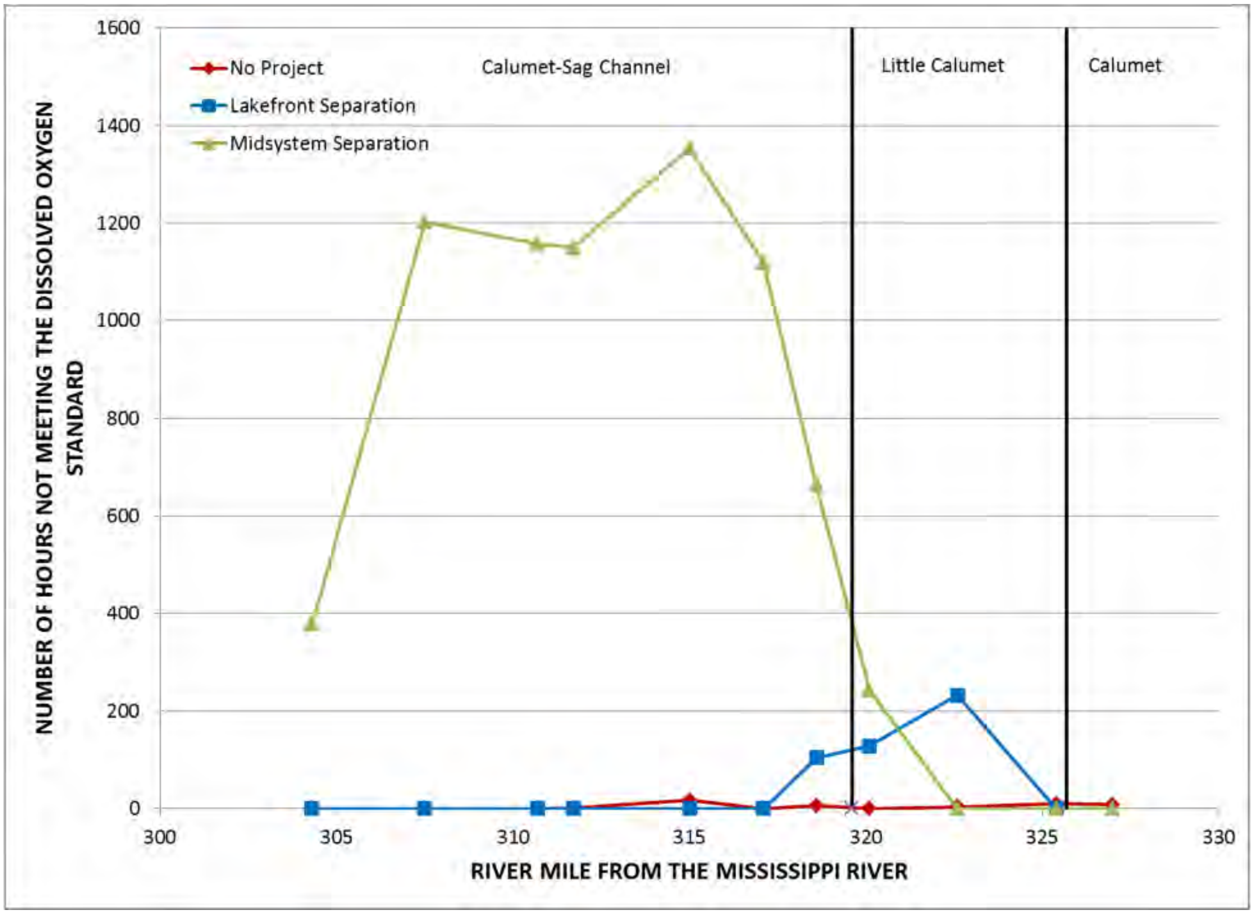


Figure 6.10. Number of hours not in compliance with the dissolved oxygen standards along the Calumet River system for Water Year 2001.

6.2 Comparison of Simulated Fecal Coliform Concentrations

6.2.1 Concentration vs. Time

The DUFLOW model yields computed values of any of the simulated water-quality constituents and properties at any the computational points in the CAWS (more than 100 points). Thus, to keep comparison manageable the comparison is focused on the measurement points in the ambient water quality monitoring network sampled monthly by the MWRDGC and used to calibrate and verify the model. In this report the results are presented for the various waterway reaches of the CAWS: the upper NSC; the lower NSC and NBCR (downstream of the O'Brien WRP); Chicago River main stem, SBCR, and upper CSSC (above the Stickney WRP); lower CSSC; Calumet River and Little Calumet River (north); and the Calumet-Sag Channel.

Figure 6.11 shows the computed fecal coliform concentrations on the upper NSC at Oakton Street (0.1 mi north of the O'Brien WRP outfall). The "Midsystem Separation" alternative yields lower fecal coliform concentrations during the storm periods in July through September as the flows from the O'Brien WRP dilute the effects of CSOs discharged to the upper NSC in this alternative (Figure 6.11). The "No Project" and "Lakefront Separation" alternatives yield nearly identical fecal coliform concentrations from October to May and September reflecting the fact that the "No Project" alternative has nearly zero flow at Wilmette during these periods. In the months of June through August the "No Project" alternative yields the lowest fecal coliform concentrations reflecting the effects of the discretionary diversion from Lake Michigan during these months. The "Midsystem Separation" and "Lakefront Separation" alternatives also yield very similar fecal coliform concentrations during dry weather indicating the dominant role of O'Brien WRP effluent on fecal coliform concentrations in the upper NSC for these alternatives.

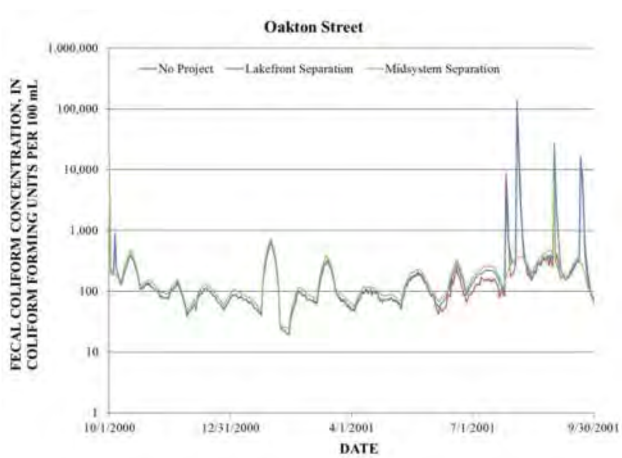


Figure 6.11. Simulated fecal coliform concentration on the upper North Shore Channel at Oakton Street for the three alternatives under future conditions for Water Year 2001.

Figure 6.12 shows the computed fecal coliform concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O'Brien WRP outfall) and at Wilson Avenue and Diversey Parkway on the NBCR. It can be seen that the "No Project" and "Lakefront Separation" alternatives yield nearly identical fecal coliform concentrations at all points and times in these reaches. The effects of discretionary diversion on fecal coliform concentrations are small in these reaches. Finally, at Touhy Avenue and Wilson Avenue all three alternatives yield similar fecal coliform concentrations. However, as the flows reach the downstream NBCR (Diversey Parkway, 6.8 mi downstream of the O'Brien WRP) the decrease in flows in these reaches for the "Midsystem Separation" alternative increases the travel time, thus, decreasing the fecal coliform concentrations relative to the other alternatives.

Figure 6.13 shows the computed fecal coliform concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street, and CSSC at Western Avenue and Cicero Avenue. At Wells Street on the Chicago River main stem the trend of decreasing fecal coliform concentrations for the "Midsystem Separation" alternative observed at Diversey Parkway continues until fecal coliform concentrations less than the 200 CFU/100 mL standard are achieved during most dry weather periods. The "No Project" and "Lakefront Separation" alternatives yield similar fecal coliform concentrations at Wells Street except for June through August when discretionary diversion is taken at CRCW in the "No Project" alternative. Similar to the "Midsystem Separation" alternative, both the "No Project" and "Lakefront Separation" alternatives yield fecal coliform concentrations less than the 200 CFU/100 mL standard during most dry weather periods for WY 2001.

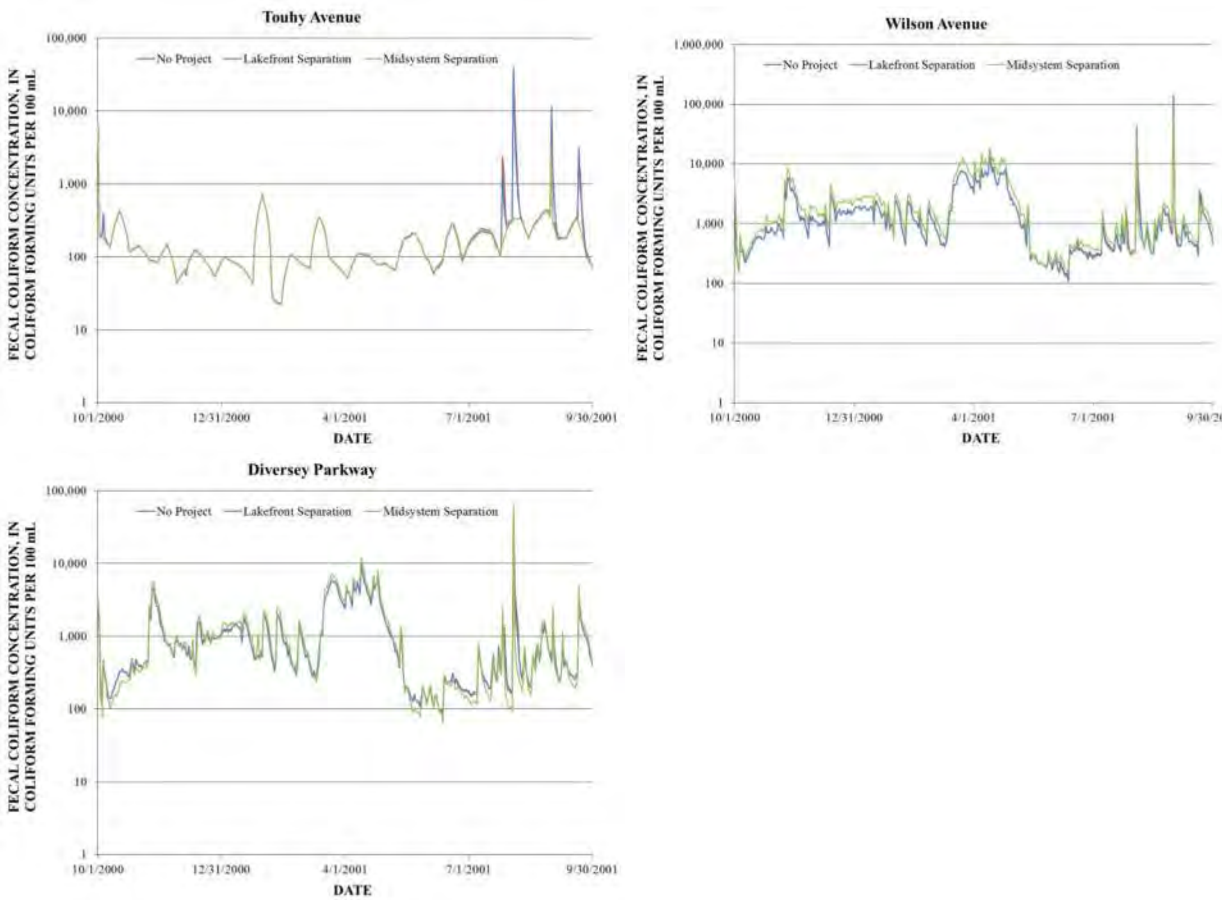


Figure 6.12. Simulated fecal coliform concentration on the North Shore Channel at Touhy Avenue and the North Branch Chicago River at Wilson Avenue and Diversey Parkway for the three alternatives under future conditions for Water Year 2001.

In Figure 6.13, all points on the SBCR and upper CSSC experience very low fecal coliform bacteria concentrations for the "Midsystem Separation" alternative because the primary source of fecal coliform bacteria to these reaches is infrequent CSOs. For the "Midsystem Separation" alternative the fecal coliform concentrations at Western Avenue and Cicero Avenue are several orders of magnitude lower than those for the other two alternatives. Because of the interchange between the Chicago River main stem and the SBCR, Madison Street experiences very similar fecal coliform concentrations to those at Clark Street for the "Midsystem Separation" alternative in Figure 6.13. Madison Street and Western Avenue experience low fecal coliform concentrations (see Figure 6.13) for the "No Project" and "Lakefront Separation" alternatives indicating the die off fecal coliform bacteria as the flows travel from the O'Brien WRP. Cicero Avenue experiences higher fecal coliform concentrations for the "No Project" and "Lakefront Separation" alternatives due to upstream propagation of the un-disinfected effluent from the Stickney WRP that cannot get to this reach in the "Midsystem Separation" alternative because of the barrier at RM 316.01.

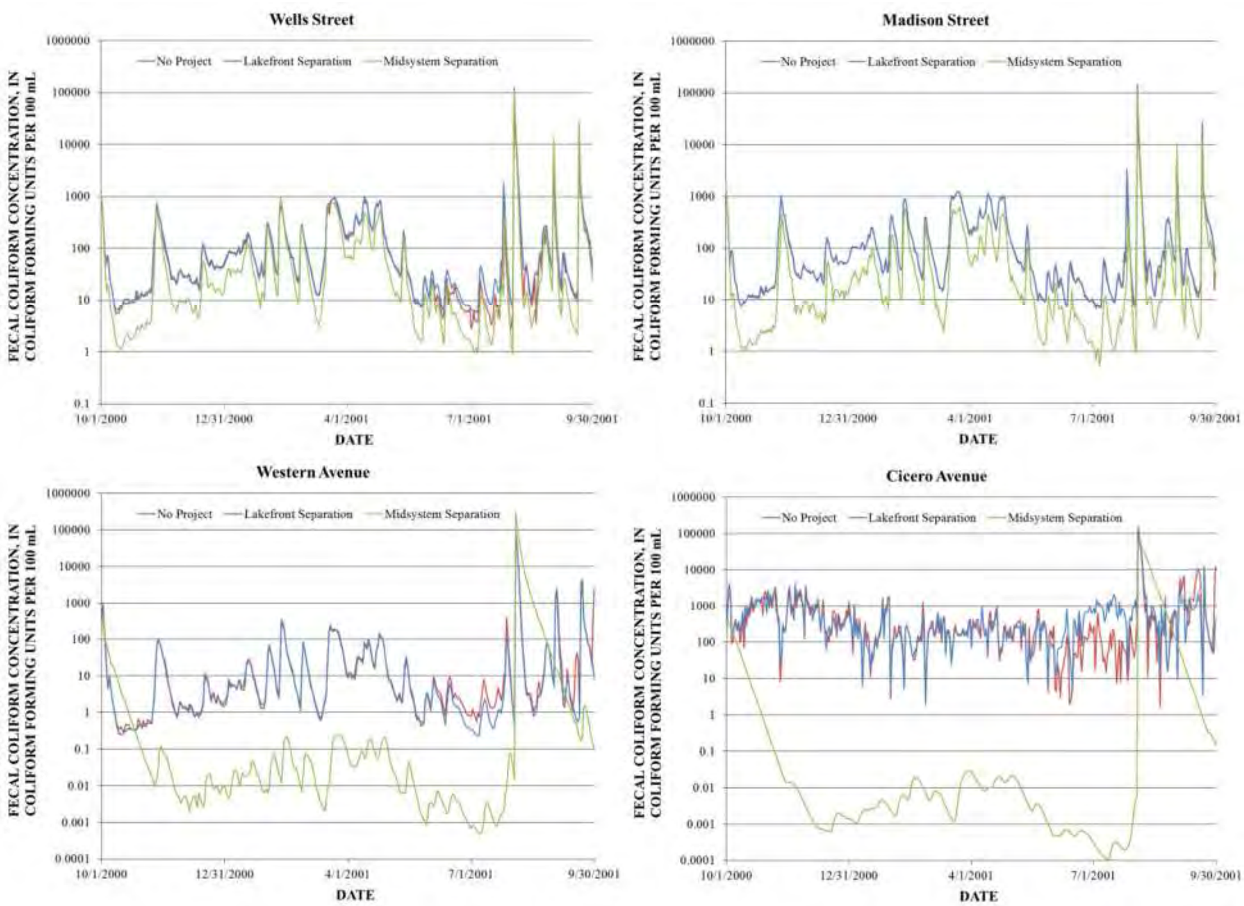


Figure 6.13. Simulated fecal coliform concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street, and Chicago Sanitary and Ship Canal at Western Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2001.

Figure 6.14 shows the computed fecal coliform concentrations on the CSSC downstream from the Stickney WRP. The results for the “No Project” and “Lakefront Separation” alternatives are nearly identical showing the dominant influence of the Stickney WRP effluent on this reach. The discretionary diversion in June through August for the “No Project” alternative has little effect on the fecal coliform bacteria in this reach. The “Midsystem Separation” alternative also yields similar fecal coliform concentrations as those for the other alternatives with only the August 2nd storm showing substantial reductions in fecal coliform bacteria. The “Midsystem Separation” alternative yields lower fecal coliform bacteria concentrations at Lockport than the other alternatives because of the longer travel time with decreased flows for this alternative. Nevertheless the results for the “Midsystem Separation” alternative also indicate the dominant influence of the Stickney WRP effluent on this reach.

Figure 6.15 shows the computed fecal coliform concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At Halsted Street the “No Project” and “Lakefront Separation” alternatives yield similar fecal coliform concentrations throughout the year. This similarity shows the discretionary diversion has only a minor effect in diluting fecal coliform bacteria in this reach. At both locations the fecal coliform concentrations are generally lower than the 200 CFU/100 mL standard for the “No Project” and “Lakefront Separation” alternatives. At Indiana Avenue, the “Midsystem Separation” alternative yields higher fecal coliform bacteria concentrations than the other two alternatives throughout the year. Indiana Avenue receives effluent from the Calumet WRP under the “Midsystem Separation” alternative raising the fecal coliform bacteria concentrations whereas in the other two alternatives Indiana Avenue only experiences some occasional backups of effluent from this WRP. These backups are more common for the "No Project" alternative than for the "Lakefront Separation" alternative, thus, the "No Project" alternative tends to have higher fecal coliform concentrations than the "Lakefront Separation" alternative at Indiana Avenue. For Halsted Street under the "Midsystem Separation" alternative the fecal coliform concentrations are dominated by the fecal coliform bacteria coming from the Little Calumet River (south) which has higher concentrations than for the disinfected Calumet WRP effluent that dominates the fecal coliform concentrations at Halsted Street for the other two alternatives.

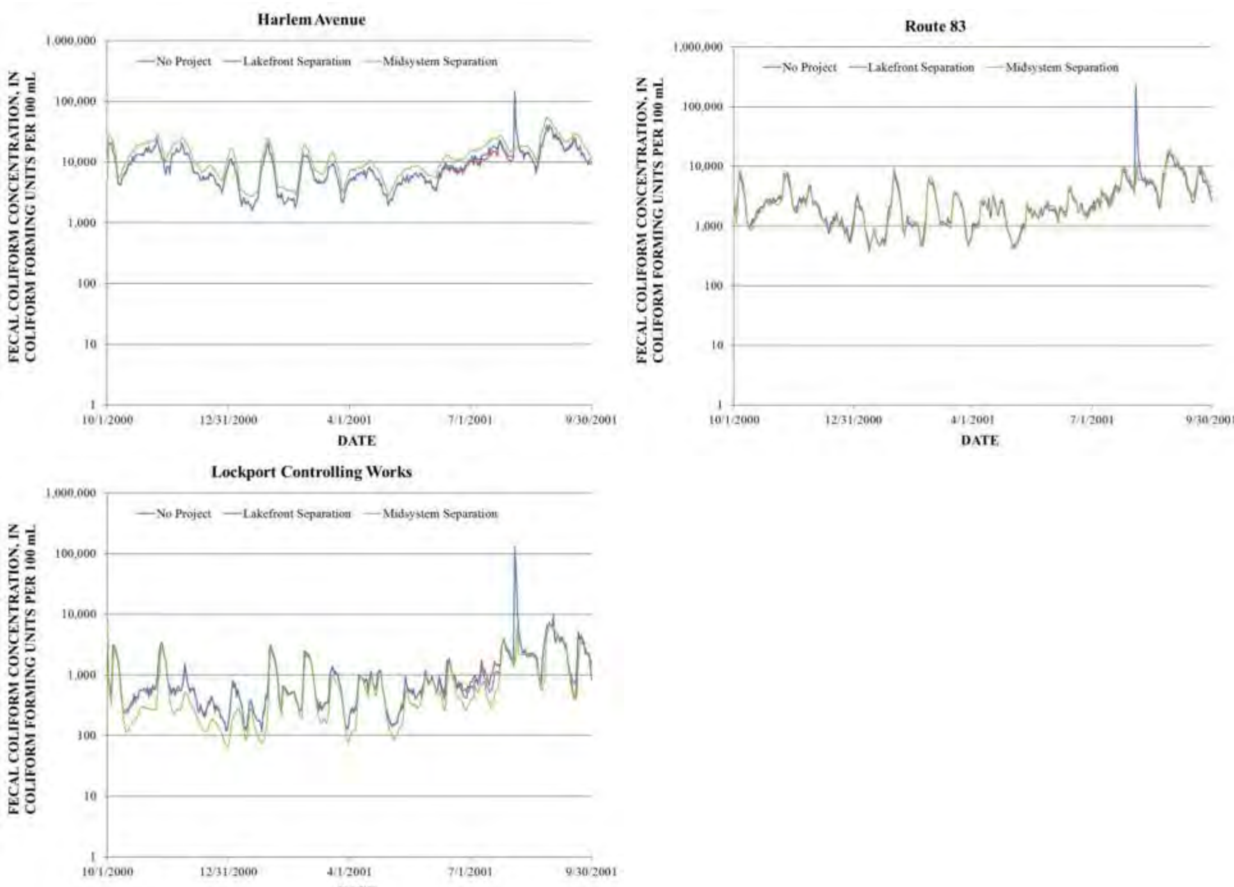


Figure 6.14. Simulated fecal coliform concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2001.

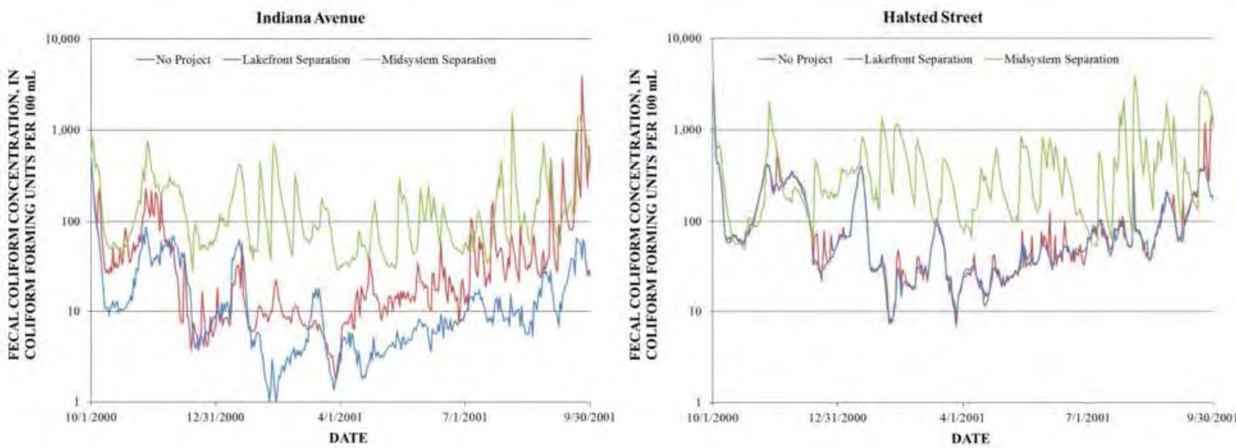


Figure 6.15. Simulated fecal coliform concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2001.

Figure 6.16 shows the computed fecal coliform concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. At all of these locations the “No Project” and “Lakefront Separation” alternatives yield similar fecal coliform concentrations showing the discretionary diversion has only a minor effect in diluting fecal coliform bacteria in this reach. The “Midsystem Separation” alternative yields fecal coliform concentrations similar to the other two alternatives at Ashland Avenue and Cicero Avenue. At Route 83, the “Midsystem Separation” alternative yields higher fecal coliform concentrations than the other two alternatives because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel for this alternative.

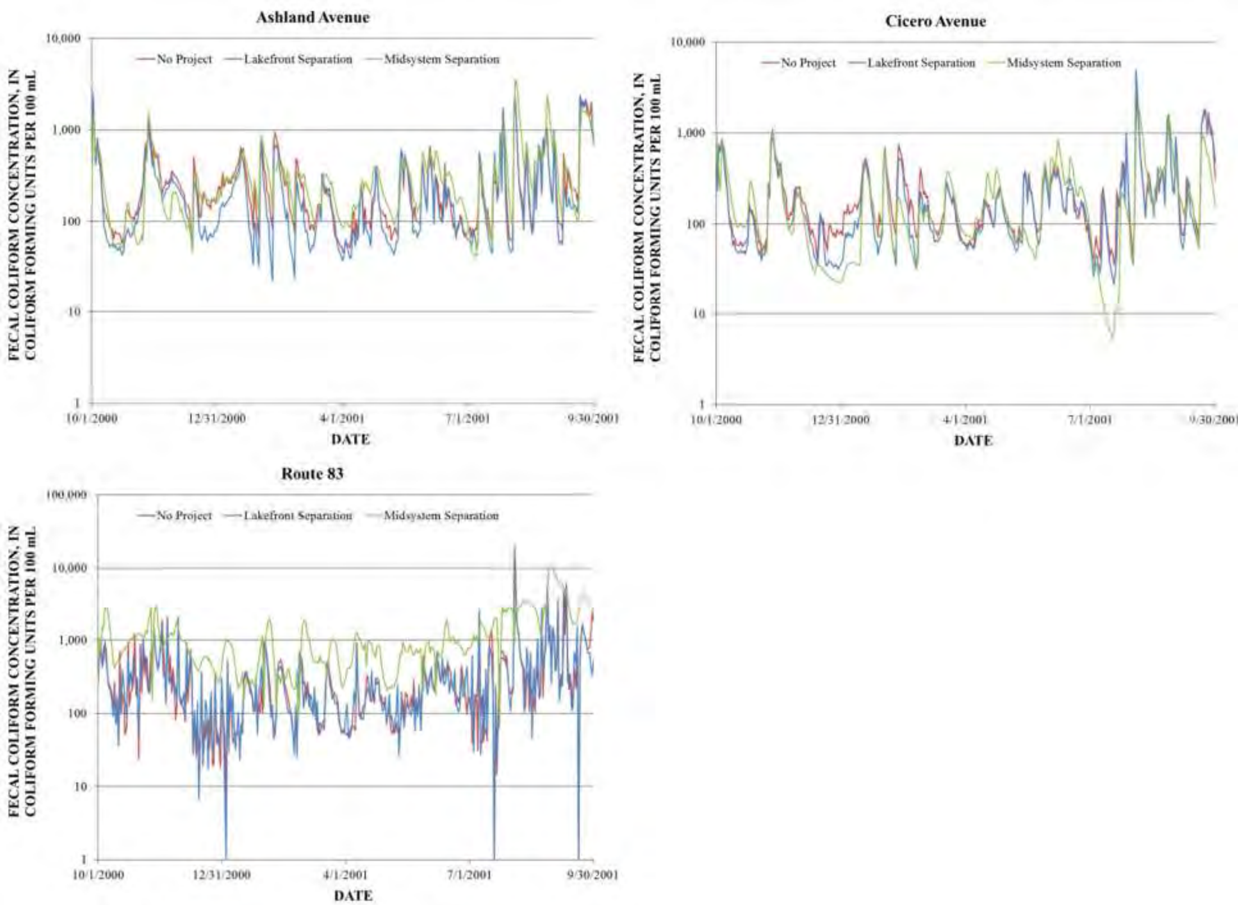


Figure 6.16. Simulated fecal coliform concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2001.

6.2.2 Compliance with the Fecal Coliform Standard

Figures 6.17 and 6.18 show the number of hours not in compliance with the fecal coliform standard along the Chicago River and Calumet River systems, respectively. As can be seen in Figure 6.17, for the NSC and Chicago River main stem (Clark Street on the main stem is shown at RM 325.9 in Figure 6.17) the “No Project” alternative yields higher compliance with the fecal coliform standard than the other two alternatives because of the availability of discretionary diversion. In all other reaches of the Chicago River system the “No Project” and “Lakefront

Separation" alternatives yield nearly identical levels of compliance and downstream of the Calumet WRP they yield similar levels of compliance with the fecal coliform standard (Figures 6.17 and 6.18).

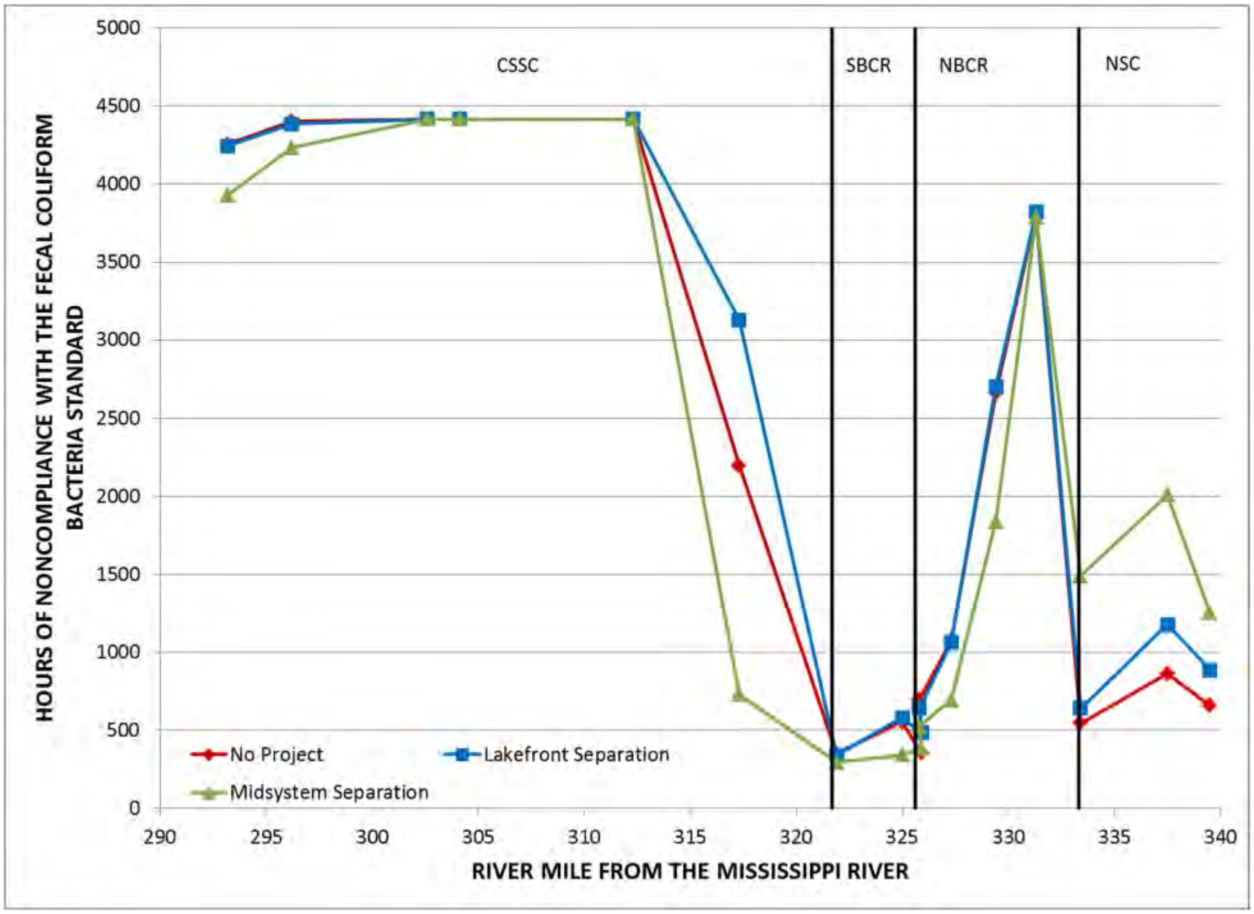


Figure 6.17. Number of hours not in compliance with the fecal coliform standard along the Chicago River system for Water Year 2001.

Downstream from the Stickney WRP (RM 315.5) on the CSSC all three alternatives yield nearly identical levels of compliance with the fecal coliform standard because of the dominance of the Stickney WRP effluent on this reach (Figure 6.17). On the NSC and NBCR, all three alternatives yield similar level of compliance with the fecal coliform standard because of the dominance of the O'Brien WRP effluent on these reaches (Figure 6.17). The low loads of fecal coliform bacteria to the SBCR and upper CSSC result in the low levels of noncompliance with the fecal coliform bacteria observed in Figure 6.17 for the "Midsystem Separation" alternative.

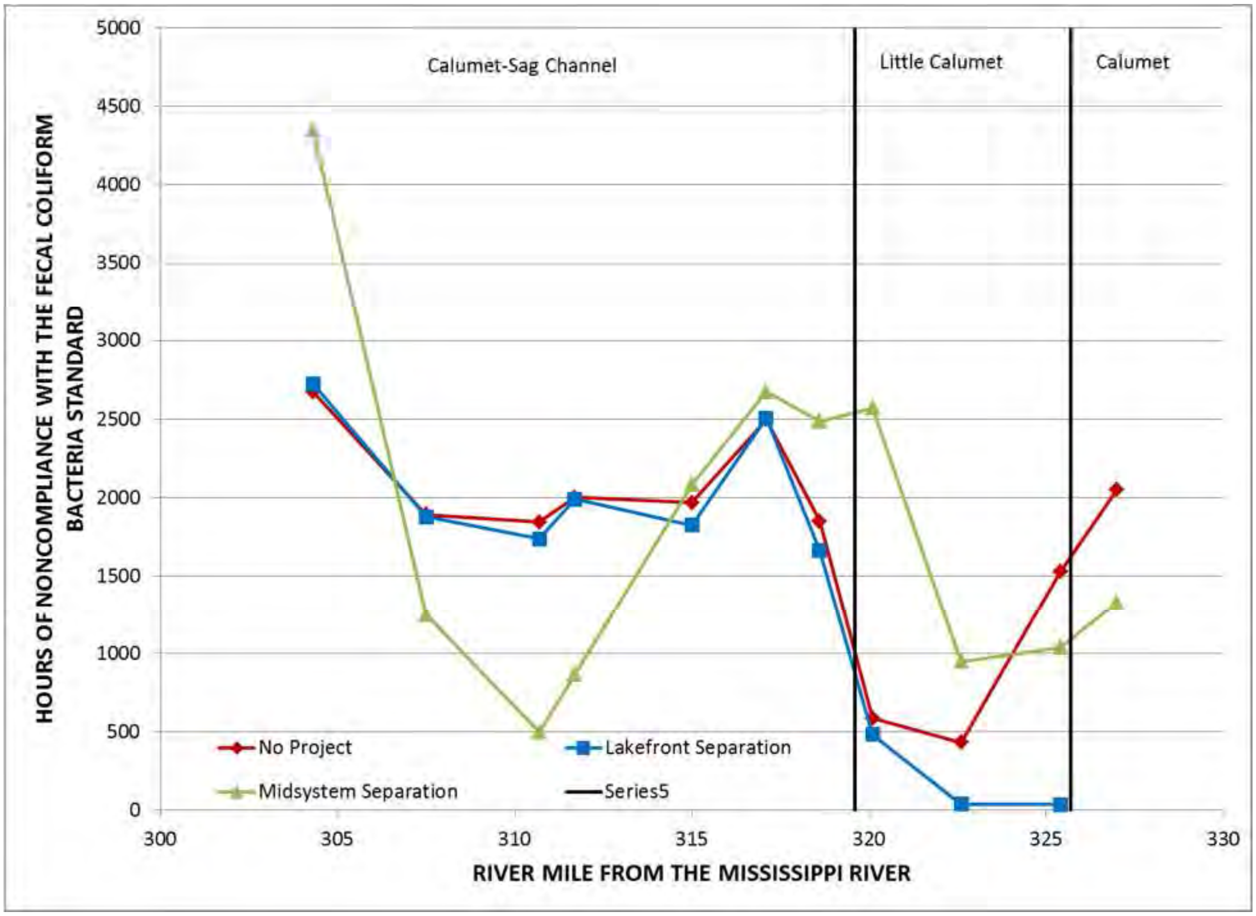


Figure 6.18. Number of hours not in compliance with the fecal coliform standard along the Calumet River system for Water Year 2001.

In the Calumet River system (Figure 6.18), the "Midsystem Separation" alternative yields higher levels of noncompliance than the Lakefront Separation alternative on the lake side of the Calumet WRP (upstream from RM 321.4) because this reach continually receives treated effluent in this alternative, whereas in the Lakefront Separation alternative this reach only occasionally receives treated effluent. The Calumet-Sag Channel (RM 303.4 to 319.6) becomes two stagnant water bodies in the "Midsystem Separation" alternative. At the two ends of the

Calumet-Sag Channel the levels of noncompliance with the fecal coliform standard are dominated by the conditions in the receiving water body (lower CSSC for the downstream end [RM 303.4] and Little Calumet River (north) for the upstream end [RM 319.6]). However, in the middle sections of the Calumet-Sag Channel the "Midsystem Separation" alternative shows low levels of noncompliance consistent with the low loads of fecal coliform bacteria to these reaches (Figure 6.18).

The high levels of noncompliance with the fecal coliform standard in the vicinities of the O'Brien (RM 336.9 in Figure 6.17) and Calumet (RM 321.4 in Figure 6.18) WRPs seem inconsistent with the fact that disinfection is applied at these plants for the Baseline and Future conditions. The MWRDGC suggested that they expected "at least" a 2-log reduction in fecal coliform concentration in the effluent after disinfection. Perhaps applying more than a 2-log reduction may be more appropriate to describe the true performance of these WRPs. However, the comparisons provided in this section give a fair and consistent comparison of the effects of the different alternatives on fecal coliform bacteria in the CAWS.

6.3 Comparison of Simulated Chloride Concentrations

6.3.1 Concentration vs. Time

Figure 6.19 shows the computed chloride concentrations on the upper NSC at Oakton Street (0.1 mi north of the O'Brien WRP outfall). Because the sampling site is so close to the O'Brien WRP outfall the chloride concentration at this point is dominated by the quality of the effluent.

Thus, all three alternatives yield nearly identical chloride concentrations except for June through August when the "No Project" alternative includes substantial discretionary diversion.

Figure 6.20 shows the computed chloride concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O'Brien WRP outfall) and at Wilson Avenue and Diversey Parkway on the NBCR. The three alternatives yield very similar chloride concentrations at these three locations except that small dilution effects can be seen reducing chloride concentrations for the "No Project" alternative in June through August.

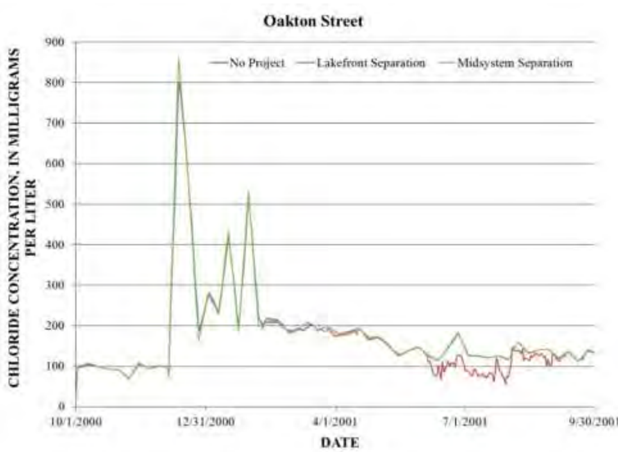


Figure 6.19. Simulated chloride concentration on the upper North Shore Channel at Oakton Street for the three alternatives under future conditions for Water Year 2001.

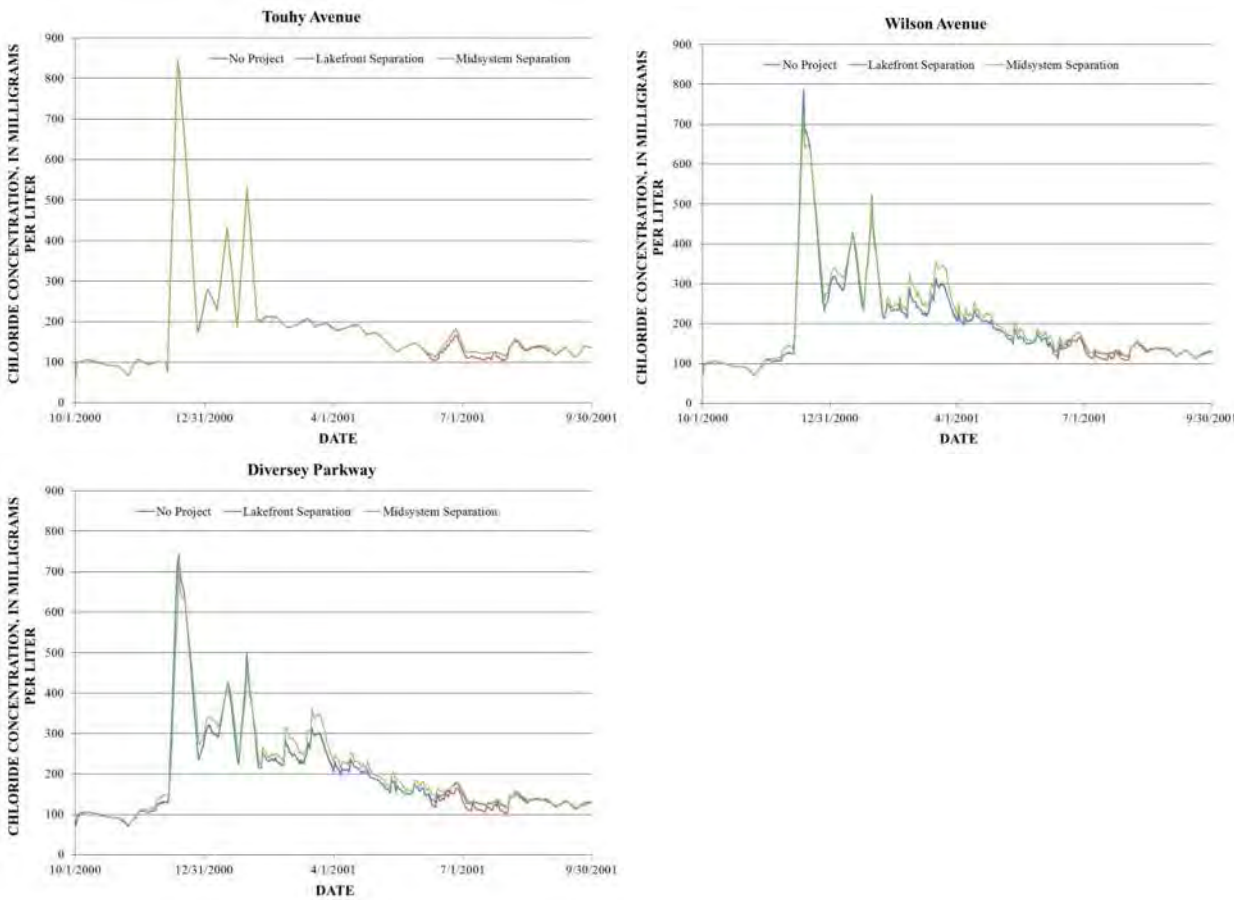


Figure 6.20. Simulated chloride concentration on the North Shore Channel at Touhy Avenue and the North Branch Chicago River at Wilson Avenue and Diversey Parkway for the three alternatives under future conditions for Water Year 2001.

Figure 6.21 shows the computed chloride concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street, and CSSC at Western Avenue and Cicero Avenue. At Wells Street the chloride concentrations for all three alternatives show substantial similarities in pattern (Figure 6.21). The "No Project" alternative generally has the lowest chloride concentrations at Wells Street, especially for days with discretionary diversion (June through August) or other diversions from Lake Michigan at CRCW.

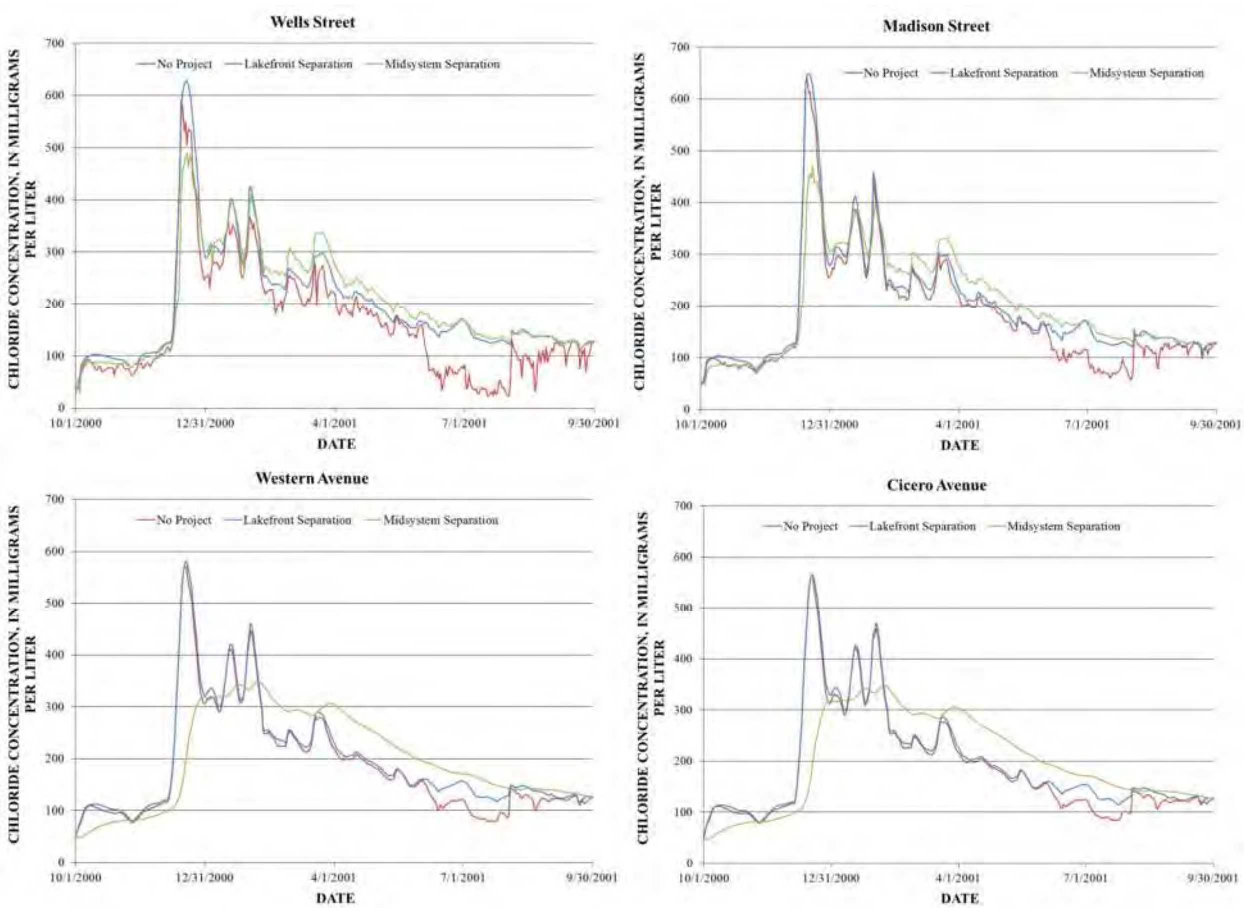


Figure 6.21. Simulated chloride concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street, and Chicago Sanitary and Ship Canal at Western Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2001.

At Madison Street the "No Project" and "Lakefront Separation" alternatives yield very similar chloride concentrations except in the months of June through August when the effects of discretionary diversion can be seen for the "No Project" alternative (Figure 7.21). The "Midsystem Separation" alternative yields a similar pattern chloride concentrations at Madison Street as at Wells Street indicating the influence of chloride concentrations at the junction of the NBCR, SBCR, and Chicago River main stem on those a short distance (0.3 mi) up the now stagnant SBCR. The pattern of chloride concentrations for the "Midsystem Separation" alternative also is similar to that of the other alternatives at Madison Street except that the

“Midsystem Separation” alternative has lower chloride concentrations during periods when the concentration peaks than the other alternatives.

At Loomis Street and Cicero Avenue the “No Project” and “Lakefront Separation” alternatives yield very similar chloride concentrations except in the months of June through August for which the dilution effects resulting from discretionary diversion at CRCW can be observed in Figure 6.21. For the “Midsystem Separation” alternative the effects of flow stagnation on chloride concentrations can easily be seen. That is, because of limited inflows to the SBCR and upper CSSC for this alternative it takes a long time to build up larger chloride concentrations and then it takes a long time for these higher chloride concentrations to diminish because of the limited flows through these reaches.

Figure 6.22 shows the computed chloride concentrations on the CSSC downstream from the Stickney WRP. The results for the “No Project” and “Lakefront Separation” alternatives are nearly identical showing the dominant influence of the Stickney WRP effluent on this reach. The discretionary diversion in June through August for the “No Project” alternative has only a small effect on chloride concentrations in this reach. The “Midsystem Separation” alternative also yields similar chloride concentrations as those for the other alternatives with only the peak chloride concentrations being substantially higher than for the other two alternatives. The results for the “Midsystem Separation” alternative are completely dominated by the Stickney WRP effluent in this reach, in the other two alternatives upstream flows with lower chloride concentrations can somewhat dilute Stickney WRP effluent with high chloride concentrations.

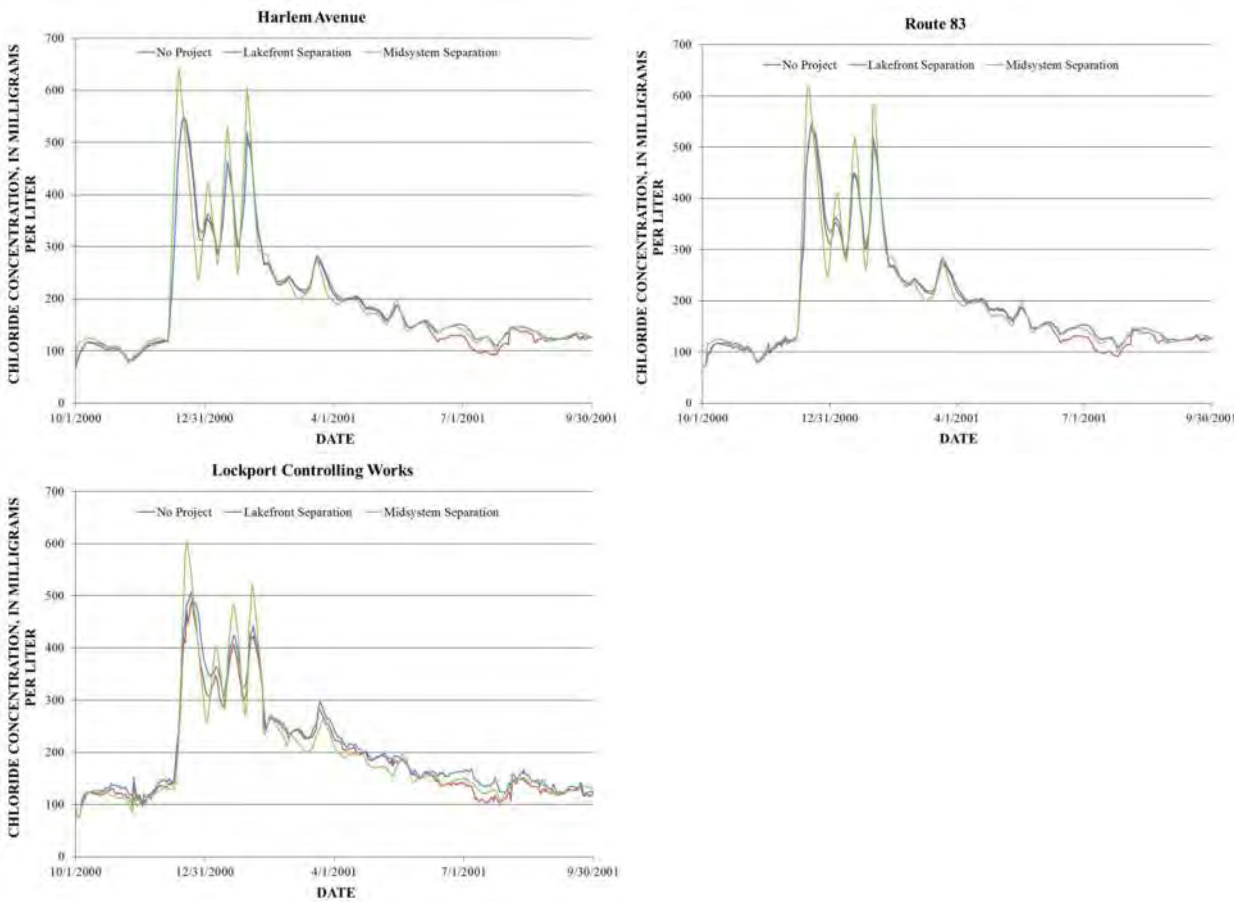


Figure 6.22. Simulated chloride concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2001.

Figure 6.23 shows the computed chloride concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At Indiana Avenue all three alternatives yield similar temporal patterns of chloride concentration with the "No Project" alternative typically yielding the lowest concentration (due to dilution effects) and the "Lakefront Separation" alternative yielding the highest concentrations. At Halsted Street, the "No Project" and "Lakefront Separation" alternatives again show similar temporal patterns of chloride concentration with the "No Project" alternative yielding substantially lower concentrations. For the "Midsystem

Separation" alternative the flow at Halsted Street is dominated by the inflow from the Little Calumet River (south), which has generally lower chloride concentrations in WY 2001.

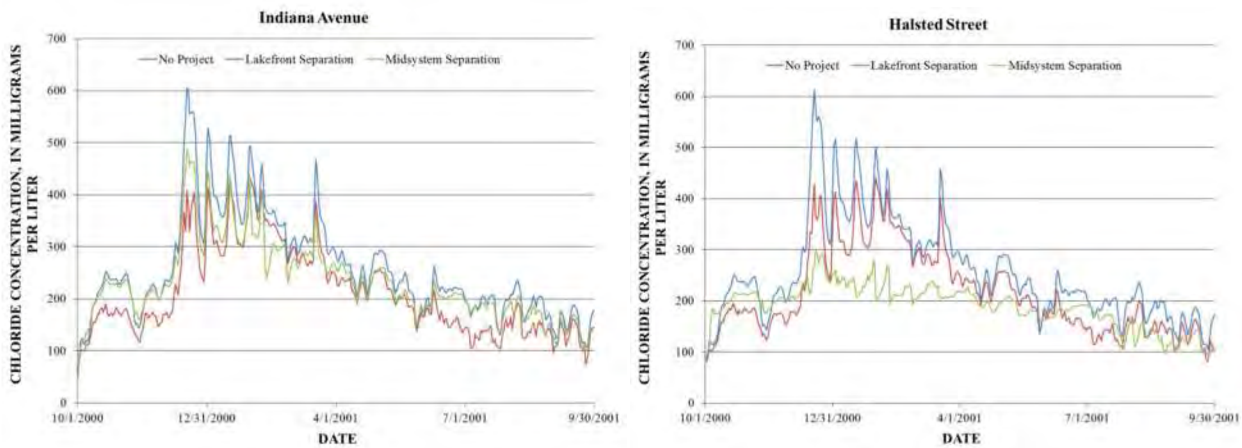


Figure 6.23. Simulated chloride concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2001.

Figure 6.24 shows the computed chloride concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. Again the "No Project" and "Lakefront Separation" alternatives show similar temporal patterns of chloride concentration at each location with the "No Project" alternative yielding substantially lower concentrations. The "Midsystem Separation" alternative yields chloride concentrations at Ashland Avenue and Cicero Avenue that reflect the chloride concentrations in the small tributary streams that discharge to these otherwise stagnant reaches on either side of the barrier at RM 315.89. At Route 83, the temporal pattern of chloride concentrations for the "Midsystem Separation" alternative follows the pattern of the CSSC at Route 83 (Figure 6.22) because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel.

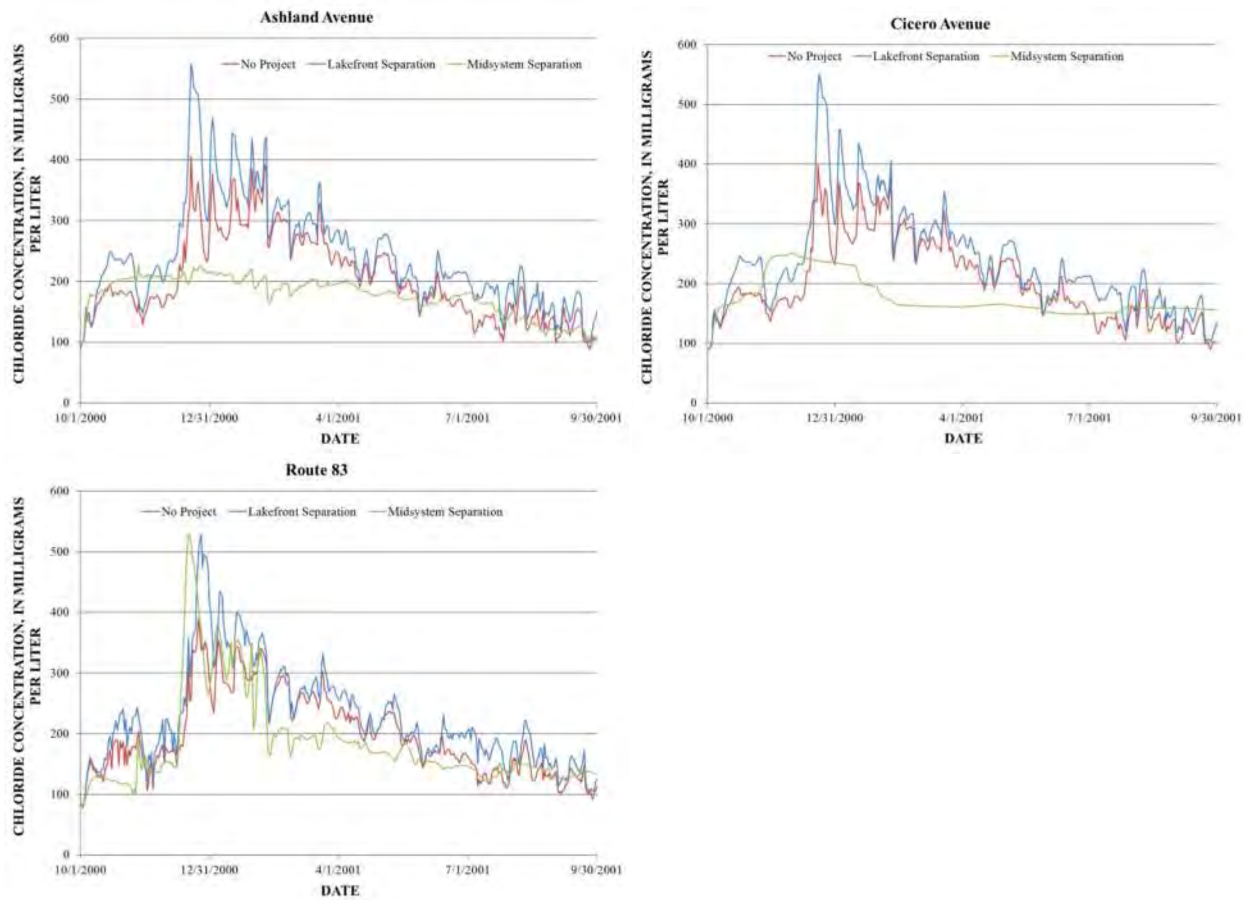


Figure 6.24. Simulated chloride concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2001.

6.3.2 Compliance with Chloride Standards

Figure 6.25 shows the number of hours not in compliance with the chloride chronic toxicity standard along the Chicago River system. Throughout the Chicago River system the "No Project" alternative yields the lowest level of noncompliance among the three alternatives above the Stickney WRP (RM 315.5). However, the difference in compliance only is large on the most upstream part of the NSC, Chicago River main stem (Clark Street on the main stem is shown at RM 325.9 in Figure 6.25), and SBCR. In the other reaches the difference between the

“Lakefront Separation” alternative and the next best alternative ranges from 5 to 230 hrs. Upstream of the Stickney WRP (RM 315.5) the “Midsystem Separation” alternative yielded the highest levels of noncompliance except for the NSC where the “Lakefront Separation” alternative yielded the highest level of noncompliance. Downstream of the Stickney WRP the “Lakefront Separation” alternative yielded the highest level of noncompliance. Downstream from Sag Junction (RM 303.4) the “Midsystem Separation” alternative yielded substantially better compliance than the other alternatives.

Figure 6.26 shows the number of hours not in compliance with the chloride chronic toxicity standard along the Calumet River system. The “Lakefront Separation” alternative yields the highest levels of noncompliance along the entire Calumet River system. In the Little Calumet River (north) and Calumet River east of the Calumet WRP (RM 321.4) the “No Project” alternative yields the lowest level of noncompliance among the alternatives. The “Midsystem Separation” alternative yields the lowest level of noncompliance throughout the entire Calumet-Sag Channel (RM 303.4 to RM 319.6) and the Little Calumet River (north) west of the Calumet WRP (RM 321.4) even fully complying at Halsted Street (RM 320.1). Among the three study years, this representative “normal” year (WY 2001) yielded the highest level of noncompliance with the chloride chronic toxicity standard for nearly all the alternatives and locations in the Calumet River system.

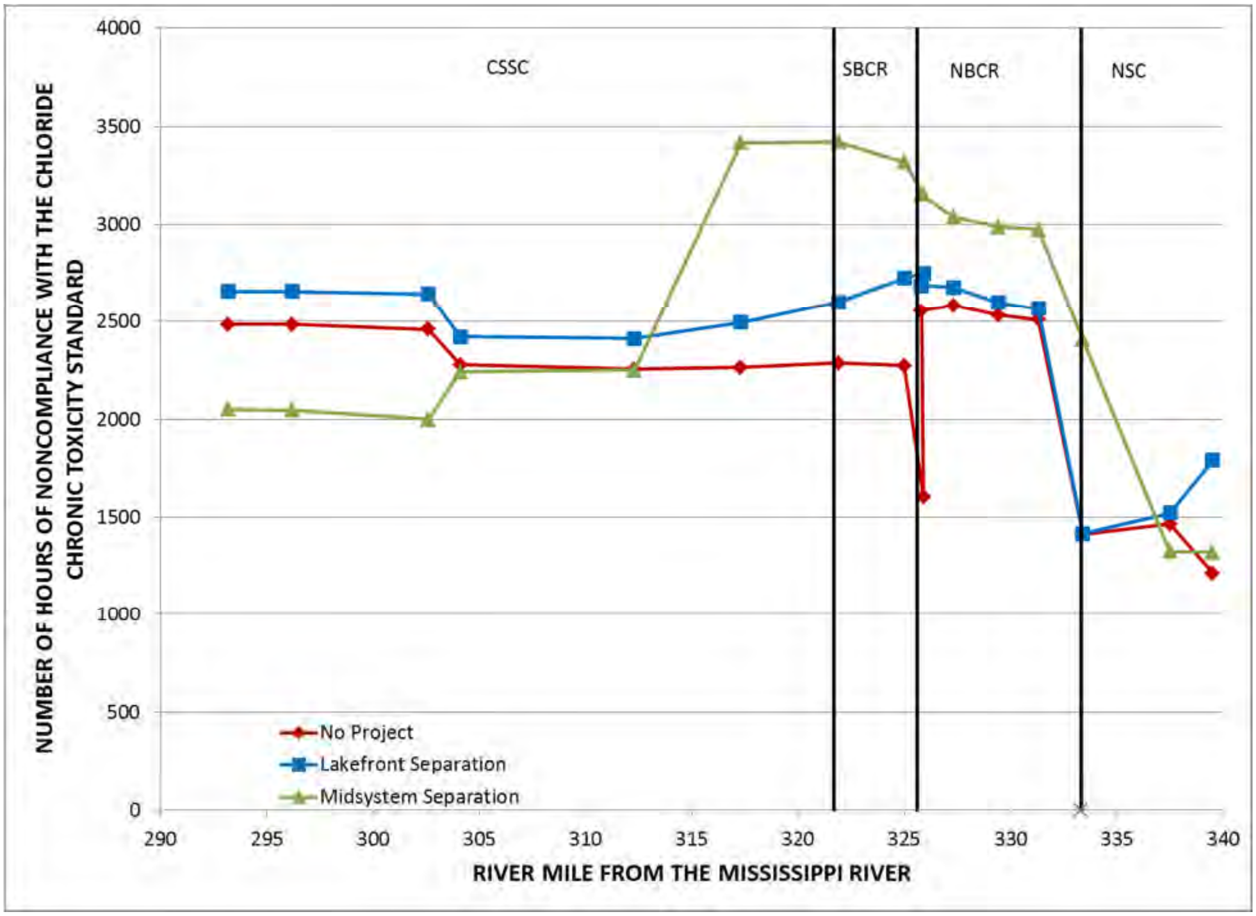


Figure 6.25. Number of hours not in compliance with the chloride chronic toxicity standard along the Chicago River system for Water Year 2001.

6.4 Comparison of Simulated Total Phosphorus Concentrations

Figure 6.27 shows the computed total phosphorus concentrations on the upper NSC at Central Street and Oakton Street (0.1 mi north of the O'Brien WRP outfall). The discretionary diversion in June through August and other flows at Wilmette substantially dilute the total phosphorus concentrations at Central Street for the "No Project" alternative, whereas at Oakton Street only the discretionary diversion in June through August substantially dilutes the total phosphorus concentrations. At Oakton Street the total phosphorus concentrations for the "No Project" and "Lakefront Separation" alternatives are within 0.1 mg/L of each other during periods with low flows at Wilmette for the "No Project" alternative. Whereas for the "Midsystem Separation" alternative the total phosphorus concentrations are similar at both locations indicating that the total phosphorus is fairly conservative in the upper NSC for this alternative in which the NSC carries O'Brien WRP effluent to Lake Michigan. At Oakton Street the "Lakefront Separation" and "Midsystem Separation" alternatives yield similar total phosphorus concentrations because for these alternatives concentrations are dominated by the O'Brien WRP effluent quality. Whereas 3.2 mi away at Central Street the total phosphorus concentration for the "Lakefront Separation" alternative diverges from that of the "Midsystem Separation" alternative indicating the stagnant conditions on the upper NSC are not completely dominated by the O'Brien WRP effluent.

Figure 6.28 shows the computed total phosphorus concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O'Brien WRP outfall) and Foster Avenue and on the NBCR at Wilson Avenue, Diversey Parkway, and Grand Avenue. Outside of the period of discretionary diversion (June through August) at Wilmette the three alternatives yield very similar total phosphorus concentrations at all 5 locations on the lower NSC and NBCR. During June through August the Lake Michigan flows at Wilmette reduce the total phosphorus concentration for the "No Project" alternative, whereas the other two alternatives yield similar total phosphorus concentrations during these months. From these results it is clear that the effluent from the O'Brien WRP dominates total phosphorus concentrations in these reaches of the CAWS.

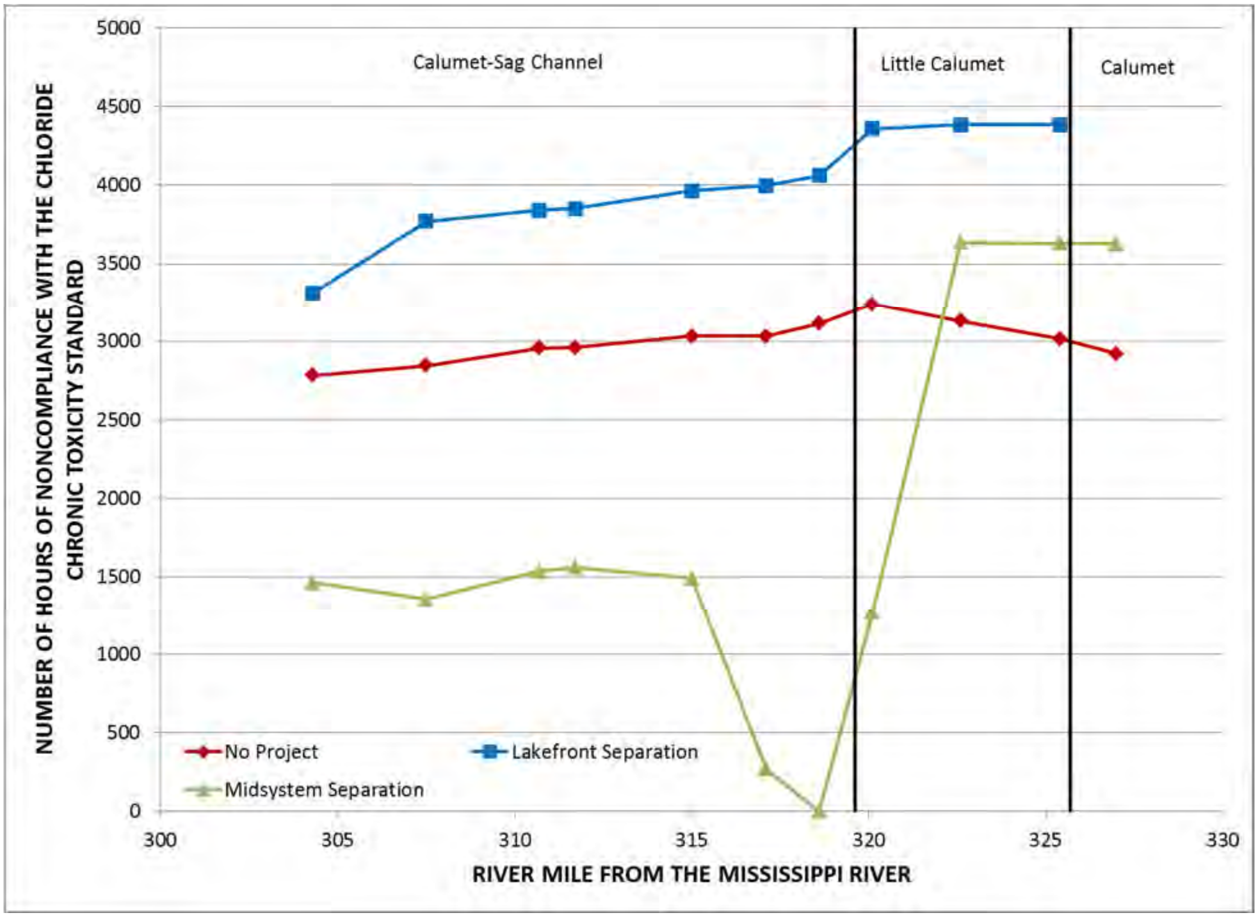


Figure 6.26. Number of hours not in compliance with the chloride chronic toxicity standard along the Calumet River system for Water Year 2001.

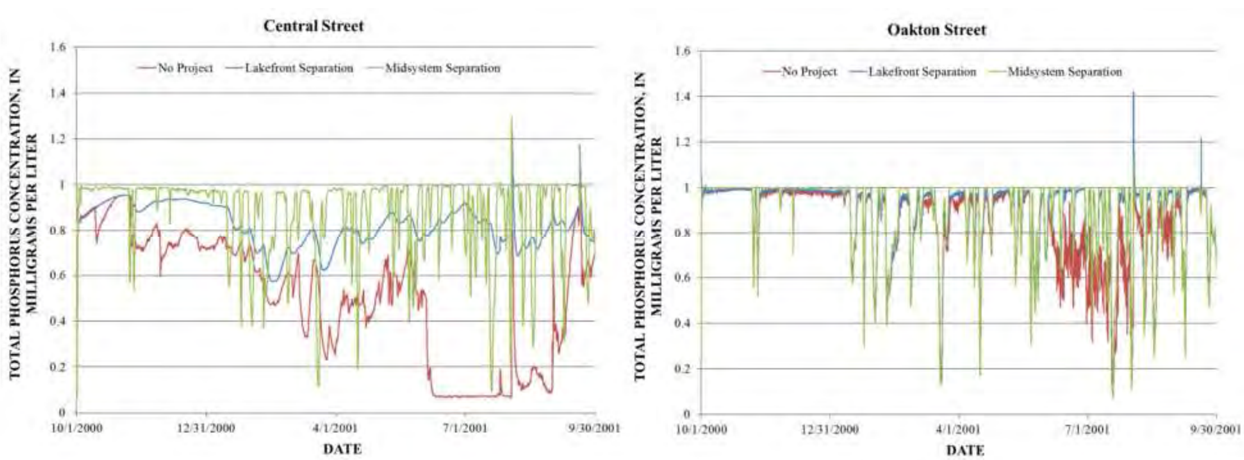


Figure 6.27. Simulated total phosphorus concentration on the upper North Shore Channel at and Central Street and Oakton Street for the three alternatives under future conditions for Water Year 2001.

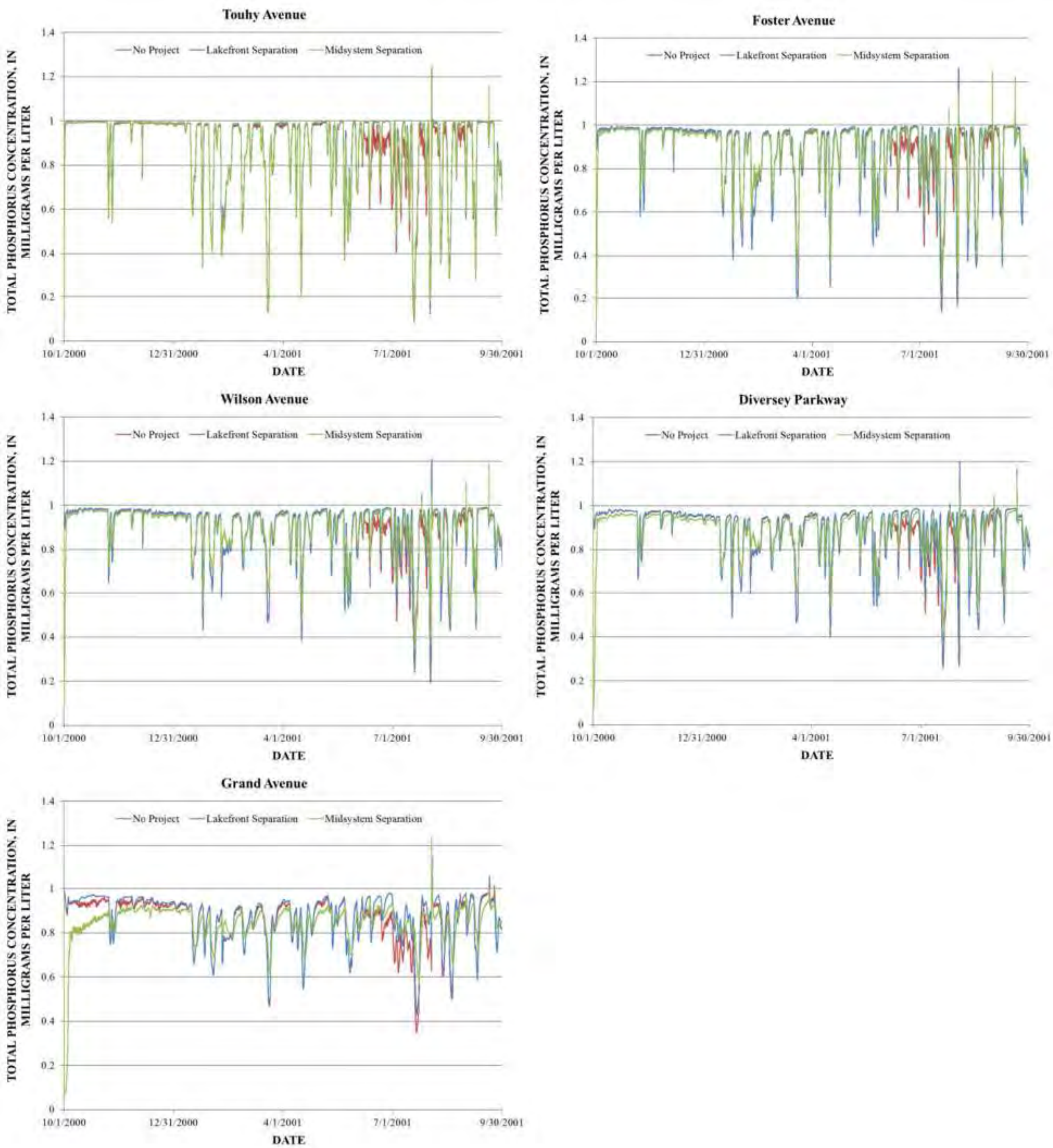


Figure 6.28. Simulated total phosphorus concentration on the North Shore Channel at Touhy Avenue and Foster Avenue and the North Branch Chicago River at Wilson Avenue, Diversey Parkway, and Grand Avenue for the three alternatives under future conditions for Water Year 2001.

Figure 6.29 shows the computed total phosphorus concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street and Loomis Street, and CSSC at Damen Avenue and Cicero Avenue. After January 10th the “Lakefront Separation” and “Midsystem Separation” alternatives yield a similar pattern of total phosphorus concentrations at Wells Street with concentrations for the “Midsystem Separation” alternative consistently less than that for the “Lakefront Separation” alternative indicating a dissipation in total phosphorus as the water travels from the O’Brien WRP to the Chicago River main stem. The “No Project” alternative shows lower total phosphorus concentrations than the other alternatives throughout the entire year (except for early October for the “Midsystem Separation” alternative) resulting from dilution by discretionary diversion and other water withdrawals from Lake Michigan at CRCW. During the discretionary diversion period—June through August—the difference among the alternatives is very large (Figure 6.29).

At Madison Street the “Lakefront Separation” and “Midsystem Separation” alternatives yield a similar pattern of total phosphorus concentrations after January 10th with concentrations for the “Midsystem Separation” alternative consistently less than that for the “Lakefront Separation” alternative indicating a dissipation in total phosphorus as the water travels from the O’Brien WRP to the Chicago River main stem, which strongly interacts with the nearby portion of the SBCR (Figure 6.29). Further, the “Lakefront Separation” and “Midsystem Separation” alternatives yield similar patterns total phosphorus concentrations at Madison Street and Wells Street indicating the influence of total phosphorus concentrations at the junction of the NBCR, SBCR, and Chicago River main stem on those a short distance (0.3 mi) away on the SBCR. At Madison Street, the “No Project” alternative shows lower total phosphorus concentrations than the other alternatives throughout the entire year (except for October for the "Midsystem Separation" alternative) resulting from dilution by discretionary diversion and other water withdrawals from Lake Michigan at CRCW. During periods when no discretionary diversion is taken the "No Project" and "Midsystem Separation" alternatives yielded similar total phosphorus concentrations, but during the discretionary diversion period—June through August—the total phosphorus concentration for the "No Project" alternative is much less than for the other alternatives.

At Loomis Street, Damen Avenue, and Cicero Avenue the "No Project" and "Lakefront Separation" alternatives yield very similar total phosphorus concentrations during periods when the flows at CRCW for the "No Project" alternative are near zero (October through May and September) (Figure 6.29). However, when there is discretionary diversion (June through August) at CRCW in the "No Project" alternative it yields substantially lower total phosphorus concentrations than the other two alternatives. At these three locations the results of the "Midsystem Separation" alternative indicate very gradual changes in total phosphorus concentrations that are characteristic of the stagnant flow conditions in the SBCR and upper CSSC.

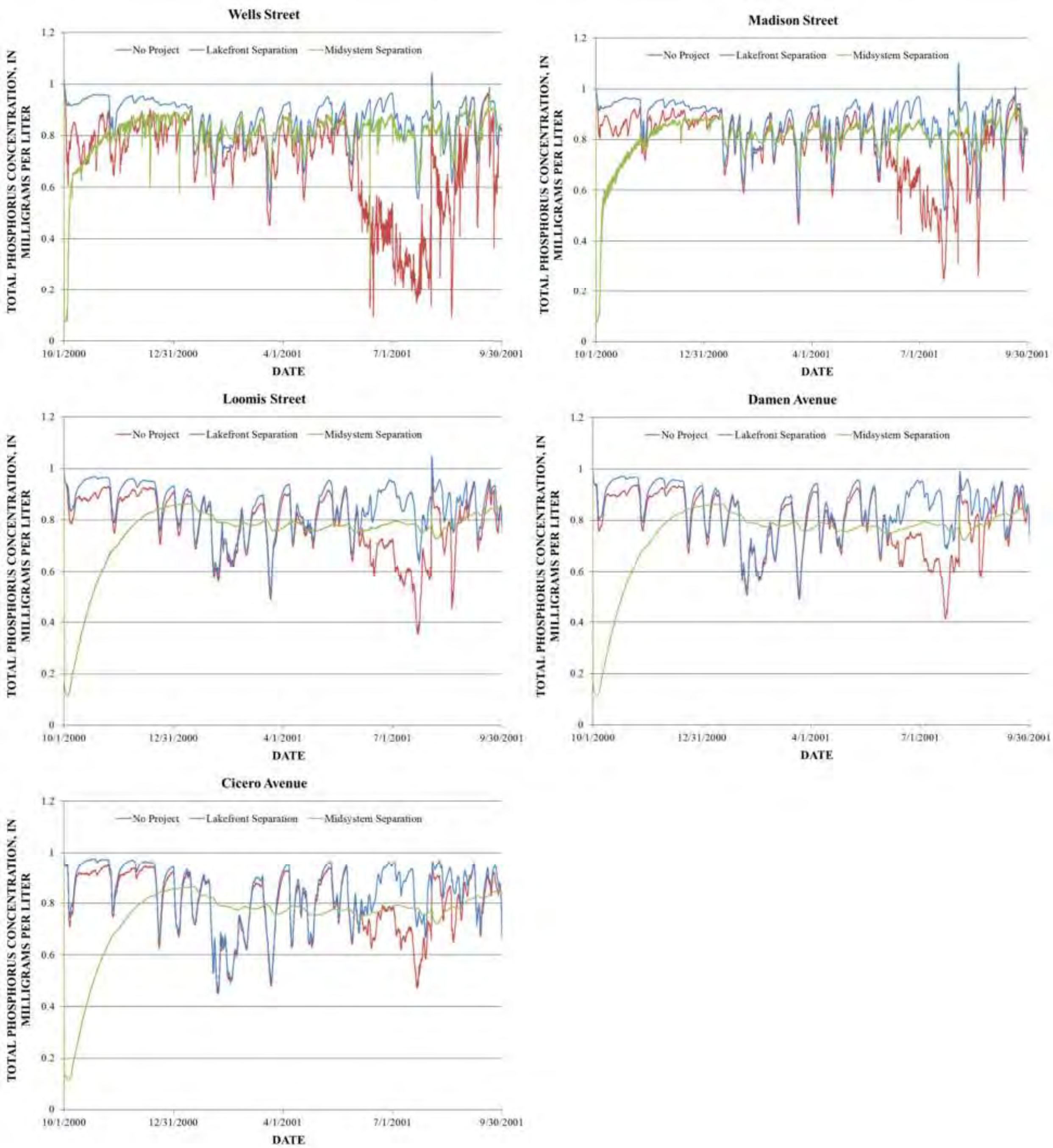


Figure 6.29. Simulated total phosphorus concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street and Loomis Street, and Chicago Sanitary and Ship Canal at Damen Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2001.

Figure 6.30 shows the computed total phosphorus concentrations on the CSSC downstream from the Stickney WRP. The "No Project" and "Lakefront Separation" alternatives yield very similar total phosphorus concentrations during periods when the flows at CRCW for the "No Project" alternative are near zero (October through May and September) at all four locations in Figure 6.30. However, when there is discretionary diversion (June through August) or other flows at CRCW in the "No Project" alternative it yields substantially lower total phosphorus concentrations than the "Lakefront Separation" alternative. The "Midsystem Separation" alternative also yields very similar total phosphorus concentrations as those for the other alternatives with only the lowest total phosphorus concentrations being substantially lower than those for the other two alternatives. The results for the "Midsystem Separation" alternative are completely dominated by the Stickney WRP effluent in this reach, in the other two alternatives upstream flows with higher total phosphorus concentrations can somewhat increase the overall total phosphorus concentrations during periods when the Stickney WRP effluent has very low total phosphorus concentrations.

Figure 6.31 shows the computed total phosphorus concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At Indiana Avenue, the "Lakefront Separation" and "Midsystem Separation" alternatives yield very similar total phosphorus concentrations because for each of these alternatives the total phosphorus at this location is dominated by the Calumet WRP effluent. The "No Project" alternative yields substantially lower total phosphorus concentrations than the other two alternatives at both locations because of discretionary diversion and other withdrawals from Lake Michigan at the O'Brien Lock and Dam. At Halsted Street the total phosphorus concentrations for the "Lakefront Separation" alternative is dominated by the effluent of the Calumet WRP, whereas for the "Midsystem Separation" alternative the total phosphorus concentrations are dominated by those coming from the Little Calumet River (south), which fluctuate with storm runoff.

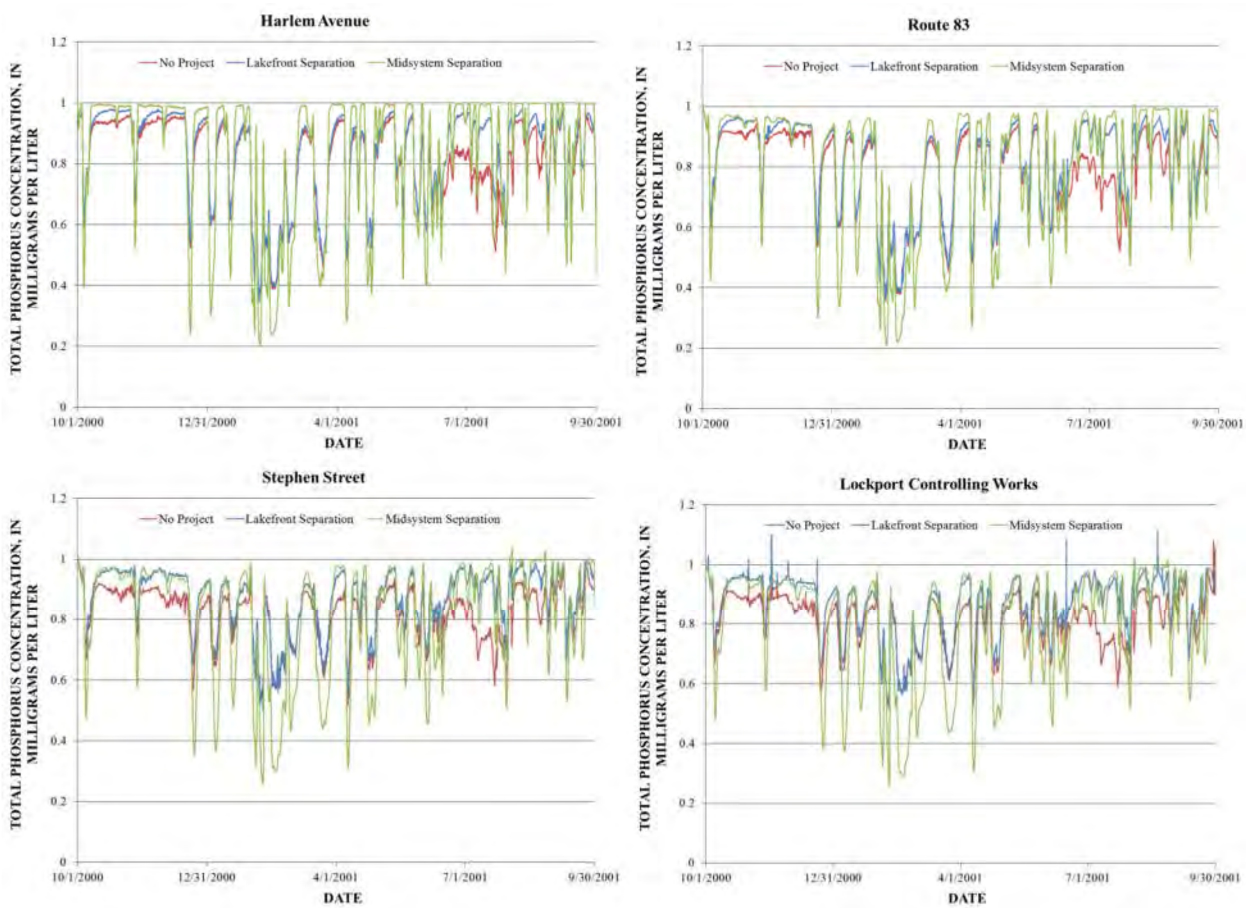


Figure 6.30. Simulated total phosphorus concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, Stephen Street, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2001.

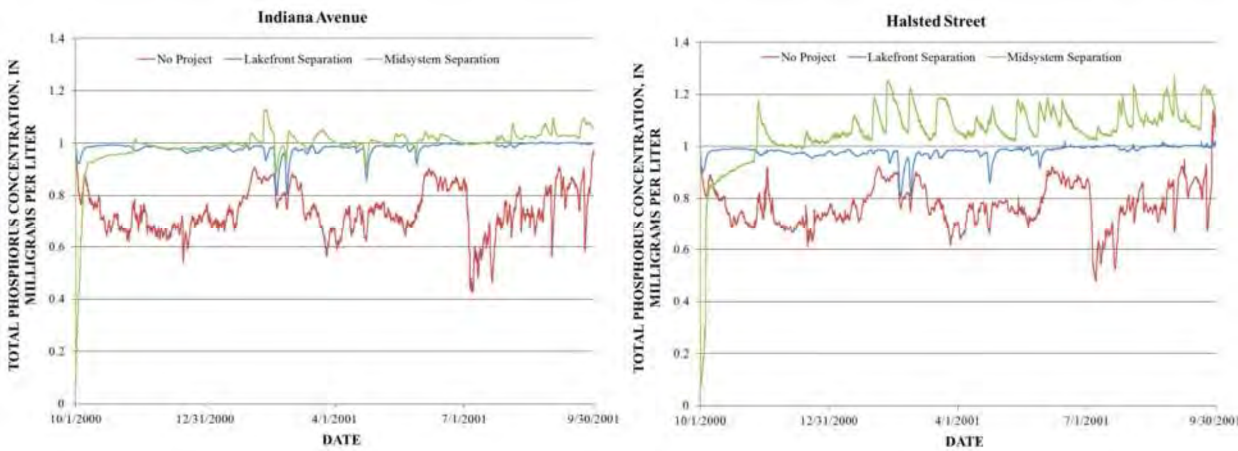


Figure 6.31. Simulated total phosphorus concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2001.

Figure 6.32 shows the computed total phosphorus concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. The "No Project" alternative yields consistently lower total phosphorus concentrations than the other alternatives at Ashland Avenue and Cicero Avenue, and consistently lower than the "Lakefront Separation" alternative at Route 83. This is the result of discretionary diversion and other withdrawals of Lake Michigan water at the O'Brien Lock and Dam in the "No Project" alternative (Figure 6.32). At Ashland Avenue, the "Lakefront Separation" and "Midsystem Separation" alternatives yield similar total phosphorus concentrations. The "Midsystem Separation" alternative yields total phosphorus concentrations at Cicero Avenue that reflect the total phosphorus concentrations in the small tributary streams that discharge to these otherwise stagnant reaches on either side of the barrier at RM 315.89. At Route 83, the "Midsystem Separation" alternative yields total phosphorus concentrations that reflect the effluent from the Stickney WRP because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel.

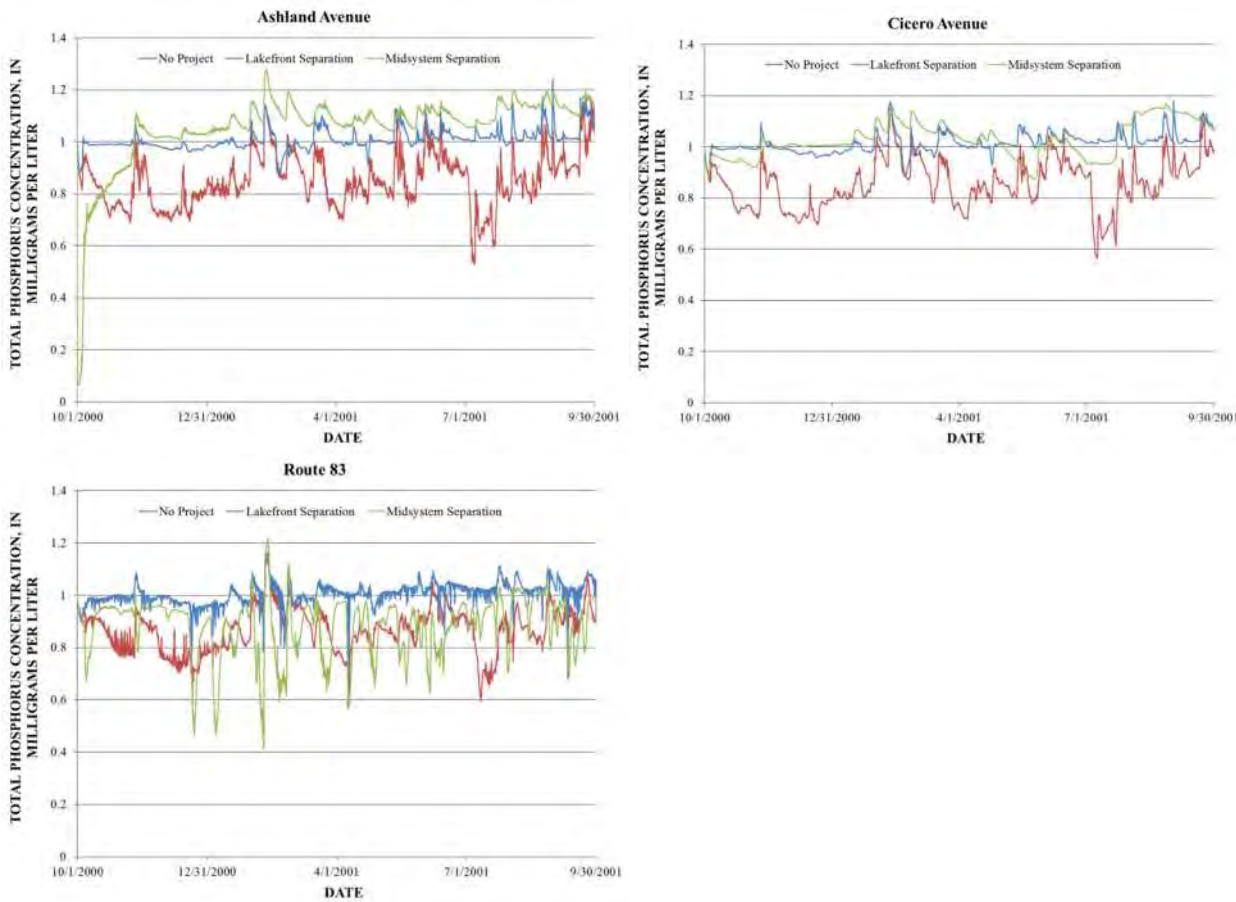


Figure 6.32. Simulated total phosphorus concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2001.

6.5 Loads to Lake Michigan

One of the key water quality impacts of the "Midsystem Separation" alternative is the load of pollutants directed to Lake Michigan under this alternative. For WY 2001 under actual conditions flow reversals to Lake Michigan occurred on August 2nd and August 31st, thus, but with the reservoirs in place the "No Project" alternative for Baseline and Future conditions will not experience flows to the lake. Table 6.1 lists the flows and loads to Lake Michigan for the "Midsystem Separation" alternative for Future conditions. For this representative "normal" year it can be seen that for the “Midsystem Separation” alternative nutrient loads in neighborhood of 14.5 and 2.0 million pounds of nitrogen and phosphorus, respectively, can be delivered to Lake Michigan during normal years. Also for the “Midsystem Separation” alternative loads in the neighborhood of 460 million pounds of chloride can be delivered to Lake Michigan during normal years.

Table 6.1. Flows and loads to Lake Michigan at Wilmette, at the Chicago River Controlling Works (CRCW), and from the Calumet River for the “Midsystem Separation” alternative for Future conditions for Water Year 2001. [note: CBOD is carbonaceous biochemical oxygen demand, TN is total nitrogen, TP is total phosphorus, and TSS is total suspended solids].

Constituent	Wilmette	CRCW	Calumet River	Total
Flow (cfs)	205.1	377.6	639.8	1222.5
Volume (ac-ft)	148,000	273,000	463,000	885,000
CBOD (lb)	1,053,000	1,954,000	2,479,000	5,487,000
TN (lb)	3,612,000	4,041,000	6,773,000	14,426,000
TP (lb)	348,000	518,000	1,134,000	2,000,000
TSS (lb)	3,163,000	10,826,000	7,997,000	21,986,000
Chloride (lb)	72,600,000	127,600,000	265,200,000	465,500,000
Fecal Coliform (CFU)	1.12×10^{16}	2.50×10^{16}	1.06×10^{14}	3.63×10^{16}

Chapter 7 – ALTERNATIVE COMPARISON FOR THE REPRESENTATIVE "DRY" YEAR (WY 2003)

The DUFLOW model yields simulated values of carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia, nitrate, organic phosphorus, inorganic phosphorus, algae as chlorophyll a, dissolved oxygen (DO), total suspended solids, chloride, pH, and fecal coliform bacteria. It was decided to report the variations in concentrations of DO, fecal coliform bacteria, chloride, and total phosphorus throughout the CAWS to compare among the three alternatives—"No Project," "Lakefront Separation," and "Midsystem Separation." Also important are the loads of the various constituents to Lake Michigan for the different alternatives. Obviously, there are no loads to Lake Michigan for the "Lakefront Separation" alternative. For the representative "dry" year (WY 2003), reported in this chapter, there are no loads to Lake Michigan for the "No Project" alternative because the year was dry enough that even under the actual conditions in WY 2003 there were no flows to Lake Michigan from the CAWS.

This chapter presents the comparison of the different alternatives in terms of concentrations throughout the CAWS and compliance with water-quality standards for DO, fecal coliform bacteria, and chloride, concentrations throughout the CAWS for total phosphorus, and loads to Lake Michigan for CBOD, total nitrogen, total phosphorus, total suspended solids, chloride, and fecal coliform bacteria. These results are reported only for the Future conditions to give a picture of the ultimate performance for any of these alternatives.

7.1 Comparison of Simulated Dissolved Oxygen Concentrations

7.1.1 Concentration vs. Time

The DUFLOW model yields computed values of any of the simulated water-quality constituents and properties at any the computational points in the CAWS (more than 100 points). Thus, to keep the comparison manageable it is focused on the DO measurement points monitored by the MWRDGC and used to calibrate and verify the model. In this report the results are presented for the various waterway reaches of the CAWS: the upper NSC; the lower NSC and NBCR (downstream of the O'Brien WRP, RM 336.9); Chicago River main stem, SBCR, and upper CSSC (above the Stickney WRP, RM 315.5); lower CSSC; Calumet River and Little Calumet River (north); and the Calumet-Sag Channel.

Figure 7.1 shows the computed DO concentrations on the upper NSC at Simpson Street and Main Street. The "Midsystem Separation" alternative yields high DO concentrations throughout most of the year. This is because the opening of the NSC to Lake Michigan yields a constant flow from the O'Brien WRP through the NSC resulting in better DO concentrations than those for the stagnant flow conditions that are present in the upper NSC throughout much of the year for the "No Project" and "Lakefront Separation" alternatives. This can be best seen in the computed DO concentrations at Main Street. The "No Project" alternative yields higher DO concentrations than the other two alternatives for the months of June and July (August only has a very small discretionary diversion in WY 2003 compared to the other years considered) reflecting the high quality Lake Michigan water released into the upper NSC as discretionary diversion during these months. At Simpson Street, the "No Project" alternative also yields the highest DO concentrations from October through mid-January and in late September because at these times small non-discretionary flows from Lake Michigan at Wilmette improve DO conditions up to Simpson Street (1.3 mi downstream). However, by the time the flows reach Main Street (2 mi downstream from Simpson Street) much of the beneficial effects of these small flows have dissipated and the "No Project" and "Lakefront Separation" alternatives yield nearly identical DO concentrations reflecting the fact that the "No Project" alternative has nearly zero flow at Wilmette outside of June and July. Finally, at both locations the "Lakefront Separation" alternative yields the lowest DO concentrations throughout the year because of the totally stagnant flows in this reach. In particular, at Simpson Street the CSOs resulting from the storms of early May drop a lot of organic load into the upper NSC that takes a long time to dissipate resulting in long periods of very low DO concentrations throughout May and early June.

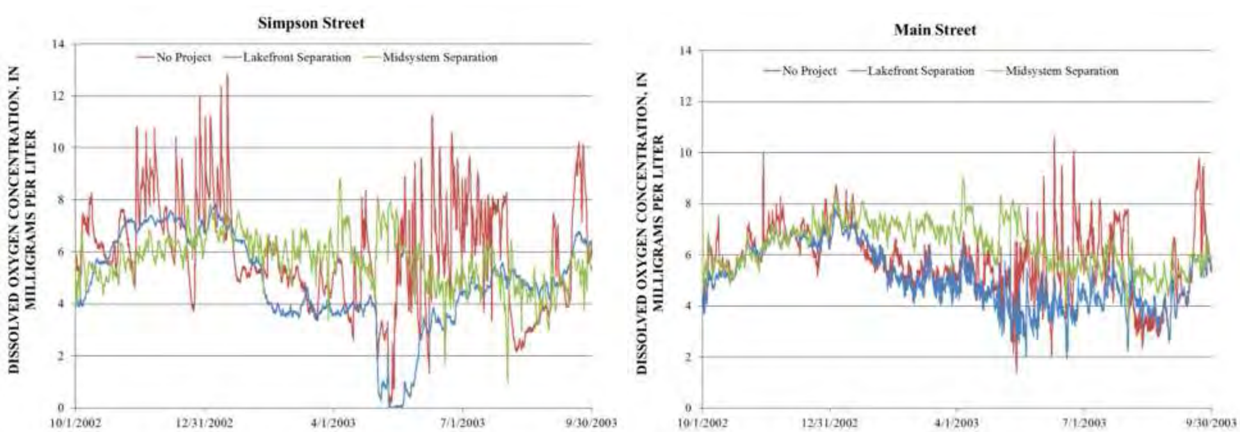


Figure 7.1. Simulated dissolved oxygen concentration on the upper North Shore Channel for the three alternatives under future conditions for Water Year 2003.

Figure 7.2 shows the computed DO concentrations on the lower NSC at Foster Avenue and on the NBCR at Addison Street, Fullerton Avenue, Division Street, and Kinzie Street. Generally, the "Midsystem Separation" alternative yields lower DO concentrations than the other two alternatives because a smaller portion of the O'Brien WRP effluent passes through these waterways for this alternative. The DO concentrations for the "No Project" and "Lakefront Separation" alternatives are similar at all locations for October through May, August, and September reflecting that these two alternatives have similar flows (or rather lack of flows) at Wilmette during these months. For June and July the "No Project" alternative yields the highest DO concentrations because of the discretionary diversion at Wilmette during these months.

Figure 7.3 shows the computed DO concentrations at Clark Street on the Chicago River main stem, Jackson Boulevard and Loomis Street on the SBCR, and Cicero Avenue on the CSSC. Cicero Avenue is included in this grouping instead of with the other locations on the CSSC because in the "Midsystem Separation" alternative Cicero Avenue is on the lake side of the separation barrier, and, thus, reflects the water quality in the stagnant SBCR and upper CSSC resulting from the hydrological/ecological separation. At Clark Street, the "No Project" alternative yields the highest DO concentrations and at Jackson Boulevard it yields high DO concentrations throughout the majority of the year. Discretionary diversion flows result in higher DO concentrations for the "No Project" alternative in June and July, and non-discretionary diversion flows, especially at CRCW, result in higher DO concentrations in other months. The "Lakefront Separation" alternative consistently has the lowest DO concentration at Clark Street and Jackson Boulevard (except for October in which the "Midsystem Separation" alternative yields the lowest DO concentrations) reflecting the stagnant conditions in the Chicago River main stem. The "Midsystem Separation" alternative yields similar DO concentrations to the "No Project" alternative for November through May, August, and September at Clark Street and Jackson Boulevard indicating the continuous flow of treated O'Brien WRP effluent through the Chicago River main stem can improve DO concentrations. The results for both the "Lakefront Separation" and "Midsystem Separation" alternatives show the interaction of the main stem and nearby points on the SBCR (Jackson Boulevard is 0.6 mi from the junction of the NBCR, SBCR, and main stem).

The "No Project" and "Lakefront Separation" alternatives yield very similar results at Loomis Street and Cicero Avenue for all months except (June and July, i.e. the period of discretionary diversion) because of the similar flows (or rather lack of flows) at Wilmette and CRCW during these months (Figure 7.3).

The results at Jackson Boulevard, Loomis Street, and Cicero Avenue for the "Midsytem Separation" alternative show extremely high, sometimes supersaturated, DO concentrations (Figure 7.3). This is the result of algal growth in the stagnant waters in these reaches under the "Midsystem Separation" alternative. The upper NBCR delivers high concentrations of algae as chlorophyll-a in April 2003 (58.8 µg/L of algae as chlorophyll-a as discussed in Melching et al. (2010), Table 3.5 and related text) that "seeded" the NBCR with algae. A portion of these algae was transported into the stagnant SBCR where it was able to grow and establish and maintain relatively high concentrations as shown in Figure 7.4. The pattern of high DO concentrations at Jackson Boulevard, Loomis Street, and Cicero Avenue in Figure 7.3 is strongly correlated with the pattern of high chlorophyll a concentrations in Figure 7.4 for the "Midsystem Separation" alternative.

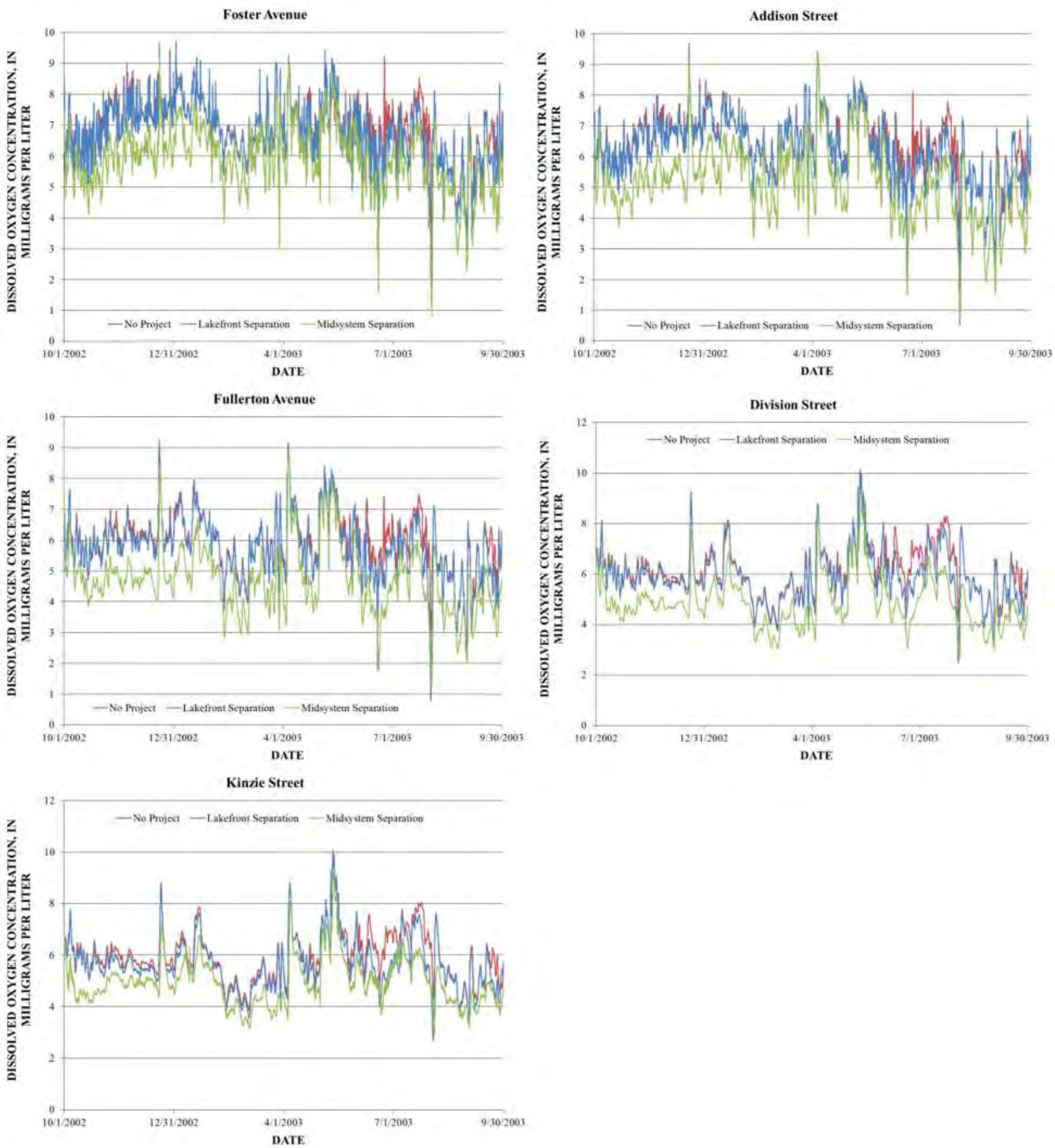


Figure 7.2. Simulated dissolved oxygen concentration on the lower North Shore Channel at Foster Avenue and the North Branch Chicago River at Addison Street, Fullerton Avenue, Division Street, and Kinzie Street for the three alternatives under future conditions for Water Year 2003.

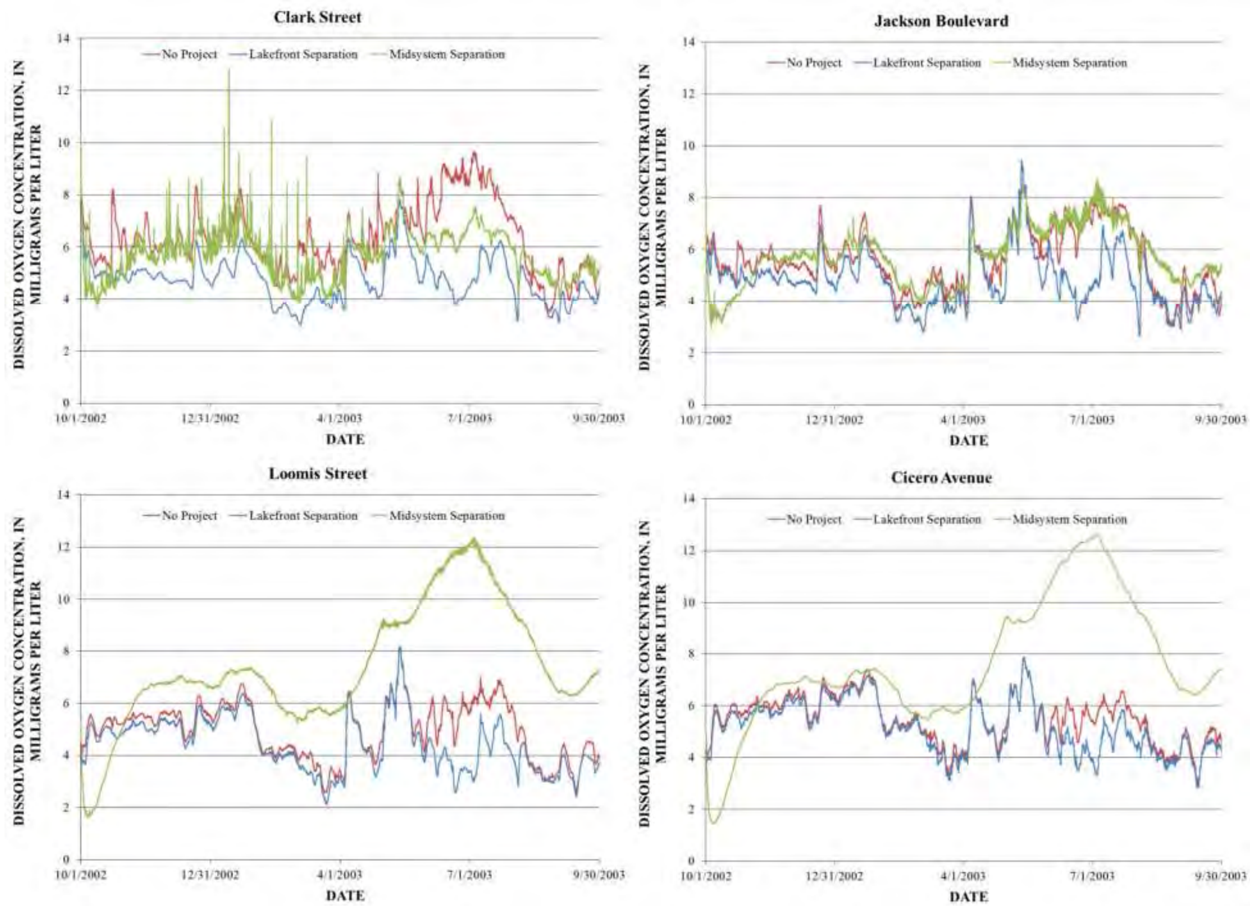


Figure 7.3. Simulated dissolved oxygen concentration on the Chicago River main stem at Clark Street, the South Branch Chicago River at Jackson Boulevard and Loomis Street, and the Chicago Sanitary and Ship Canal at Cicero Avenue for the three alternatives under future conditions for Water Year 2003.

Figure 7.5 shows the computed DO concentrations along the CSSC downstream from the Stickney WRP. Through RM 302.6 the "Midsystem Separation" alternative yields higher DO concentrations than the other alternatives because the effluent from the Stickney WRP, which is nearly the only flow in this alternative, has higher DO concentrations than the upstream flows in the SBCR and upper CSSC in the other alternatives. Once the flows reach Romeoville Road the consumption of the oxygen demanding substances in the Stickney WRP effluent bring the DO concentrations for the "Midsystem Separation" alternative to values similar to those for the other alternatives. The "No Project" and "Lakefront Separation" alternatives yield similar results throughout the year except for the discretionary diversion period of June and July. Overall, for all three alternatives relatively high DO concentrations far above the DO standard of 3.5 mg/L are achieved throughout the entire year.

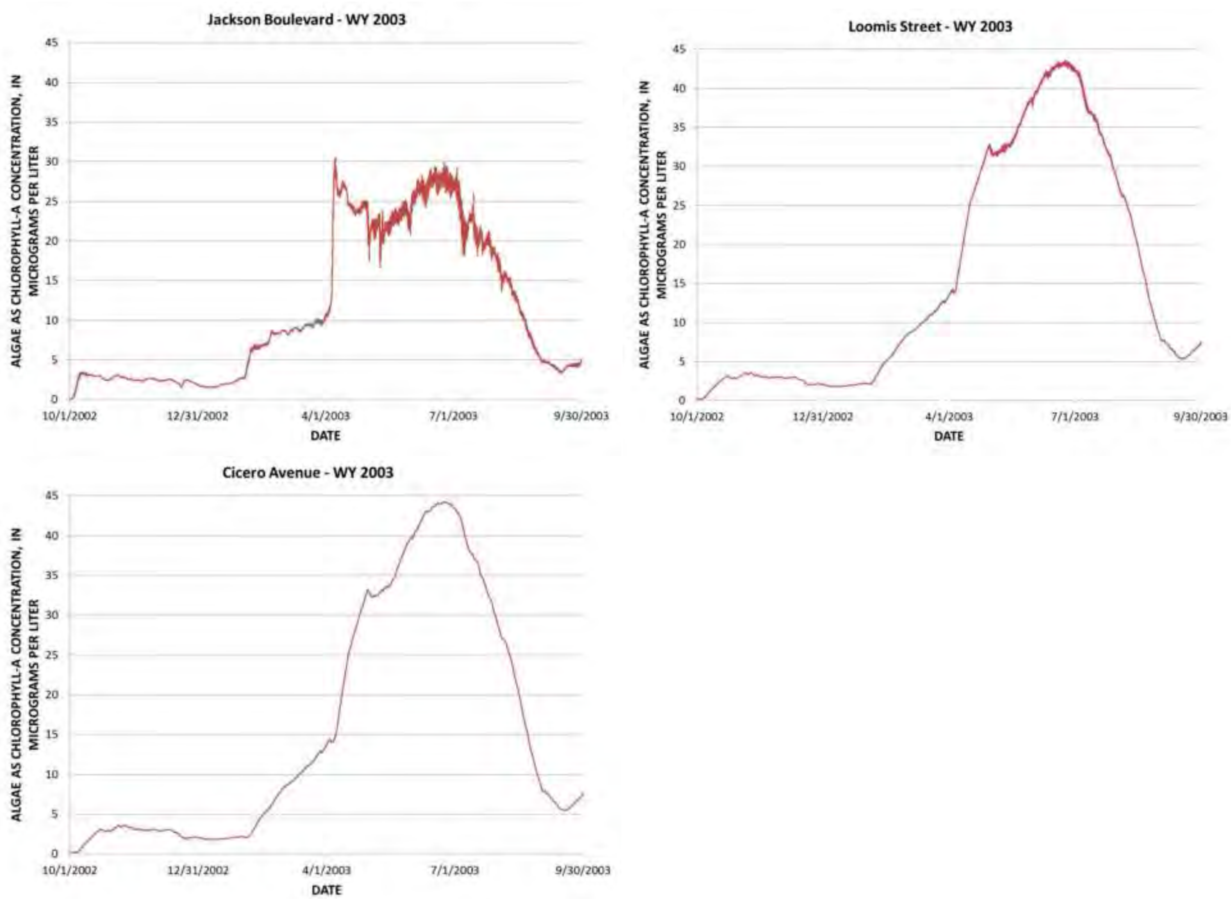


Figure 7.4. Simulated algae as chlorophyll-a concentrations on the South Branch Chicago River at Jackson Boulevard and Loomis Street and on the Chicago Sanitary and Ship Canal at Cicero Avenue for the "Midsystem Separation" alternative for Future conditions for Water Year 2003.

Figure 7.6 shows the computed DO concentrations at 130th Street on the Calumet River and at Conrail Railroad and Central & Wisconsin Railroad on the Little Calumet River (north). In fact the figure for 130th Street shows the conditions at 130th Street for the "Midsystem Separation" alternative and on the river side of the O'Brien Lock and Dam (0.5 mi south of 130th Street) for the “No Project” alternative. No result is shown for the “Lakefront Separation” alternative because the separation barrier is placed at RM 324.5 (2 mi downstream from the O’Brien Lock and Dam).

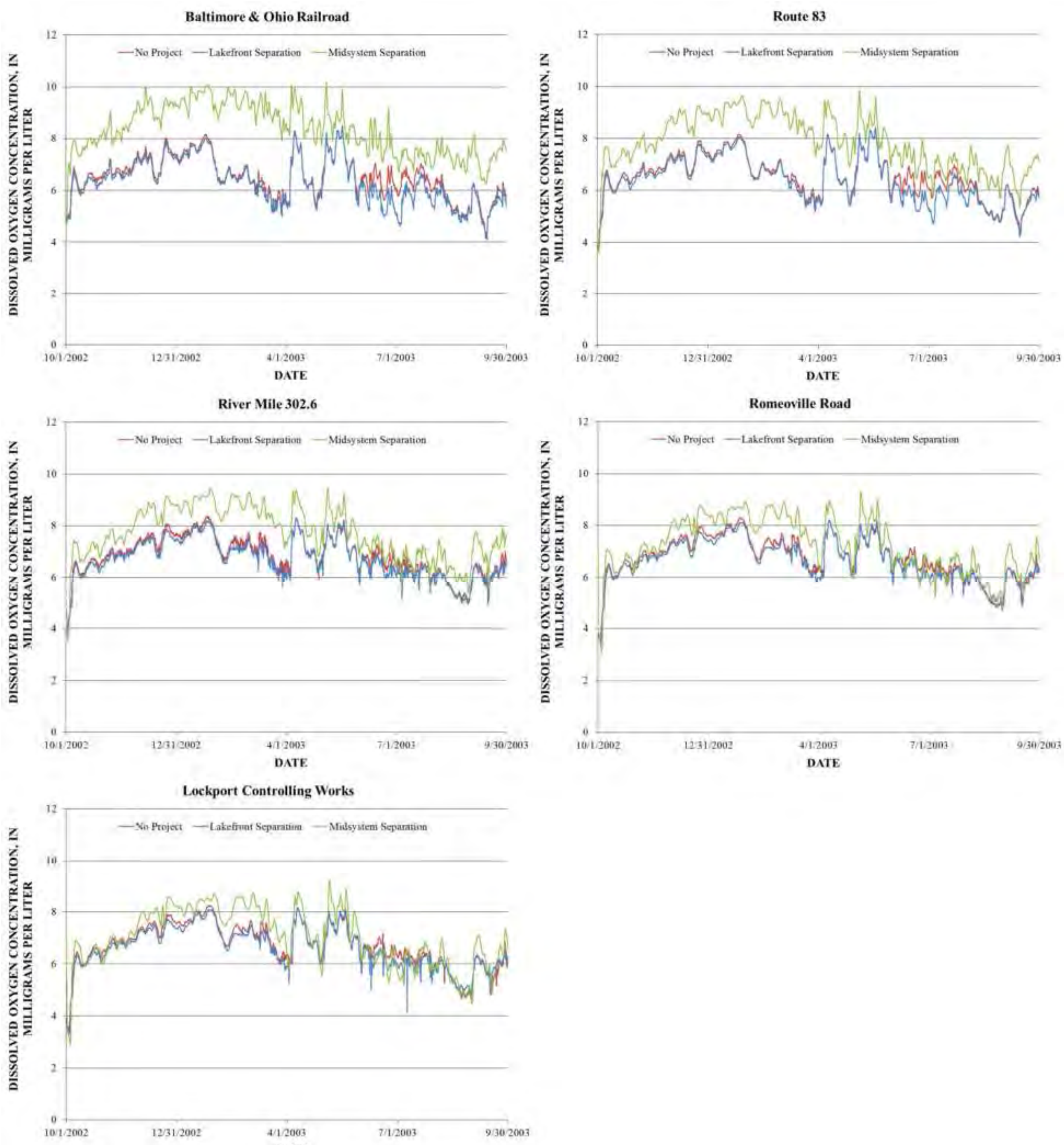


Figure 7.5. Simulated dissolved oxygen concentration on the Chicago Sanitary and Ship Canal for the three alternatives under future conditions for Water Year 2003.

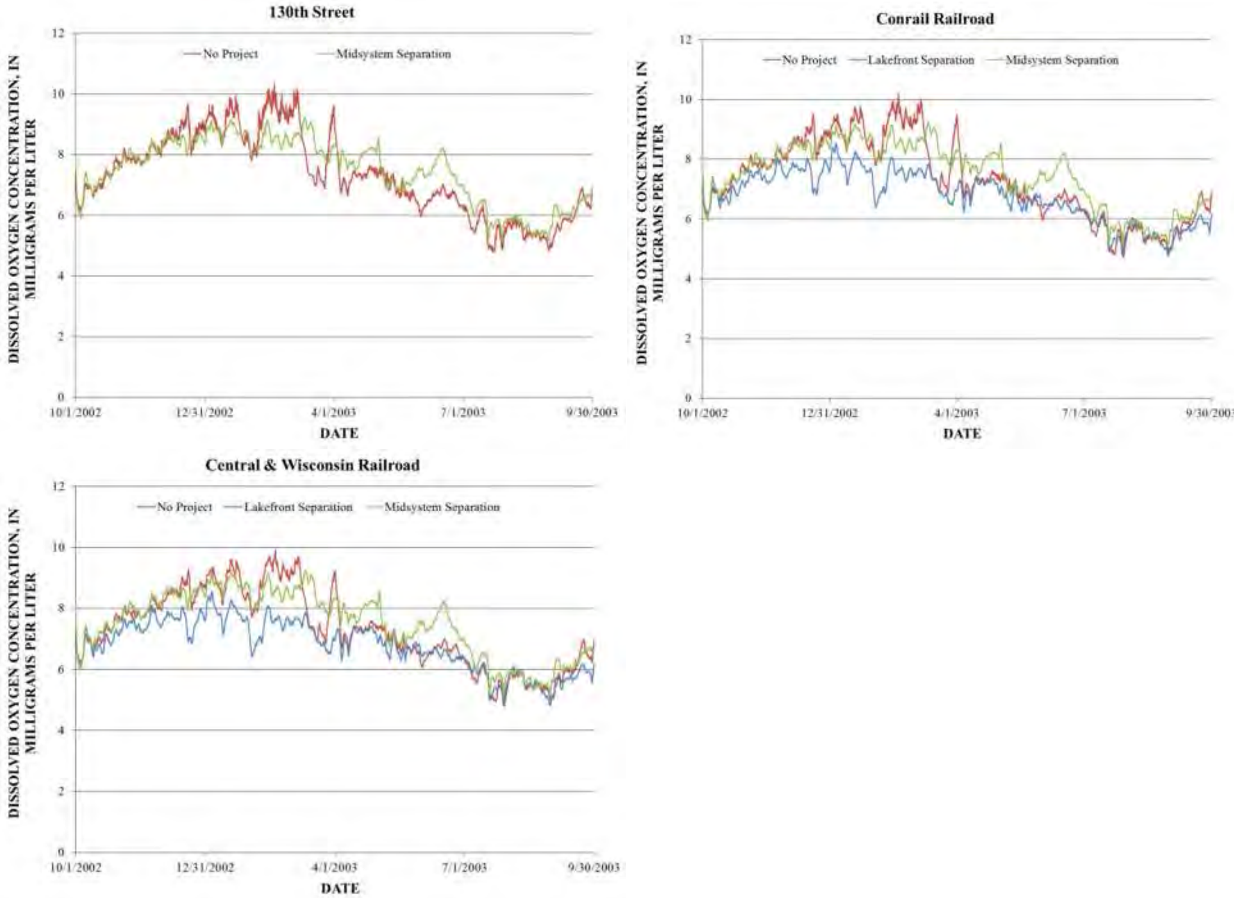


Figure 7.6. Simulated dissolved oxygen concentration on the Calumet River at 130th Street and the Little Calumet River (north) at Conrail Railroad and Central & Wisconsin Railroad for the three alternatives under future conditions for Water Year 2003.

The "Midsystem Separation" alternative yields high DO concentrations at all the locations shown in Figure 7.6 because under this alternative continuous flows pass each of these locations whereas in the other alternatives these locations generally experience stagnant flows. The "No Project" alternative also yields high DO concentrations at all the locations shown in Figure 7.6 throughout the year. The "No Project" and "Lakefront Separation" alternatives yield similar DO concentrations from October through March, and then from April through September the "No Project" and "Lakefront Separation" alternatives are similar at Conrail Railroad and Central and Wisconsin Railroad. The DO concentrations do not substantially differ for the "No Project" and

“Lakefront Separation” alternatives in June and July, thus, the discretionary diversion taken in the “No Project” alternative does not substantially affect DO concentrations in this reach for WY 2003.

Figure 7.7 shows the computed DO concentrations at Halsted Street on the Little Calumet River (north) and at seven locations along the Calumet-Sag Channel. The simulation results at Halsted Street show that for the “Midsystem Separation” alternative DO concentrations are dictated by those at Ashland Avenue on the Little Calumet River (south), which is the source of flow to Halsted Street for this alternative. The DO concentrations along the Calumet-Sag Channel for the “Midsystem Separation” alternative show the clear effects algal growth because of flow stagnation once the watersheds are separated at RM 315.89. The Little Calumet River (south) and the tributaries to the Calumet-Sag Channel bring in medium concentrations of algae as chlorophyll-a of 18.9 and 16.1 µg/L in March and April (see Table 3.5 in Melching et al. (2010)), which seed the stagnant Calumet-Sag Channel for algal growth. Figure 7.8 shows the computed algae as chlorophyll-a concentrations in the Little Calumet River (north) at Halsted Street and along the Calumet-Sag Channel for the “Midsystem Separation” alternative. It is clear that the DO concentrations shown in Figure 7.7 are strongly correlated with the algae as chlorophyll-a concentrations in Figure 7.8.

The “No Project” and “Lakefront Separation” alternatives yield similar patterns of DO concentration at each location in the Calumet-Sag Channel. However, the “No Project” alternative yields higher DO concentrations than the “Lakefront Separation” alternative for October through March, but then in April through September the two alternatives yield very similar DO concentrations. Thus, again, the discretionary diversion taken in the "No Project" alternative does not substantially affect DO concentrations in this reach for WY 2003.

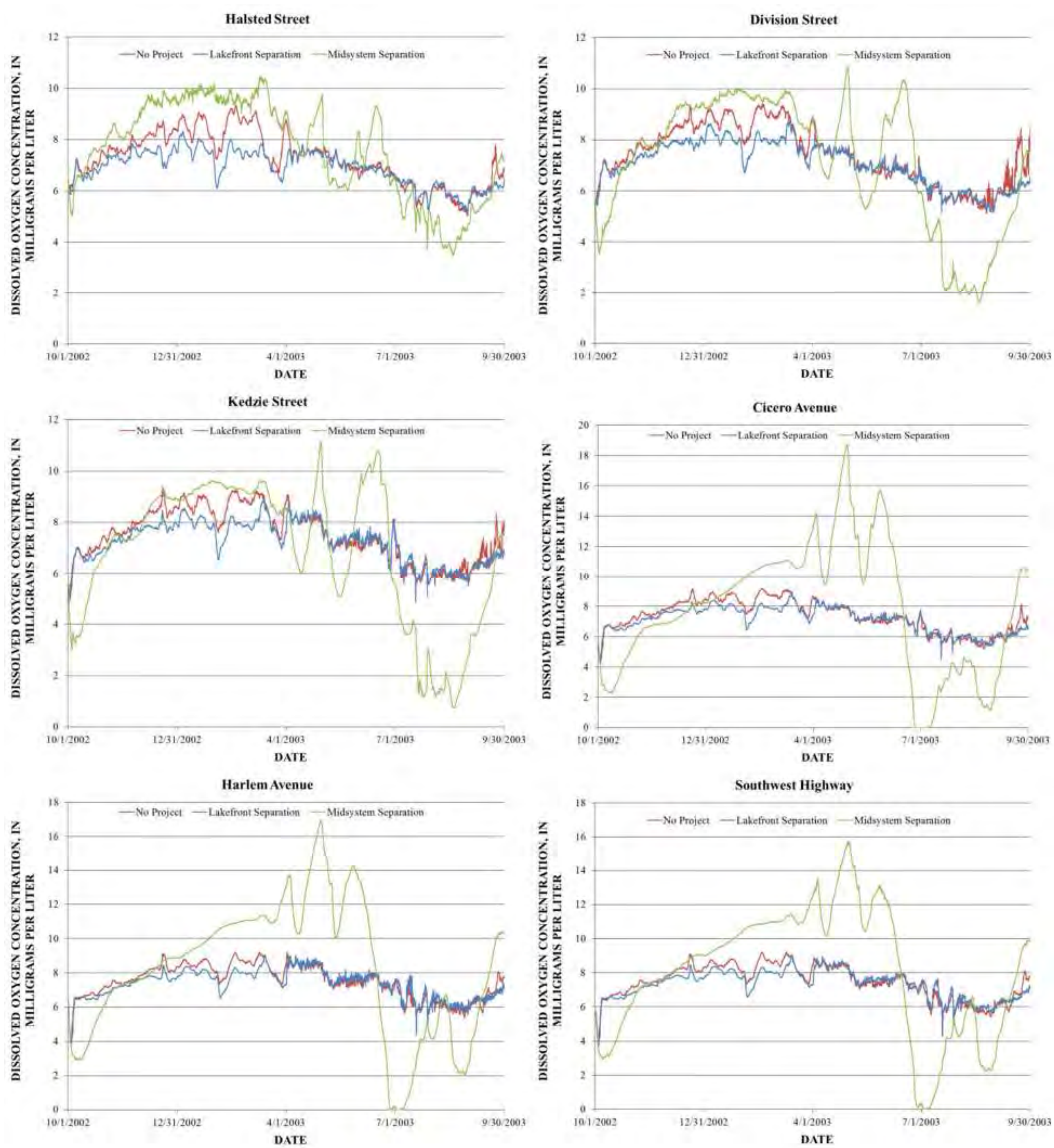


Figure 7.7. Simulated dissolved oxygen concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2003.

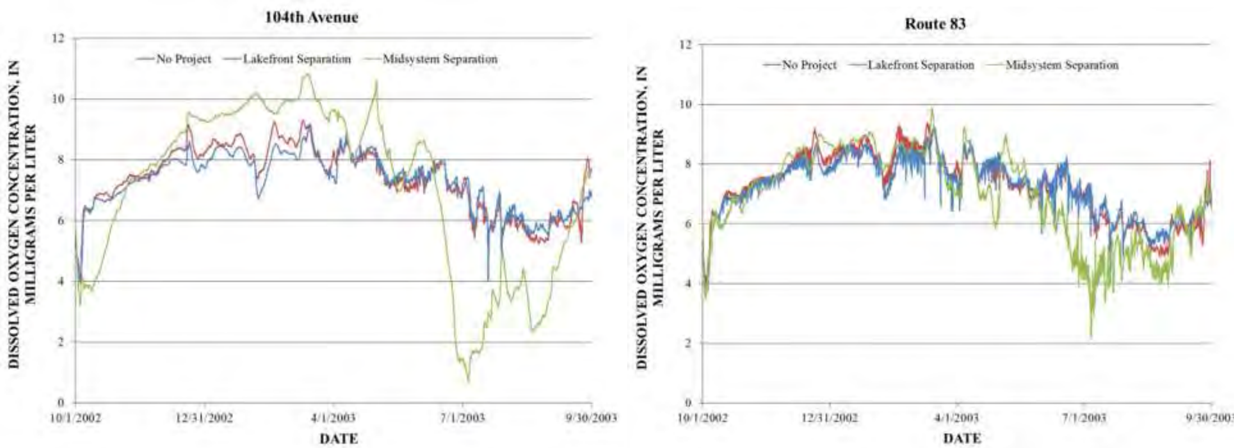


Figure 7.7 (cont.) Simulated dissolved oxygen concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2003.

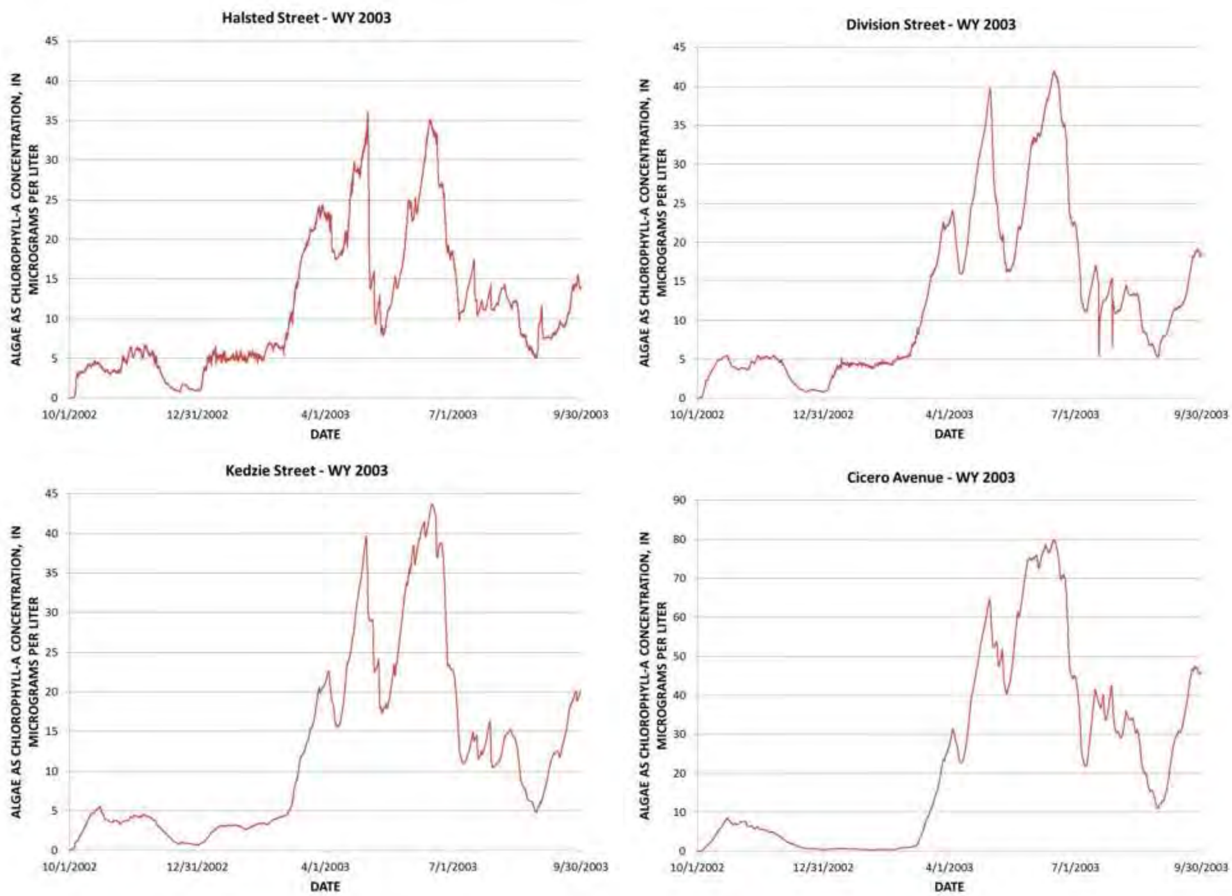


Figure 7.8. Simulated algae as chlorophyll-a concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the "Midsystem Separation" alternative under future conditions for Water Year 2003.

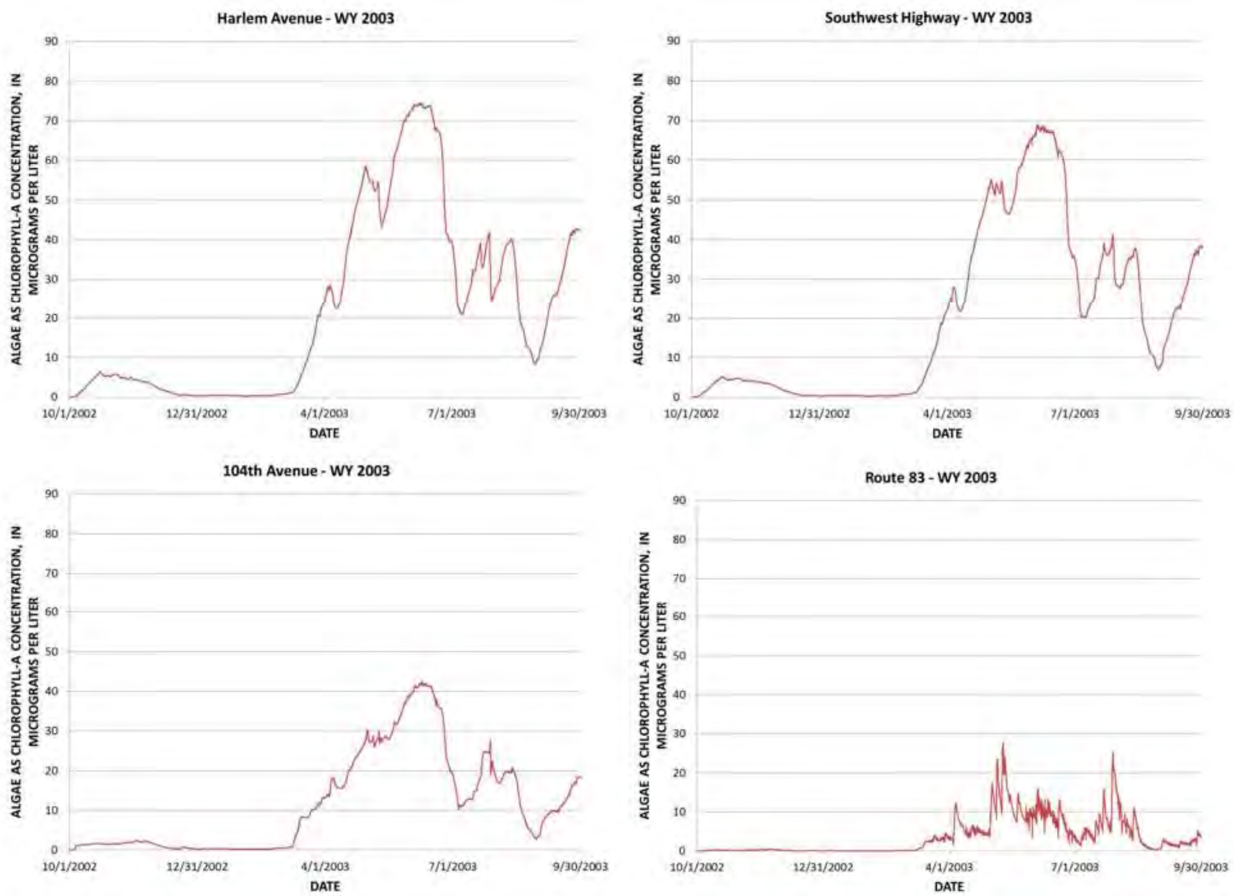


Figure 7.8 (cont.) Simulated algae as chlorophyll-a concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the "Midsystem Separation" alternative under future conditions for Water Year 2003.

7.1.2 Compliance with Dissolved Oxygen Standards

Figures 7.9 and 7.10 show the number of hours not in compliance with the DO standards along the Chicago River and Calumet River systems, respectively. It is clearly seen that stagnant reaches yield high levels of noncompliance with the DO standards. These include the upper NSC (RMs 336.9 to 340.8, Figure 7.9) and the upper Little Calumet River (north) and Calumet River (RMs 321.4 to 327, Figure 7.10) for the "No Project" and "Lakefront Separation" alternatives, the Chicago River main stem for the "Lakefront Separation" alternative (Clark

Street on the main stem is shown at RM 325.9 in Figure 7.9), and the SBCR and CSSC up to the Stickney WRP (RMs 315.5 to 325.6, Figure 7.9) and the Calumet-Sag Channel (RMs 303.4 to 319.6, Figure 7.10) for the "Midsystem Separation" alternative. For whatever alternative is enacted, mitigation is needed to eliminate stagnant zones if high levels of compliance with the DO standards are to be achieved. Also, high levels of noncompliance result around Loomis Street (RM 321.9, Figure 7.9) on the SBCR for the "No Project" and "Lakefront Separation" alternatives that would require mitigation if high levels of compliance with the DO standards are to be achieved.

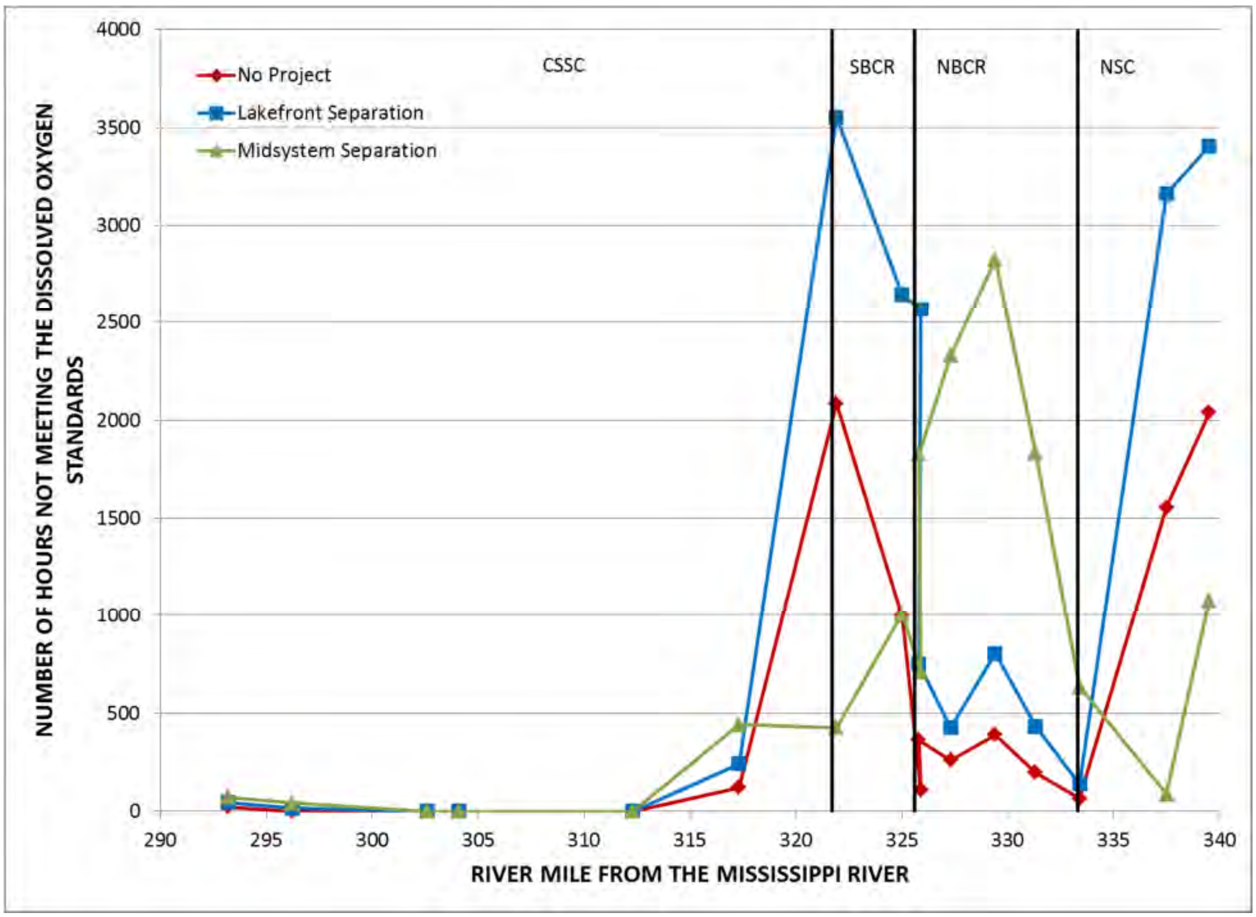


Figure 7.9. Number of hours not in compliance with the dissolved oxygen standards along the Chicago River system for Water Year 2003.

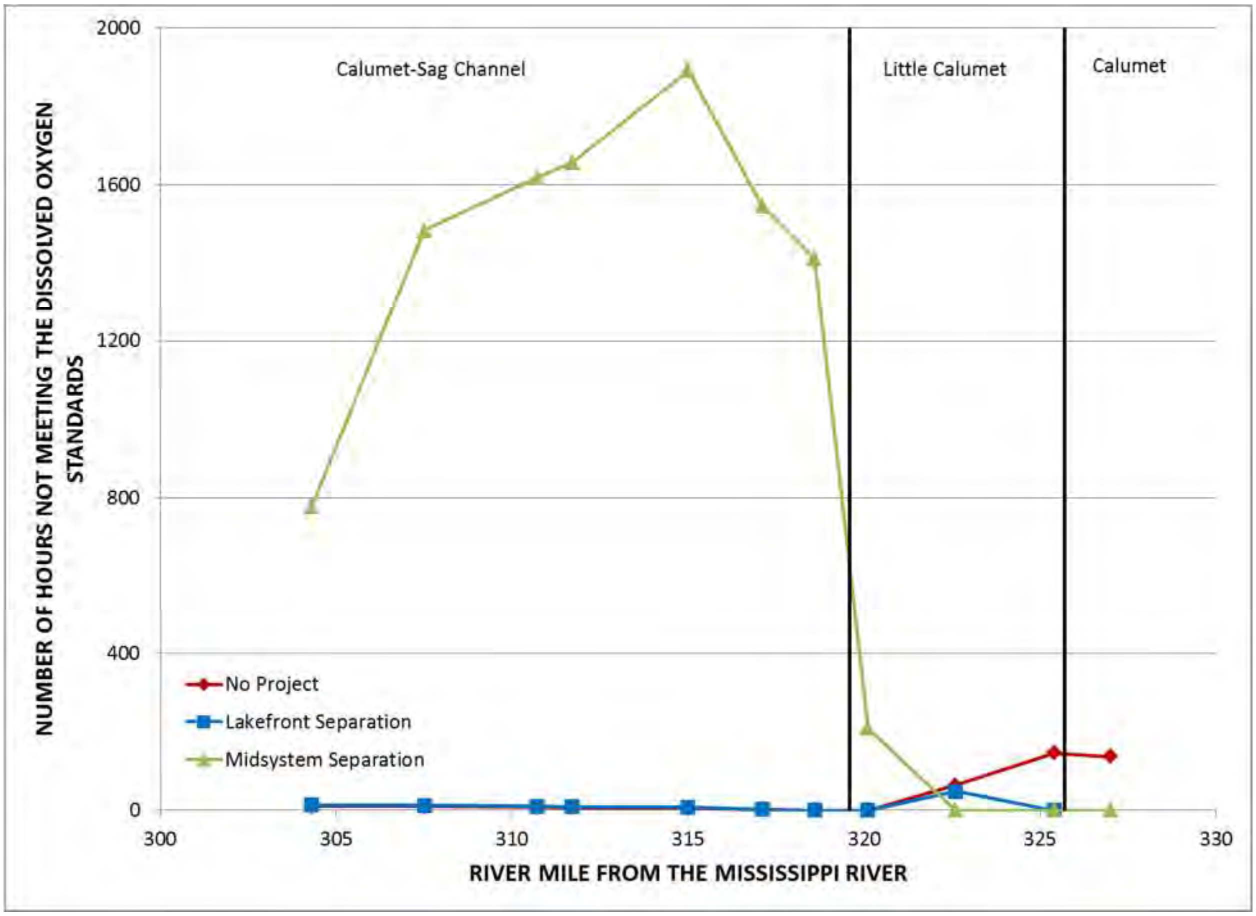


Figure 7.10. Number of hours not in compliance with the dissolved oxygen standards along the Calumet River system for Water Year 2003.

All three alternatives show very low levels of noncompliance (i.e. high levels of compliance) on the CSSC downstream from the Stickney WRP (RM 315.5) (Figure 7.9). The "No Project" and "Lakefront Separation" alternatives show very low levels of noncompliance on the Little Calumet River (north) and Calumet-Sag Channel which are downstream from the Calumet WRP (RM 321.4) in these alternatives (Figure 7.10). Conversely, the "Midsystem Separation" alternative shows very low levels of noncompliance on the Little Calumet River (north) and Calumet River (Figure 7.10), which are downstream from the Calumet WRP in this alternative. Finally, the upper NSC is downstream from the O'Brien WRP for the "Midsystem Separation" alternative and this reach shows improved compliance compared to the other alternatives for which the upper NSC mainly is stagnant (Figure 7.9). On the other hand, the noncompliance increases on the lower NSC and NBCR for the "Midsystem Separation" alternative because about one third of the O'Brien WRP effluent now passes through the upper NSC and not through these reaches.

7.2 Comparison of Simulated Fecal Coliform Concentrations

7.2.1 Concentration vs. Time

The DUFLOW model yields computed values of any of the simulated water-quality constituents and properties at any the computational points in the CAWS (more than 100 points). Thus, to keep comparison manageable the comparison is focused on the measurement points in the ambient water quality monitoring network sampled monthly by the MWRDGC and used to calibrate and verify the model for fecal coliform bacteria, chloride, and total phosphorus. In this report the results are presented for the various waterway reaches of the CAWS: the upper NSC; the lower NSC and NBCR (downstream of the O'Brien WRP, RM 336.9); Chicago River main stem, SBCR, and upper CSSC (above the Stickney WRP, RM 315.5); lower CSSC; Calumet River and Little Calumet River (north); and the Calumet-Sag Channel.

Figure 7.11 shows the computed fecal coliform concentrations on the upper NSC at Oakton Street (0.1 mi north of the O'Brien WRP outfall). It can be seen that the "Midsystem Separation" alternative yields lower fecal coliform concentrations during the storm periods in early May as the flows from the O'Brien WRP dilute the effects of CSOs discharged to the upper

NSC. The “No Project” and “Lakefront Separation” alternatives yield nearly identical fecal coliform concentrations from October to May and August through September 20 reflecting the fact that the “No Project” alternative has nearly zero flow at Wilmette during these periods. In the months of June and July the “No Project” alternative yields the lowest fecal coliform concentrations reflecting the effects of the discretionary diversion from Lake Michigan during these months. The “Midsystem Separation” and “Lakefront Separation” alternatives also yield very similar fecal coliform concentrations during dry weather indicating the dominant role of O’Brien WRP effluent on fecal coliform concentrations in the upper NSC for these alternatives.

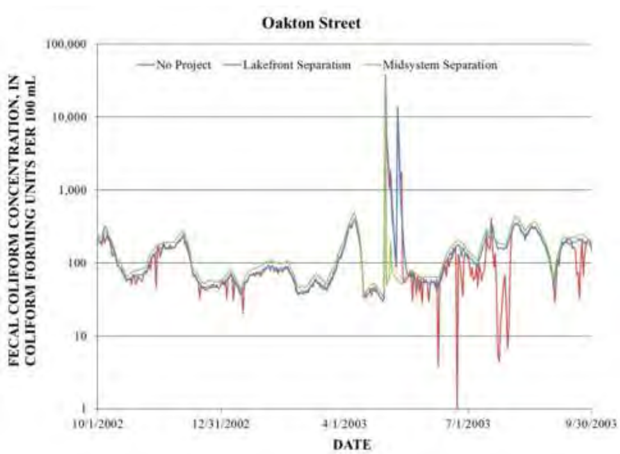


Figure 7.11. Simulated fecal coliform concentration on the upper North Shore Channel at Oakton Street for the three alternatives under future conditions for Water Year 2003.

Figure 7.12 shows the computed fecal coliform concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O’Brien WRP outfall) and at Wilson Avenue and Diversey Parkway on the NBCR. It can be seen that the “No Project” and “Lakefront Separation” alternatives yield very similar fecal coliform concentrations at all points and times in these reaches. The effects of discretionary diversion on fecal coliform concentrations are small in these reaches. Finally, at Touhy Avenue and Wilson Avenue all three alternatives yield similar fecal coliform concentrations. However, as the flows reach the downstream NBCR (Diversey Parkway, 6.8 mi downstream of the O'Brien WRP) the decrease in flows in these reaches for the "Midsystem Separation" alternative increases the travel time, thus, decreasing the fecal coliform concentrations relative to the other alternatives.

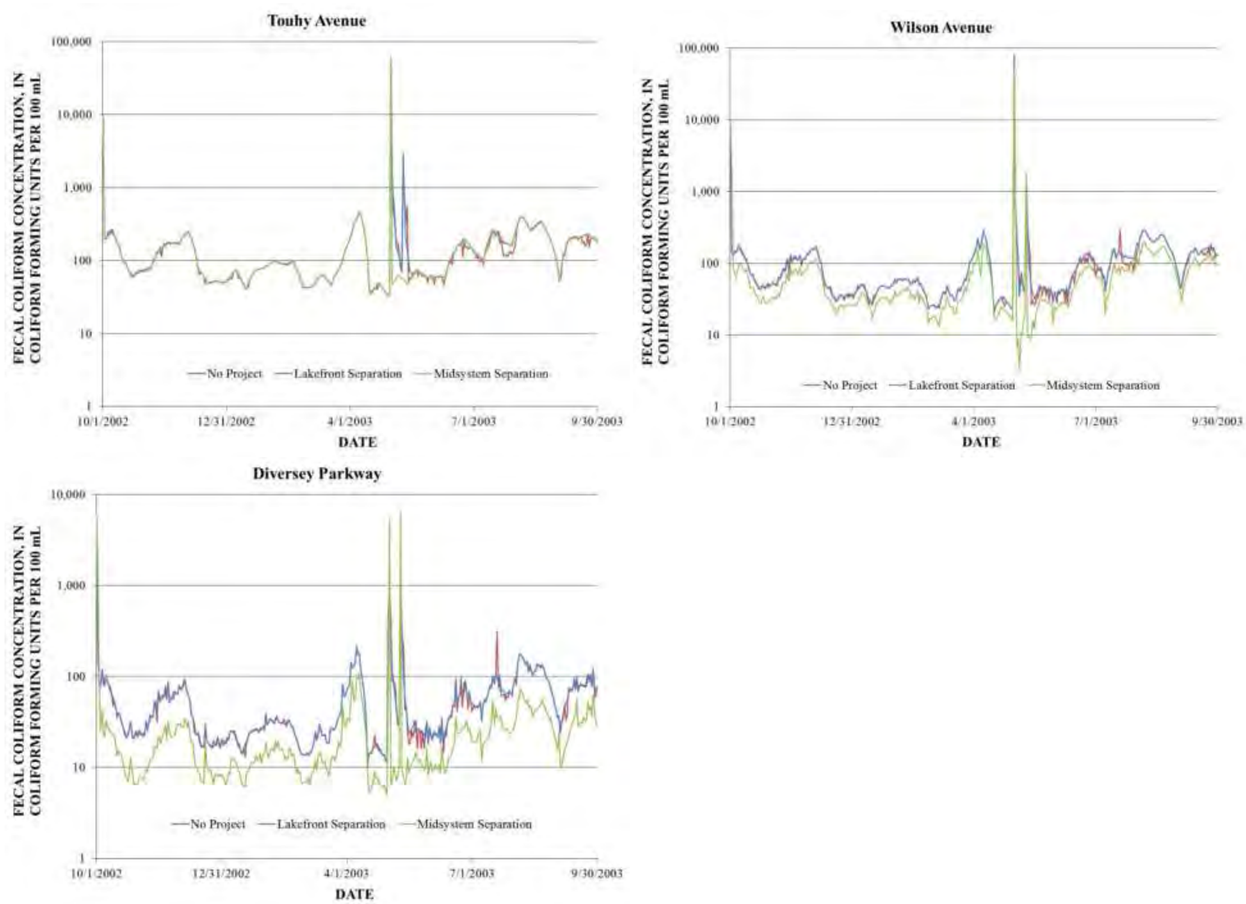


Figure 7.12. Simulated fecal coliform concentration on the North Shore Channel at Touhy Avenue and the North Branch Chicago River at Wilson Avenue and Diversey Parkway for the three alternatives under future conditions for Water Year 2003.

Figure 7.13 shows the computed fecal coliform concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street, and CSSC at Western Avenue and Cicero Avenue. At Wells Street on the Chicago River main stem the trend of decreasing fecal coliform concentrations for the “Midsystem Separation” alternative observed at Diversey Parkway continues until fecal coliform concentrations less than the 200 CFU/100 mL standard are achieved during most dry weather periods. The “No Project” and “Lakefront Separation” alternatives yield similar fecal coliform concentrations at Wells Street except for June and July when discretionary diversion is taken at CRCW in the “No Project” alternative. Similar to the “Midsystem Separation” alternative, both the “No Project” and “Lakefront Separation” alternatives yield fecal coliform concentrations less than the 200 CFU/100 mL standard during most dry weather periods.

In Figure 7.13 all points on the SBCR and upper CSSC experience very low fecal coliform bacteria concentrations for the “Midsystem Separation” alternative because the primary source of fecal coliform bacteria to these reaches is infrequent CSOs. Madison Street and Western Avenue experience low fecal coliform concentrations (see Figure 7.13) for the “No Project” and “Lakefront Separation” alternatives indicating the die off fecal coliform bacteria as the flows travel from O’Brien WRP. Cicero Avenue experiences higher fecal coliform concentrations for the “No Project” and “Lakefront Separation” alternatives due to upstream propagation of the un-disinfected effluent from the Stickney WRP that cannot get to this reach in the “Midsystem Separation” alternative because of the barrier at RM 316.01.

At Cicero Avenue the improvement in fecal coliform concentrations due to discretionary diversion can be clearly seen in June and July for the “No Project” alternative compared to the “Lakefront Separation” alternative (Figure 7.13). However, at Western Avenue the “No Project” alternative yields higher fecal coliform concentrations than the “Lakefront Separation” alternative during the period of discretionary diversion, but it should noted that both alternatives yield very low fecal coliform concentrations and the large differences in log space represent very small differences in real space.

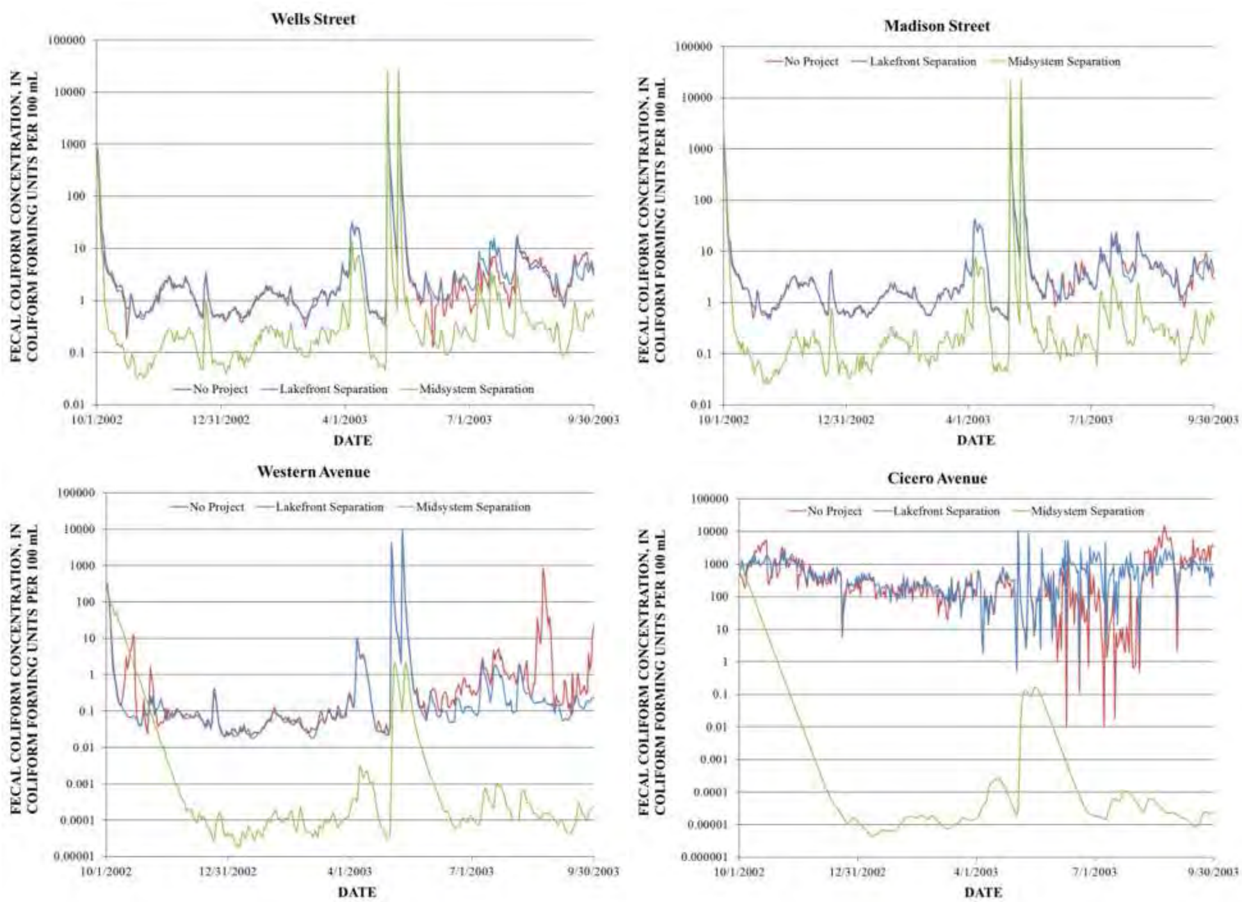


Figure 7.13. Simulated fecal coliform concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street, and Chicago Sanitary and Ship Canal at Western Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2003.

Figure 7.14 shows the computed fecal coliform concentrations on the CSSC downstream from the Stickney WRP. The results for the "No Project" and "Lakefront Separation" alternatives are nearly identical showing the dominant influence of the Stickney WRP effluent on this reach. The discretionary diversion in June and July for the "No Project" alternative has little effect on the fecal coliform bacteria in this reach. The “Midsystem Separation” alternative also yields similar fecal coliform bacteria concentrations as those for the other alternatives with only the storm periods of early May showing substantial reductions in fecal coliform bacteria. The results for the “Midsystem Separation” alternative also indicate the dominant influence of the Stickney WRP effluent on this reach.

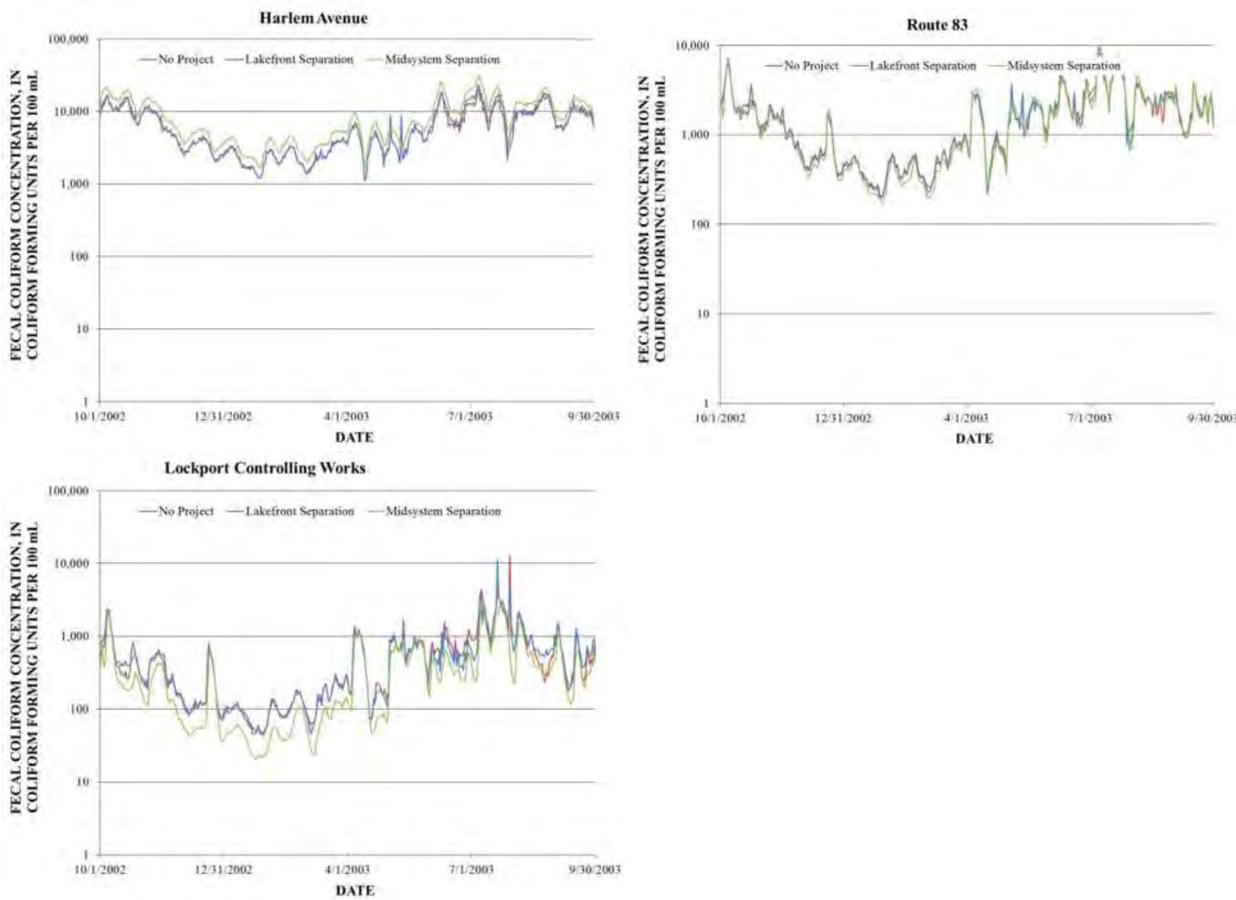


Figure 7.14. Simulated fecal coliform concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2003.

Figure 7.15 shows the computed fecal coliform concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At both of these locations the “No Project” and “Lakefront Separation” alternatives yield very similar fecal coliform bacteria concentrations throughout the year except for the period of high fecal coliform concentrations for the "No Project" alternative between June 23rd and September 2nd. This similarity shows the discretionary diversion has only a minor effect in diluting fecal coliform bacteria in this reach. At Indiana Avenue, the "Midsystem Separation" alternative yields higher fecal coliform concentrations than the other two alternatives throughout the year. Indiana Avenue receives effluent from the Calumet WRP under the "Midsystem Separation" alternative raising the fecal coliform concentrations whereas in the other two alternatives Indiana Avenue only experiences some occasional backups of effluent from this WRP. For Halsted Street under the "Midsystem Separation" alternative the fecal coliform concentrations are dominated by the fecal coliform bacteria coming from the Little Calumet River (south) which has higher concentrations than for the disinfected Calumet WRP effluent that dominates the fecal coliform bacteria concentrations at Halsted Street for the other two alternatives. The Little Calumet River (south) has especially high fecal coliform bacteria concentrations (> 1000 CFU/100 mL) from July 6th to September 8th which result in the periods of high fecal coliform concentrations yielded in the simulations for both the "No Project" and "Midsystem Separation" alternatives seen in Figure 7.15.

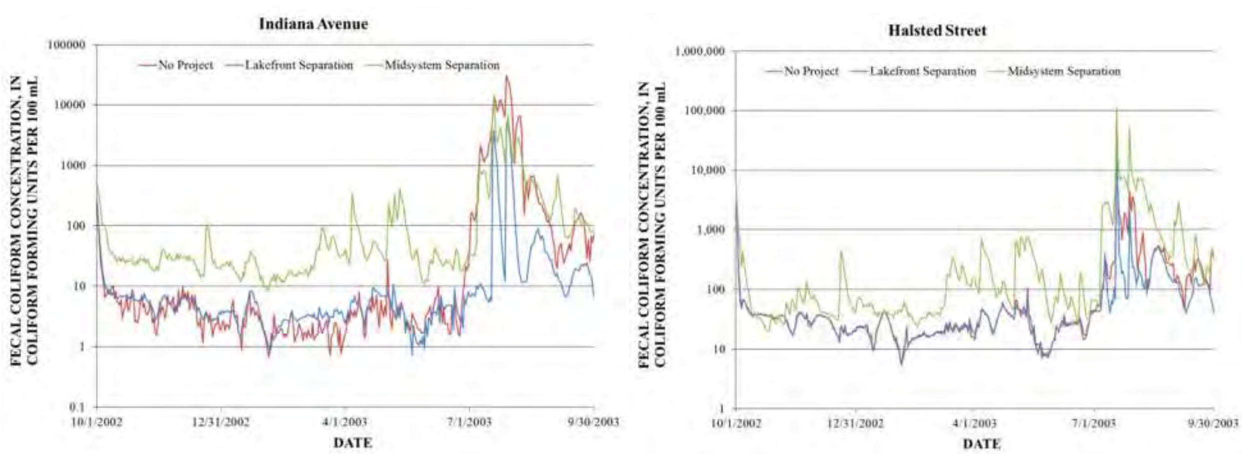


Figure 7.15. Simulated fecal coliform concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2003.

Figure 7.16 shows the computed fecal coliform concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. At all of these locations the "No Project" and "Lakefront Separation" alternatives yield similar fecal coliform bacteria concentrations showing the discretionary diversion has only a minor effect in diluting fecal coliform bacteria in this reach. The "Midsystem Separation" alternative yields fecal coliform bacteria concentrations similar to the other two alternatives at Ashland Avenue. At Cicero Avenue, the "Midsystem Separation" alternative yields similar fecal coliform concentrations similar to those of the other alternatives except for the period of July 7^{th} to August 30^{th} when the high concentrations from the Little Calumet River (south) move through the Calumet-Sag Channel for the other alternatives. For the "Midsystem Separation" alternative flows from the Little Calumet River (south) do not reach Cicero Avenue (RM 315) because of the barrier at RM 315.89. At Route 83, the "Midsystem Separation" alternative yields higher fecal coliform concentrations than the other two alternatives because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel for this alternative.

7.2.2 Compliance with the Fecal Coliform Standard

Figures 7.17 and 7.18 show the number of hours not in compliance with the fecal coliform standard along the Chicago River and Calumet River systems, respectively. As can be seen in Figure 7.17, for the NSC the "No Project" alternative yields higher compliance with the fecal coliform standard than do the other two alternatives because of the availability of discretionary diversion. In all other reaches of the Chicago River system the "No Project" and "Lakefront

Separation" alternatives yield nearly identical levels of compliance with the fecal coliform standard except for Cicero Avenue on the CSSC (RM 317.3 in Figure 7.17).

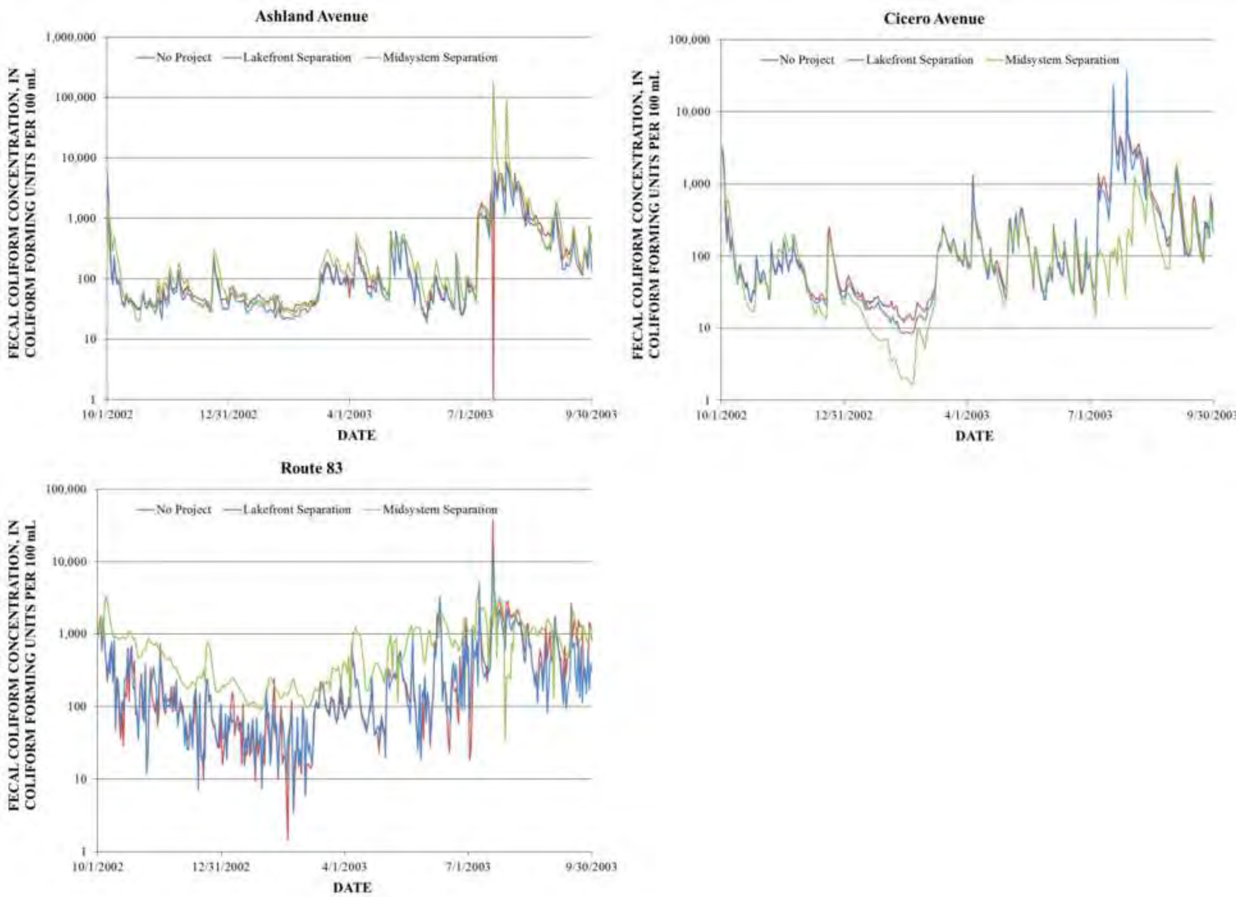


Figure 7.16. Simulated fecal coliform concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2003.

Downstream from the Stickney WRP (RM 315.5) on the CSSC all three alternatives yield nearly identical levels of compliance with the fecal coliform standard because of the dominance of the Stickney WRP effluent on this reach (Figure 7.17). On the NBCR from Fullerton Avenue (RM 329.4) and continuing downstream all three alternatives yield similar levels of compliance with the fecal coliform standard because of the dominance of the O'Brien WRP effluent on this reach (Figure 7.17). The low loads of fecal coliform bacteria to the SBCR and upper CSSC result in the low levels of noncompliance (high levels of compliance) with the fecal coliform standard observed in Figure 7.17 for the "Midsystem Separation" alternative.

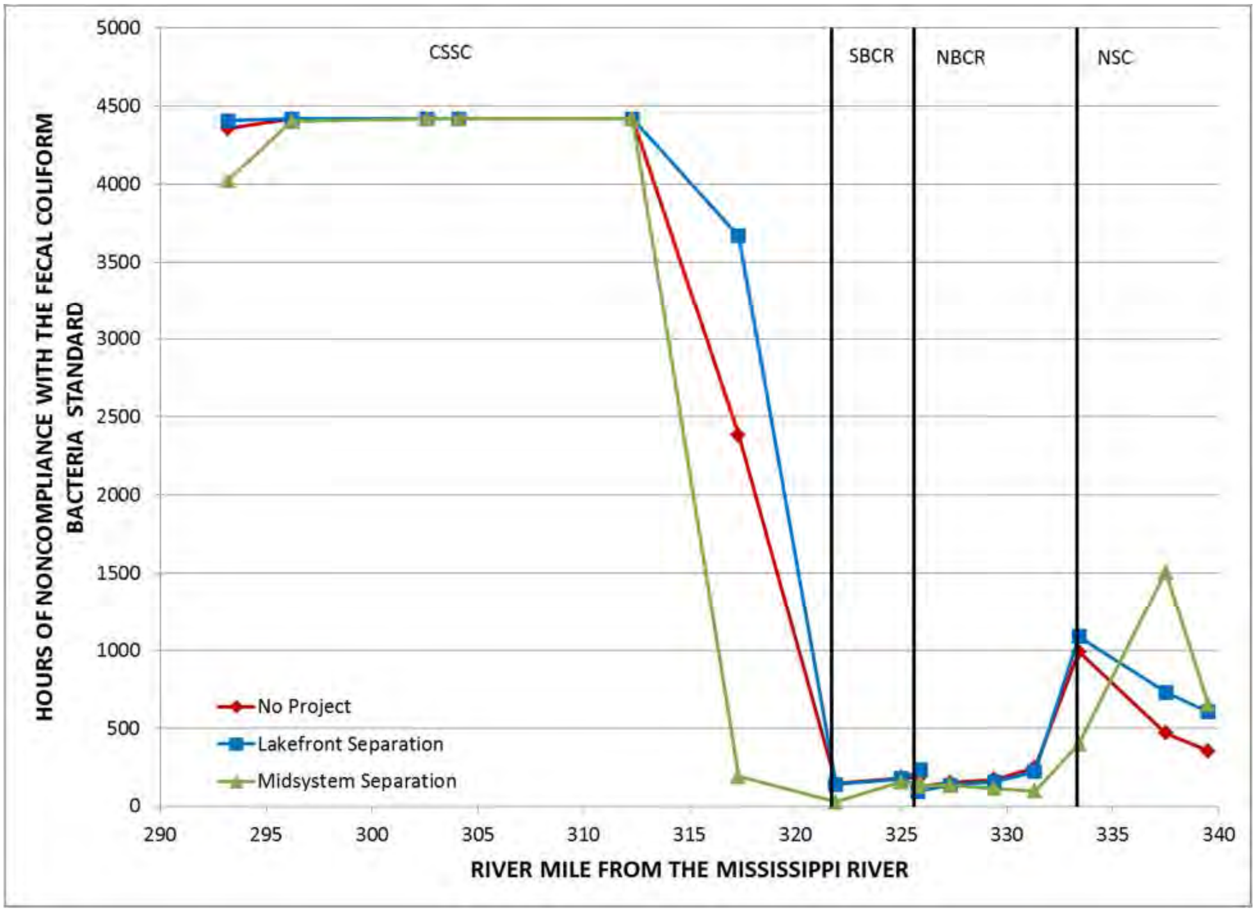


Figure 7.17. Number of hours not in compliance with the fecal coliform standard along the Chicago River system for Water Year 2003.

In the Calumet River system (Figure 7.18), the "Midsystem Separation" alternative yields higher levels of noncompliance than the other two alternatives at 130th Street (RM 327) and Central & Wisconsin Railroad (RM 322.6), but the "No Project" alternative yields higher levels of noncompliance than the other two alternatives at Conrail Railroad (RM 325.4) on the lake side of the Calumet WRP (321.4). This reach continually receives treated effluent in the "Midsystem Separation" alternative, whereas in the other alternatives this reach only occasionally receives treated effluent. The Little Calumet River (north) upstream of the Calumet WRP in the

“Midsystem Separation” alternative (RM 319.6 to 321.4) also experiences high levels of noncompliance with the fecal coliform standard resulting from the high fecal coliform concentrations in the flows from the Little Calumet River (south). The Calumet-Sag Channel (RM 303.4 to 319.6) becomes two stagnant water bodies in the “Midsystem Separation” alternative. At the two ends of the Calumet-Sag Channel the levels of noncompliance with the fecal coliform standard are dominated by the conditions in the receiving water body (lower CSSC for the downstream end [RM 303.4] and Little Calumet River (north) for the upstream end [RM 319.6]). However, in the middle sections of the Calumet-Sag Channel the “Midsystem Separation” alternative shows low levels of noncompliance consistent with the low loads of fecal coliform bacteria to these reaches (Figure 7.18).

In the Little Calumet River (north) the “No Project” and “Midsystem Separation” alternatives yielded similar levels of noncompliance because both of these alternatives are dominated by the Calumet WRP effluent in this reach (Figure 7.18). In the Calumet-Sag Channel the “No Project” and “Lakefront Separation” alternatives yield similar levels of noncompliance because both alternatives are dominated by Calumet WRP effluent and Little Calumet River (south) inflows of fecal coliform bacteria in this reach.

The high levels of noncompliance with the fecal coliform standard in the vicinities of the O’Brien (RM 336.9, Figure 7.17) and Calumet (RM 321.4, Figure 7.18) WRPs seem inconsistent with the fact that disinfection is applied at these plants for the Baseline and Future conditions. The MWRDGC suggested that they expected “at least” a 2-log reduction in fecal coliform concentration in the effluent after disinfection. Perhaps applying more than a 2-log reduction may be more appropriate to describe the true performance of these WRPs. However, the comparisons provided in this section give a fair and consistent comparison of the effects of the different alternatives on fecal coliform bacteria in the CAWS.

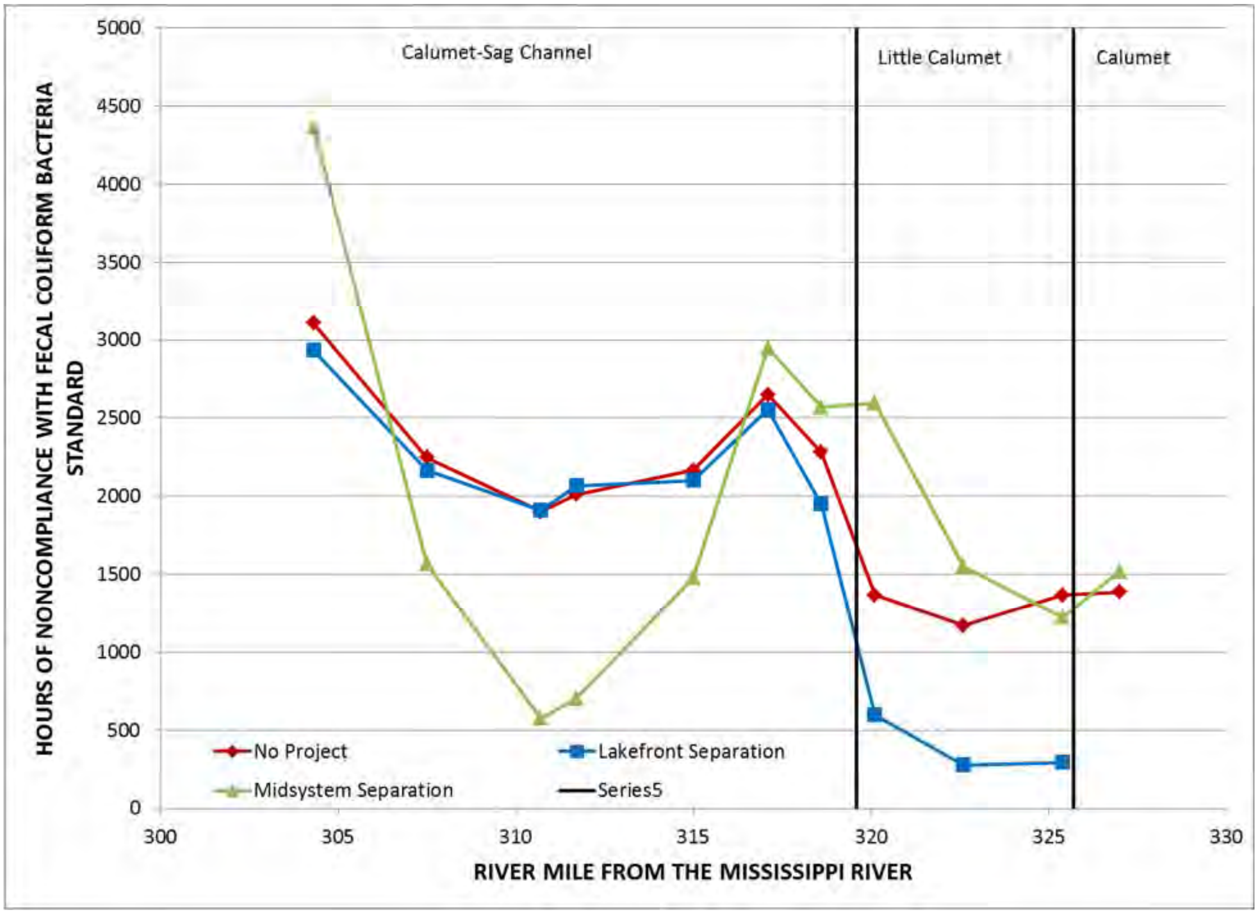


Figure 7.18. Number of hours not in compliance with the fecal coliform standard along the Calumet River system for Water Year 2003.

7.3 Comparison of Simulated Chloride Concentrations

7.3.1 Concentration vs. Time

Figure 7.19 shows the computed chloride concentrations on the upper NSC at Oakton Street (0.1 mi north of the O'Brien WRP outfall). Because the sampling site is so close to the O'Brien

WRP outfall the chloride concentration at this point is dominated by the quality of the effluent. Thus, all three alternatives yield nearly identical chloride concentrations except for June and July when the "No Project" alternative includes substantial discretionary diversion and portions of September and October when the "No Project" alternative includes other non-discretionary diversion flows from Lake Michigan.

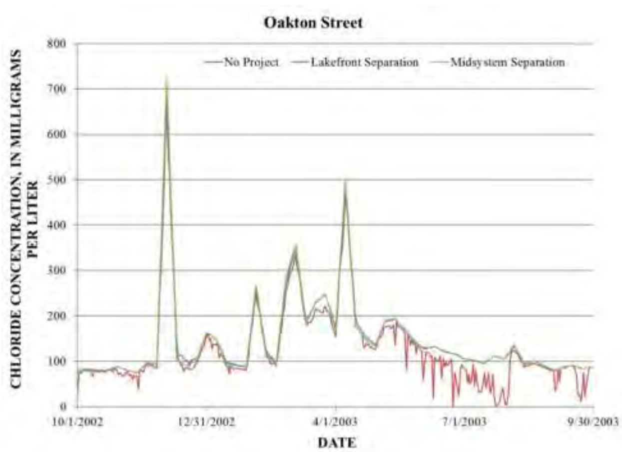


Figure 7.19. Simulated chloride concentration on the upper North Shore Channel at Oakton Street for the three alternatives under future conditions for Water Year 2003.

Figure 7.20 shows the computed chloride concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O'Brien WRP outfall) and at Wilson Avenue and Diversey Parkway on the NBCR. The three alternatives yield nearly identical chloride concentrations at these three locations except that small dilution effects can be seen reducing chloride concentrations for the "No Project" alternative in June and July and portions of September and October.

Figure 7.21 shows the computed chloride concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street, and CSSC at Western Avenue and Cicero Avenue. At Wells Street the chloride concentrations for all three alternatives show substantial similarities in pattern (Figure 7.21). The "No Project" alternative generally has the lowest chloride concentrations at Wells Street, especially for days with discretionary diversion (June and July) or other diversions from Lake Michigan at CRCW.

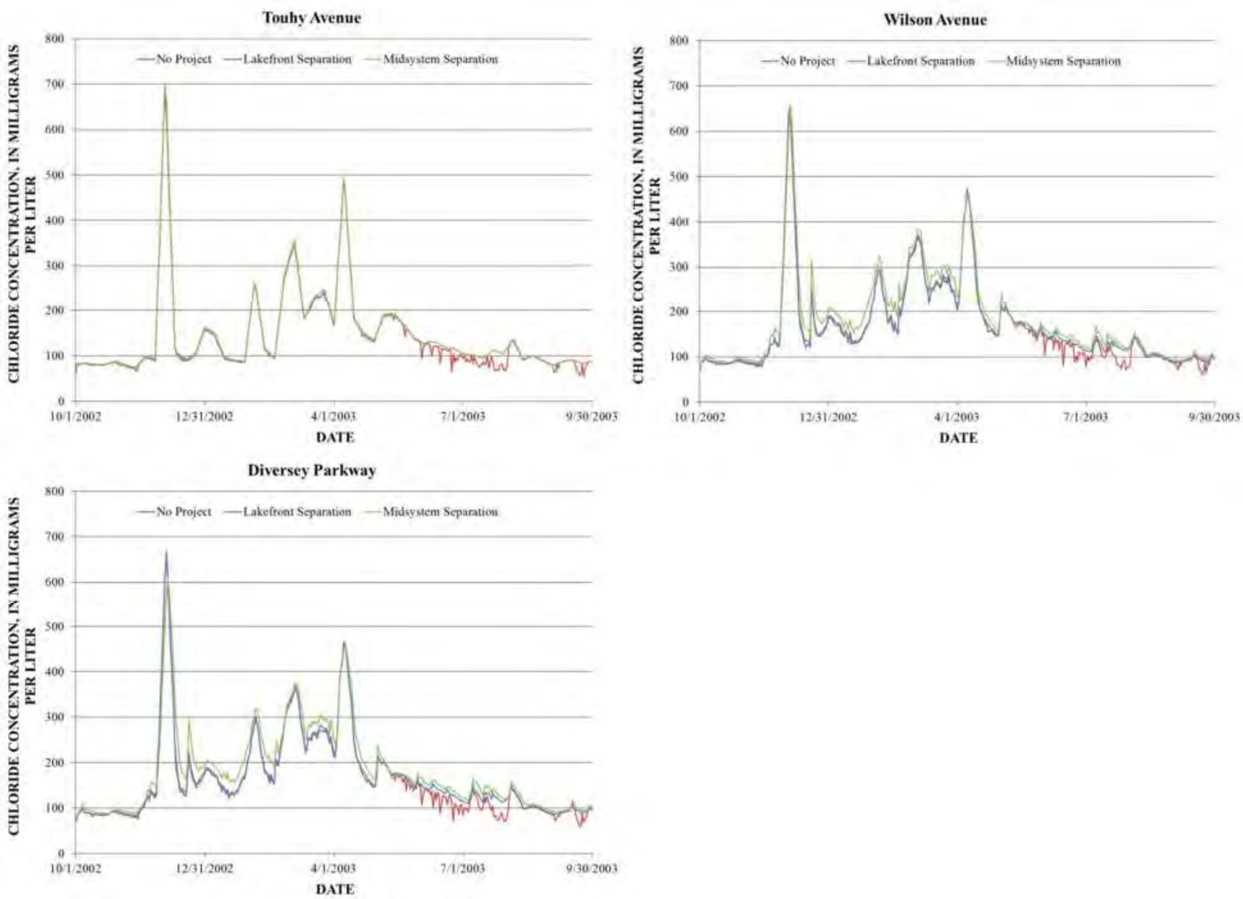


Figure 7.20. Simulated chloride concentration on the North Shore Channel at Touhy Avenue and the North Branch Chicago River at Wilson Avenue and Diversey Parkway for the three alternatives under future conditions for Water Year 2003.

At Madison Street the "No Project" and "Lakefront Separation" alternatives yield very similar chloride concentrations except in the months of June and July when the effects of discretionary diversion can be seen for the "No Project" alternative (Figure 7.21). The "Midsystem Separation" alternative yields a similar pattern chloride concentrations at Madison Street as at Wells Street indicating the influence of chloride concentrations at the junction of the NBCR, SBCR, and Chicago River main stem on those a short distance (0.3 mi) up the now stagnant SBCR. The pattern of chloride concentrations for the “Midsystem Separation” alternative also is similar to that of the other alternatives at Madison Street except that the “Midsystem Separation” alternative has lower chloride concentrations during periods when the concentration peaks than the other alternatives.

At Western Avenue and Cicero Avenue the “No Project” and “Lakefront Separation” alternatives yield very similar chloride concentrations except in the months of June and July for which the dilution effects resulting from discretionary diversion at CRCW can be observed in Figure 7.21. For the “Midsystem Separation” alternative the effects of flow stagnation on chloride concentrations can easily be seen. That is, because of limited inflows to the SBCR and upper CSSC for this alternative it takes a long time to build up higher chloride concentrations and then it takes a long time for these higher chloride concentrations to diminish because of the limited flows through these reaches.

Figure 7.22 shows the computed chloride concentrations on the CSSC downstream from the Stickney WRP. The results for the “No Project” and “Lakefront Separation” alternatives are nearly identical showing the dominant influence of the Stickney WRP effluent on this reach. The discretionary diversion in June and July for the “No Project” alternative has only a small effect on chloride concentrations in this reach. The “Midsystem Separation” alternative also yields similar chloride concentrations as those for the other alternatives with only the peak chloride concentrations being substantially higher than for the other two alternatives. The results for the “Midsystem Separation” alternative are completely dominated by the Stickney WRP effluent in this reach, in the other two alternatives upstream flows with lower chloride concentrations can somewhat dilute Stickney WRP effluent with high chloride concentrations.

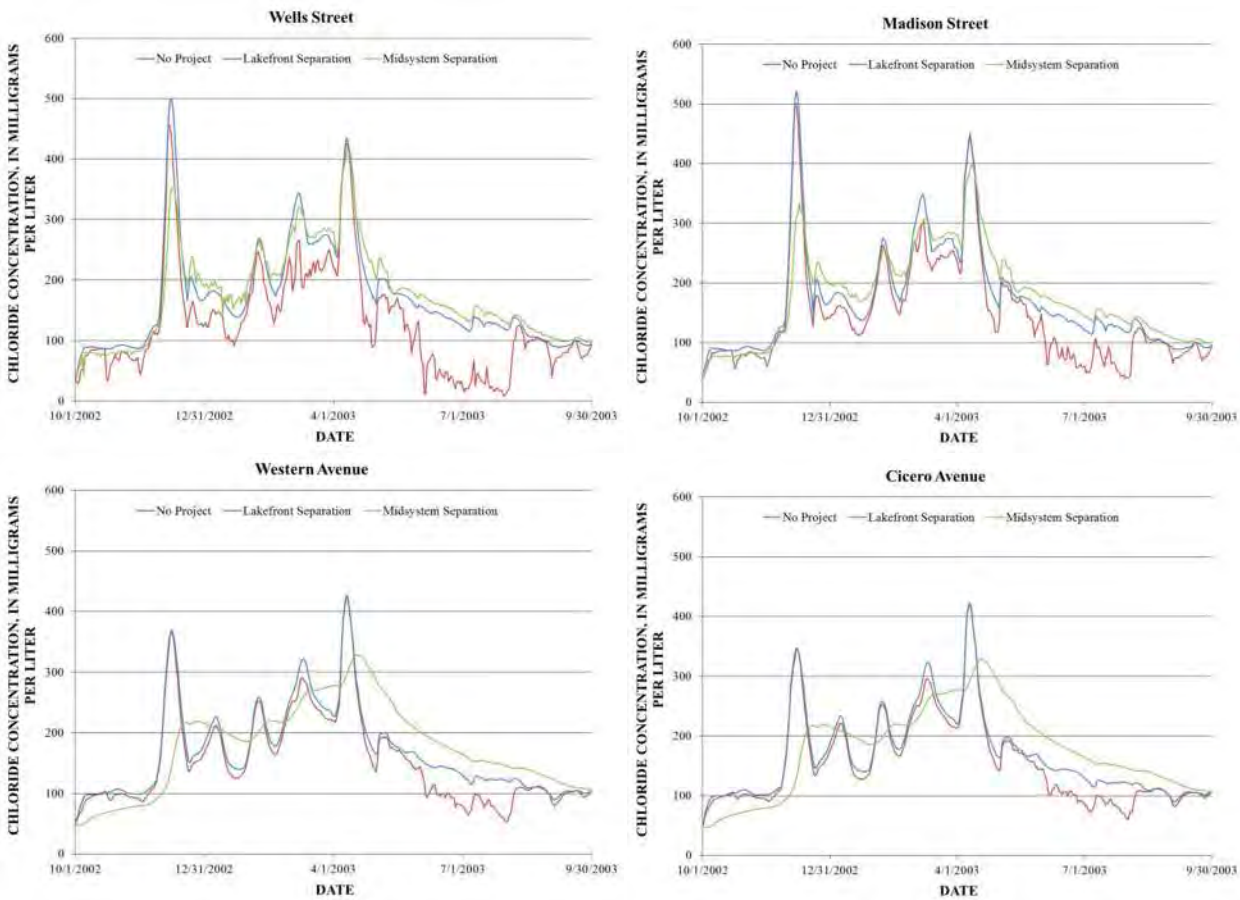


Figure 7.21. Simulated chloride concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street, and Chicago Sanitary and Ship Canal at Western Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2003.

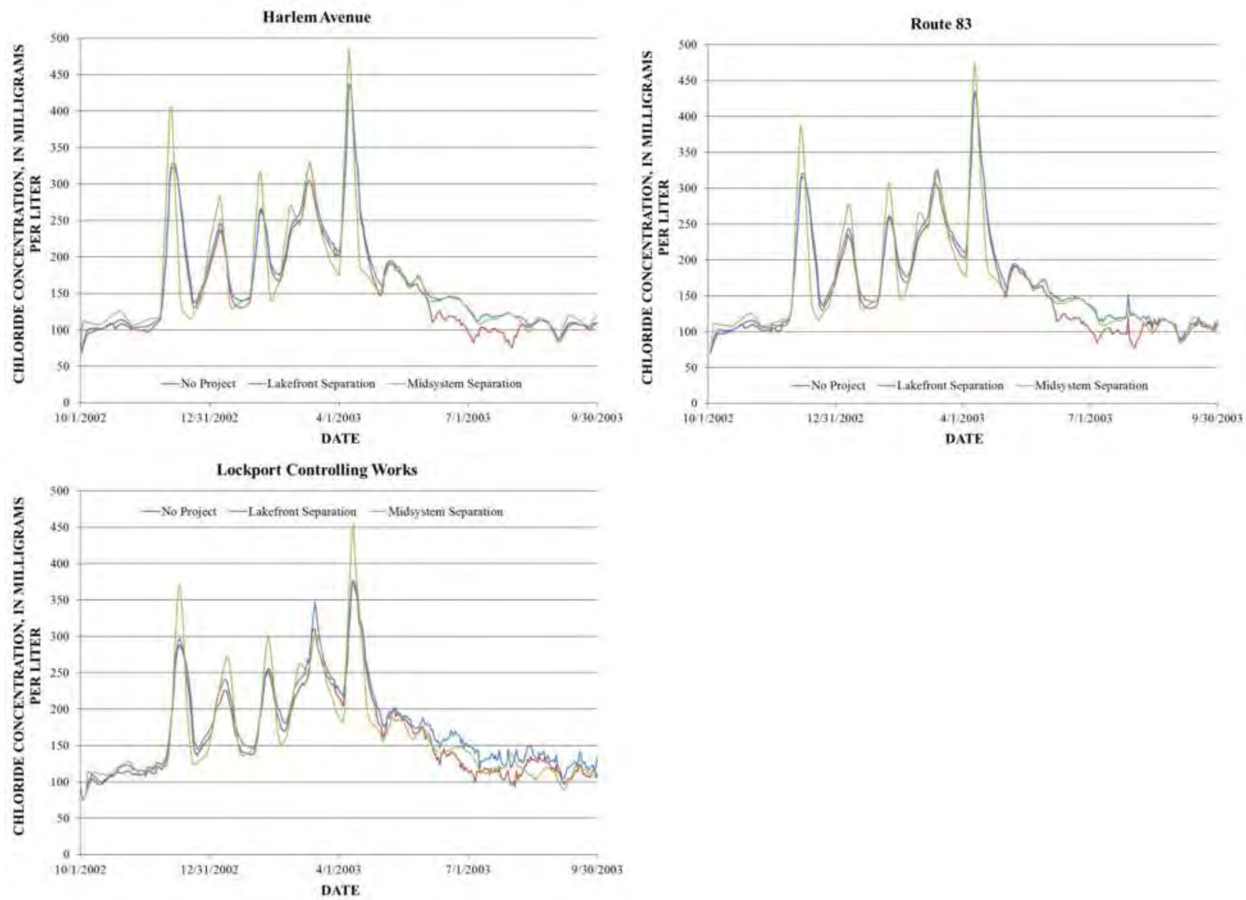


Figure 7.22. Simulated chloride concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2003.

Figure 7.23 shows the computed chloride concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At Indiana Avenue all three alternatives yield similar temporal patterns of chloride concentration with the "No Project" alternative typically yielding the lowest concentration (due to dilution effects), the "Lakefront Separation" alternative yielding the highest concentrations from March through September, and the "Midsystem Separtion" alternative yielding the highest concentrations from October through February. At Halsted Street, the "No Project" and "Lakefront Separation" alternatives again show similar temporal patterns of chloride concentration with the "No Project" alternative yielding lower concentrations. For the “Midsystem Separation” alternative the flow at Halsted Street is dominated by the inflow from the Little Calumet River (south), which has generally lower chloride concentrations in WY 2003.

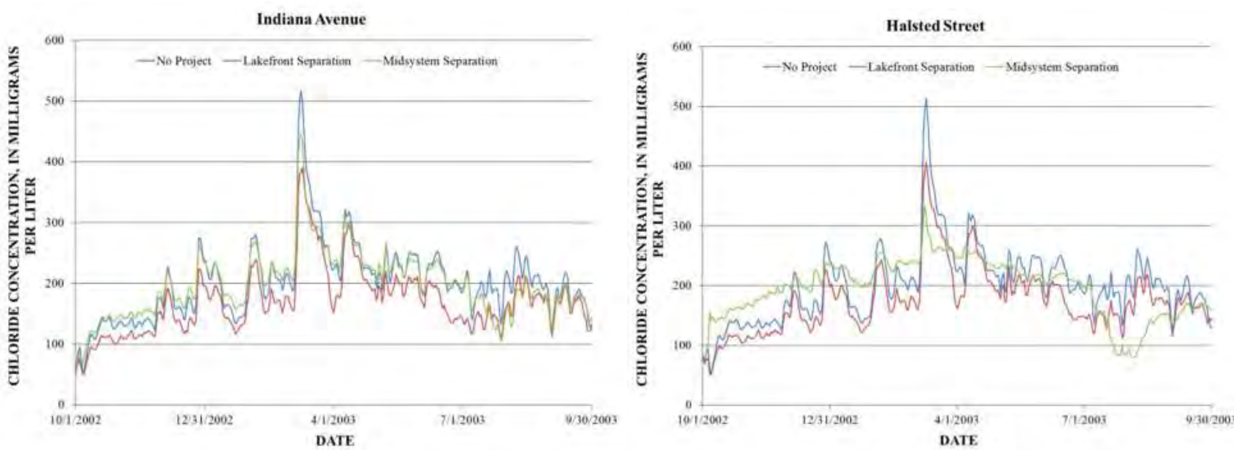


Figure 7.23. Simulated chloride concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2003.

Figure 7.24 shows the computed chloride concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. Again the “No Project” and “Lakefront Separation” alternatives show similar temporal patterns of chloride concentration at each location with the “No Project” alternative yielding the lower concentrations. The “Midsystem Separation” alternative yields chloride concentrations at Ashland Avenue and Cicero Avenue that reflect the chloride concentrations in the small tributary streams that discharge to these otherwise stagnant reaches on either side of the barrier at RM 315.89. At Route 83, the temporal pattern of chloride concentrations for the “Midsystem Separation” alternative follows the pattern of the CSSC at Route 83 (Figure 7.22) because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel for this alternative.

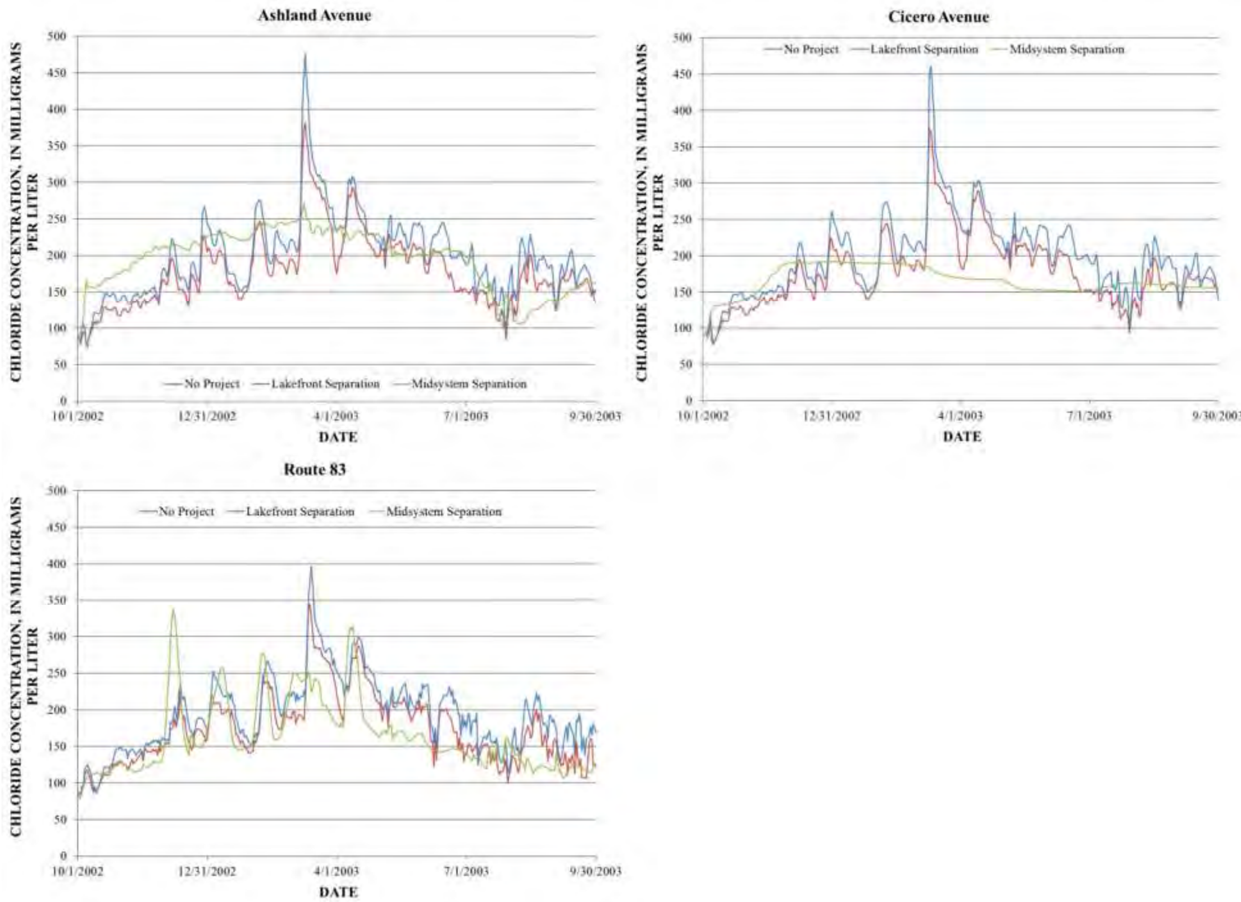


Figure 7.24. Simulated chloride concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2003.

7.3.2 Compliance with Chloride Standards

Figure 7.25 shows the number of hours not in compliance with the chloride chronic toxicity standard along the Chicago River system. Throughout the Chicago River system the "No Project" alternative yields the lowest level of noncompliance among the three alternatives. However, the difference in compliance only is large on the NSC and Chicago River main stem (Clark Street on the main stem is shown at RM 325.9 in Figure 7.25). In the other reaches the difference between the "No Project" alternative and the next best alternative ranges from 49 to

312 hrs. Upstream of the Stickney WRP (RM 315.5) the "Midsystem Separation" alternative yielded the highest levels of noncompliance except for the extreme upstream end of the NSC where the "Lakefront Separation" alternative yielded the highest level of noncompliance. Downstream of the Stickney WRP the "Lakefront Separation" alternative yielded the highest level of noncompliance.

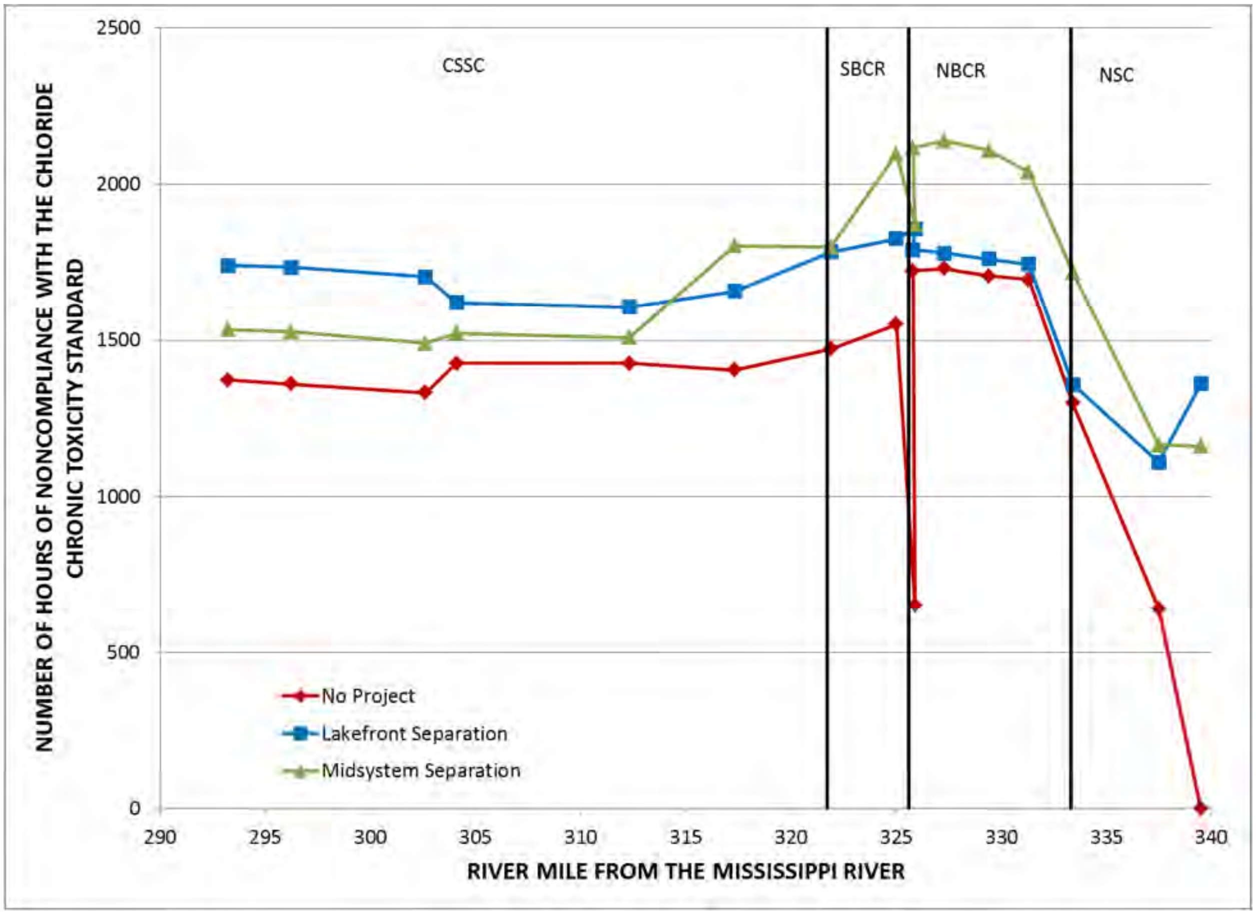


Figure 7.25. Number of hours not in compliance with the chloride chronic toxicity standard along the Chicago River system for Water Year 2003.

Figure 7.26 shows the number of hours not in compliance with the chloride chronic toxicity standard along the Calumet River system. The "Lakefront Separation" alternative yields the highest levels of noncompliance along the entire Calumet River system except for Halsted Street for which the “Midsystem Separation” alternative yielded the highest level of noncompliance. In the Little Calumet River (north) on the lake side of the Calumet WRP (RM 321.4) the “Lakefront Separation” and “Midsystem Separation” alternatives yield similar levels of noncompliance. For the “Midsystem Separation” alternative much of the stagnant Calumet-Sag Channel (RM 303.4 to RM 319.6) fully complies with the chloride chronic toxicity standard except for the two ends of the Calumet-Sag Channel, one which is influenced by conditions in the CSSC (Figure 7.25) and the other is influenced by inflows from the Little Calumet River (south). The “No Project" alternative yields substantially lower levels of noncompliance on the Little Calumet River (north) and Calumet River than the other alternatives, but for the Calumet-Sag Channel its level of noncompliance is in between those of the other two alternatives.

Among the three study years, this representative “dry” year (WY 2003) yielded the lowest level of noncompliance (highest level of compliance) with the chloride chronic toxicity standard for nearly all the alternatives and locations.

7.4 Comparison of Simulated Total Phosphorus Concentrations

Figure 7.27 shows the computed total phosphorus concentrations on the upper NSC at Central Street and Oakton Street (0.1 mi north of the O’Brien WRP outfall). The discretionary diversion in June and July and other flows at Wilmette in October substantially dilute the total phosphorus concentrations for the “No Project” alternative at both locations. At Oakton Street the total phosphorus concentrations for the “No Project” and “Lakefront Separation” alternatives are within 0.1 mg/L of each other during periods with low flows at Wilmette for the “No Project” alternative. Whereas for the “Midsystem Separation” alternative the total phosphorus concentrations are similar at both locations indicating that the total phosphorus is fairly conservative in the upper NSC for this alternative in which the NSC carries O’Brien WRP effluent to Lake Michigan. At Oakton Street the “Lakefront Separation” and “Midsystem Separation” alternatives yield similar total phosphorus concentrations because for these alternatives concentrations are dominated by the O’Brien WRP effluent. Whereas 3.2 mi away at Central Street the total phosphorus concentration for the “Lakefront Separation” alternative diverges from that of the “Midsystem Separation” alternative indicating the stagnant conditions on the upper NSC are not completely dominated by the O’Brien WRP effluent.

Figure 7.28 shows the computed total phosphorus concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O’Brien WRP outfall) and Foster Avenue and on the NBCR at Wilson Avenue, Diversey Parkway, and Grand Avenue. Outside of the periods with substantial flows at Wilmette for the “No Project” alternative (i.e. the period with discretionary diversion, June and July) the three alternatives yield very similar total phosphorus concentrations at all 5 locations on the lower NSC and NBCR. During June and July the Lake Michigan flows at Wilmette reduce the total phosphorus concentration for the “No Project” alternative, whereas the other two alternatives yield similar total phosphorus concentrations during these months. From these results it is clear that the effluent from the O’Brien WRP dominates total phosphorus concentrations in these reaches of the CAWS.

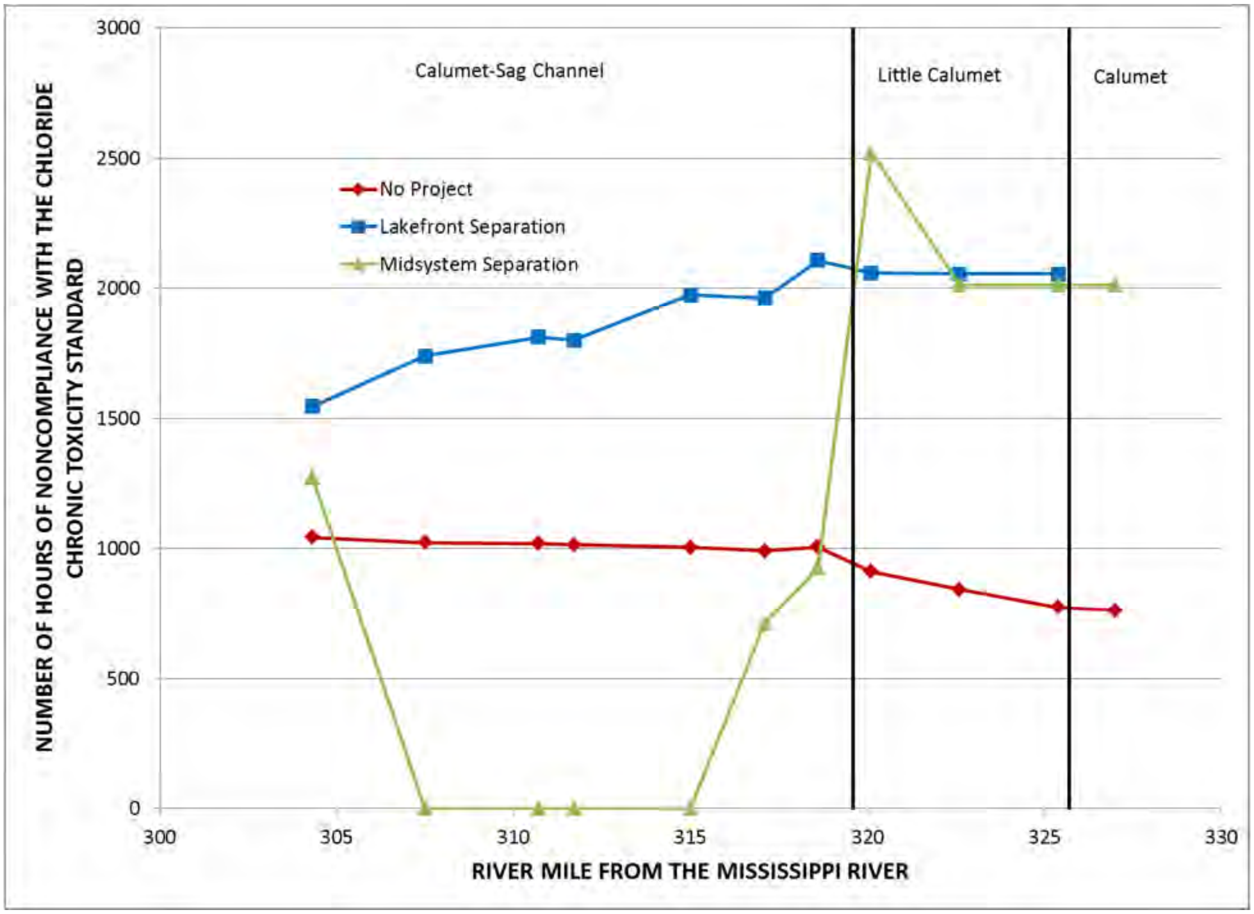


Figure 7.26. Number of hours not in compliance with the chloride chronic toxicity standard along the Calumet River system for Water Year 2003.

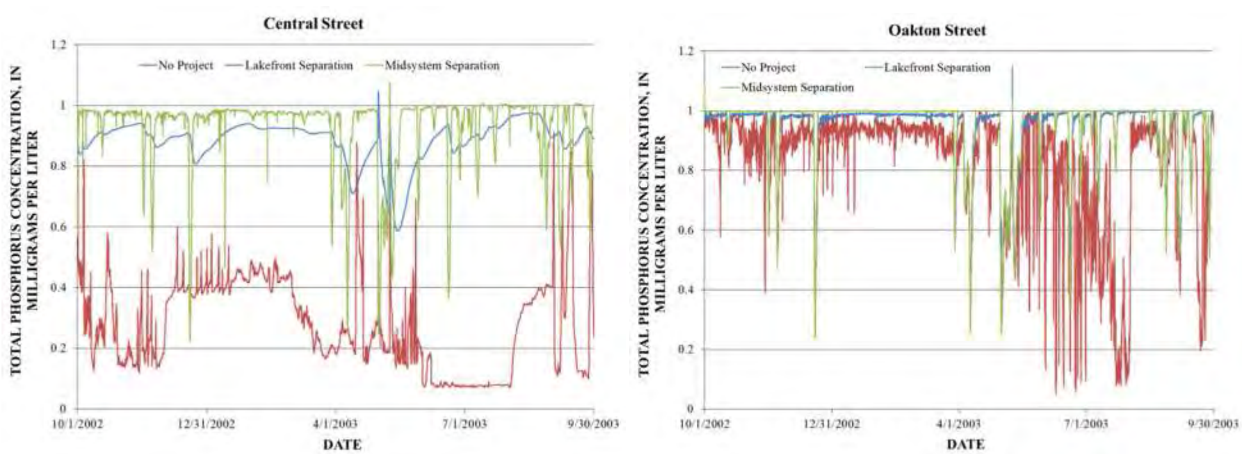


Figure 7.27. Simulated total phosphorus concentration on the upper North Shore Channel at and Central Street and Oakton Street for the three alternatives under future conditions for Water Year 2003.

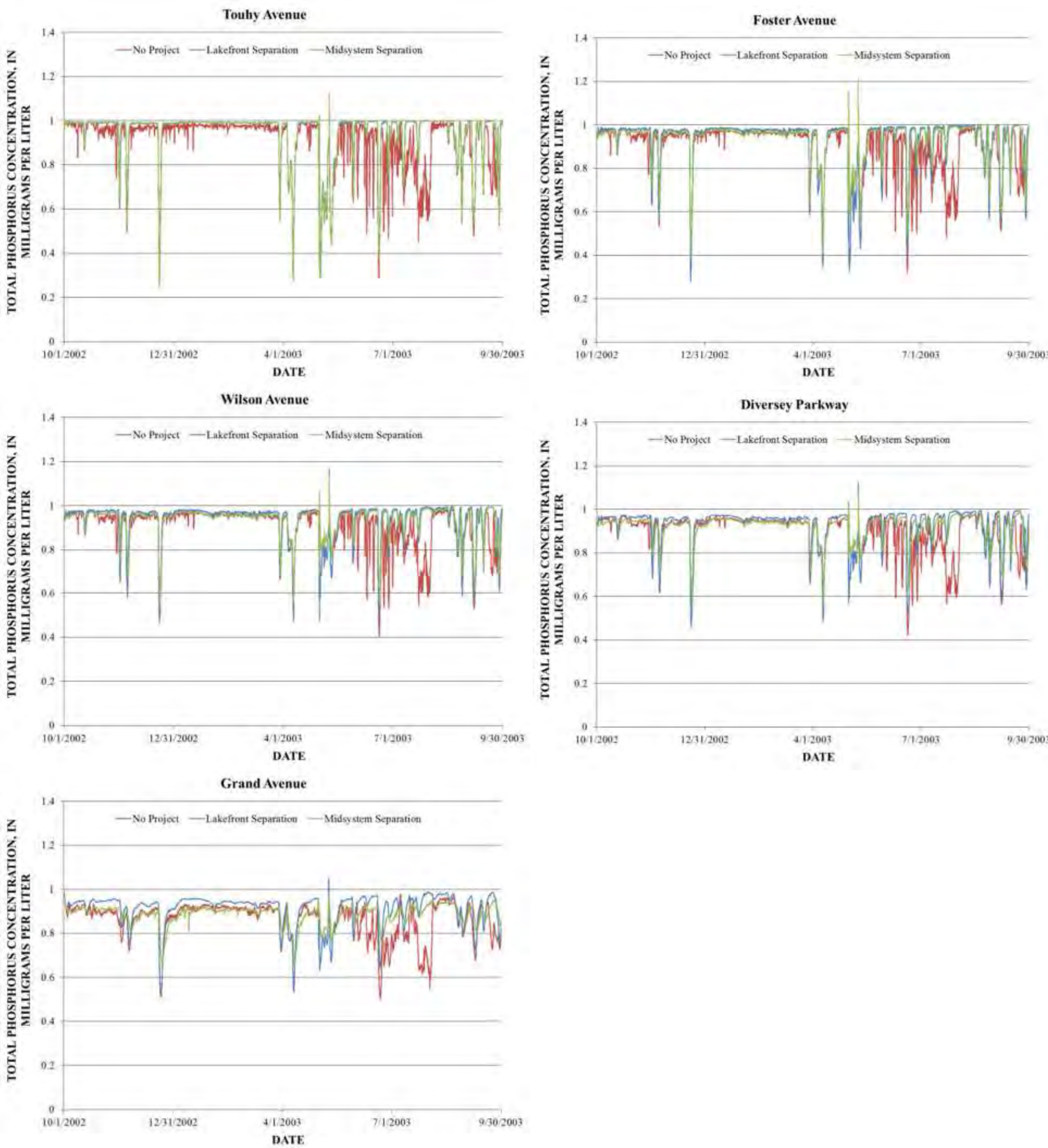


Figure 7.28. Simulated total phosphorus concentration on the North Shore Channel at Touhy Avenue and Foster Avenue and the North Branch Chicago River at Wilson Avenue, Diversey Parkway, and Grand Avenue for the three alternatives under future conditions for Water Year 2003.

Figure 7.29 shows the computed total phosphorus concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street and Loomis Street, and CSSC at Damen Avenue and Cicero Avenue. The “Lakefront Separation” and “Midsystem Separation” alternatives yield a similar pattern of total phosphorus concentrations at Wells Street with concentrations for the “Midsystem Separation” alternative consistently less than that for the “Lakefront Separation” alternative indicating a dissipation in total phosphorus as the water travels from the O’Brien WRP to the Chicago River main stem. The “No Project” alternative shows lower total phosphorus concentrations than the other alternatives throughout the entire year resulting from dilution by discretionary diversion and other water withdrawals from Lake Michigan at CRCW. During the discretionary diversion period—June and July—the difference among the alternatives is very large (Figure 7.29).

At Madison Street the “Lakefront Separation” and “Midsystem Separation” alternatives yield a similar pattern of total phosphorus concentrations with concentrations for the “Midsystem Separation” alternative consistently less than that for the “Lakefront Separation” alternative indicating a dissipation in total phosphorus as the water travels from the O’Brien WRP to the Chicago River main stem, which strongly interacts with the nearby portion of the SBCR (Figure 7.29). Further, the “Lakefront Separation” and “Midsystem Separation” alternatives yield similar patterns total phosphorus concentrations at Madison Street and Wells Street indicating the influence of total phosphorus concentrations at the junction of the NBCR, SBCR, and Chicago River main stem on those a short distance (0.3 mi) away on the SBCR. At Madison Street, the “No Project” alternative shows lower total phosphorus concentrations than the other alternatives throughout the entire year resulting from dilution by discretionary diversion and other water withdrawals from Lake Michigan at CRCW. During periods when no discretionary diversion is taken (especially November through mid-May) the “No Project” and “Midsystem

Separation" alternatives yielded similar total phosphorus concentrations, but during the discretionary diversion period—June and July—the total phosphorus concentration for the "No Project" alternative is much less than for the other alternatives.

At Loomis Street, Damen Avenue, and Cicero Avenue the "No Project" and "Lakefront Separation" alternatives yield very similar total phosphorus concentrations during periods when the flows at CRCW for the "No Project" alternative are near zero (October through May and August and September) (Figure 7.29). However, when there is discretionary diversion (June and July) at CRCW in the "No Project" alternative it yields substantially lower total phosphorus concentrations than the other two alternatives. At these three locations the results of the "Midsystem Separation" alternative indicate very gradual changes in total phosphorus concentrations that are characteristic of the stagnant flow conditions in the SBCR and upper CSSC.

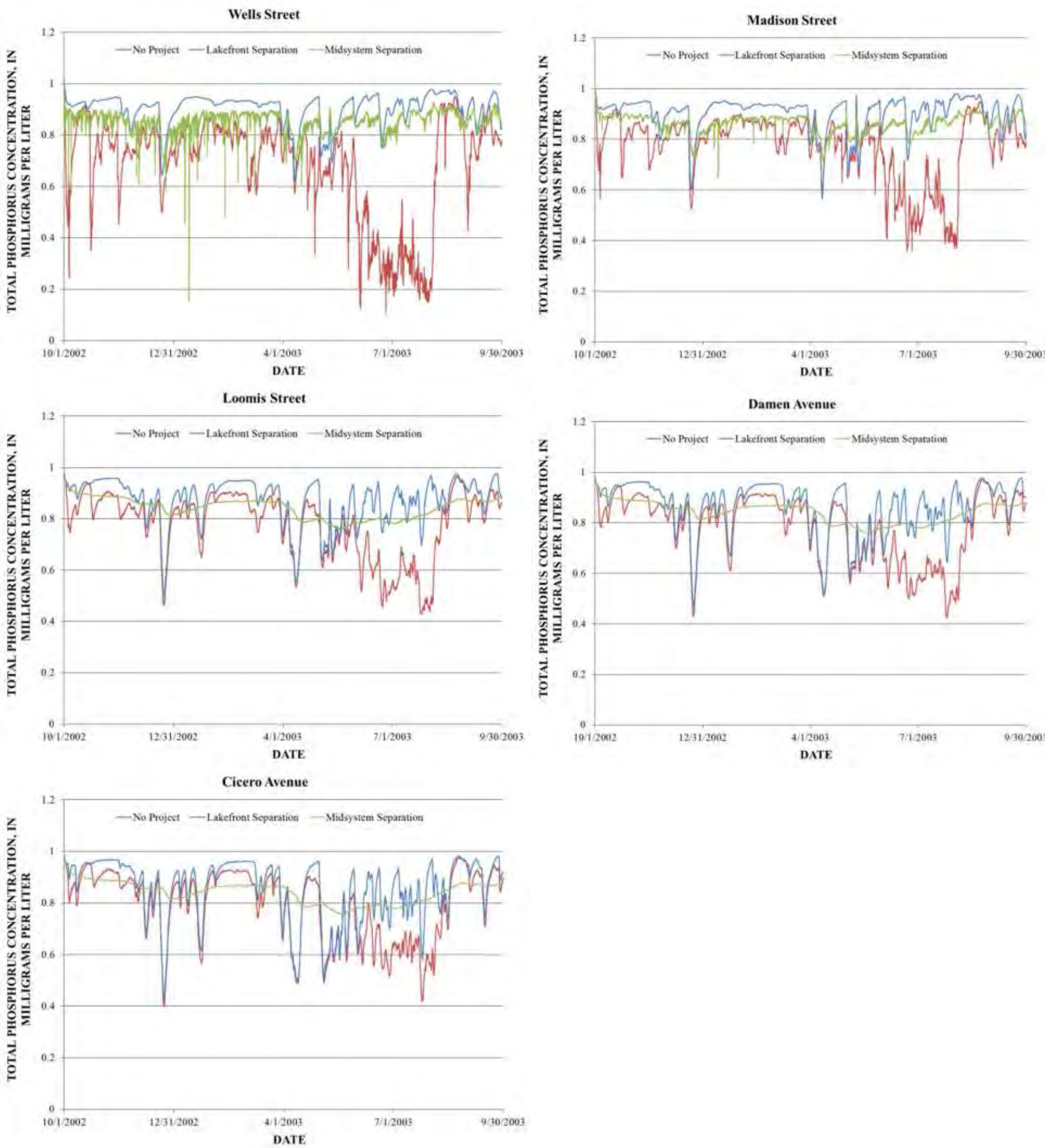


Figure 7.29. Simulated total phosphorus concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street and Loomis Street, and Chicago Sanitary and Ship Canal at Damen Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2003.

Figure 7.30 shows the computed total phosphorus concentrations on the CSSC downstream from the Stickney WRP. Again the “No Project” and “Lakefront Separation” alternatives yield very similar total phosphorus concentrations during periods when the flows at CRCW for the “No Project” alternative are near zero (October through May and August and September) at all four locations in Figure 7.30. However, when there is discretionary diversion (June and July) or other flows at CRCW in the “No Project” alternative it yields substantially lower total phosphorus concentrations than the “Lakefront Separation” alternative. The “Midsystem Separation” alternative also yields very similar total phosphorus concentrations as those for the other alternatives with only the lowest total phosphorus concentrations being substantially lower than those for the other two alternatives. The results for the “Midsystem Separation” alternative are completely dominated by the Stickney WRP effluent in this reach, in the other two alternatives upstream flows with higher total phosphorus concentrations can somewhat increase the overall total phosphorus concentrations during periods when the Stickney WRP effluent has very low total phosphorus concentrations.

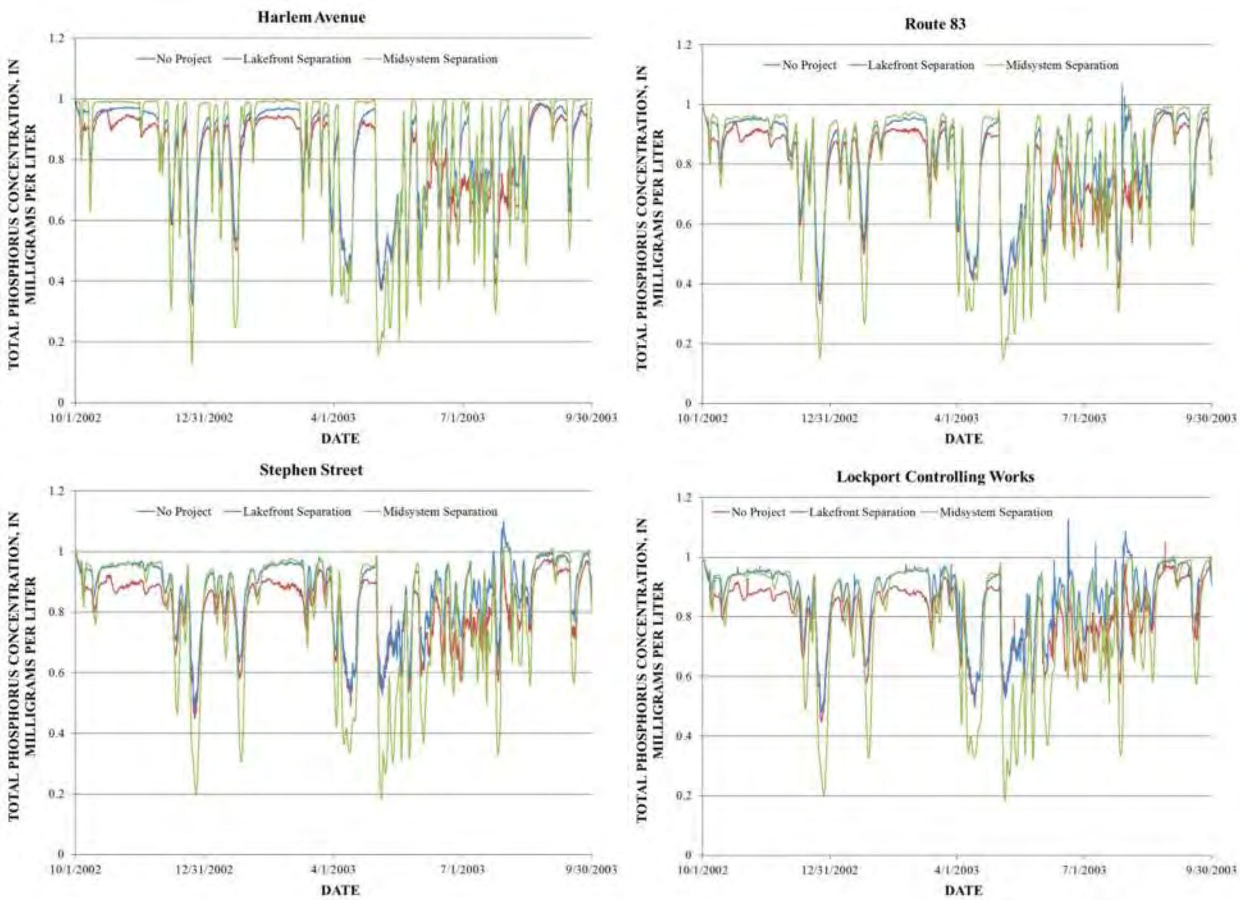


Figure 7.30. Simulated total phosphorus concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, Stephen Street, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2003.

Figure 7.31 shows the computed total phosphorus concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At Indiana Avenue, the “Lakefront Separation” and “Midsystem Separation” alternatives yield very similar total phosphorus concentrations because for each of these alternatives the total phosphorus at this location is dominated by the Calumet WRP effluent. The “No Project” alternative yields substantially lower total phosphorus concentrations than the other two alternatives at both locations because of discretionary diversion and other withdrawals from Lake Michigan at the O’Brien Lock and Dam. At Halsted Street the total phosphorus concentrations for the “Lakefront Separation” alternative is dominated by the effluent of the Calumet WRP, whereas for the “Midsystem Separation” alternative the total phosphorus concentrations are dominated by those coming from the Little Calumet River (south), which fluctuate with storm runoff.

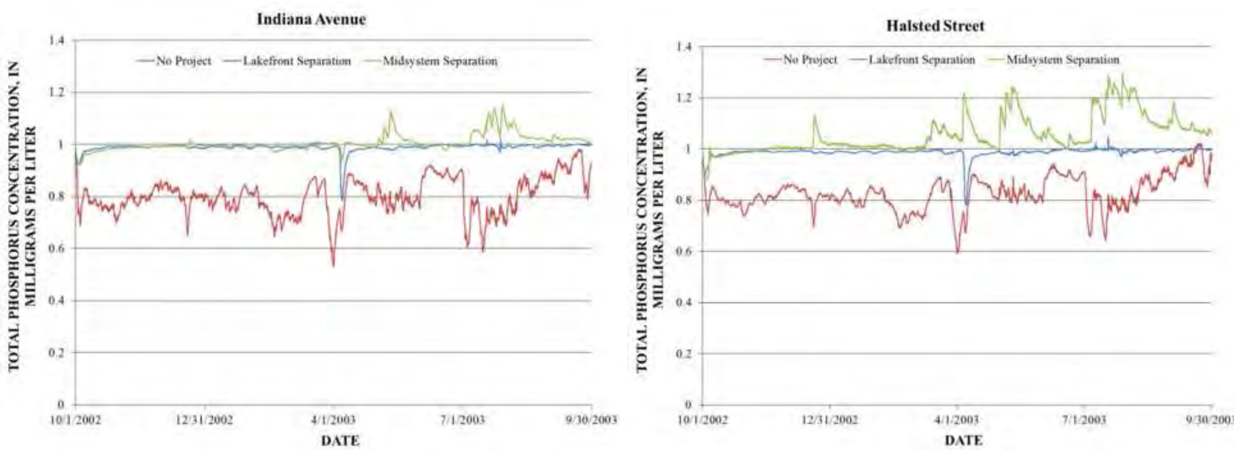


Figure 7.31. Simulated total phosphorus concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2003.

Figure 7.32 shows the computed total phosphorus concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. The “No Project” alternative yields consistently lower total phosphorus concentrations than the other alternatives at Ashland Avenue and Cicero Avenue, and consistently lower than the “Lakefront Separation” alternative at Route 83. This is the result of discretionary diversion and other withdrawals of Lake Michigan water at the O’Brien Lock and Dam in the “No Project” alternative (Figure 7.32). At Ashland Avenue, the “Lakefront Separation” and “Midsystem Separation” alternatives yield similar total phosphorus concentrations. The “Midsystem Separation” alternative yields total phosphorus concentrations at Cicero Avenue that reflect the total phosphorus concentrations in the small tributary streams that discharge to these otherwise stagnant reaches on either side of the barrier at RM 315.89. At

Route 83, the "Midsystem Separation" alternative yields total phosphorus concentrations that reflect the effluent from the Stickney WRP because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel for this alternative.

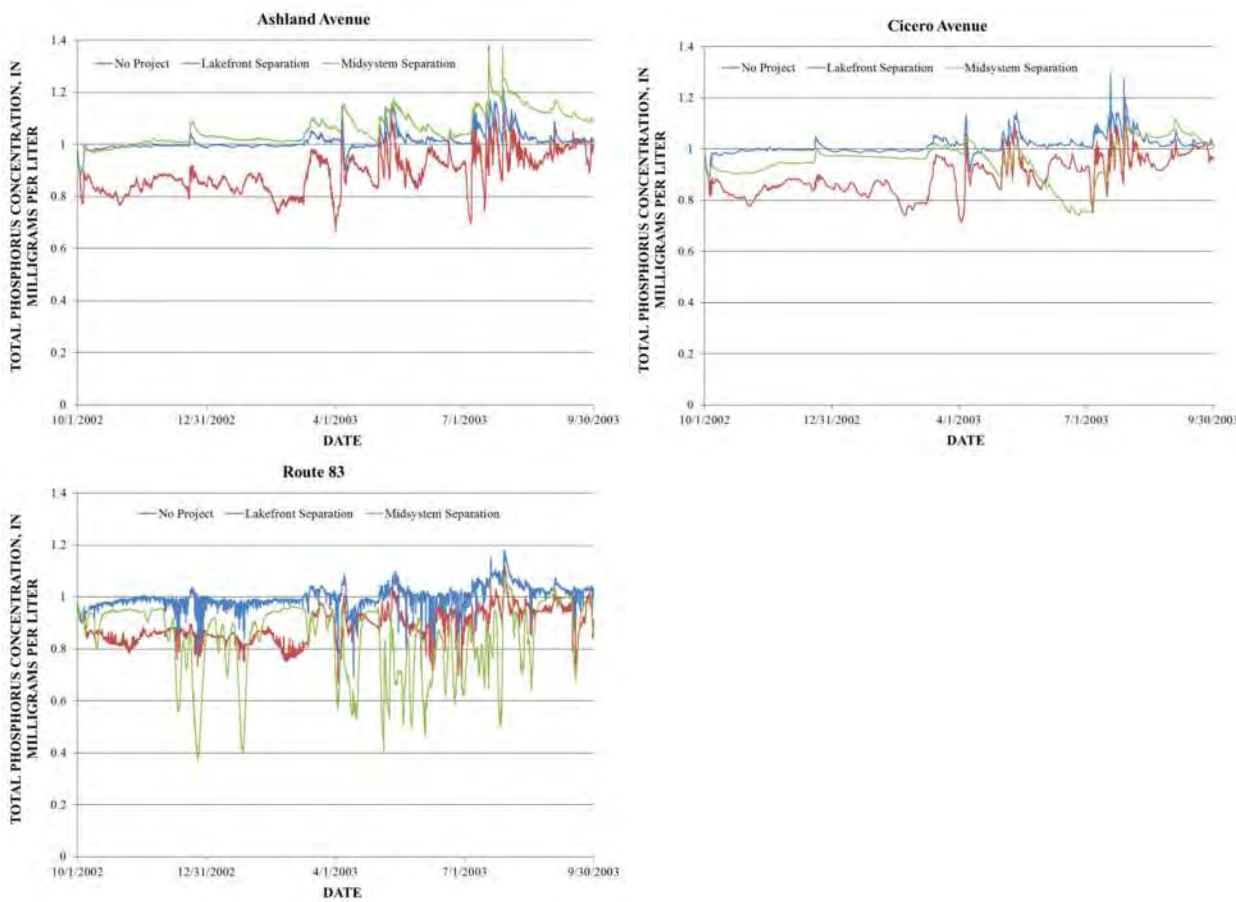


Figure 7.32. Simulated total phosphorus concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2003.

7.5 Loads to Lake Michigan

One of the key water quality impacts of the “Midsystem Separation” alternative is the load of pollutants directed to Lake Michigan under this alternative. For WY 2003 under actual conditions no flow reversals to Lake Michigan occurred, thus, the “No Project” alternative for Baseline and Future conditions will not experience flows to the lake. Table 7.1 lists the flows and loads to Lake Michigan for the “Midsystem Separation” alternative for Future conditions. For this representative “dry” year it can be seen that for the “Midsystem Separation” alternative nutrient loads in neighborhood of 13 and 1.7 million pounds of nitrogen and phosphorus, respectively, can be delivered to Lake Michigan during dry years. Also for the “Midsystem Separation” alternative loads in the neighborhood of 330 million pounds of chloride can be delivered to Lake Michigan during dry years.

The fact that this is a “dry” year can be seen in the fecal coliform loads to Lake Michigan. Compared to WY 2003, the “normal” year (WY 2001) delivers 7.4 times more fecal coliform bacteria to Lake Michigan and the “wet” year (WY 2008) delivers 26.7 times more. The low bacteria load to Lake Michigan results because of the greatly reduced storm loads in WY 2003 compared to the other years.

Table 7.1. Flows and loads to Lake Michigan at Wilmette, at the Chicago River Controlling Works (CRCW), and from the Calumet River for the "Midsystem Separation" alternative for Future conditions for Water Year 2003. [note: CBOD is carbonaceous biochemical oxygen demand, TN is total nitrogen, TP is total phosphorus, and TSS is total suspended solids].

Constituent	Wilmette	CRCW	Calumet River	Total
Flow (cfs)	168.8	287.5	573.2	1029.5
Volume (ac-ft)	122,000	208,000	415,000	745,000
CBOD (lb)	697,000	977,000	2,077,000	3,751,000
TN (lb)	2,943,000	2,956,000	6,900,000	12,800,000
TP (lb)	299,000	394,000	1,036,000	1,729,000
TSS (lb)	2,240,000	4,315,000	7,468,000	14,054,000
Chloride (lb)	50,500,000	84,400,000	197,100,000	332,100,000
Fecal Coliform (CFU)	1.90×10^{15}	9.00×10^{14}	2.11×10^{15}	4.91×10^{15}

Chapter 8 – ALTERNATIVE COMPARISON FOR THE REPRESENTATIVE "WET" YEAR (WY 2008)

The DUFLOW model yields simulated values of carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia, nitrate, organic phosphorus, inorganic phosphorus, algae as chlorophyll a, dissolved oxygen (DO), total suspended solids, chloride, pH, and fecal coliform bacteria. It was decided to report the variations in concentrations of DO, fecal coliform bacteria, chloride, and total phosphorus throughout the CAWS to compare among the three alternatives—"No Project," "Lakefront Separation," and "Midsystem Separation." Also important are the loads of the various constituents to Lake Michigan for the different alternatives. Obviously, there are no loads to Lake Michigan for the "Lakefront Separation" alternative. Also, for the representative "dry" and "normal" years (WYs 2003 and 2001, respectively) there are no loads to Lake Michigan for the "No Project" alternative because the CSO storage in the TARP reservoirs avoids the need for flow reversals to Lake Michigan that were needed under actual operations for WY 2001. However, for WY 2008 even with the CSO storage in the TARP reservoirs there would be flow to Lake Michigan for the "No Project" alternative.

This chapter presents the comparison of the different alternatives in terms of concentrations throughout the CAWS and compliance with water-quality standards for DO, fecal coliform bacteria, and chloride, concentrations throughout the CAWS for total phosphorus, and loads to Lake Michigan for CBOD, total nitrogen, total phosphorus, total suspended solids, chloride, and fecal coliform bacteria. These results are reported only for the Future conditions to give a picture of the ultimate performance for any of these alternatives.

8.1 Comparison of Simulated Dissolved Oxygen Concentrations

8.1.1 Concentration vs. Time

The DUFLOW model yields computed values of any of the simulated water-quality constituents and properties at any the computational points in the CAWS (more than 100 points). Thus, to keep the comparison manageable it is focused on the DO measurement points monitored by the MWRDGC and used to calibrate and verify the model. In this report the results are presented for the various waterway reaches of the CAWS: the upper NSC; the lower NSC and NBCR (downstream of the O'Brien WRP, RM 339.6); Chicago River main stem, SBCR, and upper CSSC (above the Stickney WRP, RM 315.5); lower CSSC; Calumet River and Little Calumet River (north); and the Calumet-Sag Channel.

Figure 8.1 shows the computed DO concentrations on the upper NSC at Simpson Street and Main Street. It can be seen that the "Midsystem Separation" alternative yields higher DO concentrations throughout most of the year than the other two alternatives. This is because the opening of the NSC to Lake Michigan yields a constant flow from the O'Brien WRP through the NSC resulting in better DO concentrations than for those during the stagnant flow conditions that are present in the upper NSC throughout most of the year for the "No Project" and "Lakefront Separation" alternatives. The "No Project" alternative yields higher DO concentrations than the other two alternatives for the months of June through August reflecting the high quality Lake Michigan water released into the upper NSC as discretionary diversion during these months. From late December through May and in September the "No Project" and "Lakefront

Separation" alternatives yield nearly identical DO concentrations reflecting the fact that the "No Project" alternative has nearly zero flow at Wilmette during these periods. At Simpson Street there are substantial differences in the simulated DO concentrations for October through the end of December between the "No Project" and "Lakefront Separation" alternatives. This is the result of non-discretionary diversion flows at Wilmette during these months. In October these flows keep the DO concentrations higher in response to the storm of October 1-2, 2007. However, later the simulated DO concentrations at Simpson Street are low because the estimated DO concentrations at Linden Street (described in Chapter 4) are used to characterize the inflows at Wilmette and these values drop into the 3.5 to 5 mg/L range.

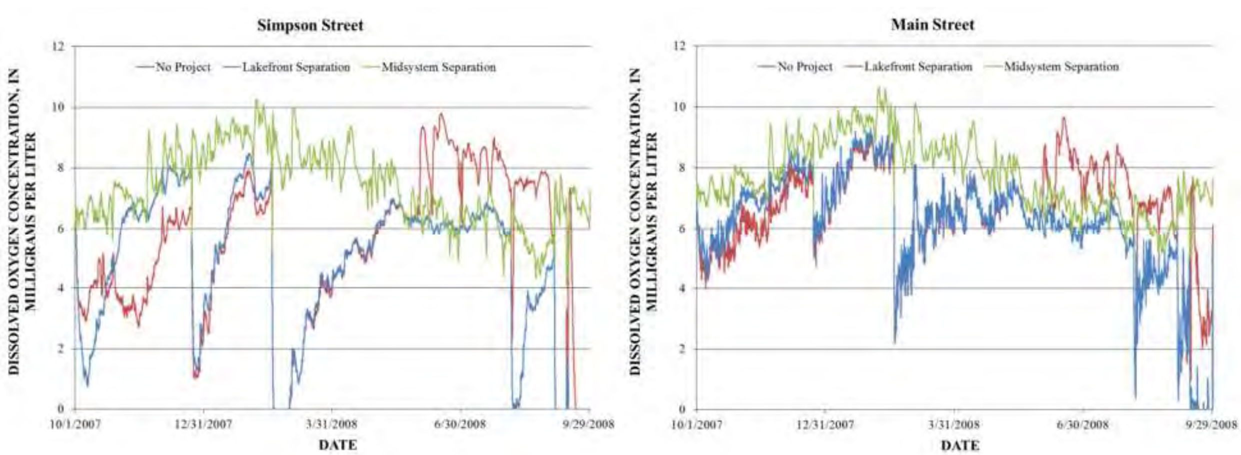


Figure 8.1. Simulated dissolved oxygen concentration on the upper North Shore Channel for the three alternatives under future conditions for Water Year 2008.

Figure 8.2 shows the computed DO concentrations on the lower NSC at Foster Avenue and on the NBCR at Addison Street, Fullerton Avenue, Division Street, and Kinzie Street. Generally, the "Midsystem Separation" alternative yields lower DO concentrations than the other two alternatives because a smaller portion of the O'Brien WRP effluent passes through these waterways for this alternative. The DO concentrations for the "No Project" and "Lakefront

Separation" alternatives are similar at all locations for October through May and September reflecting that these two alternatives have similar flows (or rather lack of flows) at Wilmette during these months. Again for June through August the "No Project" alternative yields the highest DO concentrations because of the discretionary diversion at Wilmette during these months.

Figure 8.3 shows the computed DO concentrations at Clark Street on the Chicago River main stem, Jackson Boulevard and Loomis Street on the SBCR, and Cicero Avenue on the CSSC. Cicero Avenue is included in this grouping instead of with the other locations on the CSSC because in the "Midsystem Separation" alternative Cicero Avenue is on the lake side of the separation barrier, and, thus, reflects the water quality in the stagnant SBCR and upper CSSC resulting from the hydrological/ecological separation. The "No Project" alternative yields the highest DO concentrations throughout the majority of the year. Discretionary diversion flows result in higher DO concentrations for the "No Project" alternative in June through August, and non-discretionary diversion flows, especially at CRCW, result in higher DO concentrations in October, November, and September. Whereas the "No Project" and "Lakefront Separation" alternatives yield similar results for December through May because of the similar flows (or rather lack of flows) at Wilmette and CRCW during these months. It is interesting that the "Lakefront Separation" and "Midsystem Separation" alternatives yield very similar DO concentrations throughout the year (except for after the August and September storms) at Clark Street and Jackson Boulevard because flow is stagnant at Clark Street for the "Lakefront Separation" alternative whereas it is stagnant at Jackson Boulevard for the "Midsystem Separation" alternative.

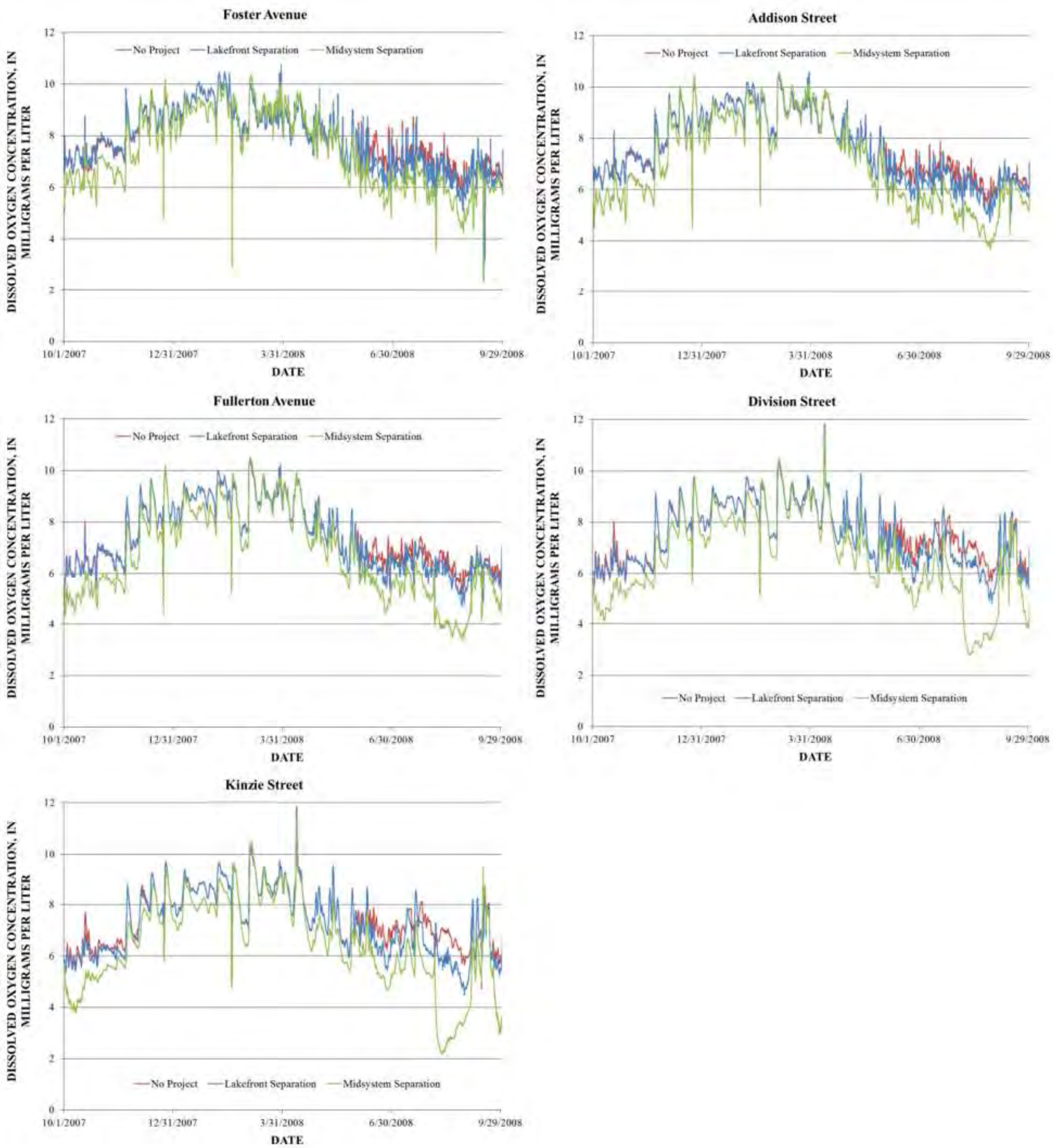


Figure 8.2. Simulated dissolved oxygen concentration on the lower North Shore Channel at Foster Avenue and the North Branch Chicago River at Addison Street, Fullerton Avenue, Division Street, and Kinzie Street for the three alternatives under future conditions for Water Year 2008.

The results at Jackson Boulevard, Loomis Street, and Cicero Avenue for the "Midsytem Separation" alternative in Figure 8.3 show the standard pattern for stagnant waters that high DO concentrations can occur during periods with no loads, but when loads occur in October and August through September very low DO concentrations occur that take a long time to recover to high DO concentrations because of the low rate of water exchange to and from the stagnant reaches to the reaches with flows. Unlike WYs 2001 and 2003, algal growth does not have much effect on DO concentrations in the SBCR and upper CSSC in WY 2008.

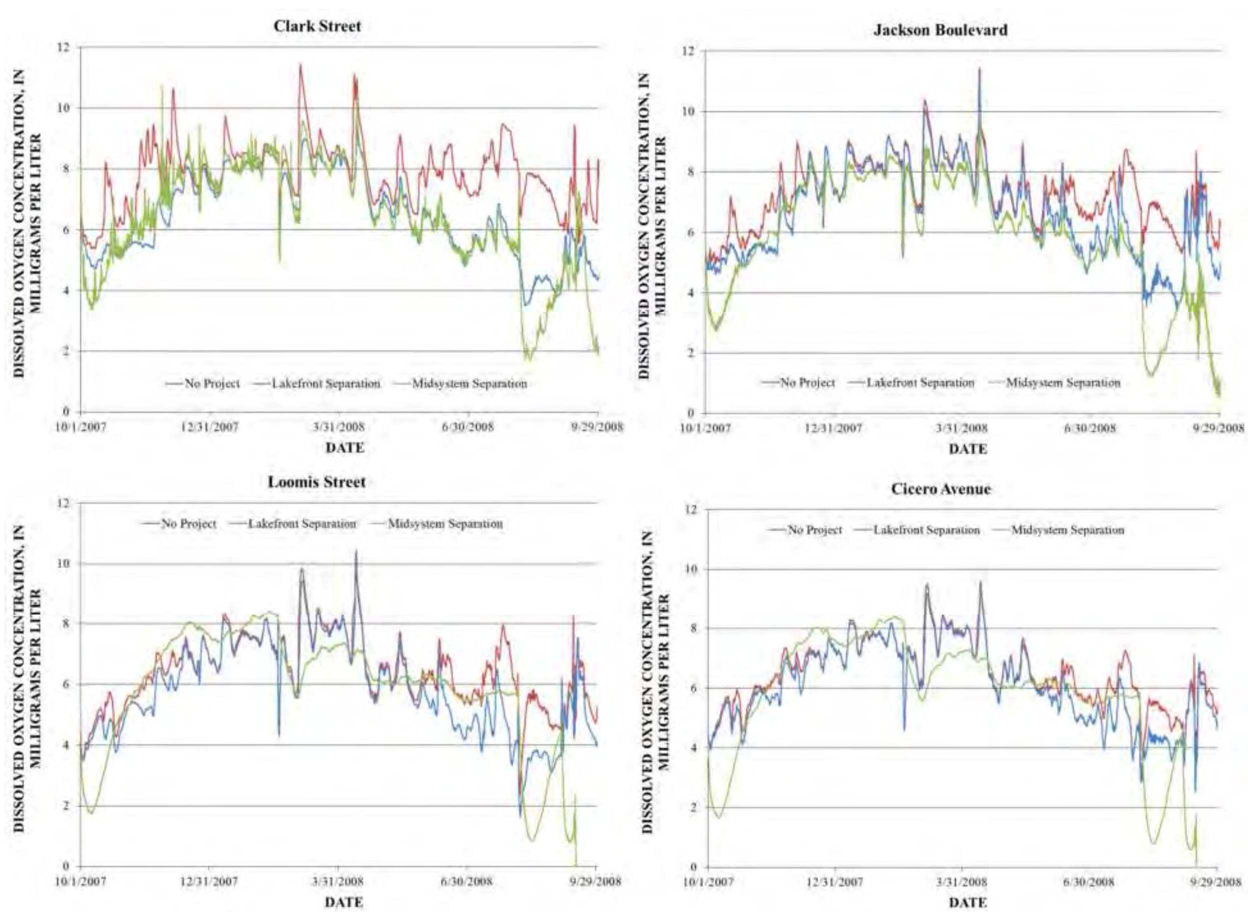


Figure 8.3. Simulated dissolved oxygen concentration on the Chicago River main stem at Clark Street, the South Branch Chicago River at Jackson Boulevard and Loomis Street, and the Chicago Sanitary and Ship Canal at Cicero Avenue for the three alternatives under future conditions for Water Year 2008.

Figure 8.4 shows the computed DO concentrations along the CSSC downstream from the Stickney WRP. Through RM 302.6 the "Midsystem Separation" alternative yields higher DO concentrations than the other alternatives because the effluent from the Stickney WRP, which is nearly the only flow in this alternative, has higher DO concentrations than the upstream flows in the SBCR and upper CSSC in the other alternatives. Once the flows reach Romeoville Road the consumption of the oxygen demanding substances in the Stickney WRP effluent drive DO concentrations lower for the "Midsystem Separation" alternative than the other alternatives for which the higher flows can dilute the effects of the Stickney WRP effluent in the downstream portion of the CSSC. Again the "No Project" and "Lakefront Separation" alternatives yield similar results for December through May because of the similar flows (or rather lack of flows) at Wilmette and CRCW during these months. Comparing the "No Project" and "Lakefront Separation" alternatives the discretionary diversion flows result in higher DO concentrations for the "No Project" alternative in June through August, and non-discretionary diversion flows, especially at CRCW, result in higher DO concentrations in October, November, and September. Overall, for all three alternatives relatively high DO concentrations far above the DO standard of 3.5 mg/L are achieved throughout the entire year.

Figure 8.5 shows the computed DO concentrations at 130th Street on the Calumet River and at Conrail Railroad and Central & Wisconsin Railroad on the Little Calumet River (north). In fact the figure for 130th Street shows the conditions at 130th Street for the "Midsystem Separation" alternative and on the river side of the O'Brien Lock and Dam (0.5 mi south of 130th Street) for the "No Project" alternative. No result is shown for the "Lakefront Separation" alternative because the separation barrier is placed at RM 324.5 (2 mi downstream from the O'Brien Lock and Dam).

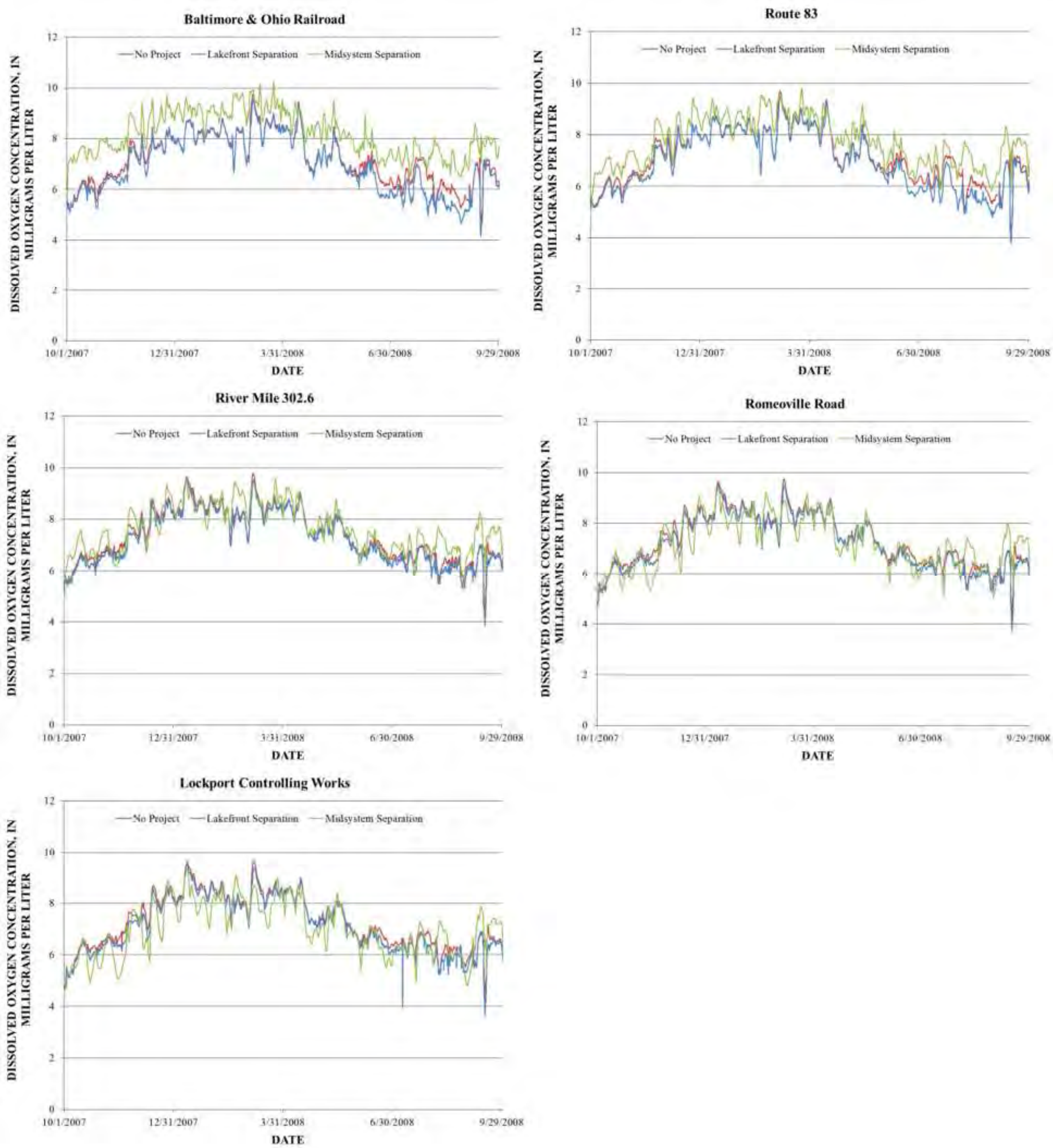


Figure 8.4. Simulated dissolved oxygen concentration on the Chicago Sanitary and Ship Canal for the three alternatives under future conditions for Water Year 2008.

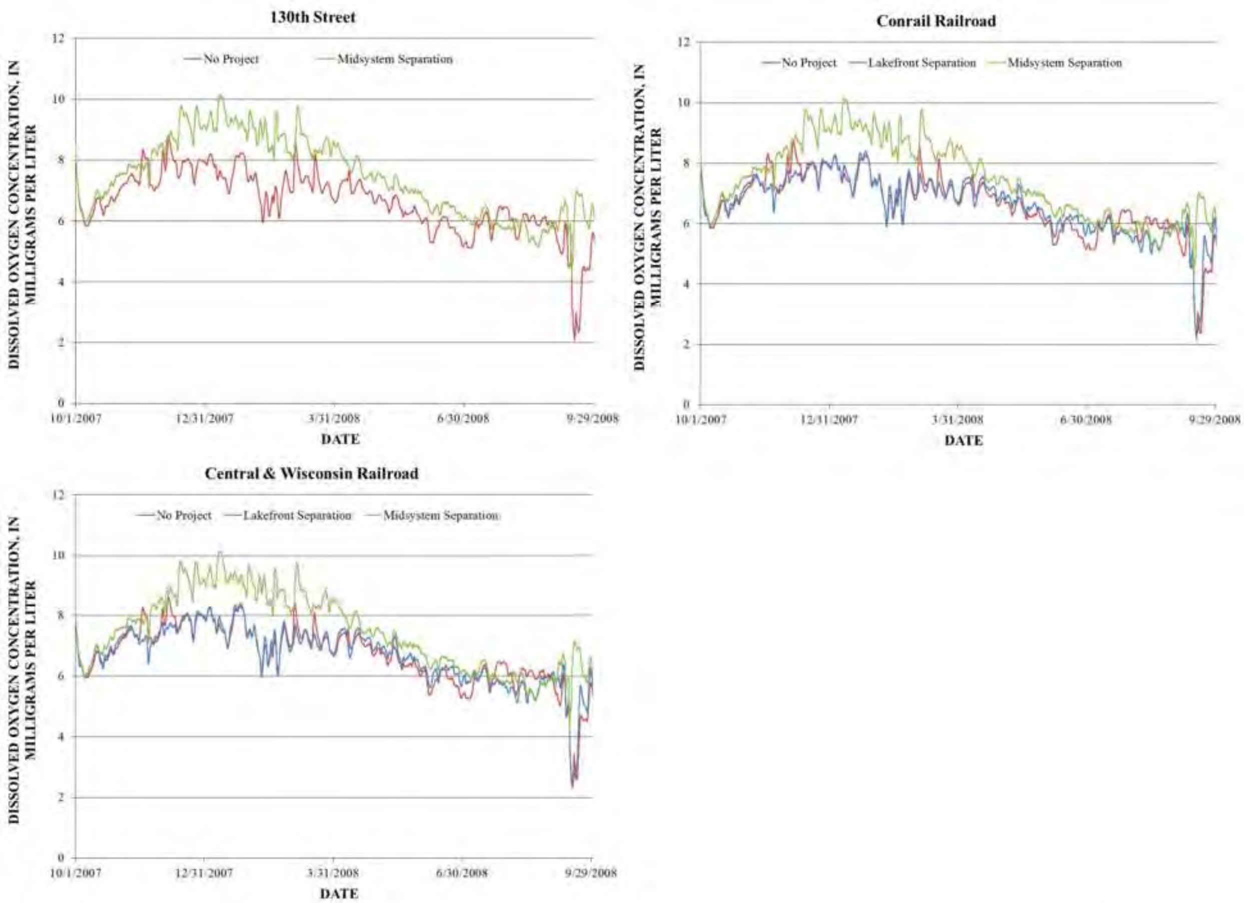


Figure 8.5. Simulated dissolved oxygen concentration on the Calumet River at 130th Street and the Little Calumet River (north) at Conrail Railroad and Central & Wisconsin Railroad for the three alternatives under future conditions for Water Year 2008.

The "Midsystem Separation" alternative yields higher DO concentrations at all the locations shown in Figure 8.5 because under this alternative continuous flows pass each of these locations whereas in the other alternatives these locations generally experience stagnant flows. The DO concentrations for the "No Project" and "Lakefront Separation" alternatives are similar at all locations for October through May and September reflecting that these two alternatives have similar flows (or rather lack of flows) at O'Brien Lock and Dam during these months. The DO concentrations differ for June through August, but it takes until mid-July for the "No Project" alternative to yield the highest DO concentrations continuing through August because of the withdrawal of discretionary diversion at the O'Brien Lock and Dam.

Figure 8.6 shows the computed DO concentrations at Halsted Street on the Little Calumet River (north) and at seven locations along the Calumet-Sag Channel. The simulation results at Halsted Street show that for the "Midsystem Separation" alternative DO concentrations are dictated by those at Ashland Avenue on the Little Calumet River (south), which is the source of flow to Halsted Street for this alternative. The DO concentrations along the Calumet-Sag Channel for the "Midsystem Separation" alternative show the clear effects of flow stagnation once the watersheds are separated at RM 315.89. Unlike WYs 2001 and 2003, algal growth does not have much effect on DO concentrations in the Calumet-Sag Channel in WY 2008. At all of these locations the "No Project" and "Lakefront Separation" alternatives yield very similar DO concentrations. For these alternatives, the DO concentrations in these reaches of the CAWs generally are high, such that the withdrawal of discretionary diversion at O'Brien Lock and Dam in June to August does not have a major impact on computed DO concentrations for the "No Project" alternative.

8.1.2 Compliance with Dissolved Oxygen Standards

Figures 8.7 and 8.8 show the number of hours not in compliance with the DO standards along the Chicago River and Calumet River systems, respectively. It is clearly seen that stagnant reaches yield high levels of noncompliance with the DO standards. These include the upper NSC (RMs 336.9 to 340.8, Figure 8.7) and the upper Little Calumet River (north) and Calumet River (RMs

321.4 to 327, Figure 8.8) for the "No Project" and "Lakefront Separation" alternatives, the Chicago River main stem for the "Lakefront Separation" alternative (Clark Street on the main stem is shown at RM 325.9 in Figure 8.7), and the SBCR and CSSC up to the Stickney WRP (RMs 315.5 to 325.6, Figure 8.7) and the Calumet-Sag Channel (RMs 303.4 to 319.6, Figure 8.8) for the "Midsystem Separation" alternative. For whatever alternative is enacted, mitigation is needed to eliminate stagnant zones if high levels of compliance with the DO standards are to be achieved. Also, high levels of noncompliance result around Loomis Street (RM 321.9, Figure 8.7) on the SBCR for the "Lakefront Separation" alternative that would require mitigation if high levels of compliance with the DO standards are to be achieved.

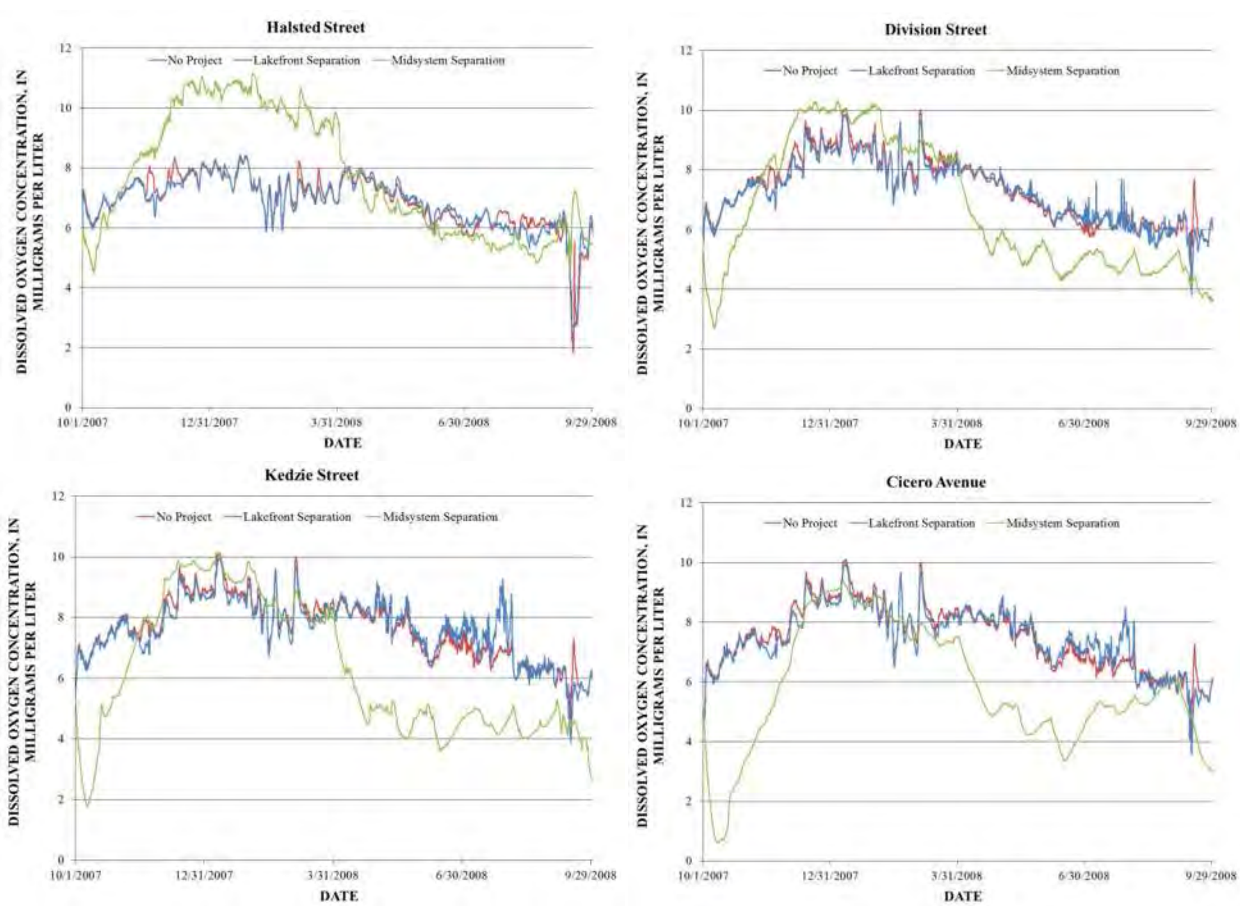


Figure 8.6. Simulated dissolved oxygen concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104^{th} Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2008.

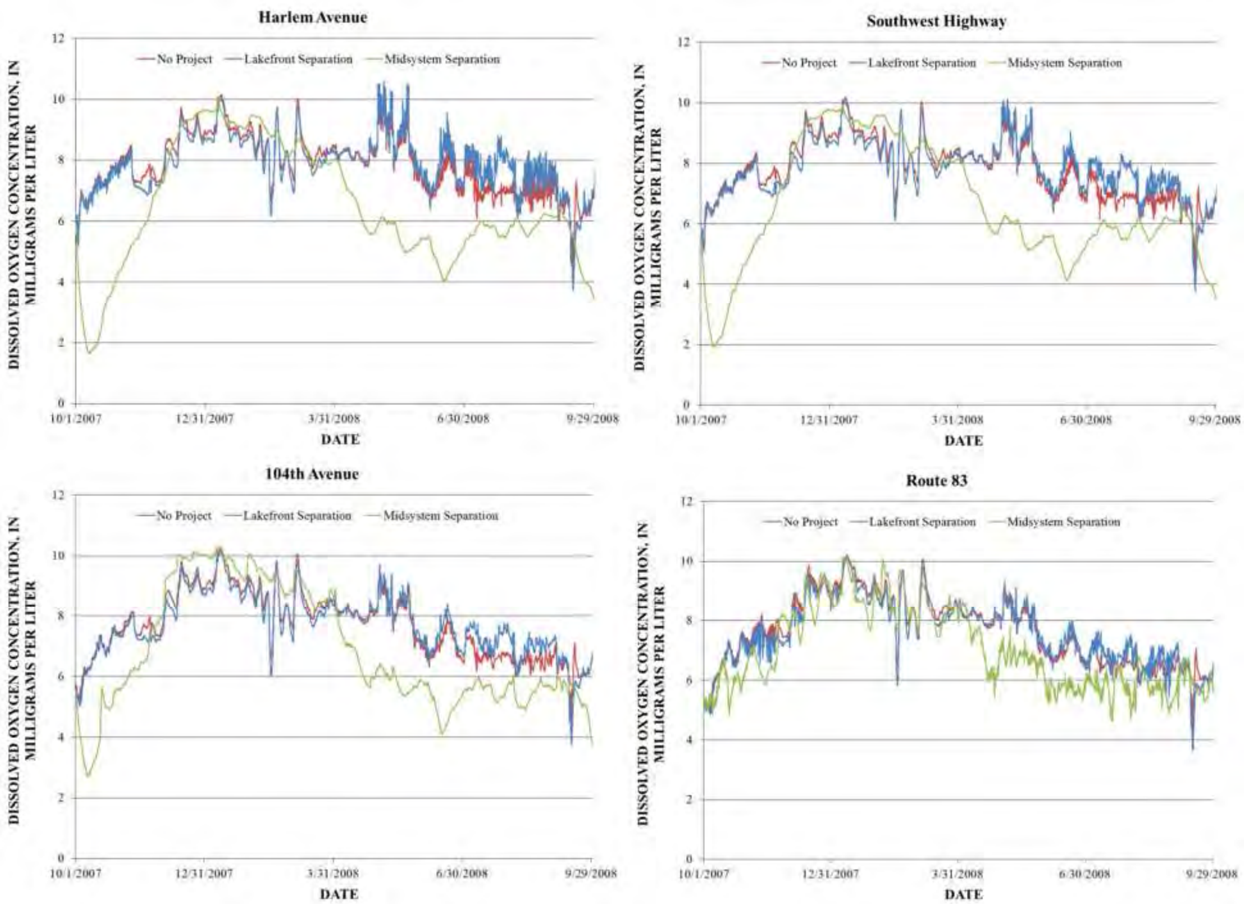


Figure 8.6 (cont.) Simulated dissolved oxygen concentration on the Little Calumet River (north) at Halsted Street and the Calumet-Sag Channel at Division Street, Kedzie Street, Cicero Avenue, Harlem Avenue, Southwest Highway, 104th Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2008.

All three alternatives show very low levels of noncompliance (i.e. high levels of compliance) on the CSSC downstream from the Stickney WRP (RM 315.5) (Figure 8.7). The “No Project” and “Lakefront Separation” alternatives show very low levels of noncompliance on the Little Calumet River (north) and Calumet-Sag Channel which are downstream from the Calumet WRP (RM 321.4) in these alternatives (Figure 8.8). Conversely, the “Midsystem Separation” alternative shows very low levels of noncompliance on the Little Calumet River (north) and Calumet River (Figure 8.8), which are downstream from the Calumet WRP in this alternative, and the upper NSC (Figure 8.7), which is downstream from the O’Brien WRP in this alternative.

On the other hand, the noncompliance increases on the lower NSC and NBCR for the "Midsystem Separation" alternative because about one third of the O'Brien WRP effluent now passes through the upper NSC and not through these reaches.

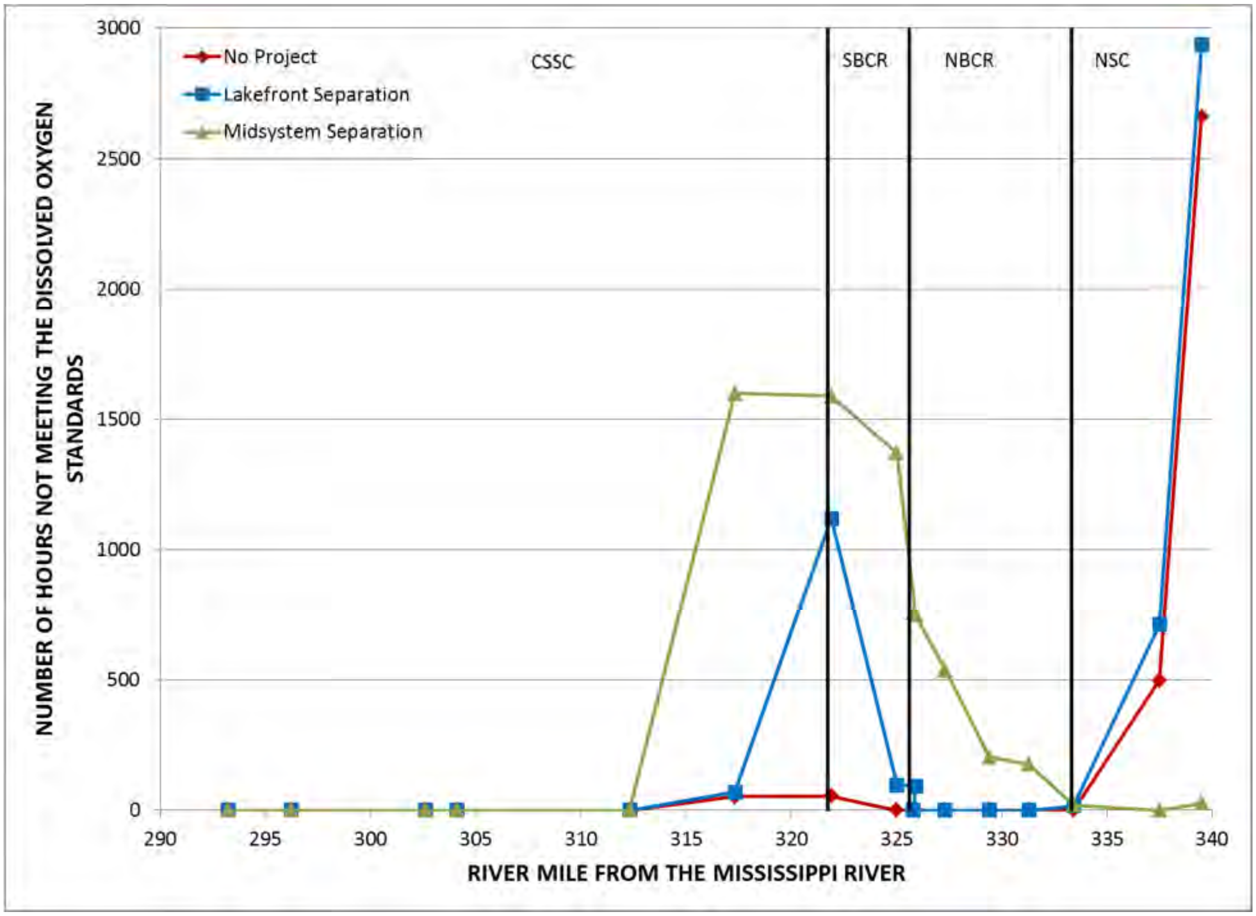


Figure 8.7. Number of hours not in compliance with the dissolved oxygen standards along the Chicago River system for Water Year 2008.

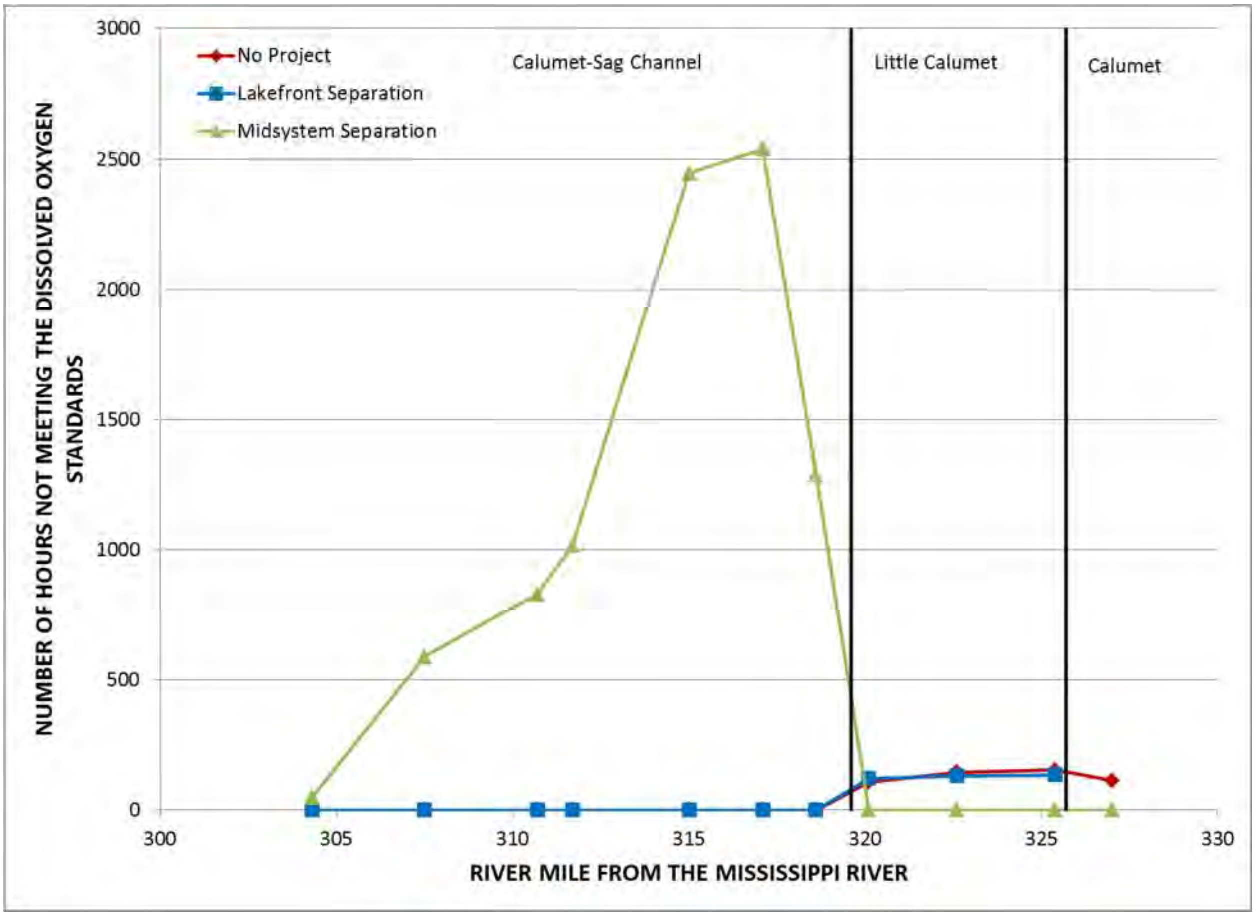


Figure 8.8. Number of hours not in compliance with the dissolved oxygen standards along the Calumet River system for Water Year 2008.

8.2 Comparison of Simulated Fecal Coliform Concentrations

8.2.1 Concentration vs. Time

The DUFLOW model yields computed values of any of the simulated water-quality constituents and properties at any the computational points in the CAWS (more than 100 points). Thus, to keep comparison manageable it is focused on the measurement points in the ambient water quality monitoring network sampled monthly by the MWRDGC and used to calibrate and verify the model for fecal coliform bacteria, chloride, and total phosphorus. In this report the results are presented for the various waterway reaches of the CAWS: the upper NSC; the lower NSC and NBCR (downstream of the O'Brien WRP, RM 336.9); Chicago River main stem, SBCR, and upper CSSC (above the Stickney WRP, RM 315.5); lower CSSC; Calumet River and Little Calumet River (north); and the Calumet-Sag Channel.

Figure 8.9 shows the computed fecal coliform concentrations on the upper NSC at Oakton Street (0.1 mi north of the O'Brien WRP outfall). It can be seen that the "Midsystem Separation" alternative yields lower fecal coliform concentrations during storm periods as the flows from the O'Brien WRP dilutes the effects of CSOs discharged to the upper NSC. The "No Project" and "Lakefront Separation" alternatives yield nearly identical fecal coliform concentrations for the months of October to May and September reflecting the fact that the "No Project" alternative has nearly zero flow at Wilmette during these periods. In the months of June to August the "No Project" alternative yields the lowest fecal coliform concentrations reflecting the effects of the discretionary diversion from Lake Michigan during these months. The "Midsystem Separation" and "Lakefront Separation" alternatives yield very similar fecal coliform concentrations during dry weather indicating the dominant role of O'Brien WRP effluent on fecal coliform concentrations in the upper NSC for these alternatives.

Figure 8.10 shows the computed fecal coliform concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O'Brien WRP outfall) and at Wilson Avenue and Diversey Parkway on the NBCR. It can be seen that the "No Project" and "Lakefront Separation" alternatives yield very similar fecal coliform concentrations at all points and times in these reaches. The effects of discretionary diversion on fecal coliform concentrations are small in these reaches. Finally, at

Touhy Avenue and Wilson Avenue all three alternatives yield similar fecal coliform concentrations. However, as the flows reach the downstream NBCR (Diversey Parkway, 6.8 mi downstream of the O'Brien WRP) the decrease in flows in these reaches for the "Midsystem Separation" alternative increases the travel time, thus, decreasing the fecal coliform concentrations relative to the other alternatives.

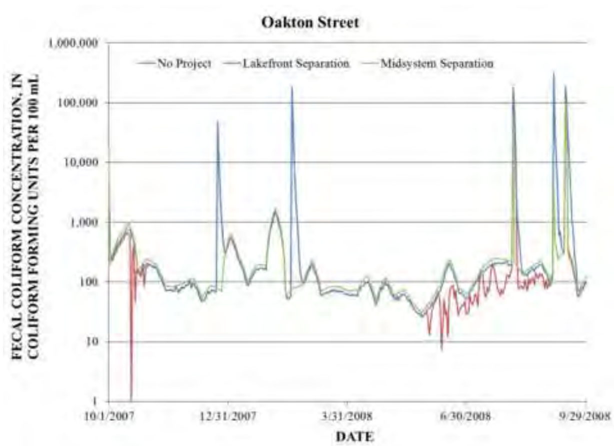


Figure 8.9. Simulated fecal coliform concentration on the upper North Shore Channel at Oakton Street for the three alternatives under future conditions for Water Year 2008.

Figure 8.11 shows the computed fecal coliform bacteria concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street, and CSSC at Western Avenue and Cicero Avenue. At Wells Street on the Chicago River main stem the trend of decreasing fecal coliform concentrations for the "Midsystem Separation" alternative observed at Diversey Parkway continues until fecal coliform concentrations less than the 200 CFU/100 mL standard are achieved during most dry weather periods. The "No Project" and "Lakefront Separation" alternatives yield similar fecal coliform bacteria concentrations at Wells Street throughout the year. The discretionary diversion from June through August has little effect on the fecal coliform concentrations for the "No Project" alternative compared to the other alternatives because all the alternatives yield very low fecal coliform concentrations at Wells Street. Similar to the "Midsystem Separation" alternative, both the "No Project" and "Lakefront Separation" alternatives yield fecal coliform concentrations less than the 200 CFU/100 mL standard during most dry weather periods.

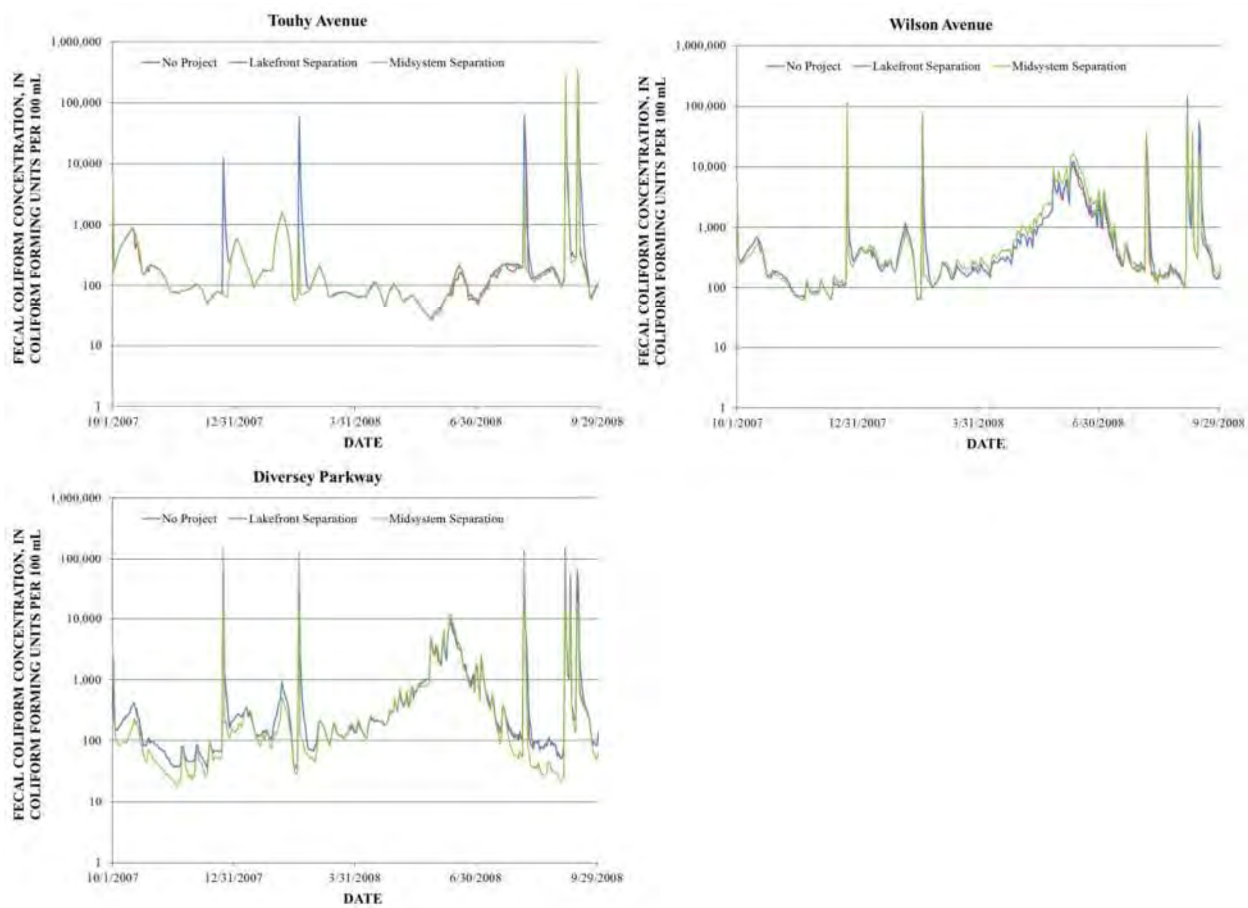


Figure 8.10. Simulated fecal coliform concentration on the North Shore Channel at Touhy Avenue and the North Branch Chicago River at Wilson Avenue and Diversey Parkway for the three alternatives under future conditions for Water Year 2008.

In Figure 8.11 all points on the SBCR and upper CSSC experience very low fecal coliform concentrations for the "Midsystem Separation" alternative because the primary source of fecal coliform bacteria to these reaches is infrequent CSOs. Madison Street and Western Avenue experience low fecal coliform concentrations (see Figure 8.11) for the “No Project” and “Lakefront Separation” alternatives indicating the die off fecal coliform bacteria as the flows travel from O’Brien WRP. Cicero Avenue experiences higher fecal coliform concentrations for the “No Project” and “Lakefront Separation” alternatives due to upstream propagation of the un-disinfected effluent from the Stickney WRP that cannot get to this reach in the “Midsystem Separation” alternative because of the barrier at RM 316.01.

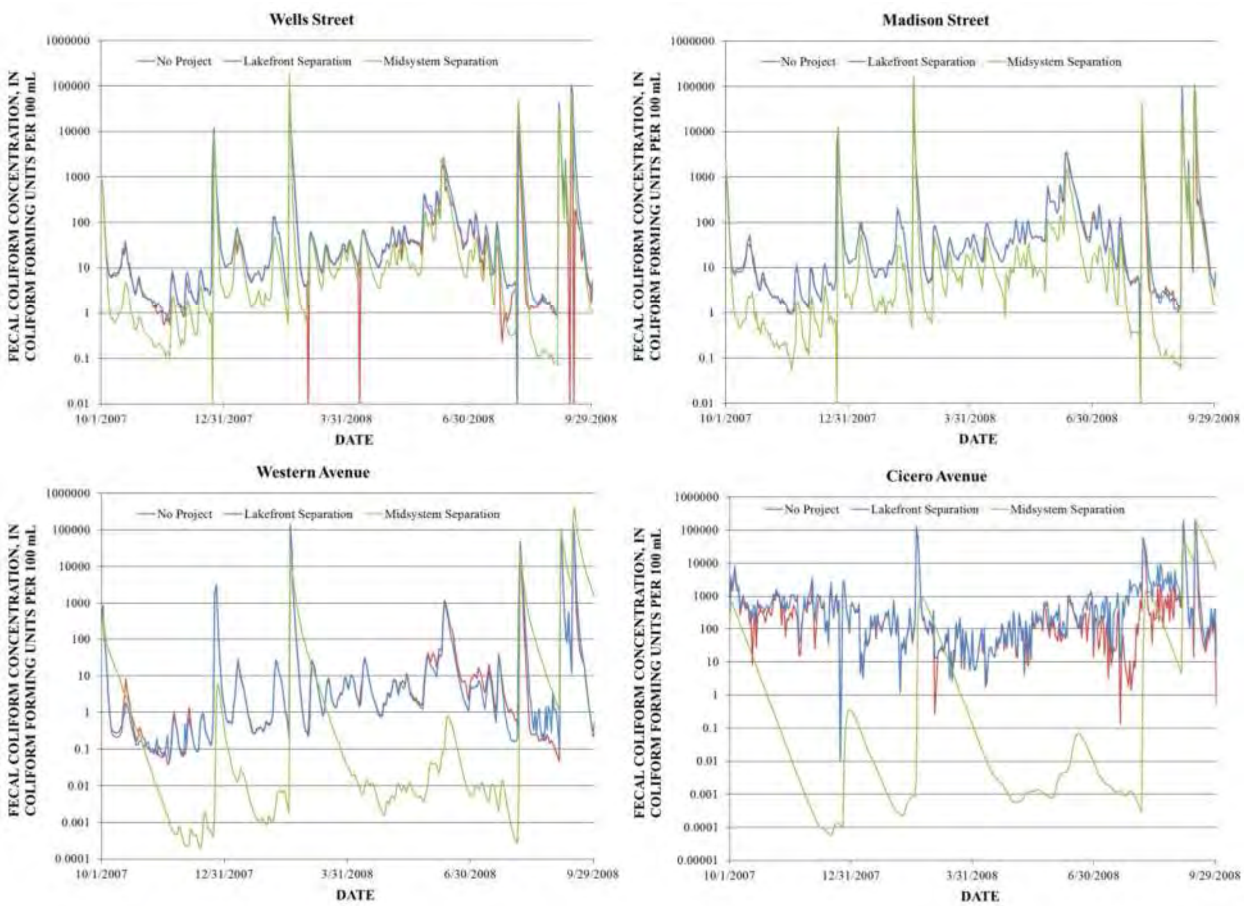


Figure 8.11. Simulated fecal coliform concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street, and Chicago Sanitary and Ship Canal at Western Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2008.

Figure 8.12 shows the computed fecal coliform concentrations on the CSSC downstream from the Stickney WRP. The results for the “No Project” and “Lakefront Separation” alternatives are nearly identical showing the dominant influence of the Stickney WRP effluent on this reach. The discretionary diversion in June through August for the “No Project” alternative has little effect on the fecal coliform bacteria in this reach. The “Midsystem Separation” alternative also yields similar fecal coliform concentrations as those for the other alternatives with only storm periods showing substantial reductions in fecal coliform bacteria. The results for the “Midsystem Separation” alternative also indicate the dominant influence of the Stickney WRP effluent on this reach.

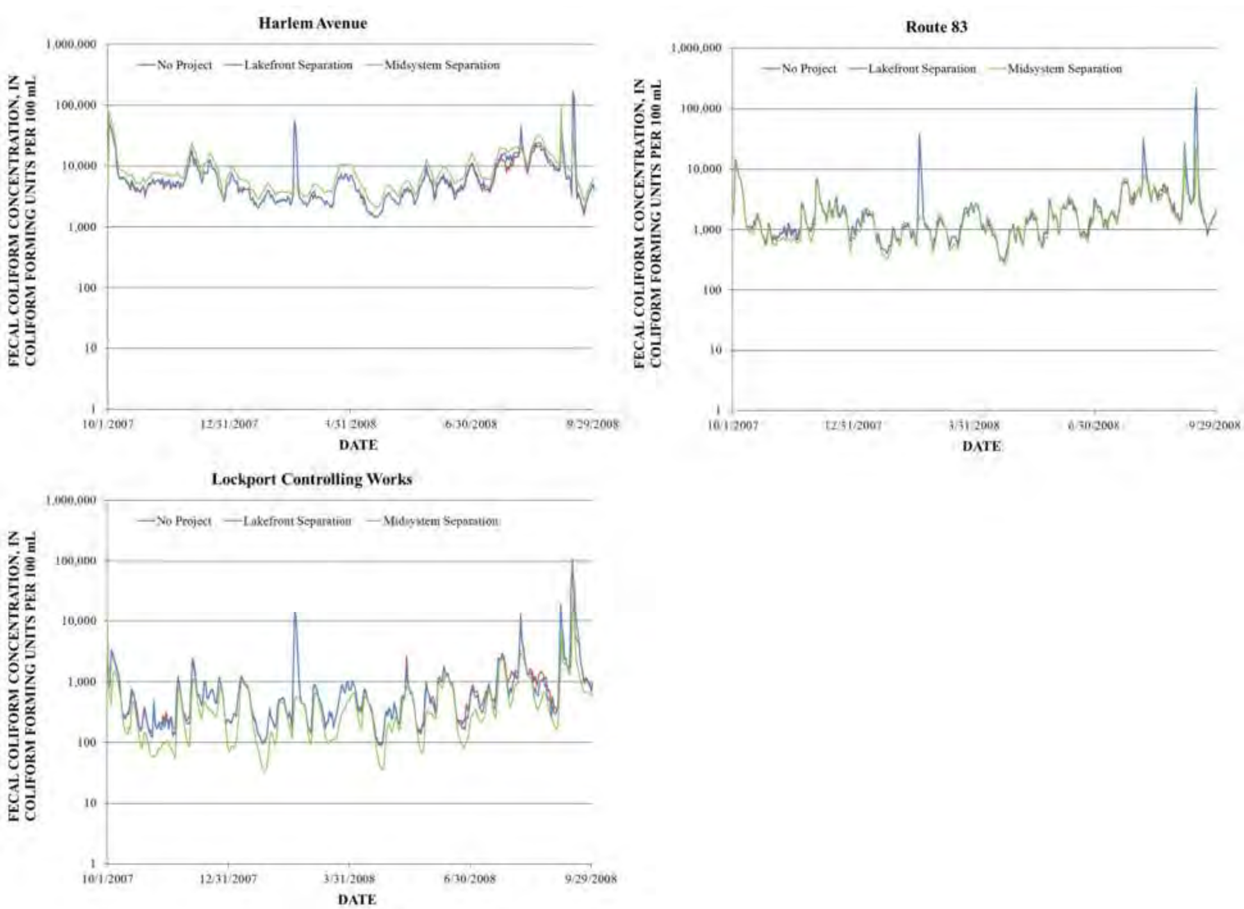
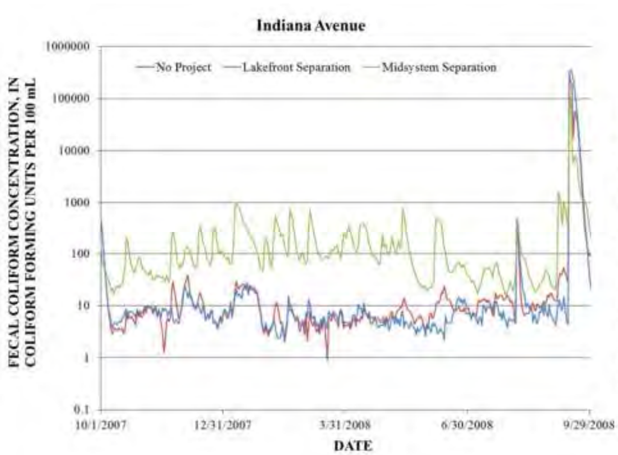


Figure 8.12. Simulated fecal coliform concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2008.

Figure 8.13 shows the computed fecal coliform concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At both of these locations the "No Project" and "Lakefront Separation" alternatives yield similar fecal coliform bacteria concentrations showing the discretionary diversion has only a minor effect in diluting fecal coliform bacteria in this reach. The "Midsystem Separation" alternative yields higher fecal coliform concentrations than the other two alternatives at these locations. Indiana Avenue receives effluent from the Calumet WRP under the "Midsystem Separation" alternative raising the fecal coliform concentrations whereas in the other two alternatives Indiana Avenue only experiences some occasional backups of effluent from this WRP. For Halsted Street under the "Midsystem Separation" alternative the fecal coliform concentrations are dominated by the fecal coliform bacteria coming from the Little Calumet River (south) which has higher concentrations than for the disinfected Calumet WRP effluent that dominates the fecal coliform concentrations at Halsted Street for the other two alternatives.



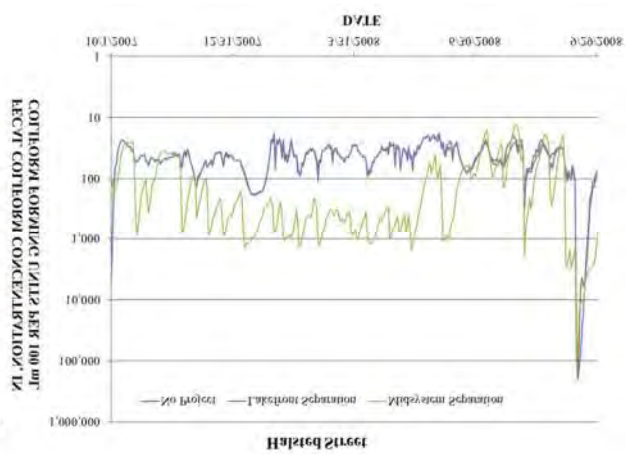


Figure 8.13. Simulated fecal coliform concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2008.

Figure 8.14 shows the computed fecal coliform concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. At all of these locations the “No Project” and “Lakefront Separation” alternatives yield similar fecal coliform concentrations showing the discretionary diversion has only a minor effect in diluting fecal coliform bacteria in this reach. The “Midsystem Separation” alternative yields fecal coliform bacteria concentrations similar to the other two alternatives at Ashland Avenue and Cicero Avenue. At Route 83, the “Midsystem Separation” alternative yields higher fecal coliform bacteria concentrations than the other two alternatives because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel for this alternative.

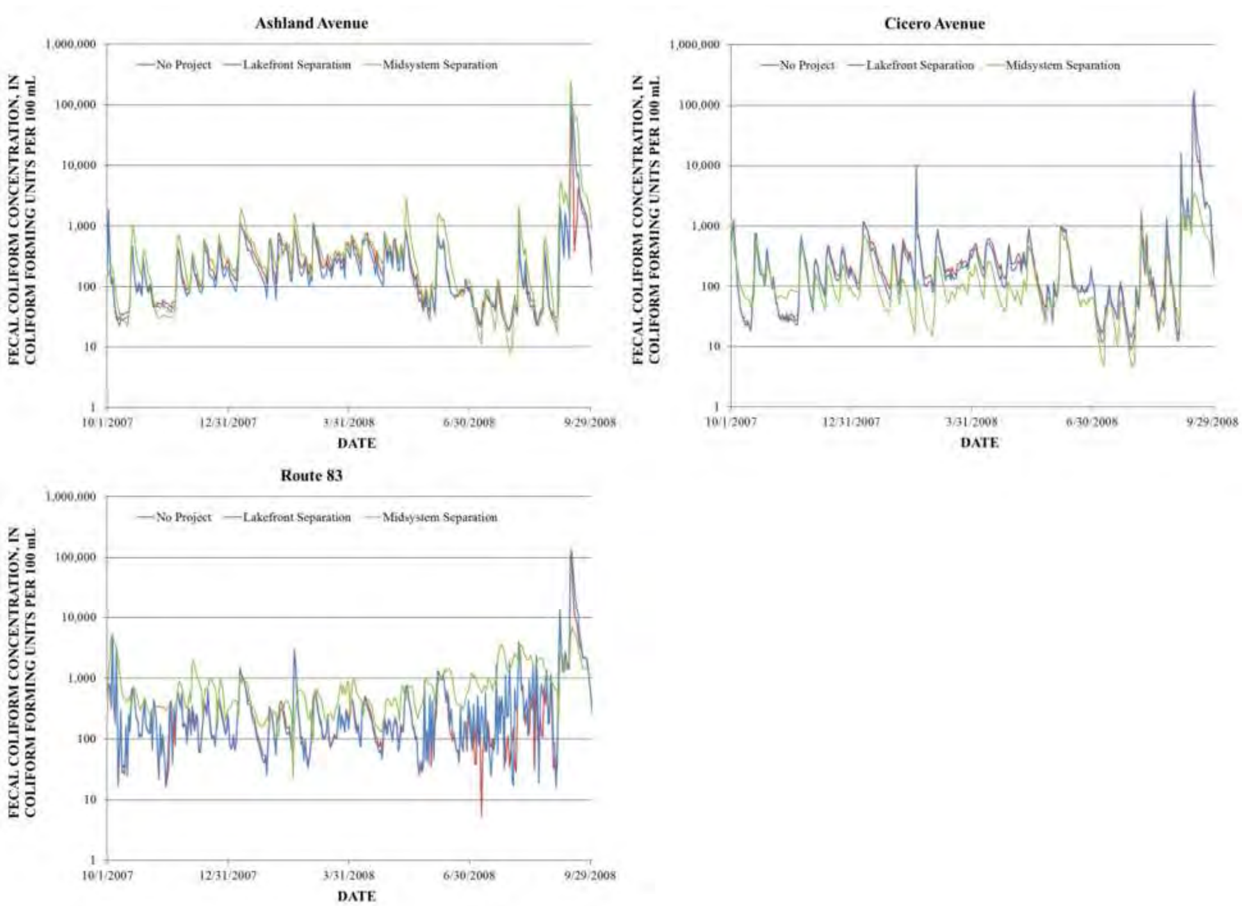


Figure 8.14. Simulated fecal coliform concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2008.

8.2.2 Compliance with the Fecal Coliform Standard

Figures 8.15 and 8.16 show the number of hours not in compliance with the fecal coliform standard along the Chicago River and Calumet River systems, respectively. As can be seen in Figure 8.15, for the NSC and Chicago River main stem (Clark Street on the main stem is shown at RM 325.9 in Figure 8.15) the “No Project” alternative yields lower noncompliance (i.e. higher compliance) with the fecal coliform standard than the other two alternatives because of the availability of discretionary diversion. In all other reaches of the CAWS the “No Project” and “Lakefront Separation” alternatives yield nearly identical levels of compliance with the fecal coliform standard (Figures 8.15 and 8.16) except for Cicero Avenue on the CSSC (RM 317.3, in Figure 8.15).

Downstream from the Stickney WRP (RM 315.5) on the CSSC all three alternatives yield nearly identical levels of compliance with the fecal coliform bacteria standard through RM 302.6 and similar levels of compliance downstream from RM 302.6 because of the dominance of the Stickney WRP effluent on this reach (Figure 8.15). On the NSC and NBCR, all three alternatives yield similar levels of compliance with the fecal coliform standard at Fullerton Avenue (RM 329.4) because of the dominance of the O’Brien WRP effluent on this location (Figure 8.15). The level of compliance for the “No Project” and “Lakefront Separation” alternatives remains very similar throughout the NBCR, but the “Midsystem Separation” alternative shows substantially lower noncompliance than the other alternatives in the NBCR. On the other hand, the “Midsystem Separation” alternative has the highest levels of noncompliance on the NSC. The low loads of fecal coliform bacteria to the SBCR and upper

CSSC result in the low levels of noncompliance with the fecal coliform standard observed in Figure 8.15 for the "Midsystem Separation" alternative.

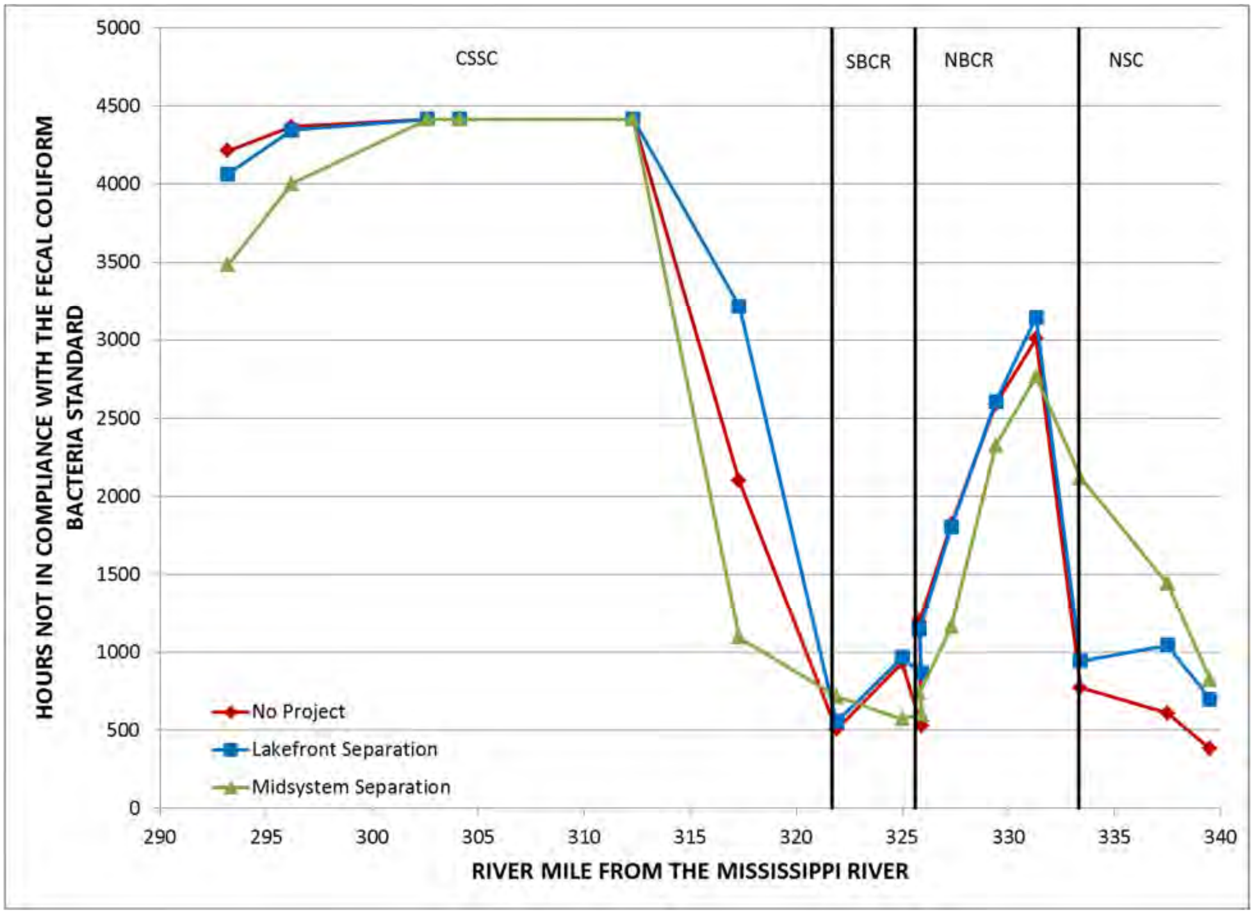


Figure 8.15. Number of hours not in compliance with the fecal coliform standard along the Chicago River system for Water Year 2008.

In the Calumet River system (Figure 8.16), the "Midsystem Separation" alternative yields higher levels of noncompliance than the other two alternatives on the lake side of the Calumet WRP (upstream from RM 321.4) because this reach continually receives treated effluent in this alternative, whereas in the other alternatives this reach only occasionally receives treated effluent. The Calumet-Sag Channel (RM 303.4 to 319.6) becomes two stagnant water bodies in the "Midsystem Separation" alternative. At the two ends of the Calumet-Sag Channel the levels of noncompliance with the fecal coliform standard are dominated by the conditions in the receiving water body (lower CSSC for the downstream end [RM 303.4] and Little Calumet River (north) for the upstream end [RM 319.6]). However, in the middle sections of the Calumet-Sag Channel the "Midsystem Separation" alternative shows lower levels of noncompliance consistent with the low loads of fecal coliform bacteria to these reaches (Figure 8.16).

The high levels of noncompliance with the fecal coliform standard in the vicinities of the O'Brien (RM 336.9, Figure 8.15) and Calumet (RM 321.4, Figure 8.16) WRPs seem inconsistent with the fact that disinfection is applied at these plants for the Baseline and Future conditions. The MWRDGC suggested that they expected "at least" a 2-log reduction in fecal coliform concentration in the effluent after disinfection. Perhaps applying more than a 2-log reduction may be more appropriate to describe the true performance of these WRPs. However, the comparisons provided in this section give a fair and consistent comparison of the effects of the different alternatives on fecal coliform bacteria in the CAWS.

8.3 Comparison of Simulated Chloride Concentrations

8.3.1 Concentration vs. Time

Figure 8.17 shows the computed chloride concentrations on the upper NSC at Oakton Street (0.1 mi north of the O'Brien WRP outfall). Because the sampling site is so close to the O'Brien WRP outfall the chloride concentration at this point is dominated by the effluent. Thus, all three alternatives yield nearly identical chloride concentrations except for June through August when the "No Project" alternative includes substantial discretionary diversion and October when the "No Project" alternative includes other non-discretionary diversion flows from Lake Michigan.

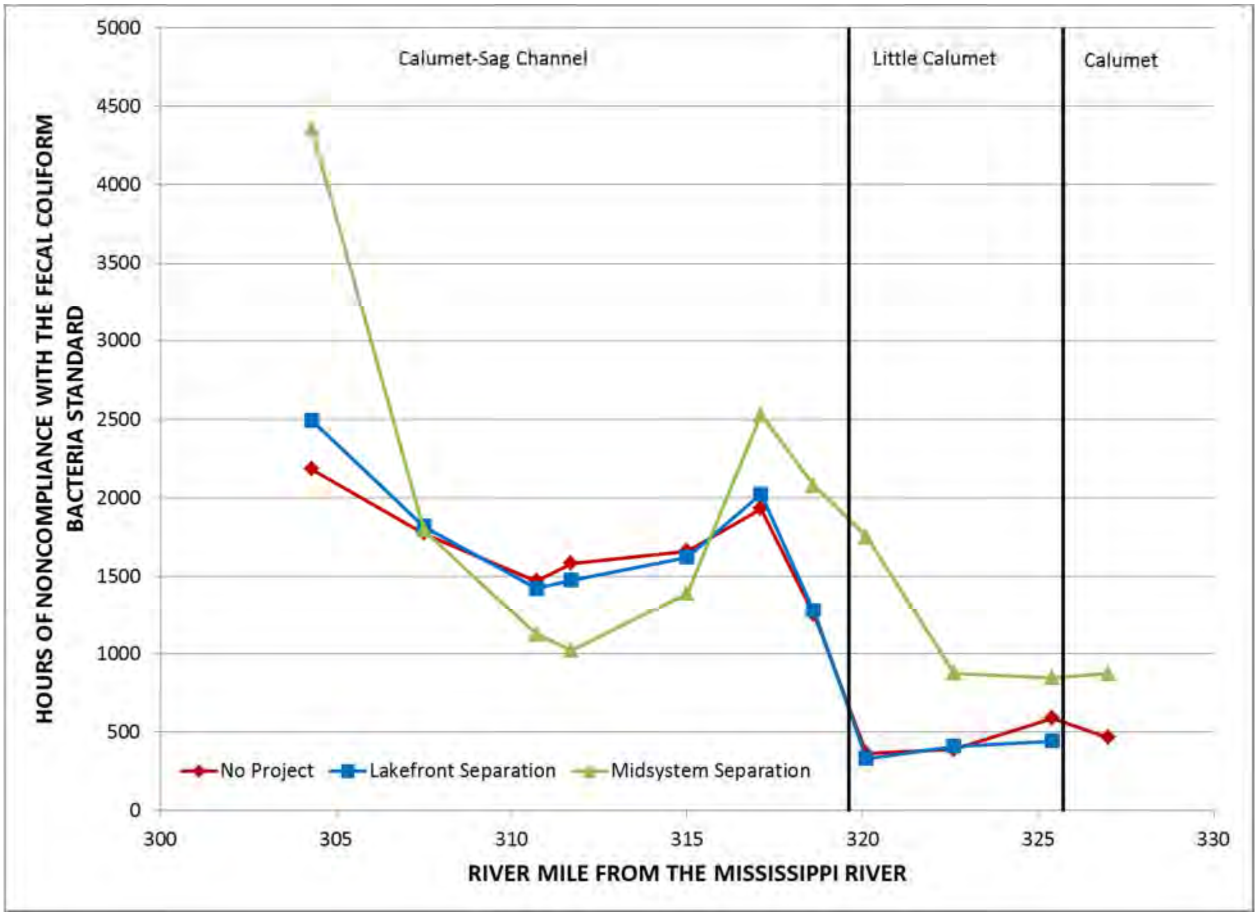


Figure 8.16. Number of hours not in compliance with the fecal coliform standard along the Calumet River system for Water Year 2008.

Figure 8.18 shows the computed chloride concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O'Brien WRP outfall) and at Wilson Avenue and Diversey Parkway on the NBCR. The three alternatives yield nearly identical chloride concentrations at these three locations except that small dilution effects can be seen reducing chloride concentrations for the "No Project" alternative in October and June through August.

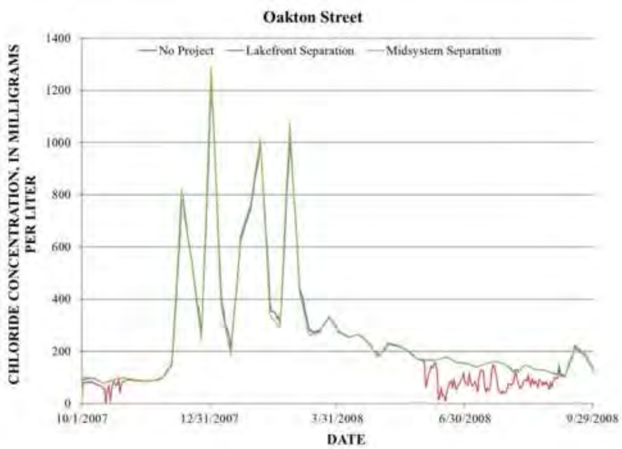


Figure 8.17. Simulated chloride concentration on the upper North Shore Channel at Oakton Street for the three alternatives under future conditions for Water Year 2008.

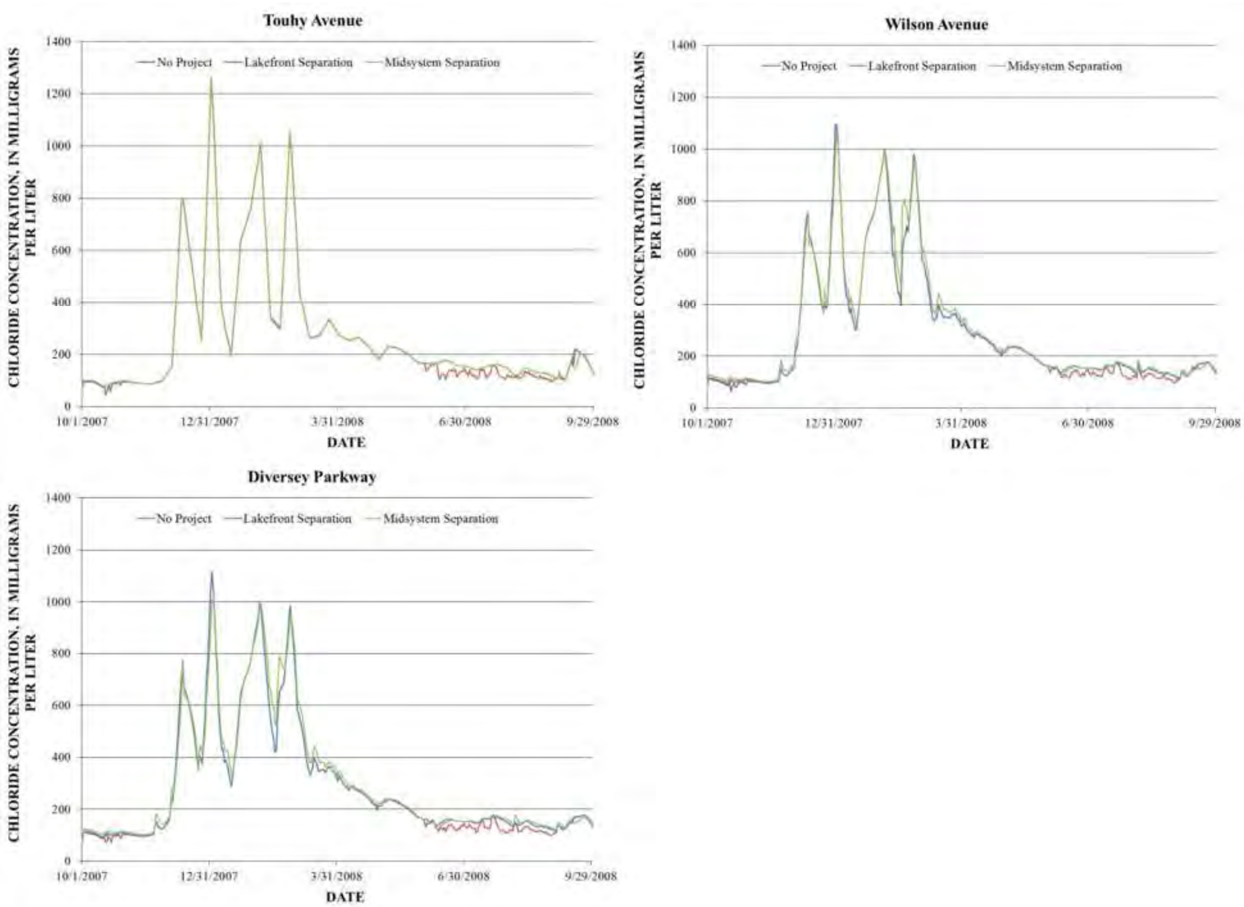


Figure 8.18. Simulated chloride concentration on the North Shore Channel at Touhy Avenue and the North Branch Chicago River at Wilson Avenue and Diversey Parkway for the three alternatives under future conditions for Water Year 2008.

Figure 8.19 shows the computed chloride concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street, and CSSC at Western Avenue and Cicero Avenue. At Wells Street the chloride concentrations for all three alternatives show substantial similarities in pattern (Figure 8.19). The “No Project” alternative generally has the lowest chloride concentrations at Wells Street, especially for days with discretionary diversion (June through August) or other diversions from Lake Michigan at CRCW.

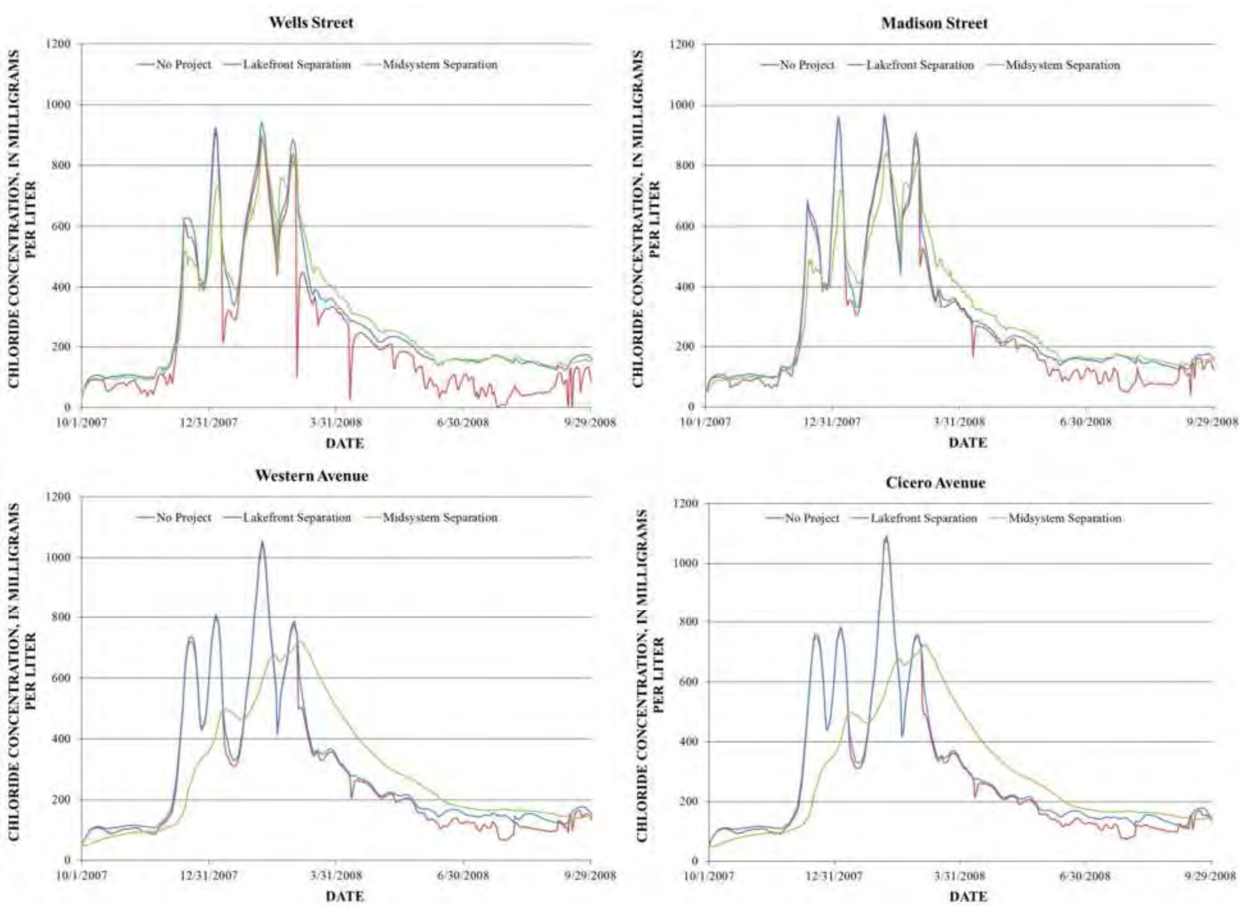


Figure 8.19. Simulated chloride concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street, and Chicago Sanitary and Ship Canal at Western Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2008.

At Madison Street the “No Project” and “Lakefront Separation” alternatives yield nearly identical chloride concentrations except in the months of June through August and October during which discretionary diversion or other flows are taken from Lake Michigan at the CRCW. The "Midsystem Separation" alternative yields a similar pattern chloride concentrations at Madison Street as at Wells Street indicating the influence of chloride concentrations at the junction of the NBCR, SBCR, and Chicago River main stem on those a short distance (0.3 mi) up the now stagnant SBCR (Figure 8.19). The pattern of chloride concentrations for the "Midsystem Separation" alternative also is similar to that of the other alternatives at Madison Street except that the "Midsystem Separation" alternative has lower chloride concentrations during periods when the concentration peaks than the other alternatives.

At Loomis Street and Cicero Avenue the "No Project" and "Lakefront Separation" alternatives yield nearly identical chloride concentrations except in the months of June through August and October for which some dilution effects resulting from diversion at CRCW can be observed in Figure 8.19. For the "Midsystem Separation" alternative the effects of flow stagnation on chloride concentrations can easily be seen. That is, because of limited inflows to the SBCR and upper CSSC for this alternative it takes a long time to build up higher chloride concentrations and then it takes a long time for these higher chloride concentrations to diminish because of the limited flows through these reaches.

Figure 8.20 shows the computed chloride concentrations on the CSSC downstream from the Stickney WRP. The results for the "No Project" and "Lakefront Separation" alternatives again are nearly identical showing the dominant influence of the Stickney WRP effluent on this reach. The discretionary diversion in June through August for the "No Project" alternative has only a small effect on chloride concentrations in this reach. The "Midsystem Separation" alternative also yields similar chloride concentrations as those for the other alternatives with only the peak chloride concentrations being substantially higher than for the other two alternatives. The results for the "Midsystem Separation" alternative are completely dominated by the Stickney WRP effluent in this reach, in the other two alternatives upstream flows with lower chloride concentrations can somewhat dilute Stickney WRP effluent with high chloride concentrations.

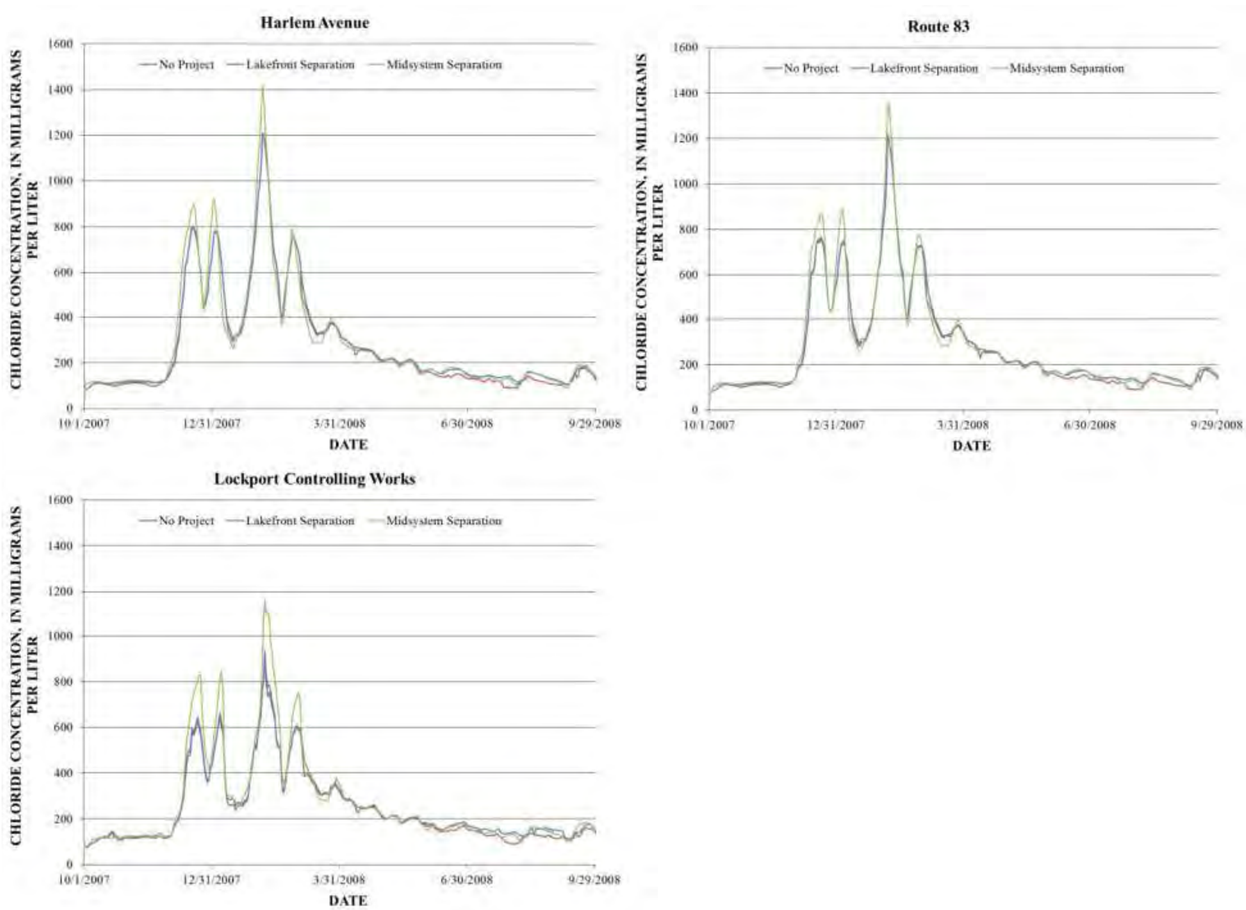


Figure 8.20. Simulated chloride concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2008.

Figure 8.21 shows the computed chloride concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. Again the "No Project" and "Lakefront Separation" alternatives yield nearly identical chloride concentrations at each location except for the months of July and August when larger amounts of discretionary diversion are taken at the O'Brien Lock and Dam in the "No Project" alternative (Figure 8.21). At Indiana Avenue, the "Midsystem Separation" alternative yields similar chloride concentrations as for the other alternatives except that in the winter and early spring it has substantially lower concentrations. At Halsted Street the flow is dominated by the inflow from the Little Calumet River (south), which has generally low (relative to the chronic toxicity standard of 230 mg/L) chloride concentrations in WY 2008.

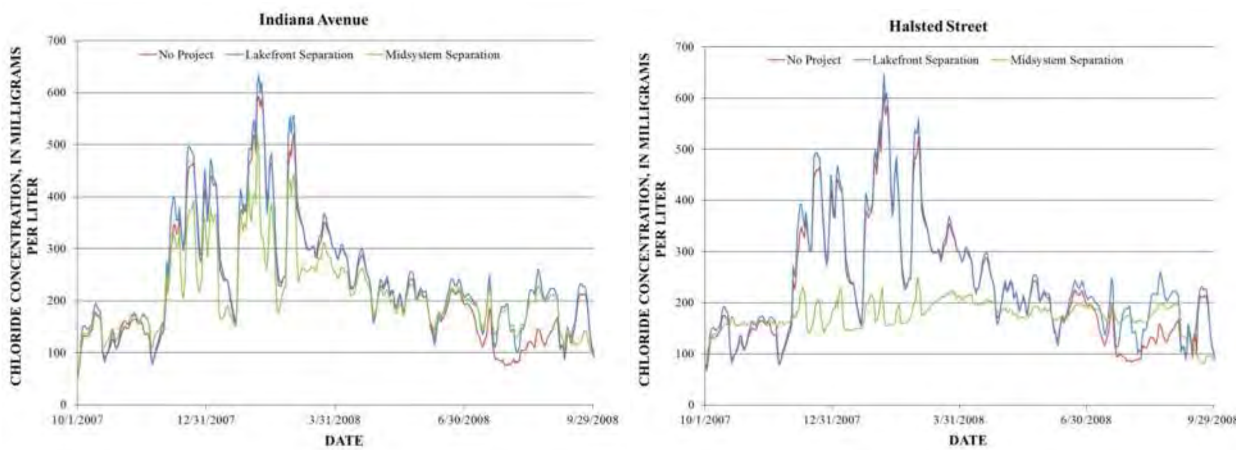


Figure 8.21. Simulated chloride concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2008.

Figure 8.22 shows the computed chloride concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. Again the "No Project" and "Lakefront Separation" alternatives yield nearly identical chloride concentrations at each location except for the months of July and August when larger amounts of discretionary diversion are taken at the O'Brien Lock and Dam in the "No Project" alternative (Figure 8.22). The "Midsystem Separation" alternative yields chloride concentrations at Ashland Avenue and Cicero Avenue that reflect the low chloride concentrations in the small tributary streams that discharge to these otherwise stagnant reaches on either side of the barrier at RM 315.89. At Route 83, the "Midsystem Separation" alternative yields higher chloride concentrations than the other two alternatives because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel for this alternative.

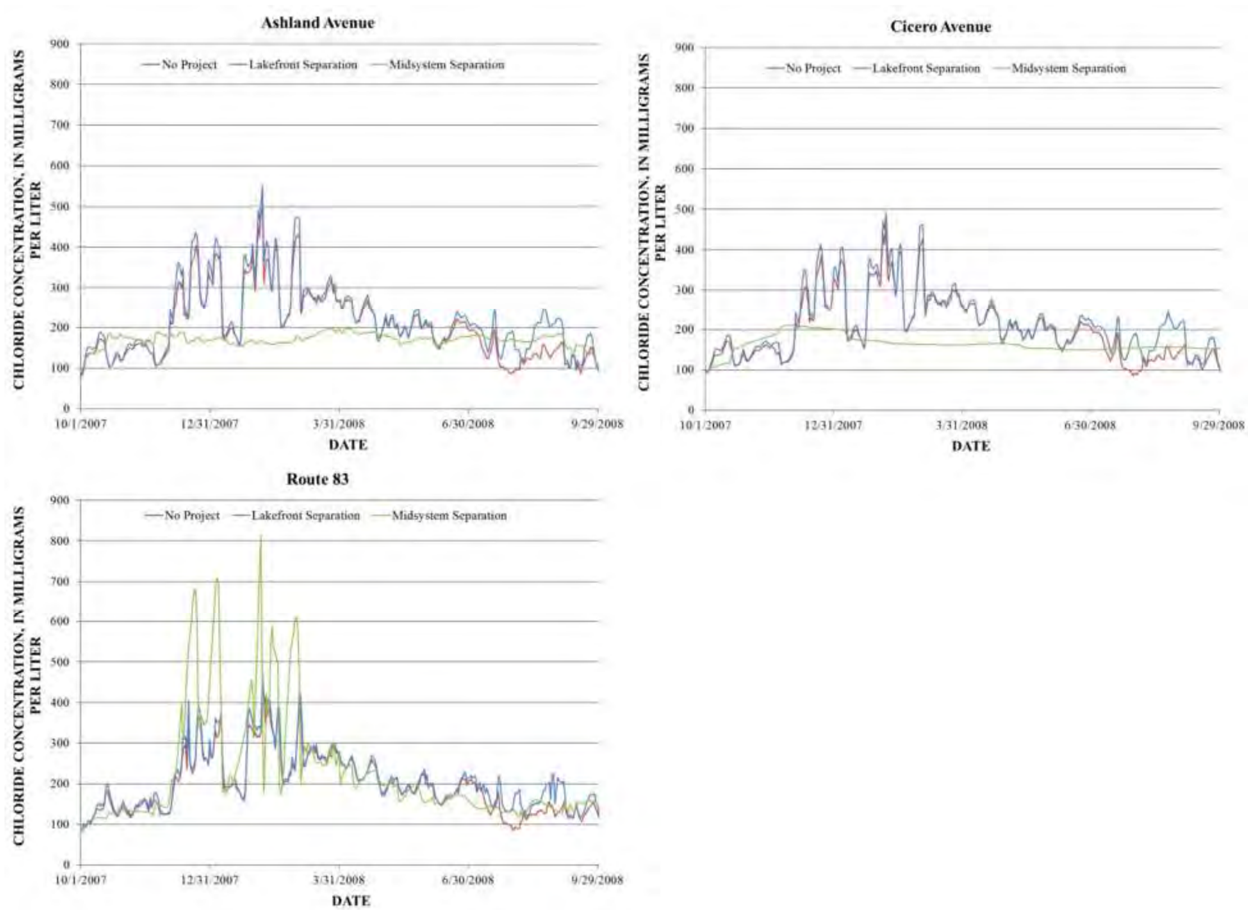


Figure 8.22. Simulated chloride concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2008.

8.3.2 Compliance with Chloride Standards

Figure 8.23 shows the number of hours not in compliance with the chloride chronic toxicity standard along the Chicago River system. Along the Chicago River system the “No Project” and “Lakefront Separation” alternatives yield almost identical levels of compliance except for the Chicago River main stem (Clark Street on the main stem is shown at RM 325.9 in Figure 8.23) and northern end of the SBCR. Downstream of the Stickney WRP on the CSSC all three alternatives yield nearly identical levels of compliance. In the upper NSC (above RM 336.9) the “Midsystem Separation” alternative yields similar levels of compliance as for the other two alternatives. However, the “Midsystem Separation” alternative yields higher levels of noncompliance on the NBCR, Chicago River main stem, and the stagnant SBCR and upper CSSC. Among the three study years, this representative “wet” year (WY 2008) yielded the highest level of noncompliance with the chloride chronic toxicity standard for nearly all the alternatives and locations in the Chicago River system.

Figure 8.24 shows the number of hours not in compliance with the chloride chronic toxicity standard along the Calumet River system. The “No Project” and “Lakefront Separation” alternatives yield similar patterns of compliance, but the “No Project” alternative yields substantially smaller levels of noncompliance throughout the entire Calumet River system. This indicates that discretionary diversion, lockage, leakage, and other flows at the O’Brien Lock and Dam positively influence chloride concentrations in the Calumet River system. The “Midsystem Separation” alternative yields by far the best compliance with the chloride chronic toxicity standard. For this alternative the entire stagnant Calumet-Sag Channel (RM 303.4 to RM 319.6) fully complies with the chloride chronic toxicity standard except for the far downstream end of the Calumet-Sag Channel, which is influenced by conditions in the CSSC (Figure 8.23). For the Little Calumet River (north) substantially lower levels of noncompliance also result for the "Midsytem Separation" alternative than for the other two alternatives.

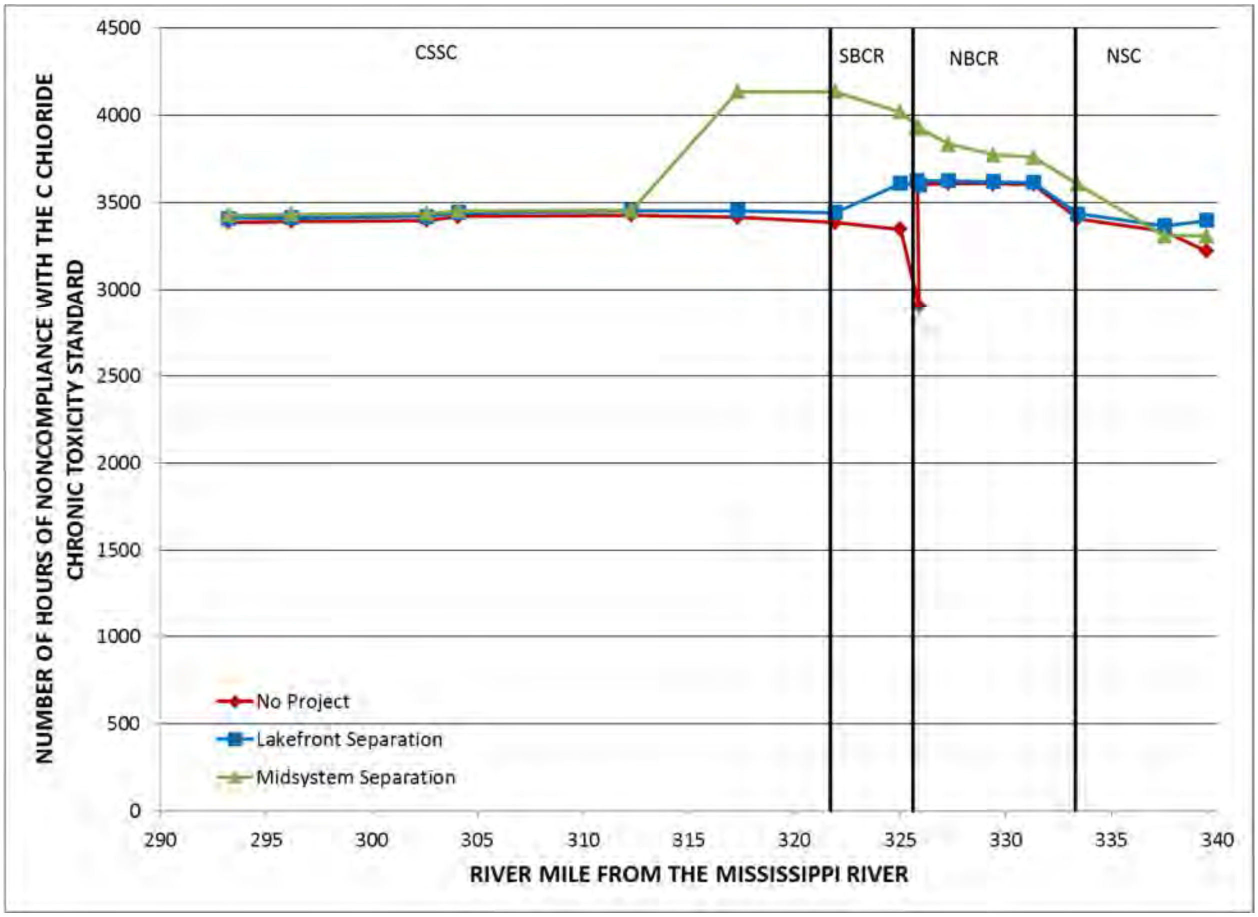


Figure 8.23. Number of hours not in compliance with the chloride chronic toxicity standard along the Chicago River system for Water Year 2008.

8.4 Comparison of Simulated Total Phosphorus Concentrations

Figure 8.25 shows the computed total phosphorus concentrations on the upper NSC at Central Street and Oakton Street (0.1 mi north of the O'Brien WRP outfall). Because the Oakton Street sampling site is so close to the O'Brien WRP outfall the total phosphorus concentration at this point is dominated by the quality of the effluent for all three alternatives. However, the discretionary diversion in June to August and other flows at Wilmette in October substantially dilute the total phosphorus concentrations for the "No Project" alternative at both locations. At Central Street the total phosphorus concentrations for the "No Project" and "Lakefront Separation" alternatives are similar during periods with low flows at Wilmette for the "No Project" alternative. Whereas for the "Midsystem Separation" alternative the total phosphorus concentrations are similar at Central Street and Oakton Street indicating that the total phosphorus is fairly conservative in the upper NSC for this alternative in which the NSC carries O'Brien WRP effluent to Lake Michigan.

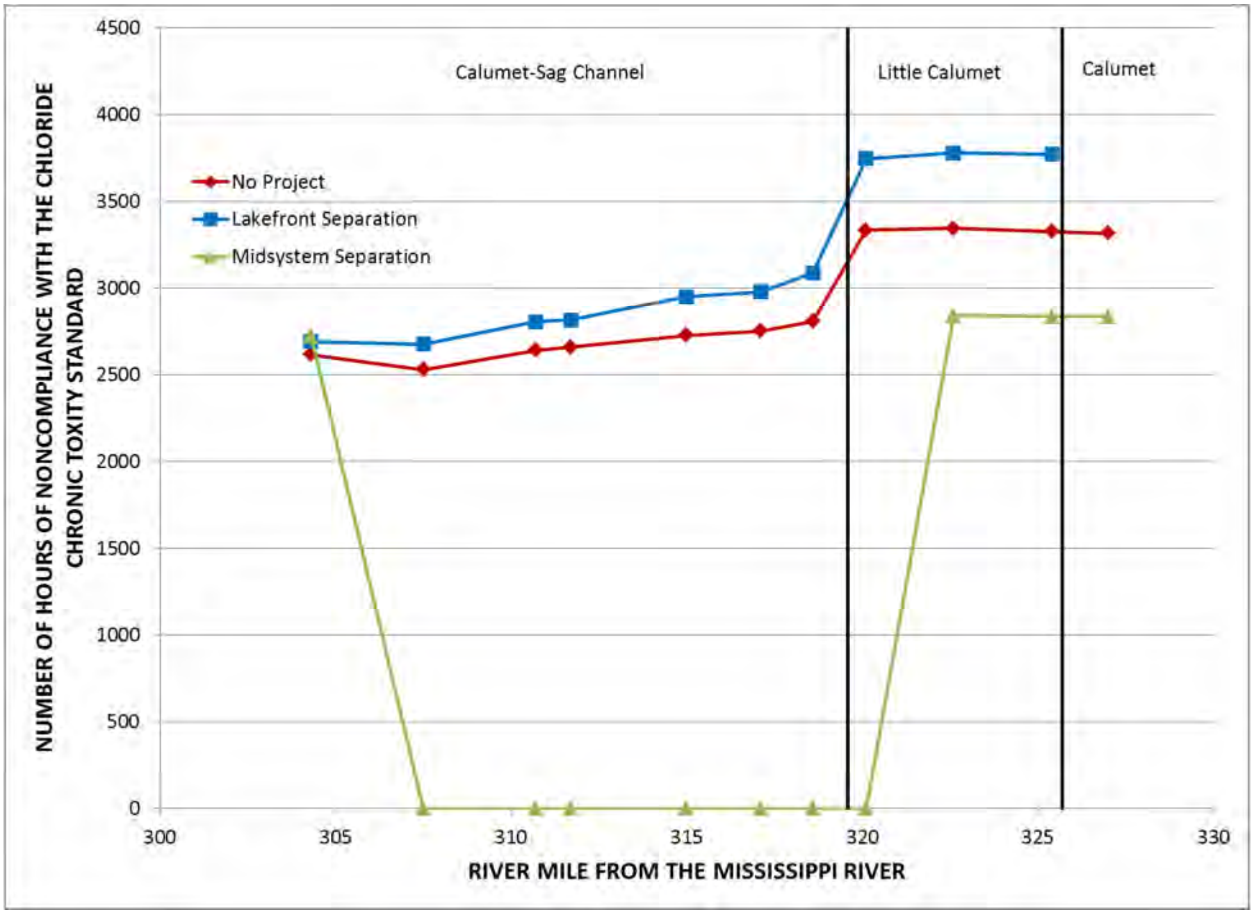


Figure 8.24. Number of hours not in compliance with the chloride chronic toxicity standard along the Calumet River system for Water Year 2008.

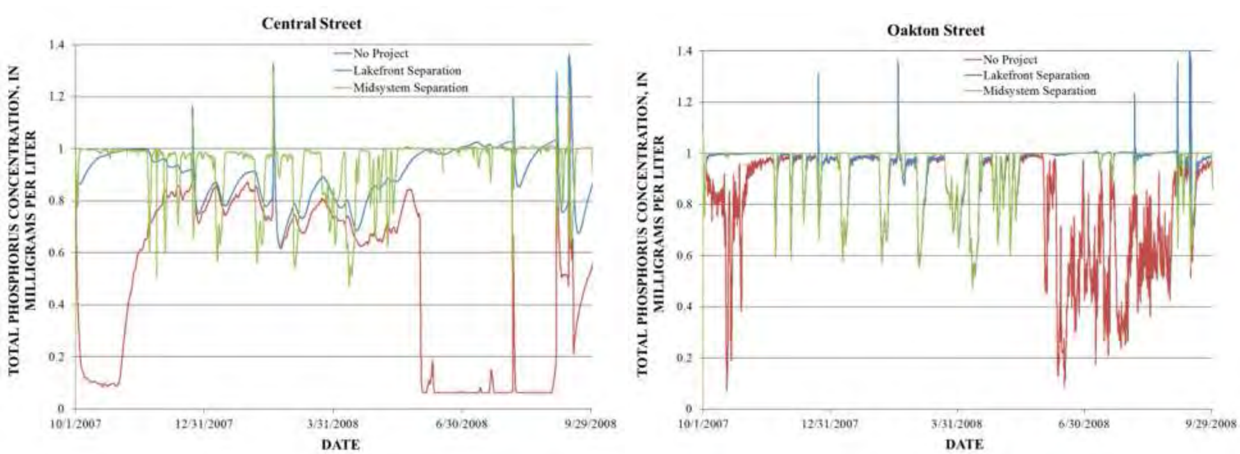


Figure 8.25. Simulated total phosphorus concentration on the upper North Shore Channel at Central Street and Oakton Street for the three alternatives under future conditions for Water Year 2008.

Figure 8.26 shows the computed total phosphorus concentrations on the NSC at Touhy Avenue (0.9 mi downstream of the O'Brien WRP outfall) and Foster Avenue and on the NBCR at Wilson Avenue, Diversey Parkway, and Grand Avenue. Outside of the periods with substantial flows at Wilmette for the "No Project" alternative (i.e. October and June through August) the three alternatives yield very similar total phosphorus concentrations at all 5 locations on the lower NSC and NBCR. During October and June through August the Lake Michigan flows at Wilmette reduce the total phosphorus concentration for the "No Project" alternative, whereas the other two alternatives yield similar total phosphorus concentrations during these months. From these results it is clear that the effluent from the O'Brien WRP dominates total phosphorus concentrations in these reaches of the CAWS.

Figure 8.27 shows the computed total phosphorus concentrations on the Chicago River main stem at Wells Street, SBCR at Madison Street and Loomis Street, and CSSC at Damen Avenue and Cicero Avenue. The "Lakefront Separation" and "Midsystem Separation" alternatives yield very similar total phosphorus concentrations at Wells Street, whereas the "No Project" alternative shows substantially lower total phosphorus concentrations resulting from dilution by discretionary diversion and other water withdrawals from Lake Michigan at CRCW.

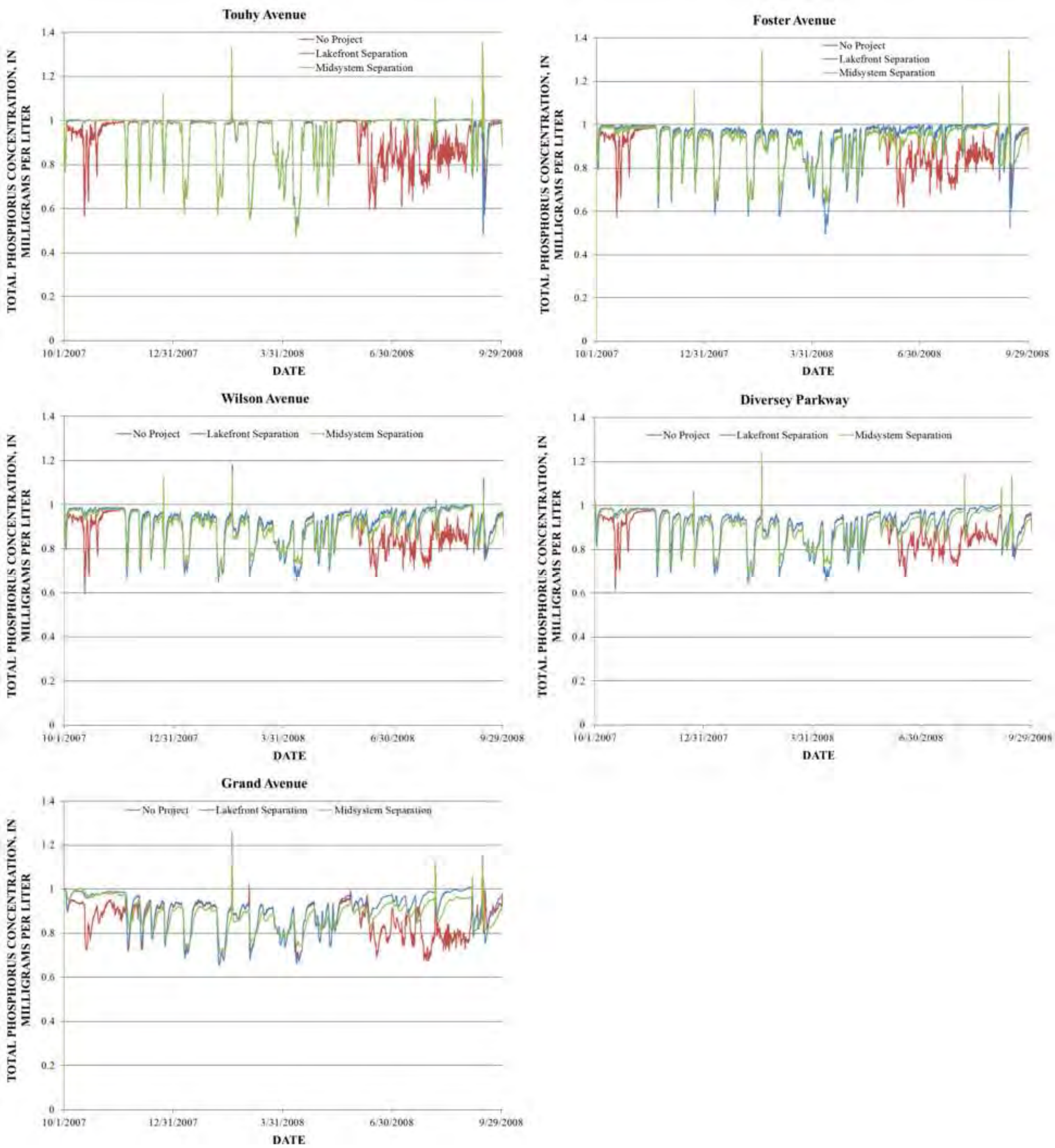


Figure 8.26. Simulated total phosphorus concentration on the North Shore Channel at Touhy Avenue and Foster Avenue and the North Branch Chicago River at Wilson Avenue, Diversey Parkway, and Grand Avenue for the three alternatives under future conditions for Water Year 2008.

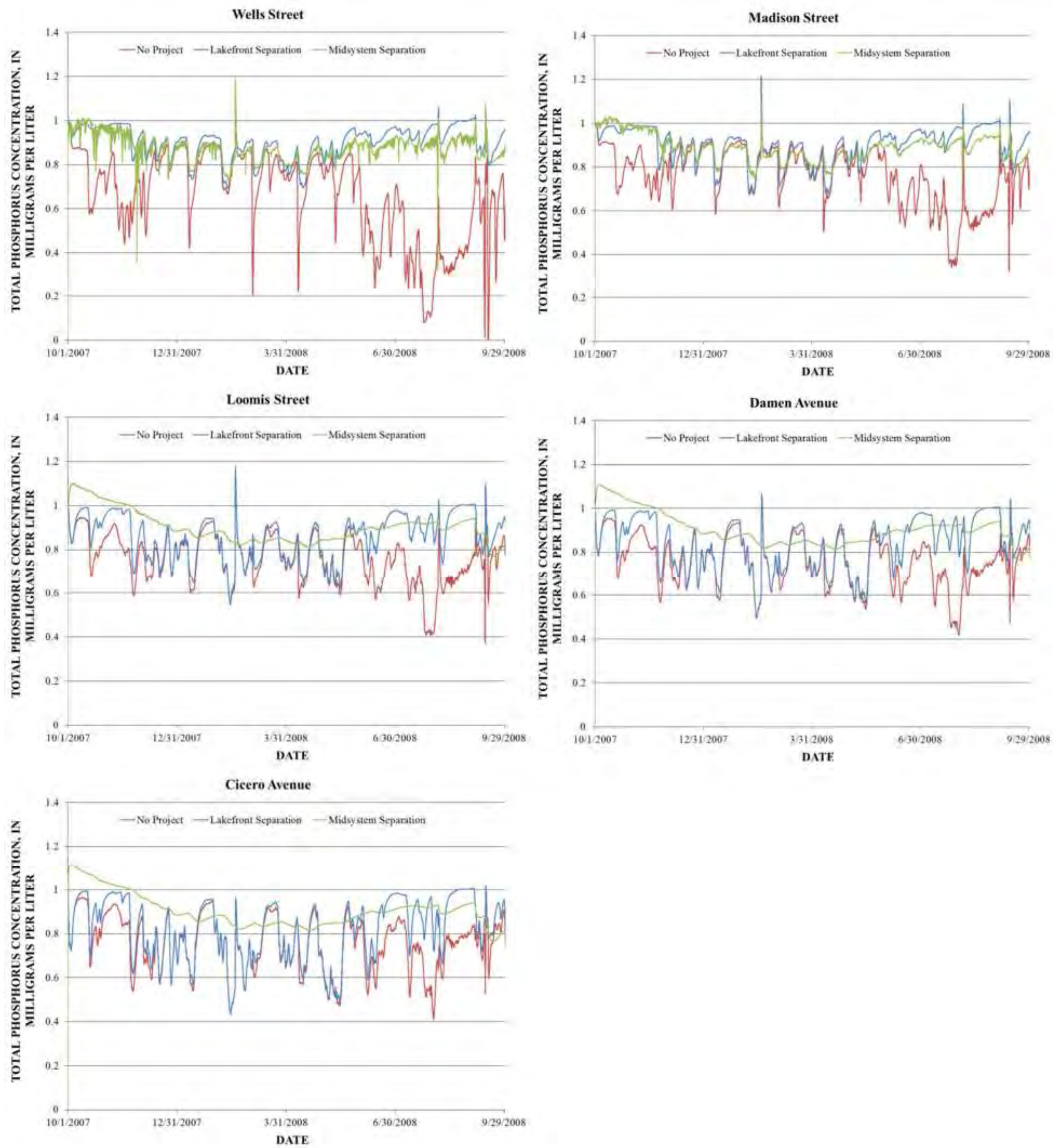


Figure 8.27. Simulated total phosphorus concentration on the Chicago River main stem at Wells Street, South Branch Chicago River at Madison Street and Loomis Street, and Chicago Sanitary and Ship Canal at Damen Avenue and Cicero Avenue for the three alternatives under future conditions for Water Year 2008.

At Madison Street the "Lakefront Separation" and "Midsystem Separation" alternatives yield very similar total phosphorus concentrations, whereas the "No Project" alternative yields substantially lower total phosphorus concentrations because of dilution by discretionary and other diversions from Lake Michigan at CRCW (Figure 8.27). The "Midsystem Separation" alternative yields a similar pattern total phosphorus concentrations at Madison Street as at Wells Street indicating the influence of total phosphorus concentrations at the junction of the NBCR, SBCR, and Chicago River main stem on those a short distance (0.3 mi) up the stagnant SBCR.

At Loomis Street, Damen Avenue, and Cicero Avenue the "No Project" and "Lakefront Separation" alternatives yield nearly identical total phosphorus concentrations during periods when the flows at CRCW for the "No Project" alternative are near zero (November through May) (Figure 8.27). However, when there is discretionary diversion (June through August) or other flows at CRCW in the "No Project" alternative it yields substantially lower total phosphorus concentrations than the other two alternatives. At these three locations the results of the "Midsystem Separation" alternative indicate very gradual changes in total phosphorus concentrations that are characteristic of the stagnant flow conditions in the SBCR and upper CSSC for this alternative.

Figure 8.28 shows the computed total phosphorus concentrations on the CSSC downstream from the Stickney WRP. Again the "No Project" and "Lakefront Separation" alternatives yield nearly identical total phosphorus concentrations during periods when the flows at CRCW for the "No Project" alternative are near zero (November through May) at all four locations in Figure 8.28. However, when there is discretionary diversion (June through August) or other flows at CRCW in the “No Project” alternative it yields substantially lower total phosphorus concentrations than the “Lakefront Separation” alternative. The “Midsystem Separation” alternative also yields similar total phosphorus concentrations as those for the other alternatives with only the lowest total phosphorus concentrations being substantially lower than those for the other two alternatives. The results for the “Midsystem Separation” alternative are completely dominated by the Stickney WRP effluent in this reach, in the other two alternatives upstream flows with higher total phosphorus concentrations can somewhat increase the overall total phosphorus concentrations during periods when the Stickney WRP effluent has very low total phosphorus concentrations.

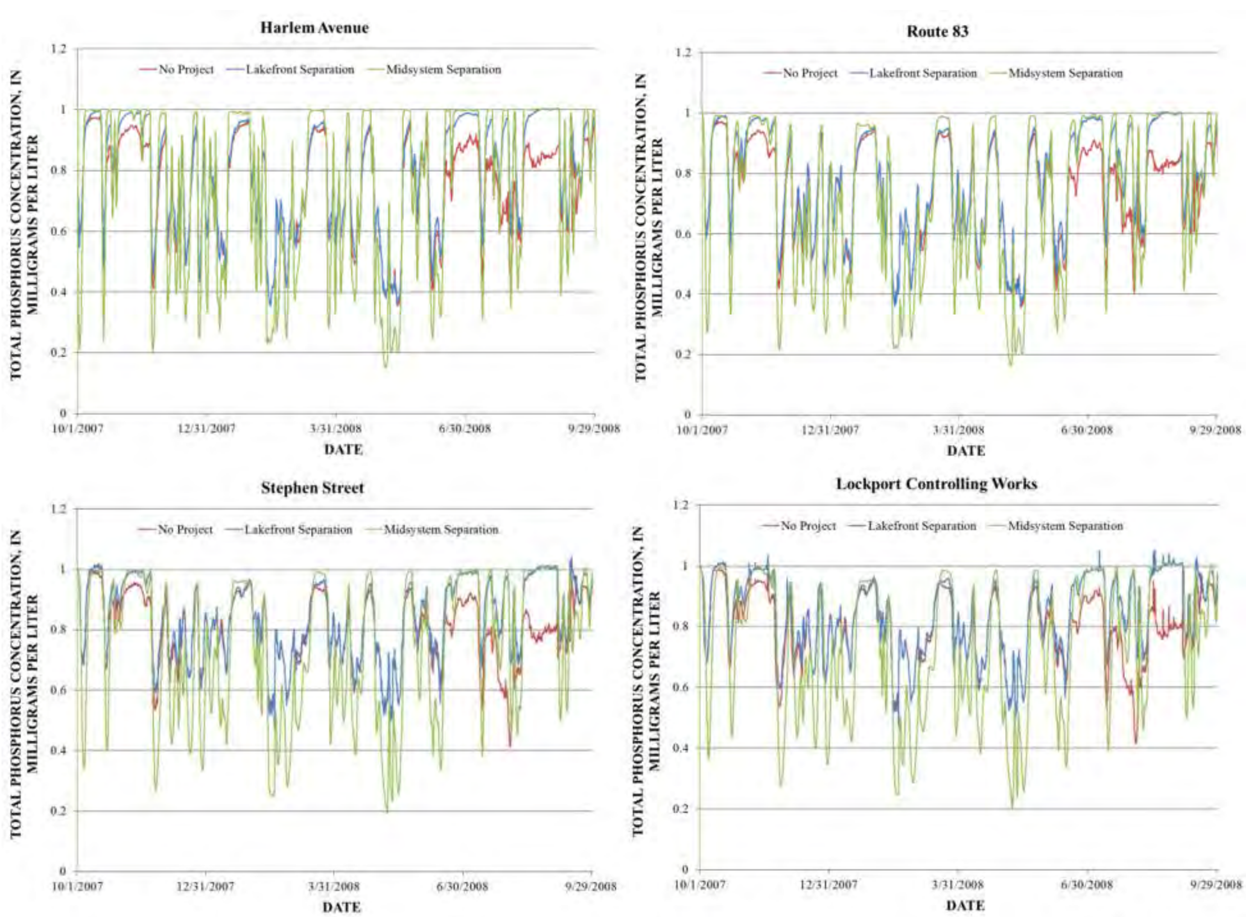


Figure 8.28. Simulated total phosphorus concentration on the Chicago Sanitary and Ship Canal at Harlem Avenue, Route 83, Stephen Street, and Lockport Controlling Works for the three alternatives under future conditions for Water Year 2008.

Figure 8.29 shows the computed total phosphorus concentrations on the Little Calumet River (north) at Indiana Avenue and Halsted Street. At Indiana Avenue, the "Lakefront Separation" and "Midsystem Separation" alternatives yield very similar total phosphorus concentrations because for each of these alternatives the total phosphorus at this location is dominated by the Calumet WRP effluent. The "No Project" alternative yields substantially lower total phosphorus concentrations than the other two alternatives at both locations because of discretionary diversion and other withdrawals from Lake Michigan at the O'Brien Lock and Dam. At Halsted Street the total phosphorus concentrations for the "Lakefront Separation" alternative is dominated by the effluent of the Calumet WRP, whereas for the "Midsystem Separation" alternative the total phosphorus concentrations are dominated by those coming from the Little Calumet River (south), which are nearly constant for WY 2008.

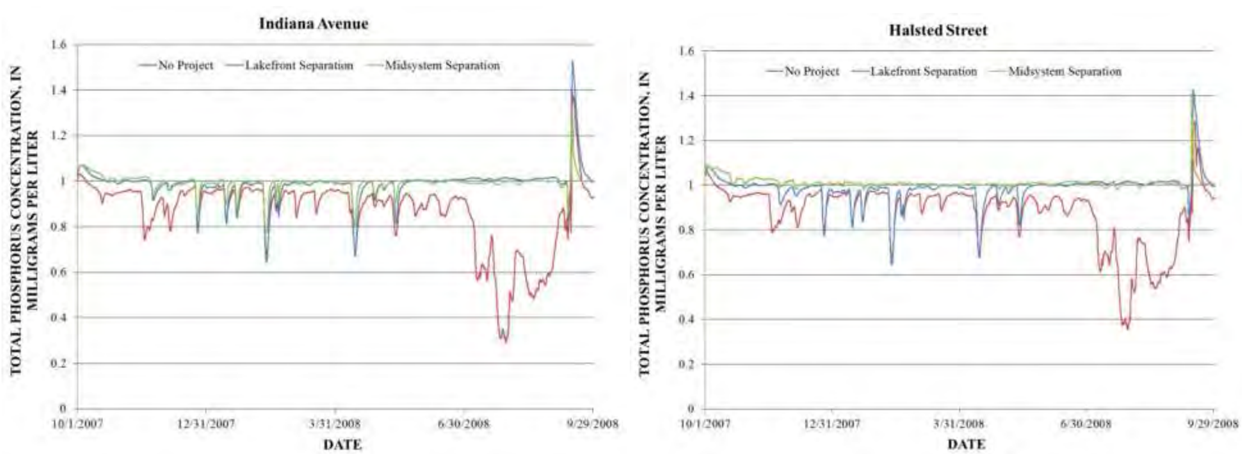


Figure 8.29. Simulated total phosphorus concentration on the Little Calumet River (north) at Indiana Avenue and Halsted Street for the three alternatives under future conditions for Water Year 2008.

Figure 8.30 shows the computed total phosphorus concentrations on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83. The "No Project" and "Lakefront Separation" alternatives yield very similar total phosphorus concentrations at each location during the periods of low flow at the O'Brien Lock and Dam for the "No Project" alternative. During months with discretionary diversion (June through August) and other periods of withdrawal of Lake Michigan water at the O'Brien Lock and Dam in the "No Project" alternative the total phosphorus concentration drops far below those for the "Lakefront Separation" alternative (Figure 8.30). The "Midsystem Separation" alternative yields total phosphorus concentrations at Ashland Avenue and Cicero Avenue that reflect the total phosphorus concentrations in the small tributary streams that discharge to these otherwise stagnant reaches on either side of the barrier at RM 315.89. At Route 83, the "Midsystem Separation" alternative yields total phosphorus concentrations that reflect the effluent from the Stickney WRP because of the backflow of water from the CSSC into the stagnant Calumet-Sag Channel in this alternative.

8.5 Loads to Lake Michigan

One of the key water quality impacts of the "Midsystem Separation" alternative is the load of pollutants directed to Lake Michigan under this alternative. The difference for WY 2008 compared to WYs 2001 and 2003 is that the September 13-16, 2008, storms will result in flows to Lake Michigan for the "No Project" alternative for both the Baseline and Future conditions. Table 8.1 lists the flows and loads to Lake Michigan for the "Midsystem Separation" and "No Project" alternatives for Future conditions. For this representative "wet" year it can be seen that for the "Midsystem Separation" alternative nutrient loads in neighborhood of 19 and 2.5 million pounds more nitrogen and phosphorus, respectively, can be delivered to Lake Michigan during wet years than for the "No Project" alternative under Future conditions. Also for the

“Midsystem Separation” alternative loads in the neighborhood of 630 million pounds more chloride can be delivered to Lake Michigan during wet years than for the “No Project” alternative under Future conditions.

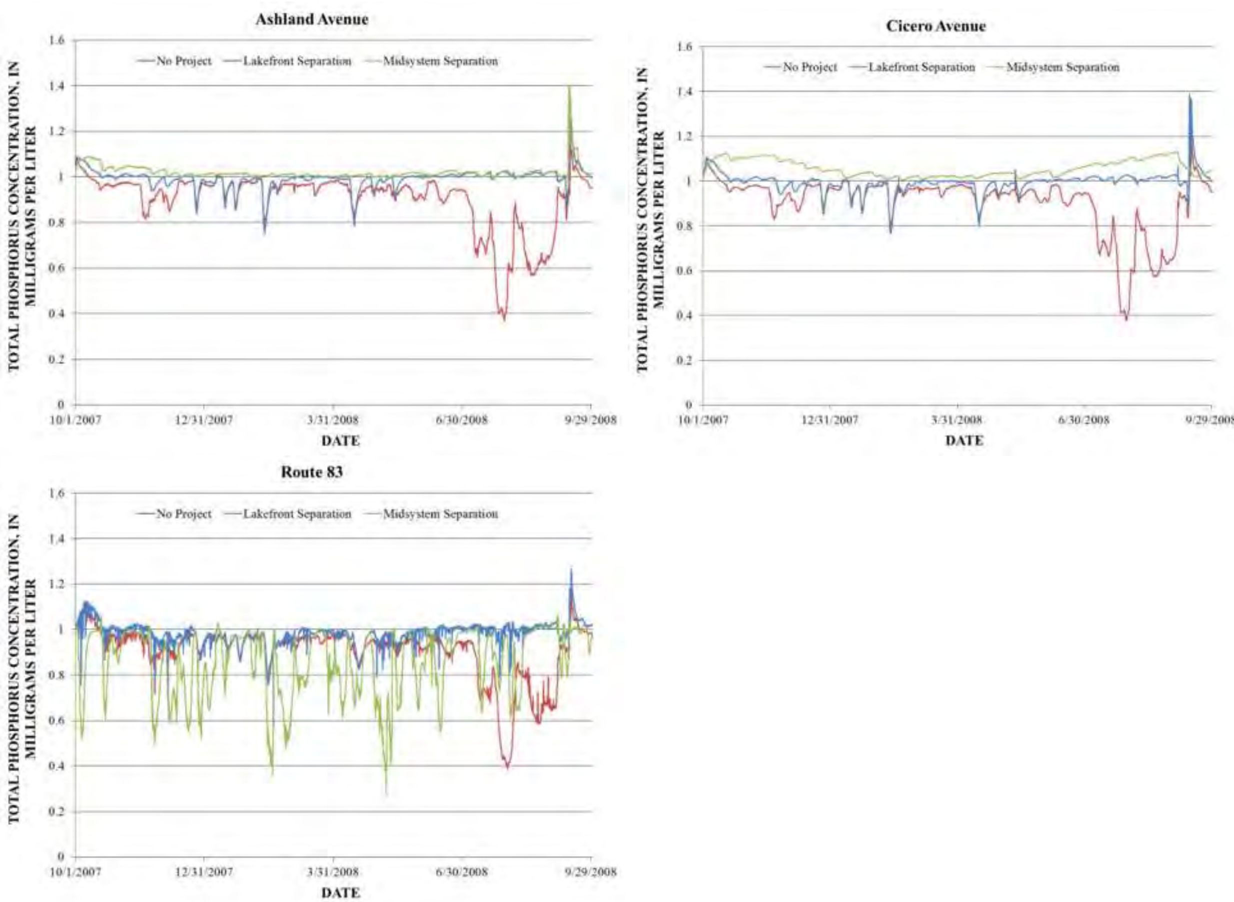


Figure 8.30. Simulated total phosphorus concentration on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for the three alternatives under future conditions for Water Year 2008.

Tables 8.2 compares the flows and loads to Lake Michigan for the “No Project” alternative for the Baseline and Future conditions. The values in Table 8.2 demonstrate the importance of Stage 2 of the McCook Reservoir with respect to water pollution. For the storms of September 13-16, 2008, Stage 2 captures an additional: 948,000 lb of CBOD; 351,000 lb of total nitrogen; 51,100 lb of total phosphorus; 3,670,000 lb of total suspended solids; and 4.29 x 10^{16} coliform forming units (CFU). Large fractions of this additional capture of pollutants will be subsequently removed at the Stickney WRP greatly reducing the pollution of the CAWS and Lake Michigan.

Table 8.1. Flows and loads to Lake Michigan at Wilmette, at the Chicago River Controlling Works (CRCW), and from the Calumet River for the "Midsystem Separation" (MS) and "No Project" (NP) alternatives for Future conditions for Water Year 2008. [note: CBOD is carbonaceous biochemical oxygen demand, TN is total nitrogen, TP is total phosphorus, and TSS is total suspended solids, na is not applicable because for this alternative the flows to Lake Michigan occur for only a few days].

Constituent	Wilmette		CRCW		Calumet River		Total	
	MS	NP	MS	NP	MS	NP	MS	NP
Flow (cfs)	205.5	na	424.1	na	836.6	na	1466.3	na
Volume (ac-ft)	149,000	5,920	293,000	0	607,000	8,270	1,050,000	14,200
CBOD (lb)	1,190,000	298,000	2,020,000	0	3,460,000	206,000	6,680,000	507,000
TN (lb)	3,750,000	123,000	4,560,000	0	11,000,000	120,000	19,300,000	243,000
TP (lb)	366,000	15,600	606,000	0	1,580,000	22,900	2,560,000	38,400
TSS (lb)	3,900,000	869,000	14,100,000	0	16,800,000	399,000	34,800,000	1,260,000
Chloride (lb)	109 x 10^6	2.82 x10^6	209 x 10^6	0	320 x 10^6	970,000	637 x 10^6	3.79 x 10^6
Fecal Coliform (CFU)	3.50 x10^{16}	1.65x10^{16}	3.84 x10^{16}	0	5.80 x10^{16}	3.3x10^{15}	13.1 x 10^{16}	1.99 x 10^{16}

Table 8.2. Flows and loads to Lake Michigan at Wilmette and the Chicago River Controlling Works (CRCW) for the "No Project" alternative for Baseline (BC) and Future (FC) conditions. [note: CBOD is carbonaceous biochemical oxygen demand, TN is total nitrogen, TP is total phosphorus, and TSS is total suspended solids; the load from the Calumet River is not included here because it does not change between Baseline and Future Conditions].

Constituent	Wilmette		CRCW		Total	
	BC	FC	BC	FC	BC	FC
Volume (ac-ft)	8,760	5,920	15,240	0	32,340	14,200
CBOD (lb)	492,000	298,000	754,000	0	1,455,000	507,000
TN (lb)	185,000	123,000	289,000	0	594,000	243,000
TP (lb)	24,300	15,600	42,300	0	89,500	38,400
TSS (lb)	1,410,000	869,000	3,130,000	0	4,930,000	1,260,000
Fecal Coliform (CFU)	2.75 x 10^{16}	1.64 x10^{16}	3.19 x10^{16}	0	6.28 x10^{16}	1.99 x 10^{16}

Chapter 9 – SUMMARY AND CONCLUSIONS

The Chicago Area Waterways System (CAWS) is an 83.2 mi branching network of navigable waterways controlled by hydraulic structures in which the majority of flow is treated wastewater effluent and there are periods of substantial combined sewer overflows (CSOs). The CAWS serves to reverse the flow of the Chicago River and carry CSOs and treated wastewater effluent away from the Chicago metropolitan area's water source, Lake Michigan. The dominant uses of the CAWS are conveyance of treated municipal wastewater, commercial navigation, and flood control. The CAWS receives pollutant loads from 3 of the largest wastewater treatment plants in the world (called water reclamation plants (WRPs) in this report), nearly 240 gravity CSOs, 5 CSO pumping stations, eleven tributary streams or drainage areas, and direct diversions from Lake Michigan.

The operation of the CAWS has been a great public health success for the Chicago area, but the CAWS provides a pathway for non-indigenous aquatic species to migrate between the Great Lakes and Mississippi River basins. The U.S. Fish and Wildlife Service (USFWS) developed a list of 21 non-indigenous aquatic species in the Mississippi River system but not yet observed in the Great Lakes, and a list of 120 non-indigenous aquatic species in the Great Lakes but not yet observed in the Mississippi River system. Among these species are the silver and big head Asian carp that have the potential to dominate a water body.

The possibility of the 141 species identified by the USFWS transferring between the basins and becoming aquatic nuisance species (ANS) harmful to the receiving ecosystem led the U.S.

Congress to direct the U.S. Army Corps of Engineers (USACE) to initiate the Great Lakes and Mississippi River Interbasin Study (GLMRIS). The specific tasks of GLMRIS include (U.S. Army Corps of Engineers, 2010b):

- Inventory current and forecast future conditions within the study area (i.e. the Great Lakes and Mississippi River basins);
- Identify aquatic pathways that may exist between the Great Lakes and Mississippi River basins (the CAWS being the most prominent among these pathways);
- Inventory current and future potential ANS;
- Analyze possible ANS controls to prevent ANS transfer, to include hydrologic separation of the basins;
- Analyze the impacts each ANS control may have on significant natural resources and existing and forecasted uses of the lakes and waterways within the study area; and
- Recommend a plan to prevent ANS transfer between the basins. If necessary, the plan will include mitigation measures for impacted waterway uses and significant natural resources.

The project described in this report supports the fifth bullet in the foregoing list by analyzing the effects of potential hydrologic separation scenarios on the water quality in the CAWS and the pollutant loads to Lake Michigan.

The DUFLOW model had previously been calibrated (for water year (WY) 2001) and verified (for WY 2003) for the simulation of dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia, nitrate, inorganic phosphorus, total phosphorus, algae as chlorophyll-a, and total suspended solids in the CAWS. In this study, the DUFLOW model was further verified for these water-quality constituents for WY 2008. The DUFLOW model also had been calibrated considering 14 years (1990 to 2003) of fecal coliform data in the CAWS and verified by application to 5 multiple month periods from 1998 to 2002. In this study, the verification of the DUFLOW fecal coliform model was extended to the full 2001, 2003, and 2008 WYs. In this study, the DUFLOW model also was extended to simulate chloride and pH in the CAWS. Finally, the DUFLOW model was extended to simulate flow and water quality in the Calumet River between the O'Brien Lock and Dam and Lake Michigan.

Once the performance of the model for all these constituents was evaluated and the reliability of the model was confirmed, the input to the model was revised to consider the "No Project" alternative and two possible alternatives for hydrological/ecological separation of the Great Lakes and Mississippi River drainage basins within the CAWS—the "Lakefront Separation" and "Midsystem Separation" alternatives. To properly compare the changes in water quality between the "No Project" alternative and each of the "Separation" alternatives, the water quality effects were evaluated for a representative "dry" year (WY 2003), a representative "normal" year (WY 2001), and a representative "wet" year (WY 2008). In simulating these representative years the measured and estimated inflows for these years were adjusted to consider hydrologic and pollutant loading changes because of planned completion of the reservoirs of the Tunnel and Reservoir Plan (TARP), planned reductions in discretionary diversion from Lake Michigan for water-quality improvement purposes, planned reductions in effluent total phosphorus concentrations at the WRPs, planned disinfection at the Calumet and O'Brien WRPs, and changes in temperature resulting from the closure of the Fisk and Crawford power plants in 2012 and from the flow changes resulting from the various inflow changes to the CAWS. With respect to the completion of the TARP reservoirs two conditions were evaluated—the Baseline condition of 2017 to 2029 when the Thornton Reservoir on the Calumet TARP system and Stage 1 of the McCook Reservoir on the Des Plaines and Mainstream (i.e. Chicago River) TARP systems are operational and the Future condition of 2029 and beyond when both Stages 1 and 2 of the McCook Reservoir are operational. The "Lakefront Separation" alternative also involves a barrier near the Illinois-Indiana border on the Little Calumet River and subtraction of flows from Indiana from the U.S. Geological Survey gage record at the Little Calumet River at South Holland boundary.

To consider the effects of the TARP reservoirs on the CSO flows, the USACE, Chicago District, ran their models of the CAWS watershed, major interceptor sewers, and TARP system to yield revised CSO flows that account for the effects of the reservoirs in capturing combined sewer flows. The revised inflows were directly input to the DUFLOW model of the CAWS at 43 representative gravity CSO locations. The results of the USACE models also were used to adjust the flows from the 5 CSO pumping stations and the inflow from the Little Calumet River and North Branch Chicago River above the boundaries of the DUFLOW model of the CAWS. The decreases in CSO flows from current to Baseline or Future conditions were used to calculate storage in the TARP reservoirs that were drained over time through the Stickney and Calumet WRPs as these plants had capacity to treat flows from the reservoirs.

To consider the effects of the flow changes and power plant closures on temperatures in the CAWS the historical hourly temperature data measured by the Metropolitan Water Reclamation District of Greater Chicago at 34 locations in and near the CAWS and the daily effluent (or influent in the case of the Calumet WRP) temperatures for the three WRPs were evaluated to develop an approach to estimate daily temperatures in the CAWs. A series of regression and mass balance equations was developed on the basis of these data to estimate temperatures throughout the CAWS considering the effects of flow changes in the system. Information on power plant shut downs were obtained from Midwest Generation that allowed regression models to be developed for the cases of the Fisk Power Plant and the Crawford Power Plant not operating. These models were used to determine the daily temperatures throughout the CAWS for Baseline and Future conditions for WYs 2001, 2003, and 2008 for each of the alternatives.

<u>“Lakefront Separation” Alternative vs. “No Project” Alternative</u>

The primary effect of the “Lakefront Separation” alternative on the water quality in the CAWS compared to the “No Project” alternative is the increase in the number of hours of noncompliance with the DO standards proposed by the Illinois Environmental Protection Agency. Figures 9.1 and 9.2 show the increase in the number of hours of noncompliance with the DO standards along the Chicago River and Calumet River systems, respectively. The reaches that become completely stagnant for the “Lakefront Separation” alternative show large increases in noncompliance. In the upper North Shore Channel (NSC) (RM 336.9 to RM 340.8), the increase in noncompliance exceeds 1000 hr in both WYs 2001 and 2003 (Figure 9.1). In the Chicago River main stem (represented by Clark Street, RM 325.9, in Figure 9.1), the increase in noncompliance is greater than 1500 in both WYs 2001 and 2003. In the upper Little Calumet River (north) (RM 321.4 to RM 325.4, Figure 9.2), the increases in noncompliance are much smaller than for the other stagnant areas, but this is because this reach generally has high levels of compliance under all alternatives for all years (especially much higher levels than for the upper NSC).

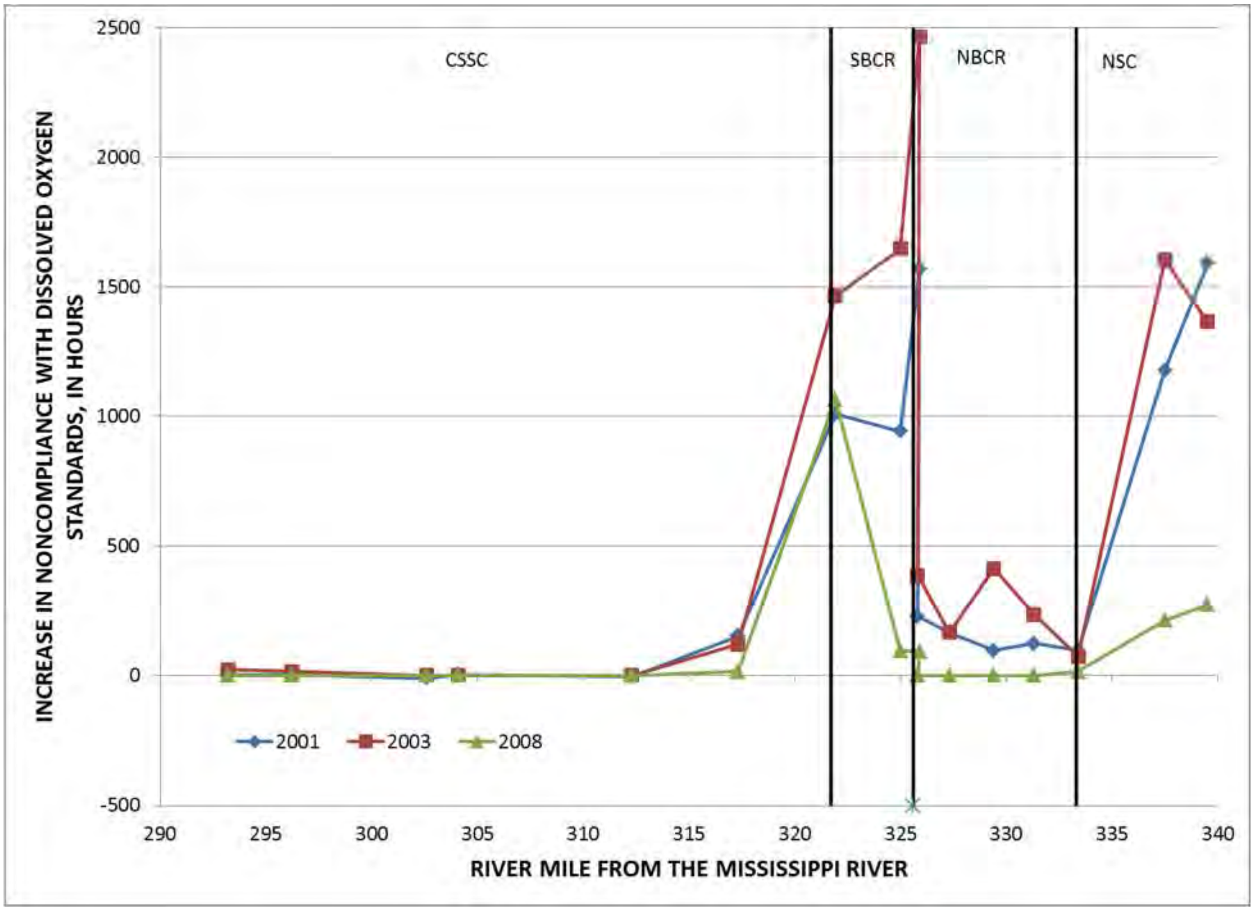


Figure 9.1. Increase in the number of hours of noncompliance with the dissolved oxygen standards along the Chicago River system for the "Lakefront Separation" alternative compared to the "No Project" alternative for Water Years 2001, 2003, and 2008.

The decrease in discretionary flows and other flows at the Chicago River Controlling Works (CRCW) and the Wilmette Pumping Station (Wilmette) also results in substantial increases in noncompliance along the South Branch Chicago River (SBCR). At Jackson Boulevard (RM 325, Figure 9.1) both WYs 2001 and 2003 had increases greater than 900 hr. At Loomis Street (RM 321.9, Figure 9.1) all three years had increases greater than 1000 hr.

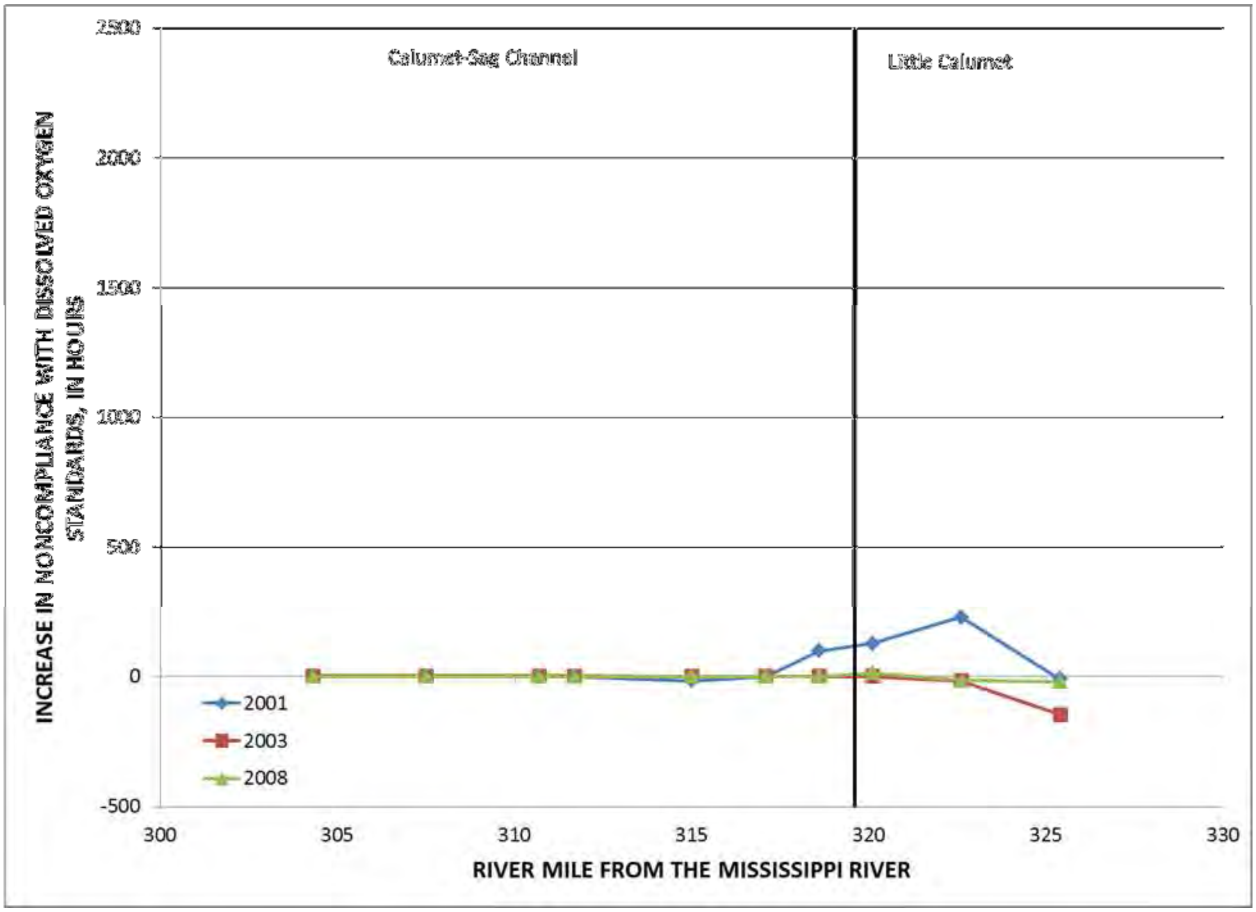


Figure 9.2. Increase in the number of hours of noncompliance with the dissolved oxygen standards along the Calumet River system for the "Lakefront Separation" alternative compared to the "No Project" alternative for Water Years 2001, 2003, and 2008.

In order for the "Lakefront Separation" alternative to yield similar levels of compliance with the DO standards as for the "No Project" alternative mitigation measures would be needed for the upper NSC, SBCR, and Chicago River main stem. The need to achieve similar levels of compliance with DO standards might be necessary to meet anti-degradation requirements for water quality. For the stagnant upper NSC and Chicago River main stem some sort of flow augmentation would be needed, such as the pumping of O'Brien WRP effluent to the upstream end of the NSC to create flow in the NSC as was proposed and evaluated in Alp and Melching (2006) and Melching et al. (2010). Whereas supplemental aeration may be necessary on the

SBCR, North Branch Chicago River (NBCR), and the NSC and Chicago River main stem (in addition to flow augmentation) as was also proposed and evaluated in Alp and Melching (2006) and Melching et al. (2010). The numbers and locations of supplemental aeration stations and the magnitude of flow augmentation would need to be determined by further modeling studies.

<u>“Midsystem Separation” alternative vs. “No Project” alternative</u>

The “Midsystem Separation” involves placement of hydraulic barriers on the Chicago Sanitary and Ship Canal (CSSC) and the Calumet-Sag Channel. Placement of a barrier on the CSSC at RM 316.01 will result in the SBCR and the upper CSSC becoming stagnant waterways. Placement of a barrier on the Calumet-Sag Channel at RM 315.89 will result in the entire Calumet-Sag Channel becoming stagnant.

Figure 9.3 shows the increase in the number of hours of noncompliance with the DO standards along the Chicago River system for the “Midsystem Separation” alternative compared to the “No Project” alternative. On the upper NSC (RM 336.9 to RM 340.8) the constant flow of O’Brien WRP effluent through this reach for the “Midsystem Separation” alternative improves compliance by more than 950 hr at Simpson Street and by more than 490 hr at Main Street for all three years. However, because about one third of the O’Brien WRP effluent is flowing through the upper NSC the reduced flows through the lower NSC and NBCR result in much higher noncompliance with the DO standards especially for WYs 2001 and 2003. For both of these years the increase in noncompliance exceeds 300 hr at Foster Avenue (RM 333.4) and rises to more than 1000 hr at Fullerton Avenue, Division Street, and Kinzie Street (RM 329.4 to RM 325.8).

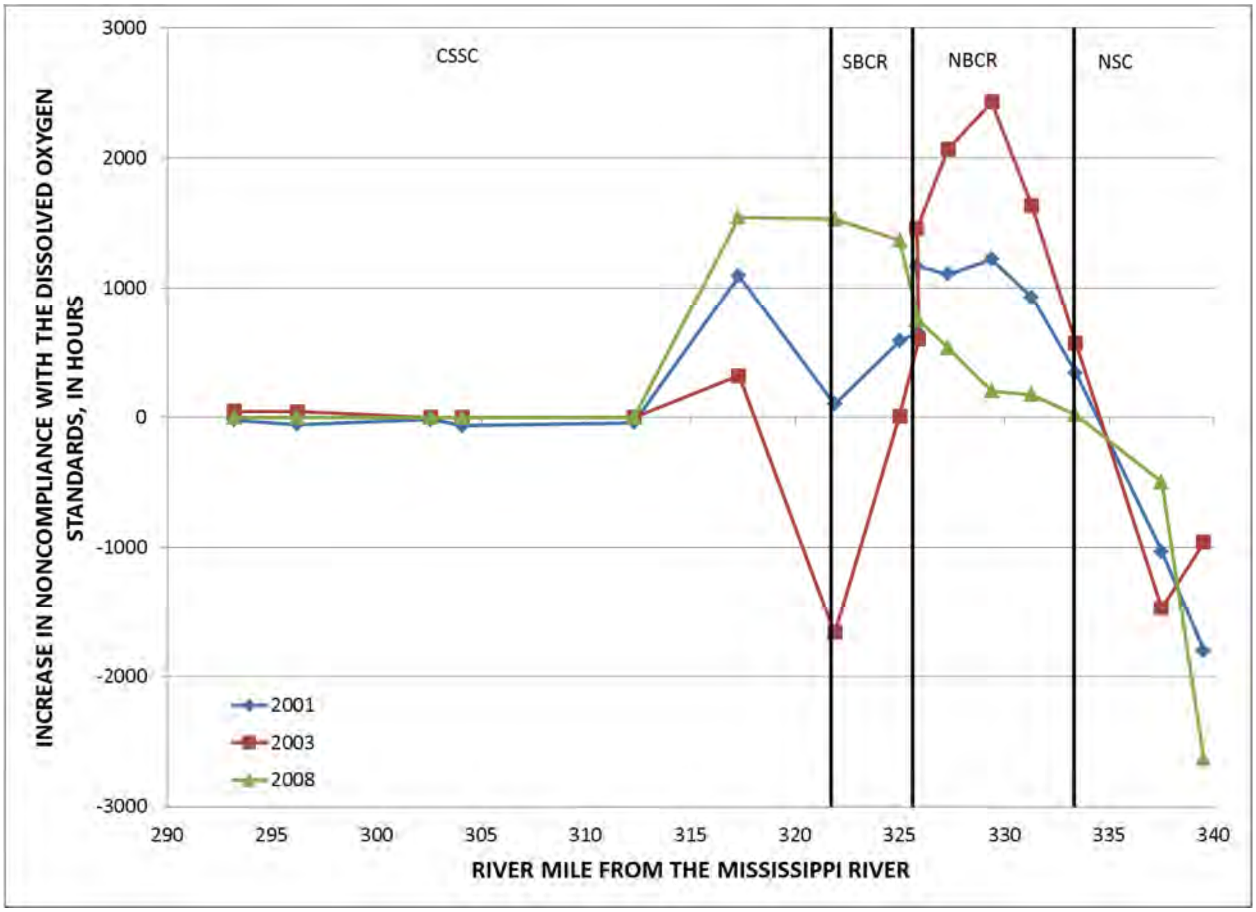


Figure 9.3. Increase in the number of hours of noncompliance with the dissolved oxygen standards along the Chicago River system for the "Midsystem Separation" alternative compared to the "No Project" alternative for Water Years 2001, 2003, and 2008.

The increases in noncompliance on the NBCR are not as large for WY 2008 as for the other years (Figure 9.3). However, for WY 2008 the stagnant SBCR and upper CSSC experience increases larger than 1000 hr. For WY 2001, Jackson Boulevard (RM 325) sees an increase greater than 300 hr and Cicero Avenue sees an increase more than a 1000 hr. Interestingly, Loomis Street sees a more than 1600 hr improvement for the "Midsystem Separation" alternative compared to the "No Project" alternative for WY 2003. This improvement results because Loomis Street is the one of the locations most prone (together with those on the upper NSC) to low DO concentrations under the current and "No Project" conditions.

Figure 9.4 shows the increase in the number of hours of noncompliance with the DO standards along the Calumet River system for the "Midsystem Separation" alternative compared to the "No Project" alternative. In the heart of the stagnant Calumet-Sag Channel from RM 307.5 to RM 318.6 the increase in noncompliance is greater than 500 hr at all locations for all years with 15 of the 18 location-years showing greater than 1000 hr increases in noncompliance.

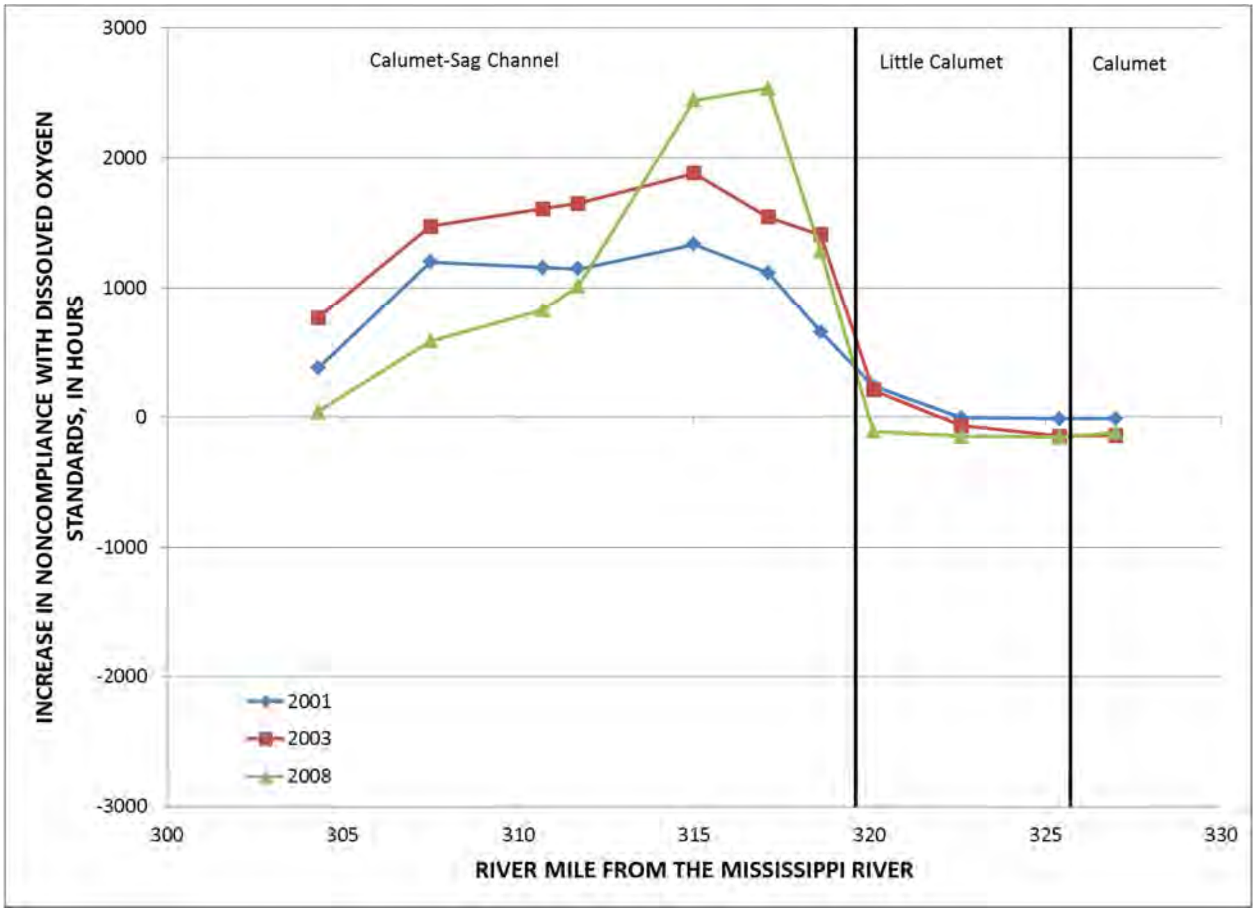


Figure 9.4. Increase in the number of hours of noncompliance with the dissolved oxygen standards along the Calumet River system for the "Midsystem Separation" alternative compared to the "No Project" alternative for Water Years 2001, 2003, and 2008.

The "Midsystem Separation" alternative yields a small improvement in compliance on the Little Calumet River (north) and Calumet River (RM 319.6 to RM 327) for WYs 2003 and 2008 because of the continual flow of Calumet WRP effluent to the reaches east of the WRP (RM 321.4 and up) (Figure 9.4). However, for WY 2001 only a small improvement (10 hr or less) in compliance occurs for RM 322.6 to RM 327. These small changes occur because this reach generally has high levels of compliance under all alternatives for all years.

In order for the "Midsystem Separation" alternative to yield similar levels of compliance with the DO standards as for the "No Project" alternative mitigation measures would be needed for the NBCR, SBCR, and Calumet-Sag Channel. The need to achieve similar levels of compliance with DO standards might be necessary to meet anti-degradation requirements for water quality. For the Calumet-Sag Channel some sort of flow augmentation would allow the existing SEPA stations 3 and 4 to become useful again (i.e. supplemental aeration stations need to discharge to flowing water for maximum effectiveness in distributing oxygen), and the combination of flows and SEPA operations might mitigate the increase in noncompliance with the DO standards. Although it is possible that additional supplemental aeration might be need to sufficiently improve compliance with DO standards to the Calumet-Sag Channel under the "Midsystem Separation" alternative. For the NBCR and SBCR additional supplemental aeration stations would be required to suitably improve the compliance with the DO standards. The numbers and locations of supplemental aeration stations and the magnitude of flow augmentation would need to be determined by further modeling studies.

Loads to Lake Michigan

Whereas the increases in noncompliance with DO standards in the CAWS are significant, the most substantial impact of the "Midsystem Separation" alternative on water quality will be in the magnitude of the loads of pollutants discharged to Lake Michigan. For the "Lakefront Separation" alternative there would be no flows and related pollutant loads to Lake Michigan. For the "No Project" alternative only the storms of September 13-16, 2008, would result in flows and related pollutant loads to Lake Michigan. For the "Midsystem Separation" alternative the treated effluent for the O'Brien and Calumet WRPs; the effluent from 5 CSO pumping stations; the discharge from nearly all the gravity CSOs; and the flows from the North Branch Chicago River, Little Calumet River, Grand Calumet River, and other small tributaries would go to Lake Michigan. Table 9.1 lists the flow rate and volume of discharges to Lake Michigan and the loads of CBOD, total nitrogen, total phosphorus, total suspended solids, chloride, and fecal coliform bacteria going to Lake Michigan for the "Midsystem Separation" and "No Project" alternatives. Comparing the representative "dry" year (WY 2003) for the "Midsystem Separation" alternative with the representative "wet" year (WY 2008) for the "No Project" alternative indicates that even for a dry year the loads of nitrogen, phosphorus, and chloride could be more than 12.5, 1.6, and 330 million pounds higher than for "No Project" conditions resulting from the event that caused the largest flow reversal to Lake Michigan since the TARP system became operational (i.e. the storms of September 13-26, 2008, storm). Further, for "wet" years (represented by WY 2008) loads to Lake Michigan may be in the neighborhood of 20 million pounds of nitrogen, 2.5 million pounds of phosphorus, and 640 million pounds of chloride. Such loads, year-after-year, will have substantial cumulative undesirable effects on Lake Michigan.

Table 9.1. Flows and loads to Lake Michigan for the "Midsystem Separation" alternative for WYs 2001, 2003, and 2008 and for the "No Project" alternative for WY 2008 all under the Future conditions.

Constituent	Midsystem Separation			No project
	WY 2001	WY 2003	WY 2008	WY 2008
Flow (cfs)	1222.5	1029.5	1466.3	*
Volume (ac-ft)	884,000	745,000	1,050,000	14,200
CBOD (lb)	5,519,000	3,773,000	6,680,000	507,000
Total Nitrogen (lb)	14,425,000	12,787,000	19,300,000	243,000
Total Phosphorus (lb)	2,001,000	1,667,000	2,560,000	38,400
Total Suspended Solids (lb)	22,075,000	14,132,000	34,800,000	1,260,000
Chloride (lb)	446,100,000	332,500,000	637,000,000	3,789,000
Fecal Coliform (CFU)	3.84×10^{16}	0.641×10^{16}	13.1×10^{16}	2.00×10^{16}

*inappropriate to compare the flows for about 2 weeks to annual average flows.

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Addendum Section A: Simulated and Measured Fecal Coliform Concentrations for WYs 2001 and 2003

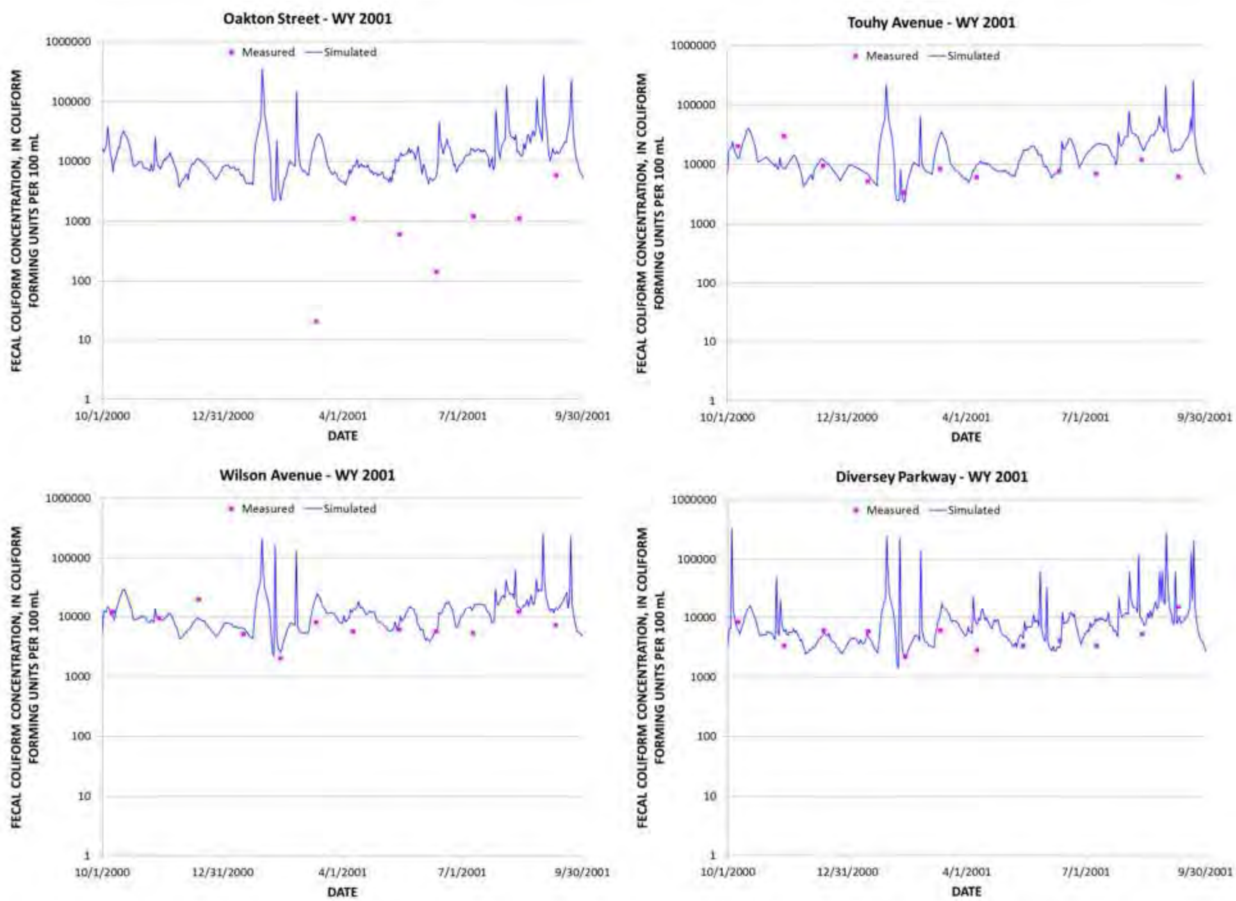


Figure A.1. Measured and simulated fecal coliform concentration on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2001.

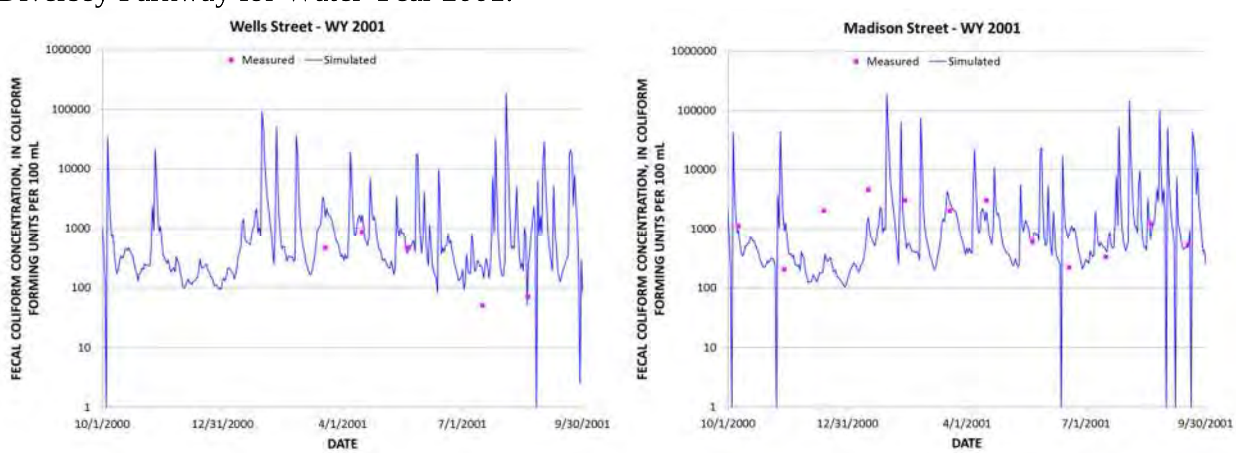


Figure A.2. Measured and simulated fecal coliform concentration on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2001.

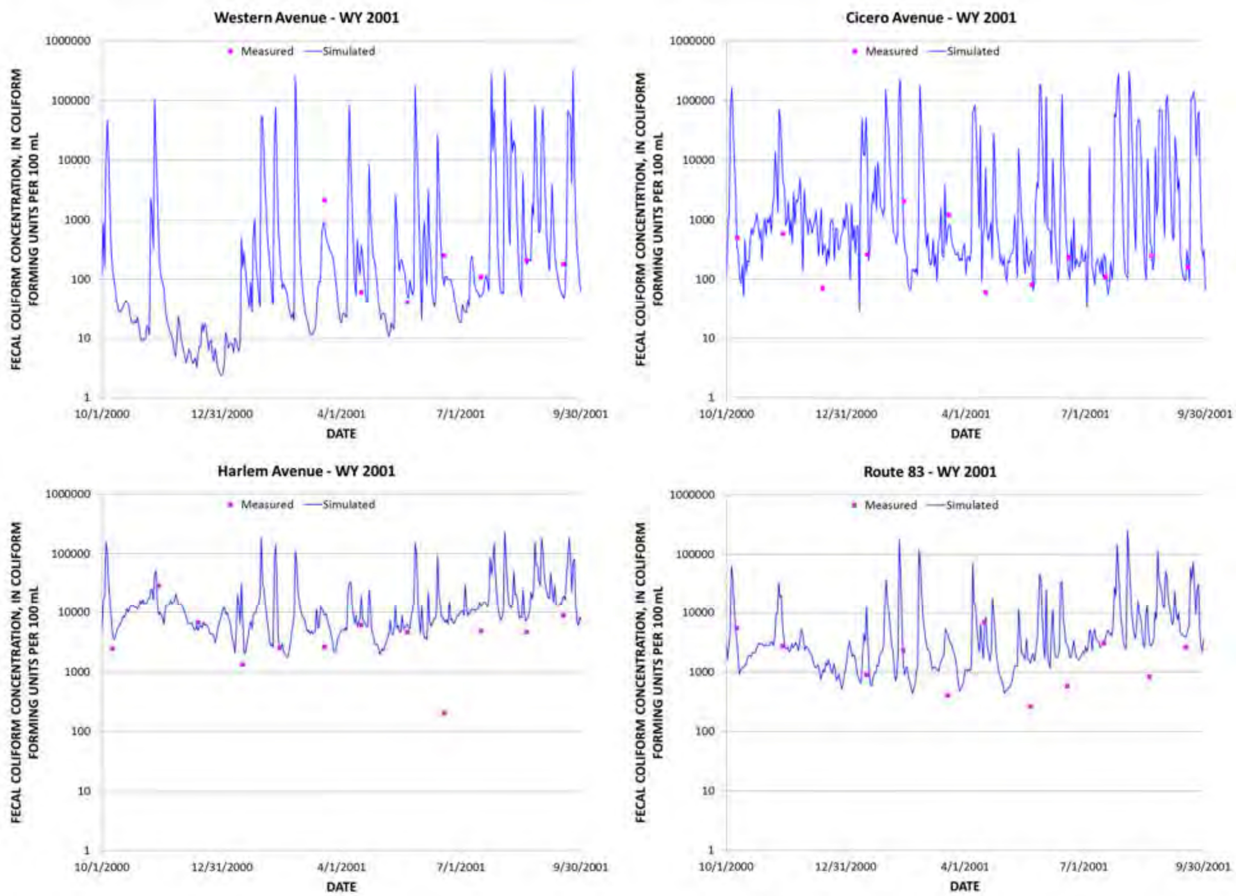


Figure A.3. Measured and simulated fecal coliform concentration on the Chicago Sanitary and Ship Canal at Western Avenue, Cicero Avenue, Harlem Avenue, and Route 83 for Water Year 2001.

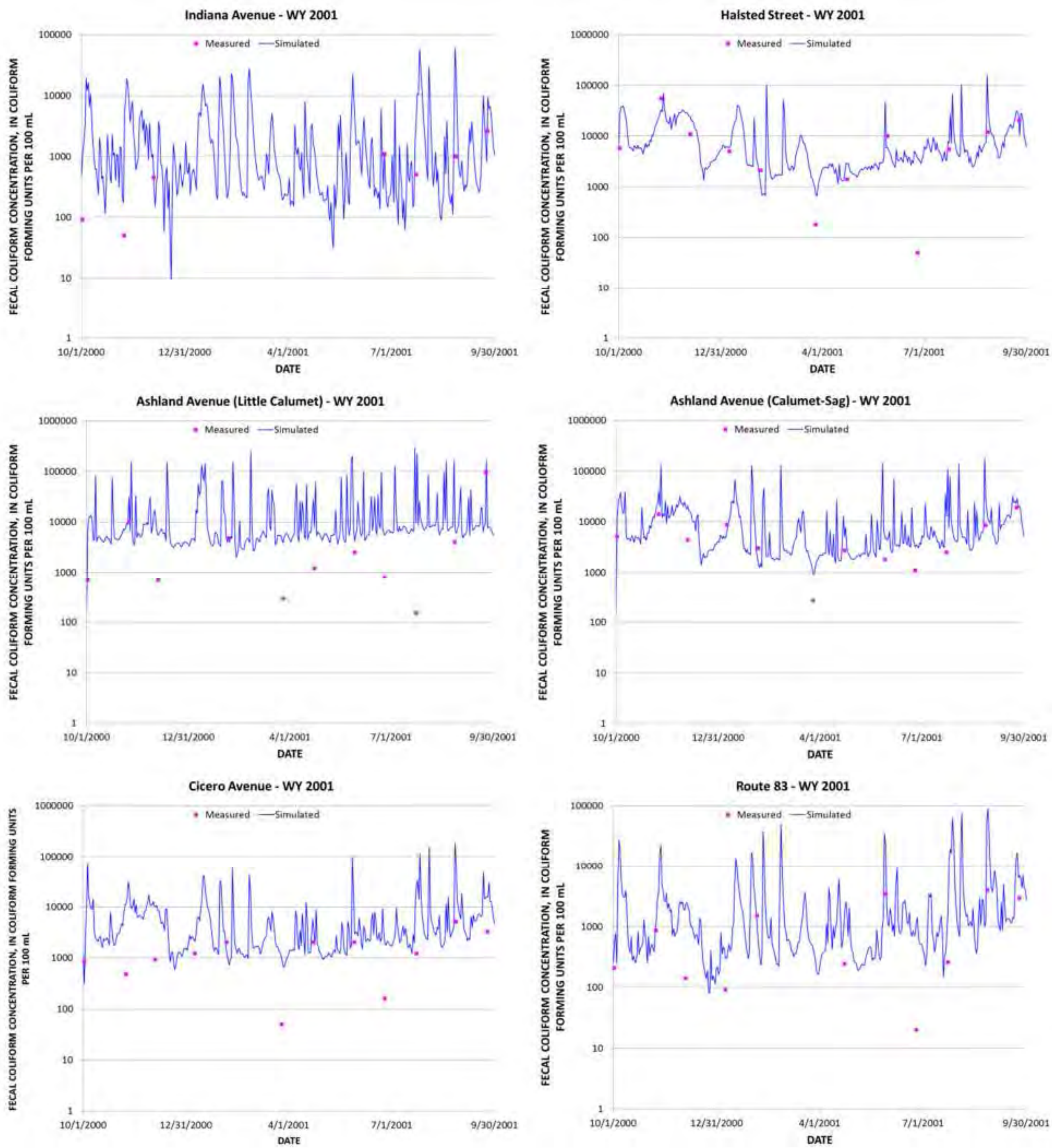


Figure A.4. Measured and simulated fecal coliform concentration on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2001.

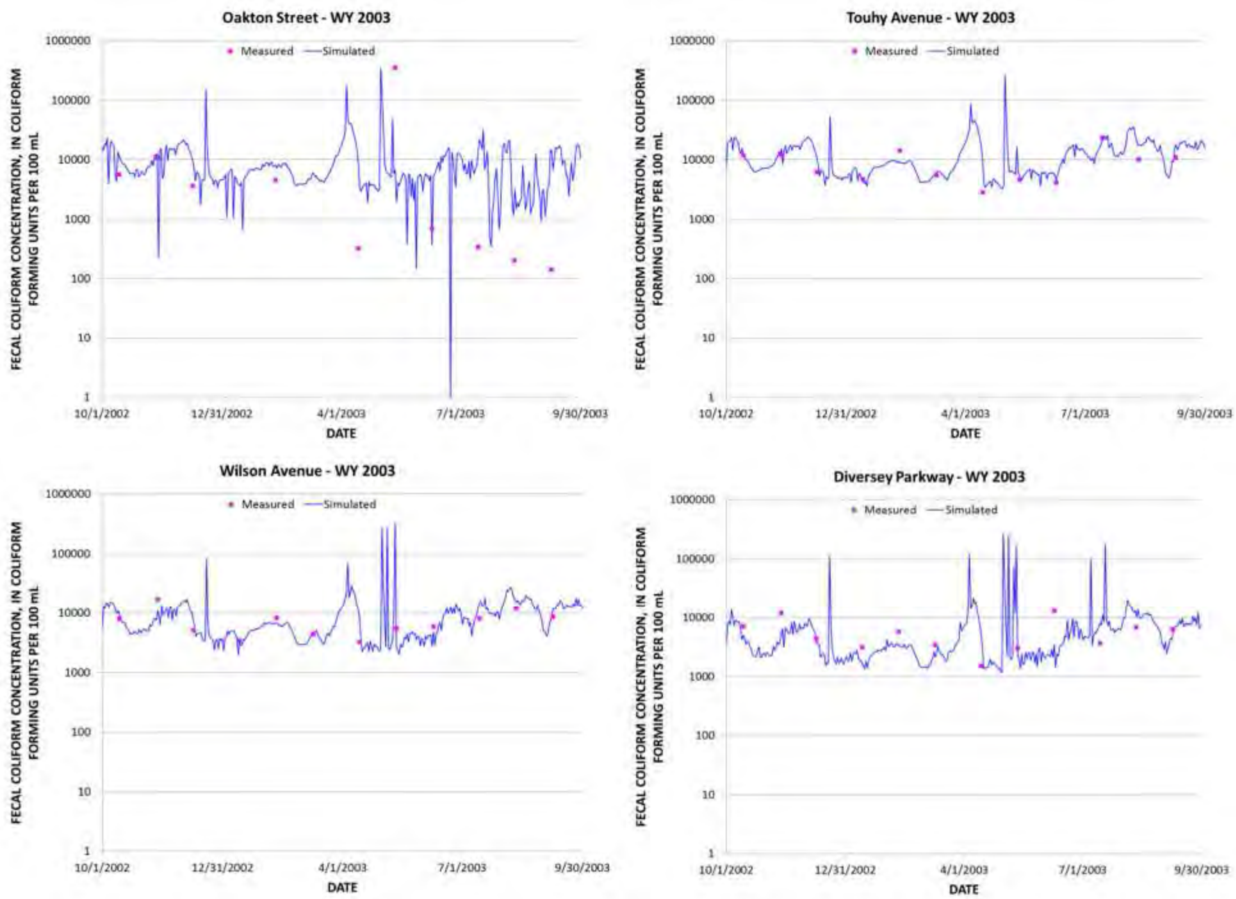


Figure A.5. Measured and simulated fecal coliform concentration on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2003.

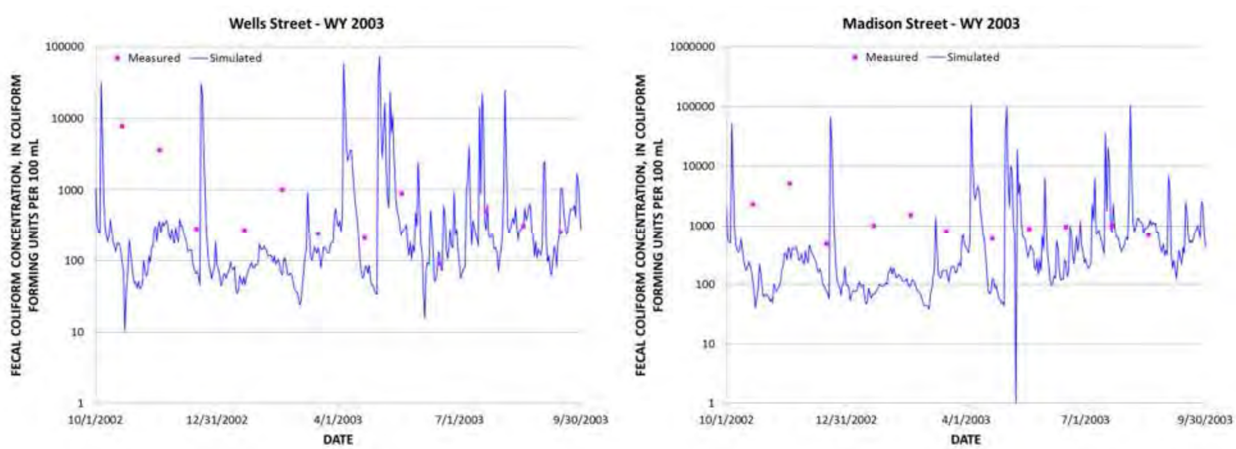


Figure A.6. Measured and simulated fecal coliform concentration on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2003.

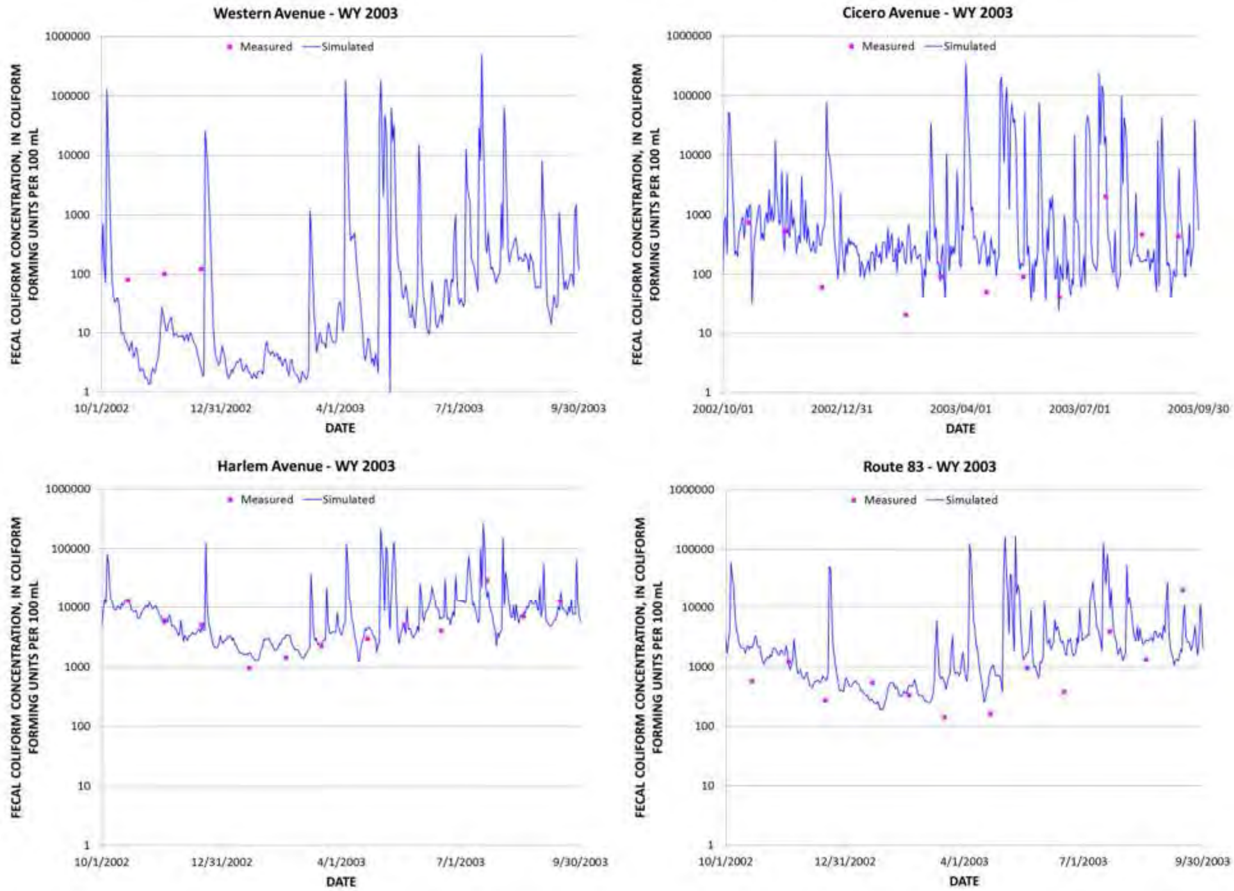


Figure A.7. Measured and simulated fecal coliform concentration on the Chicago Sanitary and Ship Canal at Western Avenue, Cicero Avenue, Harlem Avenue, and Route 83 for Water Year 2003.

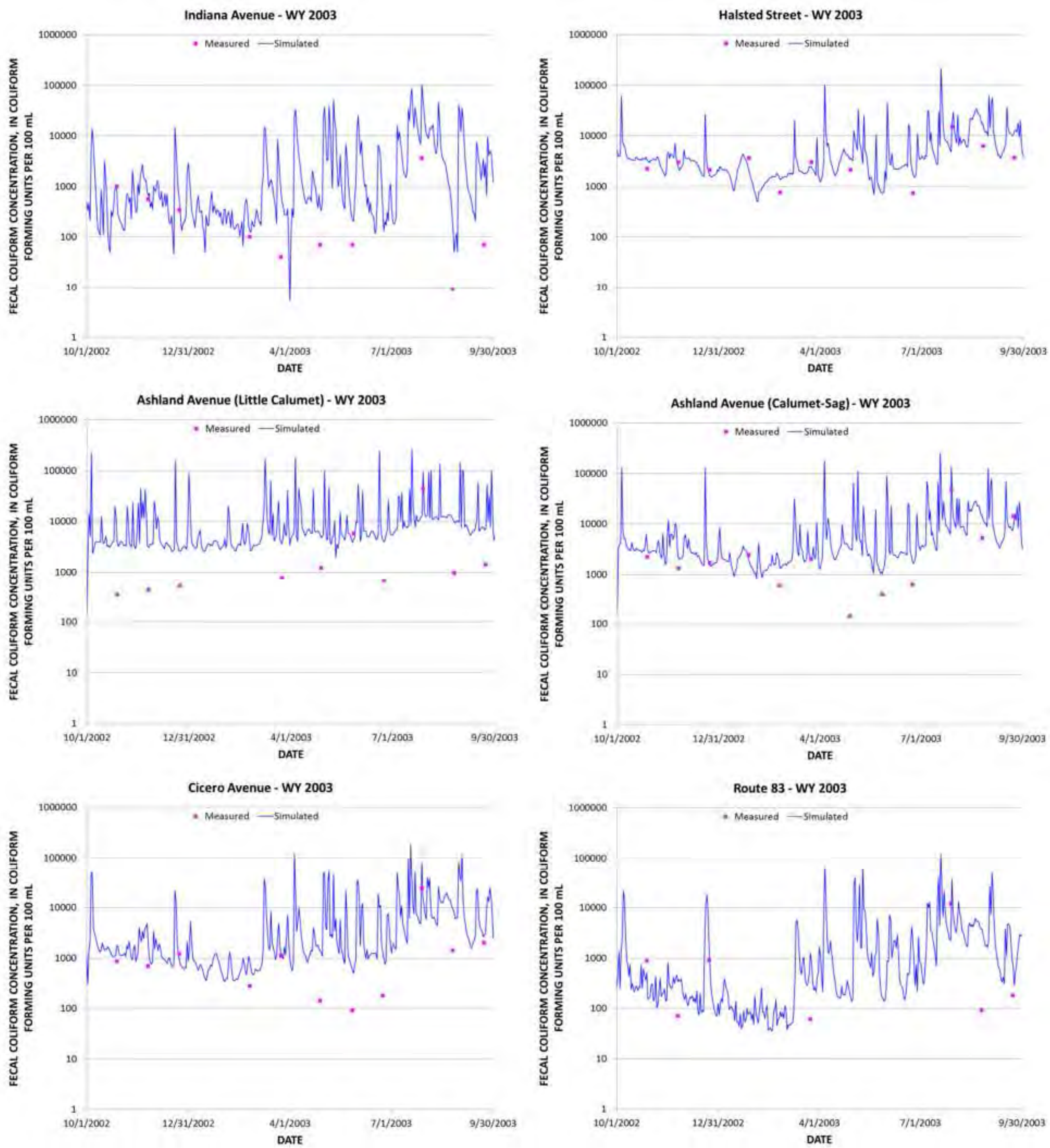


Figure A.8. Measured and simulated fecal coliform concentration on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2003.

Addendum Section B: Simulated and Measured Chloride Concentrations for WYs 2001 and 2003

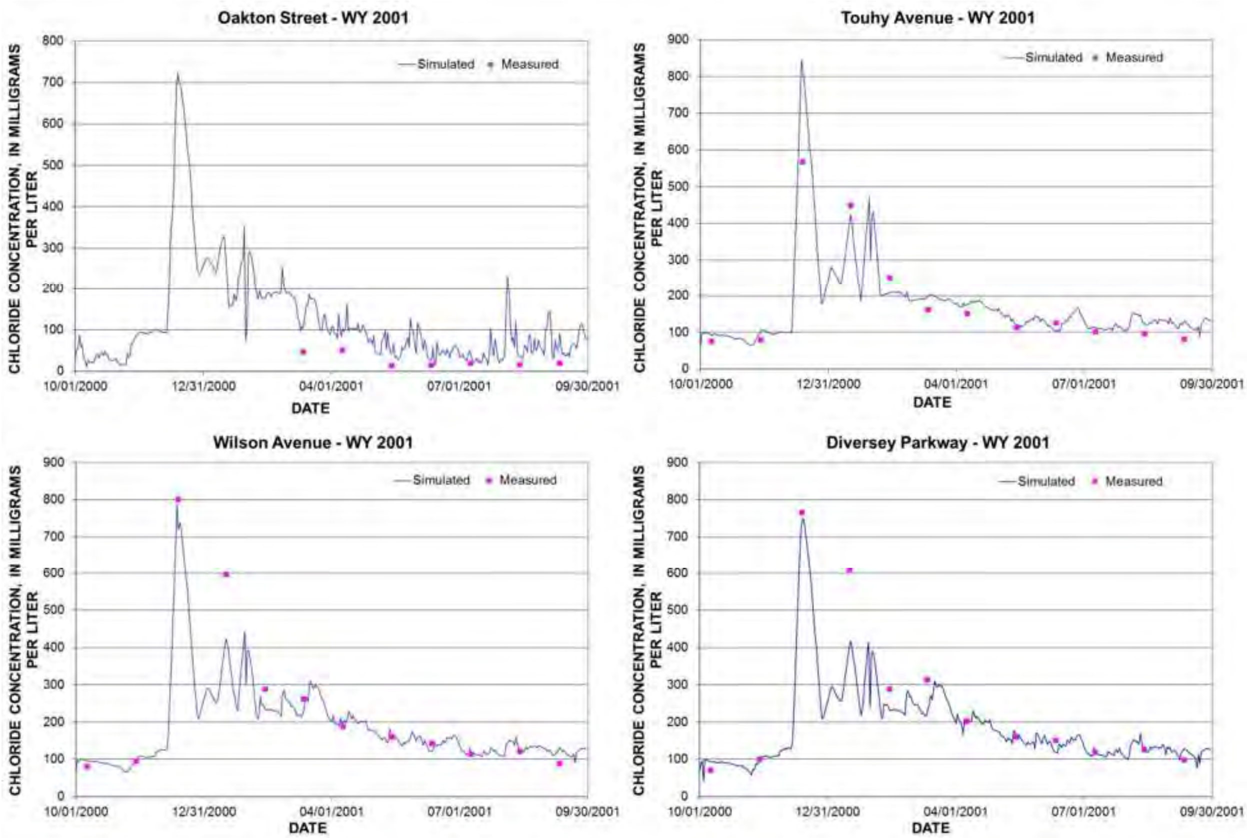


Figure B.1. Measured and simulated chloride concentration on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2001.

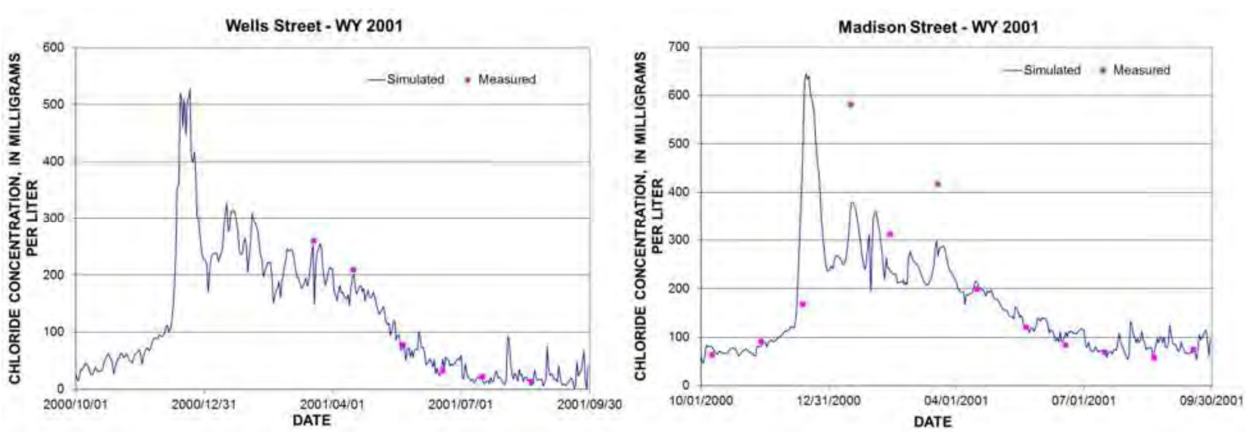


Figure B.2. Measured and simulated chloride concentration on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2001.

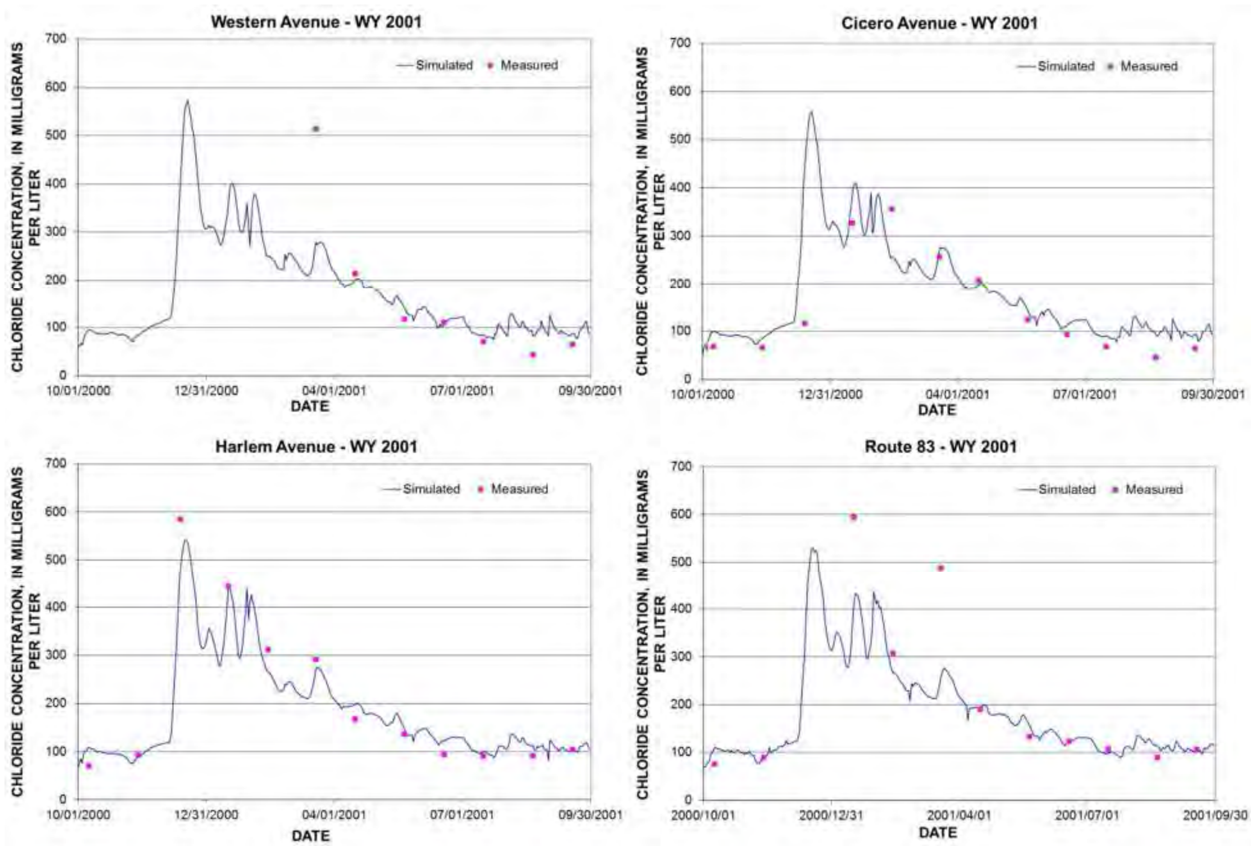


Figure B.3. Measured and simulated chloride concentration on the Chicago Sanitary and Ship Canal at Western Avenue, Cicero Avenue, Harlem Avenue, and Route 83 for Water Year 2001.

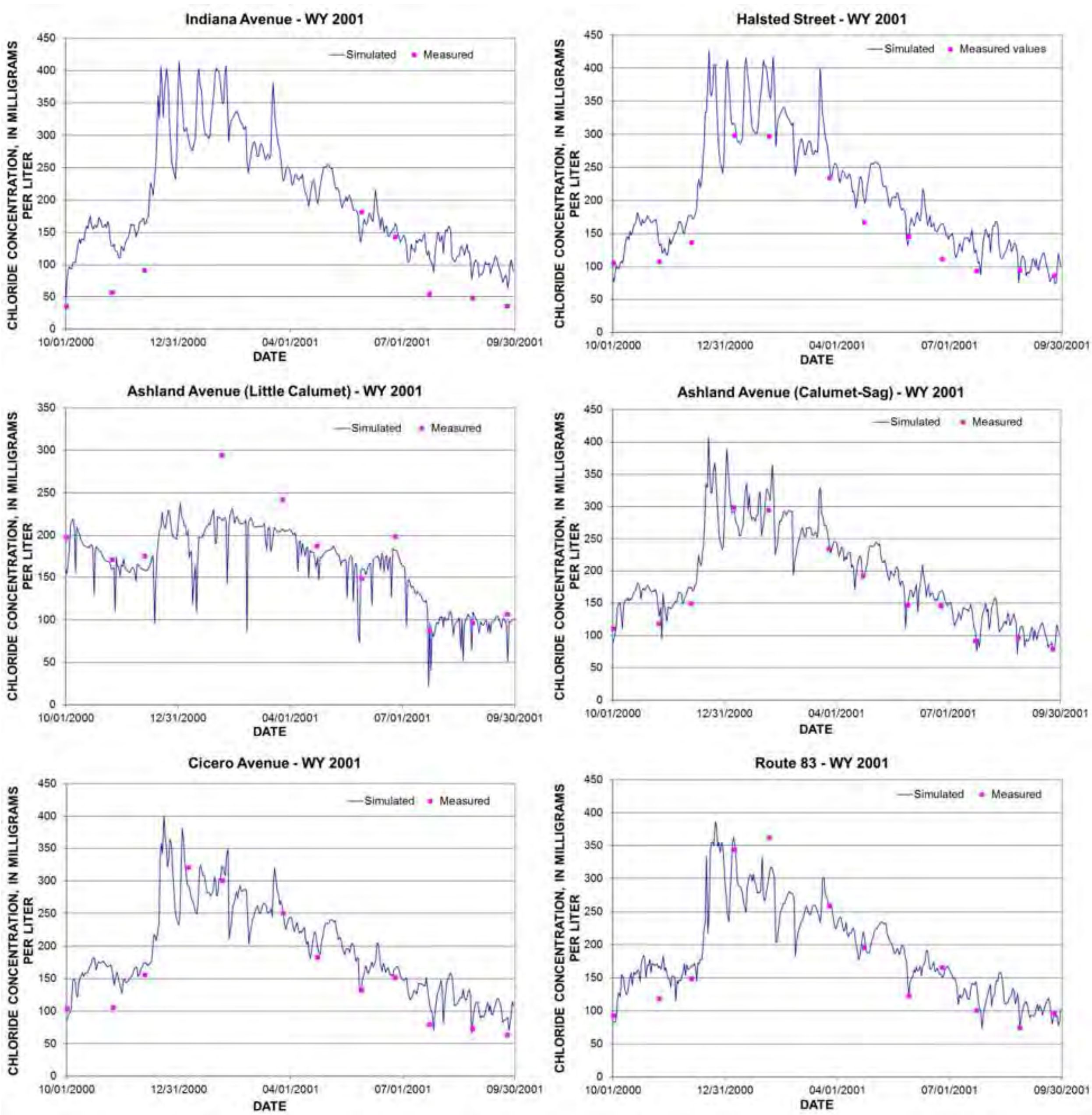


Figure B.4. Measured and simulated chloride concentration on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2001.

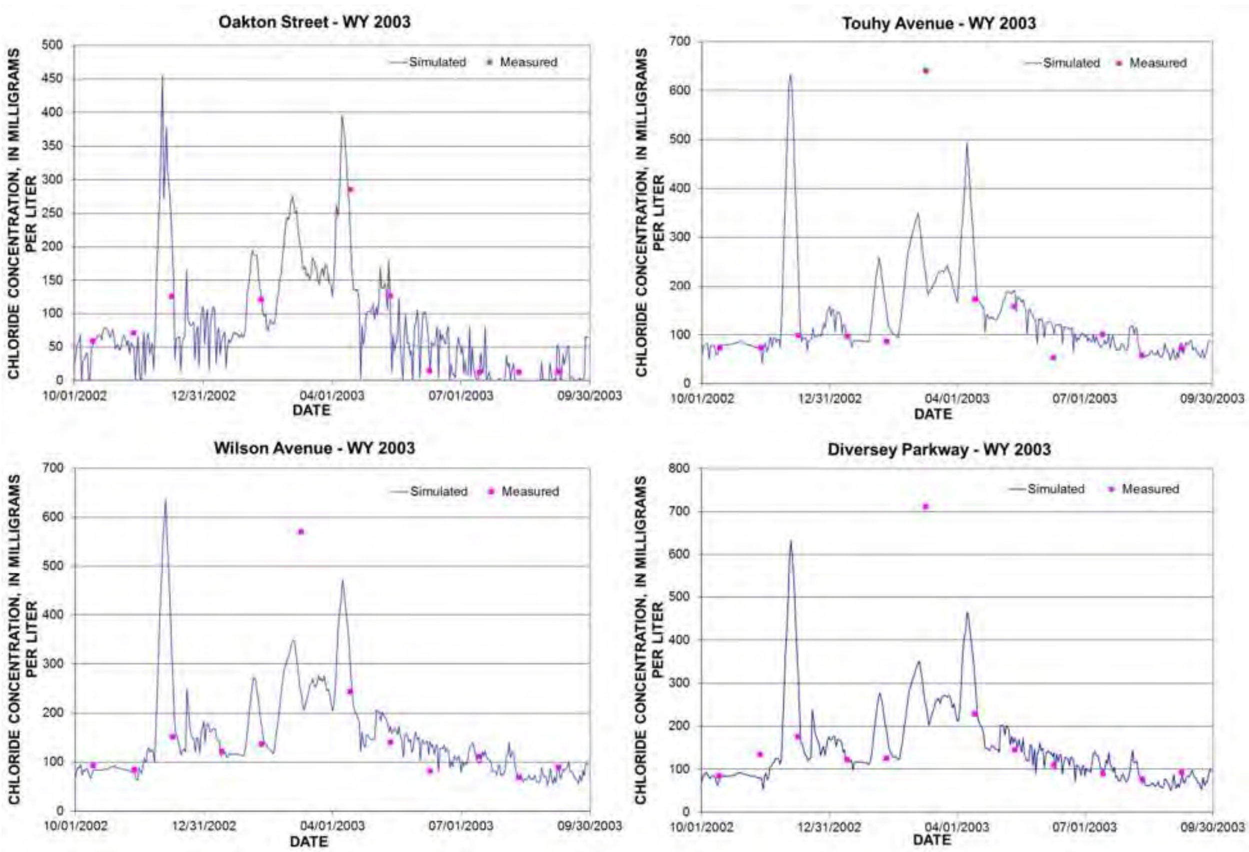


Figure B.5. Measured and simulated chloride concentration on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2003.

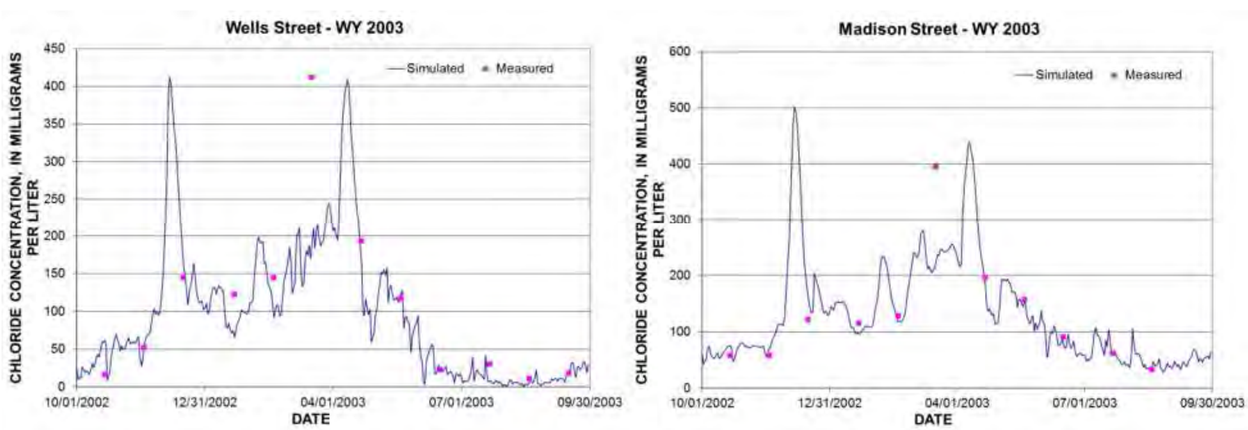


Figure B.6. Measured and simulated chloride concentration on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2003.

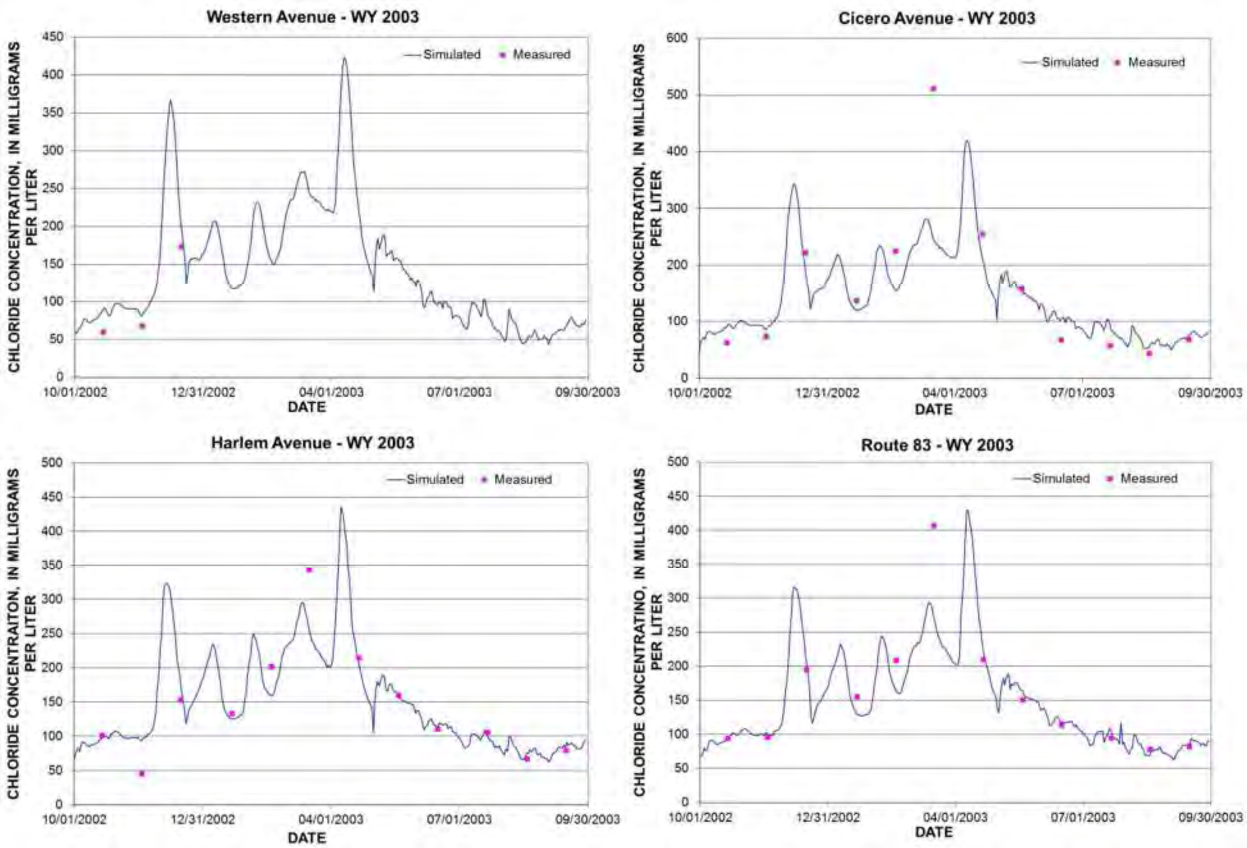


Figure B.7. Measured and simulated chloride concentration on the Chicago Sanitary and Ship Canal at Western Avenue, Cicero Avenue, Harlem Avenue, and Route 83 for Water Year 2003.

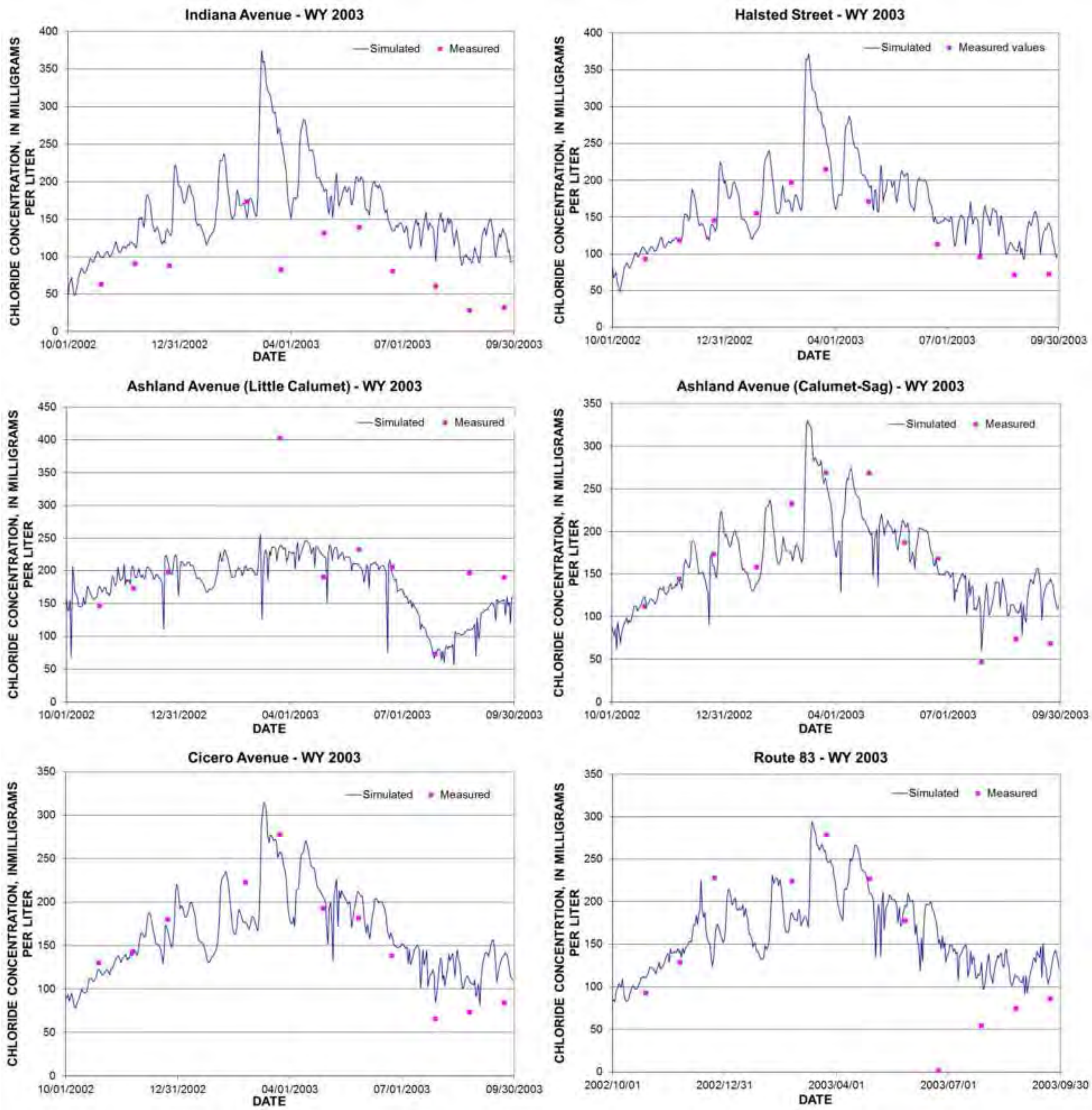


Figure B.8. Measured and simulated chloride concentration on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2003.

Addendum Section C: Simulated and Measured pH Values for WYs 2001 and 2003

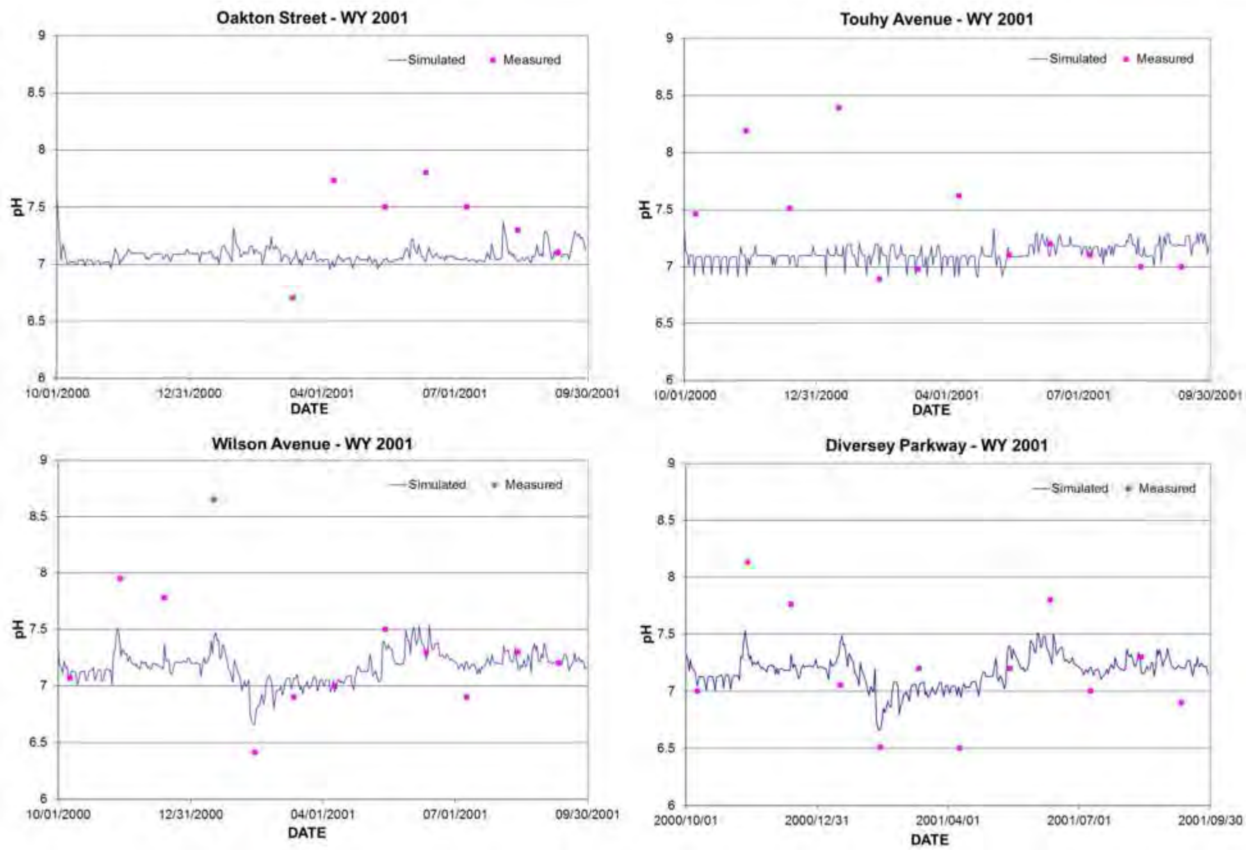


Figure C.1. Measured and simulated pH values on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2001.

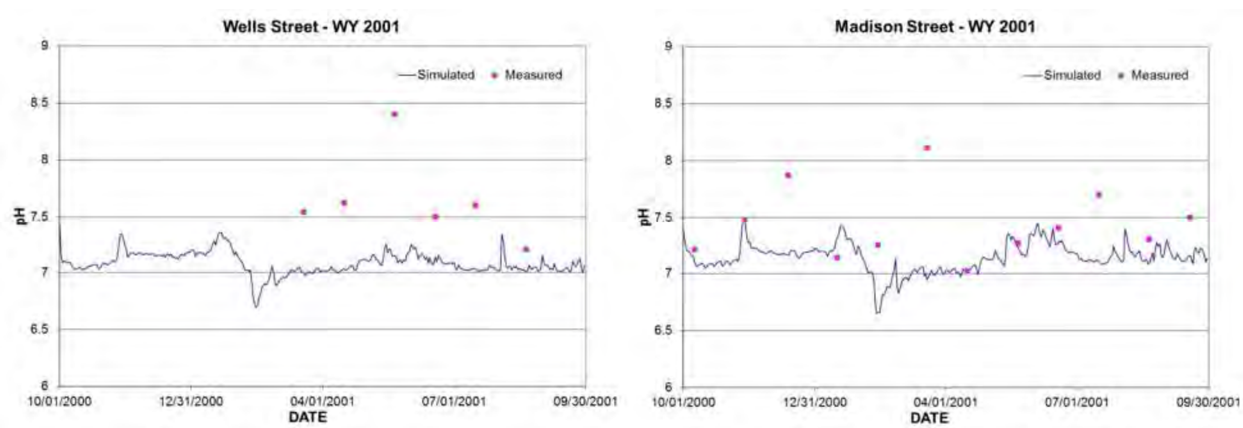


Figure C.2. Measured and simulated pH values on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2001.

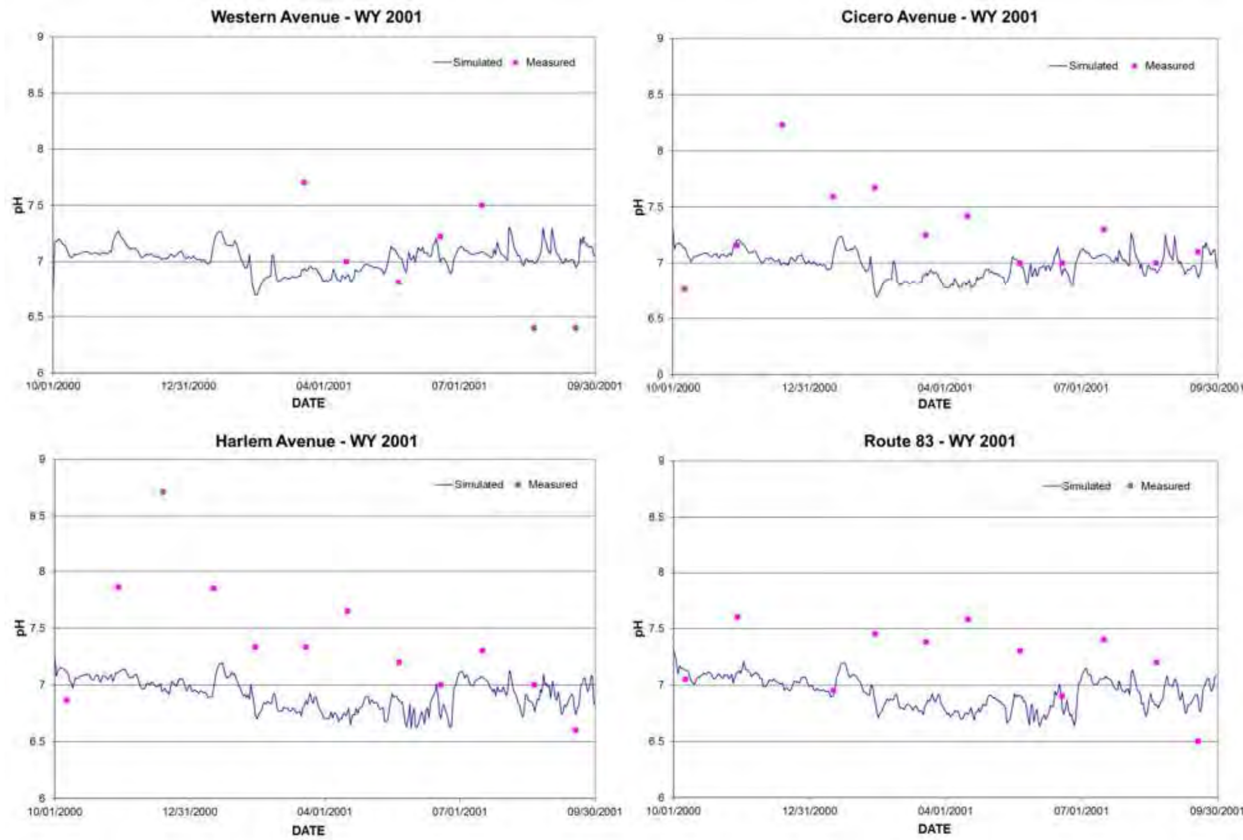


Figure C.3. Measured and simulated pH values on the Chicago Sanitary and Ship Canal at Western Avenue, Cicero Avenue, Harlem Avenue, and Route 83 for Water Year 2001.

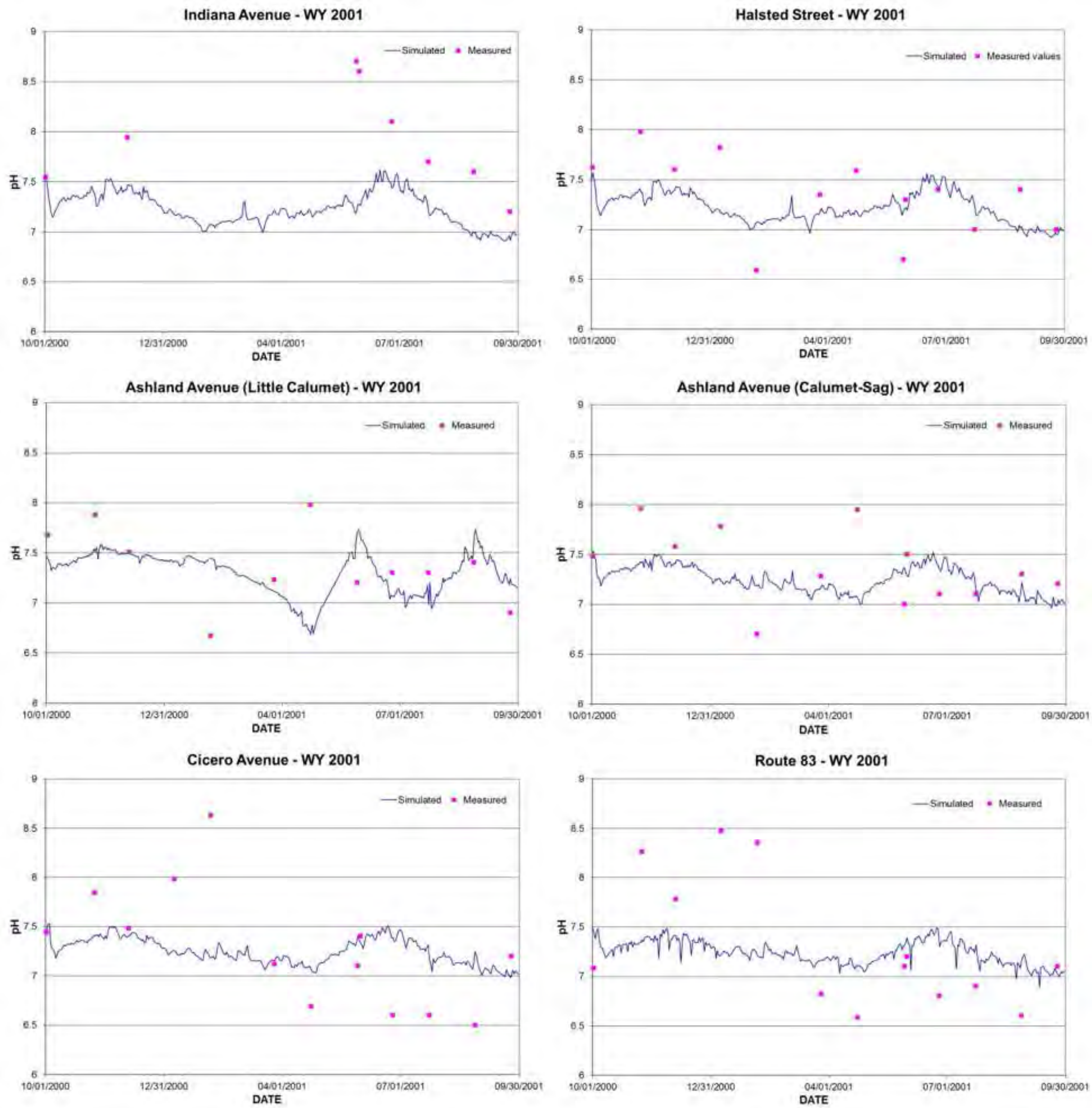


Figure C.4. Measured and simulated pH values on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2001.

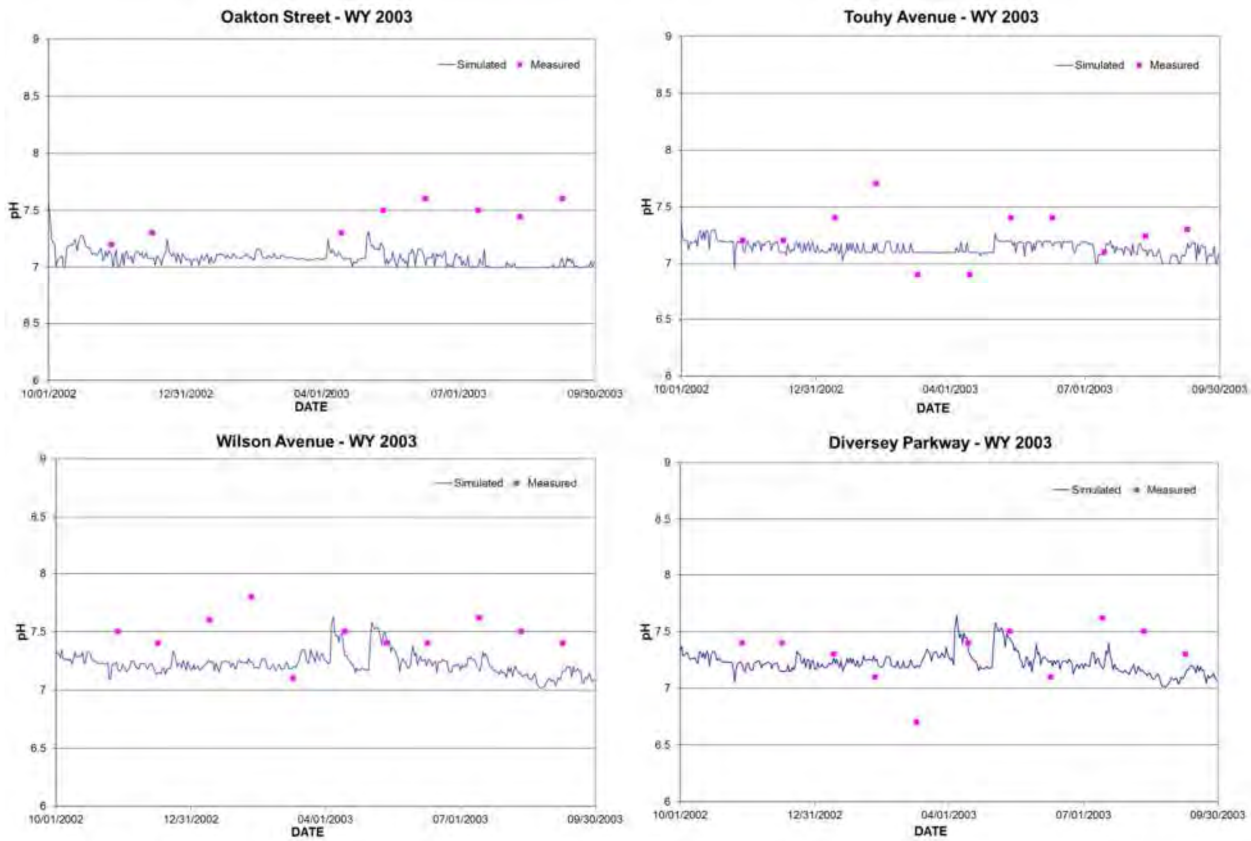


Figure C.5. Measured and simulated pH values on the North Shore Channel at Oakton Street and Touhy Avenue and on the North Branch Chicago River at Wilson Avenue and Diversey Parkway for Water Year 2003.

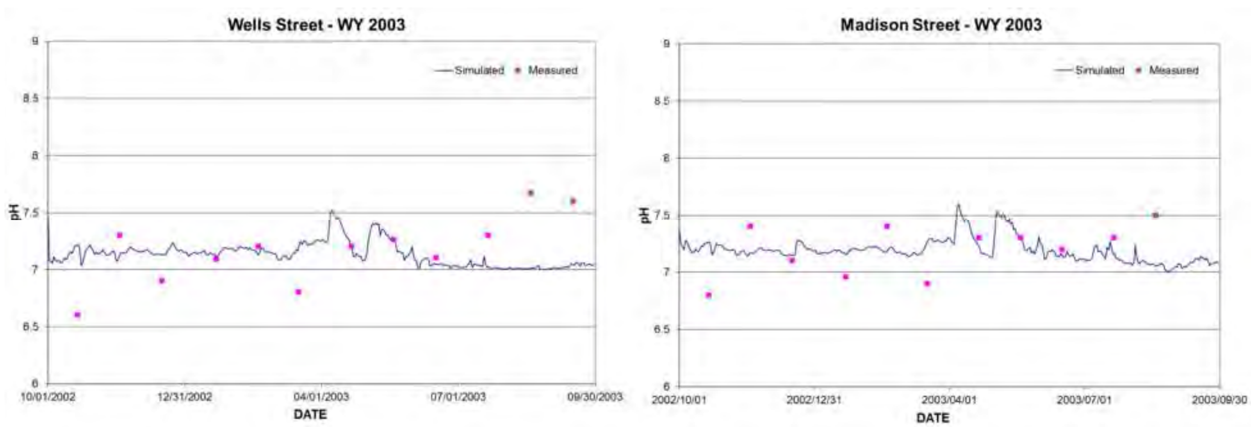


Figure C.6. Measured and simulated pH values on the Chicago River main stem at Wells Street and the South Branch Chicago River at Madison Street for Water Year 2003.

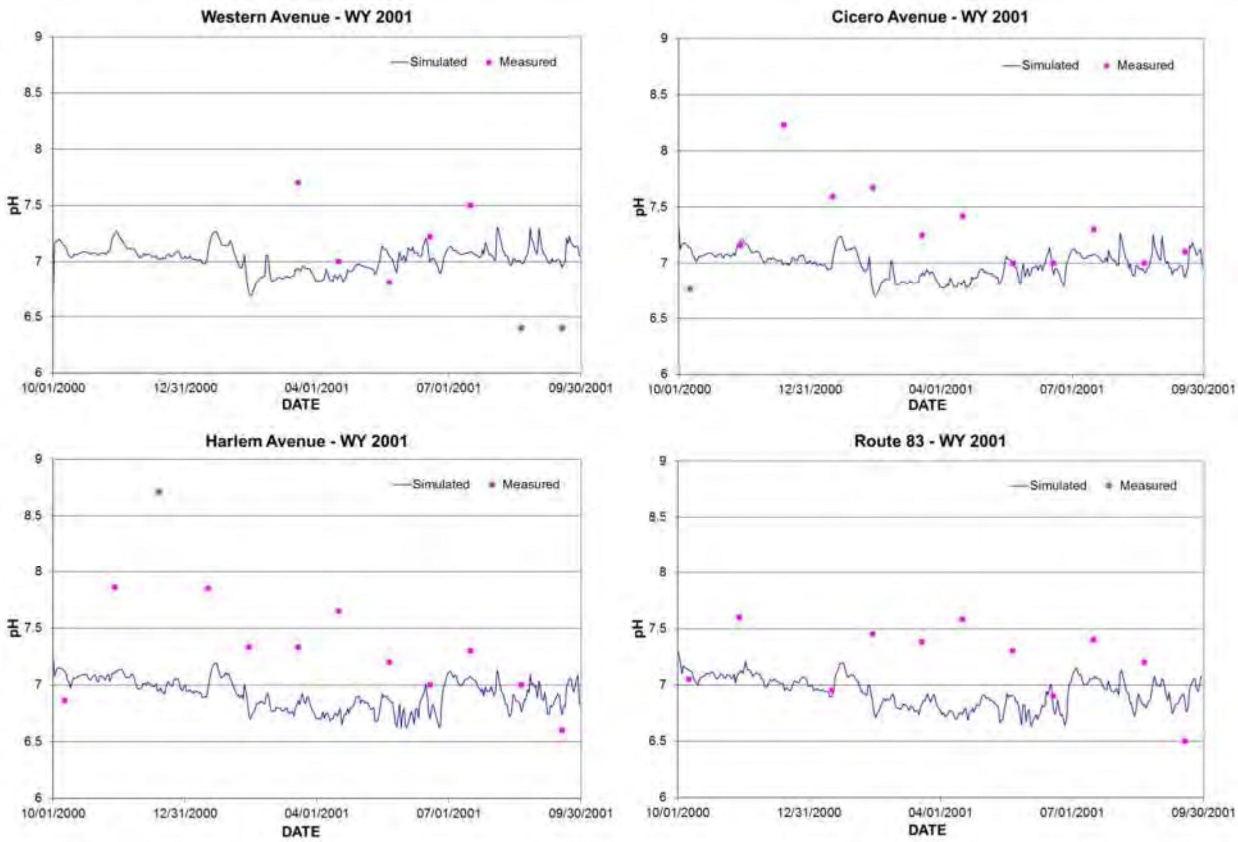


Figure C.7. Measured and simulated pH values on the Chicago Sanitary and Ship Canal at Western Avenue, Cicero Avenue, Harlem Avenue, and Route 83 for Water Year 2003.

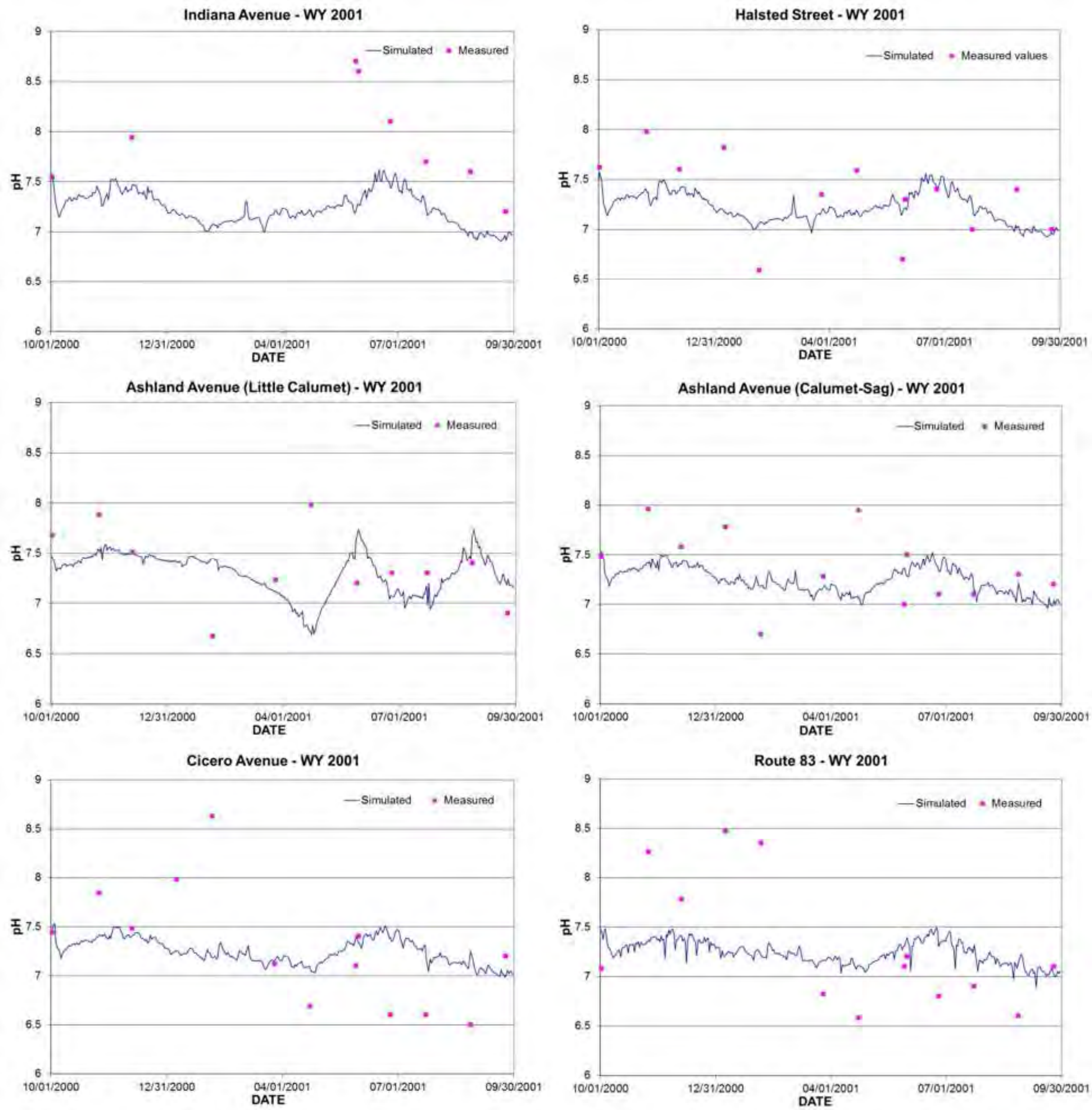


Figure C.8. Measured and simulated pH values on the Little Calumet River at Indiana Avenue, Halsted Street, and Ashland Avenue and on the Calumet-Sag Channel at Ashland Avenue, Cicero Avenue, and Route 83 for Water Year 2003.

Addendum Section D: Initial Conditions Used in the DUFLOW model of the CAWS

	Flow	Level	a1	ab	bodb	bodw	nh4b	nh4w	no3b	no3w	o2b	o2w	ssw	tipb	tipw	tonb	tonw	topb	topw
SEC00000 - begin	3.25	-0.41	0.08	1.2	2303	0.8	0.1	0.1	0.4	0.3	3.0	7.5	8.8	1	0.05	3555	0.4	419	0.05
SCH00034 - begin	3.25	-0.42	0.07	1.2	2235	0.8	0.1	0.1	0.4	0.3	3.0	7.4	6.5	1	0.05	3482	0.3	412	0.05
SCH00034 - end	3.25	-0.42	0.07	1.2	2235	0.8	0.1	0.1	0.4	0.3	3.0	7.4	6.5	1	0.05	3482	0.3	412	0.05
SCH00035 - begin	3.25	-0.42	0.06	1.3	2172	0.8	0.1	0.1	0.4	0.3	2.9	7.4	4.3	1	0.05	3413	0.3	406	0.05
SCH00035 - end	3.25	-0.42	0.06	1.3	2172	0.8	0.1	0.1	0.4	0.3	2.9	7.4	4.3	1	0.05	3413	0.3	406	0.05
SEC00000 - end	3.25	-0.42	0.04	1.3	2089	0.8	0.1	0.1	0.4	0.3	2.8	7.4	1.0	1	0.05	3317	0.2	395	0.05
SEC00001 - begin	3.25	-0.42	0.04	1.3	2089	0.8	0.1	0.1	0.4	0.3	2.8	7.4	1.0	1	0.05	3317	0.2	395	0.05
SCH00037 - begin	3.25	-0.43	0.04	1.3	2011	0.8	0.1	0.1	0.4	0.2	2.8	7.4	1.6	1	0.05	3245	0.2	387	0.05
SCH00037 - end	3.25	-0.43	0.04	1.3	2011	0.8	0.1	0.1	0.4	0.2	2.8	7.4	1.6	1	0.05	3245	0.2	387	0.05
SCH00063 - begin	3.25	-0.43	0.05	1.3	1914	0.8	0.1	0.1	0.4	0.2	2.7	7.4	2.4	1	0.05	3172	0.2	377	0.05
SCH00063 - end	3.25	-0.43	0.05	1.3	1914	0.8	0.1	0.1	0.4	0.2	2.7	7.4	2.4	1	0.05	3172	0.2	377	0.05
SCH00064 - begin	3.25	-0.44	0.05	1.3	1804	0.8	0.1	0.1	0.5	0.2	2.7	7.4	3.5	1	0.05	3169	0.2	374	0.05
SCH00064 - end	3.25	-0.44	0.05	1.3	1804	0.8	0.1	0.1	0.5	0.2	2.7	7.4	3.5	1	0.05	3169	0.2	374	0.05
SEC00001 - end	3.25	-0.44	0.05	1.2	1763	0.8	0.1	0.1	0.5	0.2	2.6	7.4	3.8	1	0.05	3189	0.2	375	0.05
SEC00002 - begin	3.25	-0.44	0.05	1.2	1763	0.8	0.1	0.1	0.5	0.2	2.6	7.4	3.8	1	0.05	3189	0.2	375	0.05
SCH00065 - begin	3.25	-0.45	0.06	1.2	1675	0.8	0.1	0.2	0.7	0.2	2.5	7.4	4.7	1	0.05	3350	0.2	388	0.05
SCH00065 - end	3.25	-0.45	0.06	1.2	1675	0.8	0.1	0.2	0.7	0.2	2.5	7.4	4.7	1	0.05	3350	0.2	388	0.05
SCH00066 - begin	3.25	-0.46	0.06	1.1	1877	0.8	0.1	0.2	1.1	0.2	2.4	7.4	6.3	2	0.05	3980	0.2	437	0.05
SCH00066 - end	3.25	-0.46	0.06	1.1	1877	0.8	0.1	0.2	1.1	0.2	2.4	7.4	6.3	2	0.05	3980	0.2	437	0.05
SCH00067 - begin	3.25	-0.46	0.07	0.9	1793	0.8	0.2	0.2	2.1	0.2	2.3	7.4	7.3	4	0.05	5014	0.2	516	0.05
SCH00067 - end	3.25	-0.46	0.07	0.9	1793	0.8	0.2	0.2	2.1	0.2	2.3	7.4	7.3	4	0.05	5014	0.2	516	0.05
SEC00002 - end	3.25	-0.47	0.07	0.7	1714	0.8	0.3	0.2	3.4	0.2	2.4	7.3	8.0	7	0.05	6361	0.2	619	0.05
SEC00005 - begin	16	-0.49	0.06	0.1	200	1.8	1.0	0.4	6.8	5.6	1.9	7.1	1.0	24	0.86	13214	1.0	1087	0.07
SCH00078 - begin	16	-0.5	0.06	0.1	199	1.8	1.0	0.4	6.8	5.7	1.9	7.0	1.0	24	0.86	13098	0.9	1078	0.07
SCH00078 - end	16	-0.5	0.06	0.1	199	1.8	1.0	0.4	6.8	5.7	1.9	7.0	1.0	24	0.86	13098	0.9	1078	0.07
SCH00071 - begin	16	-0.5	0.05	0.1	199	1.8	0.9	0.5	6.8	5.8	1.9	7.0	1.0	24	0.86	12973	0.9	1068	0.07
SCH00071 - end	16	-0.5	0.05	0.1	199	1.8	0.9	0.5	6.8	5.8	1.9	7.0	1.0	24	0.86	12973	0.9	1068	0.07
SCH00072 - begin	16	-0.51	0.05	0.1	198	1.8	0.9	0.5	6.8	5.8	1.9	6.8	1.0	24	0.86	12793	0.9	1055	0.07
SCH00072 - end	16	-0.51	0.05	0.1	198	1.8	0.9	0.5	6.8	5.8	1.9	6.8	1.0	24	0.86	12793	0.9	1055	0.07
SEC00005 - end	16	-0.51	0.05	0.1	198	1.8	0.9	0.5	6.8	5.9	1.9	6.8	1.0	24	0.86	12754	0.9	1052	0.07
SEC00014 - begin	17.1	-0.55	0.05	0.5	1463	1.8	0.4	0.6	6.7	6.3	0.9	6.4	8.0	17	0.85	10298	0.9	882	0.06
SCH00039 - begin	17.1	-0.56	0.05	0.5	1411	1.8	0.4	0.5	6.7	6.2	0.9	6.4	8.6	17	0.85	10006	0.9	861	0.06
SCH00039 - end	17.1	-0.56	0.05	0.5	1411	1.8	0.4	0.5	6.7	6.2	0.9	6.4	8.6	17	0.85	10006	0.9	861	0.06
SEC00014 - end	17.1	-0.57	0.05	0.5	1378	1.8	0.4	0.5	6.7	6.2	0.8	6.3	9.0	17	0.85	9818	0.8	846	0.06
SEC00009 - begin	17.1	-0.57	0.05	0.5	1378	1.8	0.4	0.5	6.7	6.2	0.8	6.3	9.0	17	0.85	9818	0.8	846	0.06
SCH00040 - begin	17.1	-0.58	0.05	0.6	1378	1.8	0.4	0.4	6.6	6.2	0.6	6.1	9.7	17	0.85	9442	0.8	829	0.06

	Flow	Level	a1	ab	bodb	bodw	nh4b	nh4w	no3b	no3w	o2b	o2w	ssw	tipb	tipw	tonb	tonw	topb	topw
SCH00040 - end	17.1	-0.58	0.05	0.6	1378	1.8	0.4	0.4	6.6	6.2	0.6	6.1	9.7	17	0.85	9442	0.8	829	0.06
SEC00009 - end	17.1	-0.59	0.05	0.6	1345	1.8	0.3	0.4	6.6	6.1	0.8	6.0	10.0	17	0.85	9232	0.8	812	0.06
SEC00010 - begin	17.1	-0.59	0.05	0.6	1345	1.8	0.3	0.4	6.6	6.1	0.8	6.0	10.0	17	0.85	9232	0.8	812	0.06
SEC00010 - end	17.1	-0.6	0.05	0.6	1328	1.8	0.4	0.4	6.5	5.8	0.9	5.9	12.5	17	0.85	8796	0.8	781	0.06
SEC00011 - begin	17.1	-0.6	0.05	0.6	1328	1.8	0.4	0.4	6.5	5.8	0.9	5.9	12.5	17	0.85	8796	0.8	781	0.06
SCH00041 - begin	17.1	-0.6	0.05	0.6	89	1.8	1.3	0.4	6.5	5.7	-25.4	6.1	13.5	31	0.85	8645	0.8	773	0.06
SCH00041 - end	17.1	-0.6	0.05	0.6	89	1.8	1.3	0.4	6.5	5.7	-25.4	6.1	13.5	31	0.85	8645	0.8	773	0.06
SCH00032 - begin	17.1	-0.61	0.05	0.6	90	1.8	1.3	0.5	6.4	5.5	-25.3	6.6	15.3	31	0.85	8345	0.9	751	0.06
SCH00032 - end	17.1	-0.61	0.05	0.6	90	1.8	1.3	0.5	6.4	5.5	-25.3	6.6	15.3	31	0.85	8345	0.9	751	0.06
SEC00011 - end	17.1	-0.62	0.06	0.6	91	1.8	1.3	0.5	6.3	5.2	-24.9	6.2	17.9	30	0.85	7686	0.9	704	0.06
SEC00016 - begin	20.36	-0.66	0.06	0.6	19	1.7	3.3	0.6	4.0	3.6	-24.2	5.4	23.1	61	0.72	5593	0.9	588	0.06
SCH00045 - begin	20.36	-0.67	0.06	0.6	481	1.7	0.4	0.3	4.5	3.0	1.9	5.3	27.0	11	0.72	5243	0.4	552	0.06
SCH00045 - end	20.36	-0.67	0.06	0.6	481	1.7	0.4	0.3	4.5	3.0	1.9	5.3	27.0	11	0.72	5243	0.4	552	0.06
SCH00013 - begin	20.36	-0.69	0.06	0.6	461	1.7	0.3	0.3	4.6	2.9	1.5	5.3	24.6	12	0.72	5006	0.3	525	0.06
SCH00013 - end	20.36	-0.69	0.06	0.6	461	1.7	0.3	0.3	4.6	2.9	1.5	5.3	24.6	12	0.72	5006	0.3	525	0.06
SCH00046 - begin	20.36	-0.69	0.05	0.6	451	1.7	0.3	0.3	4.8	2.8	1.3	5.3	23.4	12	0.72	4672	0.3	481	0.06
SCH00046 - end	20.36	-0.69	0.05	0.6	451	1.7	0.3	0.3	4.8	2.8	1.3	5.3	23.4	12	0.72	4672	0.3	481	0.06
SEC00016 - end	20.36	-0.7	0.05	0.6	438	1.7	0.3	0.3	5.1	2.7	1.1	5.3	22.6	12	0.72	4632	0.2	464	0.06
SEC00019 - begin	20.36	-0.74	0.06	0.3	257	1.7	0.4	0.2	6.3	2.5	1.4	4.8	16.6	16	0.72	3700	0.4	303	0.06
SCH00048 - begin	20.36	-0.74	0.06	0.3	260	1.7	0.4	0.3	6.4	2.6	1.4	4.5	16.0	17	0.72	3719	0.4	299	0.06
SCH00048 - end	20.36	-0.74	0.06	0.3	260	1.7	0.4	0.3	6.4	2.6	1.4	4.5	16.0	17	0.72	3719	0.4	299	0.06
SCH00049 - begin	20.36	-0.74	0.07	0.3	269	1.7	0.5	0.3	6.6	2.6	1.3	4.0	14.8	17	0.72	3870	0.4	297	0.06
SCH00049 - end	20.36	-0.74	0.07	0.3	269	1.7	0.5	0.3	6.6	2.6	1.3	4.0	14.8	17	0.72	3870	0.4	297	0.06
SEC00019 - end	20.36	-0.74	0.07	0.3	276	1.7	0.5	0.3	6.8	2.6	1.4	3.6	14.0	18	0.72	4018	0.4	300	0.06
SEC00033 - begin	48.84	-0.75	0.05	0.2	0	1.9	350.8	0.3	0.4	6.6	-152.9	5.7	20.0	615	0.44	5861	0.9	402	0.08
SCH00011 - begin	48.84	-0.75	0.05	0.2	0	1.9	328.8	0.3	0.4	6.4	-153.9	5.8	19.3	609	0.44	5546	0.9	382	0.08
SCH00011 - end	48.84	-0.75	0.05	0.2	0	1.9	328.8	0.3	0.4	6.4	-153.9	5.8	19.3	609	0.44	5546	0.9	382	0.08
SCH00052 - begin	48.84	-0.75	0.05	0.2	0	1.9	308.5	0.3	0.4	6.2	-153.9	5.9	18.8	608	0.44	5270	0.9	363	0.08
SCH00052 - end	48.84	-0.75	0.05	0.2	0	1.9	308.5	0.3	0.4	6.2	-153.9	5.9	18.8	608	0.44	5270	0.9	363	0.08
SEC00033 - end	48.84	-0.75	0.05	0.2	0	1.9	307.6	0.3	0.4	6.2	-154.0	5.9	18.8	607	0.44	5255	0.9	362	0.08
SEC00034 - begin	48.84	-0.59	0.06	0.2	0	1.9	231.1	0.4	0.4	4.5	-161.8	4.4	14.4	584	0.44	4056	0.6	284	0.08
SEC00034 - end	48.84	-0.56	0.06	0.2	0	1.9	223.8	0.4	0.4	4.4	-161.5	4.3	14.0	599	0.44	3941	0.6	284	0.08
SEC00008 - begin	3.26	-0.7	0.06	0.6	25	1.1	1.9	0.1	1.0	0.8	-27.7	8.5	6.3	12	0.05	3778	0.3	543	0.06
SCH00044 - begin	3.26	-0.68	0.03	0.5	22	1.1	2.2	0.1	1.7	0.4	-25.4	6.9	7.6	22	0.05	3888	0.2	516	0.06
SCH00044 - end	3.26	-0.68	0.03	0.5	22	1.1	2.2	0.1	1.7	0.4	-25.4	6.9	7.6	22	0.05	3888	0.2	516	0.06
SEC00008 - end	3.26	-0.67	0.02	0.6	21	1.1	2.3	0.1	2.2	0.3	-24.9	6.5	8.0	29	0.05	4149	0.2	523	0.06
SEC00021 - begin	0.83	-0.6	0.14	1.5	249	1.3	0.4	0.3	4.3	4.5	-5.7	7.3	47.0	37	0.97	3754	1.1	1366	0.06
SCH00056 - begin	0.83	-0.61	0.14	1.5	269	1.3	0.4	0.3	4.3	4.5	-6.5	7.3	47.0	36	0.97	3739	1.1	1329	0.06
SCH00056 - end	0.83	-0.61	0.14	1.5	269	1.3	0.4	0.3	4.3	4.5	-6.5	7.3	47.0	36	0.97	3739	1.1	1329	0.06
SCH00002 - begin	0.83	-0.61	0.14	1.5	270	1.3	0.4	0.3	4.3	4.5	-6.5	7.3	47.0	36	0.97	3698	1.1	1312	0.06

	Flow	Level	a1	ab	bodb	bodw	nh4b	nh4w	no3b	no3w	o2b	o2w	ssw	tipb	tipw	tonb	tonw	topb	topw
SCH00002 - end	0.83	-0.61	0.14	1.5	270	1.3	0.4	0.3	4.3	4.5	-6.5	7.3	47.0	36	0.97	3698	1.1	1312	0.06
SCH00004 - begin	0.95	-0.62	0.14	1.6	266	1.3	0.4	0.3	4.3	4.5	-6.1	7.3	47.0	34	0.97	3606	1.1	1282	0.06
SCH00004 - end	0.95	-0.62	0.14	1.6	266	1.3	0.4	0.3	4.3	4.5	-6.1	7.3	47.0	34	0.97	3606	1.1	1282	0.06
SCH00057 - begin	0.95	-0.65	0.13	1.6	361	1.3	0.5	0.2	4.2	5.8	-9.7	6.7	39.3	32	0.97	3703	1.1	1145	0.06
SCH00057 - end	0.95	-0.65	0.13	1.6	361	1.3	0.5	0.2	4.2	5.8	-9.7	6.7	39.3	32	0.97	3703	1.1	1145	0.06
SCH00005 - begin	0.95	-0.66	0.12	1.6	361	1.3	0.5	0.2	4.2	6.5	-9.5	6.3	35.0	31	0.97	3618	1.1	1116	0.06
SCH00005 - end	0.95	-0.66	0.12	1.6	361	1.3	0.5	0.2	4.2	6.5	-9.5	6.3	35.0	31	0.97	3618	1.1	1116	0.06
SCH00058 - begin	0.95	-0.67	0.11	1.6	377	1.3	0.4	0.2	4.2	7.3	-9.9	5.9	29.9	30	0.97	3525	1.1	1060	0.06
SCH00058 - end	0.95	-0.67	0.11	1.6	377	1.3	0.4	0.2	4.2	7.3	-9.9	5.9	29.9	30	0.97	3525	1.1	1060	0.06
SCH00001 - begin	0.95	-0.69	0.10	1.6	371	1.3	0.4	0.2	4.3	8.3	-9.5	5.4	24.0	28	0.97	3381	1.0	1008	0.06
SCH00001 - end	0.95	-0.69	0.10	1.6	371	1.3	0.4	0.2	4.3	8.3	-9.5	5.4	24.0	28	0.97	3381	1.0	1008	0.06
SEC00021 - end	0.95	-0.7	0.09	1.4	339	1.3	0.4	0.2	4.4	8.9	-8.5	5.1	20.0	32	0.97	3467	1.0	914	0.06
SEC00022 - begin	0.95	-0.7	0.09	1.4	339	1.3	0.4	0.2	4.4	8.9	-8.5	5.1	20.0	32	0.97	3467	1.0	914	0.06
SEC00022 - end	21.66	-0.54	0.05	0.8	475	1.9	0.3	0.2	4.8	4.5	1.0	5.3	15.2	32	1.63	4753	0.8	606	0.08
SEC00029 - begin	20.72	-0.54	0.05	0.5	432	1.9	0.3	0.2	4.9	4.3	1.3	5.3	15.0	34	1.66	5940	0.7	416	0.08
SEC00029 - end	21.66	-0.54	0.05	0.8	475	1.9	0.3	0.2	4.8	4.5	1.0	5.3	15.2	32	1.63	4753	0.8	606	0.08
SEC00007 - begin	21.66	-0.54	0.05	0.8	475	1.9	0.3	0.2	4.8	4.5	1.0	5.3	15.2	32	1.63	4753	0.8	606	0.08
SCH00055 - begin	21.66	-0.53	0.08	0.8	497	1.9	0.3	0.3	4.8	4.3	0.8	5.4	16.6	32	1.63	4745	0.7	600	0.08
SCH00055 - end	21.66	-0.53	0.08	0.8	497	1.9	0.3	0.3	4.8	4.3	0.8	5.4	16.6	32	1.63	4745	0.7	600	0.08
SEC00007 - end	21.66	-0.53	0.11	0.8	490	1.9	0.3	0.5	4.7	4.1	0.8	5.5	18.0	32	1.63	4662	0.7	590	0.08
SEC00032 - begin	22.1	-0.3	0.16	0.8	322	1.9	0.2	0.2	4.5	4.0	2.1	5.0	18.0	30	1.62	2523	0.7	413	0.08
SCH00014 - begin	22.12	-0.3	0.16	0.5	365	1.9	0.3	0.2	6.0	4.0	1.8	5.0	18.0	22	1.62	3878	0.7	415	0.08
SCH00014 - end	22.12	-0.3	0.16	0.5	365	1.9	0.3	0.2	6.0	4.0	1.8	6.0	18.0	22	1.62	3878	0.7	415	0.08
SEC00032 - end	71.03	-0.29	0.09	0.4	0	1.9	219.4	0.3	0.3	4.3	-19.3	4.8	15.3	842	0.81	3829	0.6	357	0.08
SEC00025 - begin	1.46	-0.64	0.10	0.6	21	0.8	3.5	0.1	3.7	0.3	1.4	8.5	11.3	147	0.05	6054	0.3	401	0.03
SCH00008 - begin	1.46	-0.63	0.10	0.6	20	0.8	3.6	0.1	3.8	0.3	1.5	8.5	11.3	150	0.05	6119	0.3	410	0.03
SCH00008 - end	1.46	-0.63	0.10	0.6	20	0.8	3.6	0.1	3.8	0.3	1.5	8.5	11.3	150	0.05	6119	0.3	410	0.03
SCH00062 - begin	1.46	-0.62	0.11	0.6	232	0.8	0.4	0.1	4.2	0.3	1.3	8.4	11.7	39	0.05	6146	0.3	412	0.03
SCH00062 - end	1.46	-0.62	0.11	0.6	232	0.8	0.4	0.1	4.2	0.3	1.3	8.4	11.7	39	0.05	6146	0.3	412	0.03
SCH00009 - begin	1.46	-0.62	0.13	0.5	231	0.8	0.4	0.1	4.3	0.3	1.3	8.3	12.4	39	0.05	6224	0.3	416	0.03
SCH00009 - end	1.46	-0.62	0.13	0.5	231	0.8	0.4	0.1	4.3	0.3	1.3	8.3	12.4	39	0.05	6224	0.3	416	0.03
SCH00061 - begin	1.46	-0.61	0.16	0.5	230	0.8	0.4	0.1	4.4	0.3	1.3	8.2	13.0	40	0.05	6303	0.3	421	0.03
SCH00061 - end	1.46	-0.61	0.16	0.5	230	0.8	0.4	0.1	4.4	0.3	1.3	8.2	13.0	40	0.05	6303	0.3	421	0.03
SEC00025 - end	1.46	-0.59	0.22	0.5	224	0.8	0.4	0.1	4.6	0.3	1.5	7.8	15.0	41	0.05	6657	0.3	441	0.03
SEC00041 - begin	48.84	-0.75	0.05	0.2	0	1.9	307.6	0.3	0.4	6.2	-154.0	5.9	18.8	607	0.44	5255	0.9	362	0.08
SEC00041 - end	48.84	-0.76	0.06	0.2	0	1.9	255.3	0.3	0.4	5.3	-159.0	5.1	16.4	589	0.44	4459	0.7	309	0.08
SEC00042 - begin	48.84	-0.76	0.06	0.2	0	1.9	255.3	0.3	0.4	5.3	-159.0	5.1	16.4	589	0.44	4459	0.7	309	0.08
SEC00042 - end	48.84	-0.59	0.06	0.2	0	1.9	231.1	0.4	0.4	4.5	-161.8	4.4	14.4	584	0.44	4056	0.6	284	0.08
SEC00044 - begin	48.84	-0.56	0.06	0.2	0	1.9	223.8	0.4	0.4	4.4	-161.5	4.3	14.0	599	0.44	3941	0.6	284	0.08
SCH00015 - begin	48.91	-0.54	0.06	0.4	0	1.9	222.0	0.4	0.3	4.4	-146.0	4.3	14.0	752	0.44	3801	0.6	330	0.08

	Flow	Level	a1	ab	bodb	bodw	nh4b	nh4w	no3b	no3w	o2b	o2w	ssw	tipb	tipw	tonb	tonw	topb	topw
SCH00015 - end	48.91	-0.54	0.06	0.4	0	1.9	222.0	0.4	0.3	4.4	-146.0	4.3	14.0	752	0.44	3801	0.6	330	0.08
SEC00044 - end	48.91	-0.54	0.09	0.4	0	1.9	219.4	0.3	0.3	4.3	-19.3	4.8	15.3	842	0.44	3829	0.6	357	0.08
SEC00003 - begin	3.25	-0.47	0.07	0.7	1714	0.8	0.3	0.2	3.4	0.2	2.4	7.3	8.0	7	0.05	6361	0.2	619	0.05
SCH00068 - begin	3.25	-0.47	0.07	0.6	1714	0.8	0.3	0.2	3.7	0.2	2.4	7.4	8.1	8	0.05	6685	0.2	644	0.05
SCH00068 - end	3.25	-0.47	0.07	0.6	1714	0.8	0.3	0.2	3.7	0.2	2.4	7.4	8.1	8	0.05	6685	0.2	644	0.05
SCH00069 - begin	3.25	-0.47	0.08	0.5	1735	0.8	0.4	0.2	5.1	0.2	2.5	7.4	8.7	12	0.05	8420	0.2	771	0.05
SCH00069 - end	3.25	-0.47	0.08	0.5	1735	0.8	0.4	0.2	5.1	0.2	2.5	7.4	8.7	12	0.05	8420	0.2	771	0.05
SCH00077 - begin	3.25	-0.47	0.08	0.4	1763	0.8	0.4	0.2	6.0	0.2	2.7	7.4	9.0	14	0.05	9987	0.2	881	0.05
SCH00077 - end	3.25	-0.47	0.08	0.4	1763	0.8	0.4	0.2	6.0	0.2	2.7	7.4	9.0	14	0.05	9987	0.2	881	0.05
SCH00007 - begin	16	-0.48	0.02	0.1	1801	1.8	0.5	4.2	7.0	4.2	1.9	7.5	5.0	18	0.86	13775	0.5	1128	0.07
SCH00007 - end	16	-0.48	0.02	0.1	1801	1.8	0.5	4.2	7.0	4.2	1.9	7.5	5.0	18	0.86	13775	0.5	1128	0.07
SCH00070 - begin	16	-0.48	0.03	0.1	1770	1.8	0.5	2.5	7.0	4.9	1.9	7.3	3.2	18	0.86	13553	0.7	1113	0.07
SCH00070 - end	16	-0.48	0.03	0.1	1770	1.8	0.5	2.5	7.0	4.9	1.9	7.3	3.2	18	0.86	13553	0.7	1113	0.07
SEC00003 - end	16	-0.49	0.06	0.1	200	1.8	1.0	0.4	6.8	5.6	1.9	7.1	1.0	24	0.86	13214	1.0	1087	0.07
SEC00004 - begin	16	-0.51	0.05	0.1	198	1.8	0.9	0.5	6.8	5.9	1.9	6.8	1.0	24	0.86	12754	0.9	1052	0.07
SCH00021 - begin	16	-0.51	0.05	0.1	197	1.8	0.9	0.5	6.8	5.9	1.9	6.7	1.0	24	0.86	12626	0.9	1042	0.07
SCH00021 - end	16	-0.51	0.05	0.1	197	1.8	0.9	0.5	6.8	5.9	1.9	6.7	1.0	24	0.86	12626	0.9	1042	0.07
SCH00073 - begin	16	-0.52	0.05	0.1	197	1.8	0.9	0.5	6.9	6.0	1.9	6.6	1.0	24	0.86	12541	0.9	1036	0.07
SCH00073 - end	16	-0.52	0.05	0.1	197	1.8	0.9	0.5	6.9	6.0	1.9	6.6	1.0	24	0.86	12541	0.9	1036	0.07
SCH00074 - begin	16	-0.52	0.05	0.1	196	1.8	0.9	0.5	6.9	6.0	1.9	6.5	1.0	24	0.86	12460	0.9	1030	0.07
SCH00074 - end	16	-0.52	0.05	0.1	196	1.8	0.9	0.5	6.9	6.0	1.9	6.5	1.0	24	0.86	12460	0.9	1030	0.07
SCH00075 - begin	16	-0.53	0.04	0.1	196	1.8	0.9	0.5	6.9	6.1	1.9	6.4	1.0	24	0.86	12337	0.9	1021	0.07
SCH00075 - end	16	-0.53	0.04	0.1	196	1.8	0.9	0.5	6.9	6.1	1.9	6.4	1.0	24	0.86	12337	0.9	1021	0.07
SCH00076 - begin	16	-0.53	0.04	0.1	195	1.8	0.9	0.6	6.9	6.2	1.9	6.3	1.0	24	0.86	12170	0.9	1009	0.07
SCH00076 - end	16	-0.53	0.04	0.1	195	1.8	0.9	0.6	6.9	6.2	1.9	6.3	1.0	24	0.86	12170	0.9	1009	0.07
SCH00010 - begin	17.1	-0.54	0.05	0.5	193	1.8	1.0	0.5	6.6	6.0	1.1	6.4	2.3	25	0.85	10415	0.9	889	0.06
SCH00010 - end	17.1	-0.54	0.05	0.5	193	1.8	1.0	0.5	6.6	6.0	1.1	6.4	2.3	25	0.85	10415	0.9	889	0.06
SCH00017 - begin	17.1	-0.54	0.05	0.5	1481	1.8	0.4	0.5	6.7	6.0	0.9	6.4	2.3	17	0.85	10396	0.9	890	0.06
SCH00017 - end	17.1	-0.54	0.05	0.5	1481	1.8	0.4	0.5	6.7	6.0	0.9	6.4	2.3	17	0.85	10396	0.9	890	0.06
SEC00004 - end	17.1	-0.55	0.05	0.5	1463	1.8	0.4	0.6	6.7	6.3	0.9	6.4	8.0	17	0.85	10298	0.9	882	0.06
SEC00015 - begin	3.26	-0.67	0.02	0.6	21	1.1	2.3	0.1	2.2	0.3	-24.9	6.5	8.0	29	0.05	4149	0.2	523	0.06
SEC00015 - end	20.36	-0.66	0.06	0.6	19	1.7	3.3	0.6	4.0	3.6	-24.2	5.4	23.1	61	0.72	5593	0.9	588	0.06
SEC00017 - begin	20.36	-0.7	0.05	0.6	438	1.7	0.3	0.3	5.1	2.7	1.1	5.3	22.6	12	0.72	4632	0.2	464	0.06
SCH00019 - begin	20.36	-0.71	0.04	0.5	420	1.7	0.3	0.4	5.8	2.6	0.8	5.3	21.0	14	0.72	4270	0.2	390	0.06
SCH00019 - end	20.36	-0.71	0.04	0.5	420	1.7	0.3	0.4	5.8	2.6	0.8	5.3	21.0	14	0.72	4270	0.2	390	0.06
SEC00017 - end	20.36	-0.72	0.04	0.5	415	1.7	0.3	0.4	6.1	2.6	0.7	5.3	21.0	15	0.72	3837	0.2	330	0.06
SEC00018 - begin	20.36	-0.74	0.07	0.3	276	1.7	0.5	0.3	6.8	2.6	1.4	3.6	14.0	18	0.72	4018	0.4	300	0.06
SCH00050 - begin	20.36	-0.74	0.07	0.3	277	1.7	0.5	0.4	6.8	2.7	1.4	3.8	13.7	18	0.72	4035	0.4	301	0.06
SCH00050 - end	20.36	-0.74	0.07	0.3	277	1.7	0.5	0.4	6.8	2.7	1.4	3.8	13.7	18	0.72	4035	0.4	301	0.06
SCH00020 - begin	48.84	-0.74	0.03	0.2	0	1.9	540.3	0.8	0.3	3.2	-149.5	5.5	8.8	642	0.44	6326	0.9	434	0.08

	Flow	Level	a1	ab	bodb	bodw	nh4b	nh4w	no3b	no3w	o2b	o2w	ssw	tipb	tipw	tonb	tonw	topb	topw
SCH00020 - end	48.84	-0.74	0.03	0.2	0	1.9	540.3	0.8	0.3	3.2	-149.5	5.5	8.8	642	0.44	6326	0.9	434	0.08
SCH00051 - begin	48.84	-0.74	0.04	0.2	0	1.9	367.8	0.7	0.4	4.3	-152.6	5.6	12.5	619	0.44	6107	0.9	419	0.08
SCH00051 - end	48.84	-0.74	0.04	0.2	0	1.9	367.8	0.7	0.4	4.3	-152.6	5.6	12.5	619	0.44	6107	0.9	419	0.08
SEC00018 - end	48.84	-0.75	0.05	0.2	0	1.9	350.8	0.3	0.4	6.6	-152.9	5.7	20.0	615	0.44	5861	0.9	402	0.08
SEC00020 - begin	71.03	-0.54	0.09	0.4	0	1.9	219.4	0.3	0.3	4.3	-19.3	4.8	15.3	842	0.81	3829	0.6	357	0.08
SCH00024 - begin	71.12	-0.64	0.09	0.4	0	1.9	208.1	0.3	0.3	4.3	-19.5	4.8	15.3	842	0.81	3632	0.6	341	0.08
SCH00024 - end	71.12	-0.64	0.09	0.4	0	1.9	208.1	0.3	0.3	4.3	-19.5	4.8	15.3	842	0.81	3632	0.6	341	0.08
SCH00018 - begin	71.12	-0.68	0.09	0.4	0	1.9	203.0	0.4	0.3	4.5	-19.5	4.7	15.2	840	0.81	3543	0.7	334	0.08
SCH00018 - end	71.12	-0.68	0.09	0.4	0	1.9	203.0	0.4	0.3	4.5	-19.5	4.7	15.2	840	0.81	3543	0.7	334	0.08
SCH00025 - begin	71.12	-0.71	0.10	0.4	0	1.9	197.9	0.4	0.3	4.7	-19.6	4.6	15.2	839	0.81	3486	0.8	330	0.08
SCH00025 - end	71.12	-0.71	0.10	0.4	0	1.9	197.9	0.4	0.3	4.7	-19.6	4.6	15.2	839	0.81	3486	0.8	330	0.08
SEC00020 - end	71.12	-0.76	0.11	0.4	0	1.9	192.5	0.5	0.3	5.0	-19.7	4.5	15.1	836	0.81	3392	0.9	322	0.08
SEC00024 - begin	1.46	-0.59	0.22	0.5	224	0.8	0.4	0.1	4.6	0.3	1.5	7.8	15.0	41	0.05	6657	0.3	441	0.03
SCH00060 - begin	1.46	-0.58	0.22	0.5	221	0.8	0.5	0.1	4.7	0.3	1.6	7.8	15.0	42	0.05	7022	0.3	463	0.03
SCH00060 - end	1.46	-0.58	0.22	0.5	221	0.8	0.5	0.1	4.7	0.3	1.6	7.8	15.0	42	0.05	7022	0.3	463	0.03
SCH00022 - begin	1.46	-0.56	0.22	0.5	221	0.8	0.5	0.1	4.9	0.3	1.3	7.8	15.0	43	0.05	7373	0.3	485	0.03
SCH00022 - end	1.46	-0.56	0.22	0.5	221	0.8	0.5	0.1	4.9	0.3	1.3	7.8	15.0	43	0.05	7373	0.3	485	0.03
SCH00026 - begin	20.72	-0.56	0.02	0.4	446	1.9	0.3	0.0	4.9	9.5	1.3	7.1	5.7	35	1.66	7450	1.2	489	0.08
SCH00026 - end	20.72	-0.56	0.02	0.4	446	1.9	0.3	0.0	4.9	9.5	1.3	7.1	5.7	35	1.66	7450	1.2	489	0.08
SCH00023 - begin	20.72	-0.56	0.02	0.5	442	1.9	0.3	0.1	4.9	8.9	1.4	7.3	6.7	35	1.66	7252	1.2	477	0.08
SCH00023 - end	20.72	-0.56	0.02	0.5	442	1.9	0.3	0.1	4.9	8.9	1.4	7.3	6.7	35	1.66	7252	1.2	477	0.08
SCH00059 - begin	20.72	-0.55	0.04	0.5	442	1.9	0.3	0.1	4.9	6.6	1.2	6.3	11.0	35	1.66	6448	1.0	435	0.08
SCH00059 - end	20.72	-0.55	0.04	0.5	442	1.9	0.3	0.1	4.9	6.6	1.2	6.3	11.0	35	1.66	6448	1.0	435	0.08
SEC00024 - end	20.72	-0.54	0.05	0.5	432	1.9	0.3	0.2	4.9	4.3	1.3	5.3	15.0	34	1.66	5940	0.7	416	0.08
SEC00026 - begin	21.66	-0.53	0.11	0.8	490	1.9	0.3	0.5	4.7	4.1	0.8	5.5	18.0	32	1.63	4662	0.7	590	0.08
SCH00054 - begin	21.66	-0.52	0.11	0.8	479	1.9	0.2	0.5	4.6	4.1	1.0	5.8	18.0	32	1.63	4438	0.7	566	0.08
SCH00054 - end	21.66	-0.52	0.11	0.8	479	1.9	0.2	0.5	4.6	4.1	1.0	5.8	18.0	32	1.63	4438	0.7	566	0.08
SCH00030 - begin	21.66	-0.51	0.11	0.8	475	1.9	0.2	0.5	4.6	4.1	1.3	5.9	18.1	32	1.63	4397	0.7	564	0.08
SCH00030 - end	21.66	-0.51	0.11	0.8	475	1.9	0.2	0.5	4.6	4.1	1.3	5.9	18.1	32	1.63	4397	0.7	564	0.08
SCH00003 - begin	21.71	-0.51	0.11	0.8	471	1.9	0.2	0.5	4.5	4.1	1.3	5.3	18.1	32	1.63	4347	0.7	574	0.08
SCH00003 - end	21.71	-0.51	0.11	0.8	471	1.9	0.2	0.5	4.5	4.1	1.3	5.3	18.1	32	1.63	4347	0.7	574	0.08
SCH00027 - begin	21.81	-0.5	0.11	0.8	457	1.9	0.2	0.4	4.4	4.1	1.5	5.3	18.2	31	1.63	4161	0.7	593	0.08
SCH00027 - end	21.81	-0.5	0.11	0.8	457	1.9	0.2	0.4	4.4	4.1	1.5	5.3	18.2	31	1.63	4161	0.7	593	0.08
SCH00053 - begin	21.81	-0.48	0.13	0.8	453	1.9	0.2	0.3	4.3	3.7	1.5	5.4	24.8	31	1.63	3965	0.7	565	0.08
SCH00053 - end	21.81	-0.48	0.13	0.8	453	1.9	0.2	0.3	4.3	3.7	1.5	5.4	24.8	31	1.63	3965	0.7	565	0.08
SCH00016 - begin	21.81	-0.48	0.13	0.8	448	1.9	0.2	0.3	4.3	3.5	1.4	5.4	27.0	31	1.63	3891	0.7	556	0.08
SCH00016 - end	21.81	-0.48	0.13	0.8	448	1.9	0.2	0.3	4.3	3.5	1.4	5.4	27.0	31	1.63	3891	0.7	556	0.08
SEC00026 - end	21.81	-0.47	0.14	0.9	440	1.9	0.2	0.2	4.2	3.3	1.3	5.4	32.0	31	1.63	3732	0.7	535	0.08
SEC00027 - begin	21.81	-0.47	0.14	0.9	440	1.9	0.2	0.2	4.2	3.3	1.3	5.4	32.0	31	1.63	3732	0.7	535	0.08
SCH00028 - begin	21.93	-0.45	0.14	0.9	445	1.9	0.2	0.2	4.2	3.3	1.1	5.5	32.1	31	1.62	3578	0.7	562	0.08

	Flow	Level	a1	ab	bodb	bodw	nh4b	nh4w	no3b	no3w	o2b	o2w	ssw	tipb	tipw	tonb	tonw	topb	topw
SCH00028 - end	21.93	-0.45	0.14	0.9	445	1.9	0.2	0.2	4.2	3.3	1.1	5.5	32.1	31	1.62	3578	0.7	562	0.08
SCH00038 - begin	21.93	-0.42	0.14	0.9	410	1.9	0.2	0.2	4.1	3.3	1.6	6.0	32.1	31	1.62	3181	0.7	504	0.08
SCH00038 - end	21.93	-0.42	0.14	0.9	410	1.9	0.2	0.2	4.1	3.3	1.6	6.0	32.1	31	1.62	3181	0.7	504	0.08
SCH00000 - begin	22.1	-0.38	0.14	0.9	381	1.9	0.2	0.2	4.1	3.3	1.3	5.5	32.2	32	1.62	2895	0.7	522	0.08
SCH00000 - end	22.1	-0.38	0.14	0.9	381	1.9	0.2	0.2	4.1	3.3	1.3	5.5	32.2	32	1.62	2895	0.7	522	0.08
SEC00027 - end	22.1	-0.3	0.16	0.8	322	1.9	0.2	0.2	4.5	4.0	2.1	5.0	18.0	30	1.62	2523	0.7	413	0.08
SEC00023 - begin	17.1	-0.63	0.06	0.6	91	1.8	1.2	0.6	6.2	4.9	-24.9	5.9	20.4	29	0.85	7392	0.9	684	0.06
SEC00023 - end	17.1	-0.64	0.06	0.6	92	1.8	1.2	0.7	6.0	4.5	-25.1	5.5	23.6	29	0.85	7052	0.9	661	0.06
SEC00028 - begin	17.1	-0.65	0.07	0.6	93	1.8	1.1	0.7	5.8	4.2	-24.5	5.1	26.0	28	0.85	6857	1.0	651	0.06
SEC00028 - end	20.36	-0.66	0.06	0.6	19	1.7	3.3	0.6	4.0	3.6	-24.2	5.4	23.1	61	0.72	5593	0.9	588	0.06
SEC00006 - begin	17.1	-0.62	0.06	0.6	91	1.8	1.3	0.5	6.3	5.2	-24.9	6.2	17.9	30	0.85	7686	0.9	704	0.06
SCH00042 - begin	17.1	-0.62	0.06	0.6	91	1.8	1.2	0.6	6.3	5.0	-24.9	6.0	19.3	30	0.85	7540	0.9	694	0.06
SCH00042 - end	17.1	-0.62	0.06	0.6	91	1.8	1.2	0.6	6.3	5.0	-24.9	6.0	19.3	30	0.85	7540	0.9	694	0.06
SEC00006 - end	17.1	-0.63	0.06	0.6	91	1.8	1.2	0.6	6.2	4.9	-24.9	5.9	20.4	29	0.85	7392	0.9	684	0.06
SEC00012 - begin	17.1	-0.64	0.06	0.6	92	1.8	1.2	0.7	6.0	4.5	-25.1	5.5	23.6	29	0.85	7052	0.9	661	0.06
SCH00043 - begin	17.1	-0.65	0.07	0.6	93	1.8	1.1	0.7	5.9	4.3	-24.5	5.2	25.2	28	0.85	6915	1.0	654	0.06
SCH00043 - end	17.1	-0.65	0.07	0.6	93	1.8	1.1	0.7	5.9	4.3	-24.5	5.2	25.2	28	0.85	6915	1.0	654	0.06
SEC00012 - end	17.1	-0.65	0.07	0.6	93	1.8	1.1	0.7	5.8	4.2	-24.5	5.1	26.0	28	0.85	6857	1.0	651	0.06
SEC00013 - begin	17.1	-0.62	0.06	0.6	91	1.8	1.3	0.5	6.3	5.2	-24.9	6.2	17.9	30	0.85	7686	0.9	704	0.06
SEC00013 - end	17.1	-0.63	0.06	0.6	92	1.8	1.2	0.7	6.0	4.5	-25.1	5.5	23.6	29	0.85	7052	0.9	661	0.06
SEC00043 - begin	0	-0.72	0.04	0.5	415	1.7	0.3	0.4	6.1	2.6	0.7	5.3	21.0	15	0.72	3837	0.2	330	0.06
SCH00006 - begin	0	-0.72	0.04	0.5	998	1.7	0.2	0.5	6.1	2.4	1.4	5.2	95.6	13	0.72	3716	0.6	319	0.06
SCH00006 - end	0	-0.72	0.04	0.5	998	1.7	0.2	0.5	6.1	2.4	1.4	5.2	95.6	13	0.72	3716	0.6	319	0.06
SCH00012 - begin	0	-0.72	0.03	0.5	988	1.7	0.2	0.6	6.1	2.2	1.4	5.0	200.9	13	0.72	3458	1.1	295	0.06
SCH00012 - end	0	-0.72	0.03	0.5	988	1.7	0.2	0.6	6.1	2.2	1.4	5.0	200.9	13	0.72	3458	1.1	295	0.06
SCH00029 - begin	0	-0.72	0.03	0.5	978	1.7	0.2	0.8	6.1	1.9	1.4	4.5	324.1	13	0.72	3252	1.7	275	0.06
SCH00029 - end	0	-0.72	0.03	0.5	978	1.7	0.2	0.8	6.1	1.9	1.4	4.5	324.1	13	0.72	3252	1.7	275	0.06
SCH00031 - begin	0	-0.72	0.01	0.5	959	1.7	0.2	1.2	6.1	1.3	1.4	3.5	595.4	13	0.72	2973	3.0	249	0.06
SCH00031 - end	0	-0.72	0.01	0.5	959	1.7	0.2	1.2	6.1	1.3	1.4	3.5	595.4	13	0.72	2973	3.0	249	0.06
SCH00033 - begin	0	-0.72	0.00	0.5	952	1.7	0.2	1.5	6.1	0.9	1.4	2.8	759.9	13	0.72	2888	3.8	241	0.06
SCH00033 - end	0	-0.72	0.00	0.5	952	1.7	0.2	1.5	6.1	0.9	1.4	2.8	759.9	13	0.72	2888	3.8	241	0.06
SEC00043 - end	0	-0.72	0.00	0.5	952	51.2	0.2	1.6	6.1	0.8	1.4	6.9	825.0	13	0.70	2888	4.1	241	0.20
SEC00045 - begin	20.36	-0.72	0.04	0.5	415	1.7	0.3	0.4	6.1	2.6	0.7	5.3	21.0	15	0.72	3837	0.2	330	0.06
SCH00047 - begin	20.36	-0.73	0.05	0.5	331	1.7	0.3	0.2	6.2	2.5	1.4	5.0	17.0	16	0.72	3817	0.4	317	0.06
SCH00047 - end	20.36	-0.73	0.05	0.5	331	1.7	0.3	0.2	6.2	2.5	1.4	5.0	17.0	16	0.72	3817	0.4	317	0.06
SEC00045 - end	20.36	-0.74	0.06	0.3	257	1.7	0.4	0.2	6.3	2.5	1.4	4.8	16.6	16	0.72	3700	0.4	303	0.06
SEC00030 - begin	71.12	-0.76	0.11	0.4	0	1.9	192.5	0.5	0.3	5.0	-19.7	4.5	15.1	836	0.81	3392	0.9	322	0.08
SEC00030 - end	71.12	-0.86	0.12	0.6	25	0.4	1.9	0.6	1.0	5.4	-27.7	4.2	15.0	12	1.06	3778	1.0	543	0.00

Addendum Section E: Comparison of Measured and Simulated Ammonia, Nitrate, and Dissolved Oxygen Concentrations for the Chicago River System for Water Year 2001 after correction of the O'Brien Water Reclamation Plant Effluent Ammonia Concentrations

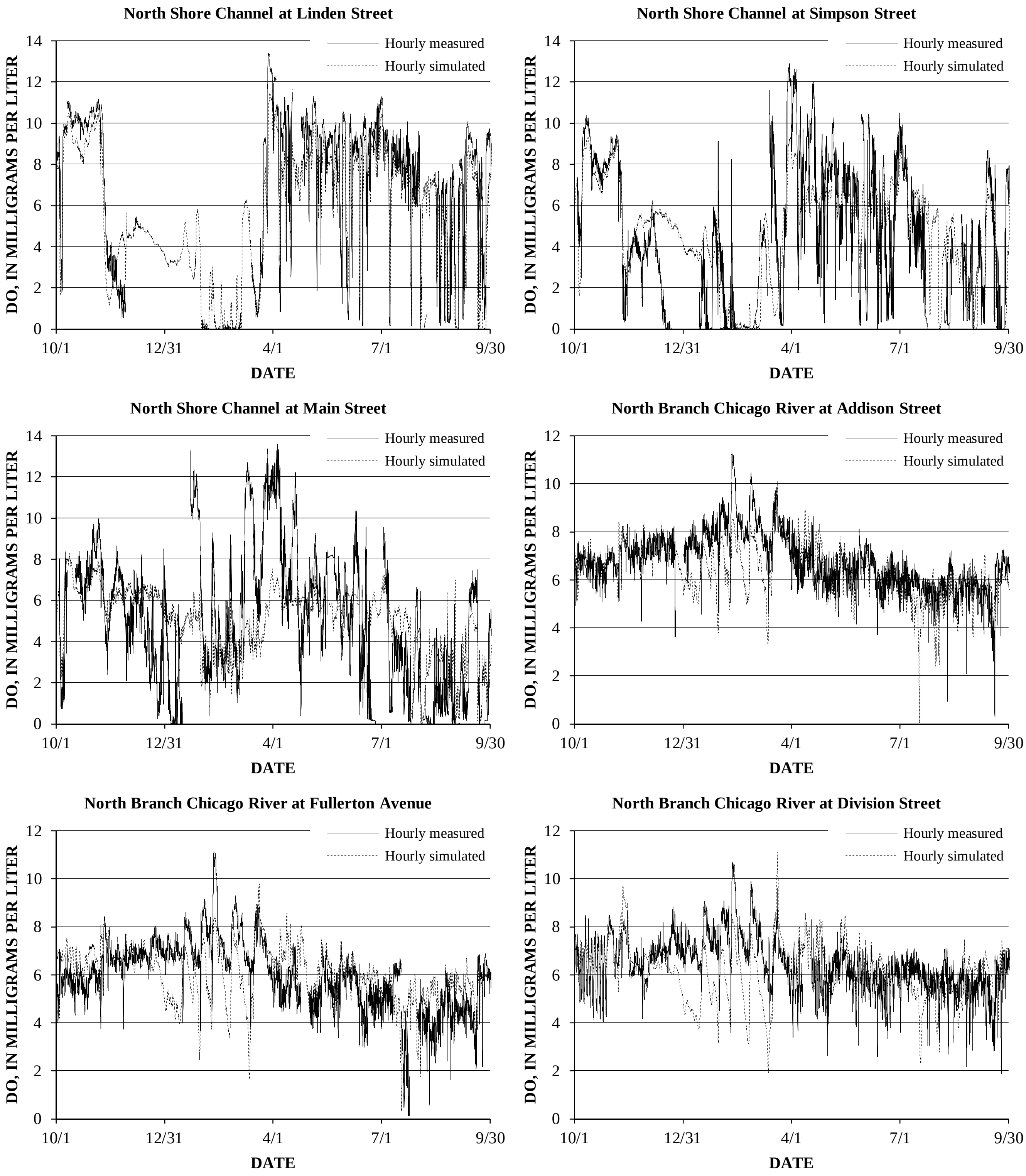


Figure E.1. Comparison of measured and simulated dissolved oxygen (DO) concentrations at 30 locations in the Chicago Area Waterways System for Water Year 2001.

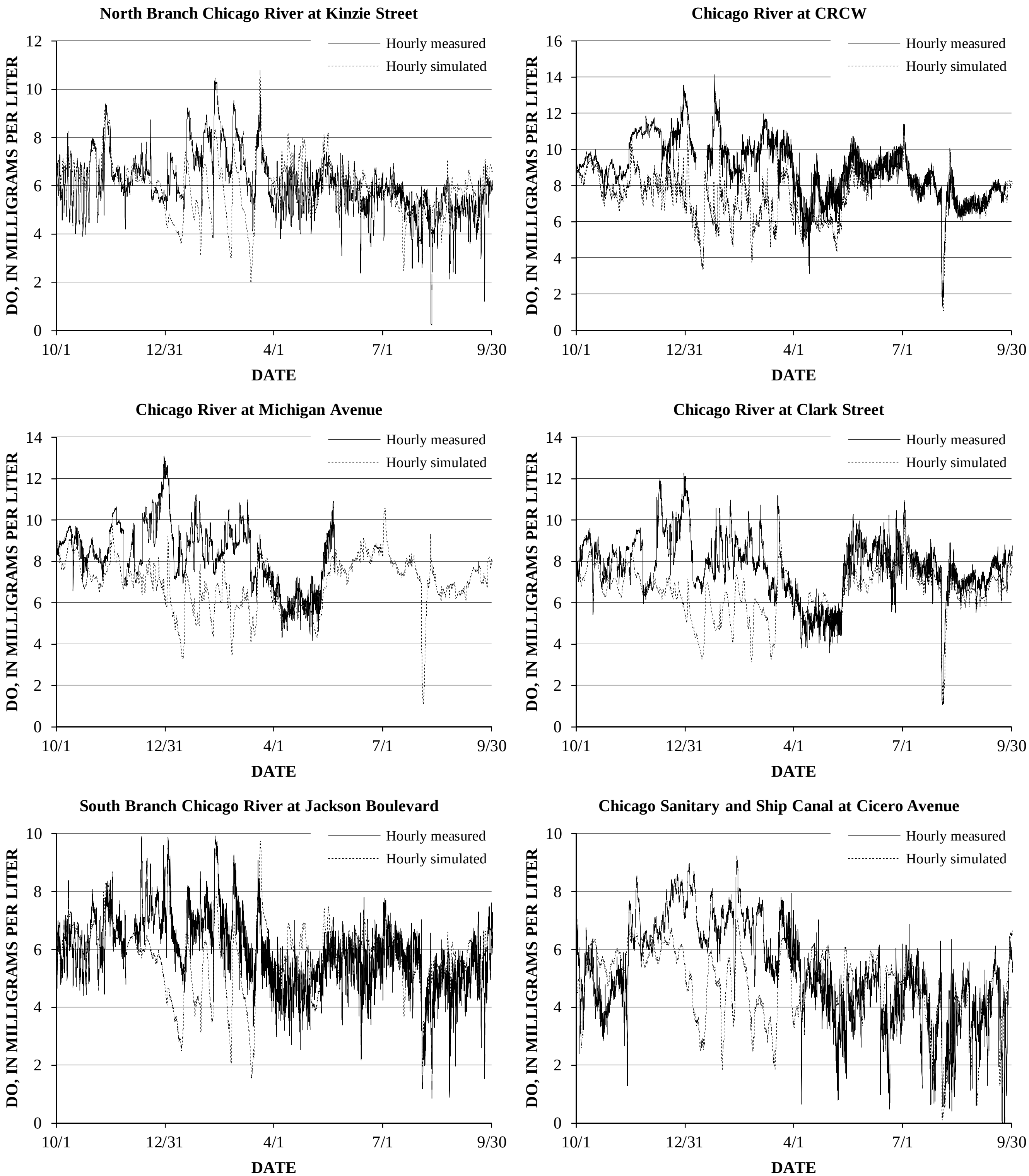


Figure E.1. (cont.) Comparison of measured and simulated dissolved oxygen (DO) concentrations at 30 locations in the Chicago Area Waterways System for Water Year 2001.

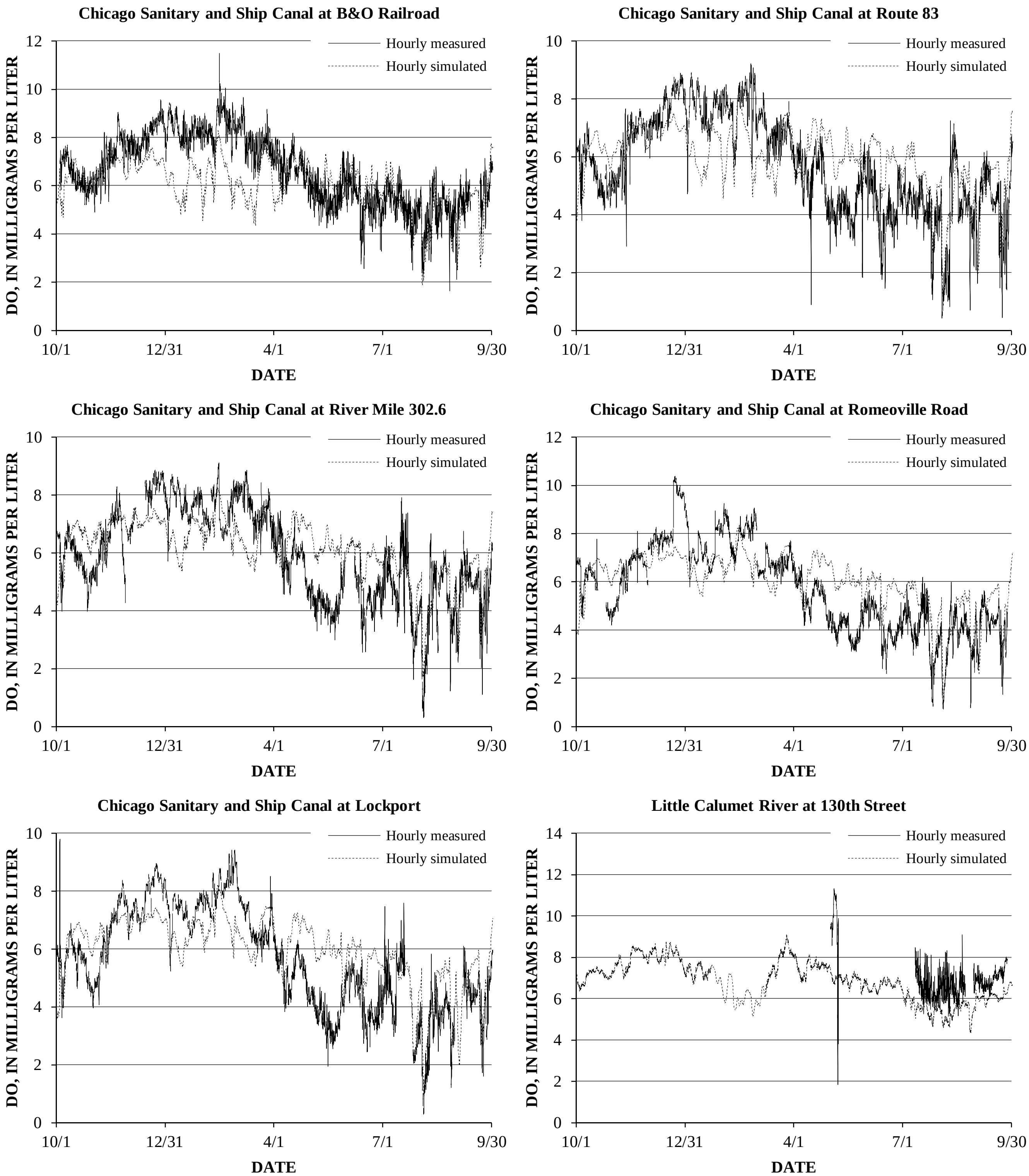


Figure E.1. (cont.) Comparison of measured and simulated dissolved oxygen (DO) concentrations at 30 locations in the Chicago Area Waterways System for Water Year 2001.

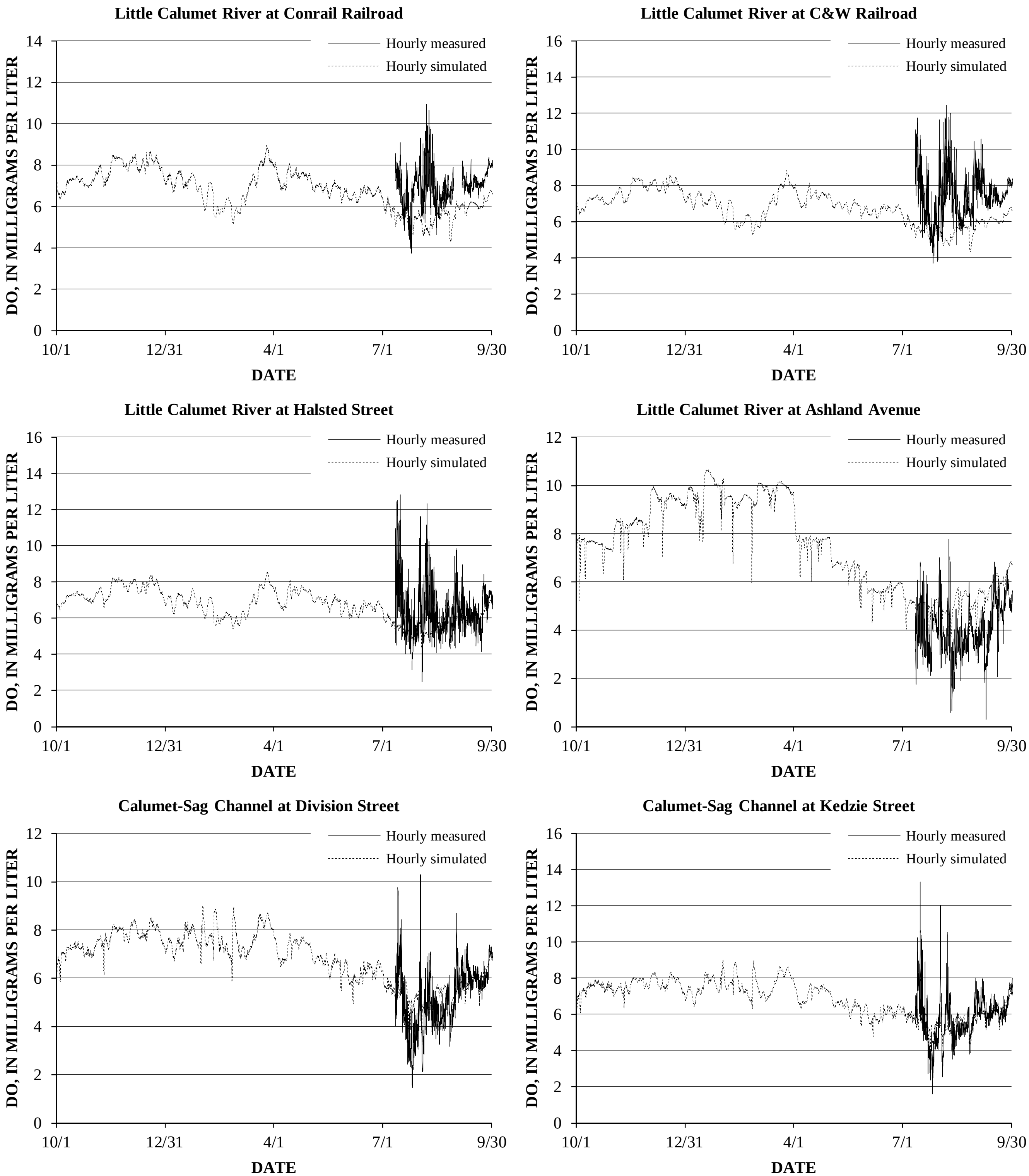


Figure E.1. (cont.) Comparison of measured and simulated dissolved oxygen (DO) concentrations at 30 locations in the Chicago Area Waterways System for Water Year 2001.

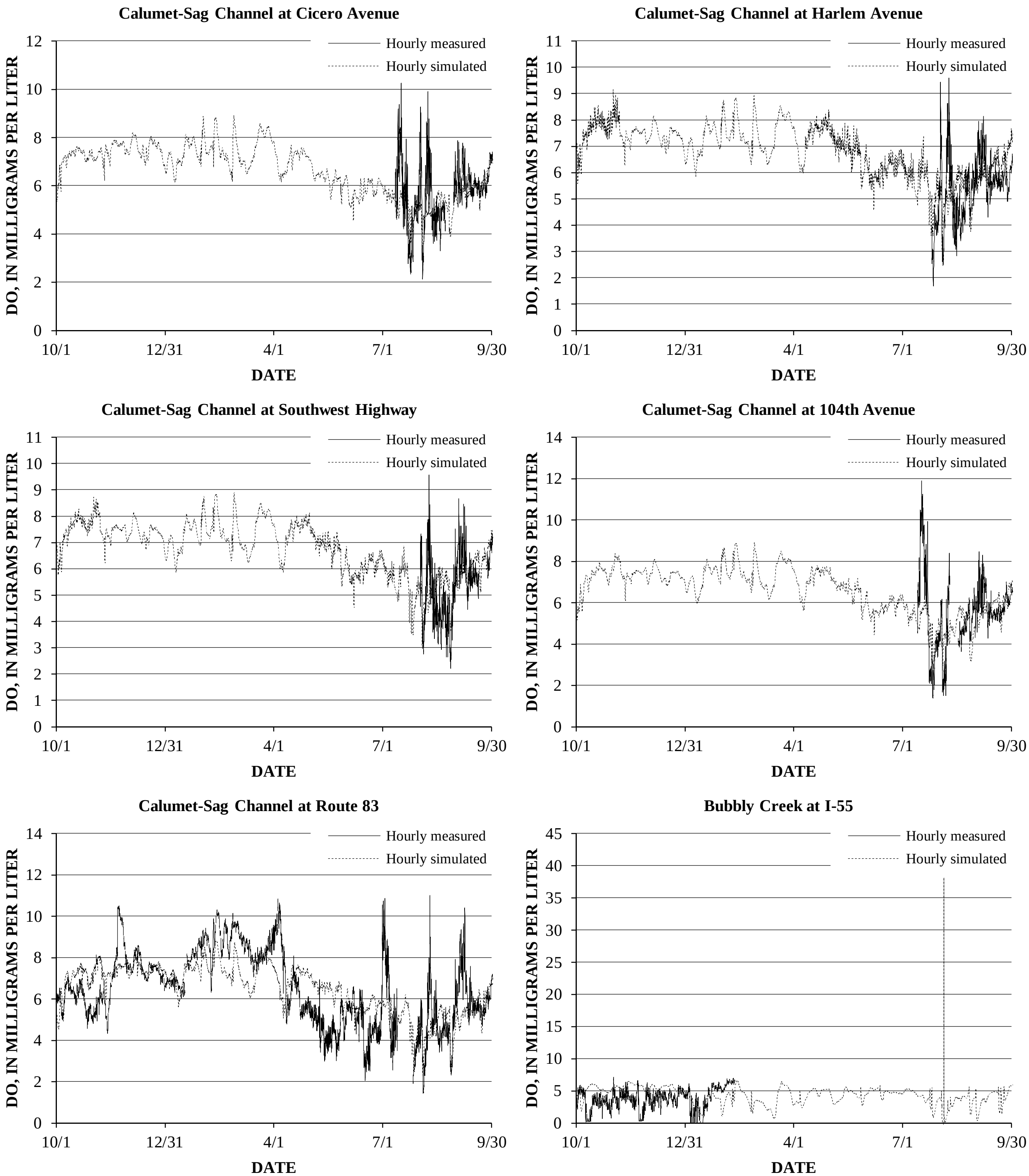


Figure E.1. (cont.) Comparison of measured and simulated dissolved oxygen (DO) concentrations at 30 locations in the Chicago Area Waterways System for Water Year 2001.

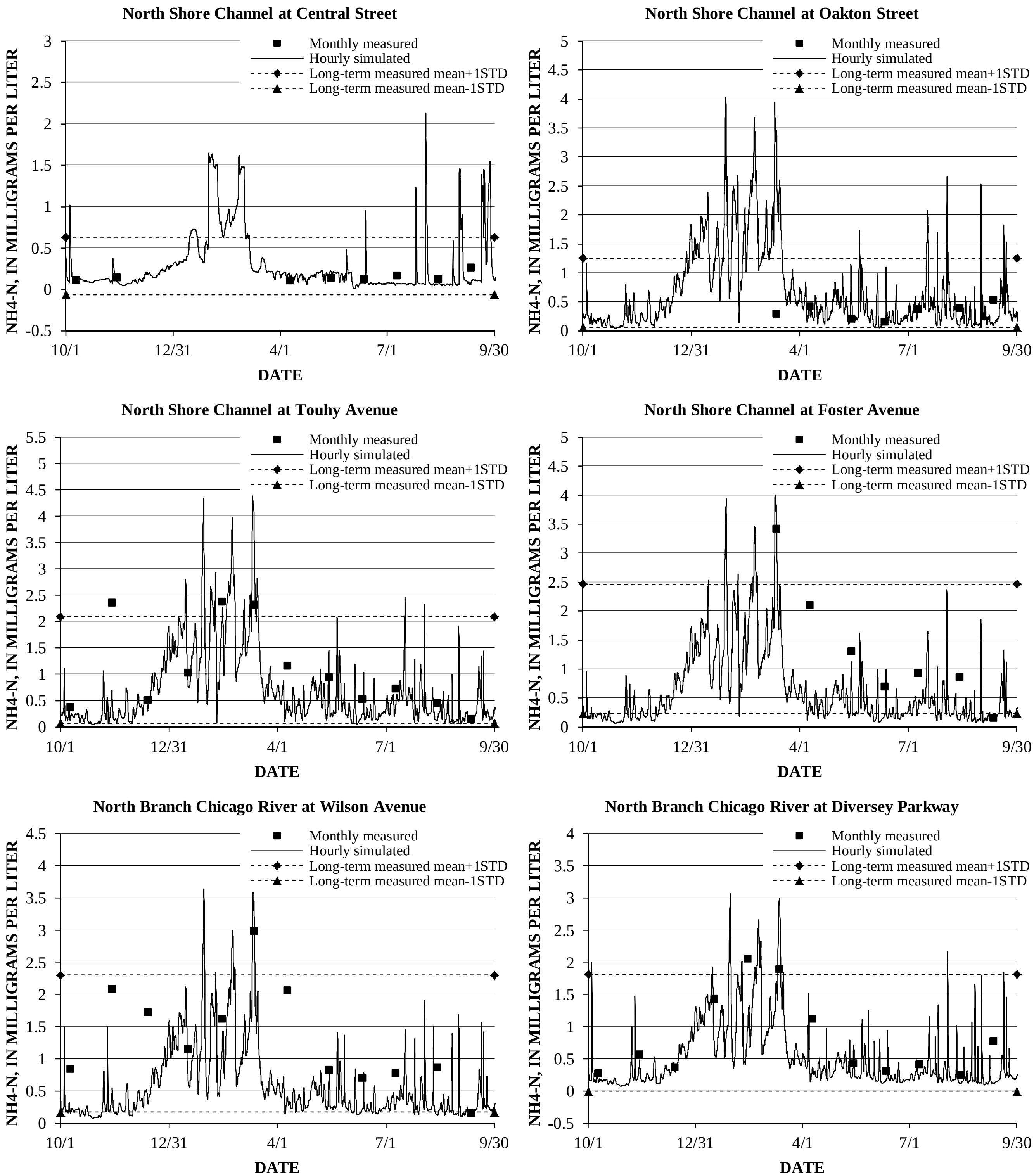


Figure E.2. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonium as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

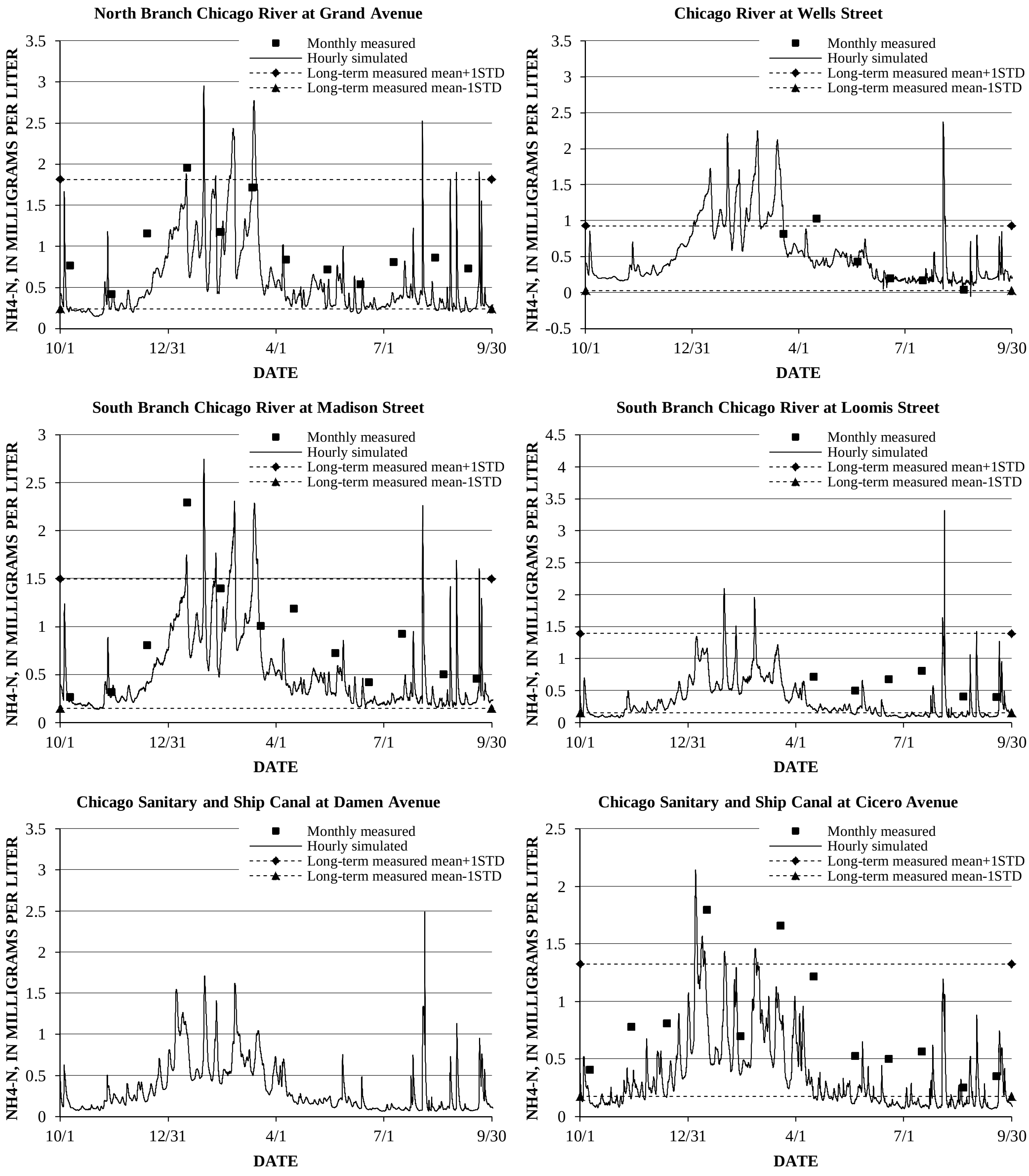


Figure E.2. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonium as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

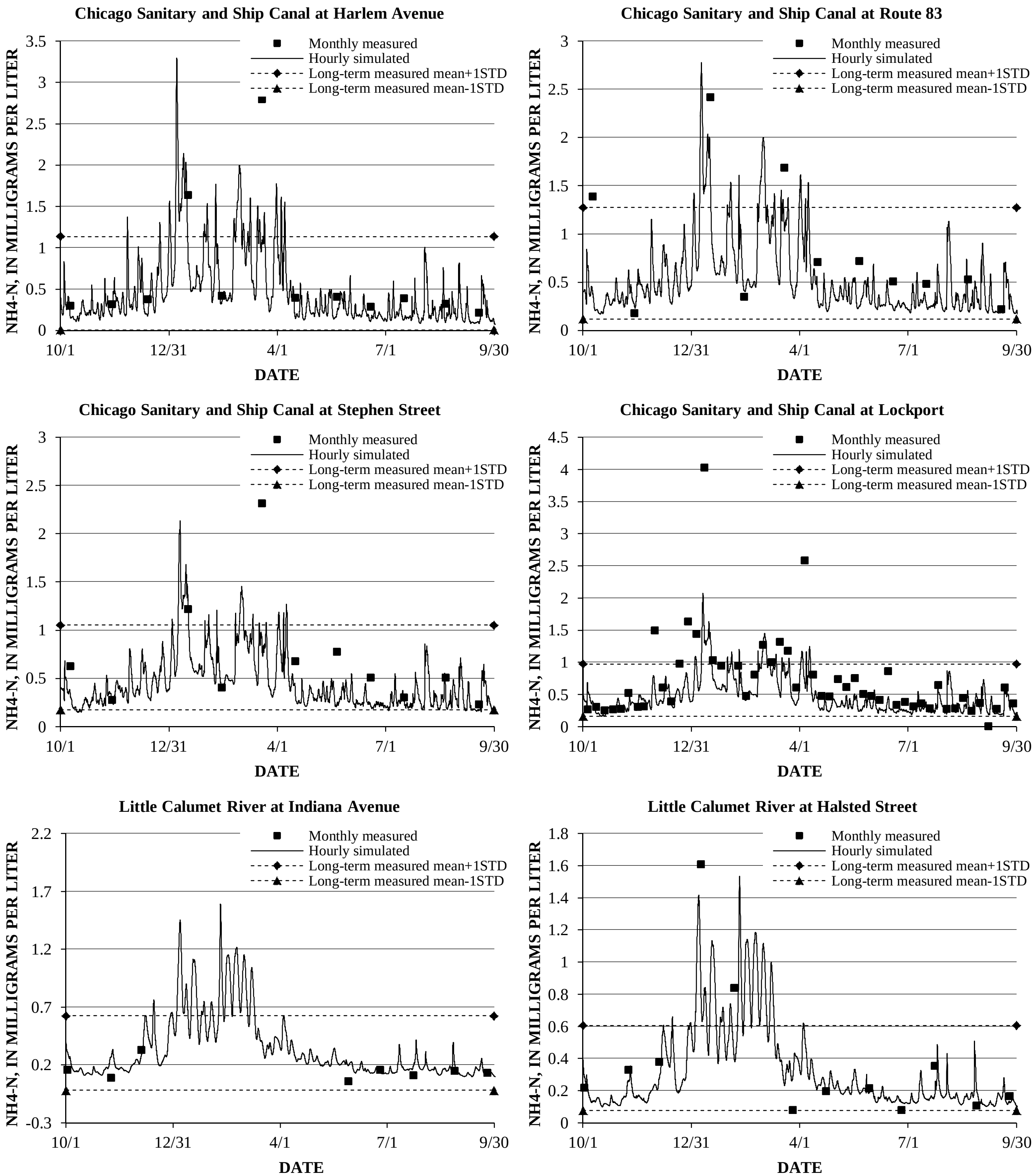


Figure E.2. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonium as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

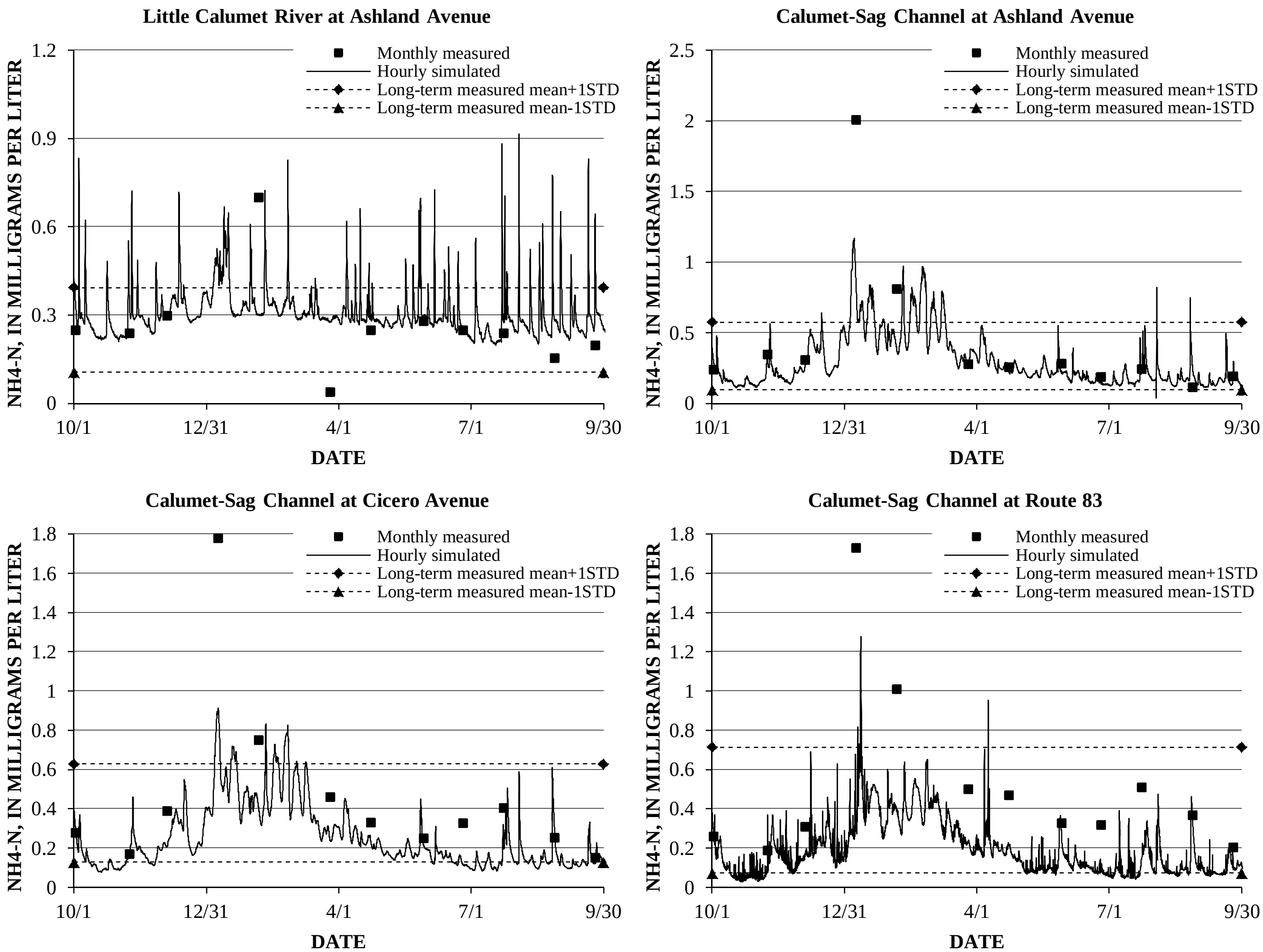


Figure E.2. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly ammonium as nitrogen (NH4-N) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

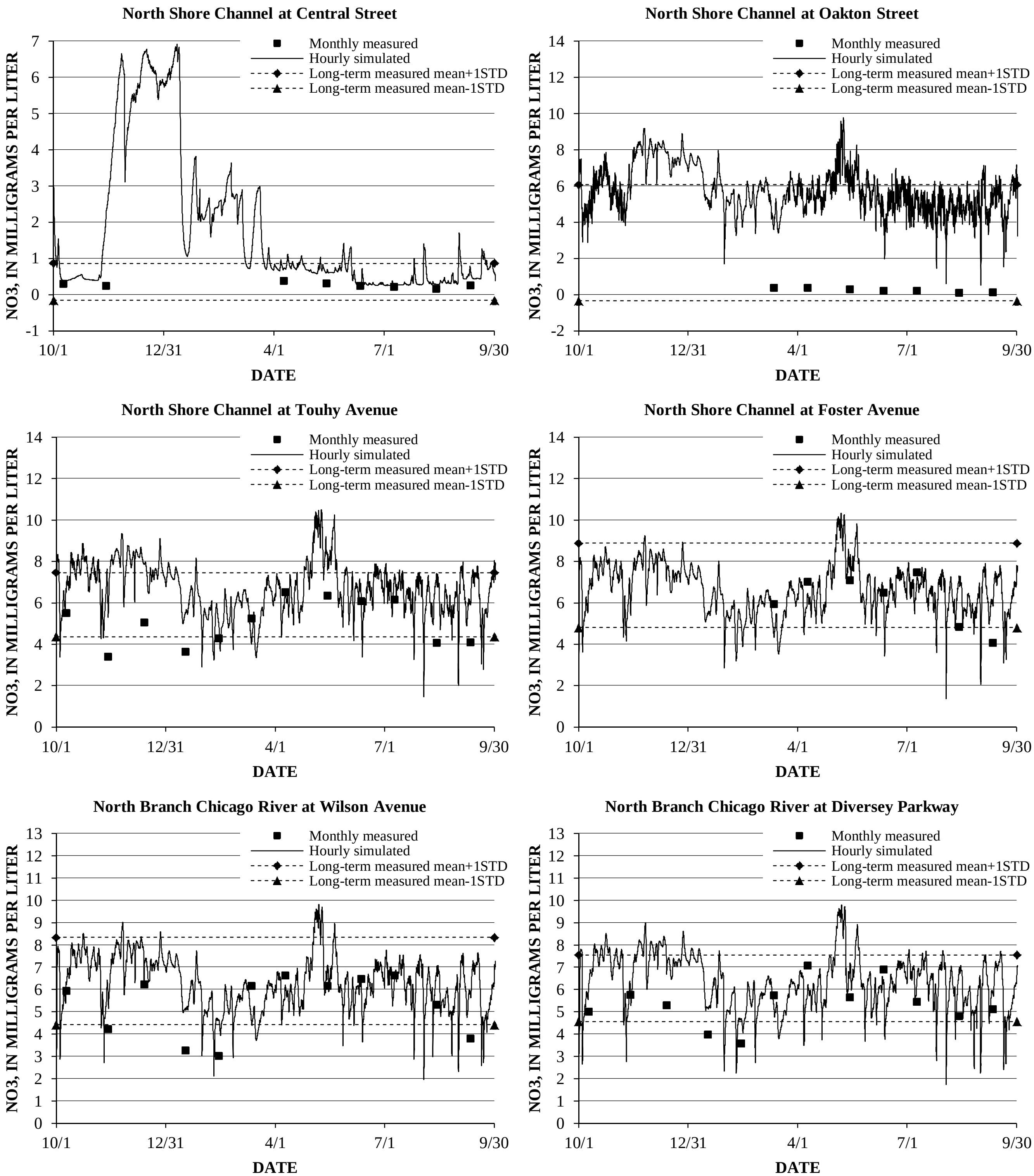


Figure E.3. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

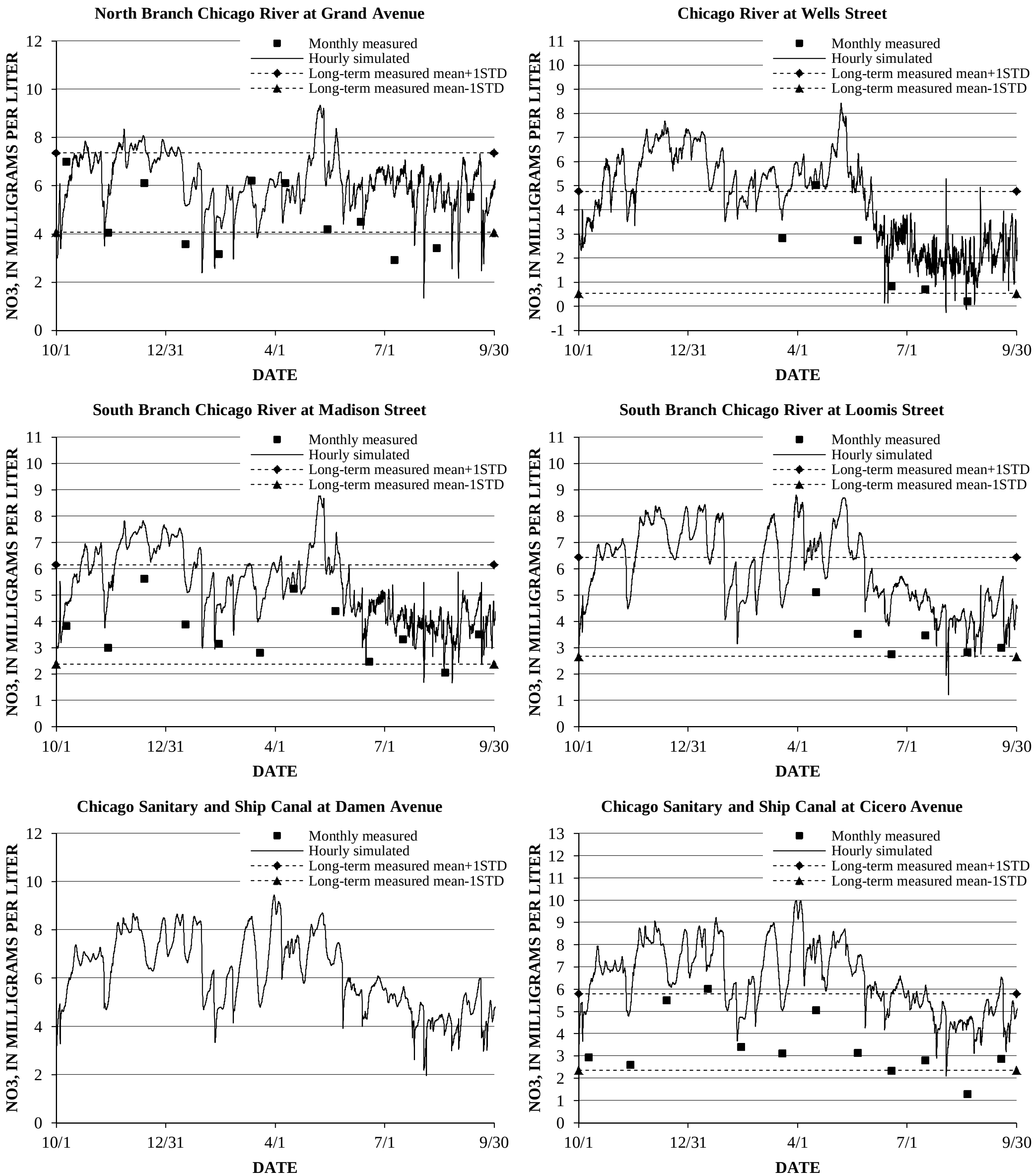


Figure E.3. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

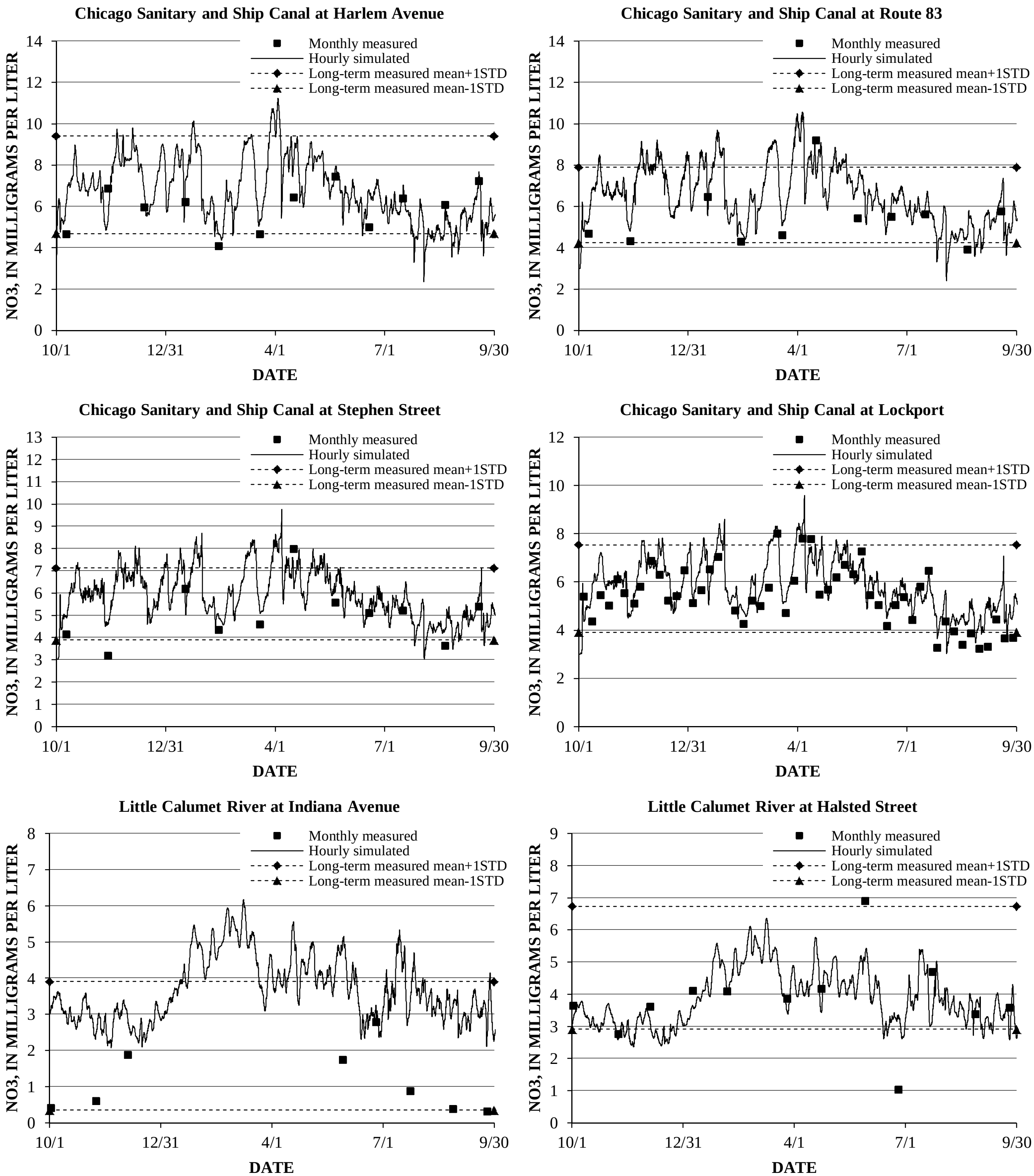


Figure E.3. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

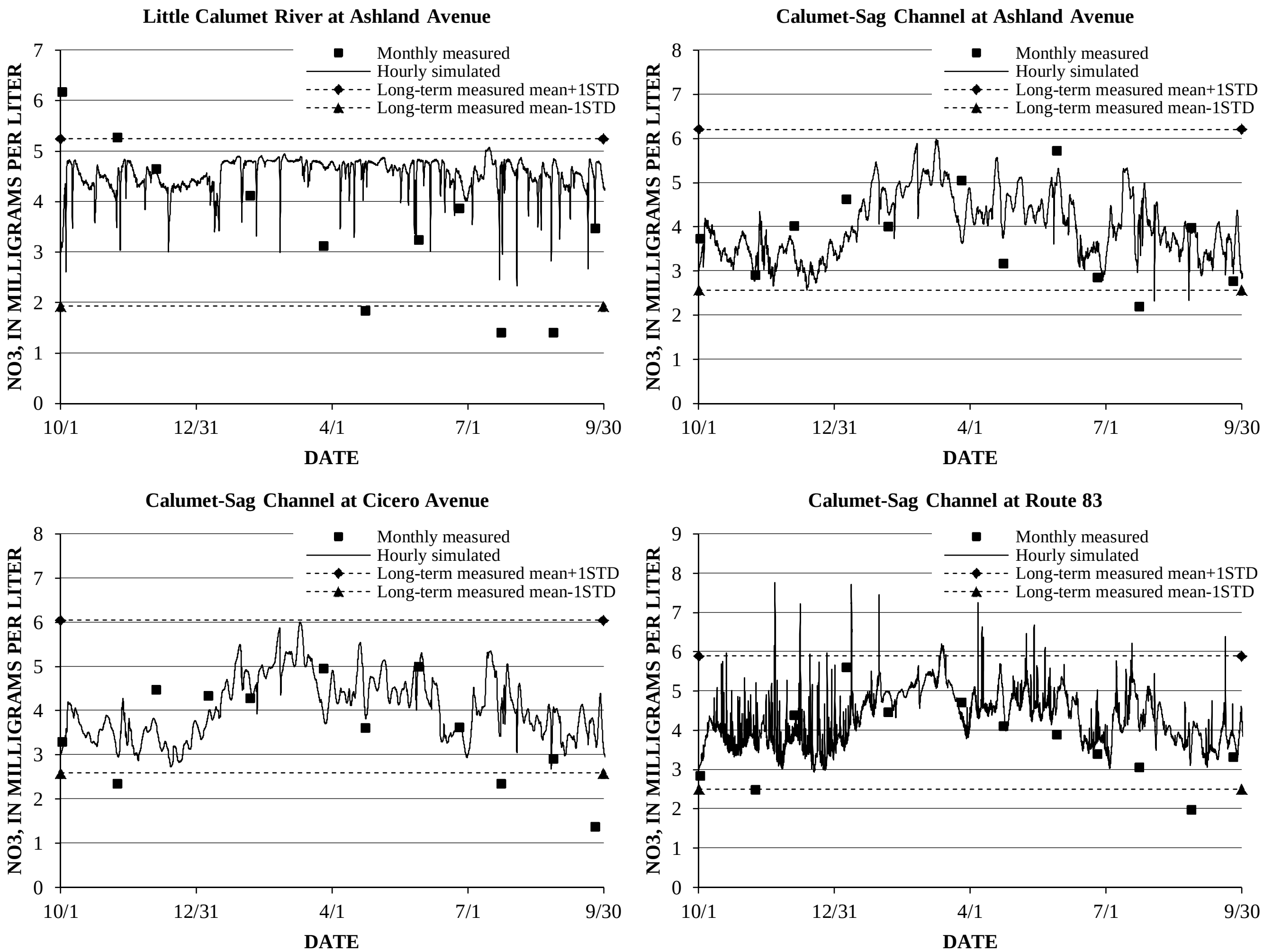


Figure E.3. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly nitrate as nitrogen (NO3) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

Addendum Section F: Measured and Simulated Total Phosphorus and Soluble (Inorganic) Phosphorus Concentrations for Water Year 2001

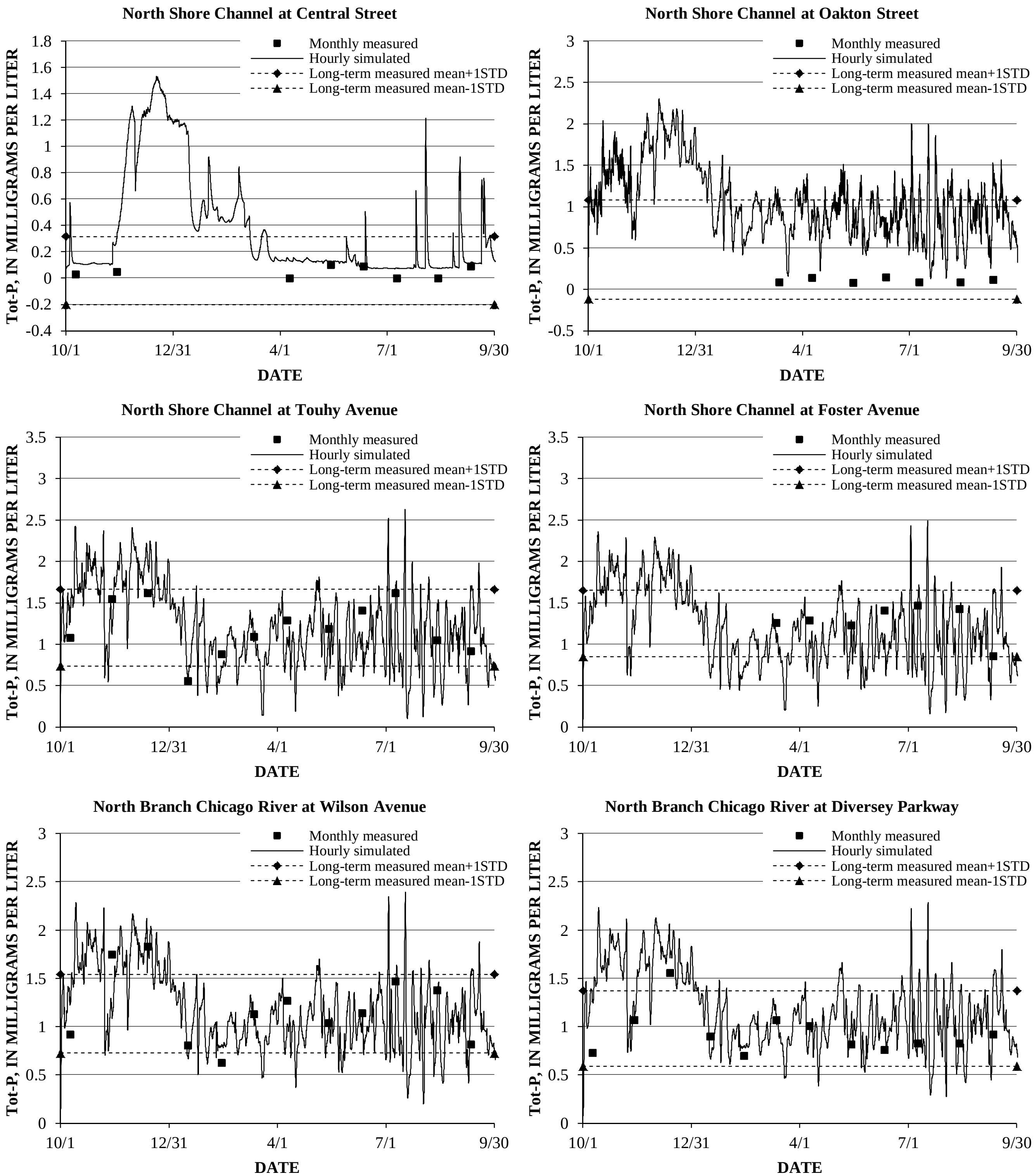


Figure F.1. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

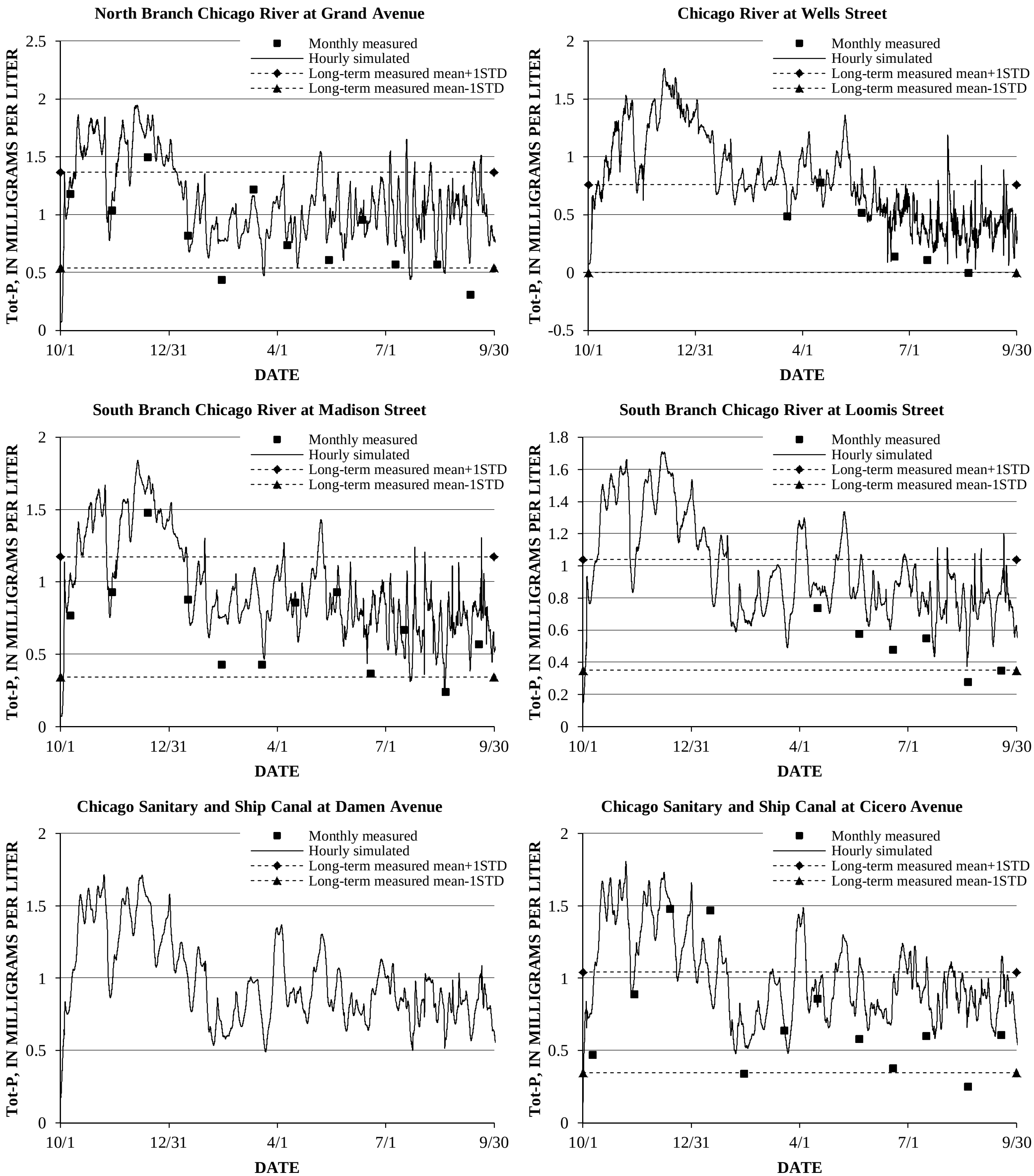


Figure F.1. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

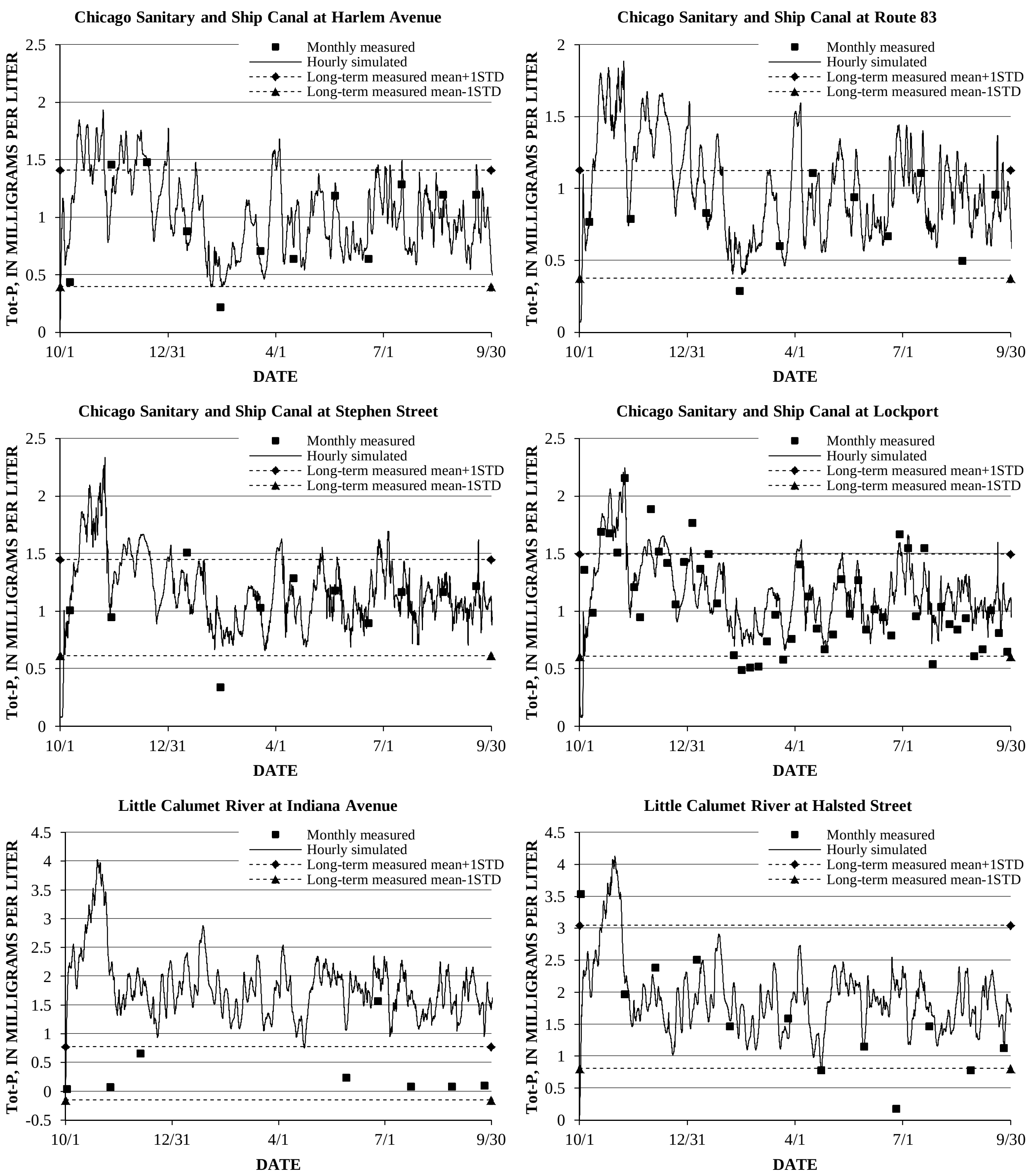


Figure F.1. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

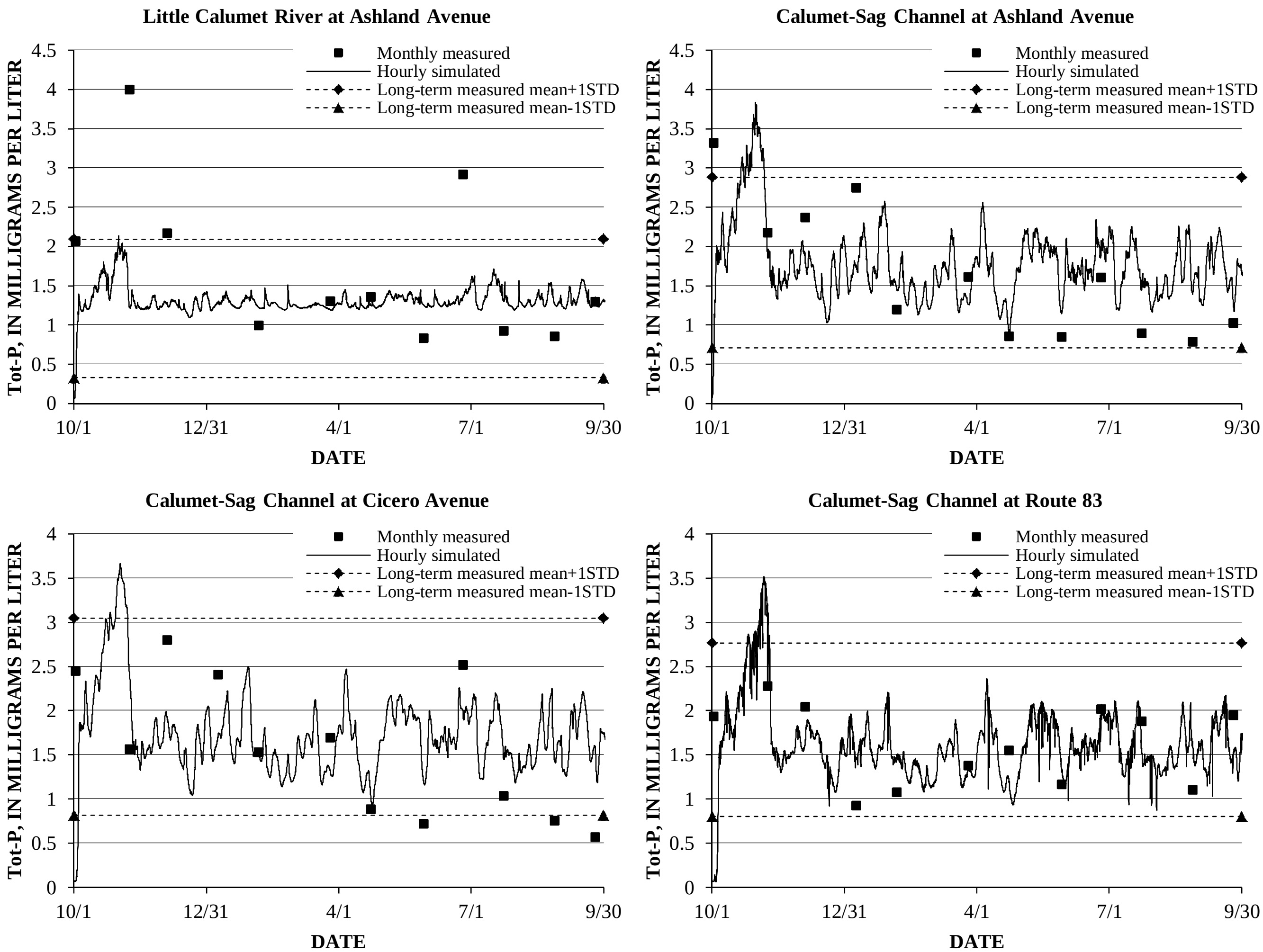


Figure F.1. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly total phosphorus (Tot-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

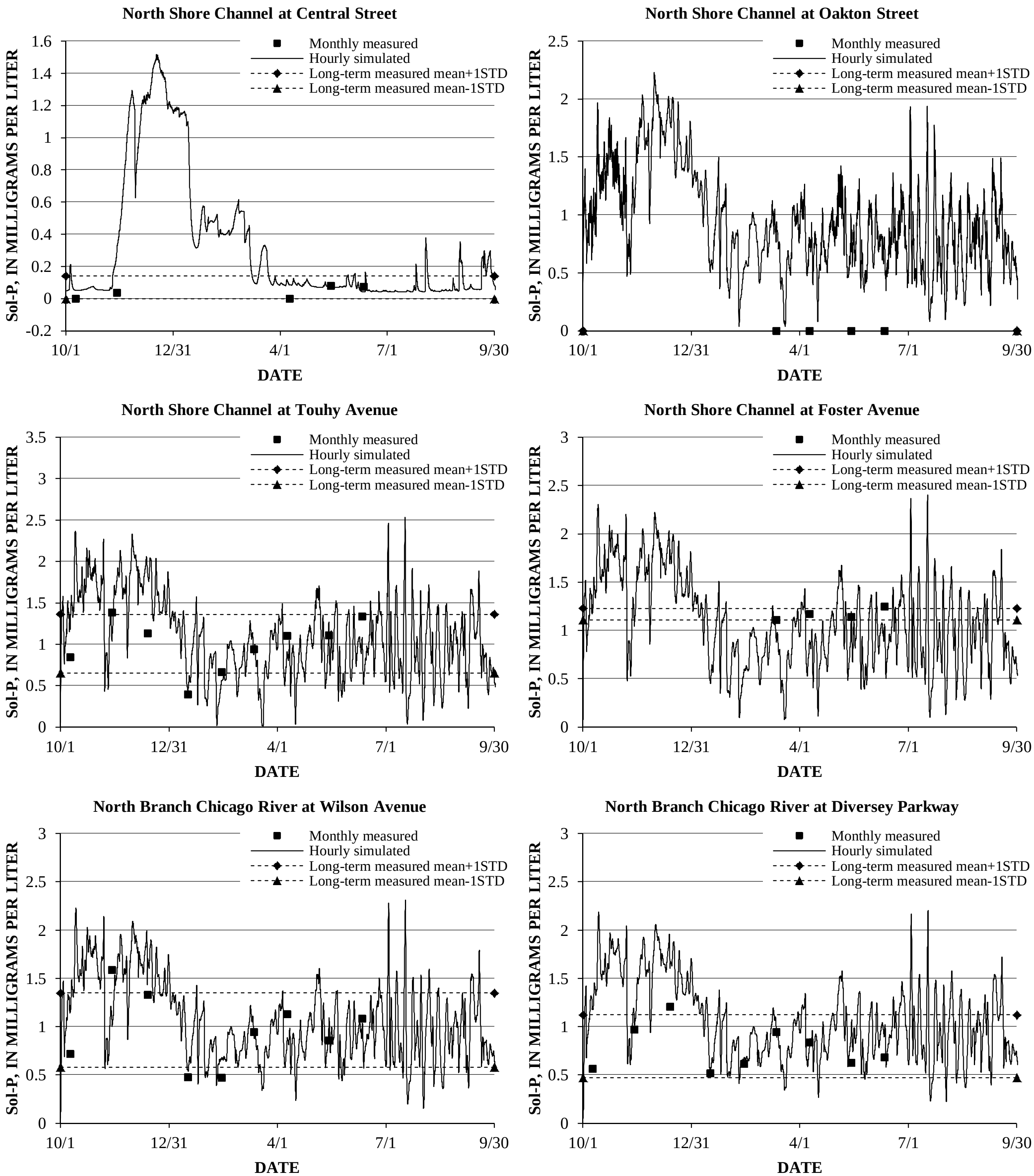


Figure F.2. Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly soluble phosphorus (Sol-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

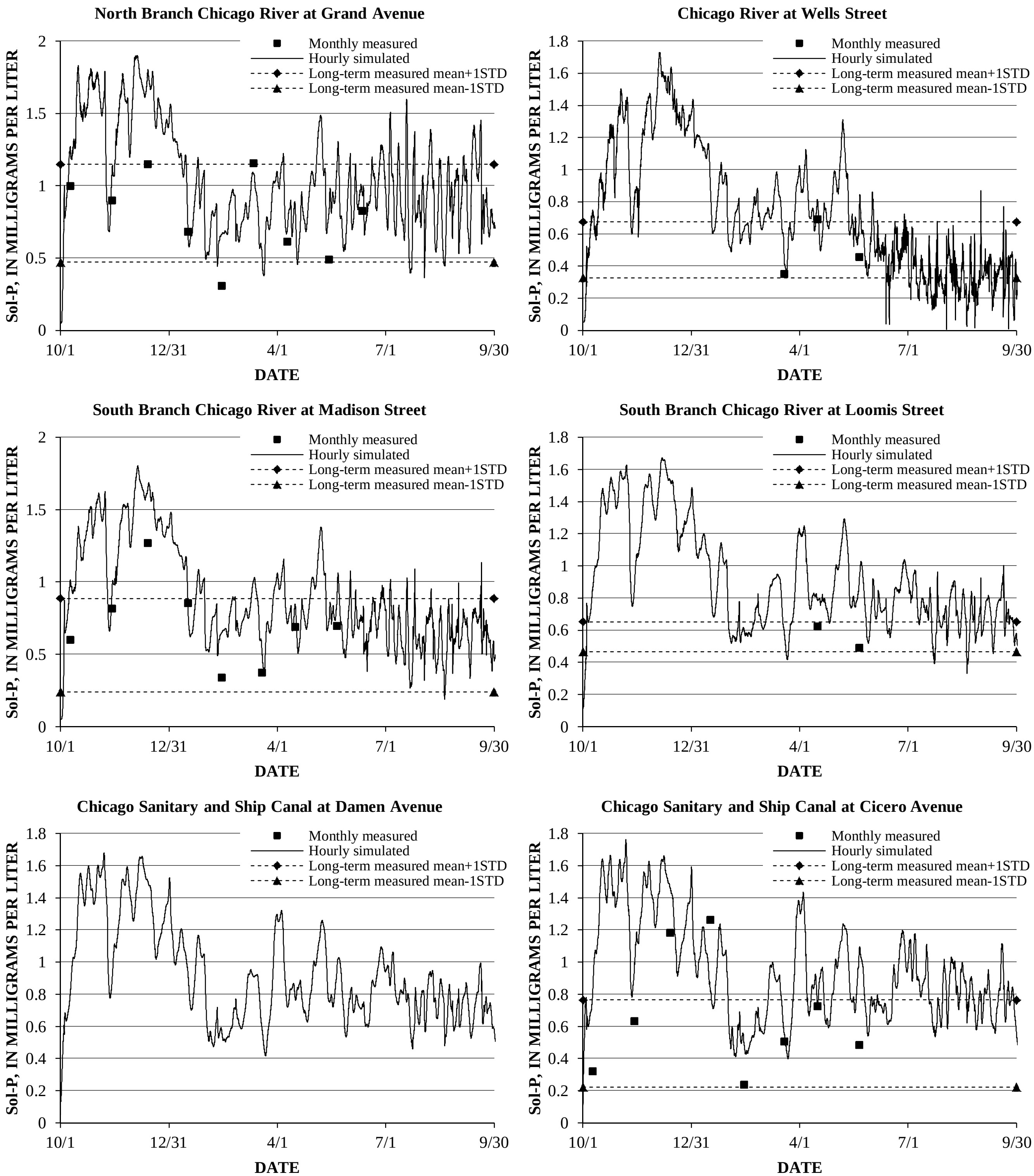


Figure F.2. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly soluble phosphorus (Sol-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

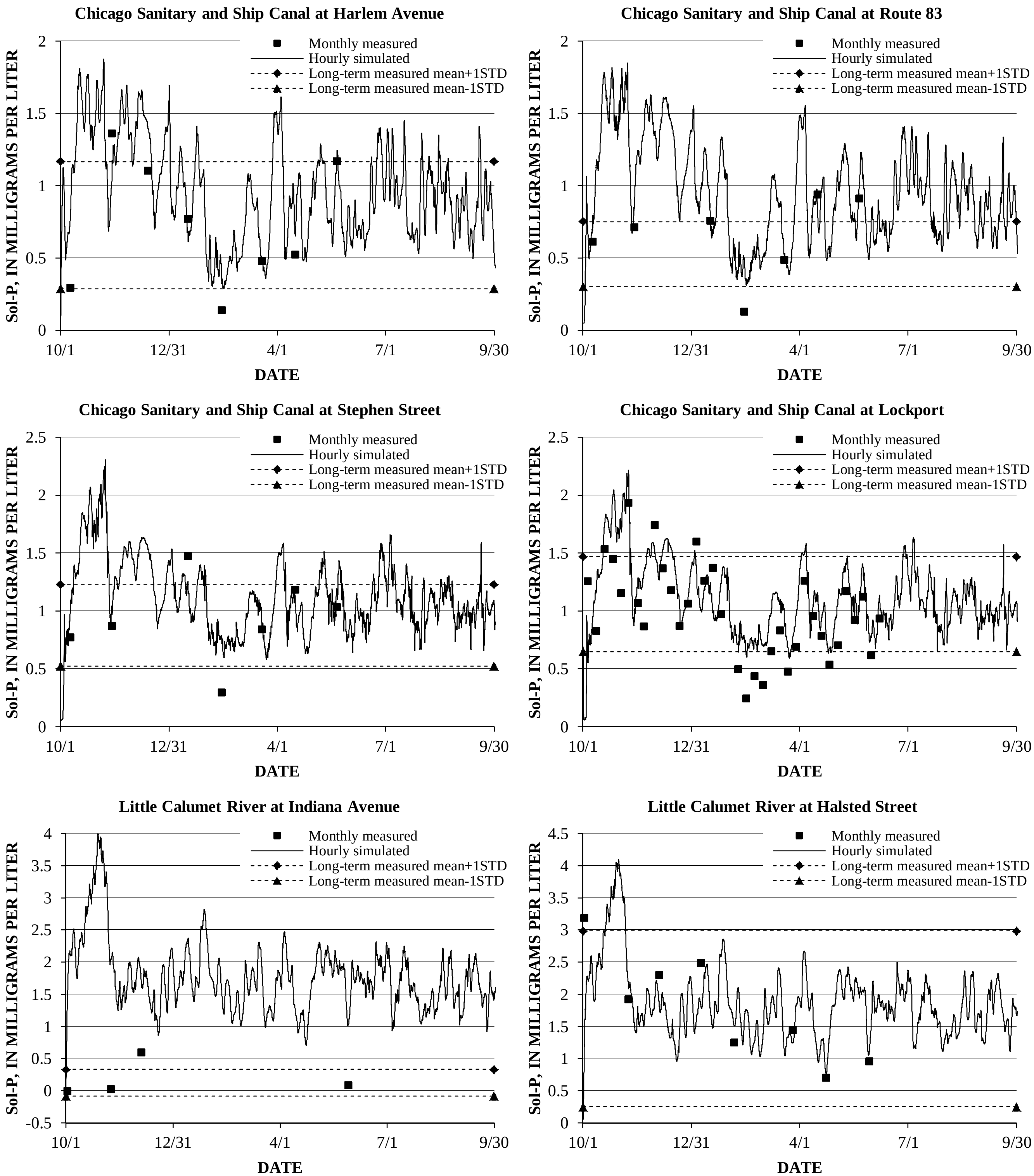


Figure F.2. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly soluble phosphorus (Sol-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

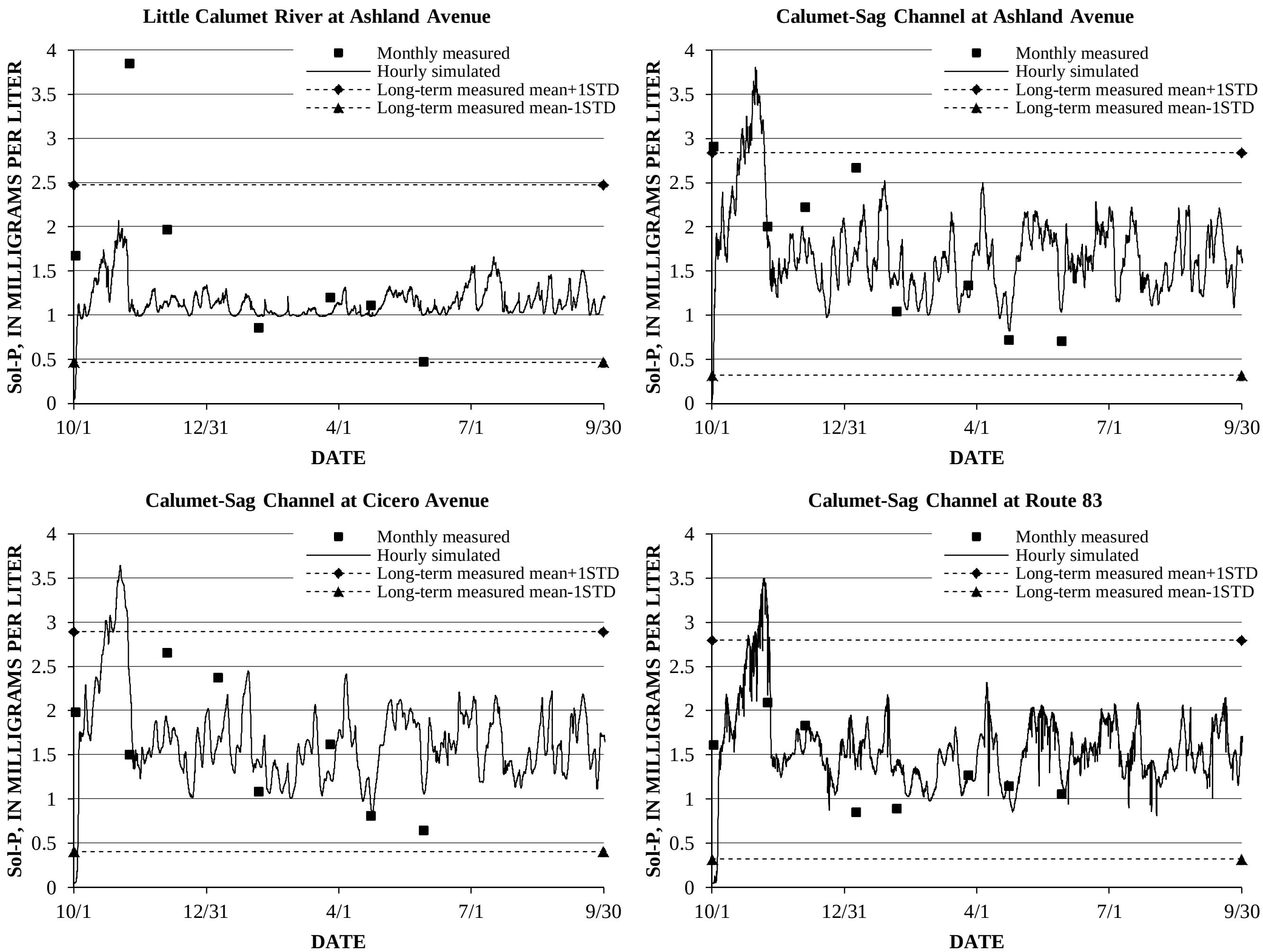


Figure F.2. (cont.) Comparison of long term (1997-2011) measured mean plus or minus one standard deviation (STD), measured, and simulated hourly soluble phosphorus (Sol-P) concentrations at 22 locations in the Chicago Area Waterways System for Water Year 2001.

Addendum Section G: Relations Between Flow and Stage at the Downstream end of the CSSC for the Case Two Lockport Powerhouse Generators On

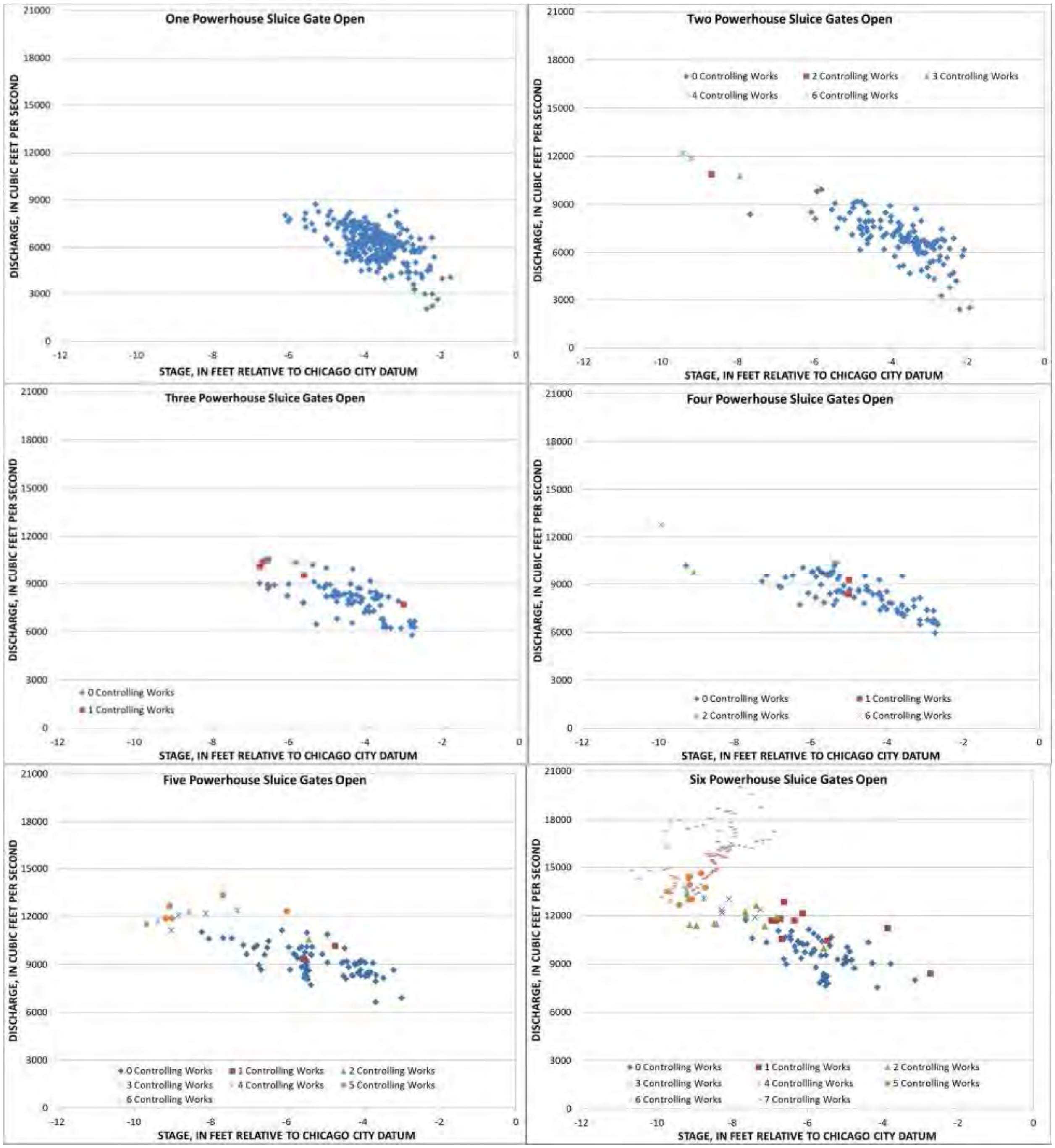


Figure G.1. Relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of two generators on at the Lockport Powerhouse and various numbers of powerhouse sluice gates and/or controlling works gates open.

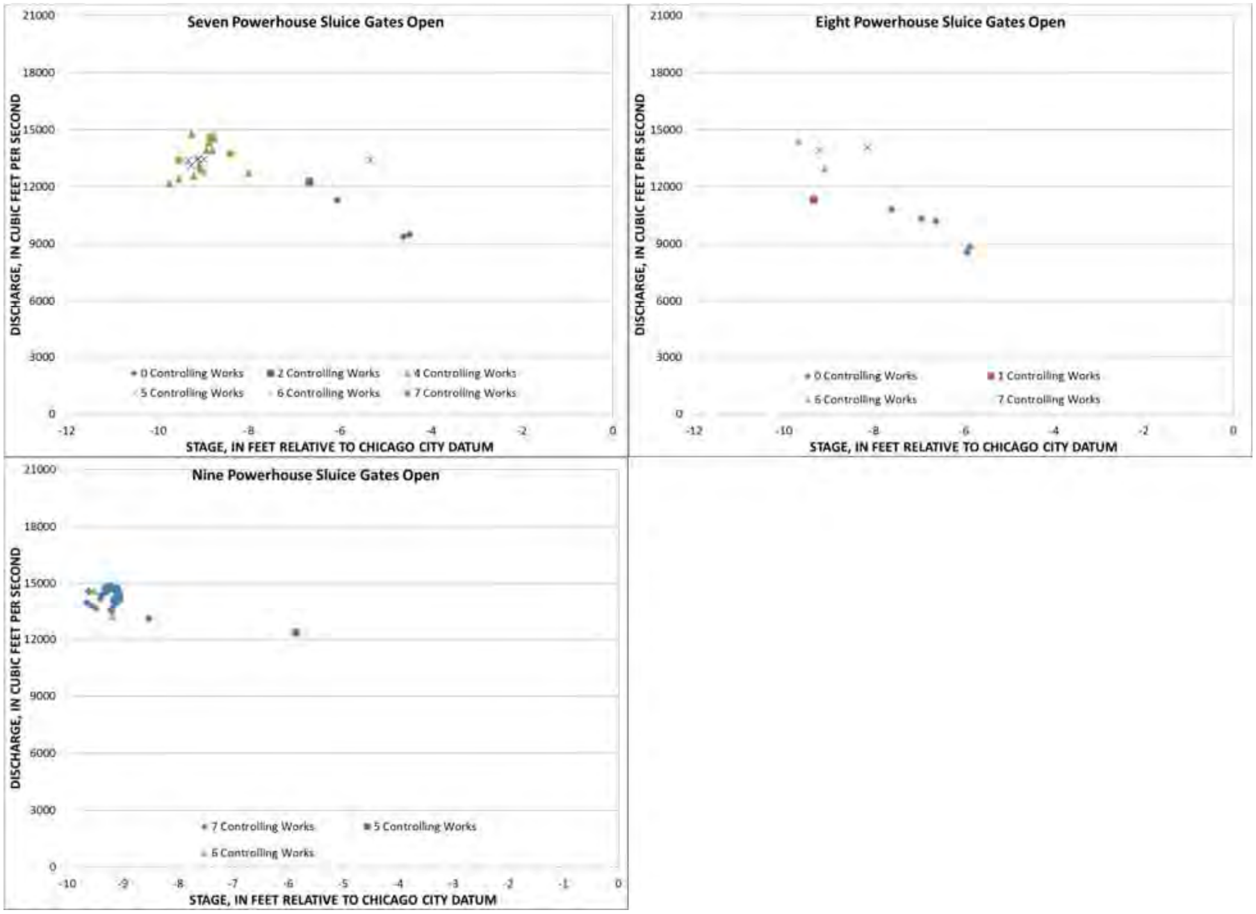


Figure G.1. (cont.) Relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of two generators on at the Lockport Powerhouse and various numbers of powerhouse sluice gates and/or controlling works gates open.

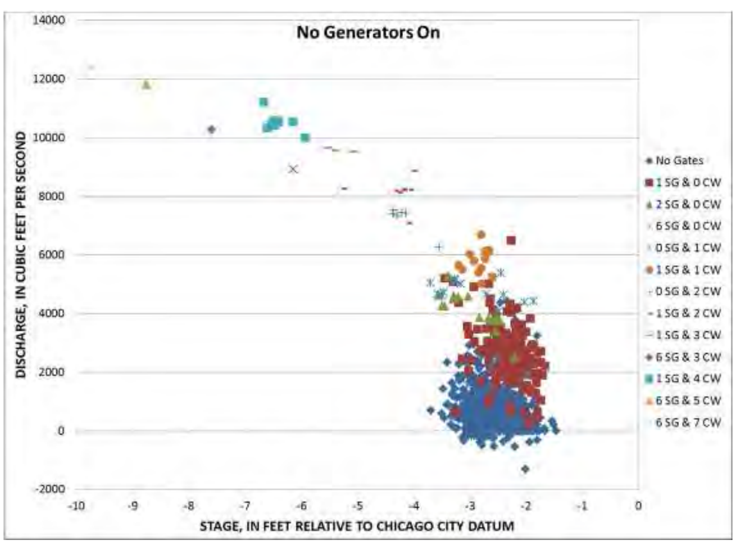


Figure G.2. Relation between flow at Romeoville or Lemont and stage at the Lockport Controlling Works for the cases of no generators on at the Lockport Powerhouse and various numbers of powerhouse sluice gates (SG) and/or controlling works (CW) gates open.

Addendum Section H: Sum of All Inflows to the Chicago Area Waterways System for Water Years 2001 and 2003

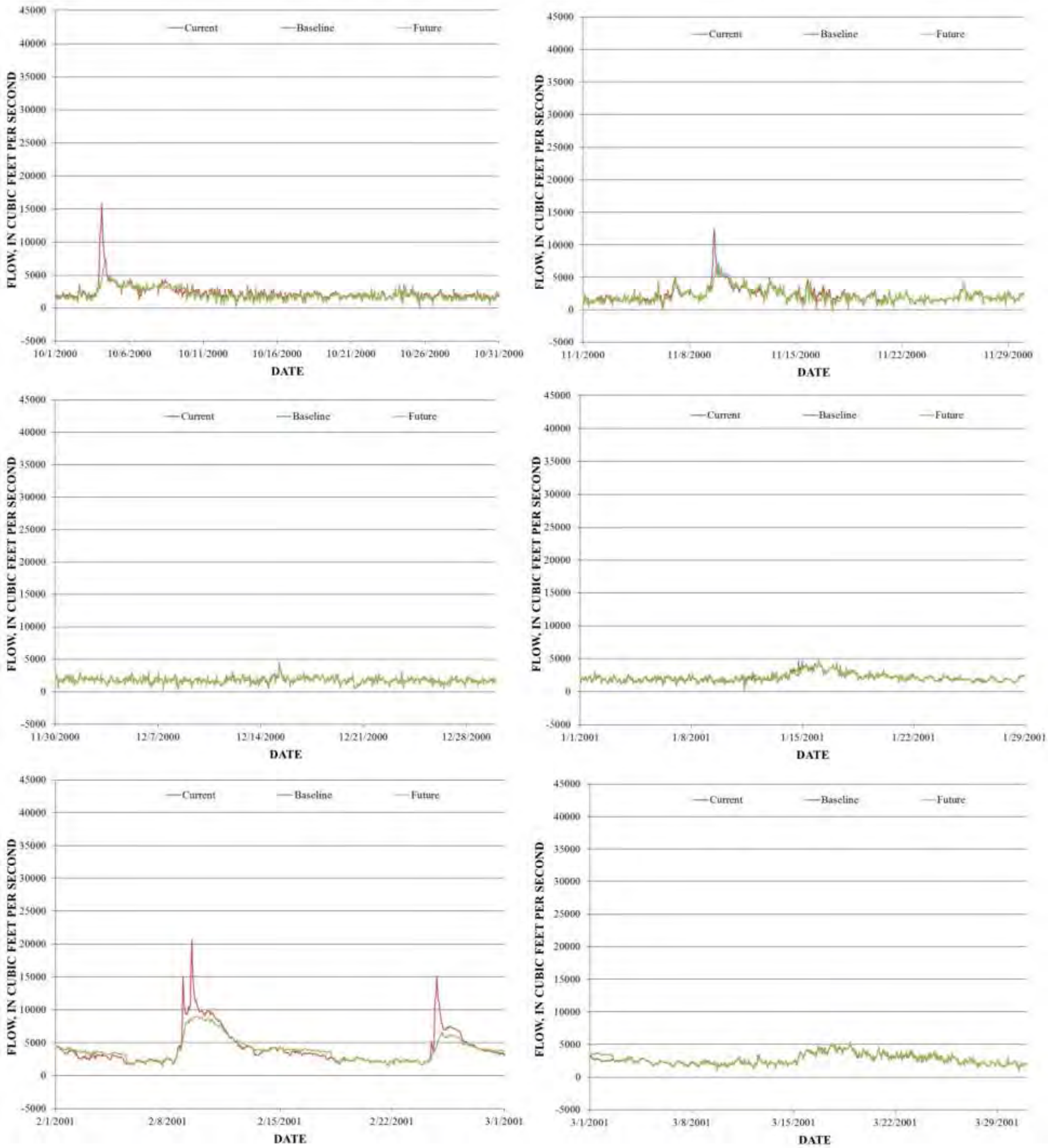


Figure H.1. Comparison of the sum of inflows to the Chicago Area Waterways System for the Current, Baseline, and Future conditions for Water Year 2001.

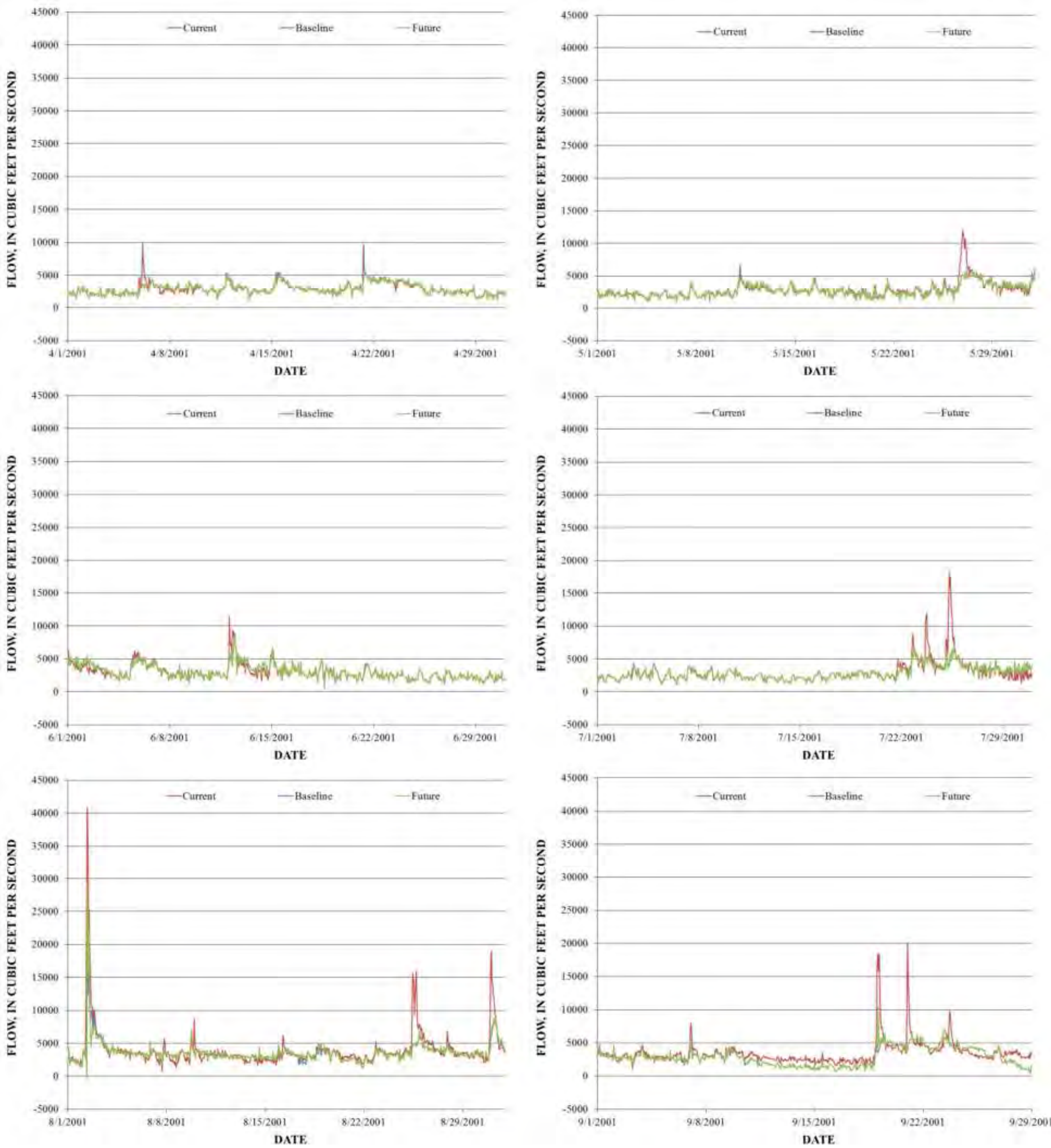


Figure H.1. (cont.) Comparison of the sum of inflows to the Chicago Area Waterways System for the Current, Baseline, and Future conditions for Water Year 2001.

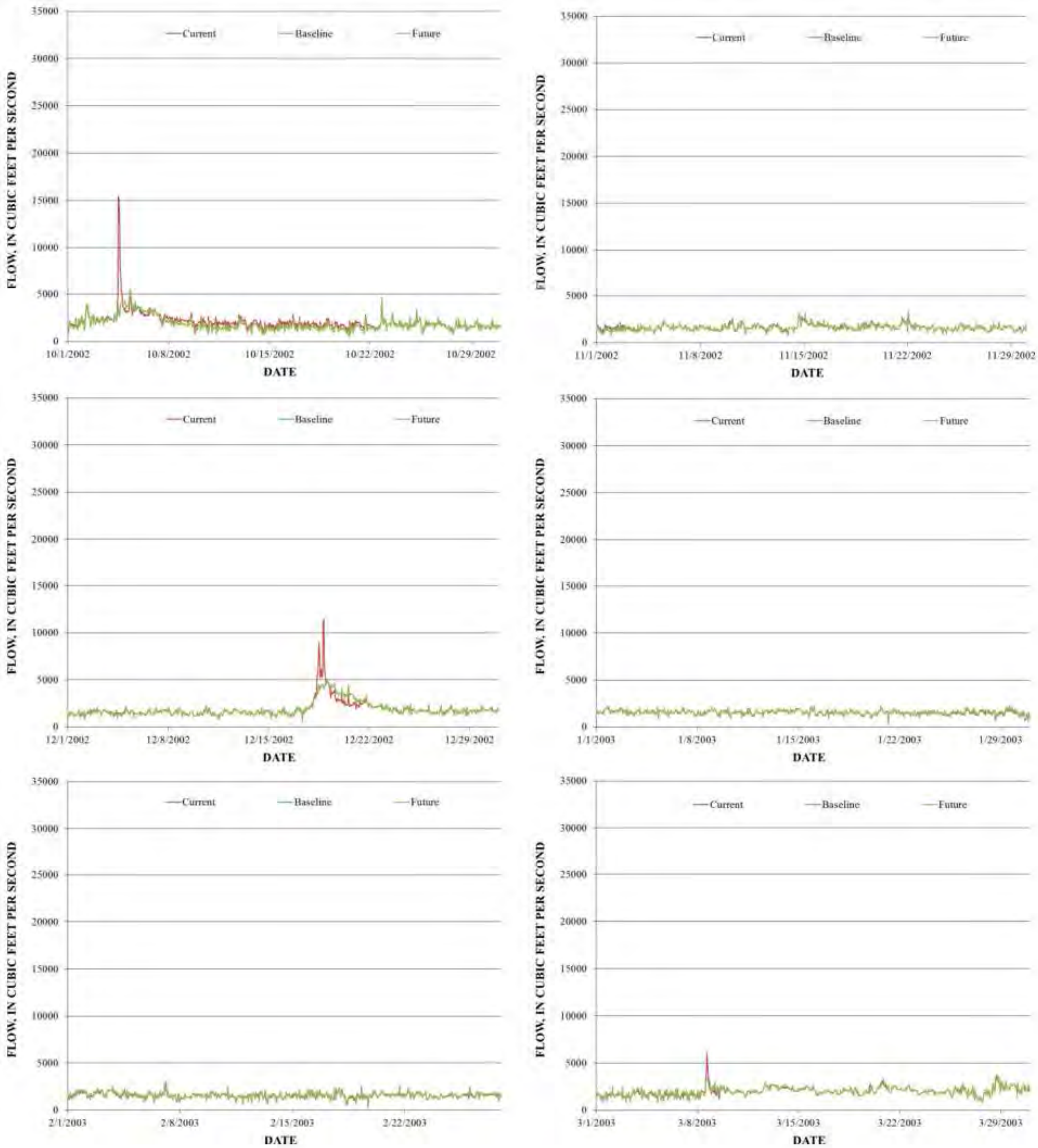


Figure H.2. Comparison of the sum of inflows to the Chicago Area Waterways System for the Current, Baseline, and Future conditions for Water Year 2003.

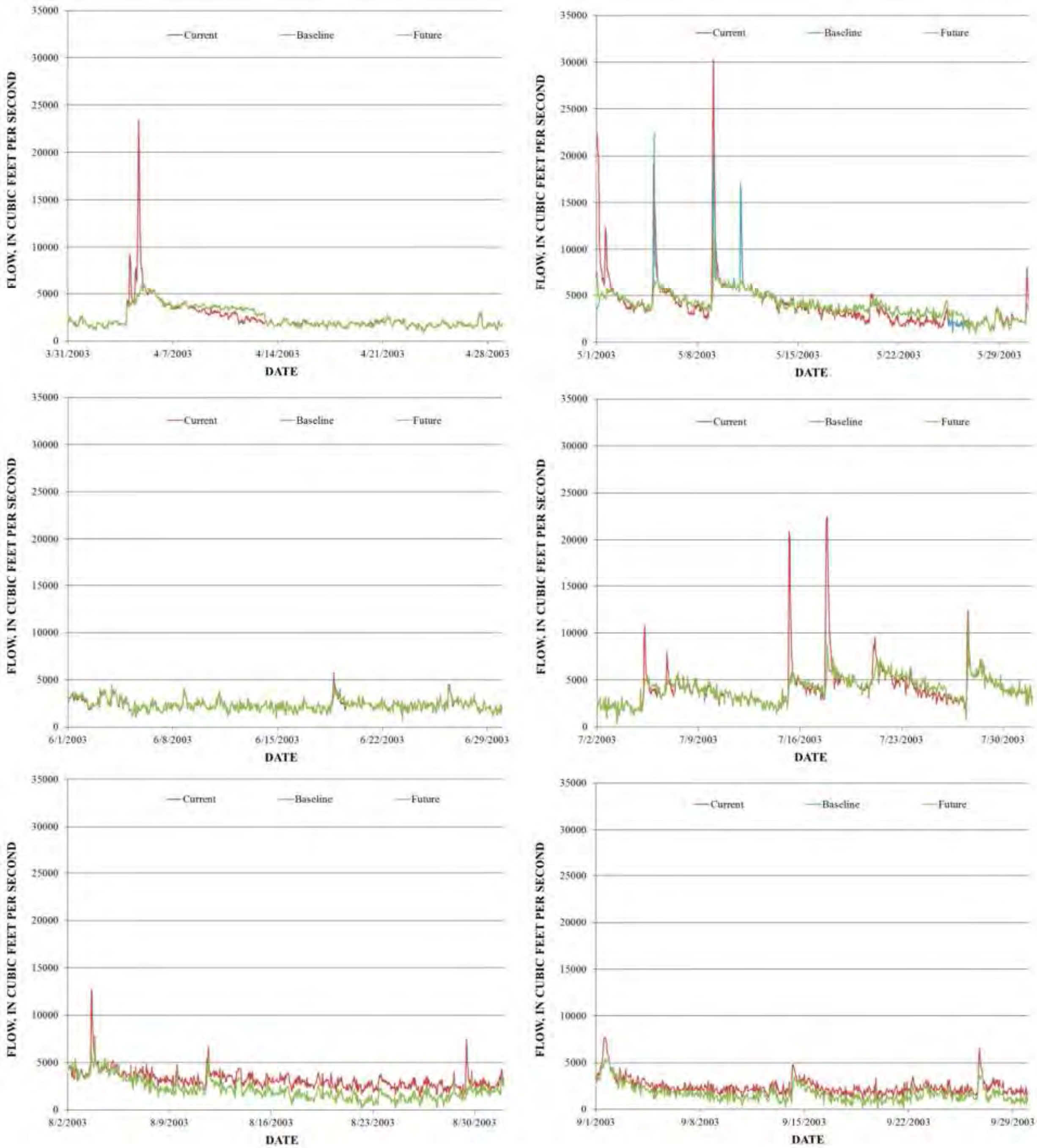


Figure H.2. (cont.) Comparison of the sum of inflows to the Chicago Area Waterways System for the Current, Baseline, and Future conditions for Water Year 2003.

Addendum Section I: Measured and Adjusted Water-Surface Elevations at the Lockport Controlling Works for Water Years 2001 and 2003

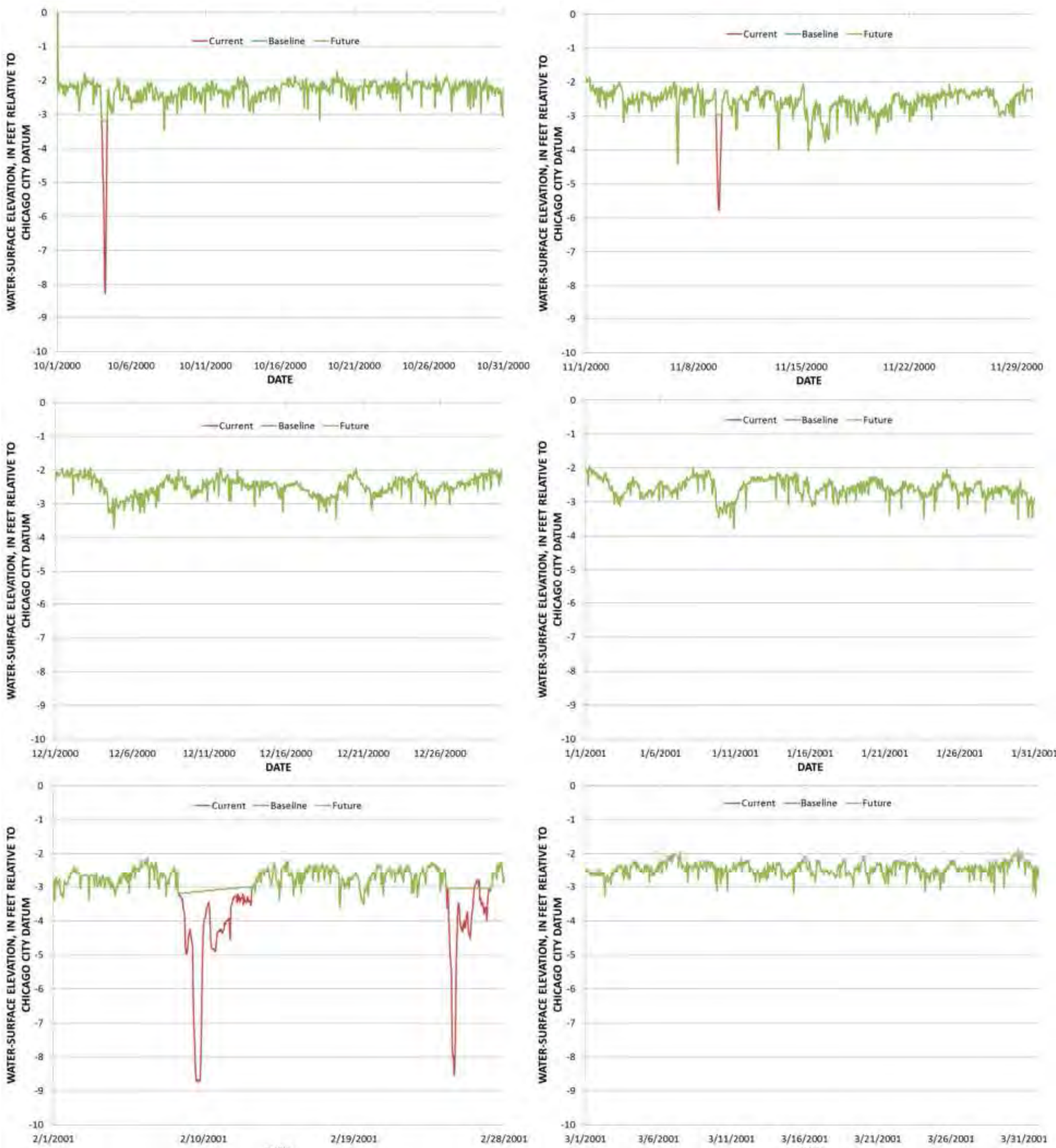


Figure I.1. Lockport Controlling Works downstream boundary for Water Year 2001: measured (Current) water-surface elevations and water-surface elevations adjusted to reflect the reduction in combined sewer overflows to the Chicago Area Waterways System for Baseline and Future conditions.

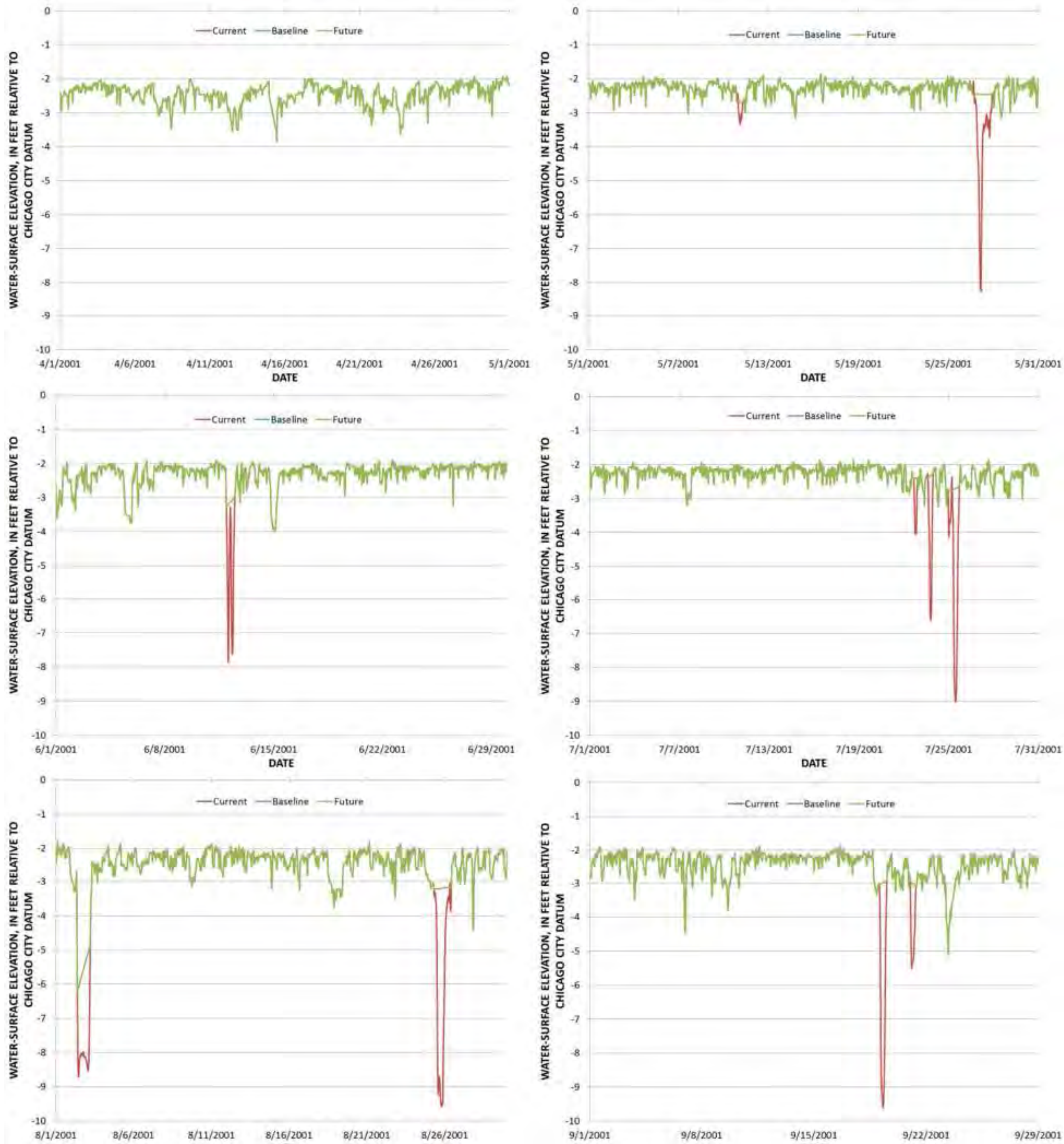


Figure I.1. (cont.) Lockport Controlling Works downstream boundary for Water Year 2001: measured (Current) water-surface elevations and water-surface elevations adjusted to reflect the reduction in combined sewer overflows to the Chicago Area Waterways System for Baseline and Future conditions.

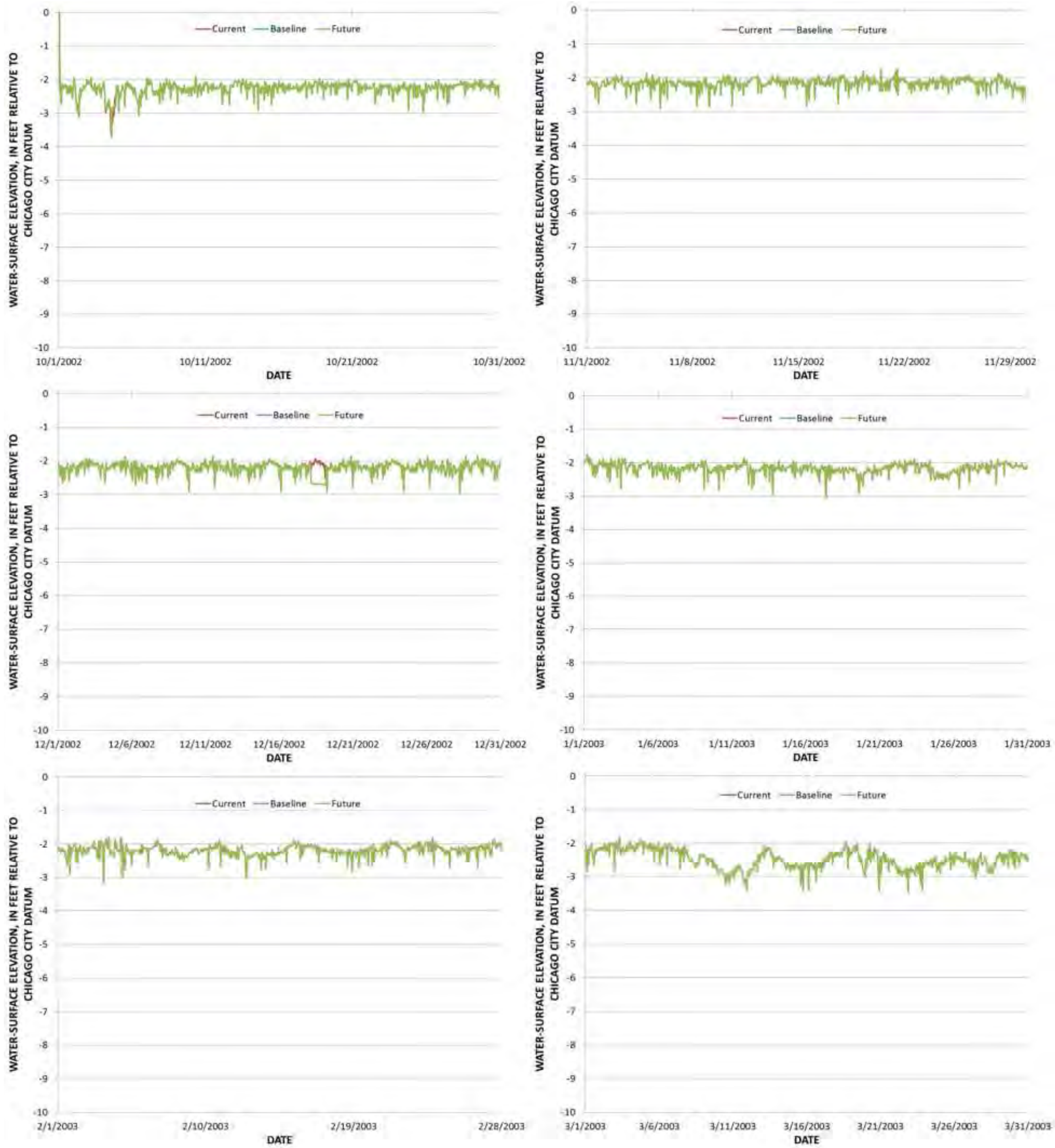


Figure I.2. Lockport Controlling Works downstream boundary for Water Year 2003: measured (Current) water-surface elevations and water-surface elevations adjusted to reflect the reduction in combined sewer overflows to the Chicago Area Waterways System for Baseline and Future conditions.

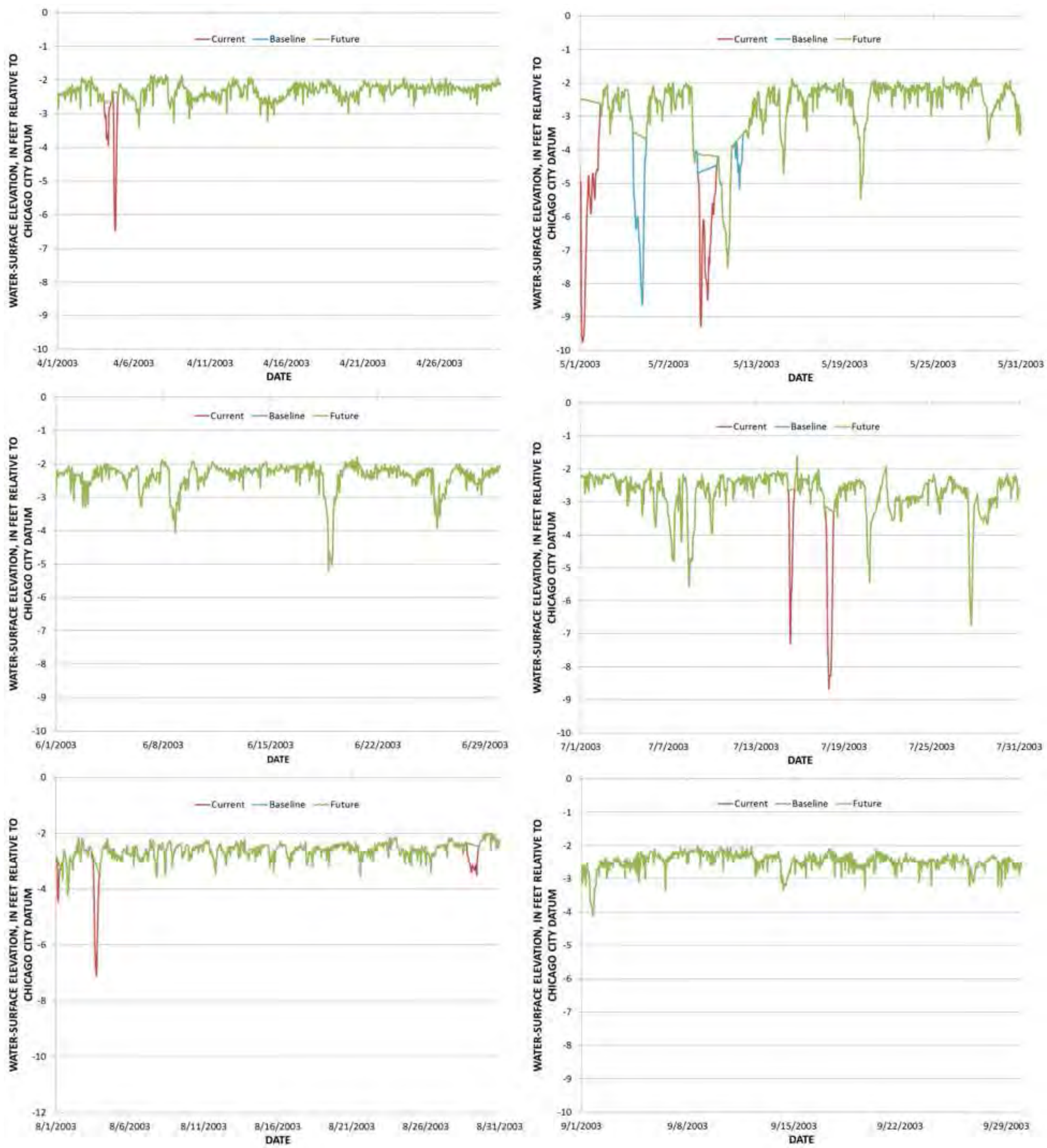


Figure I.2. (cont.) Lockport Controlling Works downstream boundary for Water Year 2003: measured (Current) water-surface elevations and water-surface elevations adjusted to reflect the reduction in combined sewer overflows to the Chicago Area Waterways System for Baseline and Future conditions.

Addendum Section J: Flows at the Lockport Controlling Works for the Current, Baseline, and Future Conditions for the “No Project”, “Lakefront Separation”, and “Midsystem Separation” Alternatives for Water Years 2001 and 2003

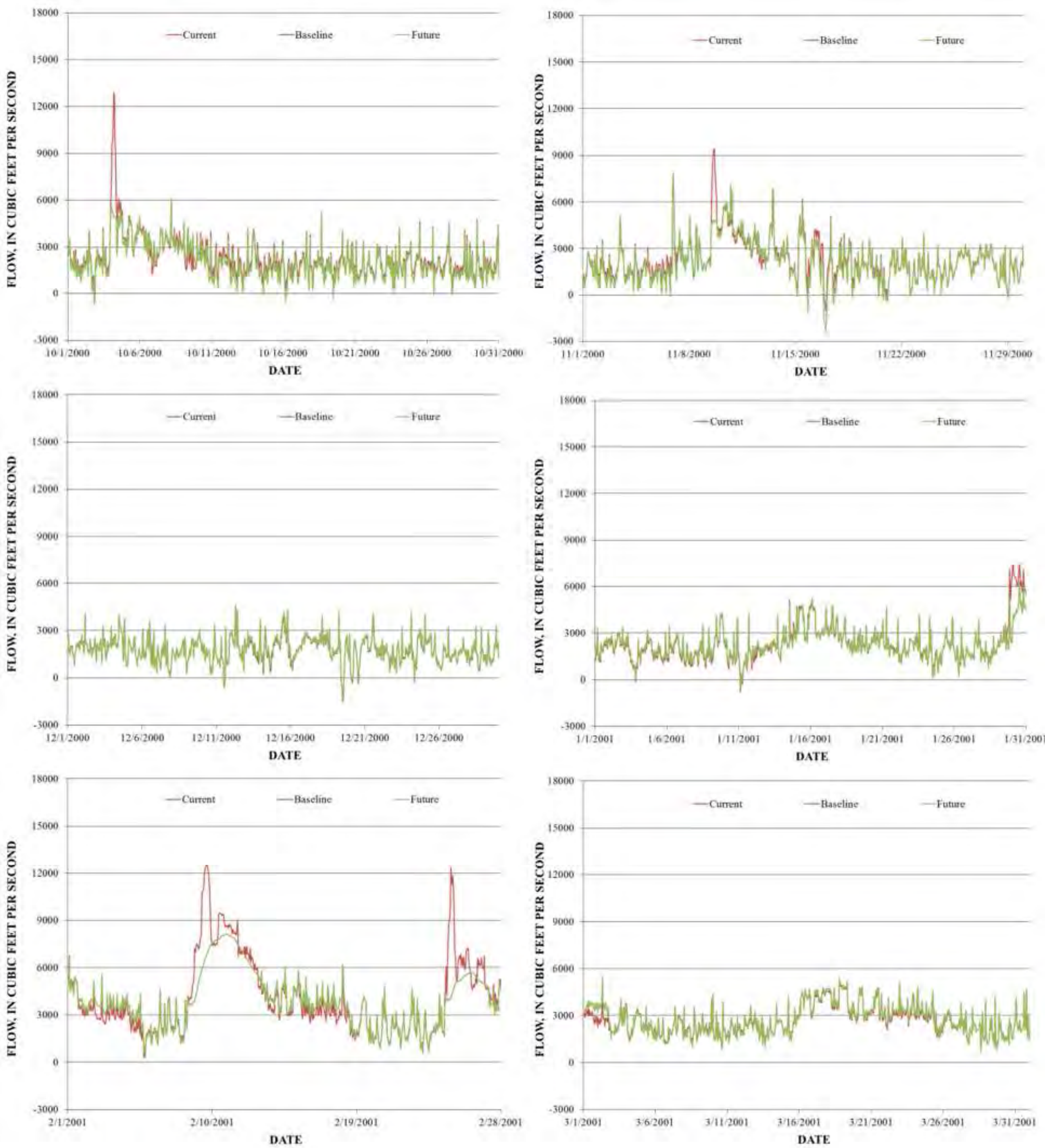


Figure J.1. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "No Project" alternative for Water Year 2001.

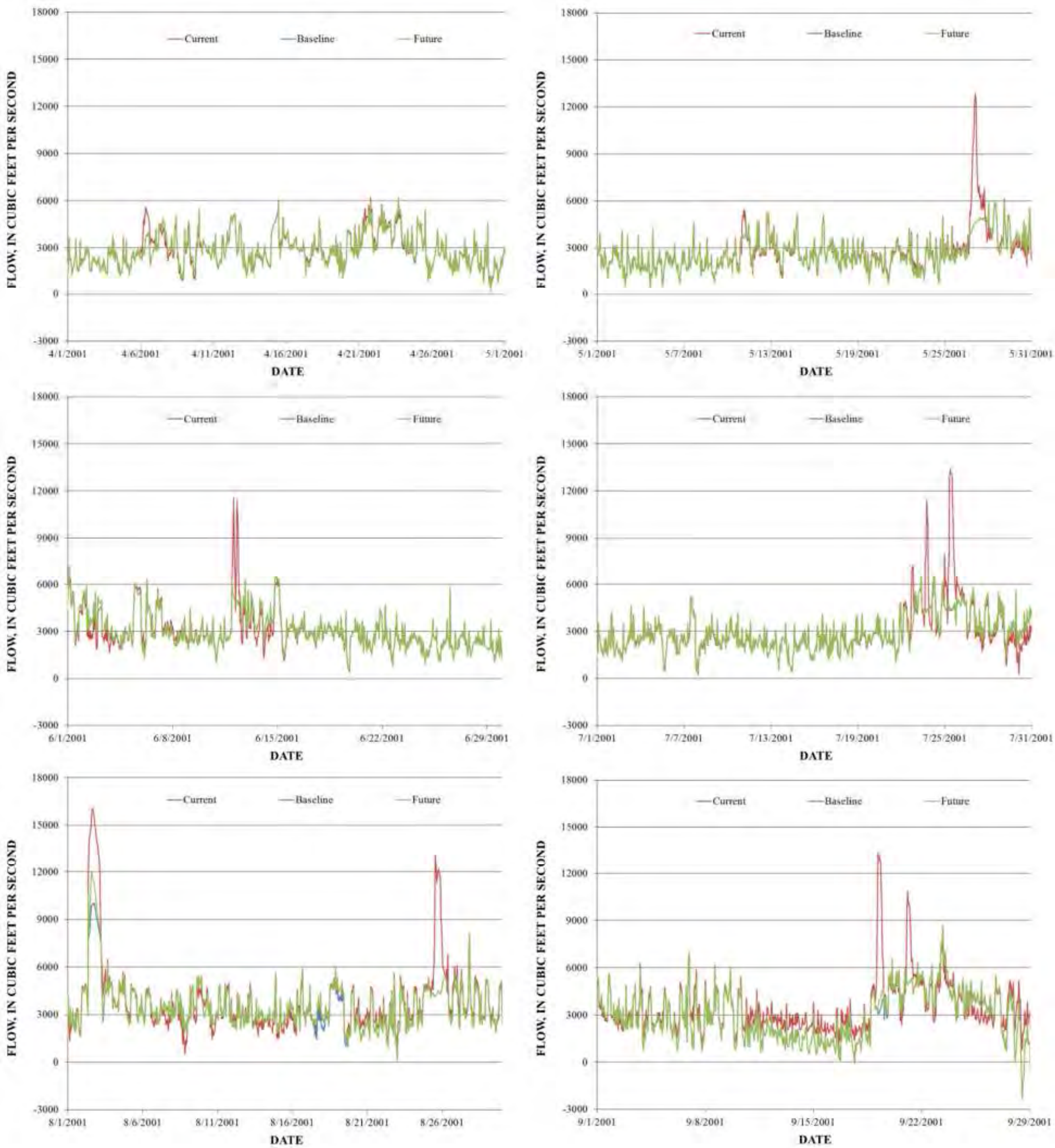


Figure J.1. (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the “No Project” alternative for Water Year 2001.

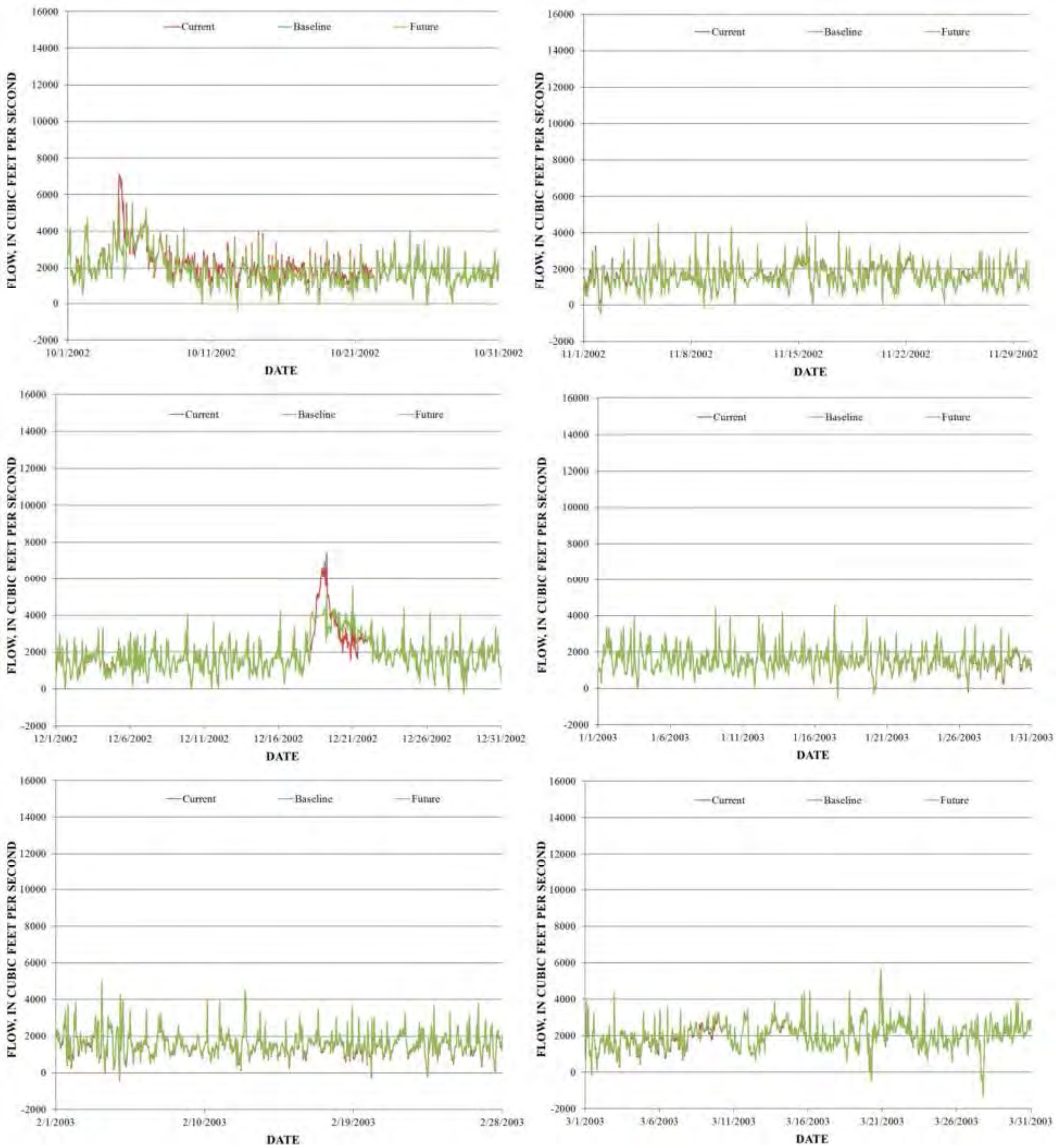


Figure J.2. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "No Project" alternative for Water Year 2003.

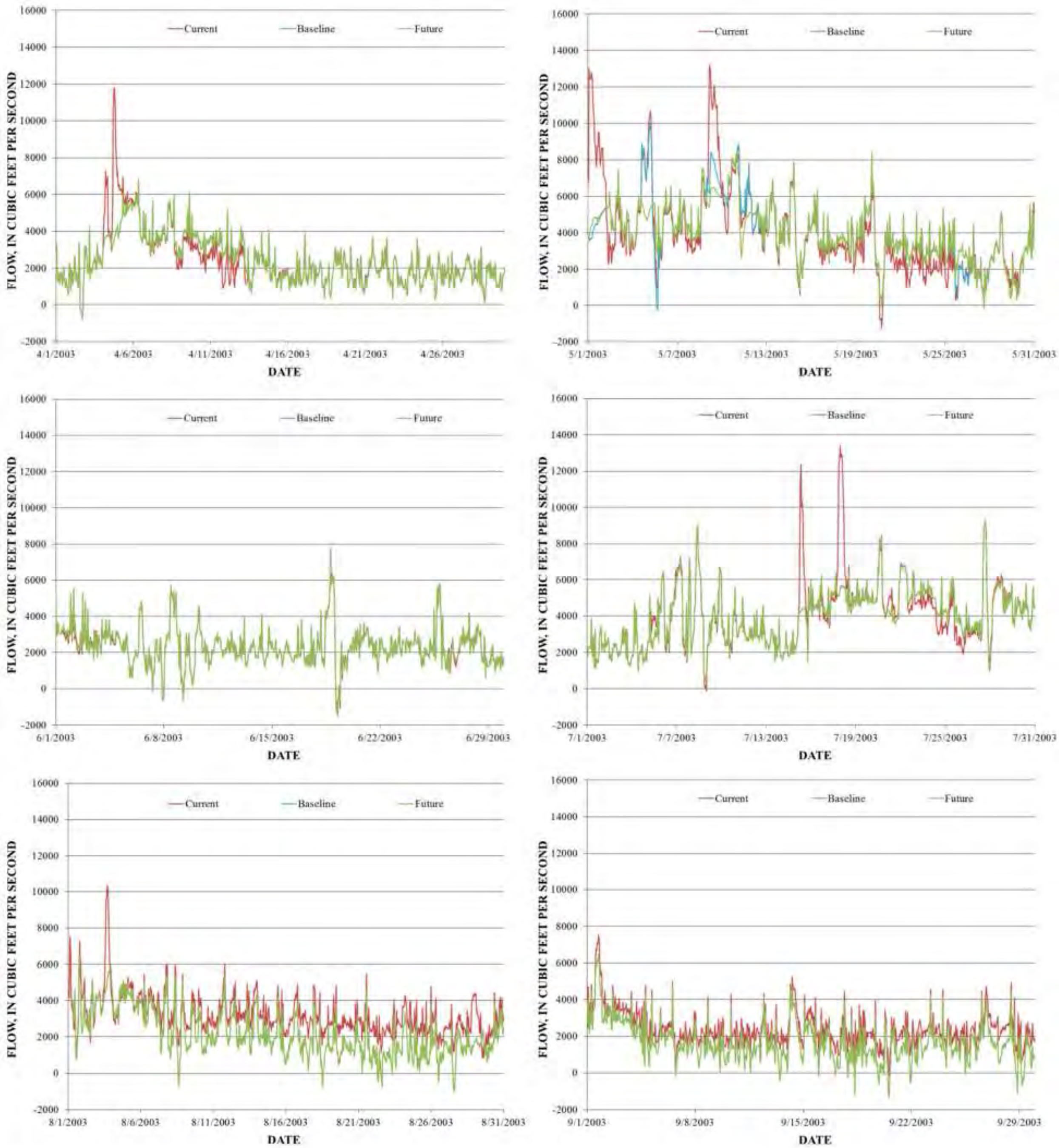


Figure J.2. (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "No Project" alternative for Water Year 2003.

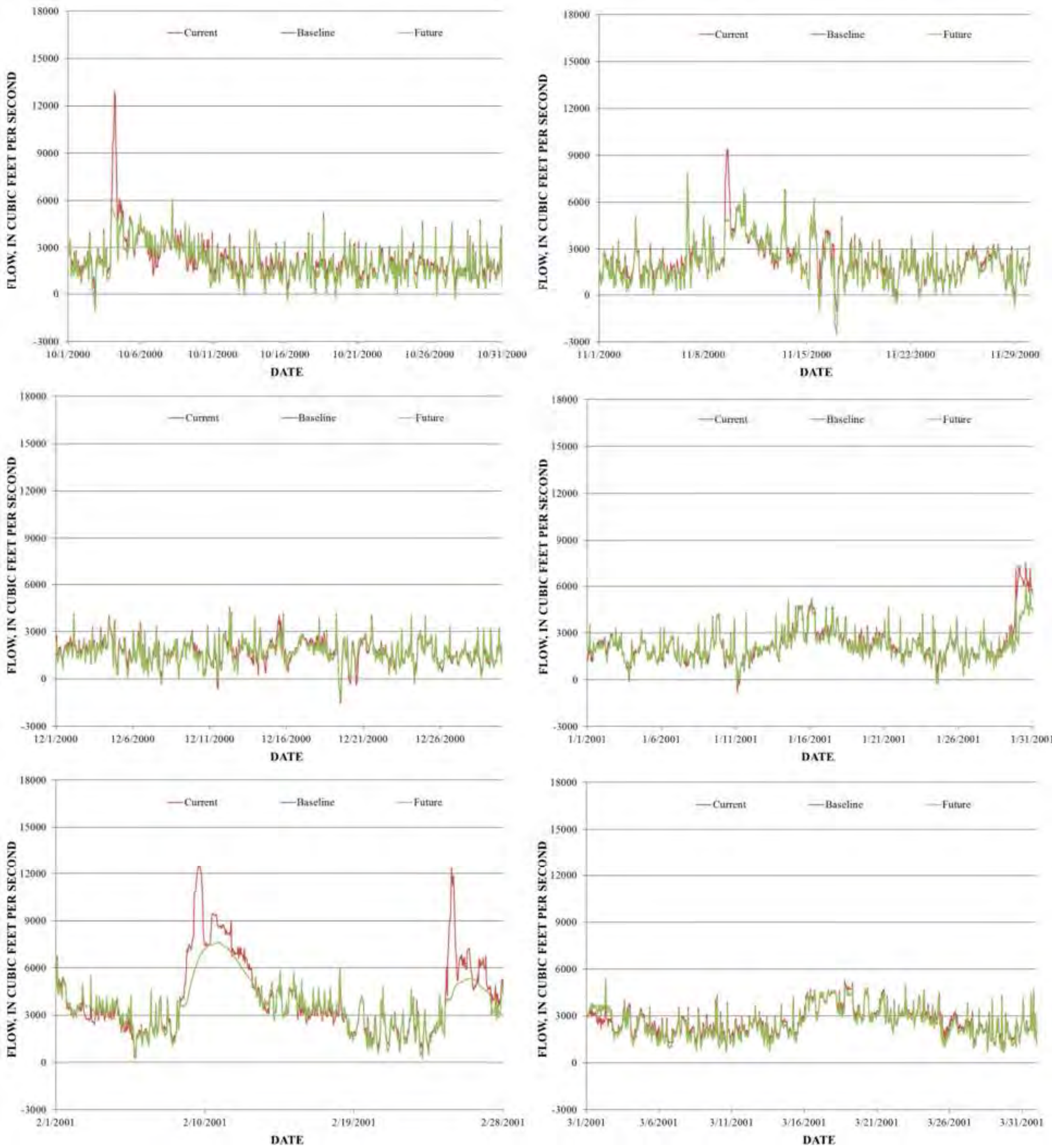


Figure J.3. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Lakefront Separation" alternative for Water Year 2001.

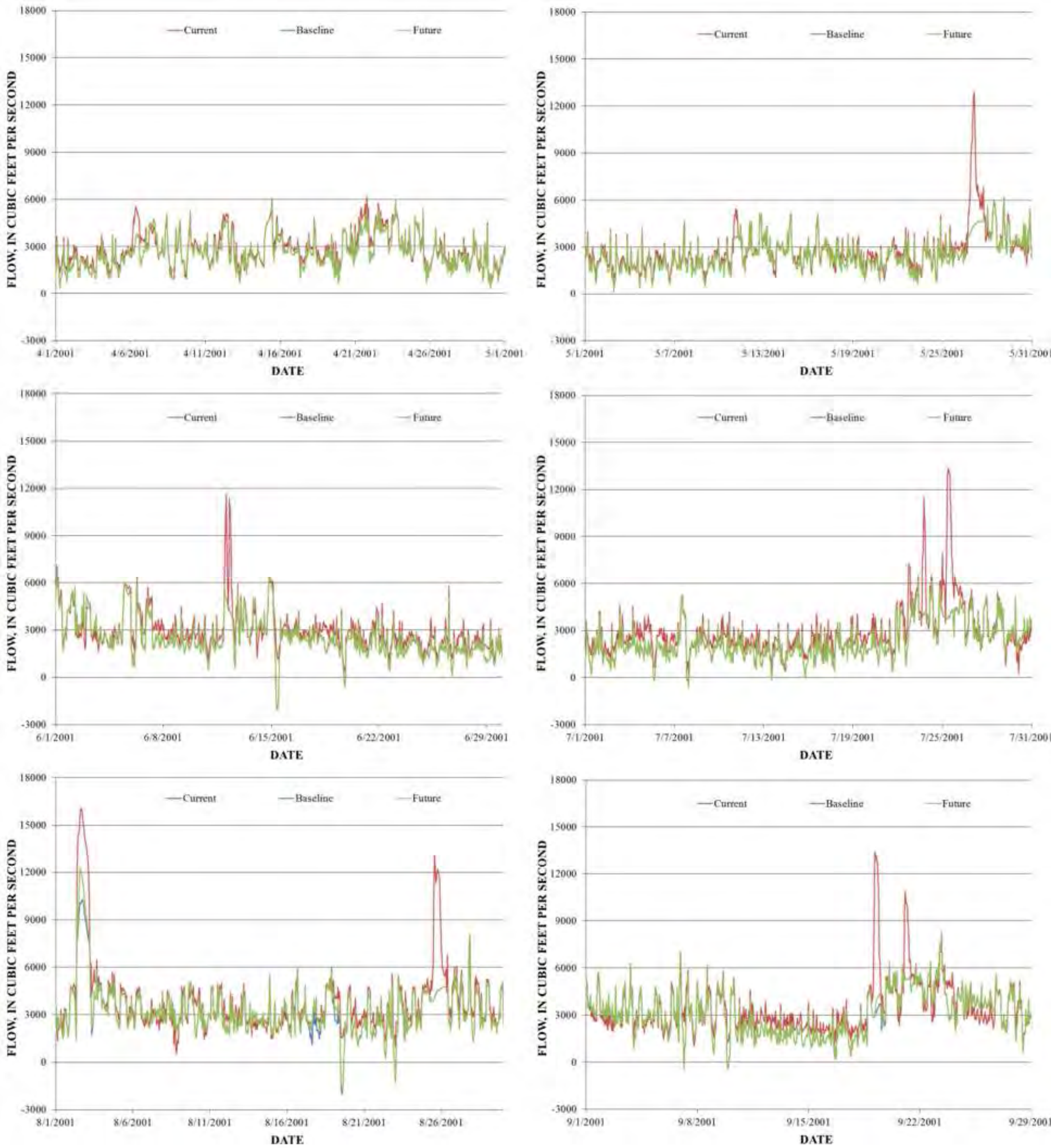


Figure J.3. (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Lakefront Separation" alternative for Water Year 2001.

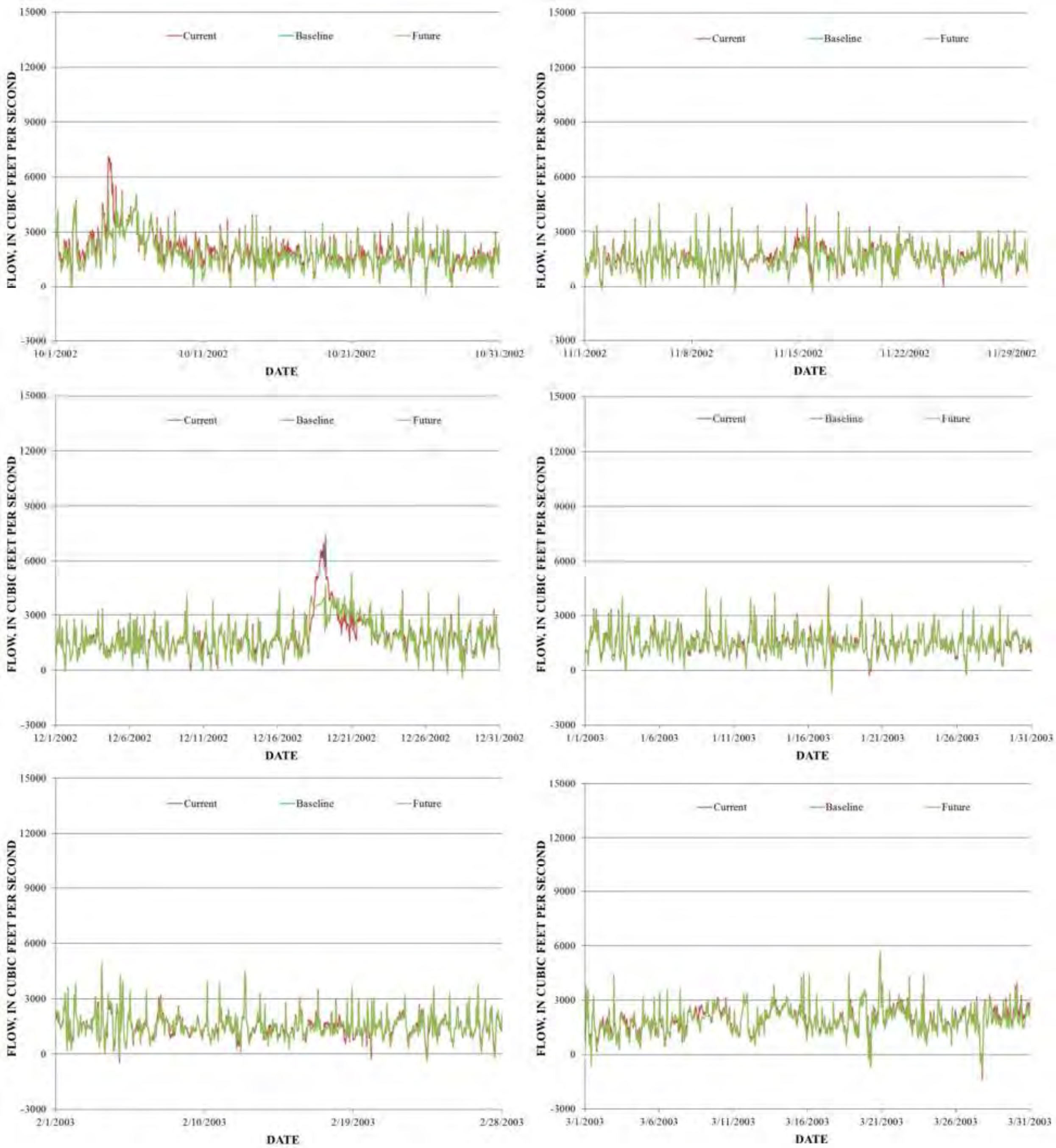


Figure J.4. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Lakefront Separation" alternative for Water Year 2003.

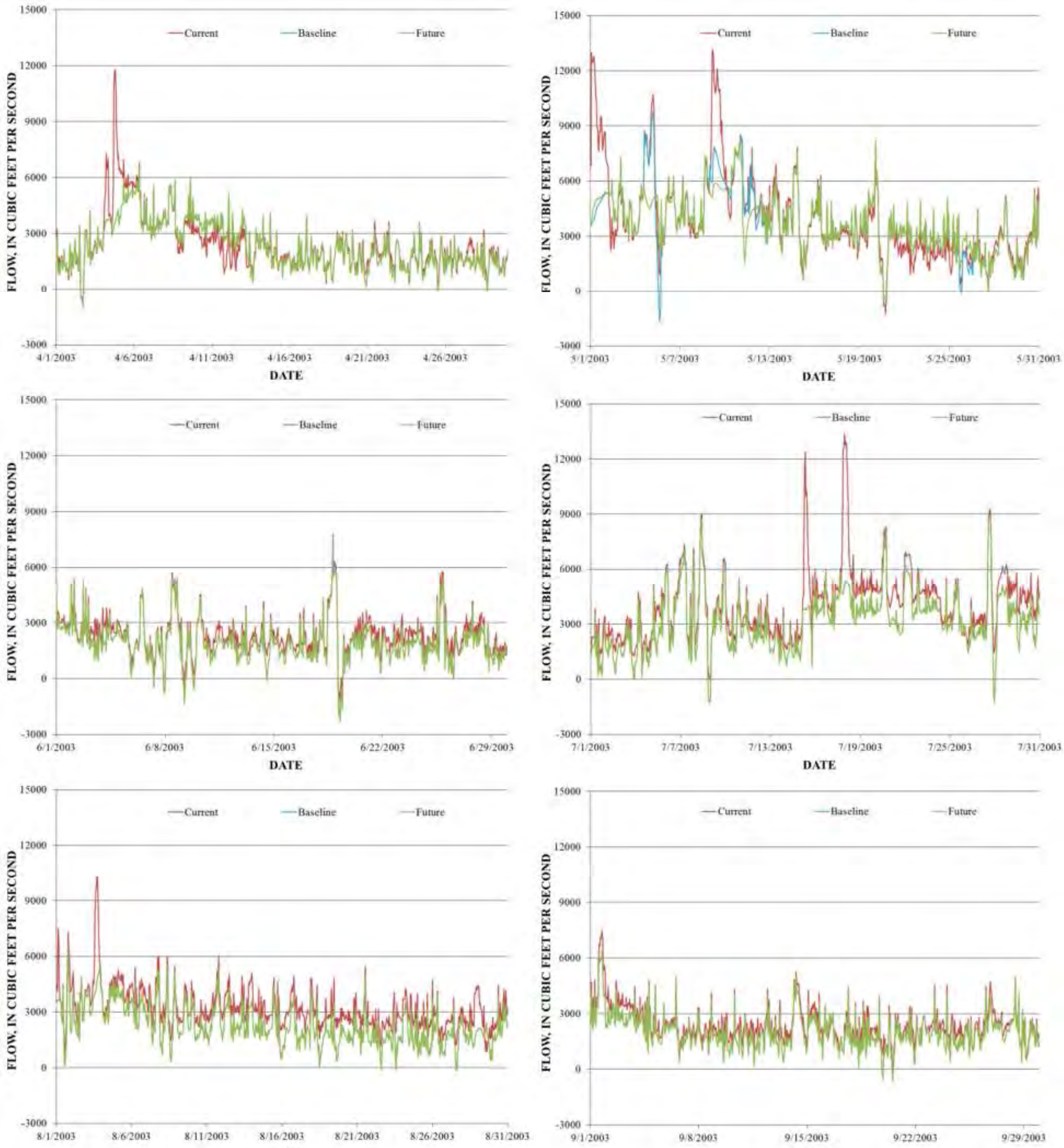


Figure J.4. (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Lakefront Separation" alternative for Water Year 2003.

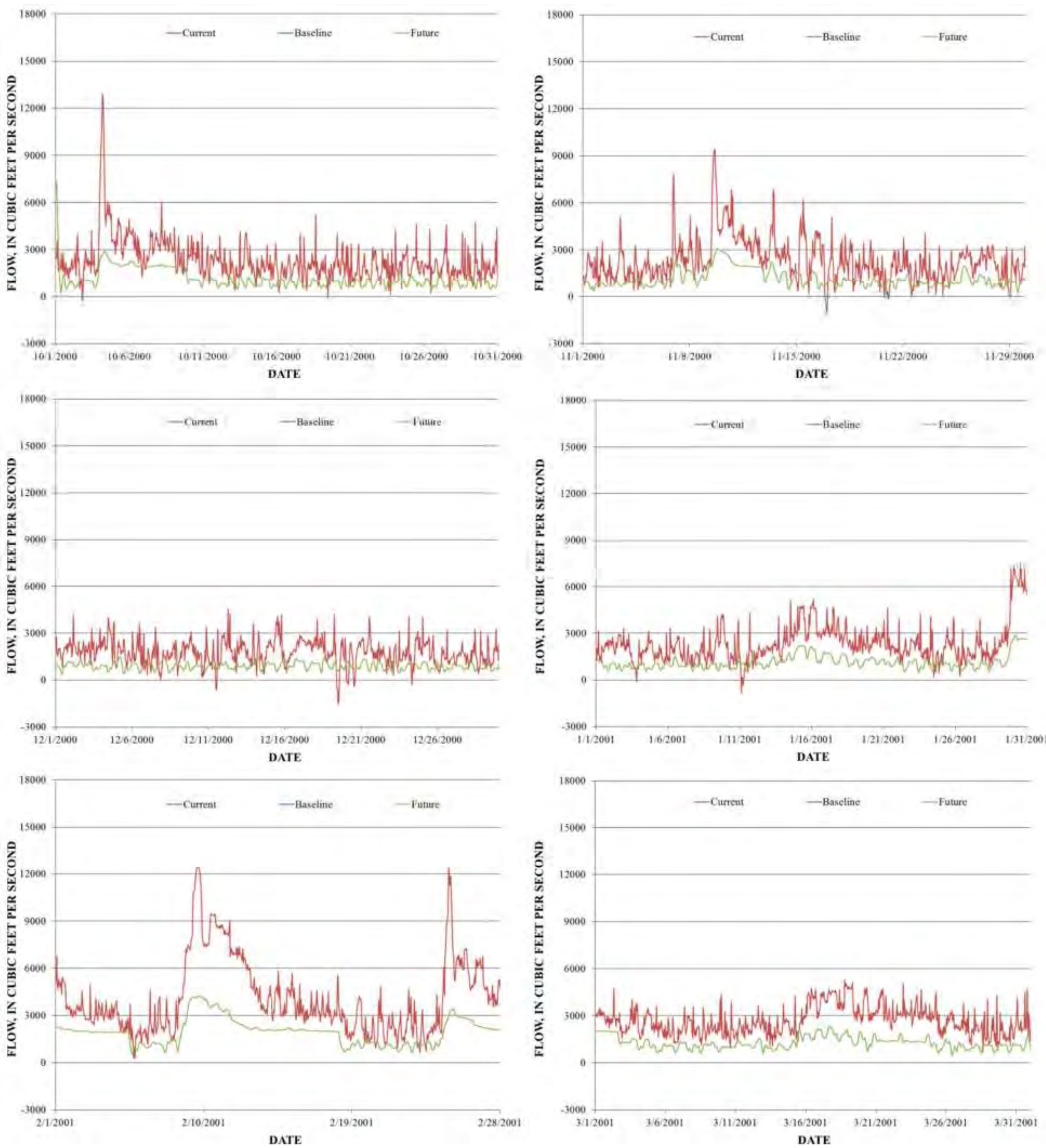


Figure J.5. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Midsystem Separation" alternative for Water Year 2001.

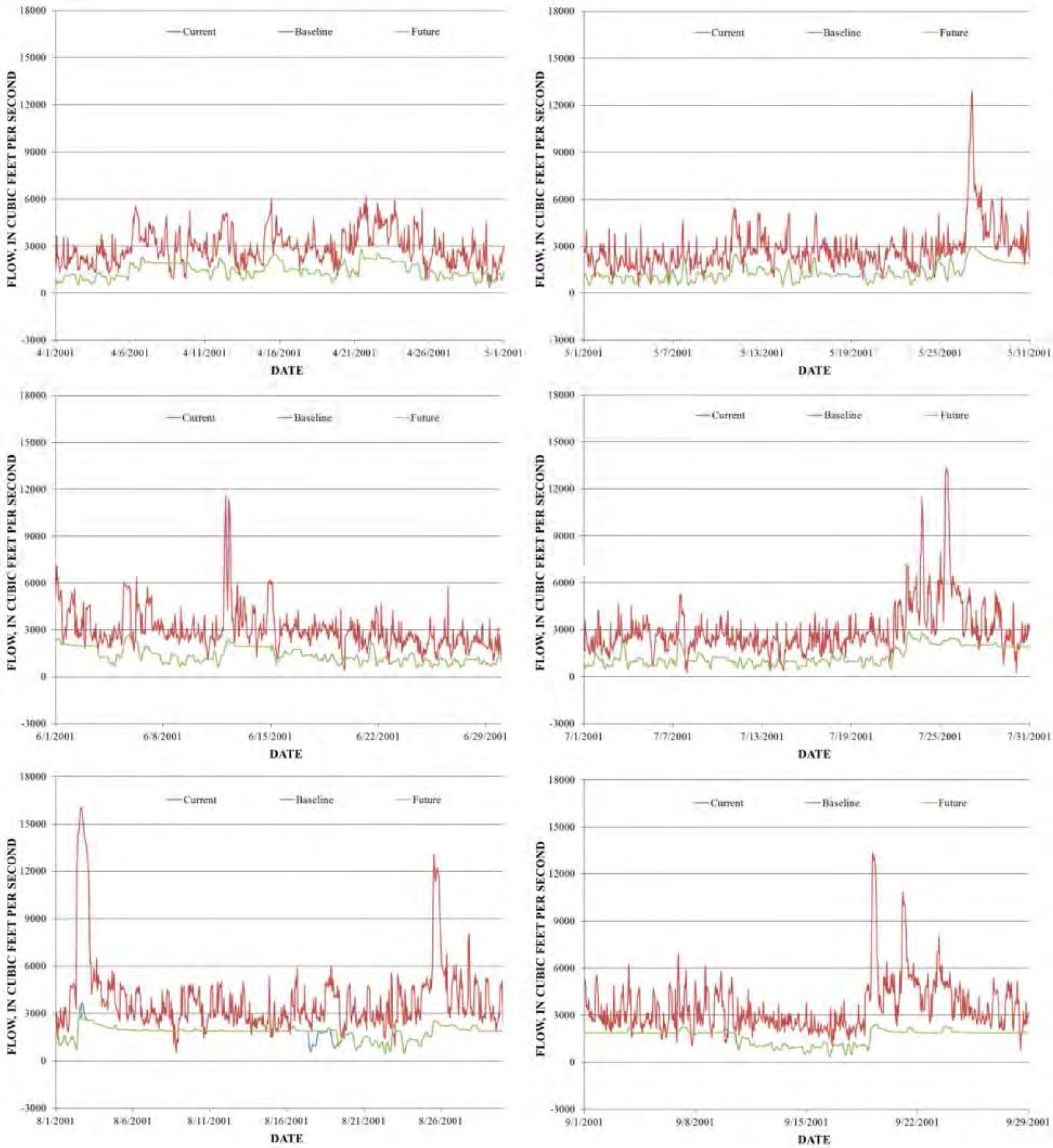


Figure J.5. (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Midsystem Separation" alternative for Water Year 2001.

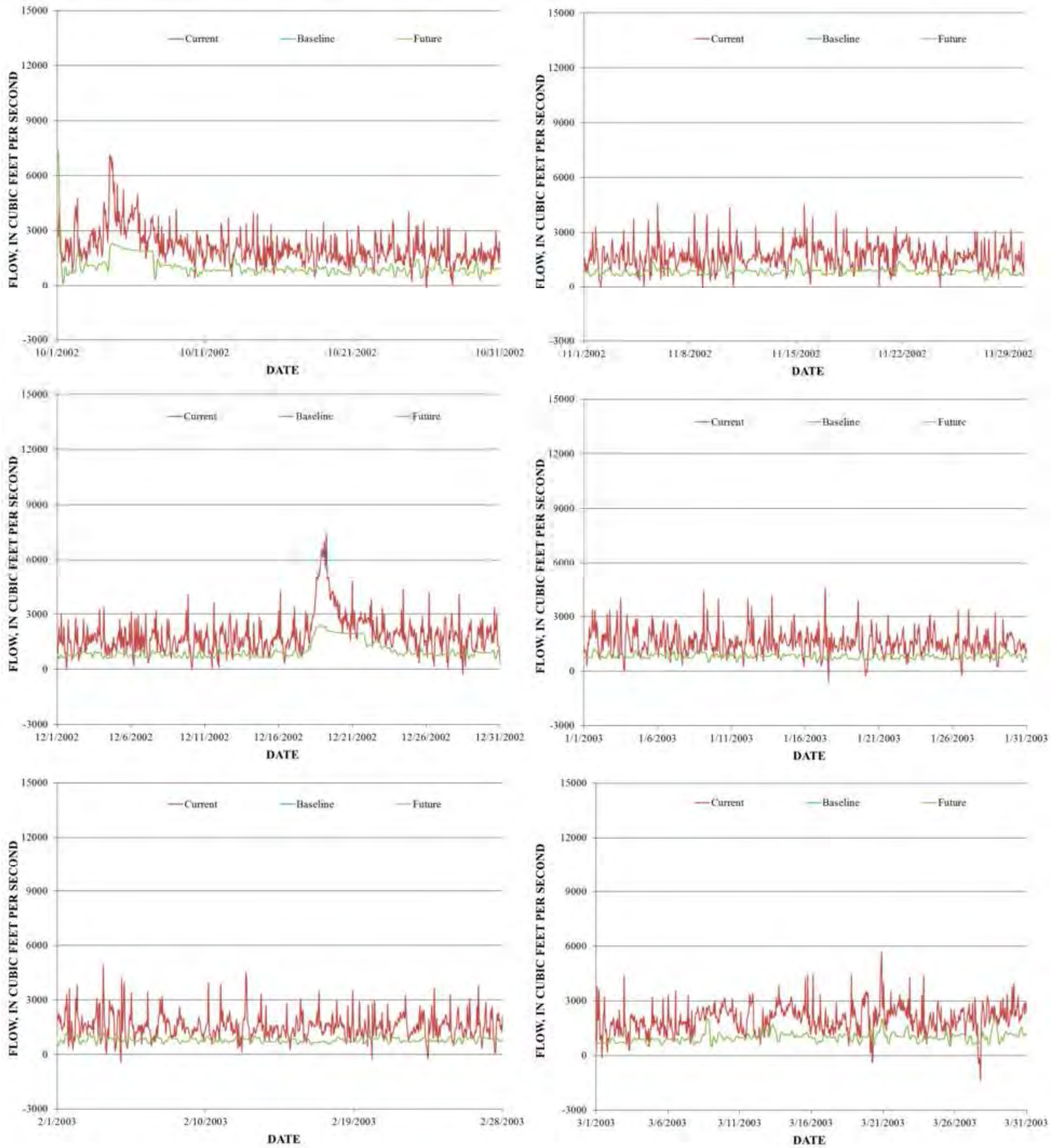


Figure J.6. Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Midsystem Separation" alternative for Water Year 2003.

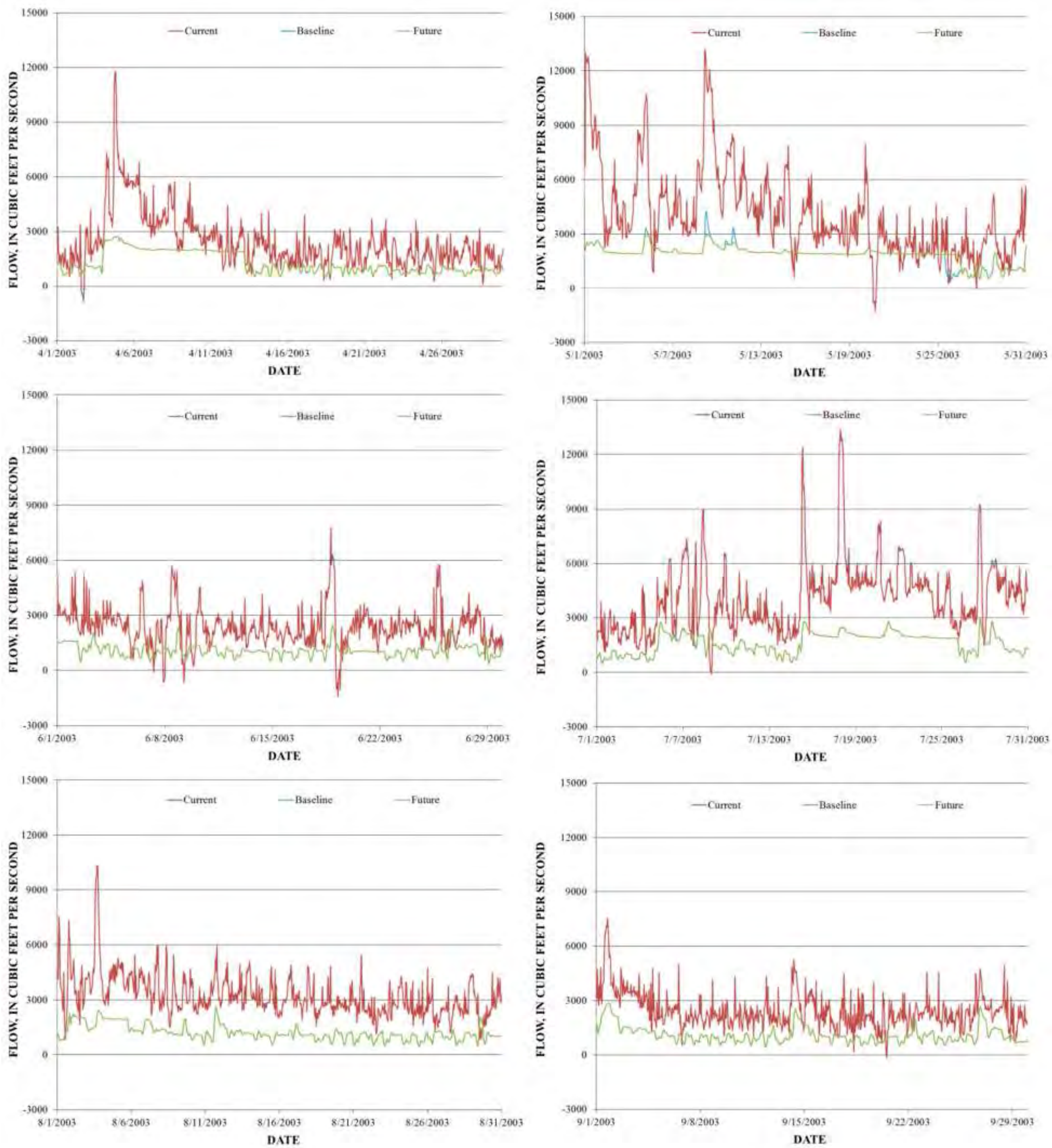


Figure J.6. (cont.) Computed flows in the Chicago Sanitary and Ship Canal at the Lockport Controlling Works for the Current conditions and Baseline and Future conditions for the "Midsystem Separation" alternative for Water Year 2003.

Addendum Section K: Temperature Comparisons for Current, Baseline, and Future Conditions for No Project, Lake Separation, and Midsystem Separation Alternatives for Water Years 2001, 2003, and 2008

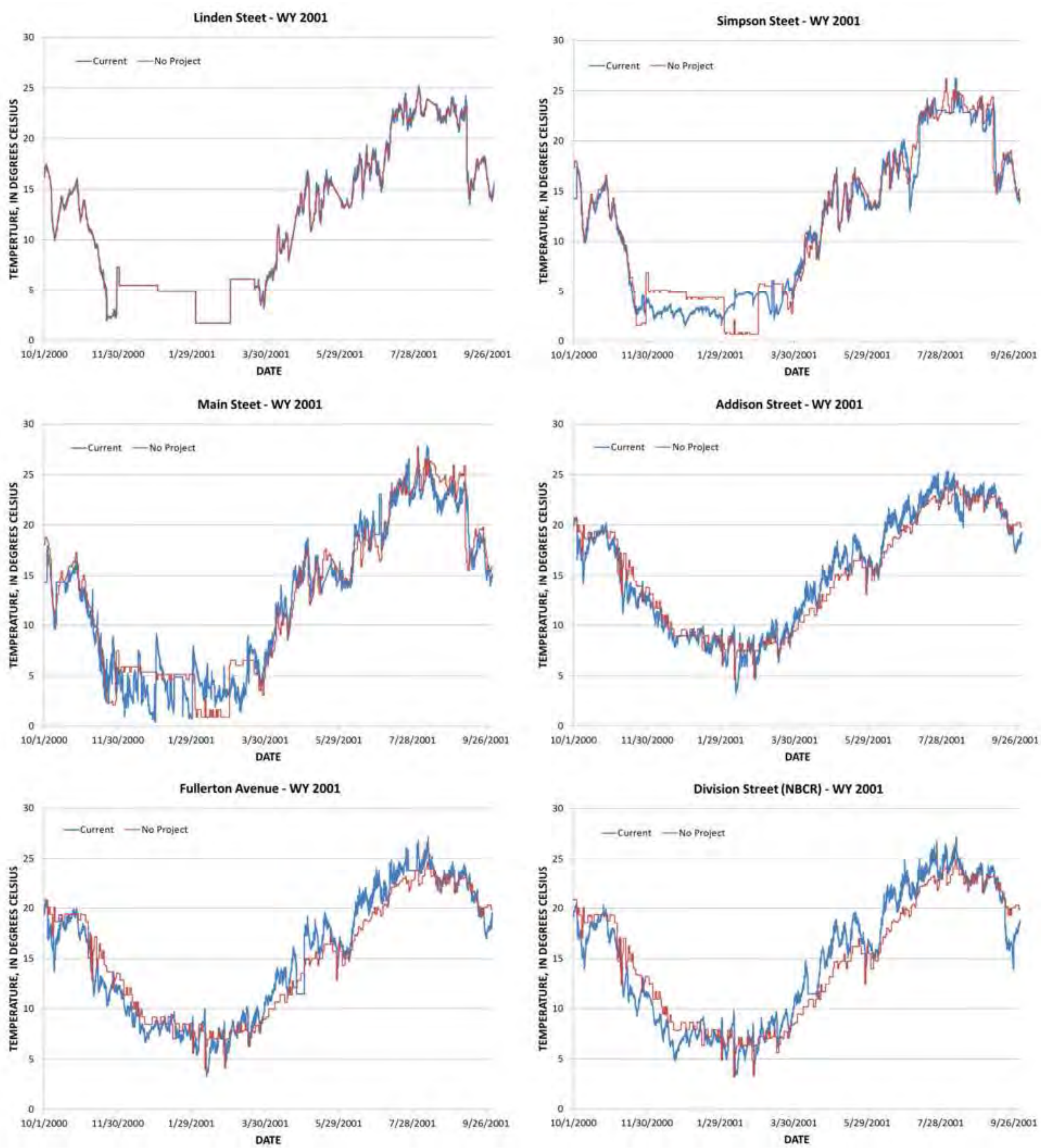


Figure K.1. Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2001.

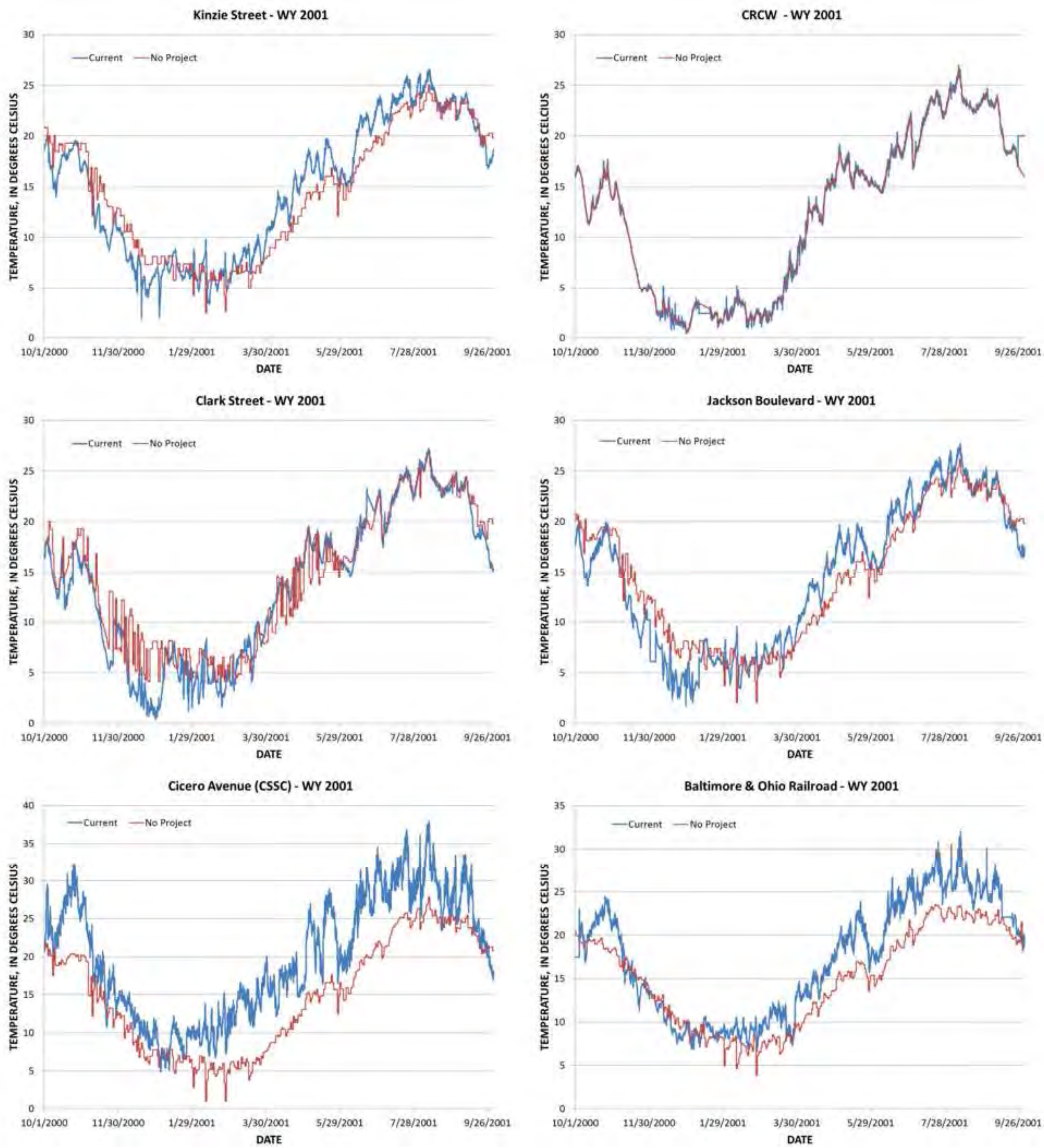


Figure K.1. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the “No Project” Alternative for Water Year 2001.

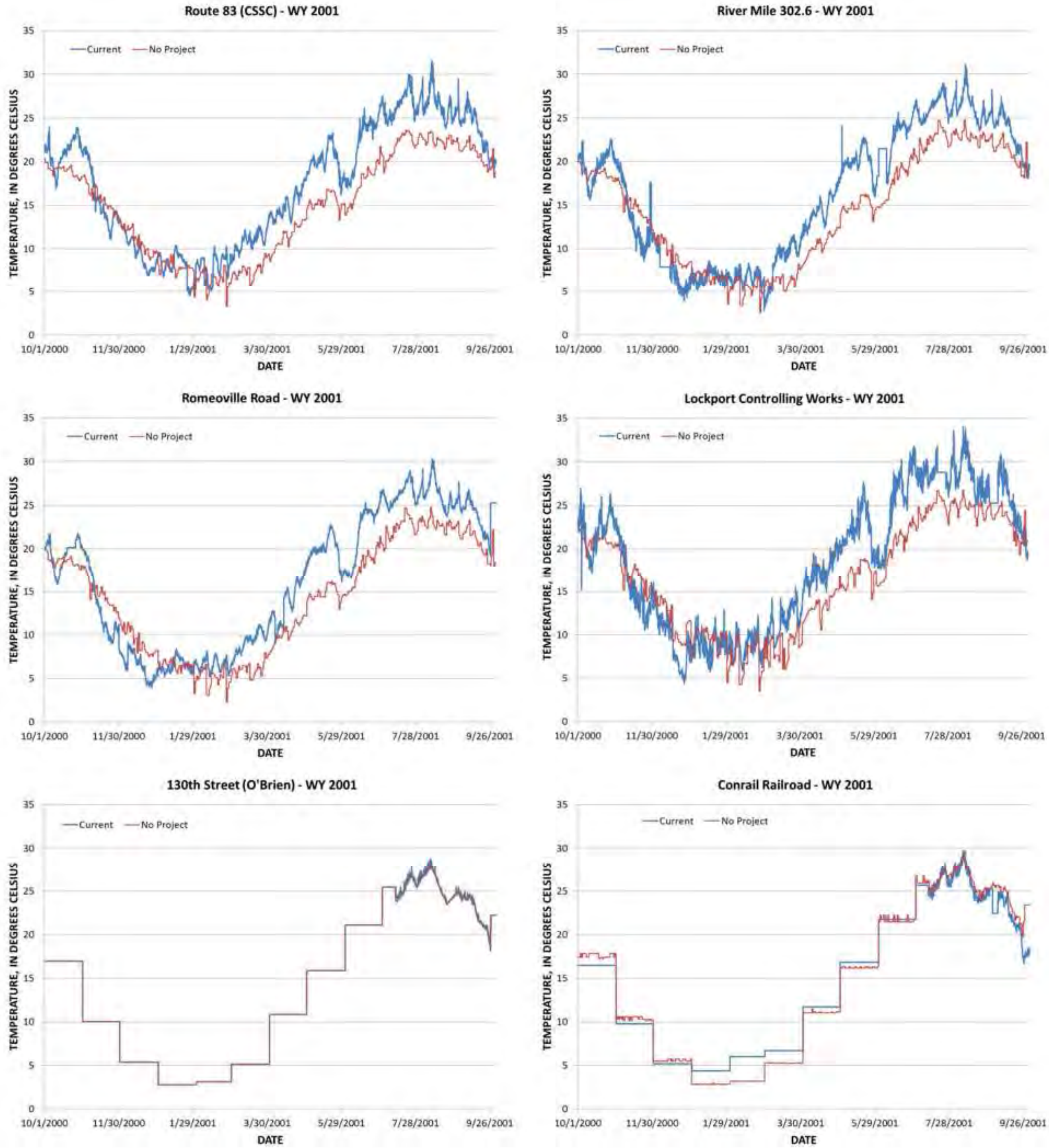


Figure K.1. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2001.

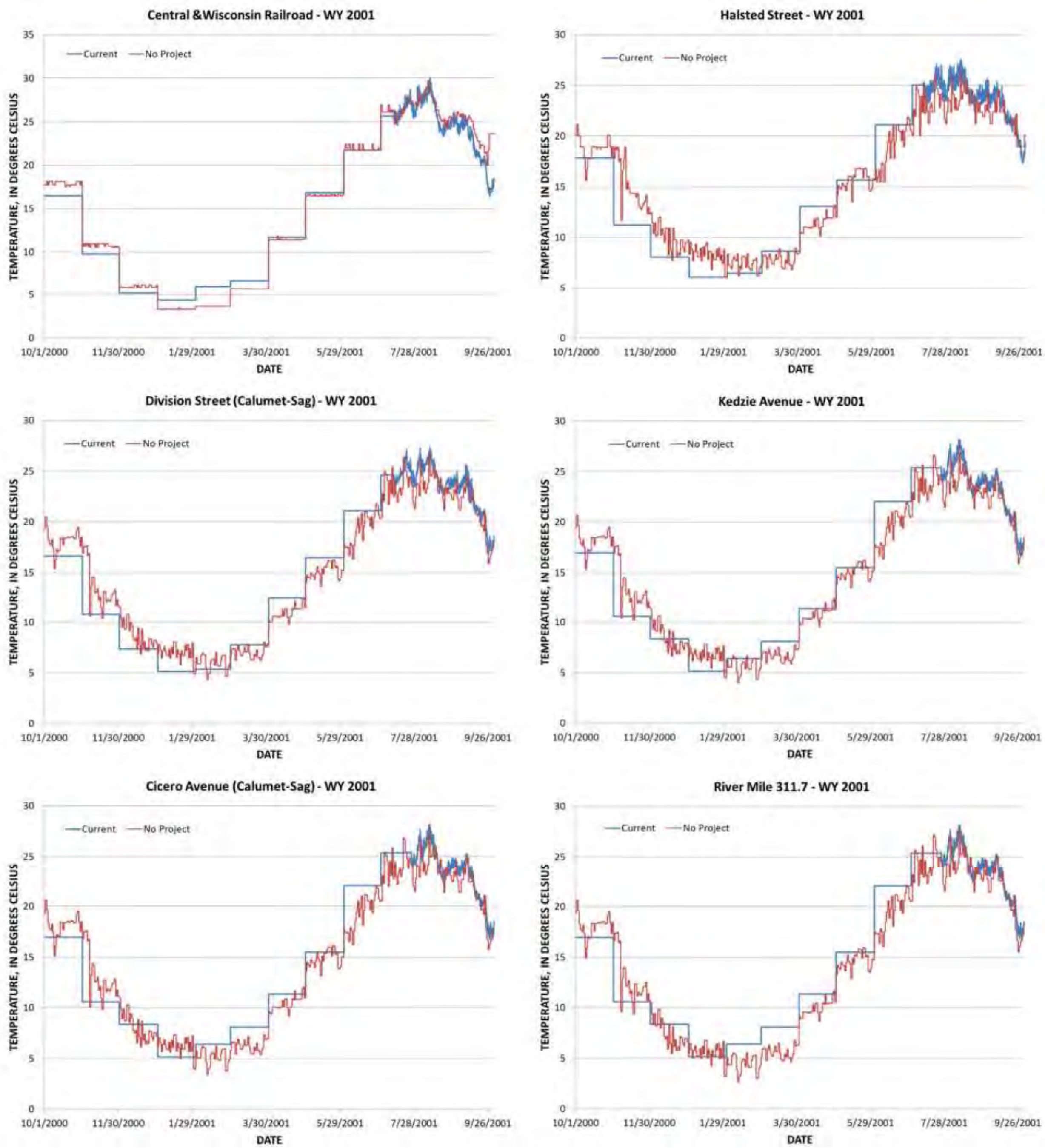


Figure K.1. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2001.

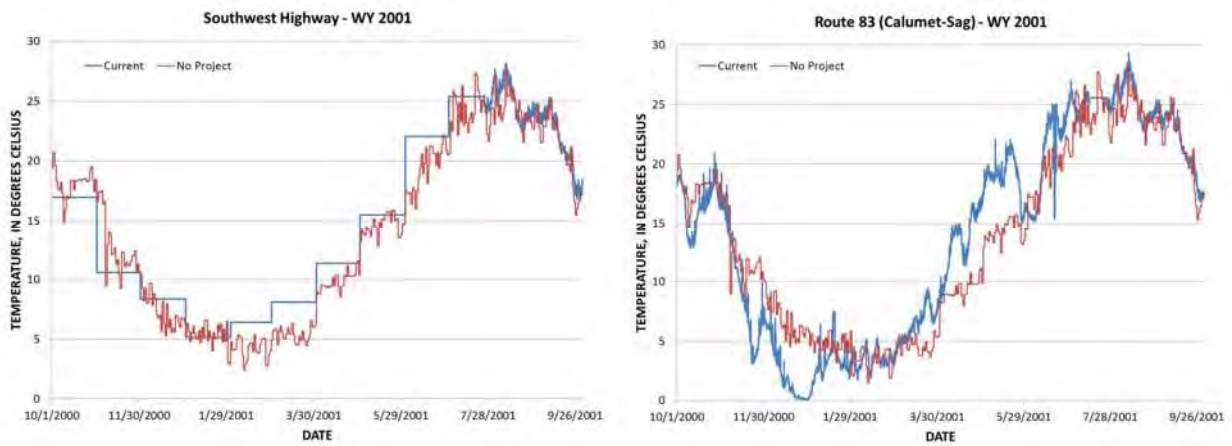


Figure K.1. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2001.

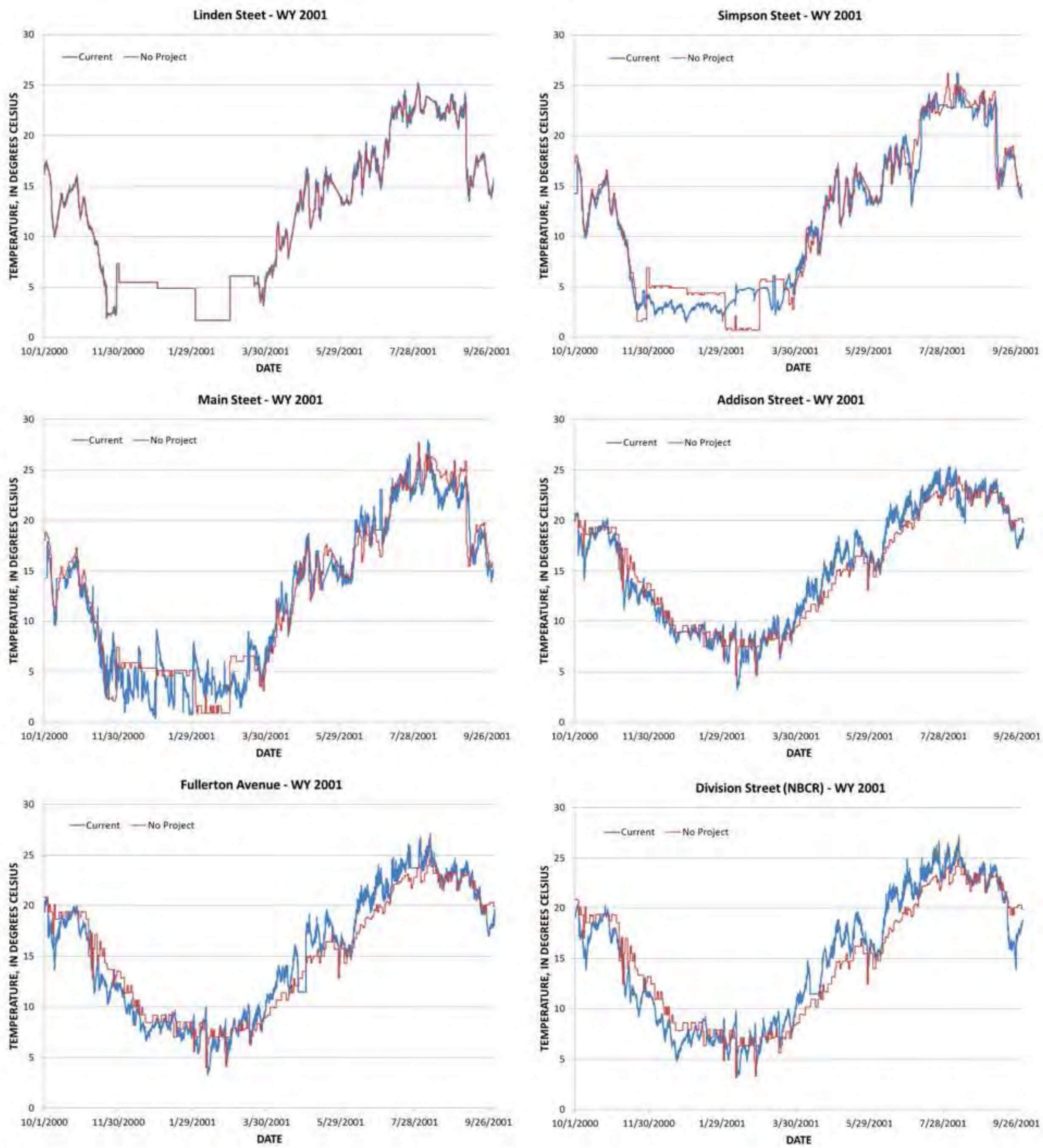


Figure K.2. Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2001.

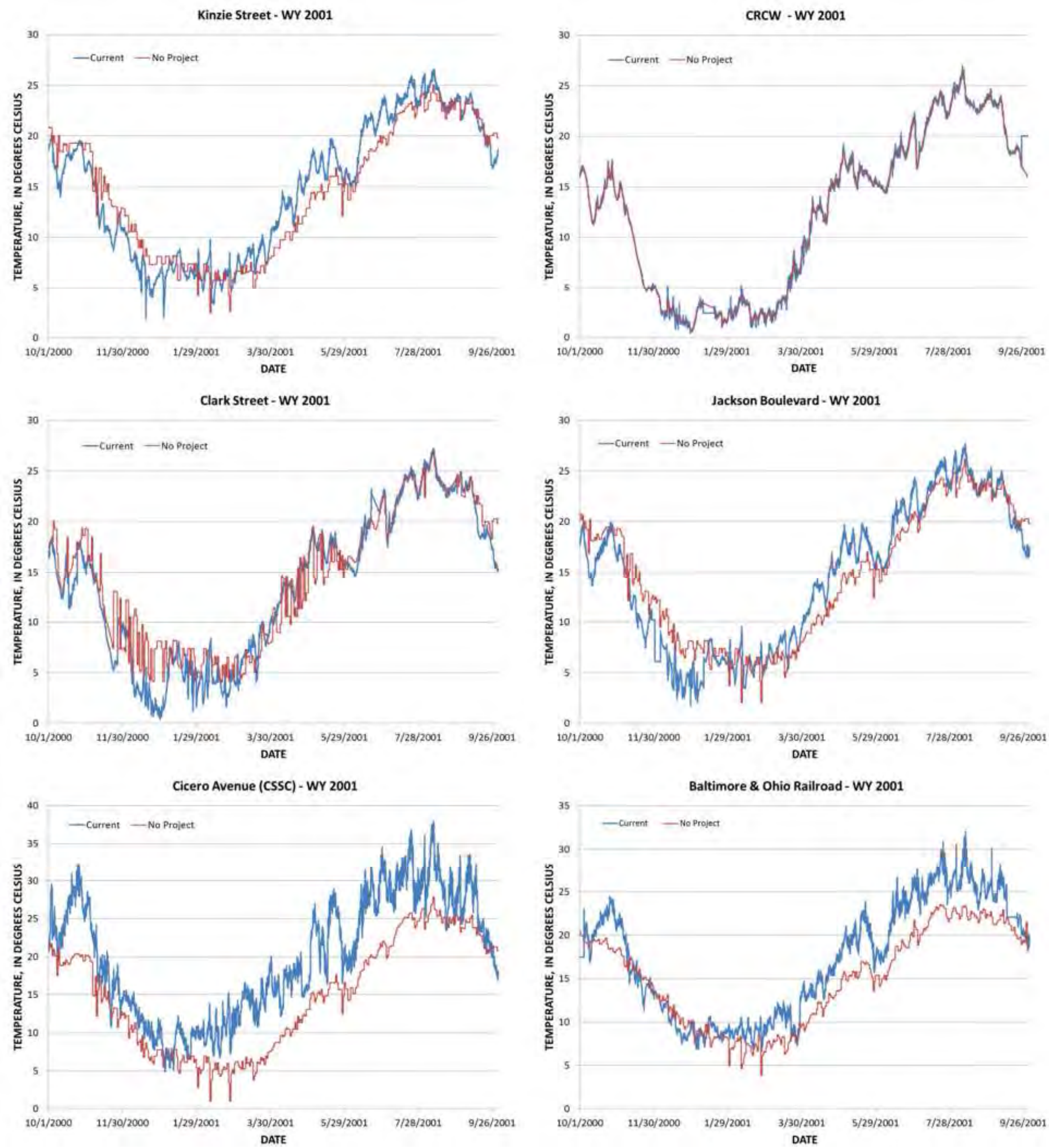


Figure K.2. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2001.

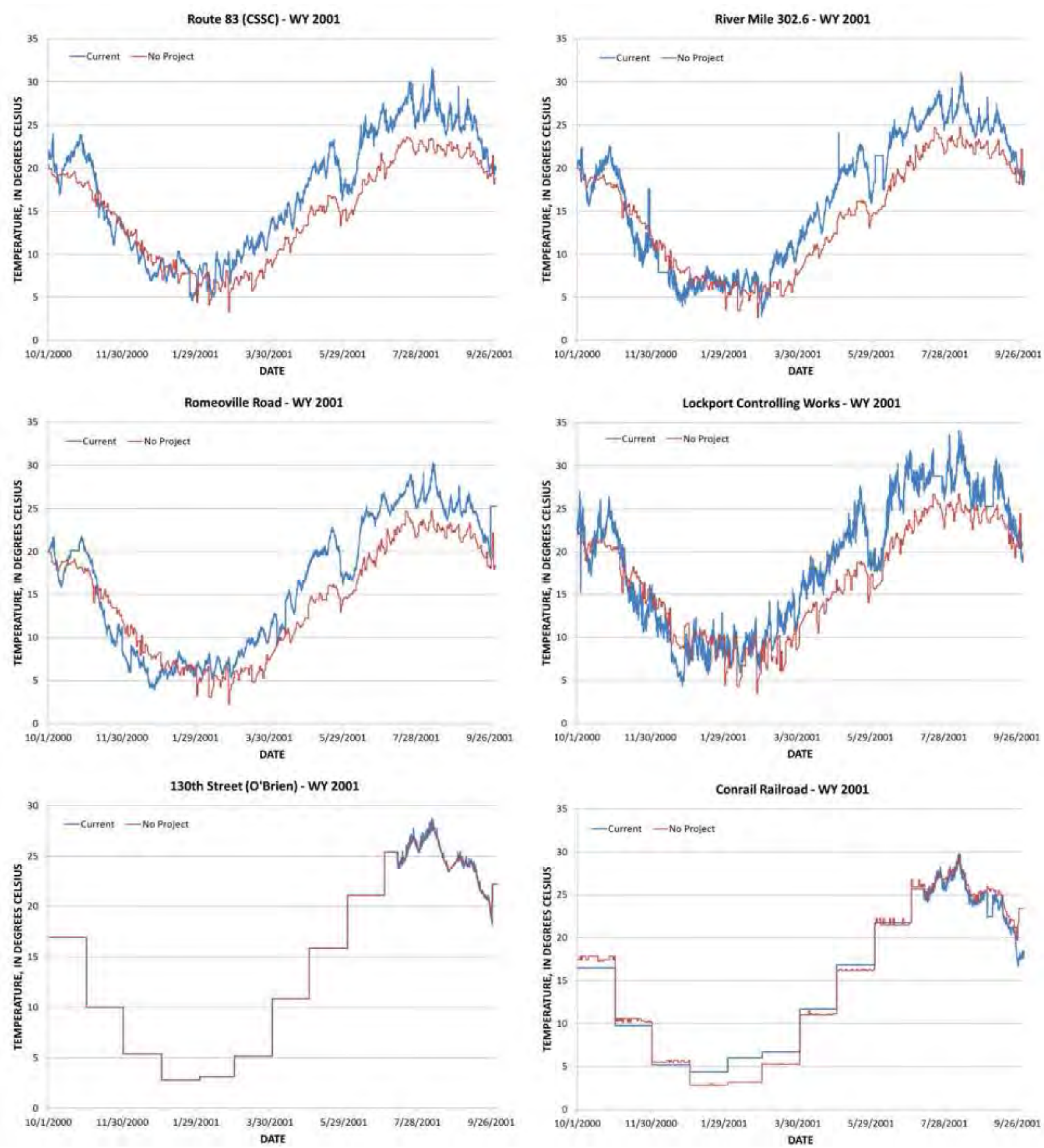


Figure K.2. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2001.

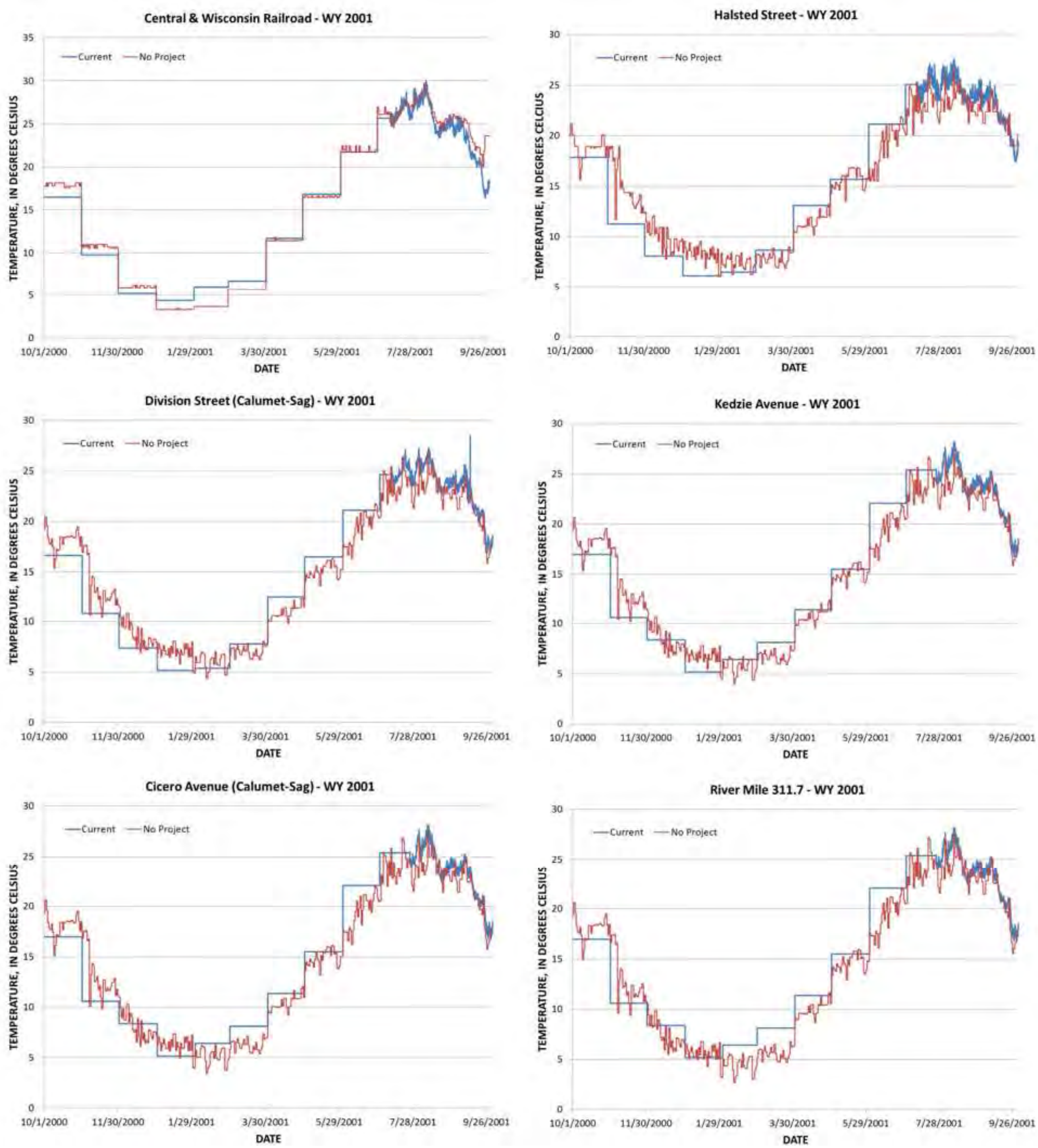
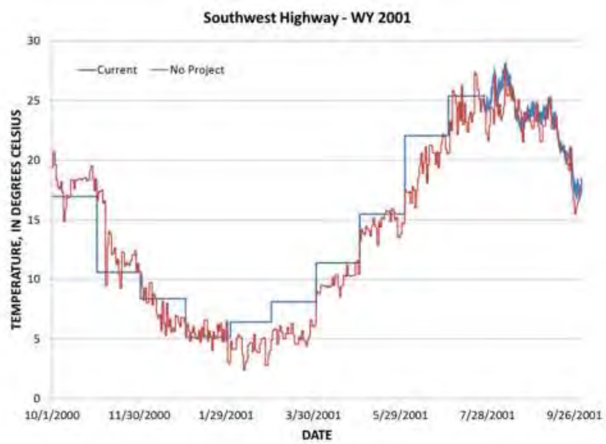


Figure K.2. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2001.



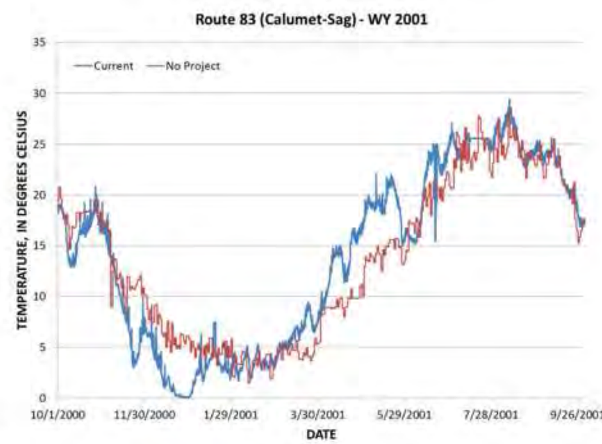


Figure K.2. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2001.

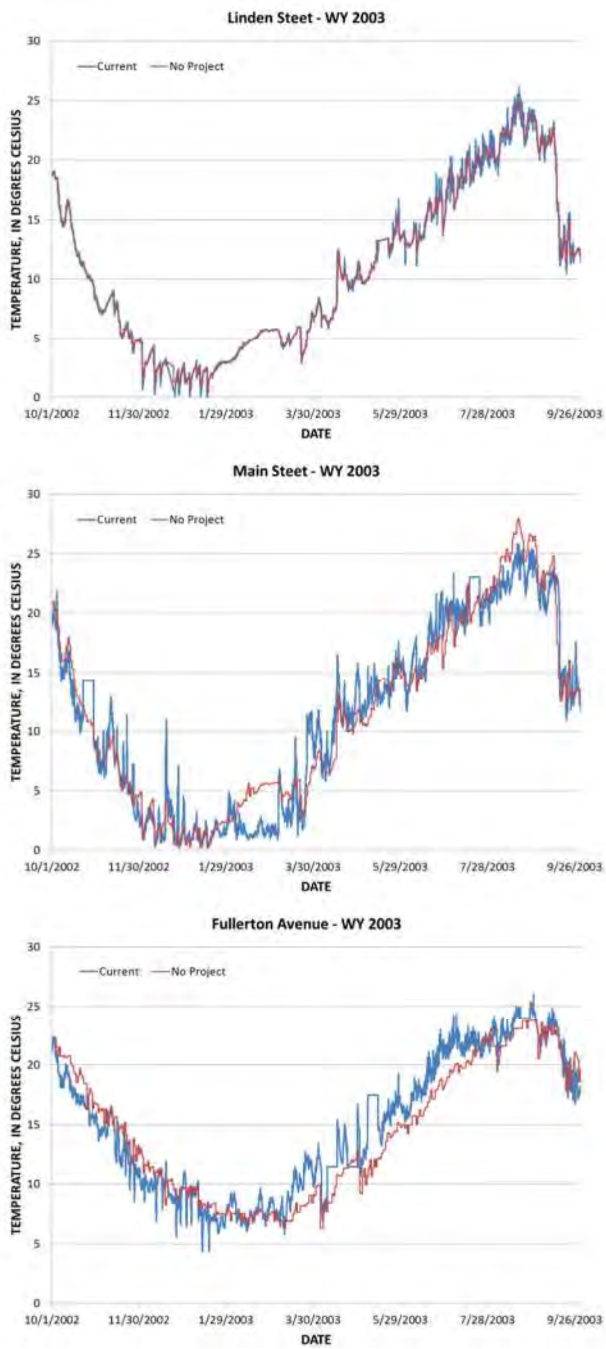


Figure K.3. Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2003.

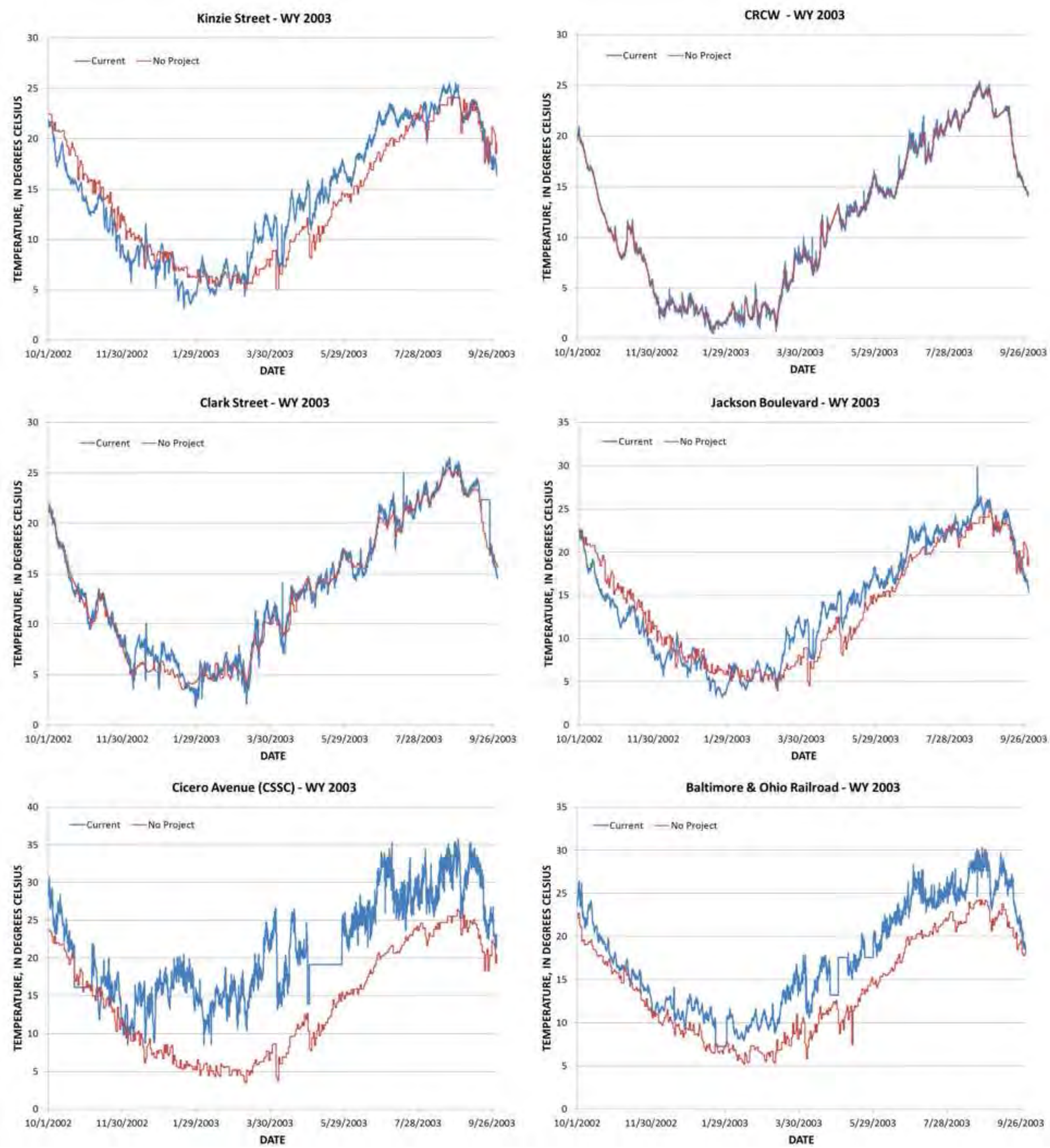


Figure K.3. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2003.

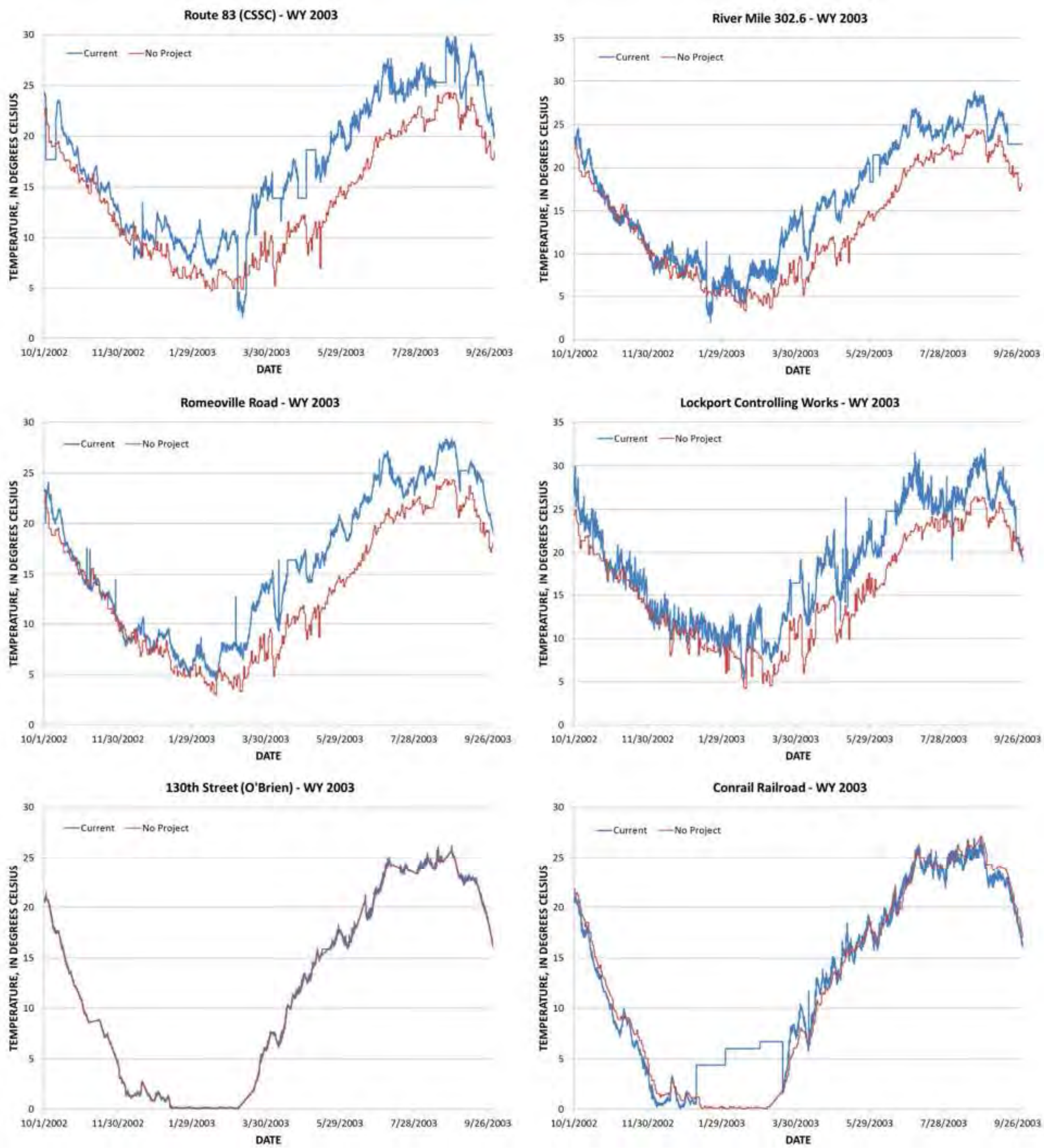


Figure K.3. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2003.

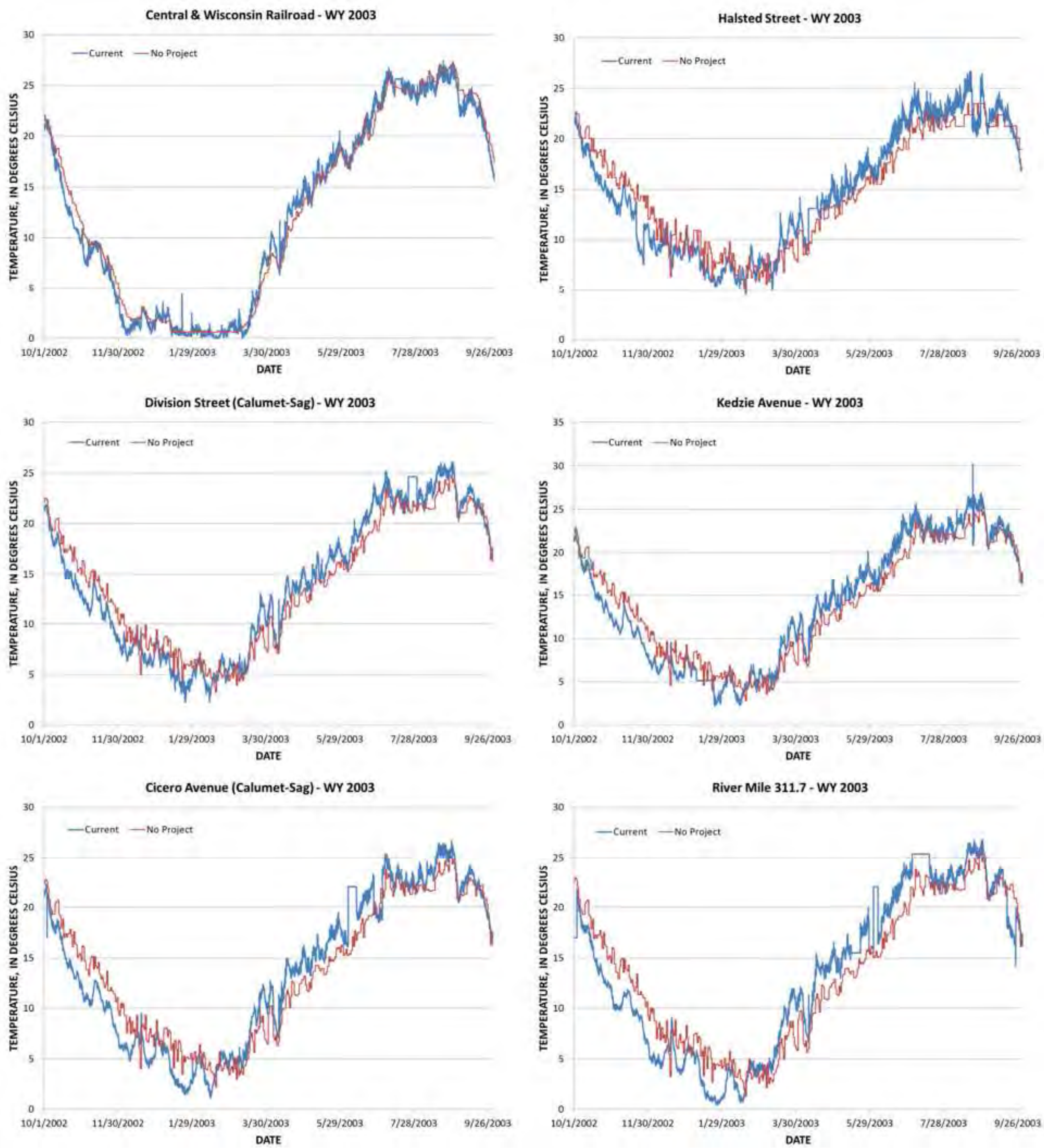


Figure K.3. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2003.

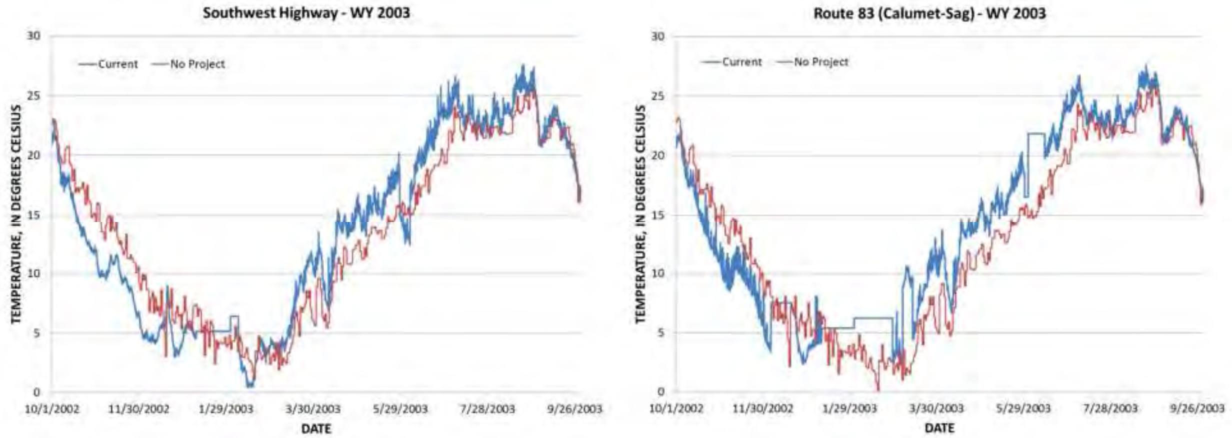


Figure K.3. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2003.

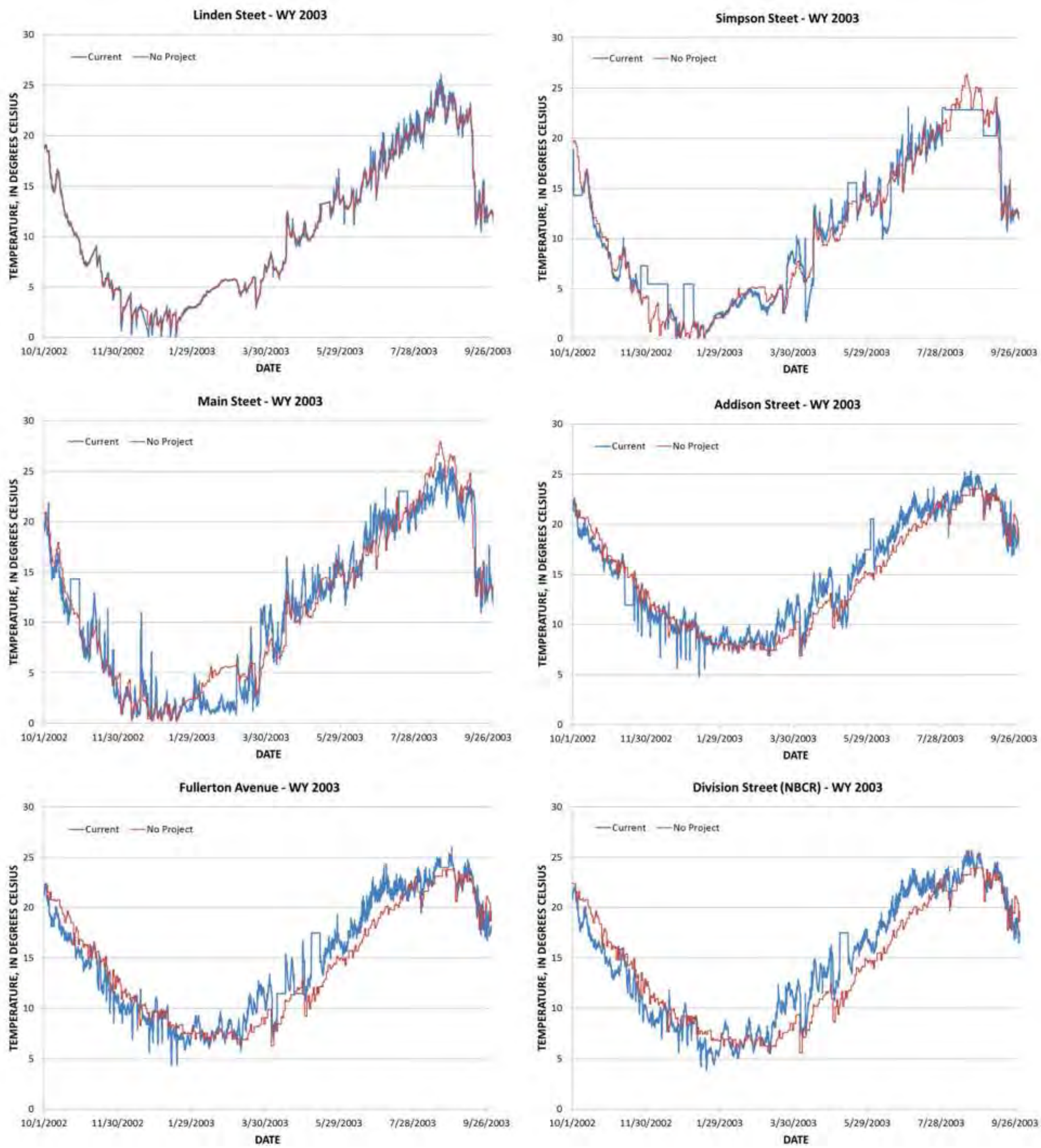


Figure K.4. Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the “No Project” Alternative for Water Year 2003.

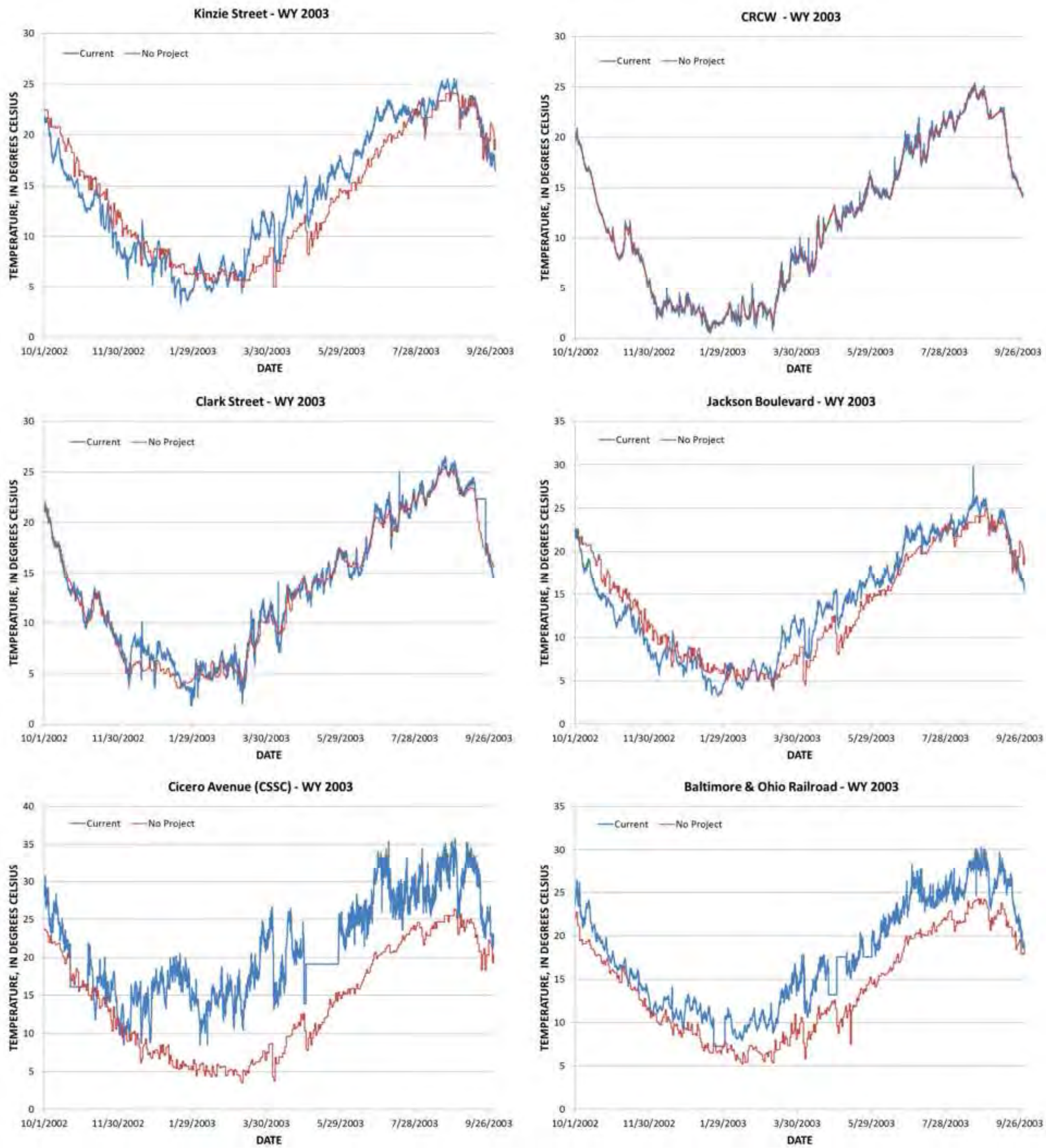


Figure K.4. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2003.

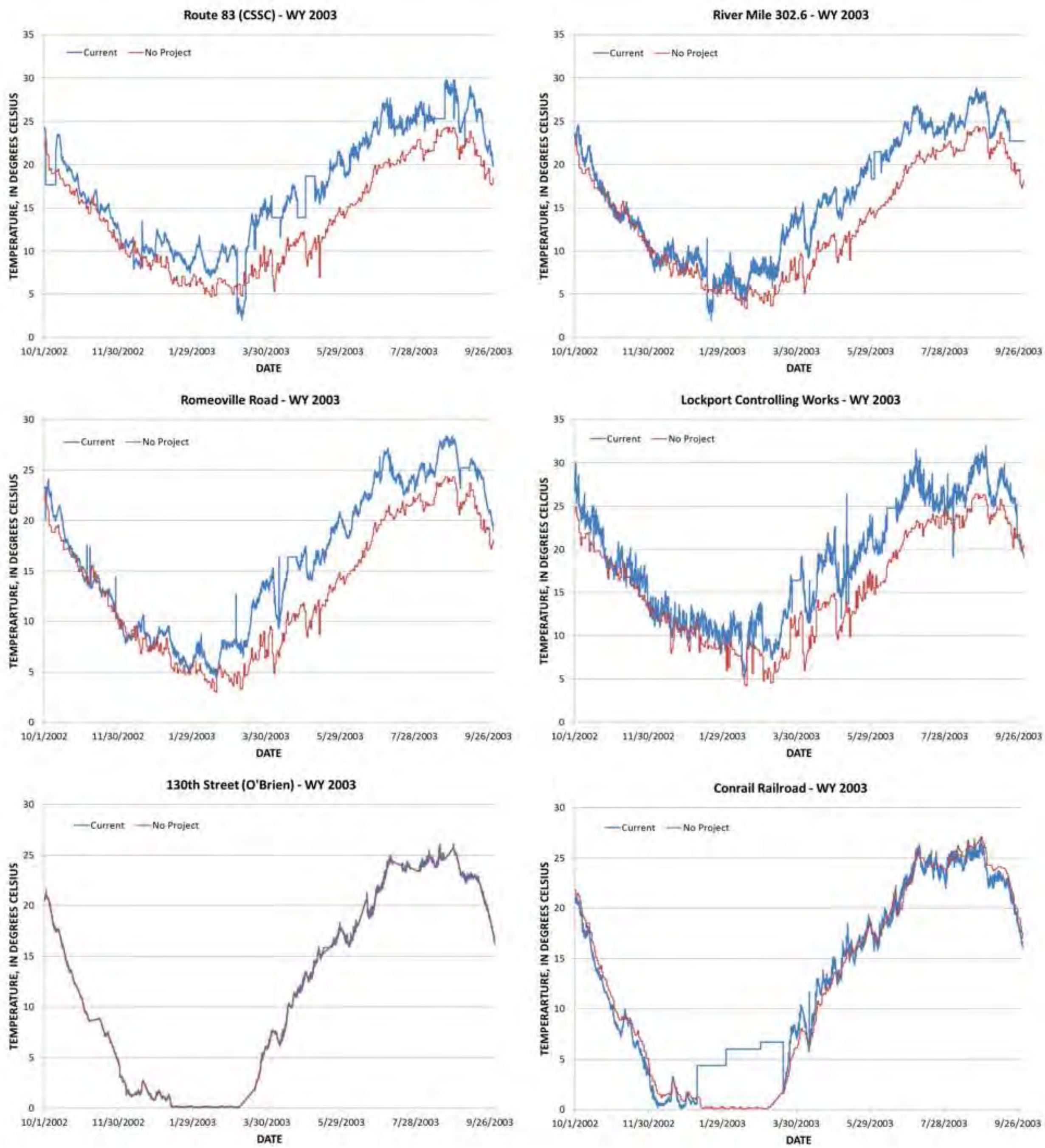


Figure K.4. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2003.

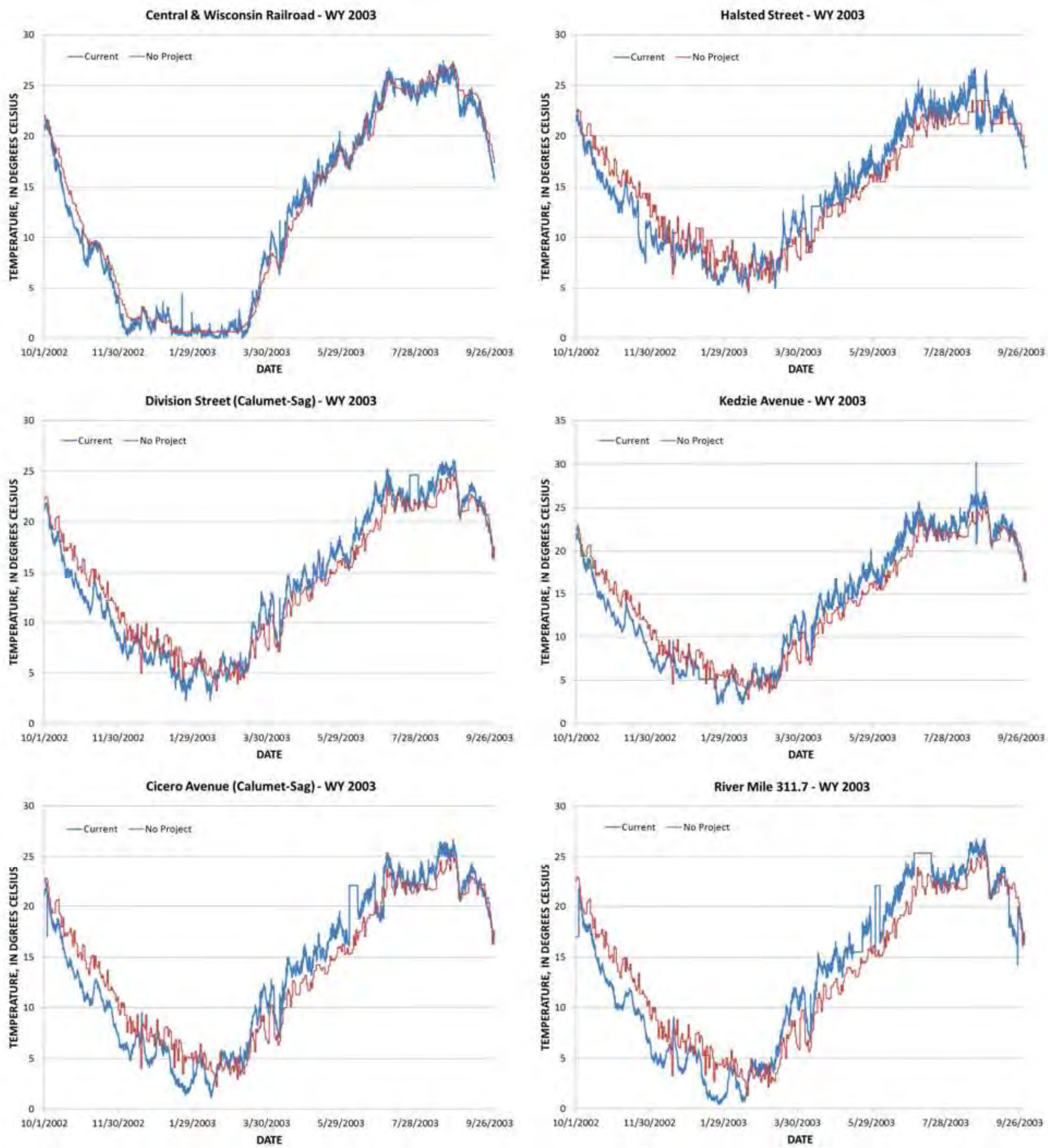


Figure K.4. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2003.

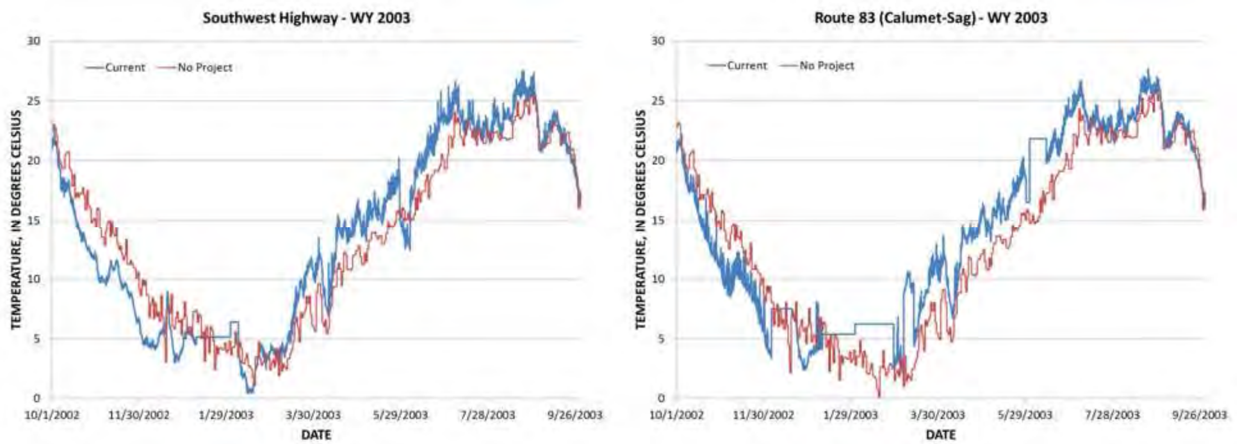


Figure K.4. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2003.

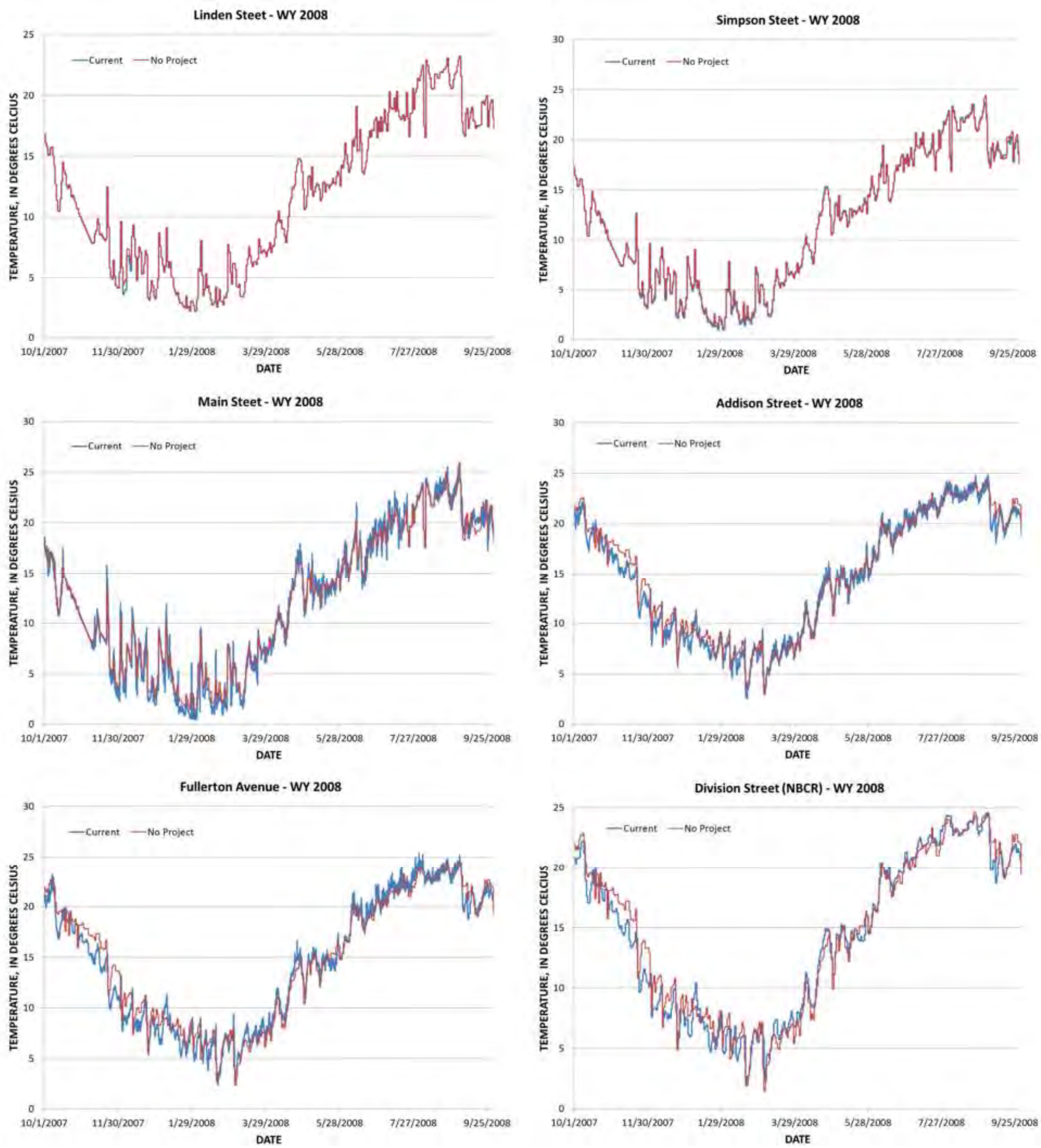


Figure K.5. Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the “No Project” Alternative for Water Year 2008.

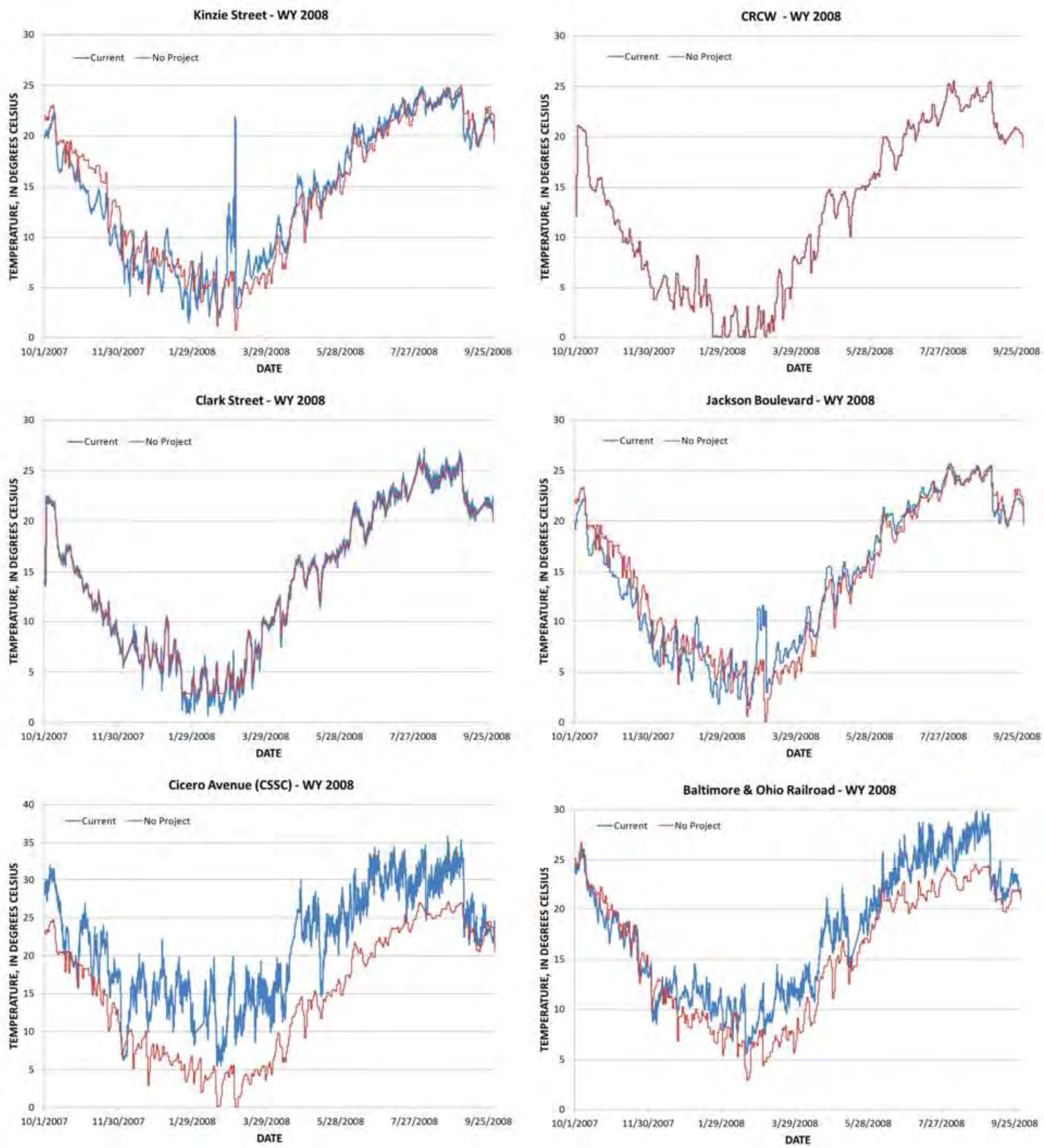


Figure K.5. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2008.

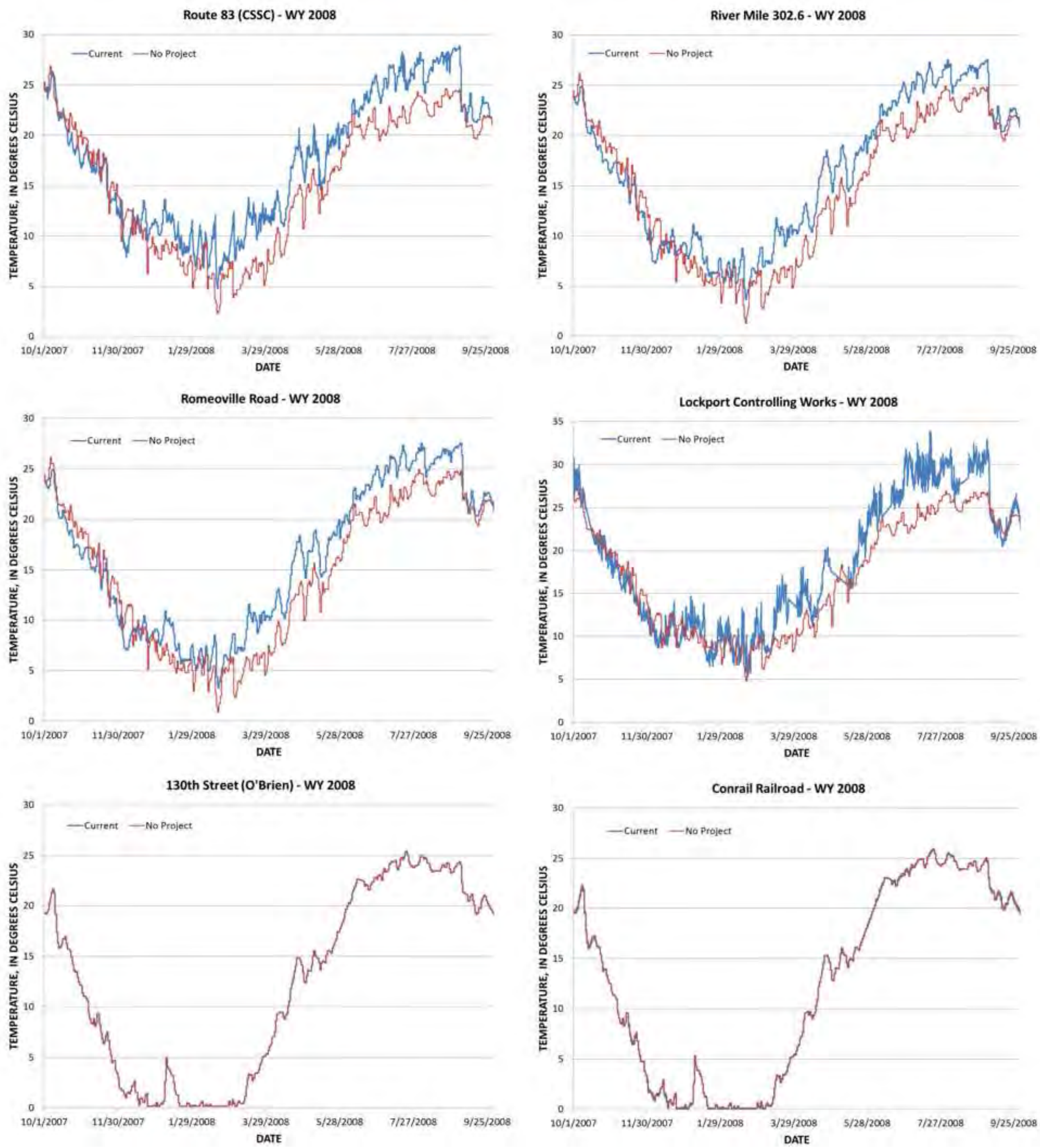


Figure K.5. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2008.

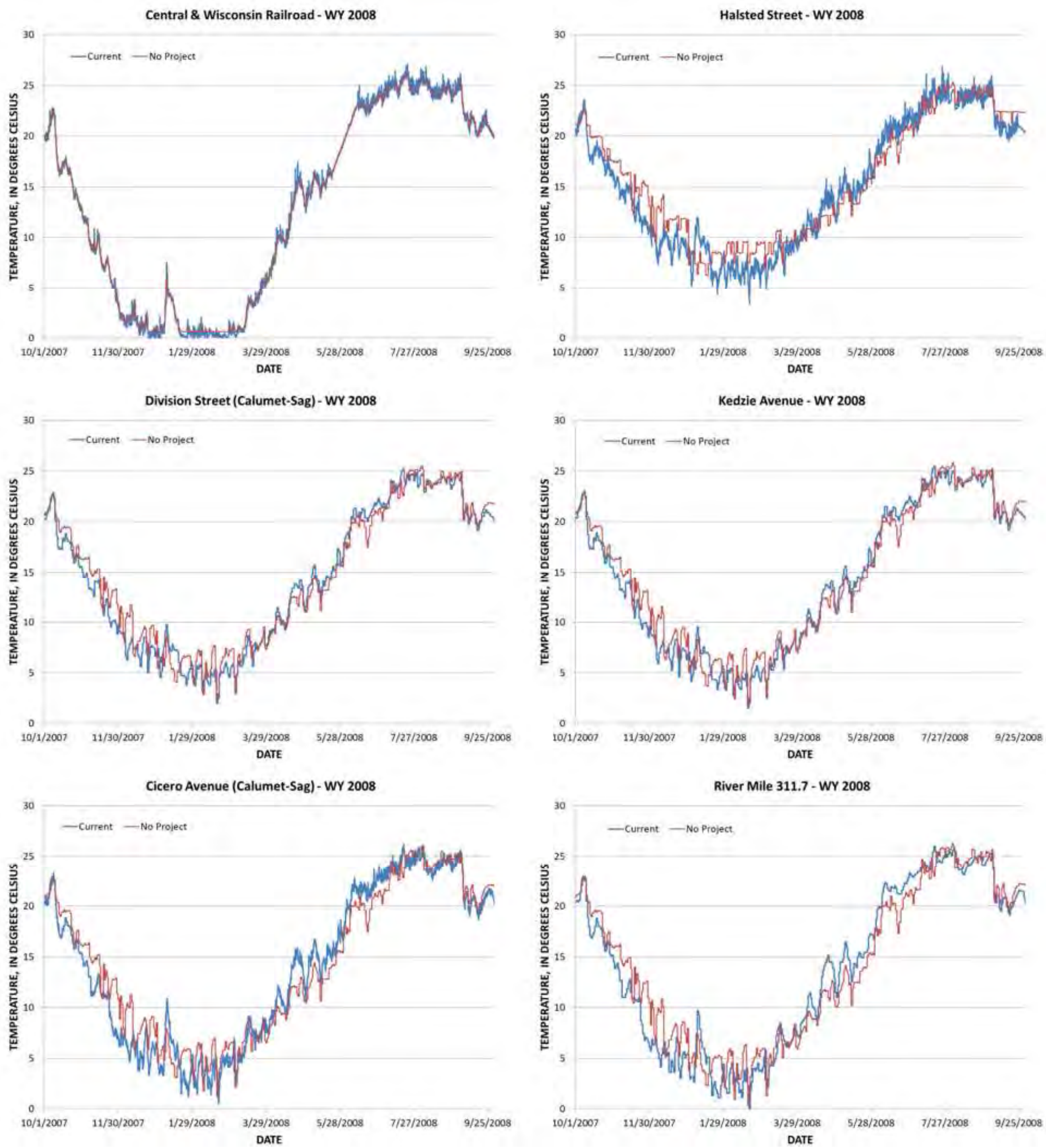


Figure K.5. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the “No Project” Alternative for Water Year 2008.

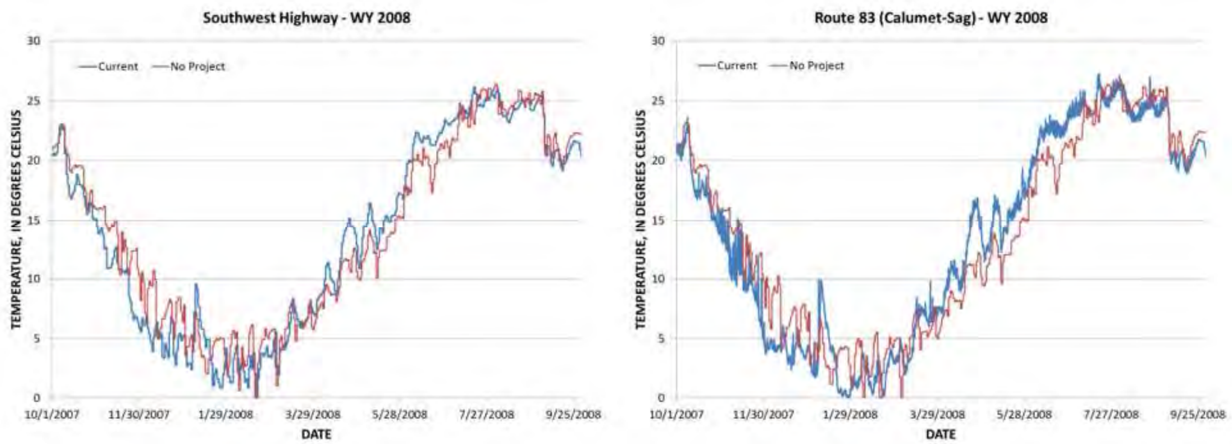


Figure K.5. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Baseline Conditions for the "No Project" Alternative for Water Year 2008.

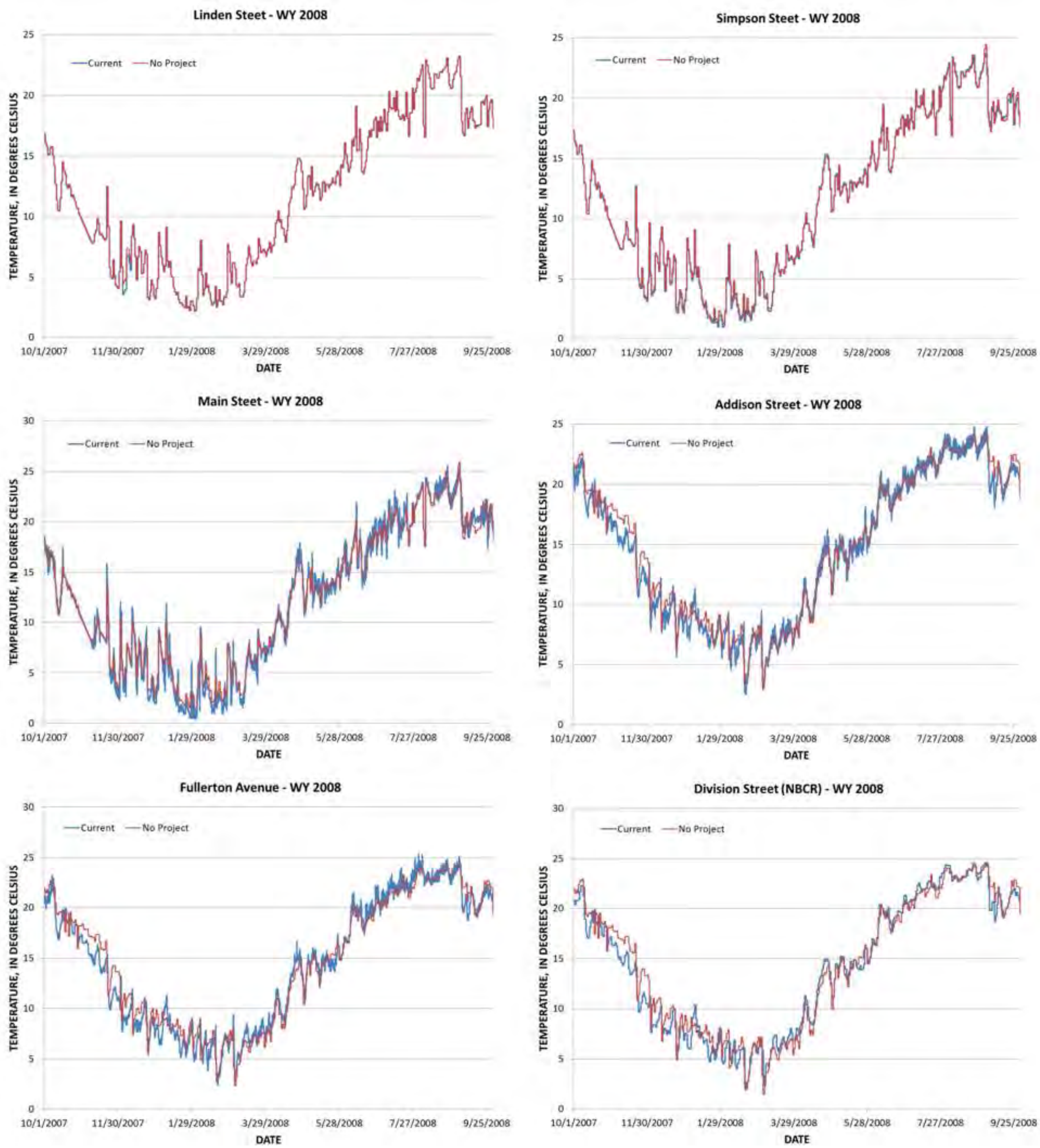


Figure K.6. Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2008.

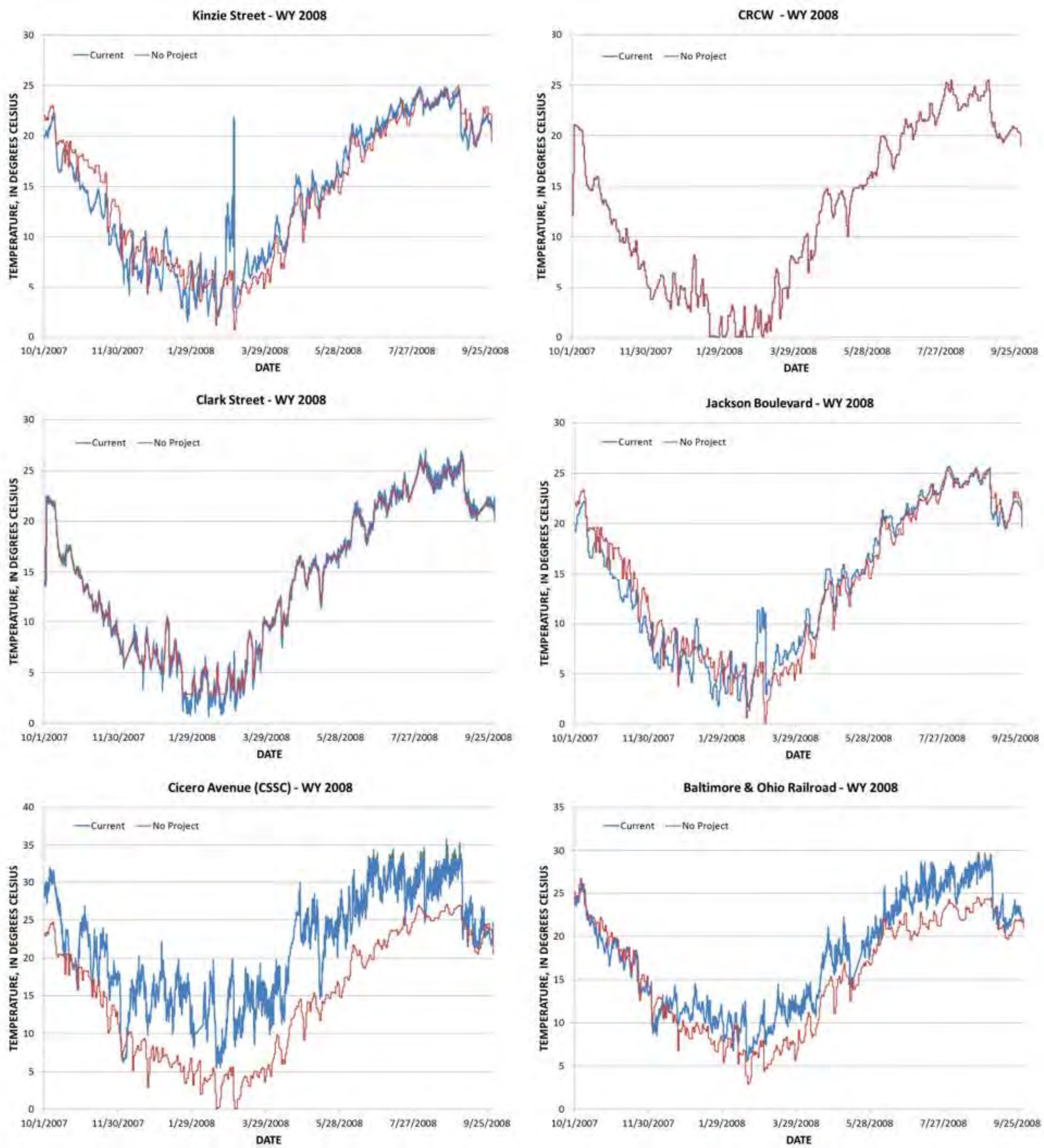


Figure K.6. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2008.

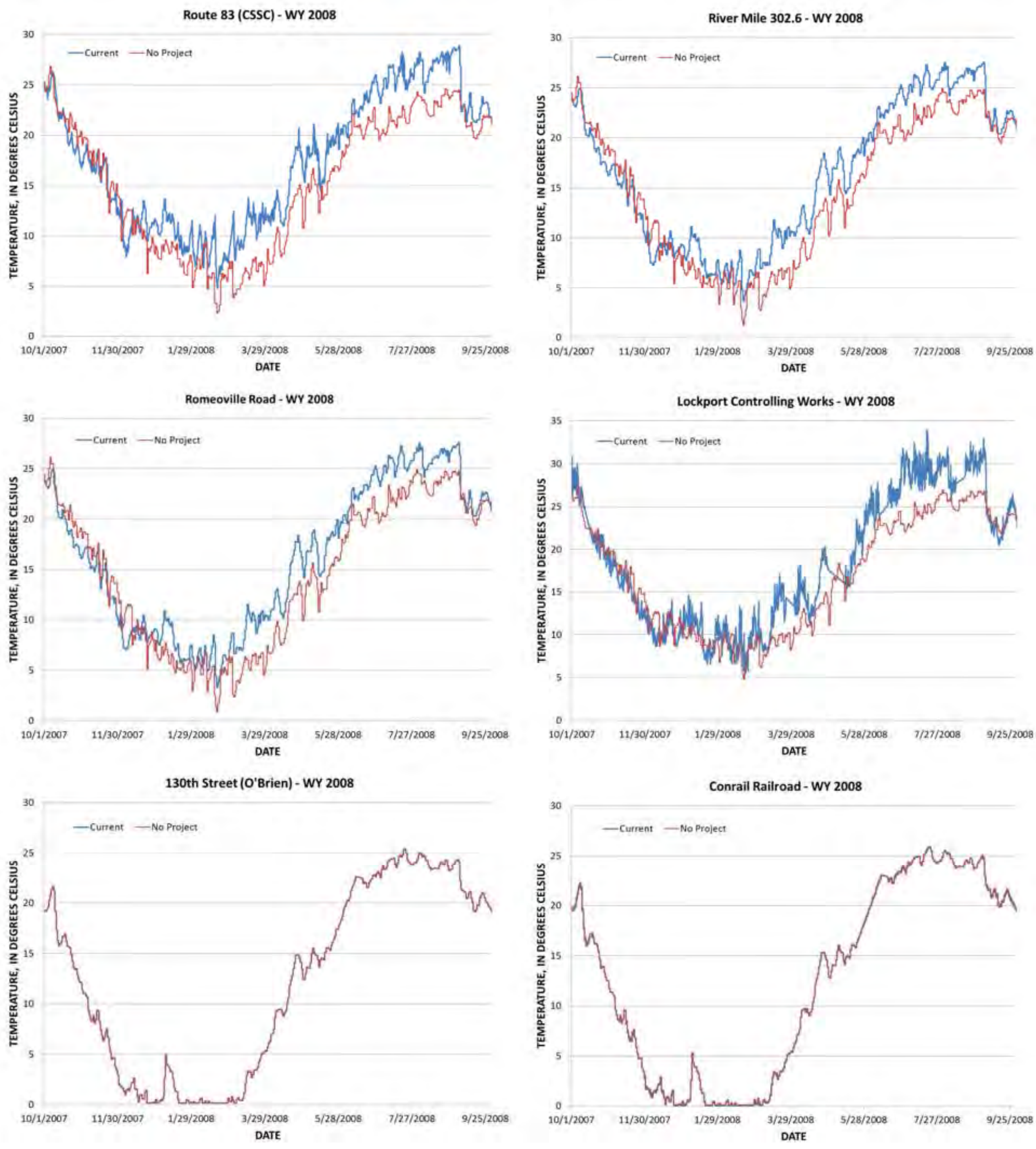


Figure K.6. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2008.

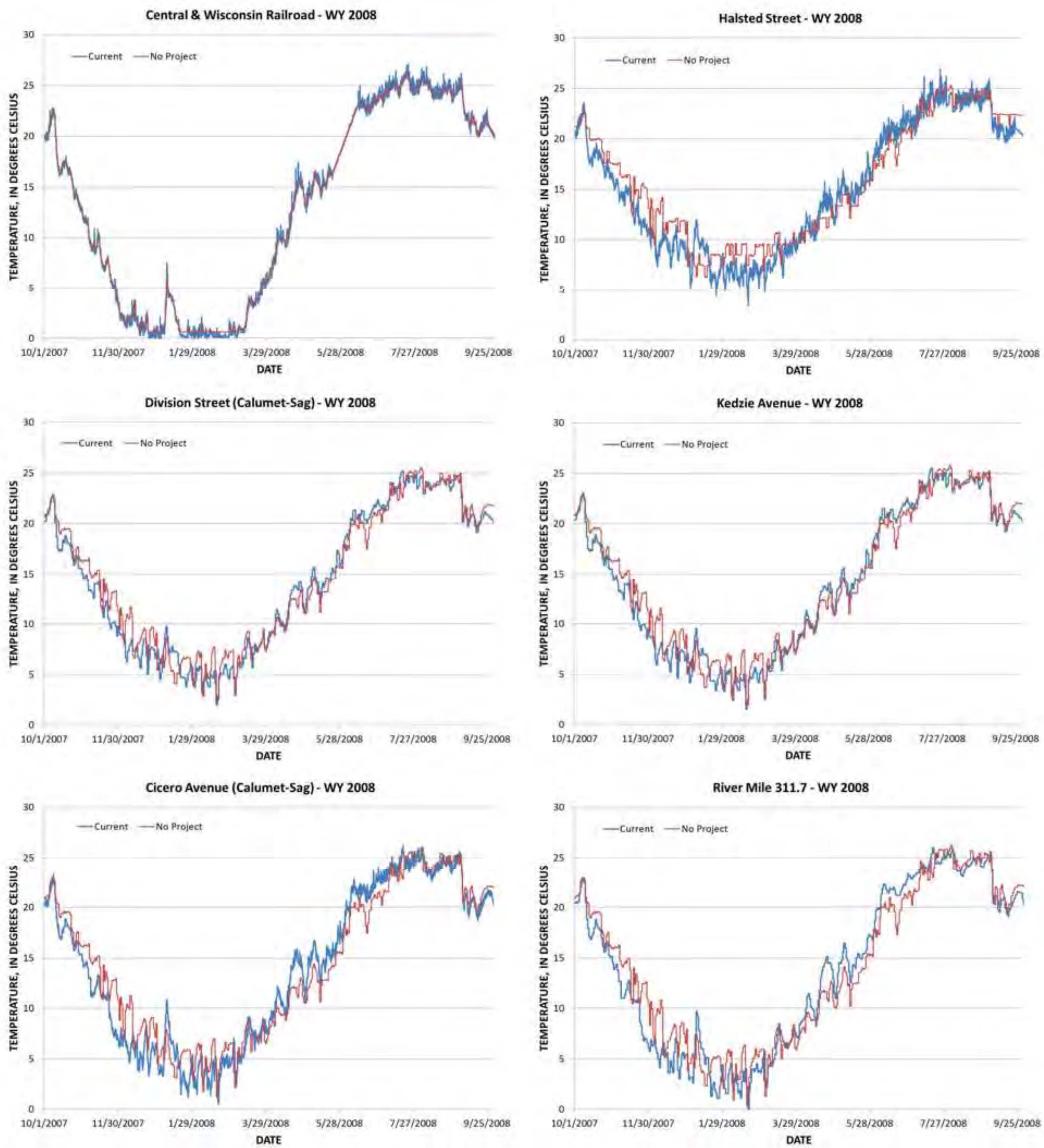


Figure K.6. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the “No Project” Alternative for Water Year 2008.

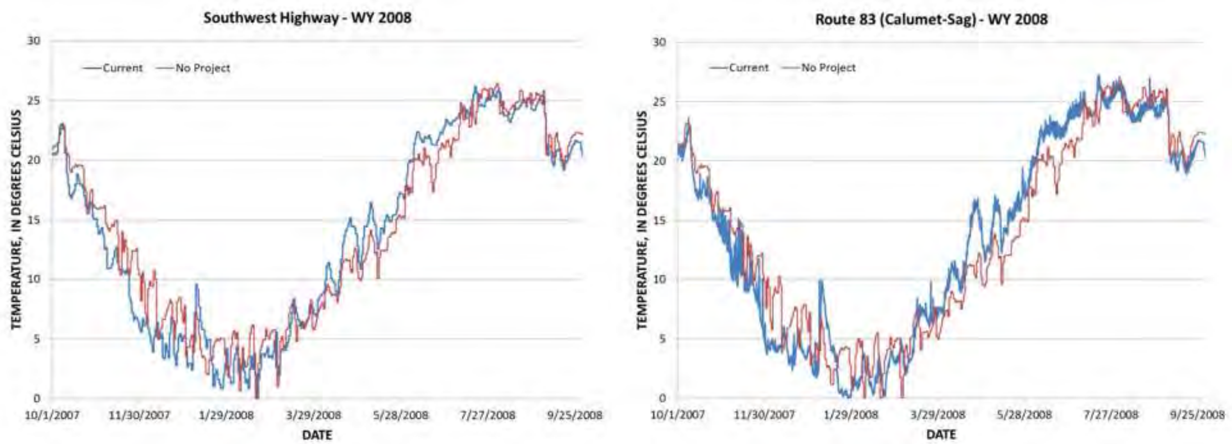


Figure K.6. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for Current and Future Conditions for the "No Project" Alternative for Water Year 2008.

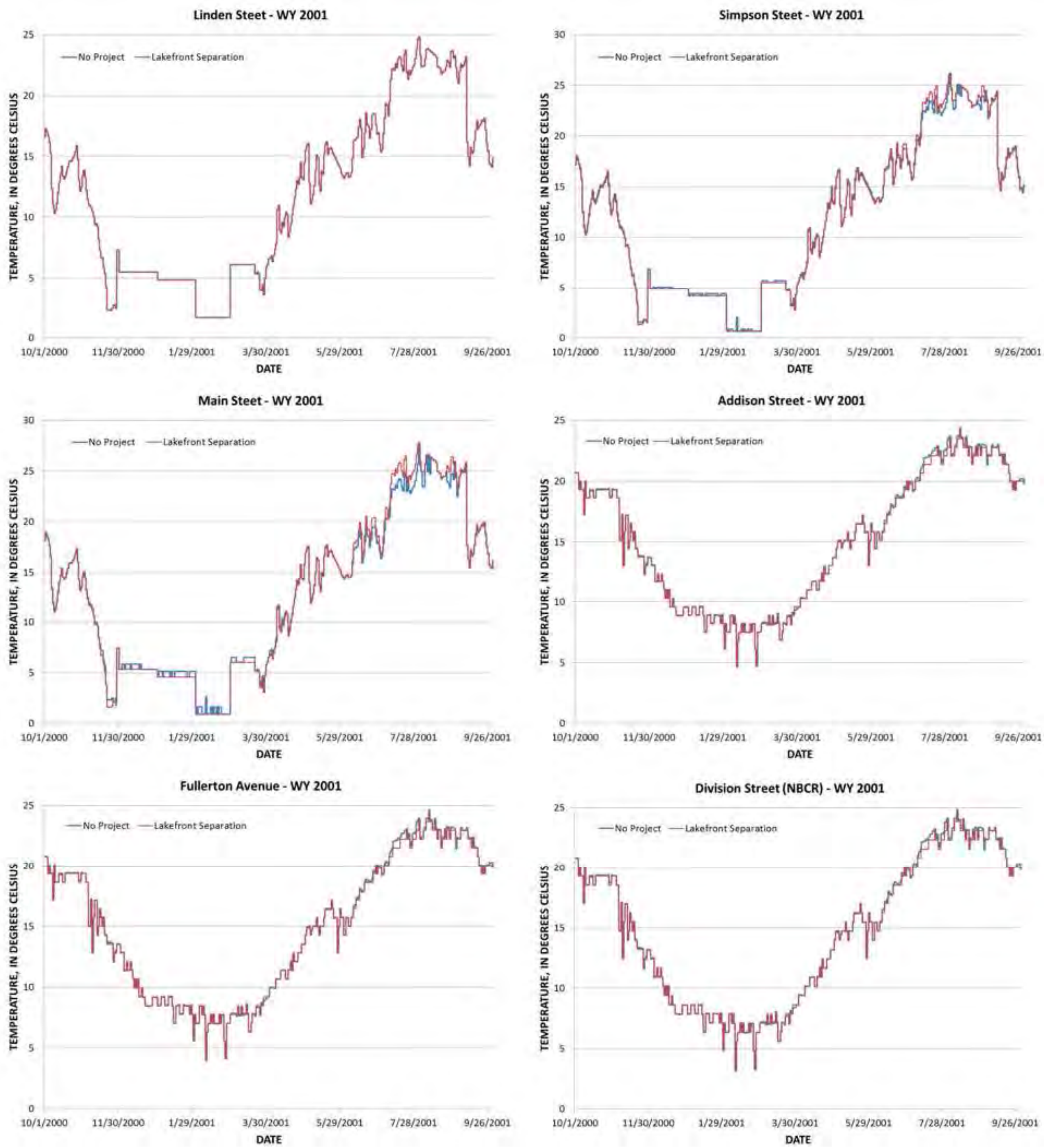


Figure K.7. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2001.

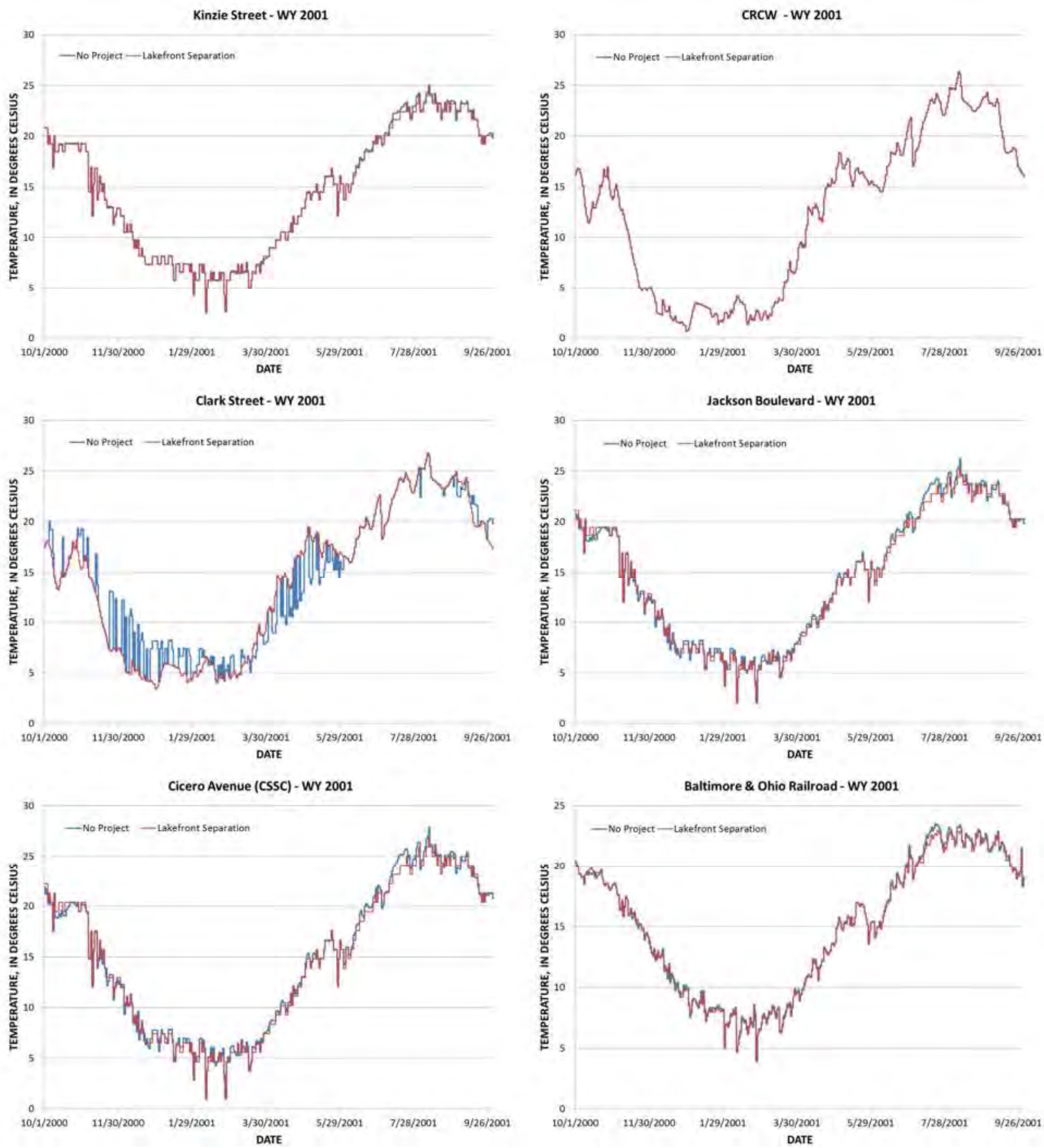


Figure K.7. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2001.

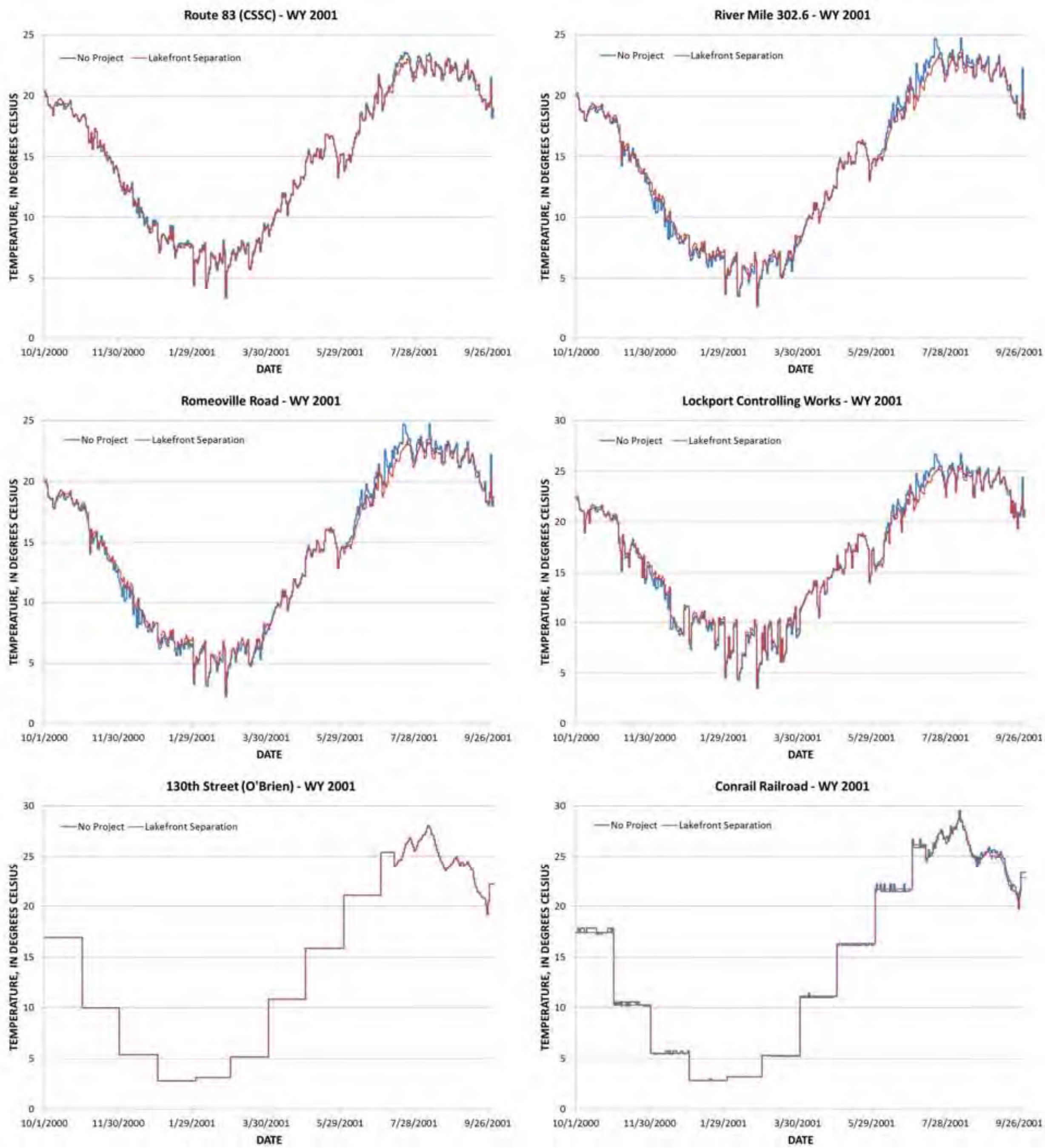
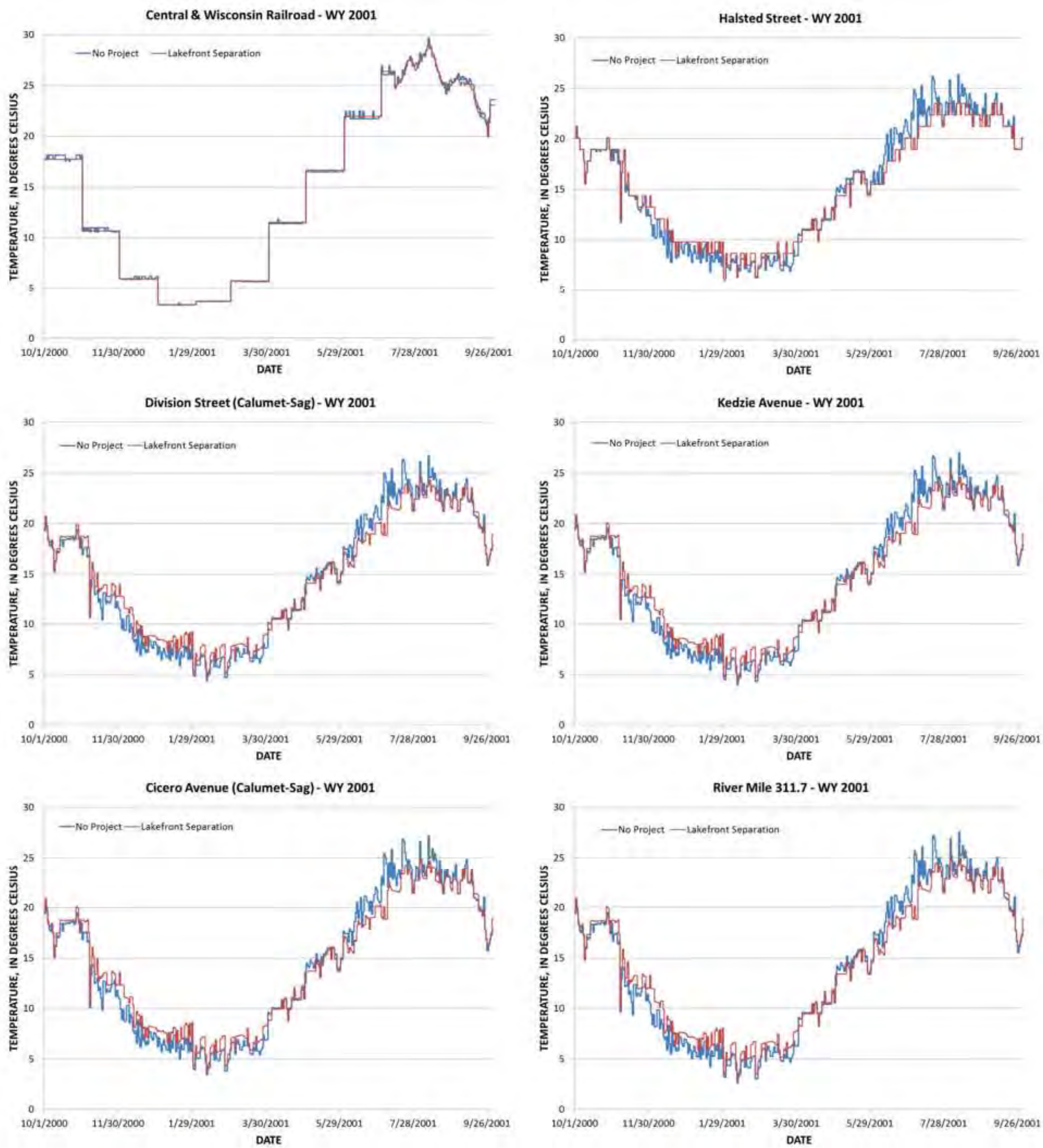


Figure K.7. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2001.



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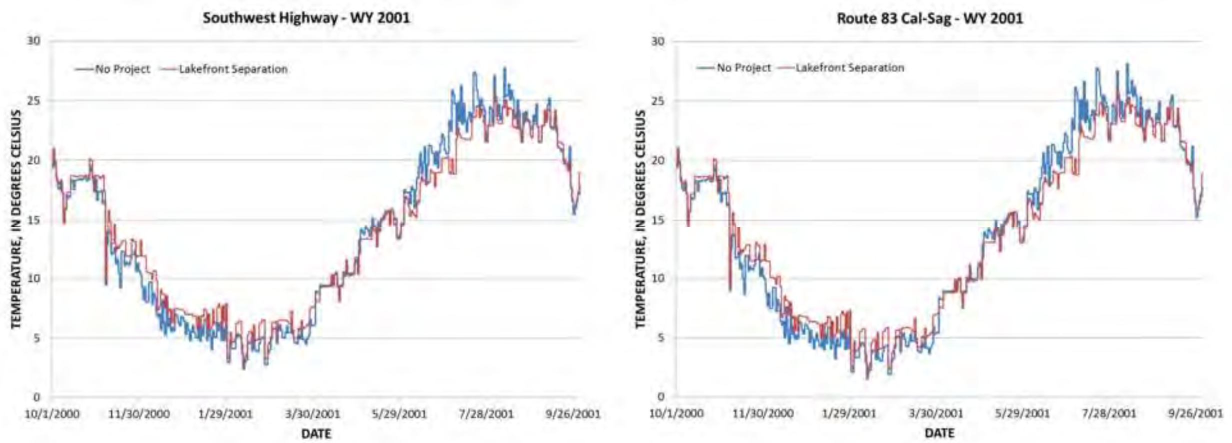


Figure K.7. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2001.

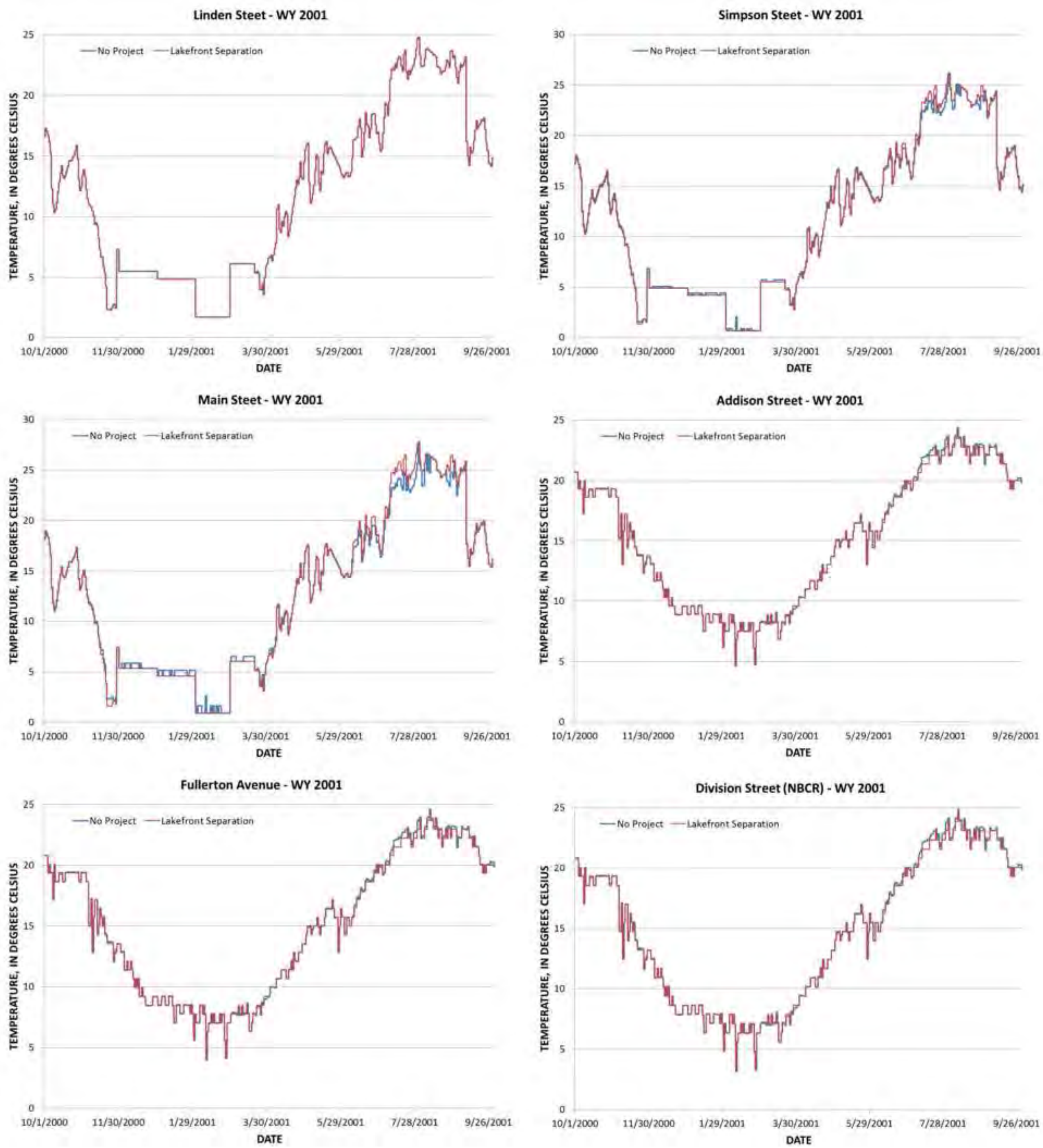


Figure K.8. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2001.

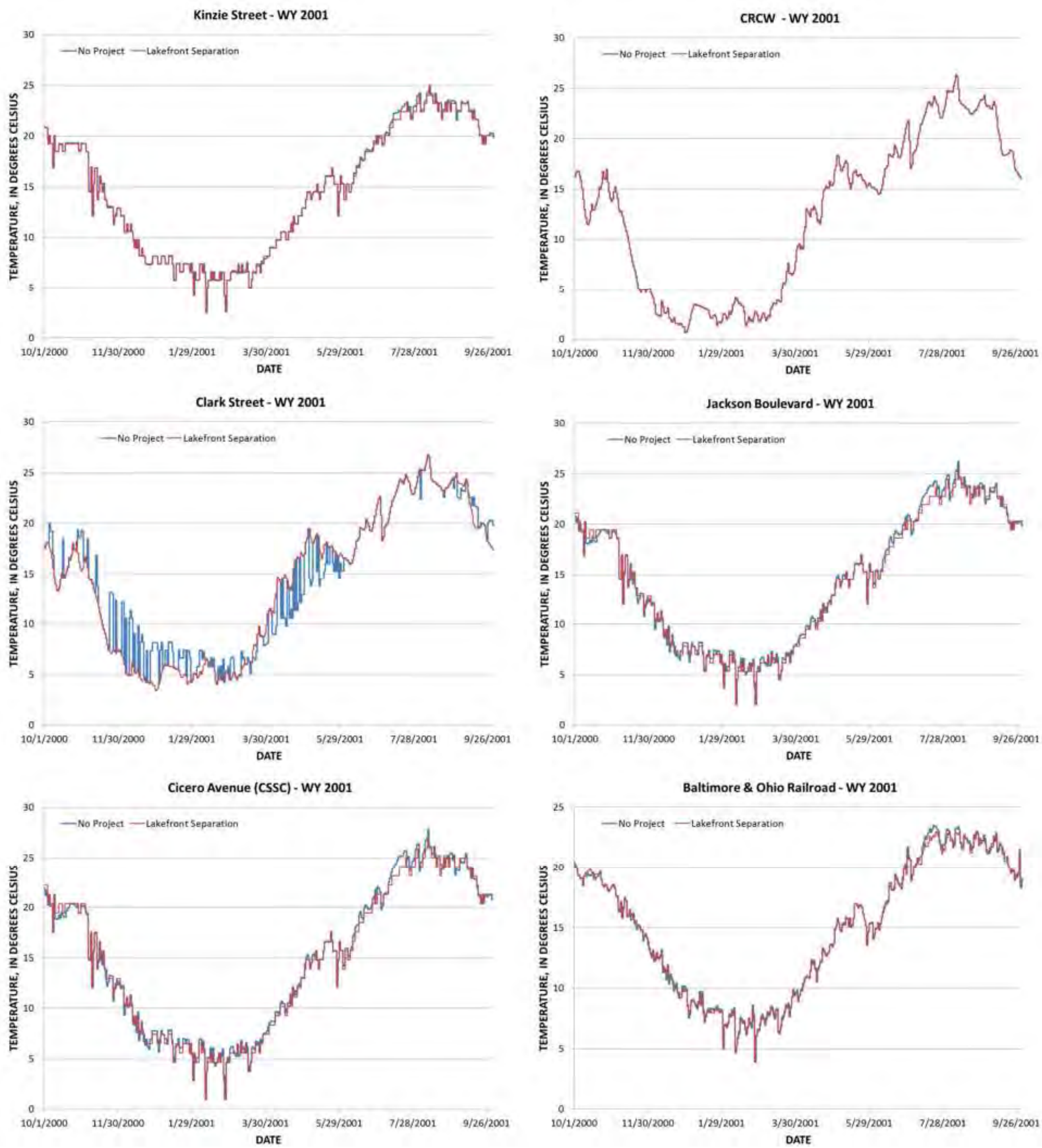


Figure K.8. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for “No Project” and “Lakefront Separation” Alternatives for Future Conditions for Water Year 2001.

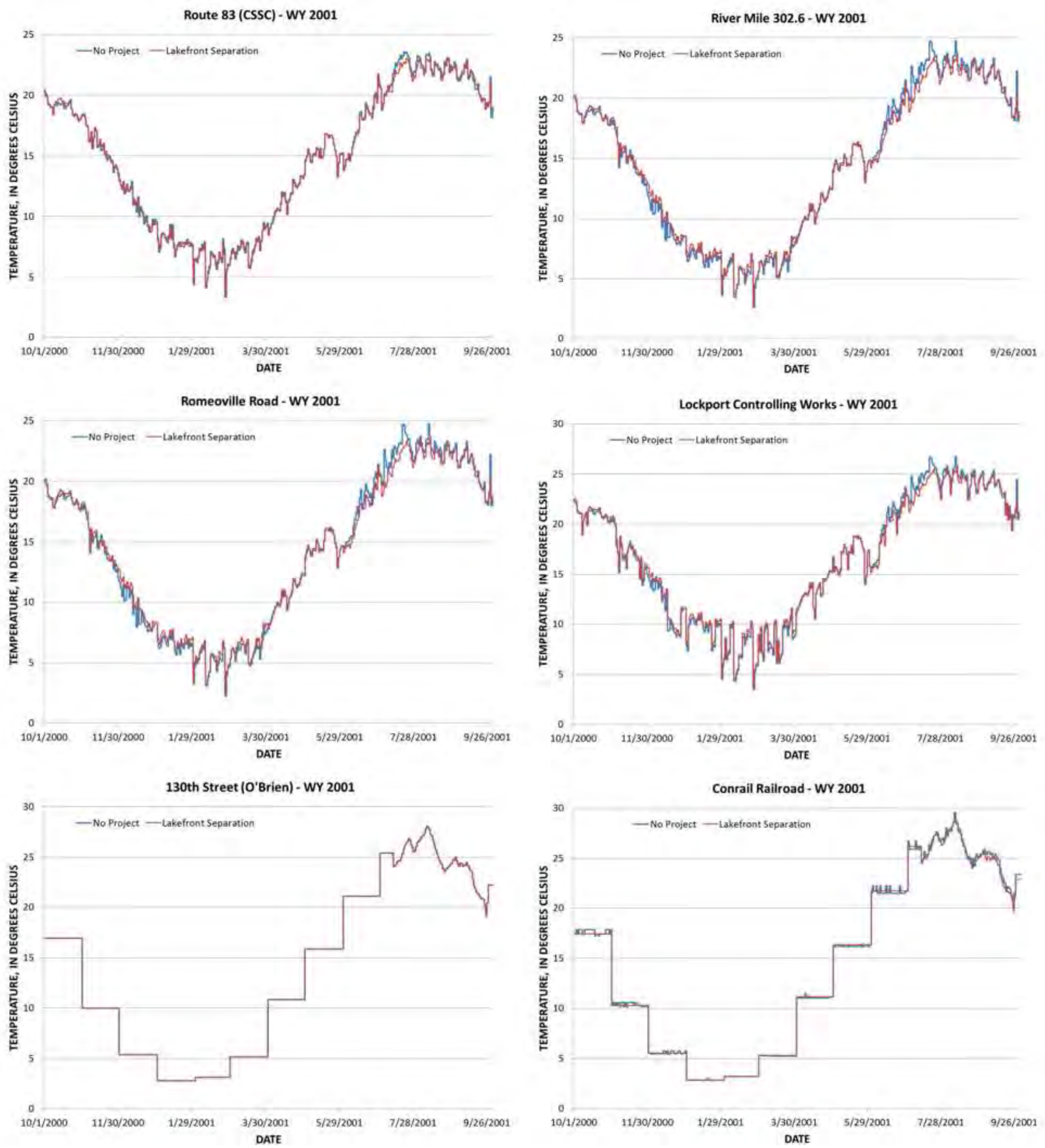


Figure K.8. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2001.

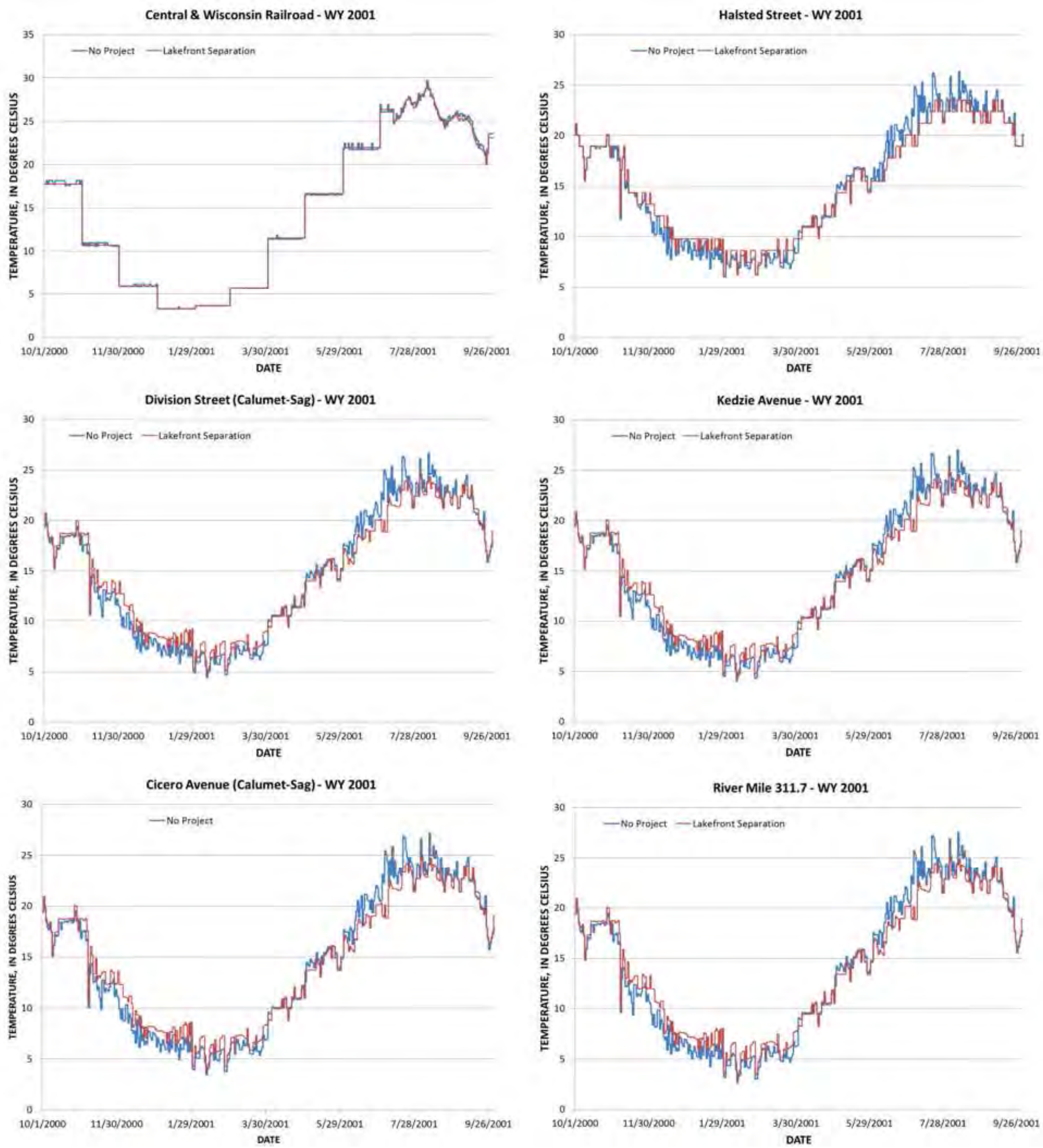


Figure K.8. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2001.

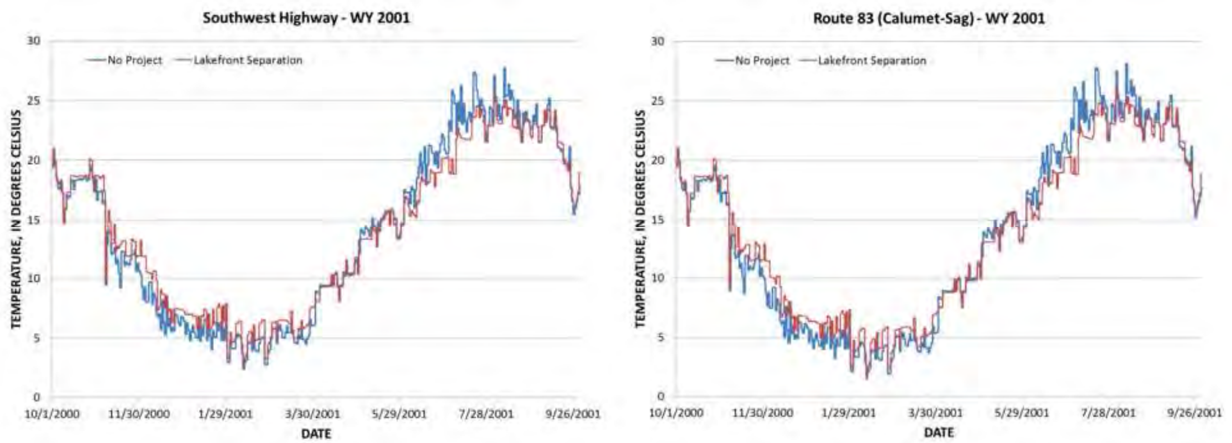


Figure K.8. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2001.

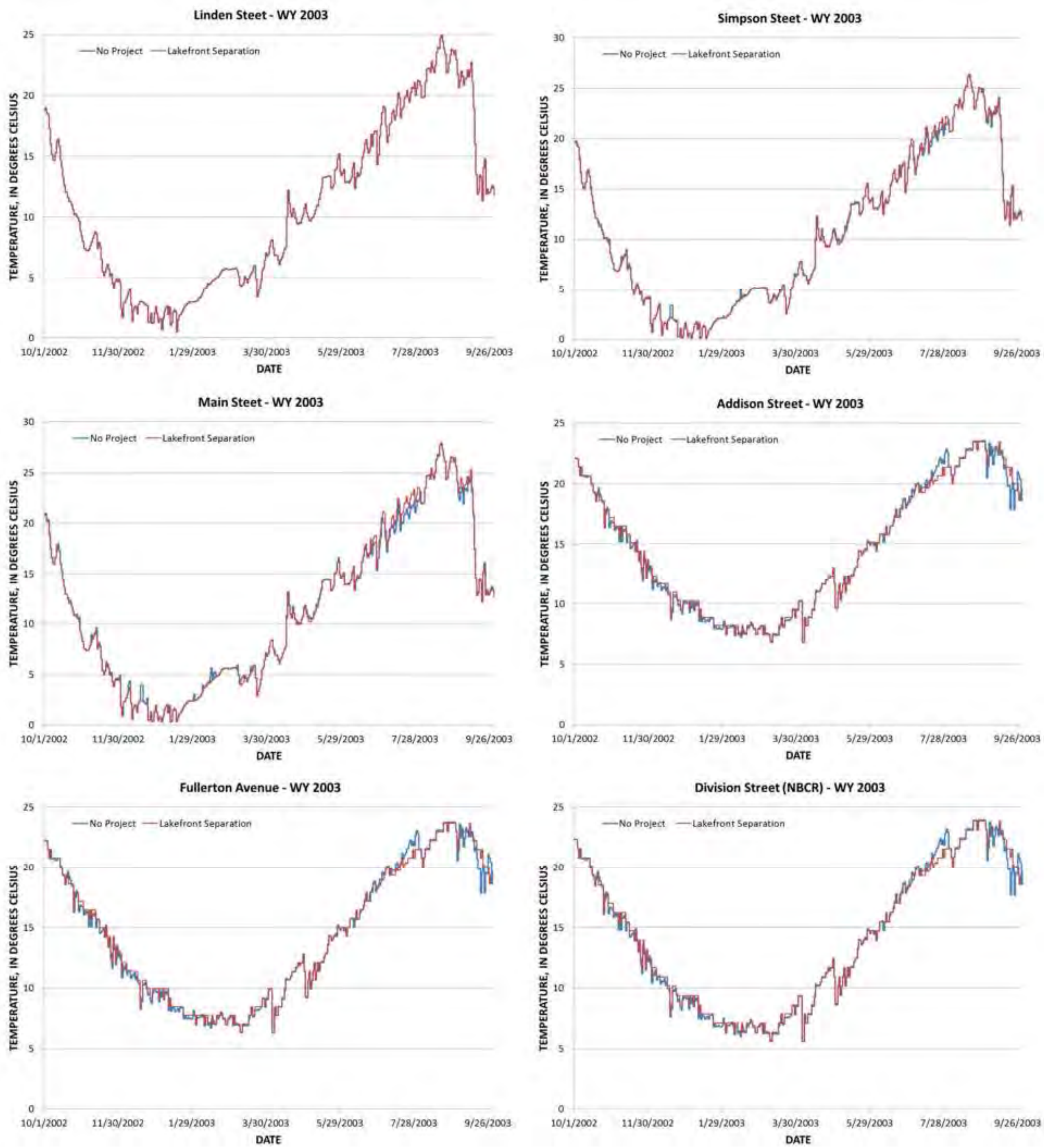
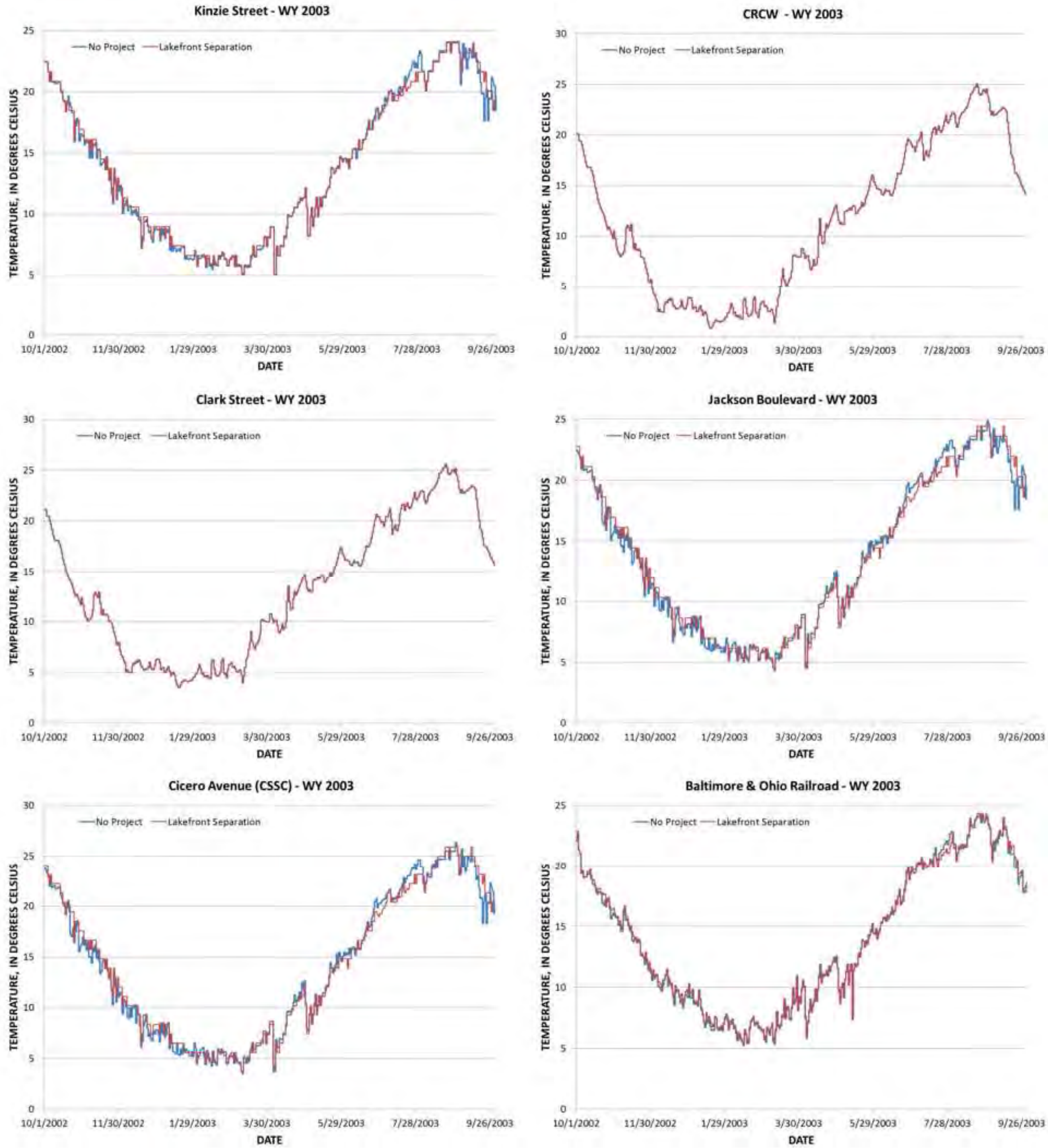


Figure K.9. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2003.



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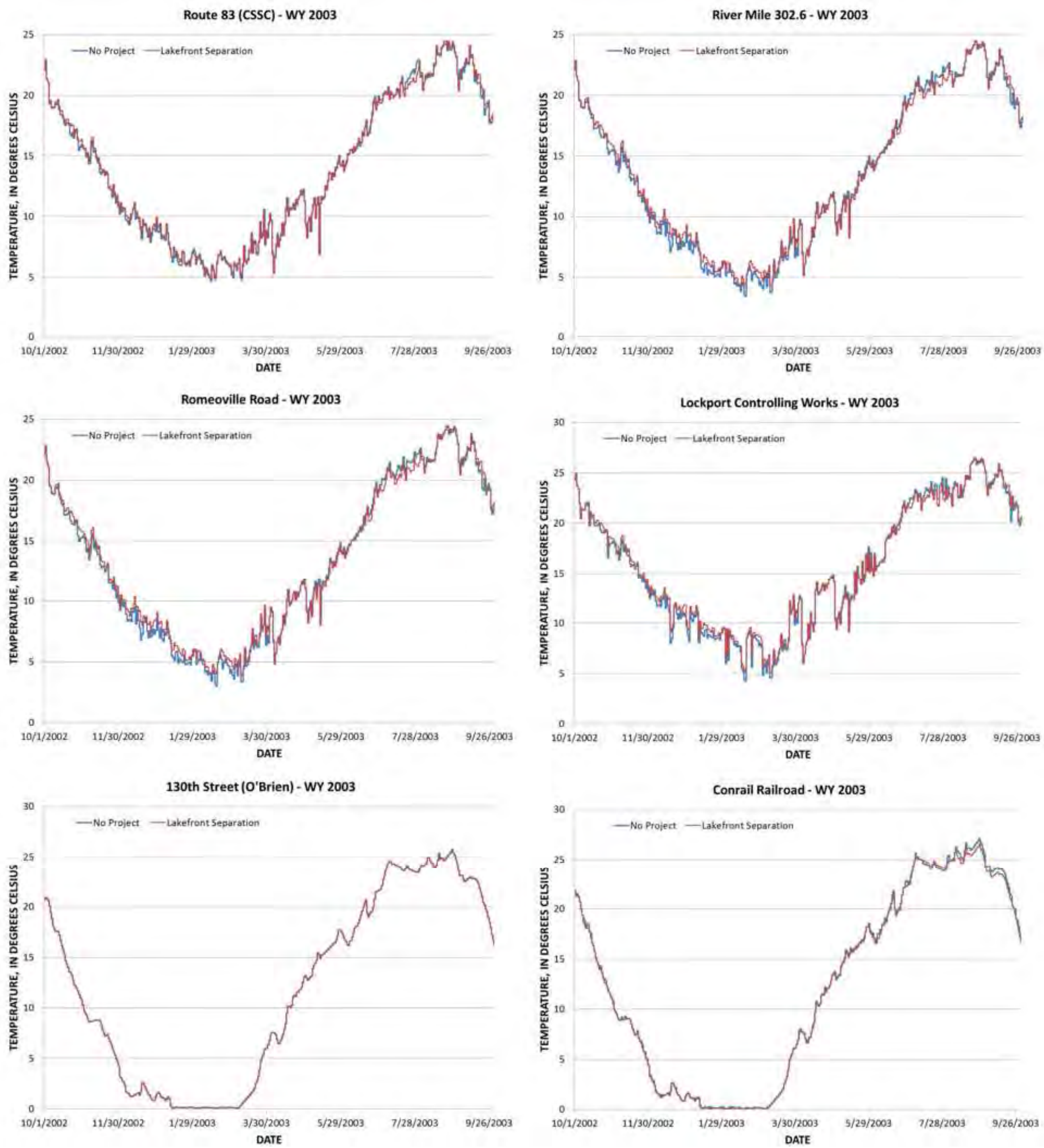


Figure K.9. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2003.

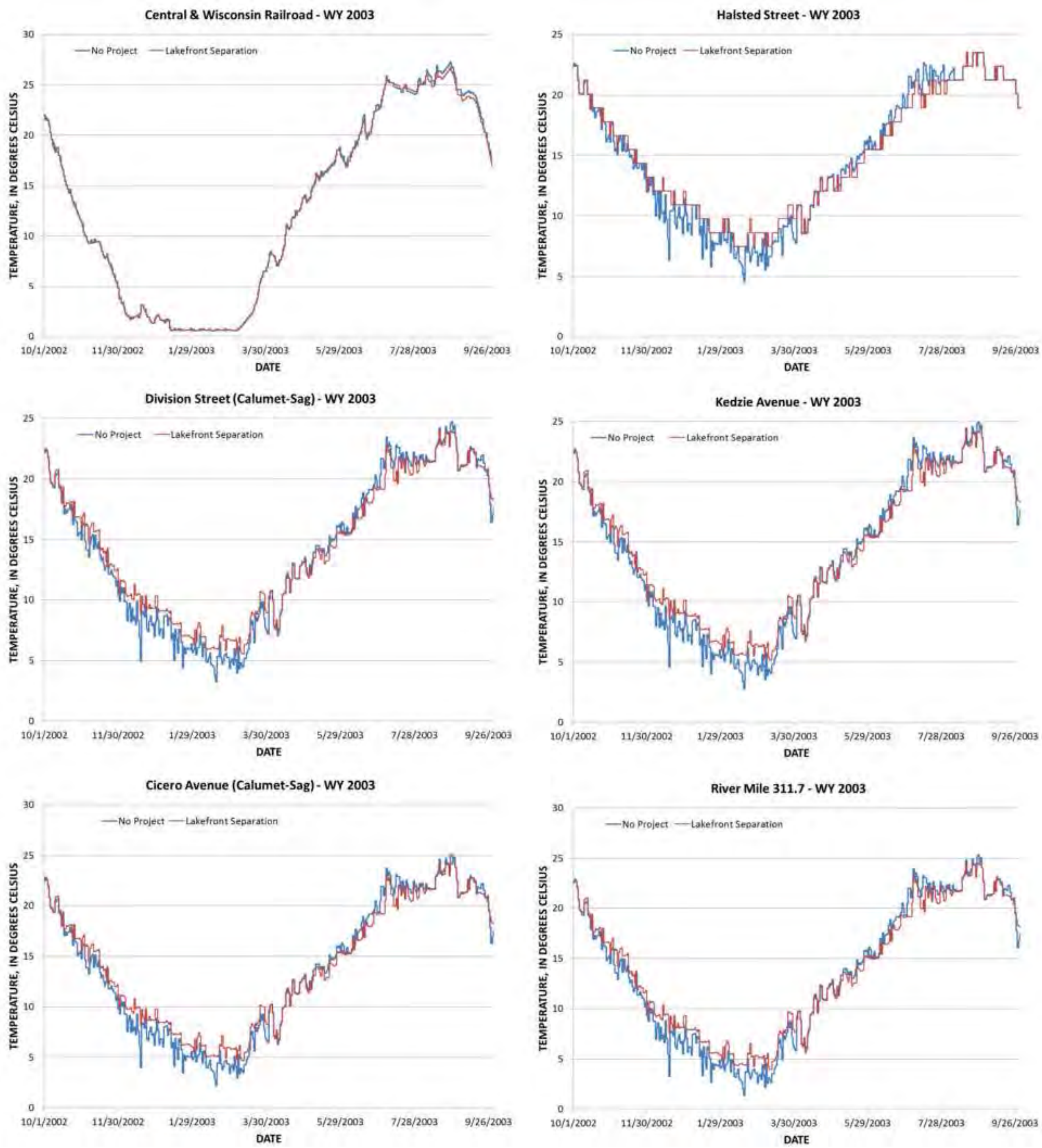
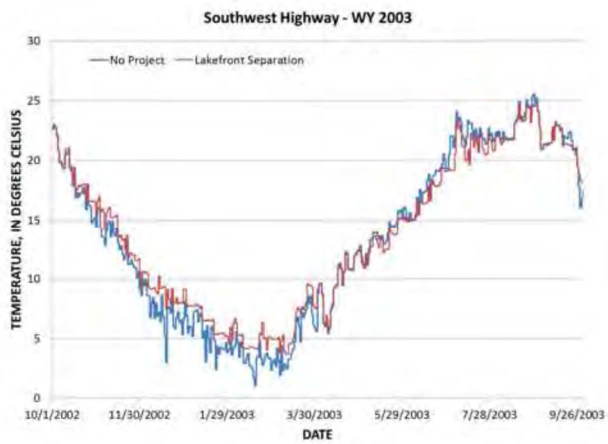


Figure K.9. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2003.



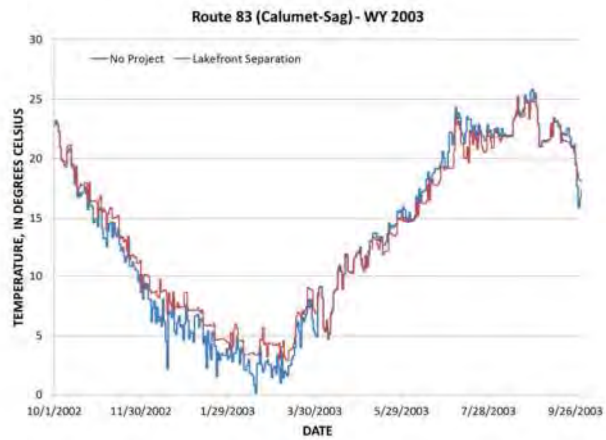


Figure K.9. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2003.

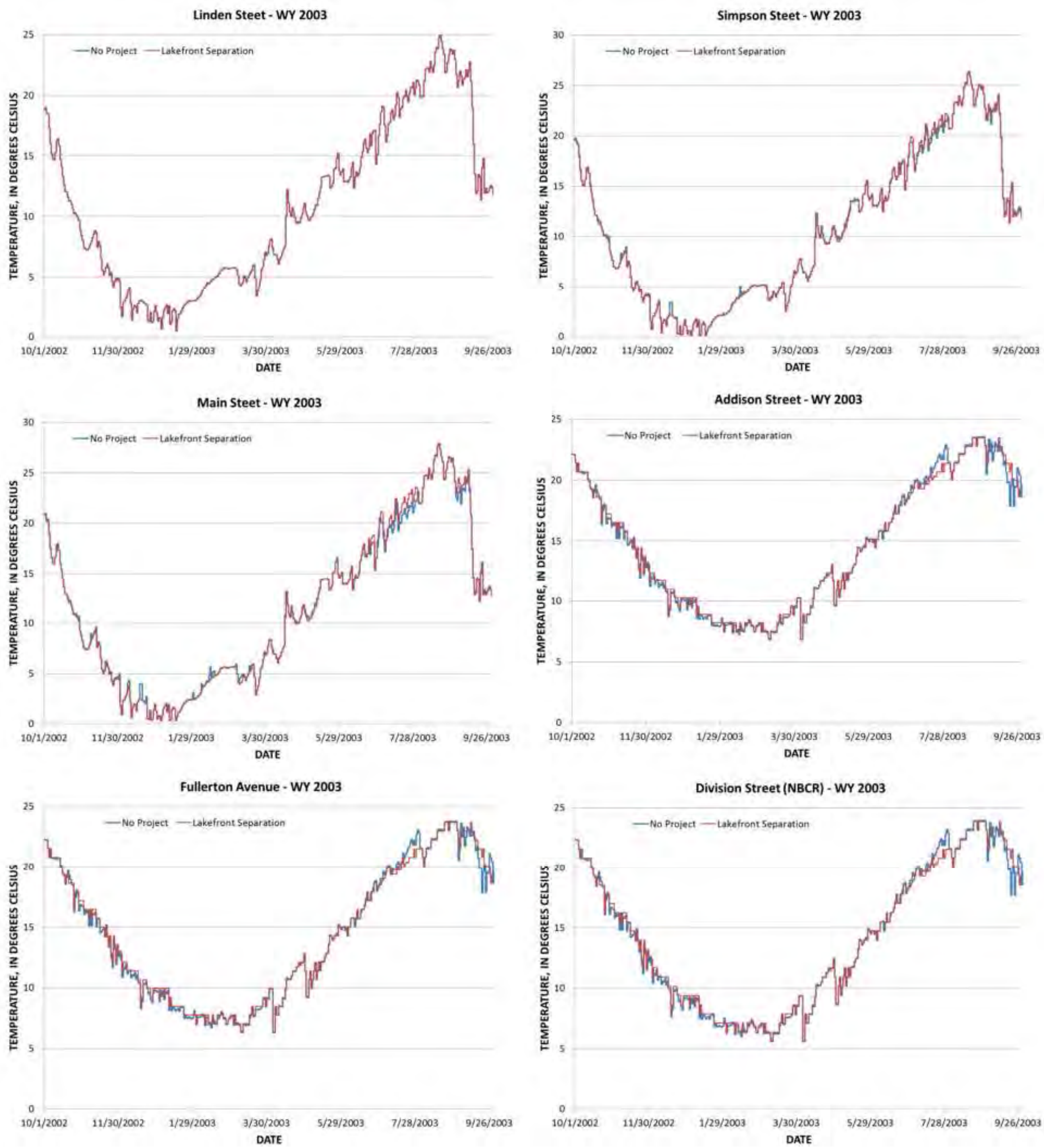
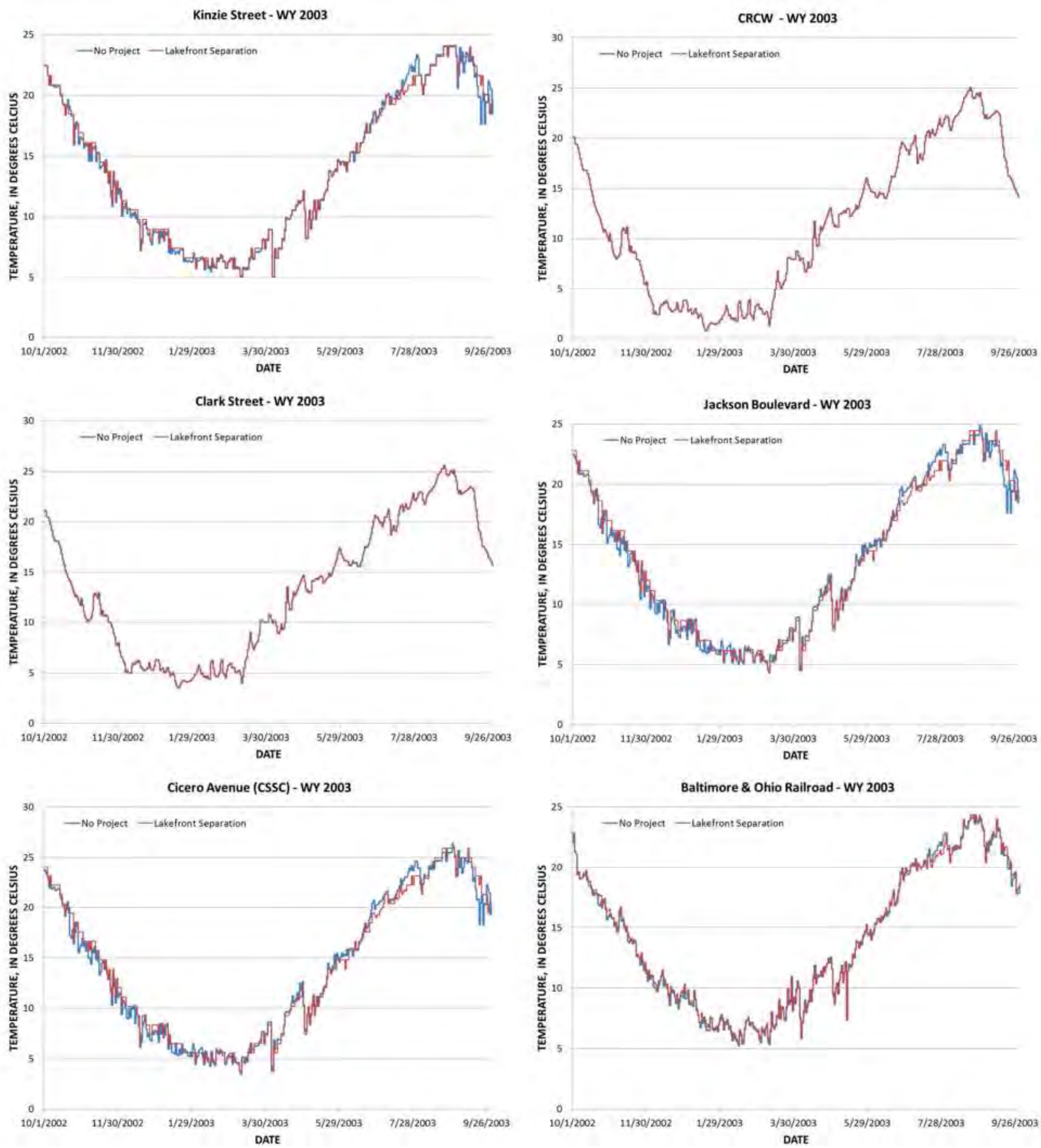


Figure K.10. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2003.



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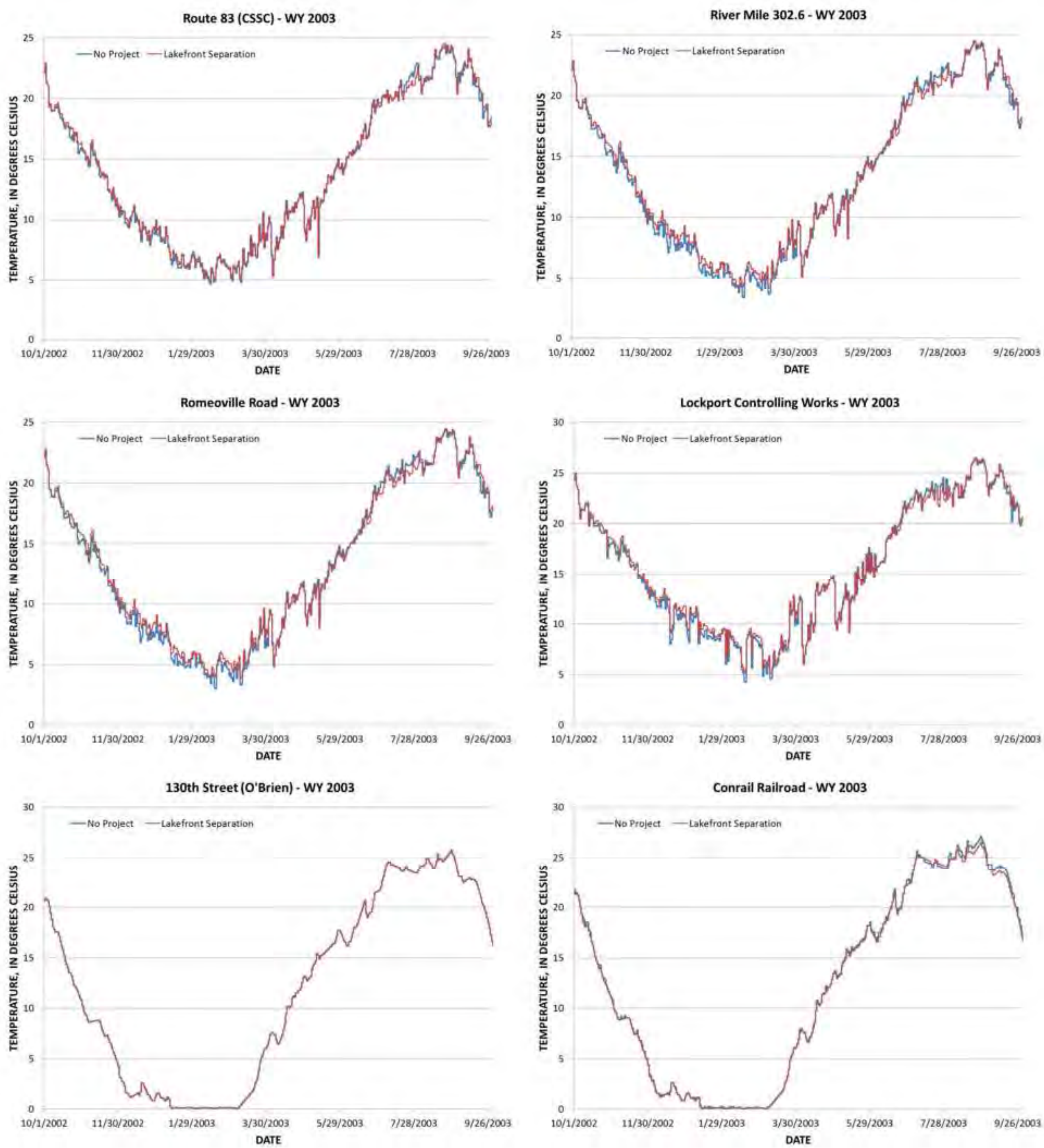

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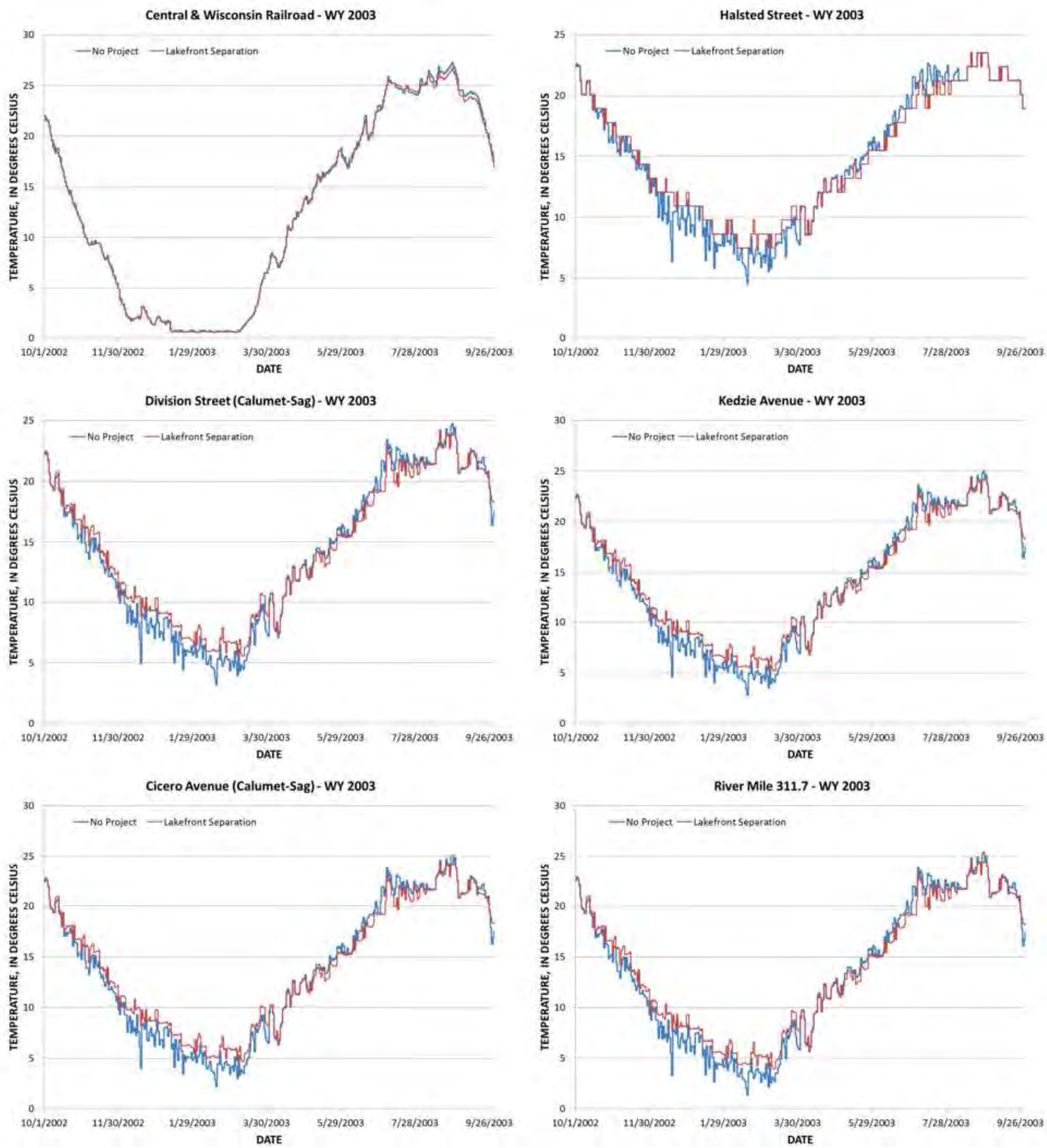


Figure K.10. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2003.

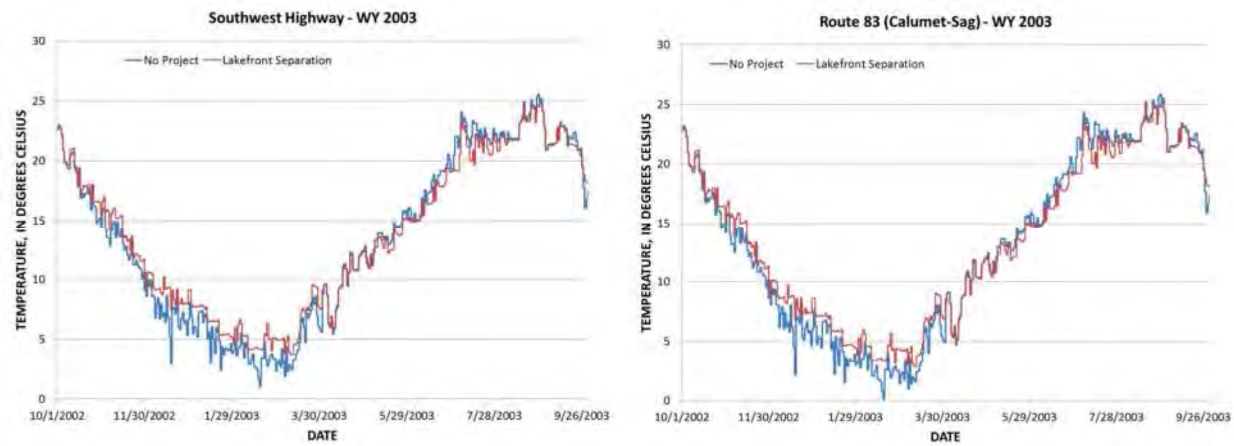


Figure K.10. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2003.

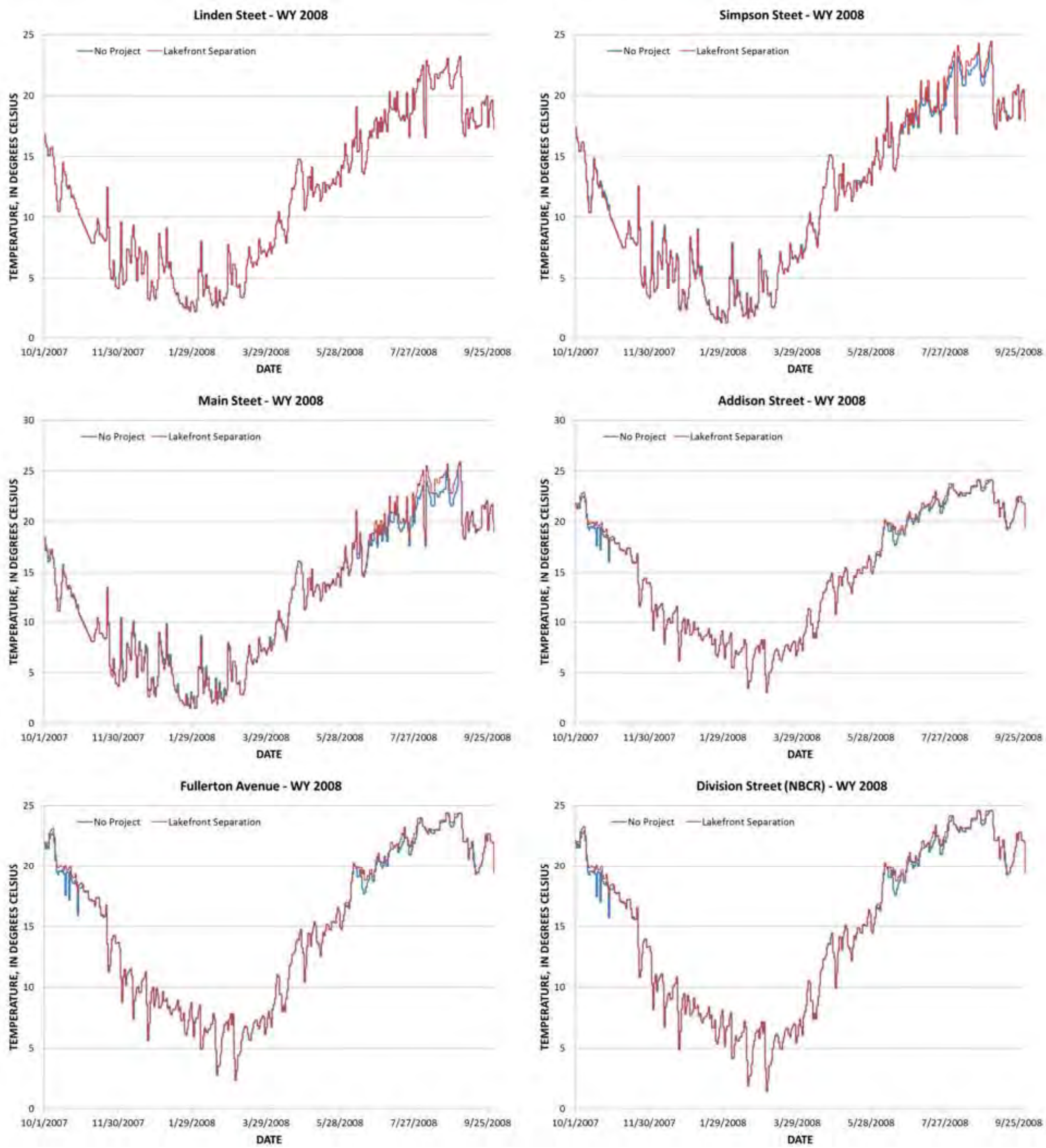


Figure K.11. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2008.

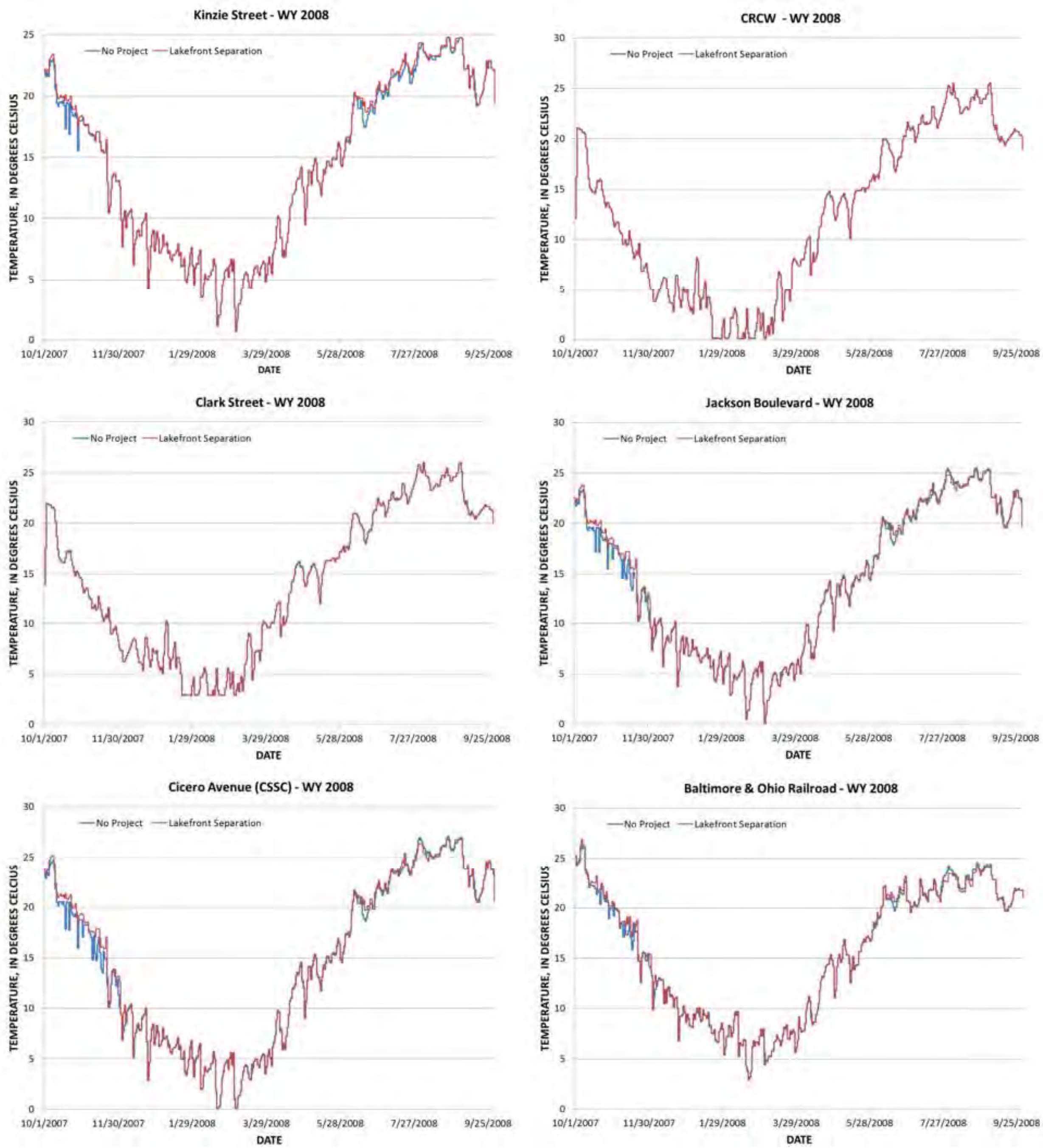


Figure K.11. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2008.

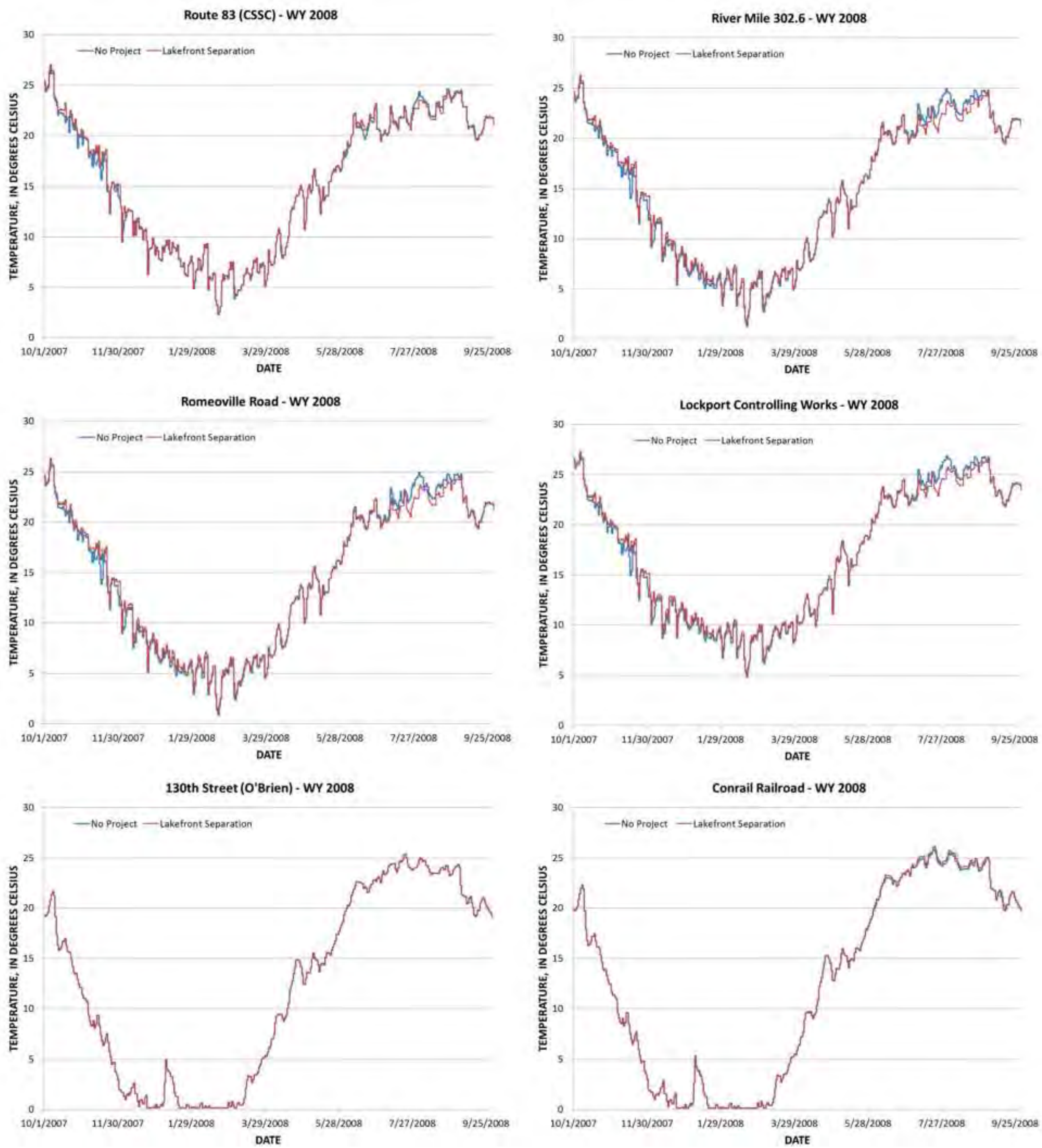
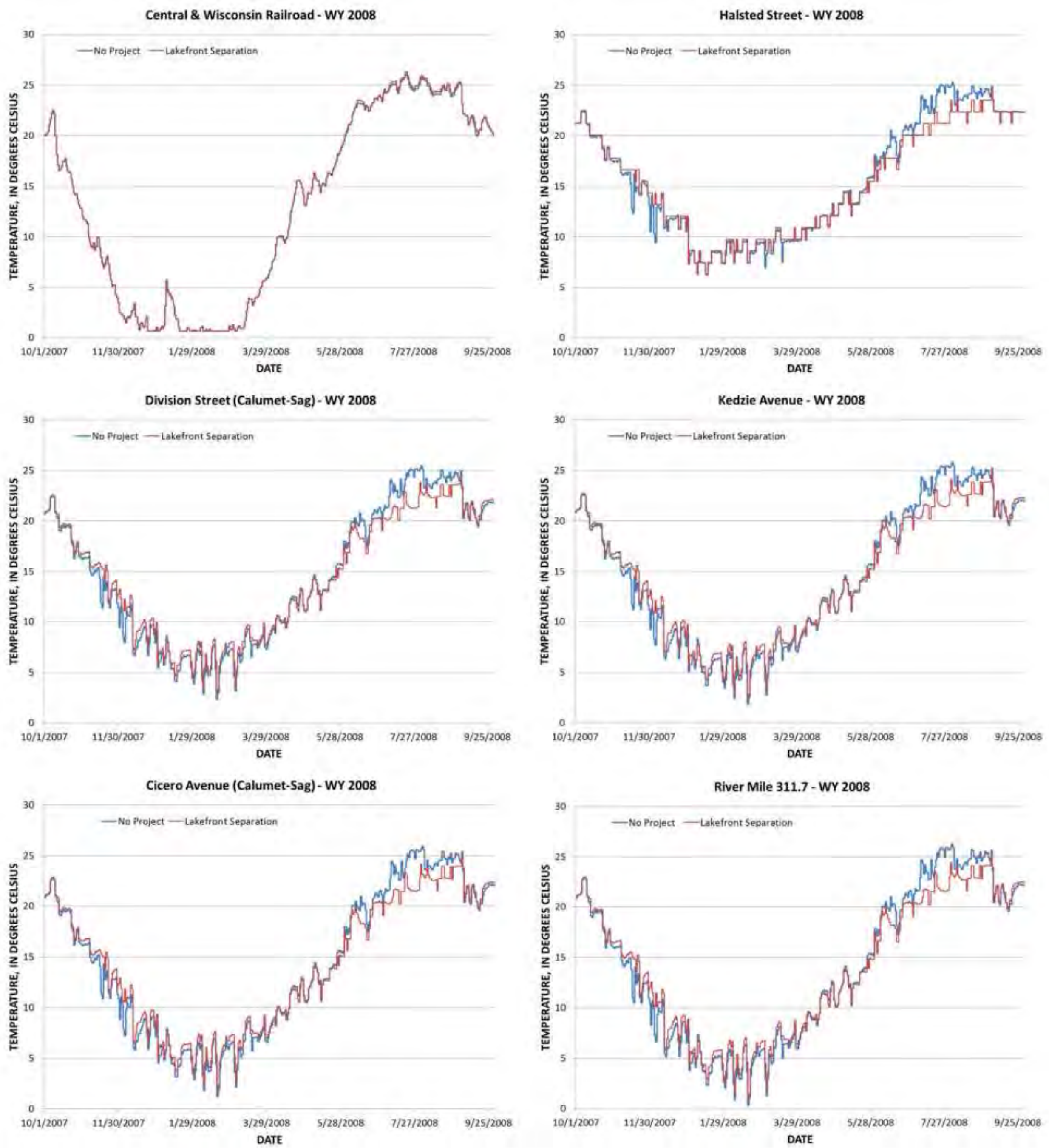


Figure K.11. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2008.



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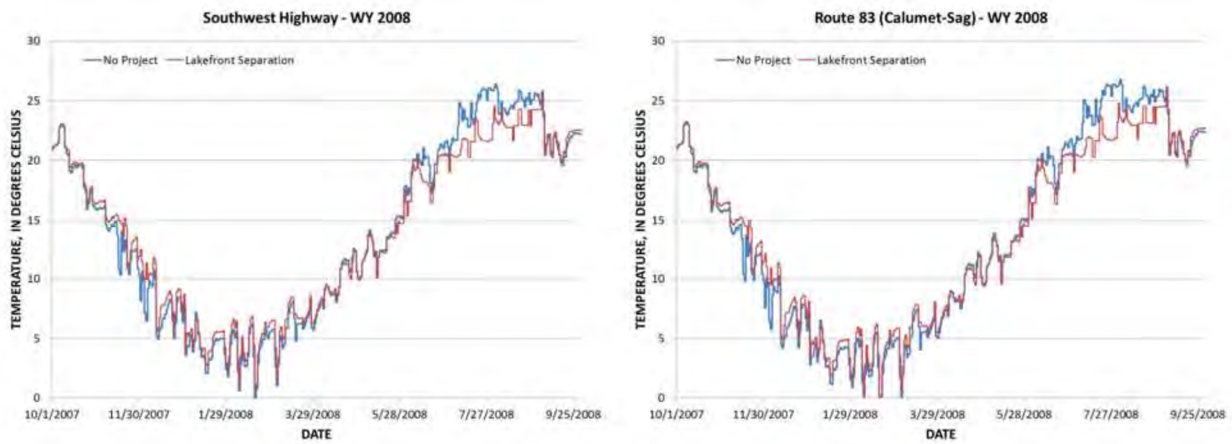


Figure K.11. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Baseline Conditions for Water Year 2008.

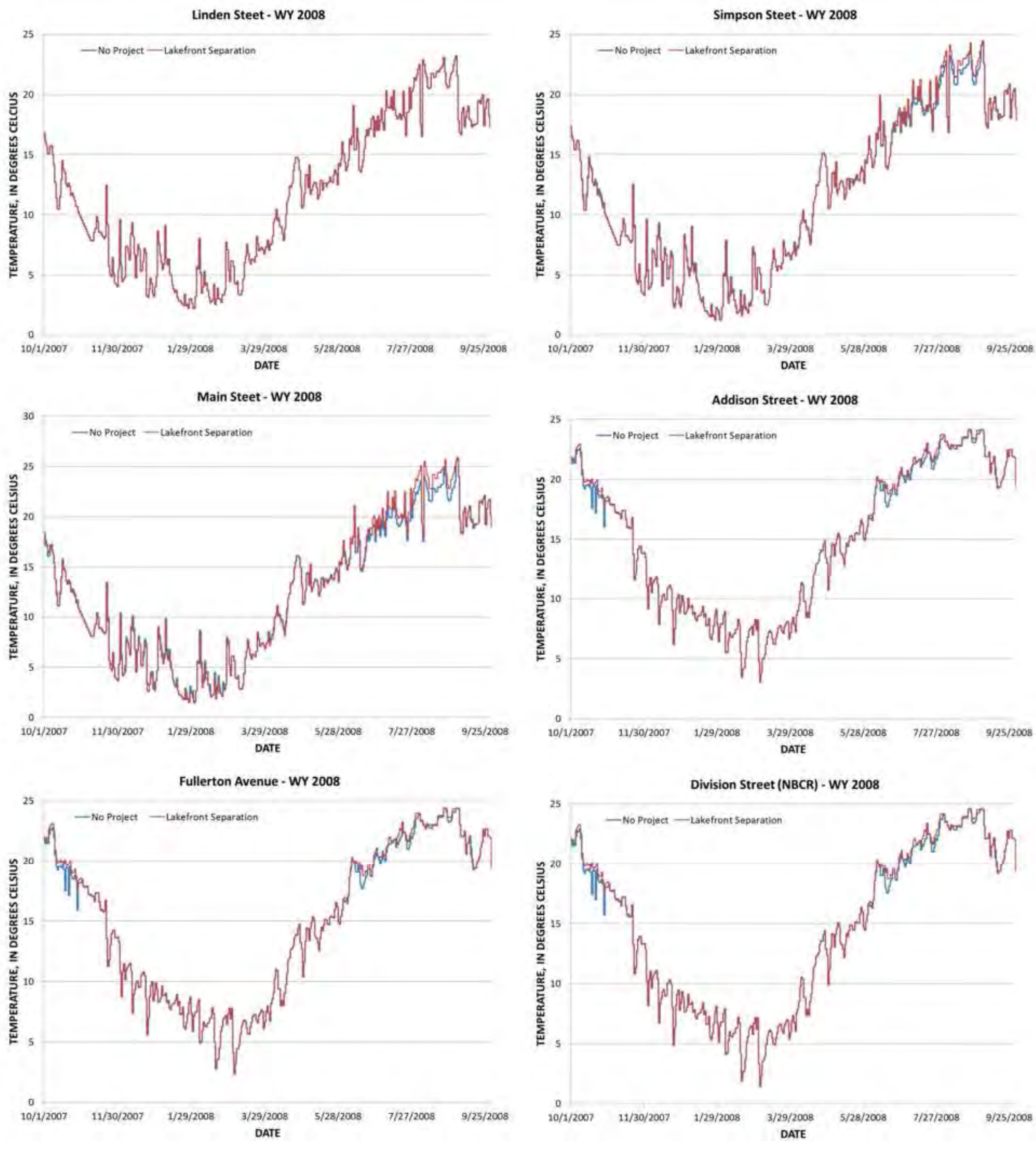


Figure K.12. Comparison of Temperatures in the Chicago Area Waterways System for “No Project” and “Lakefront Separation” Alternatives for Future Conditions for Water Year 2008.

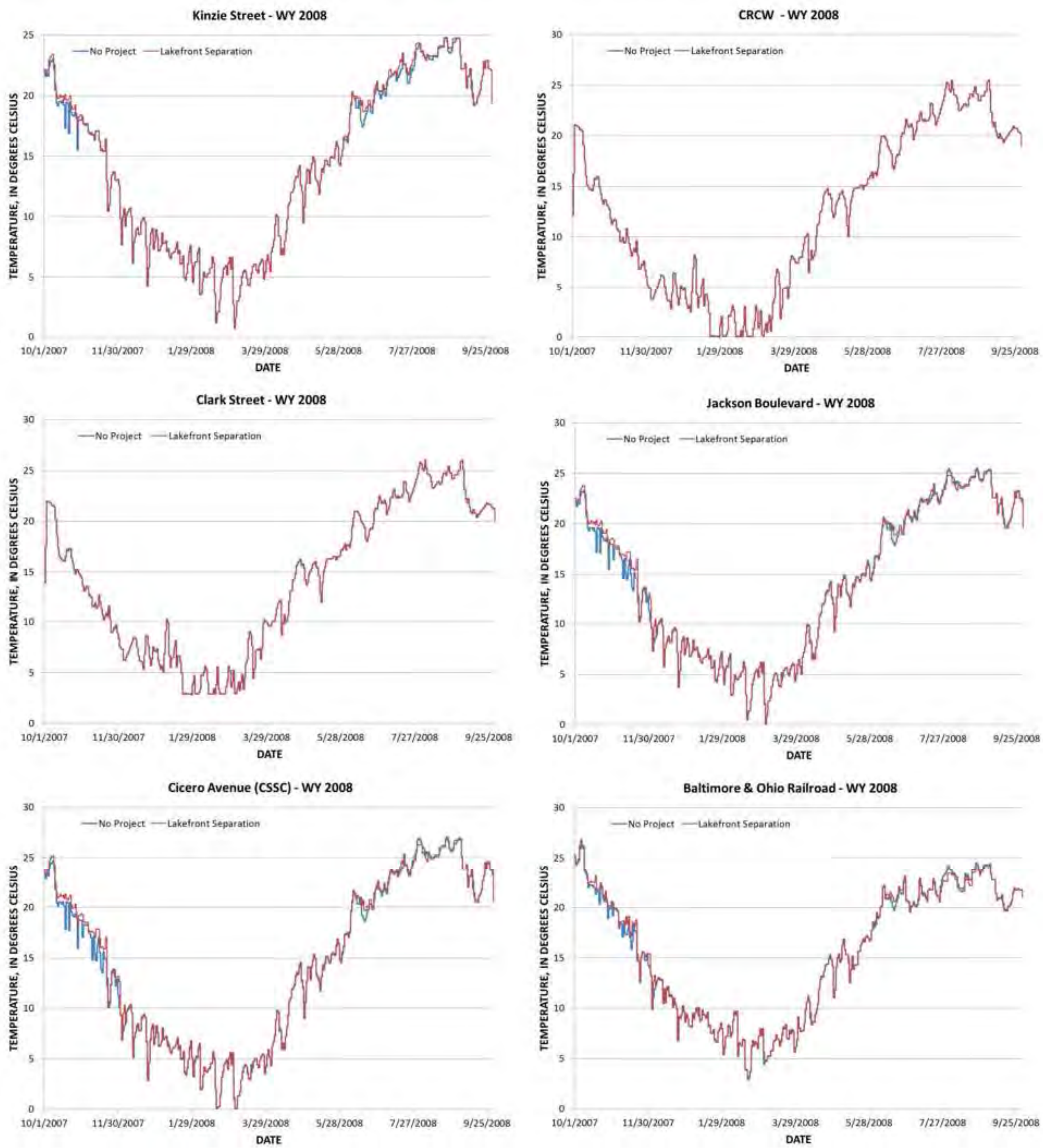


Figure K.12. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2008.

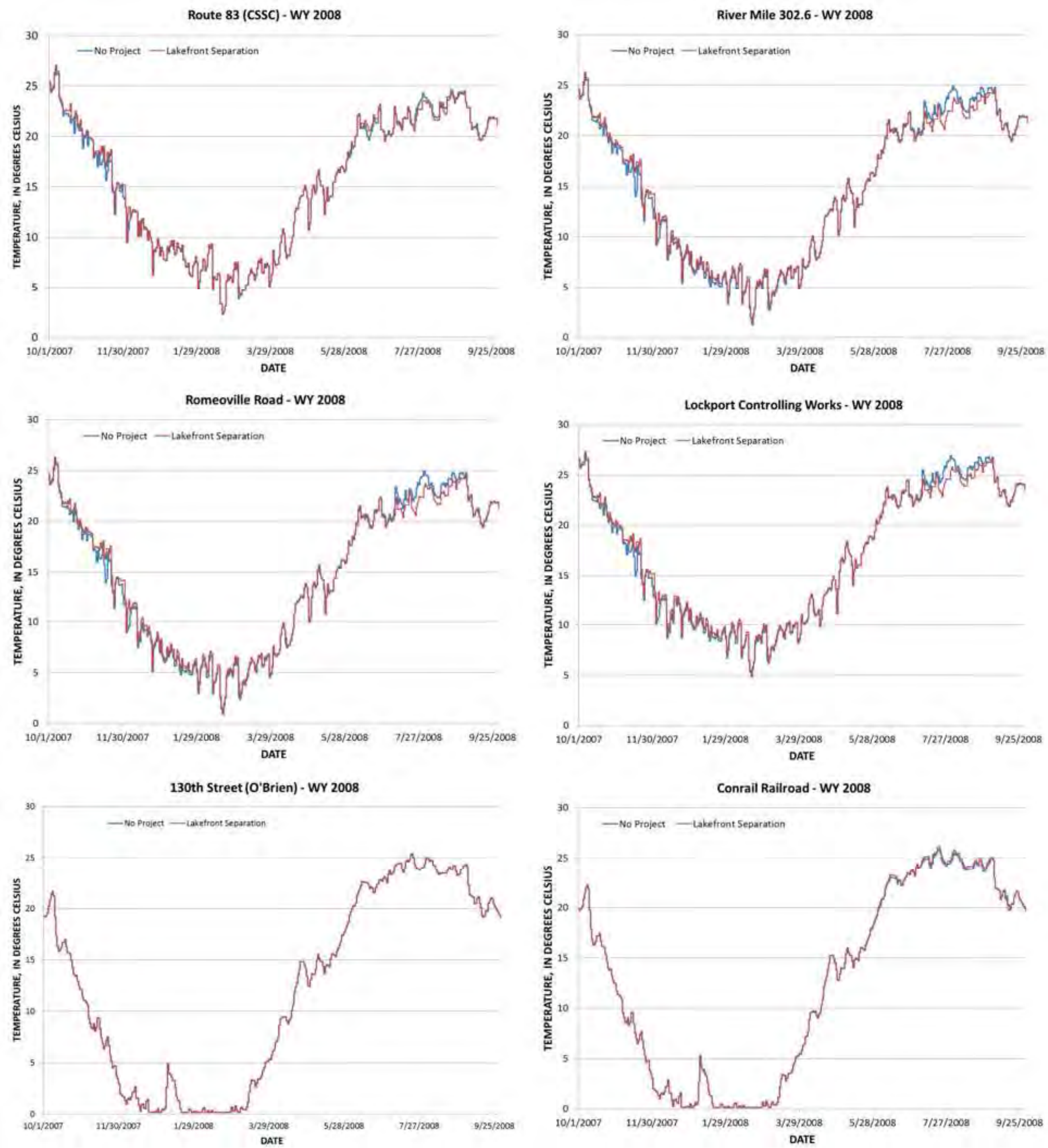
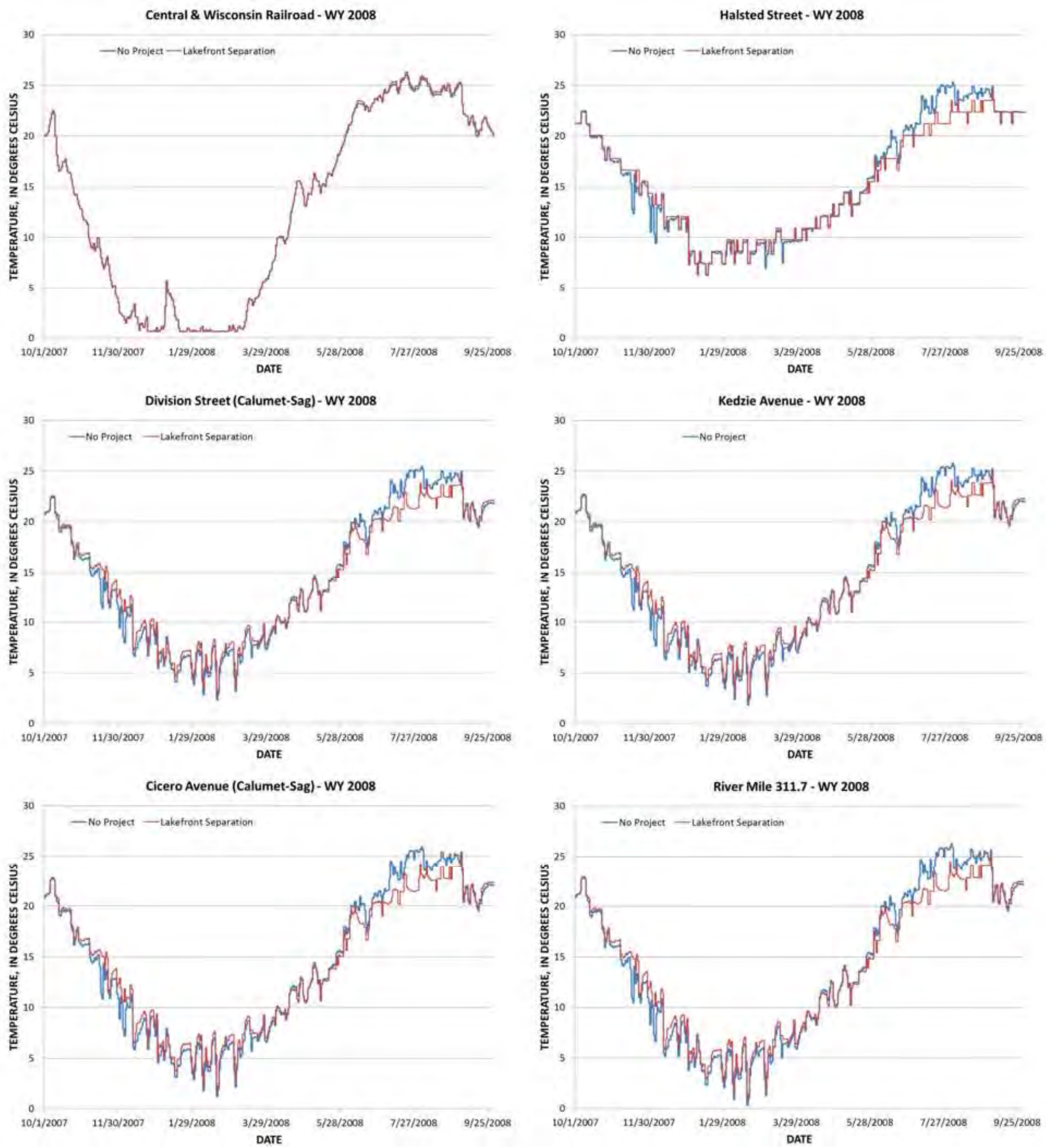


Figure K.12. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2008.



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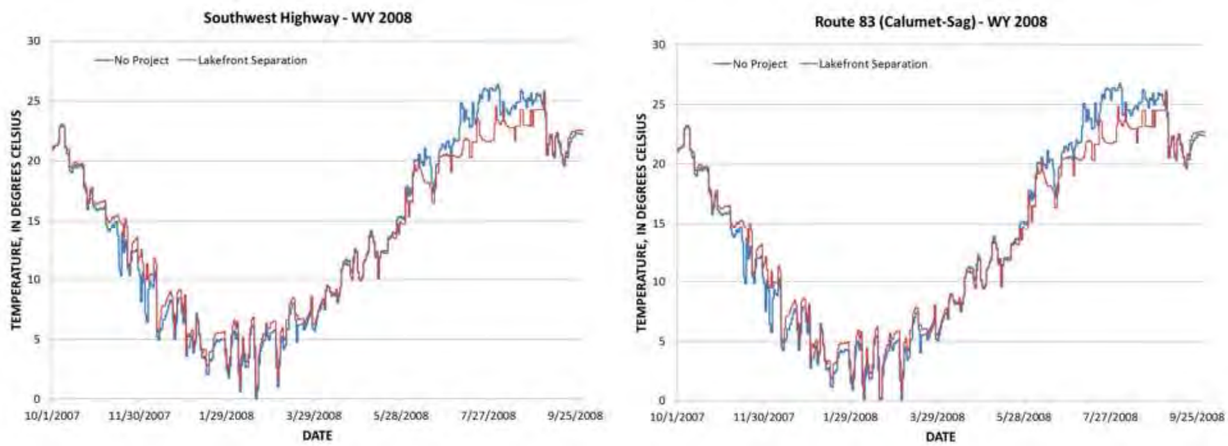


Figure K.12. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Lakefront Separation" Alternatives for Future Conditions for Water Year 2008.

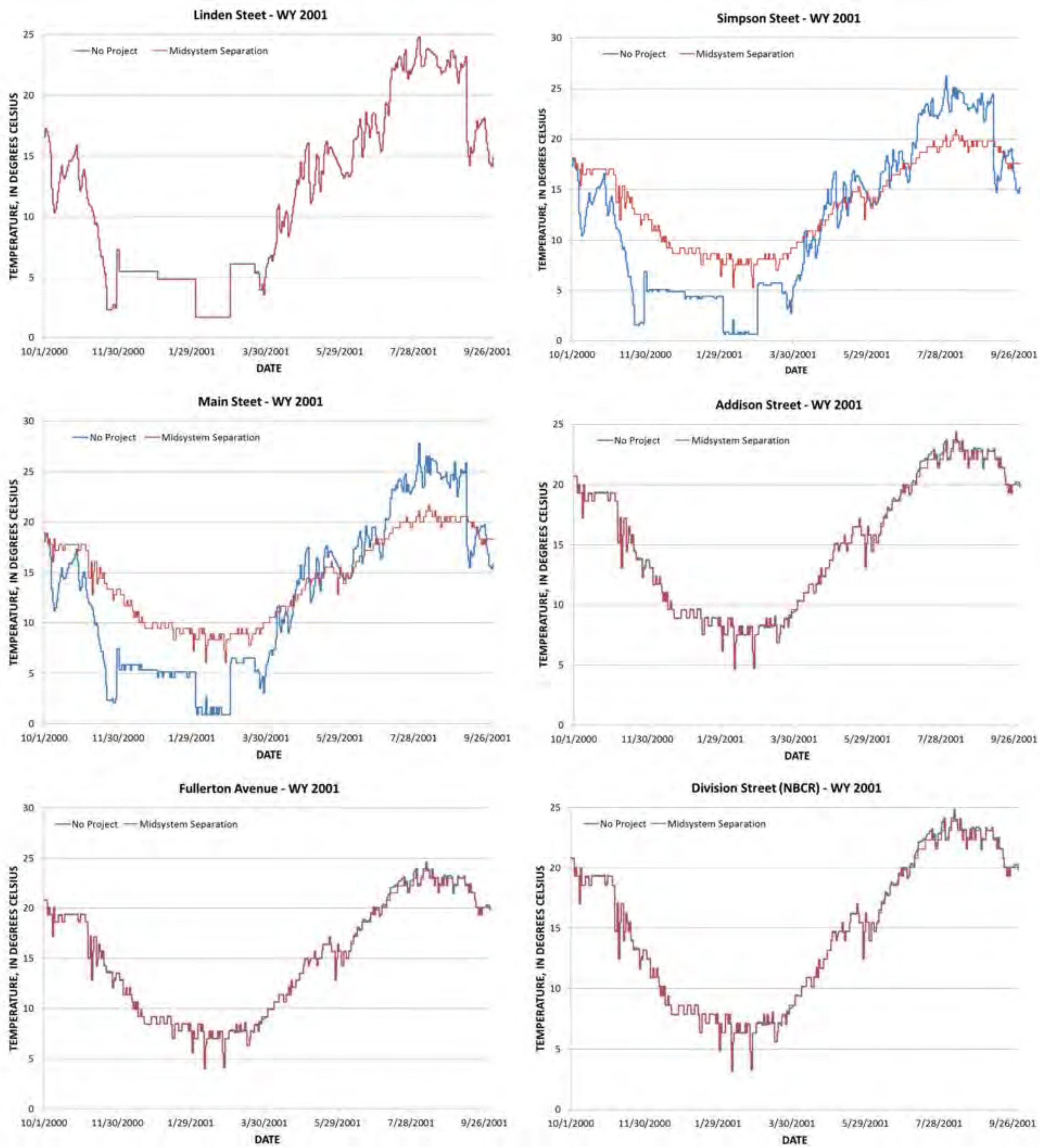


Figure K.13. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2001.

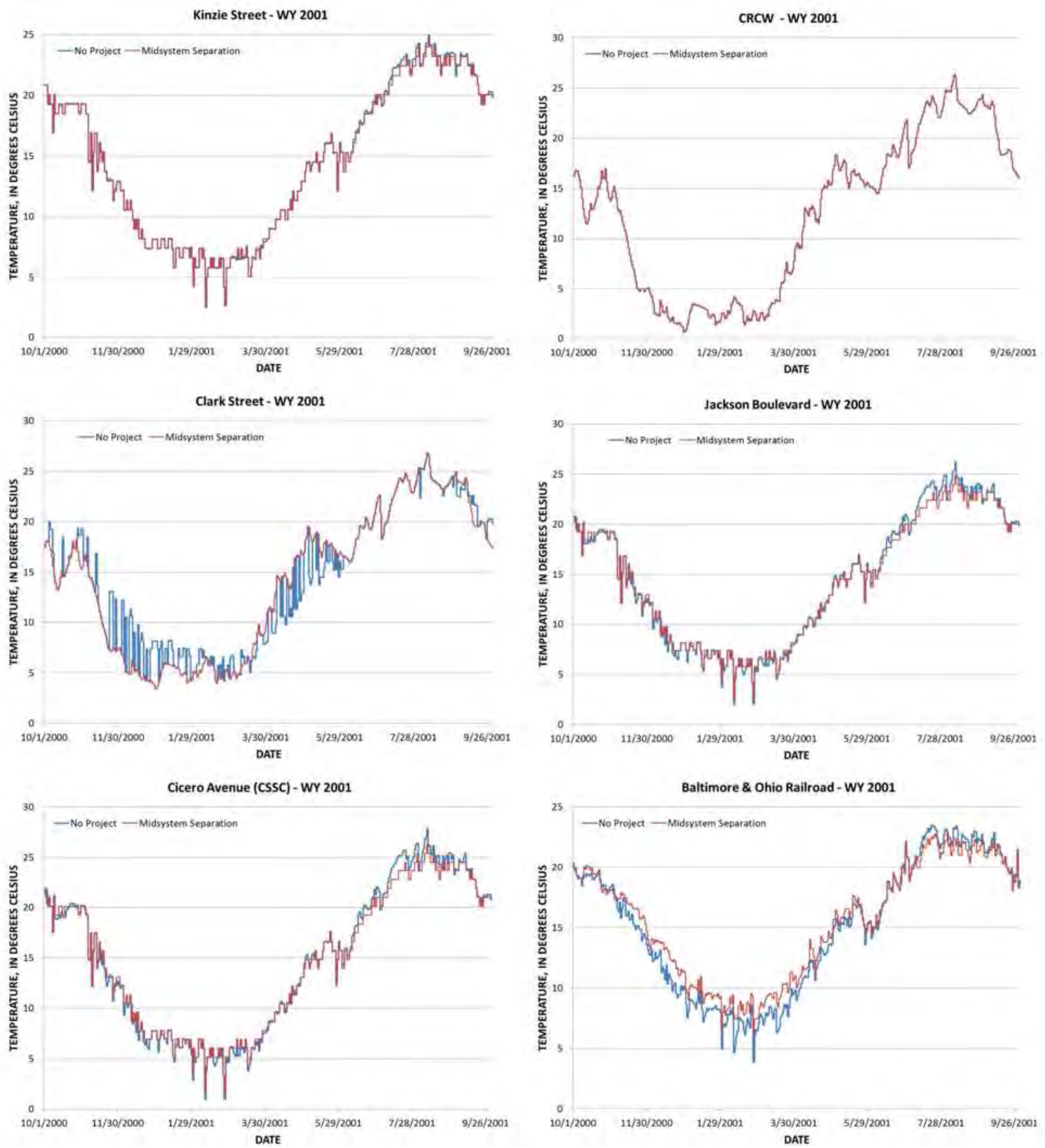


Figure K.13. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2001.

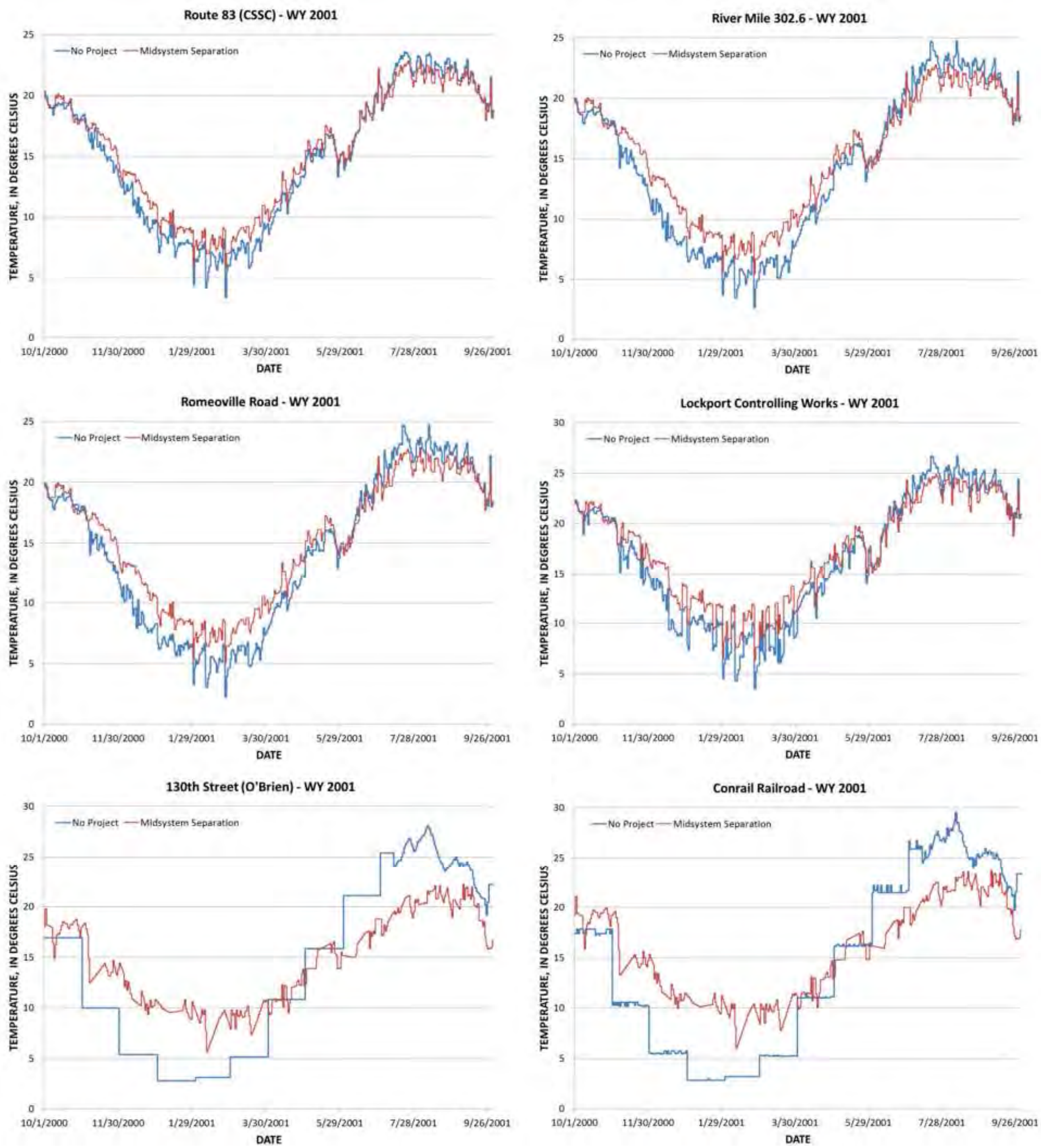


Figure K.13. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2001.

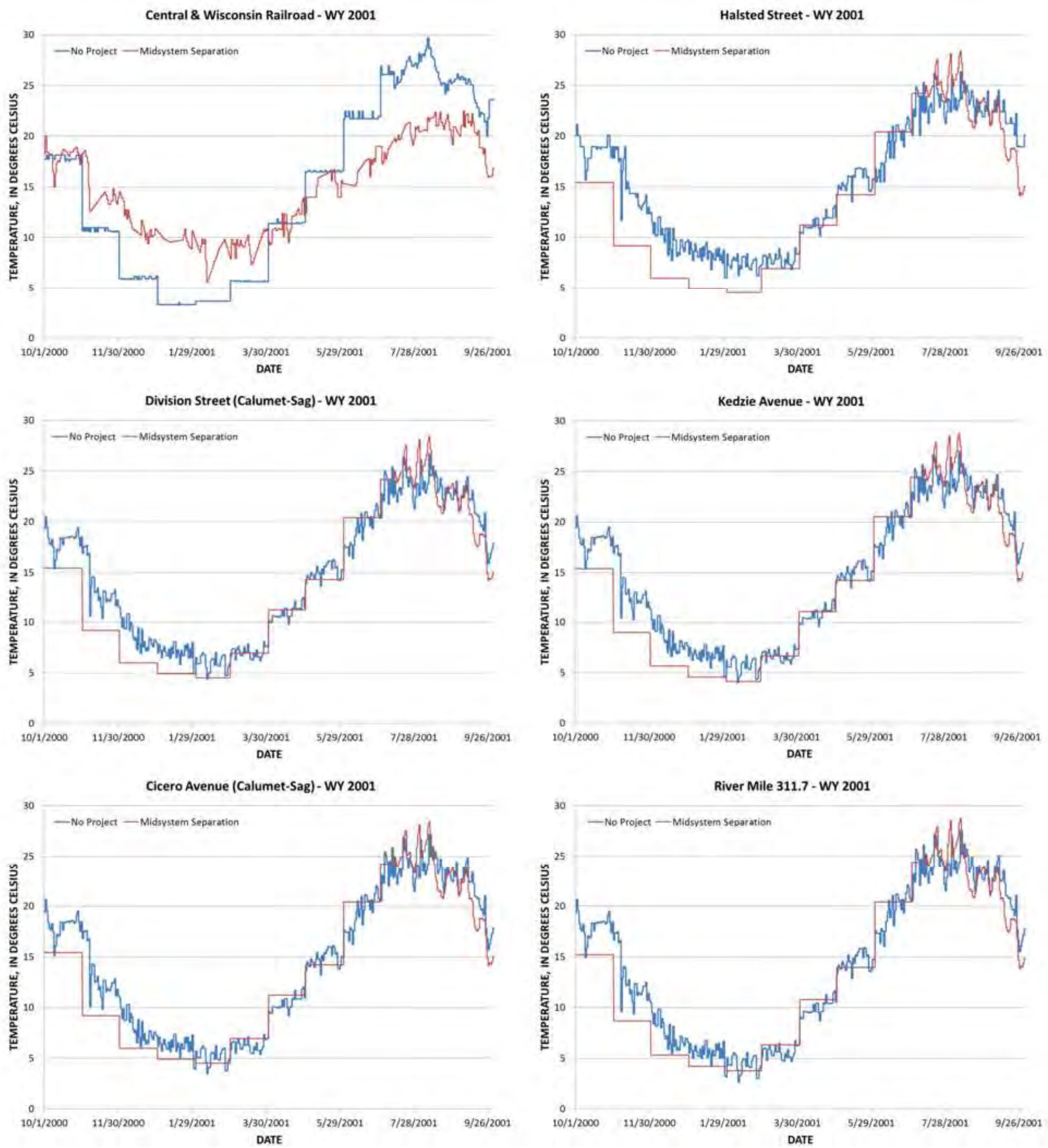
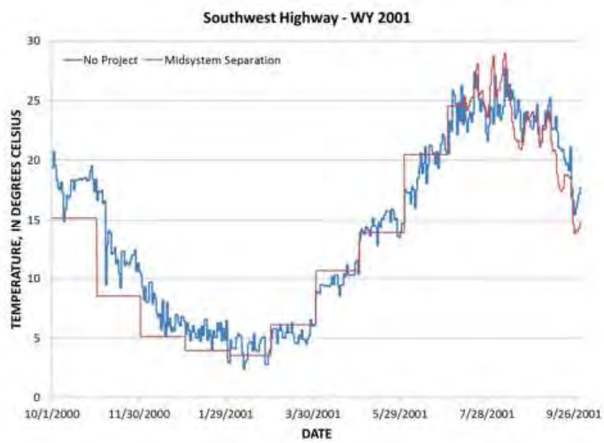


Figure K.13. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2001.



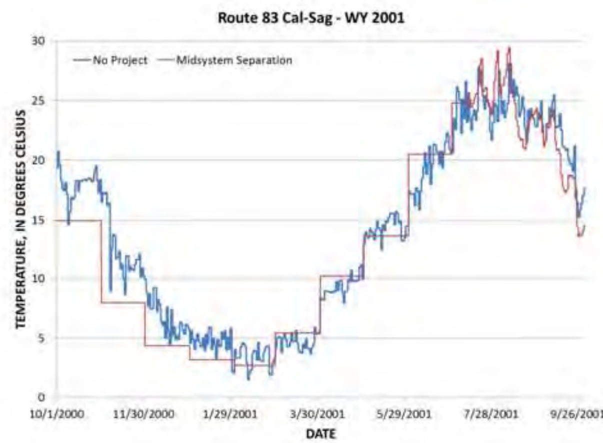


Figure K.13. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2001.

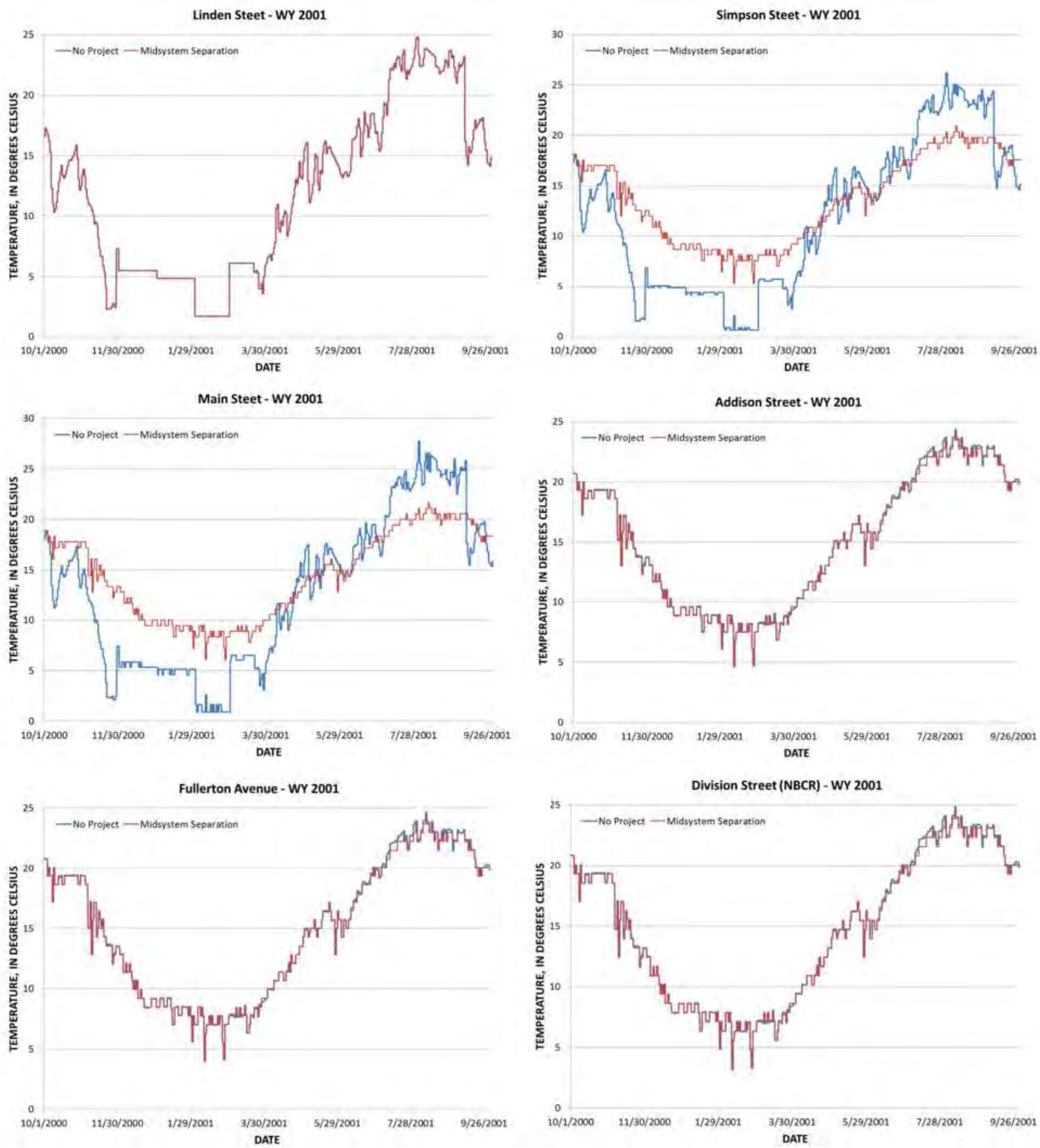


Figure K.14. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2001.

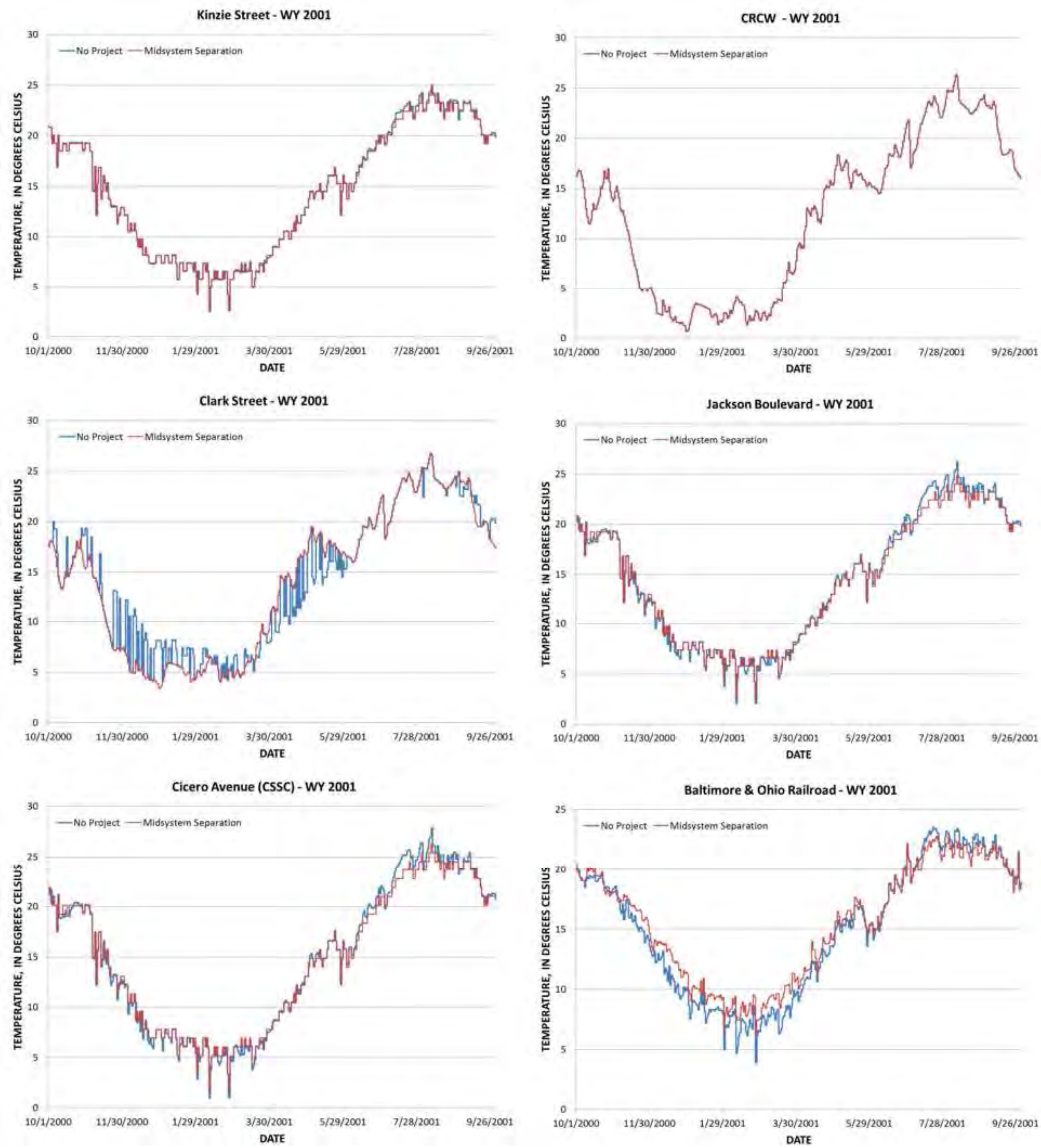


Figure K.14. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for “No Project” and “Midsystem Separation” Alternatives for Future Conditions for Water Year 2001.

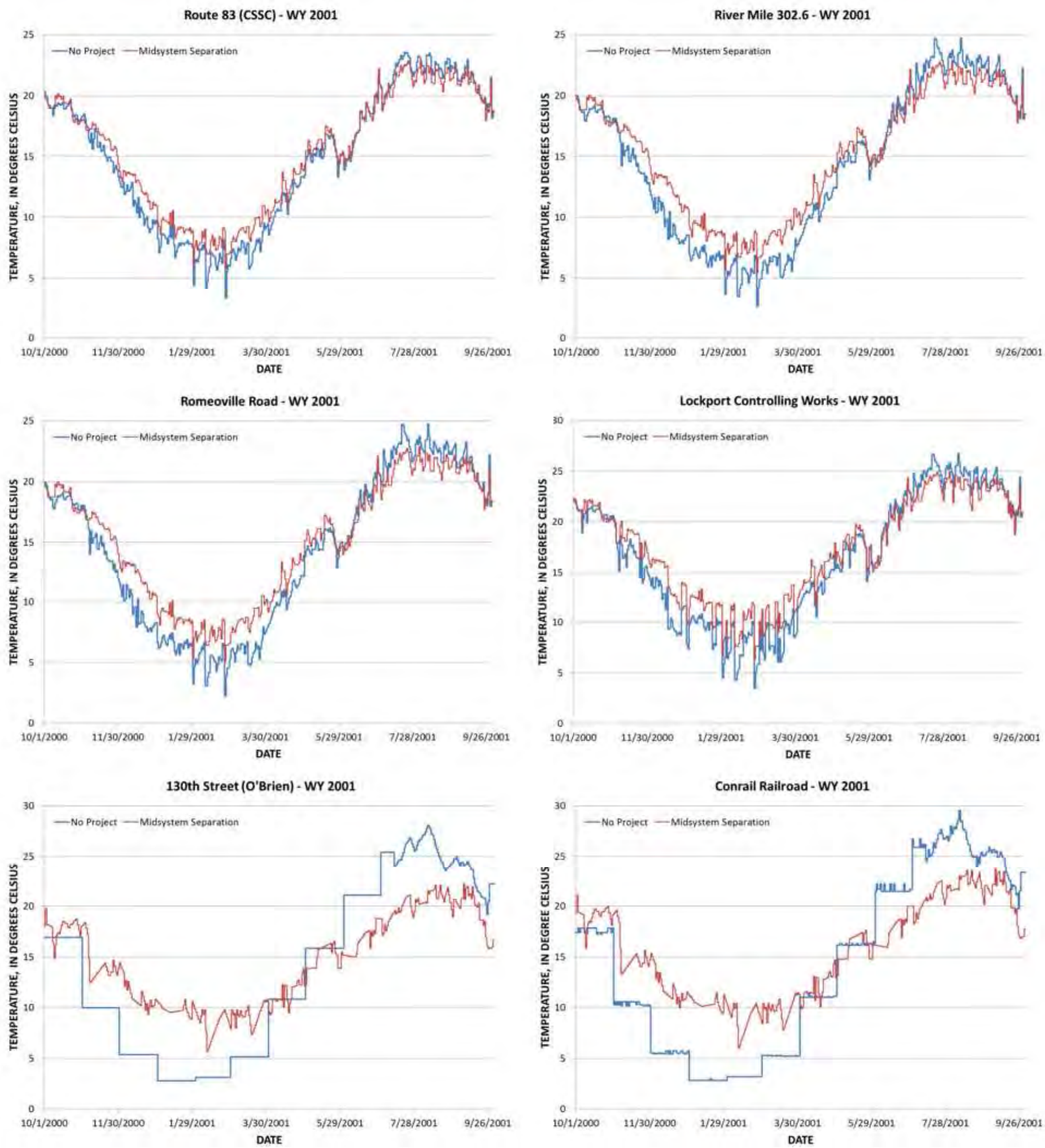
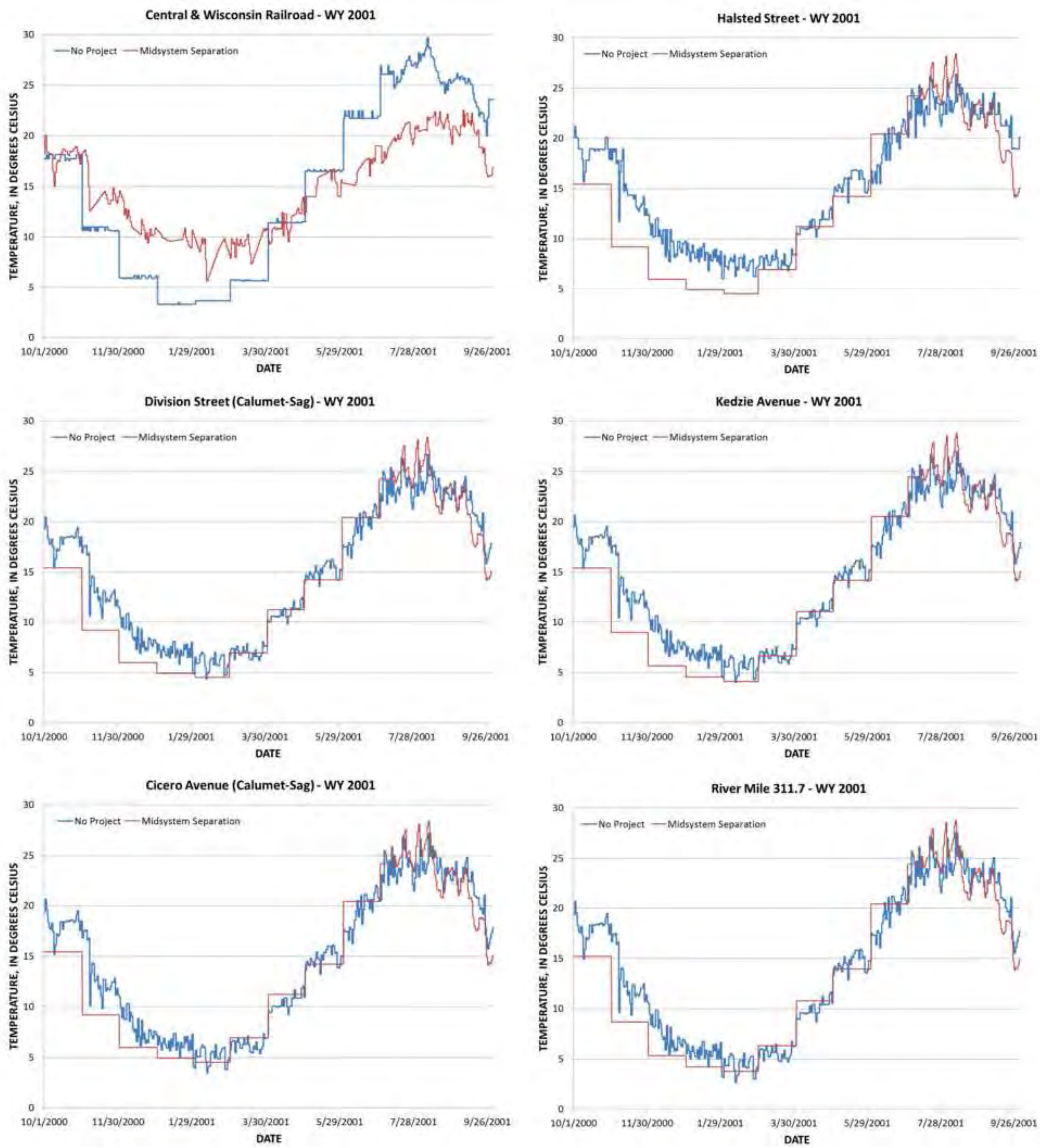


Figure K.14. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2001.



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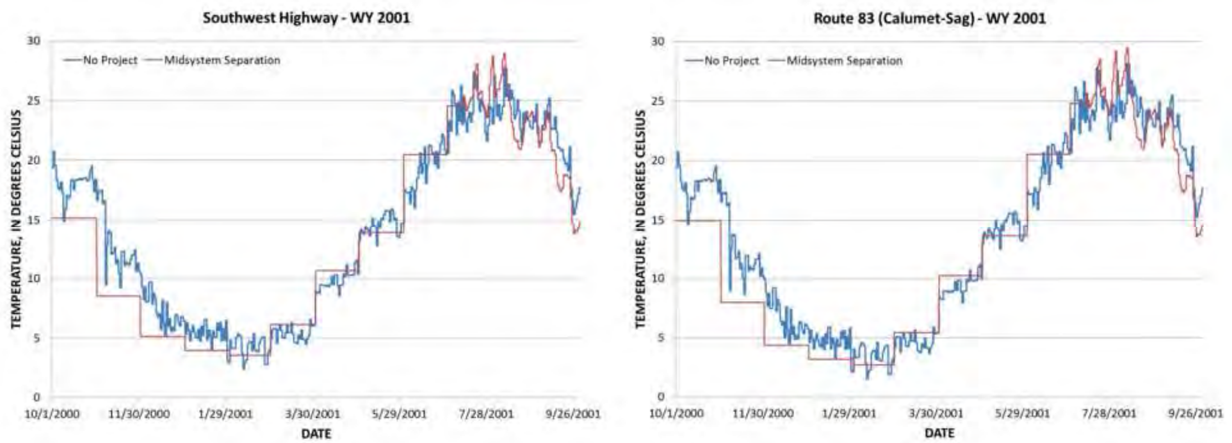


Figure K.14. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2001.

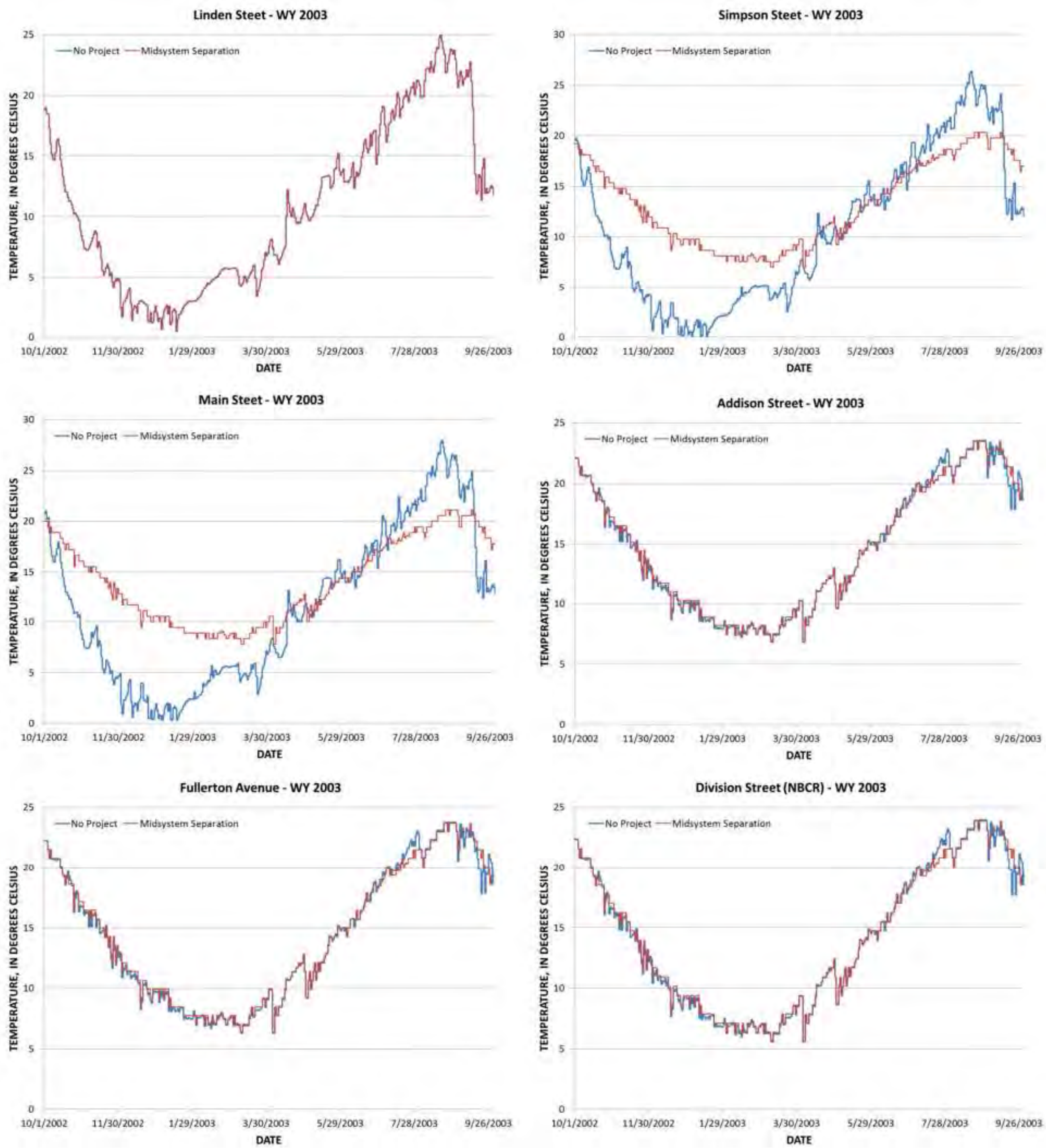


Figure K.15. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2003.

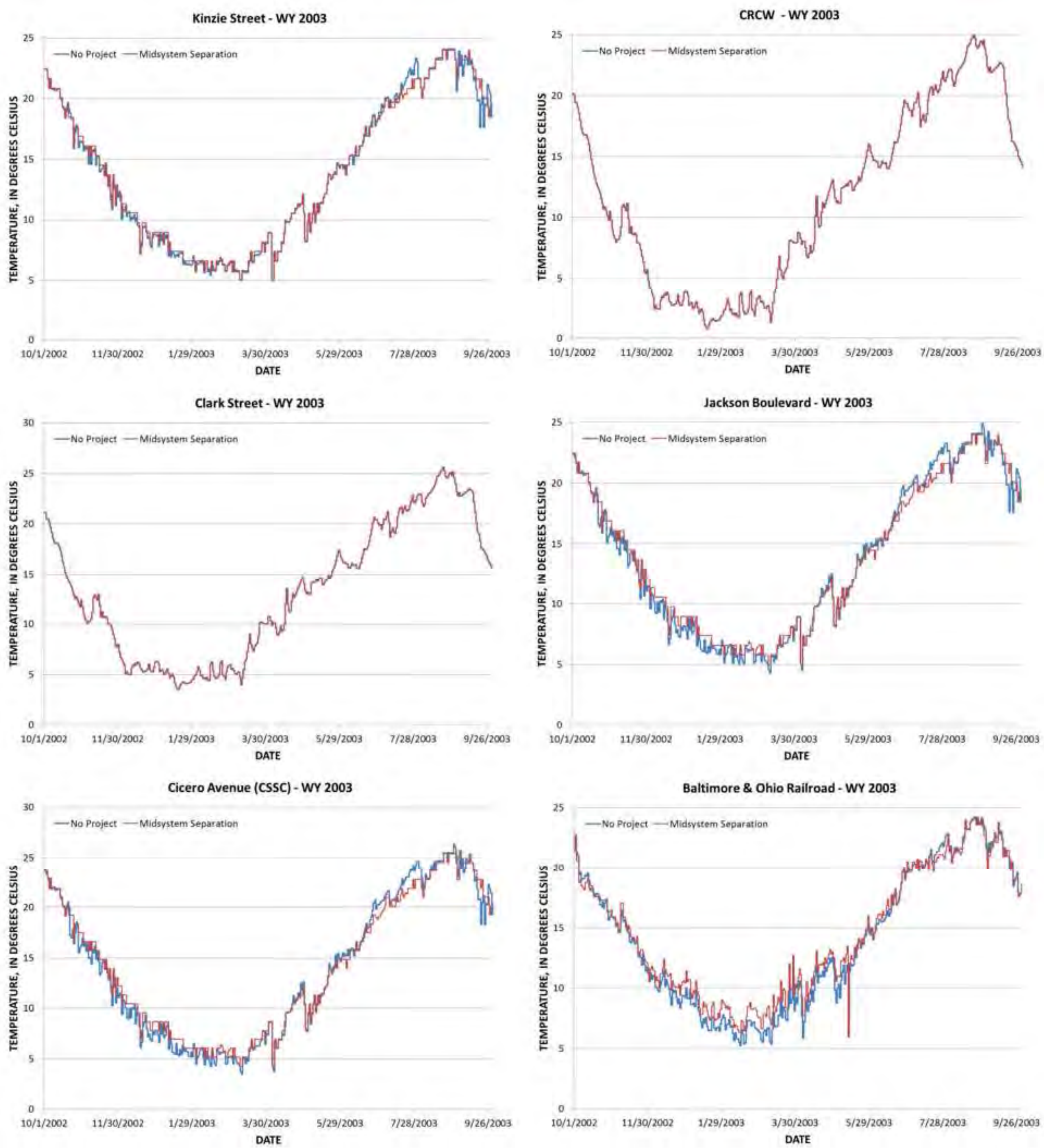
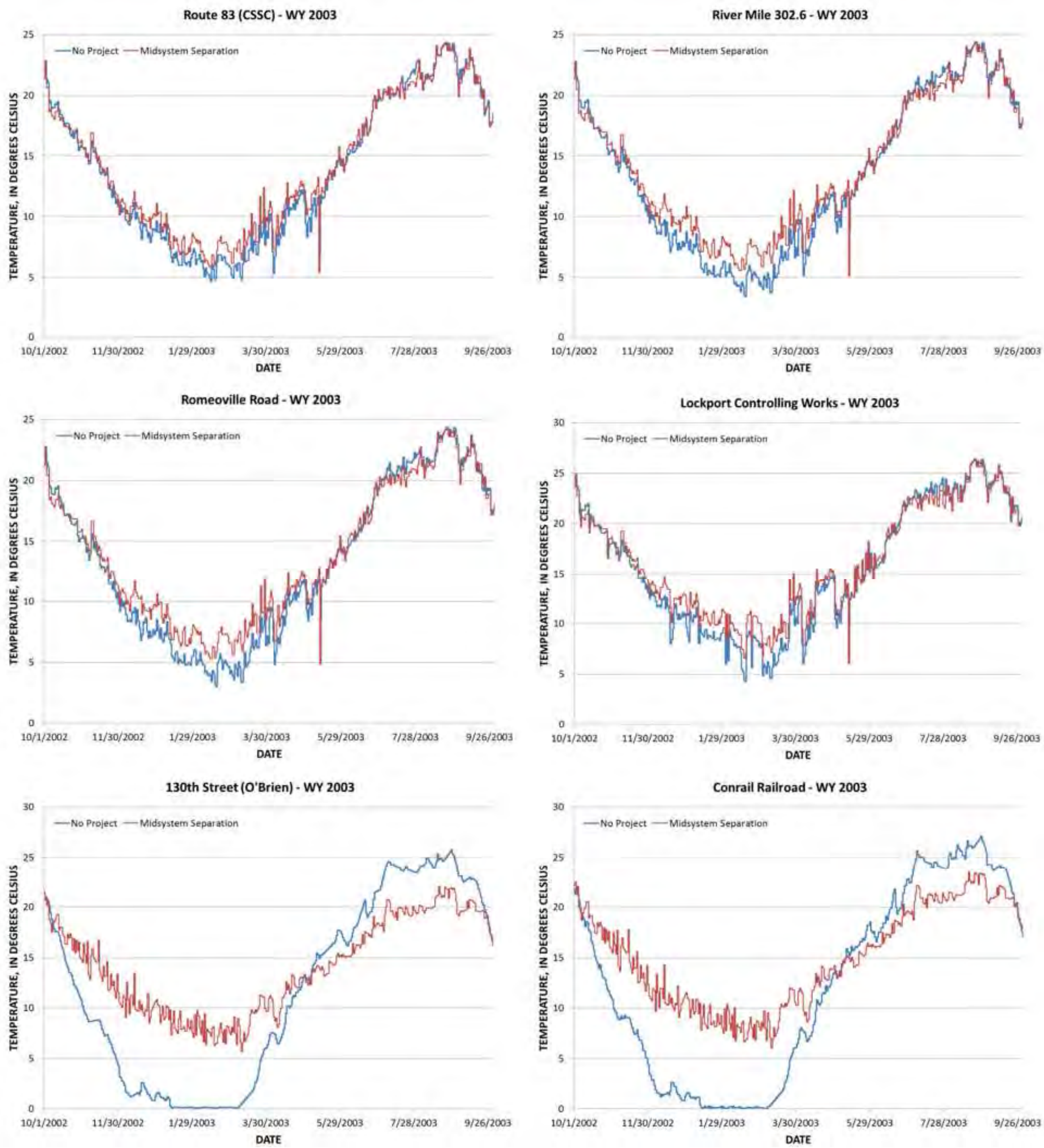


Figure K.15. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2003.



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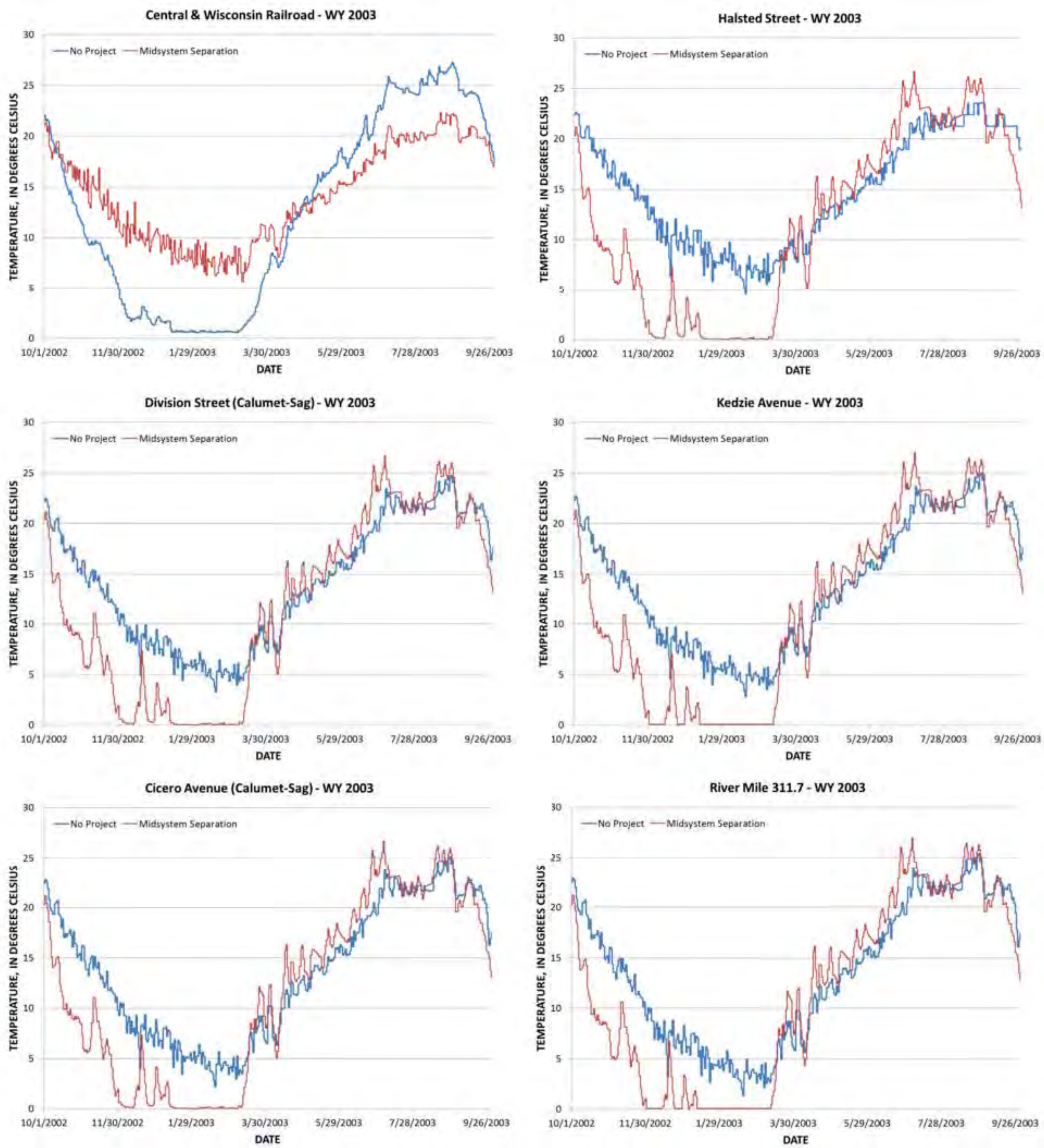

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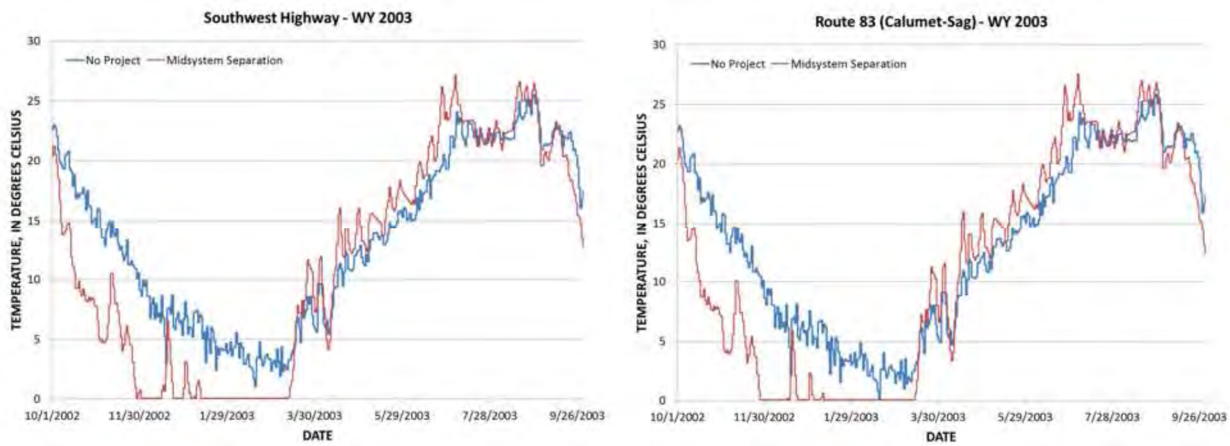


Figure K.15. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2003.

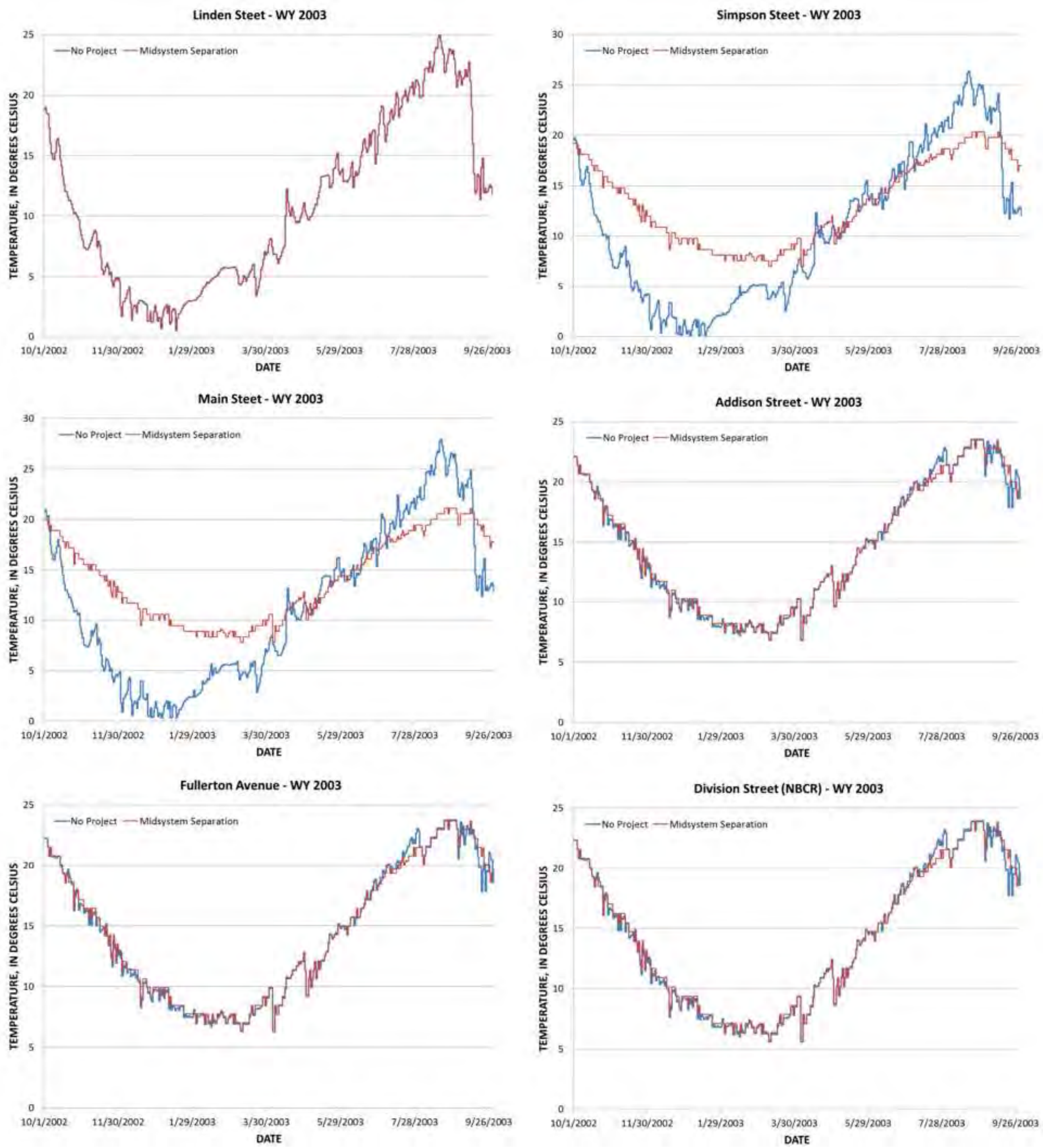


Figure K.16. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2003.

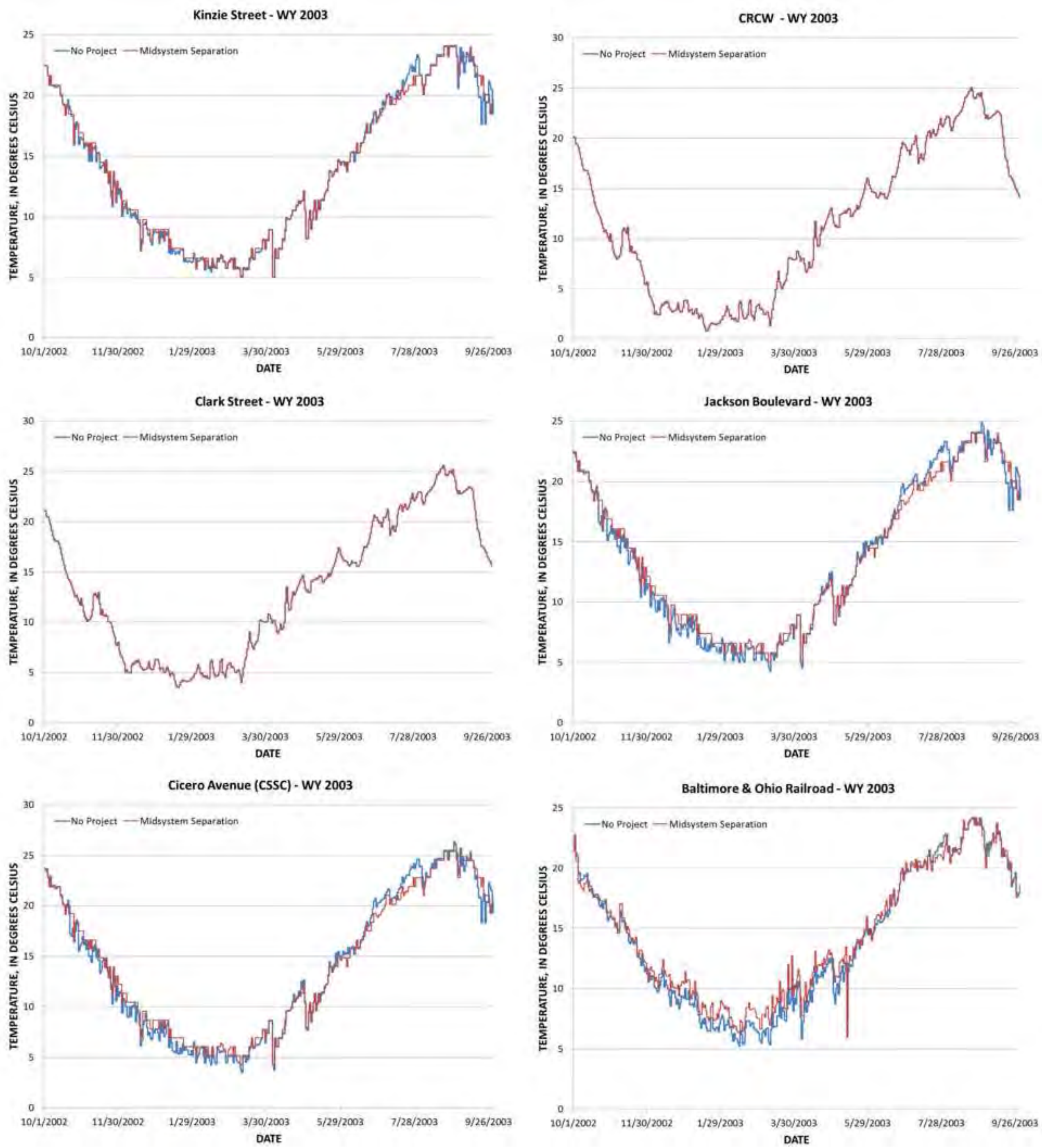


Figure K.16. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2003.

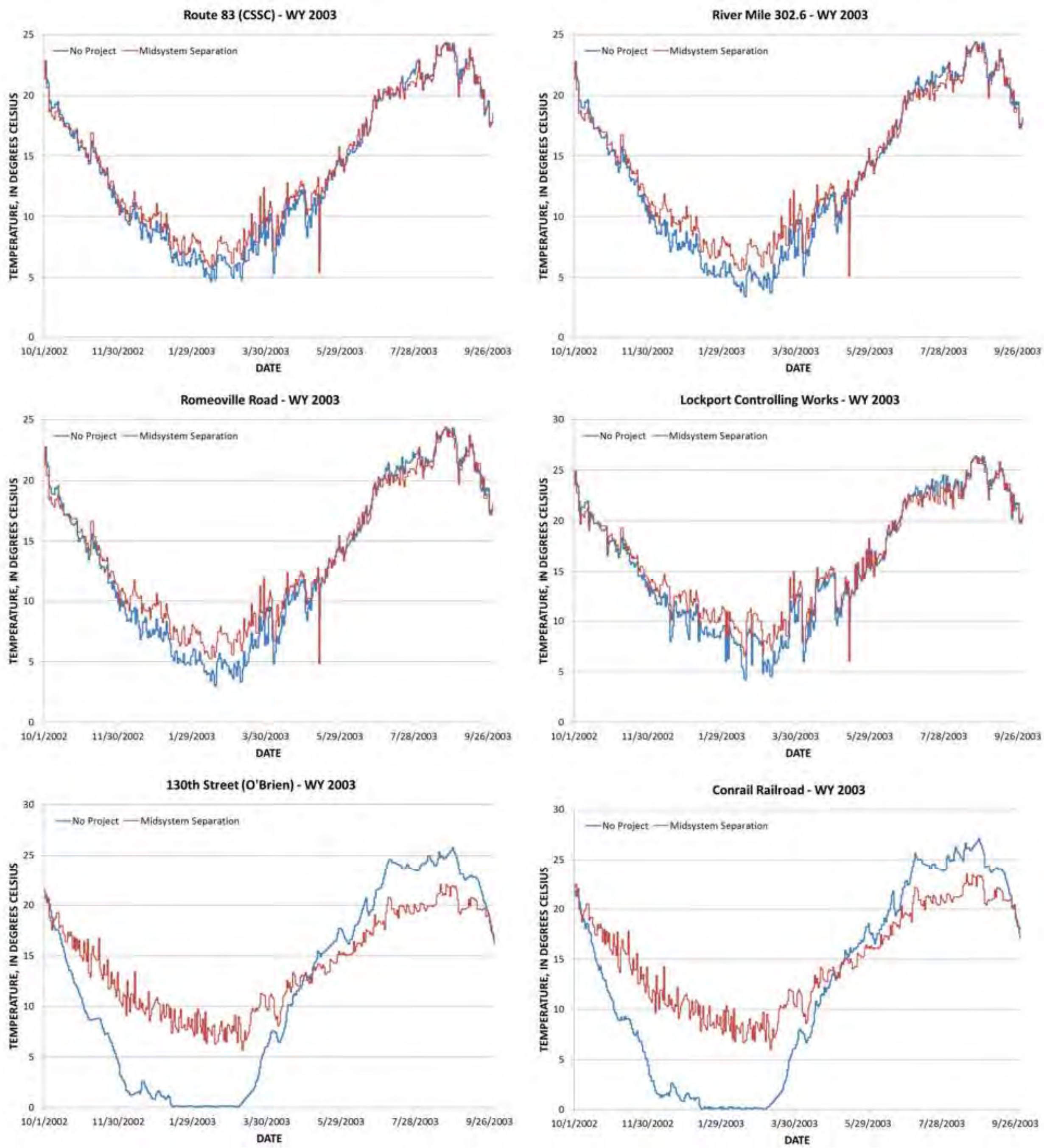


Figure K.16. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2003.

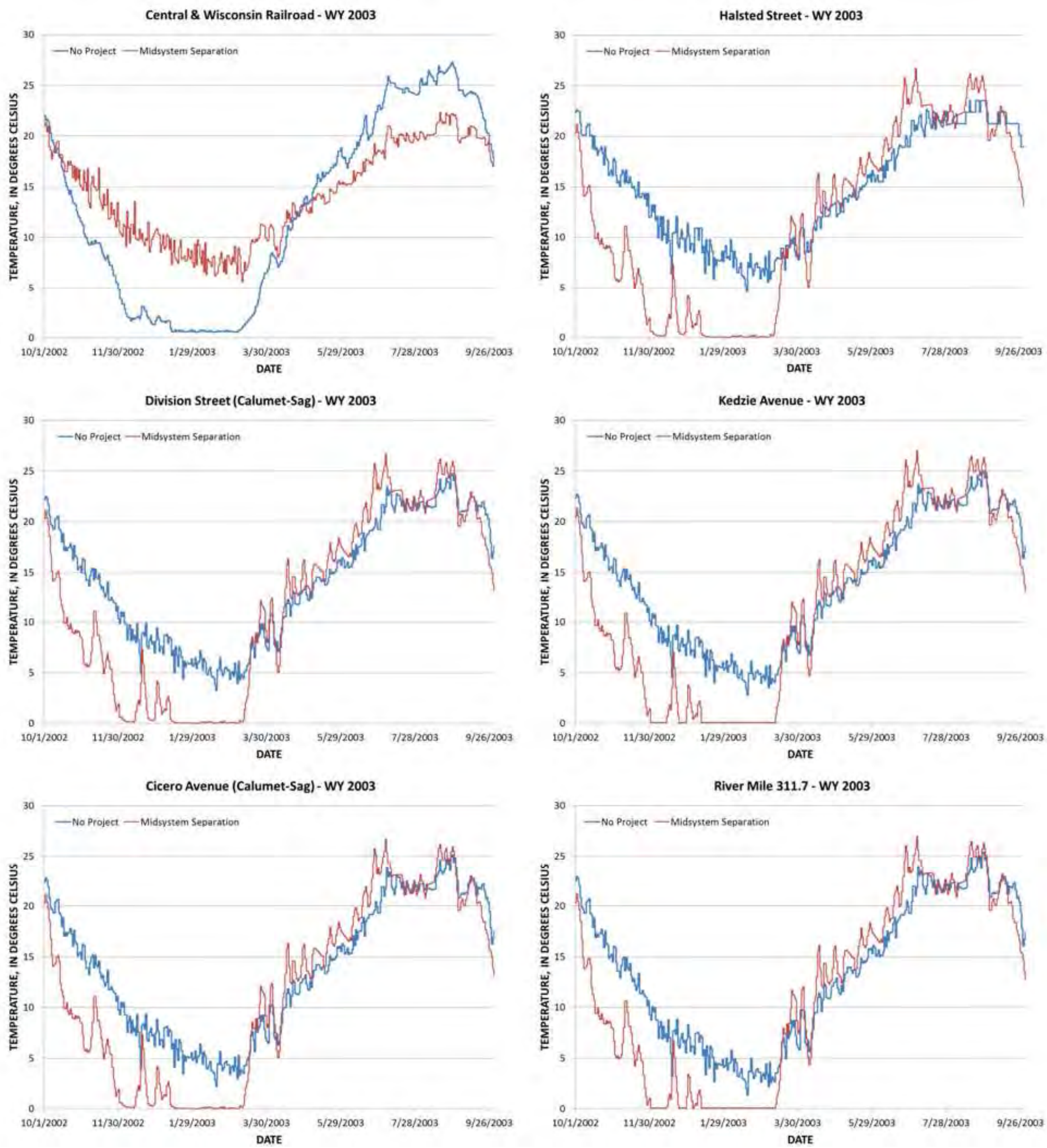


Figure K.16. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2003.

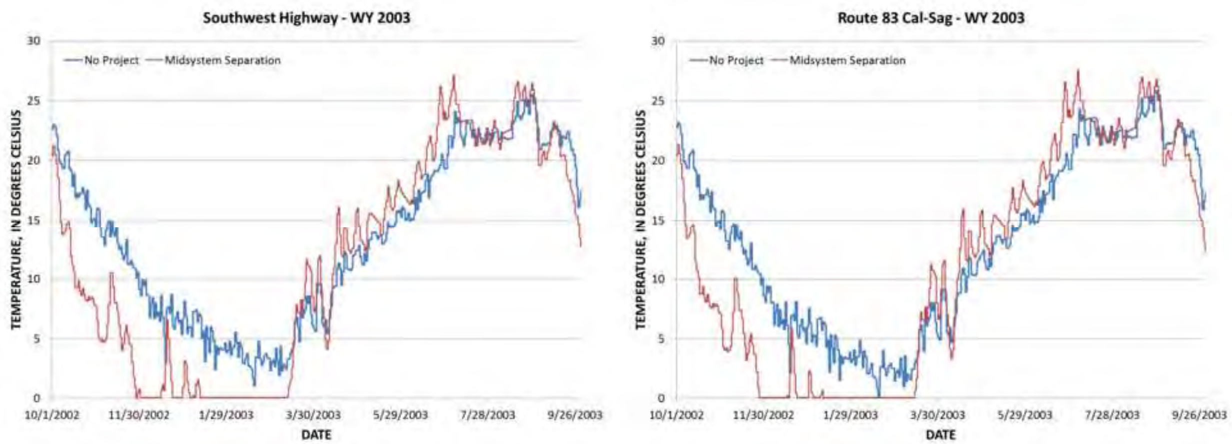


Figure K.16. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Future Conditions for Water Year 2003.

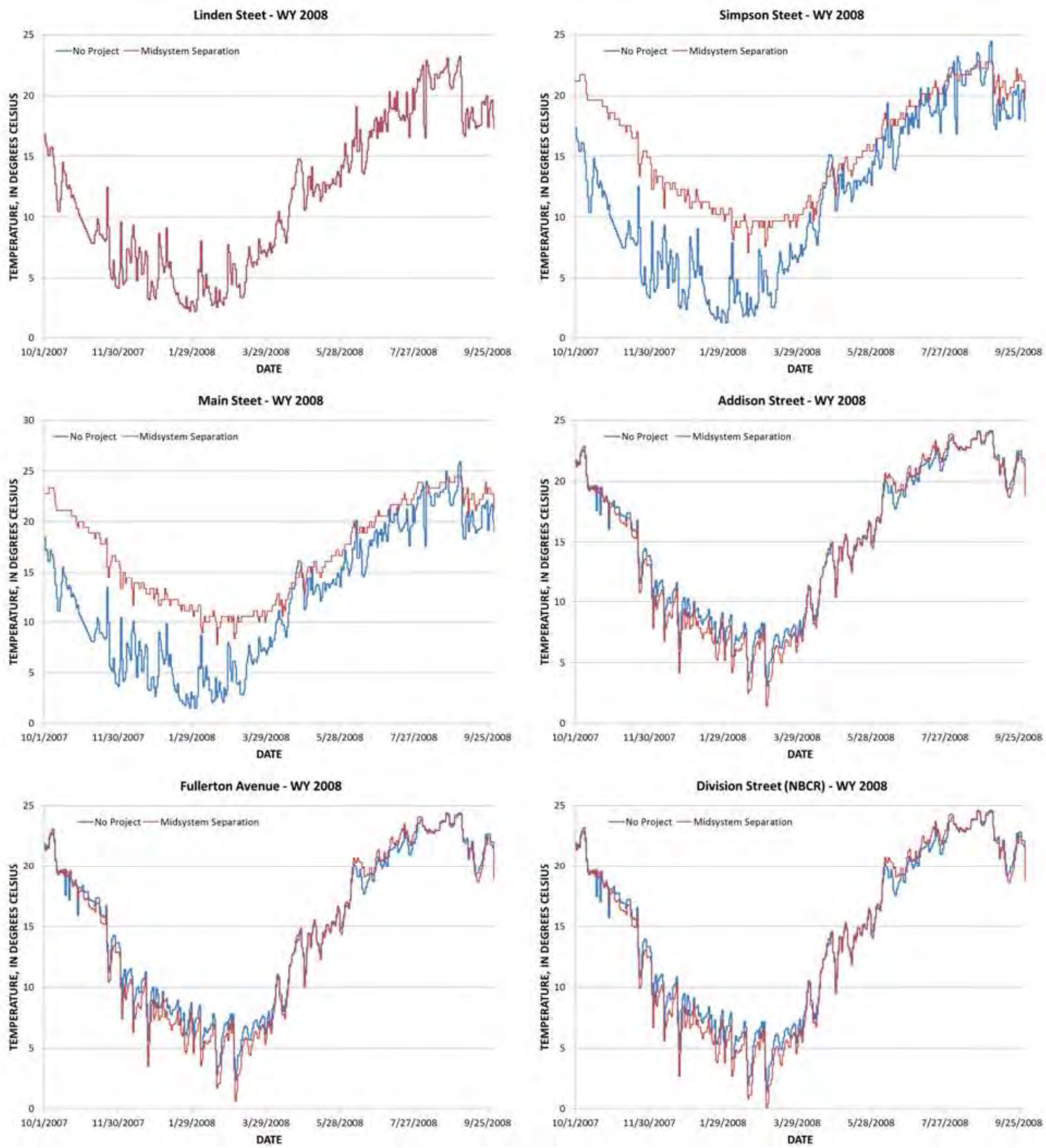


Figure K.17. Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2008.

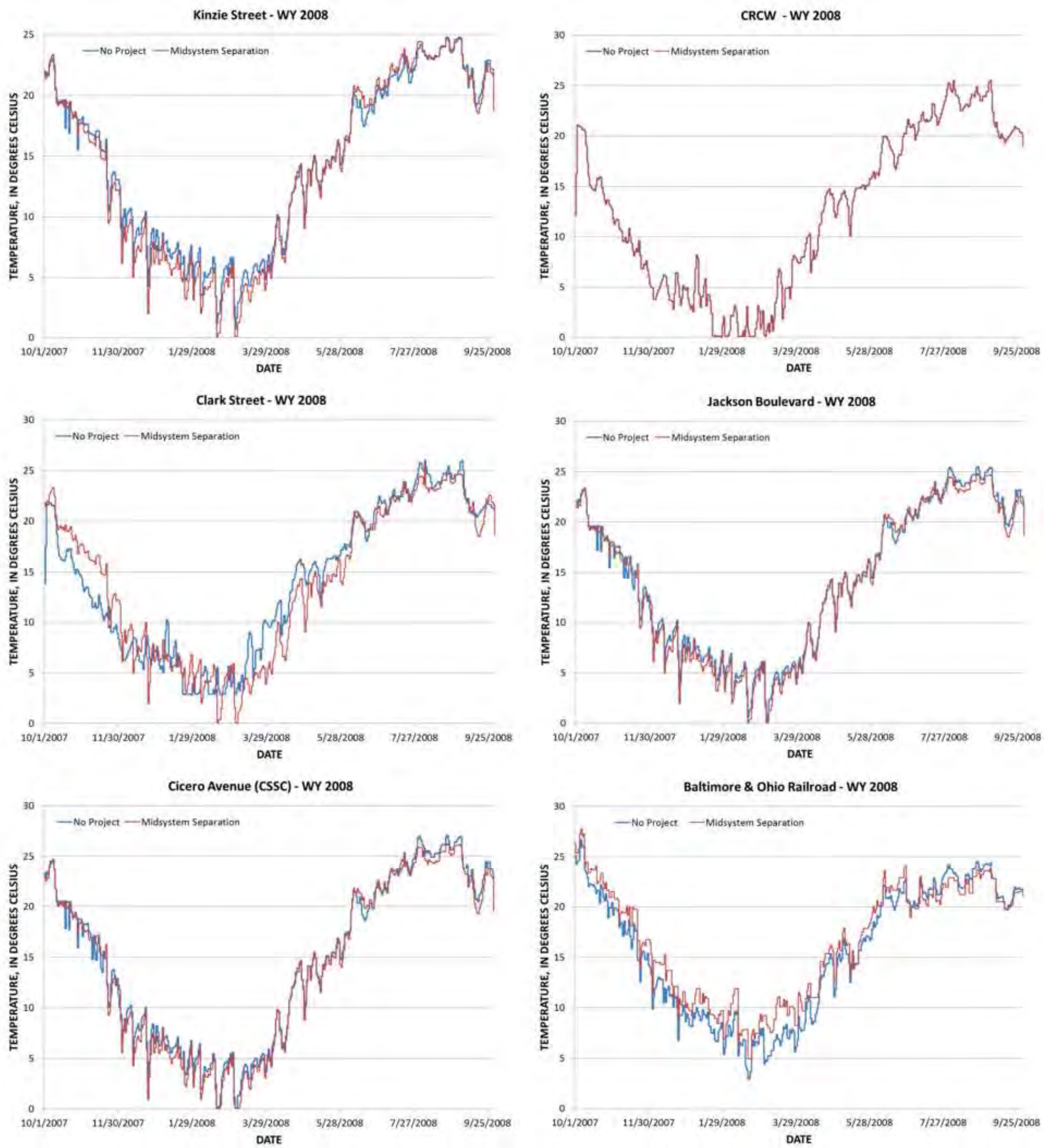


Figure K.17. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2008.

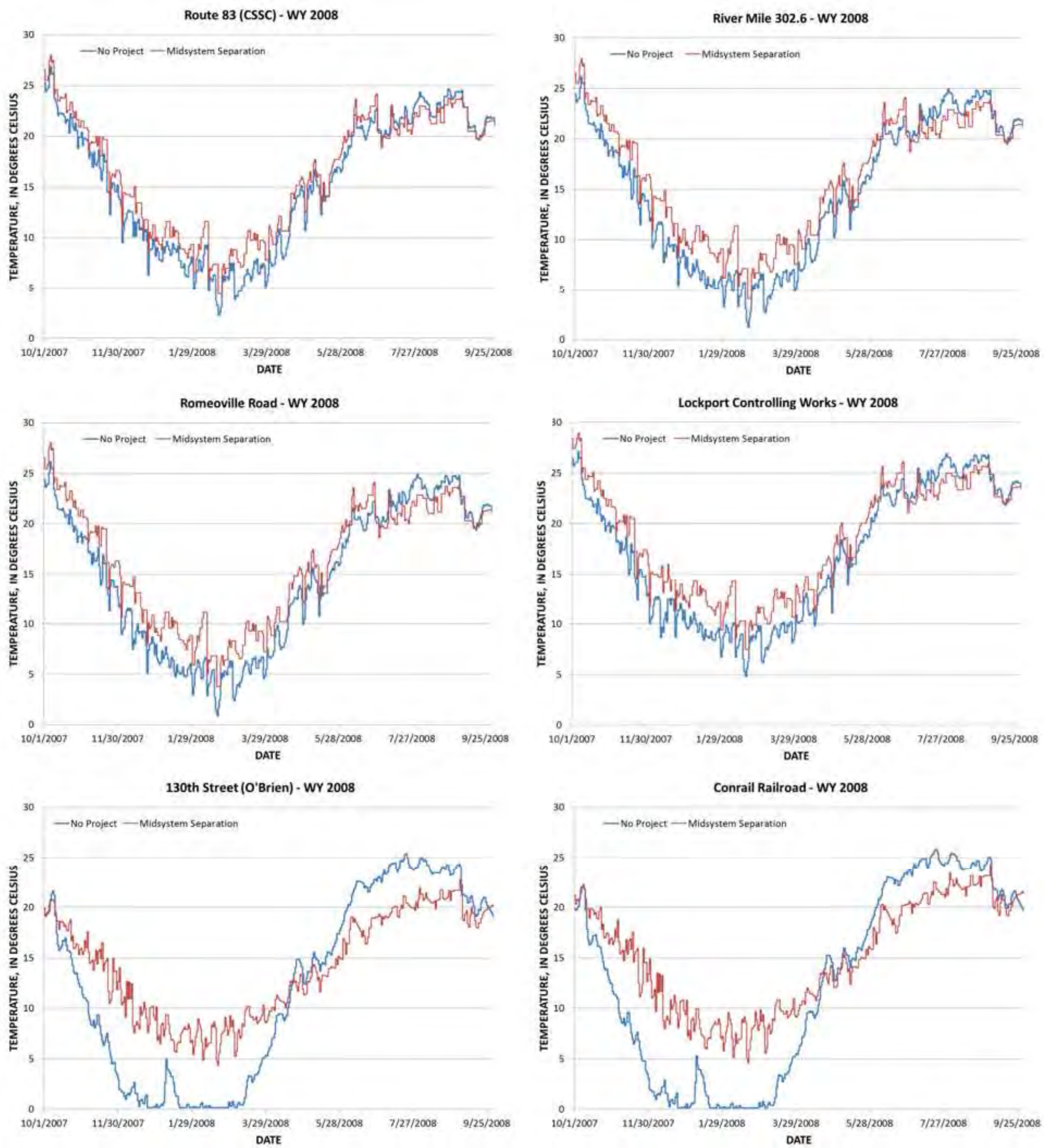


Figure K.17. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2008.

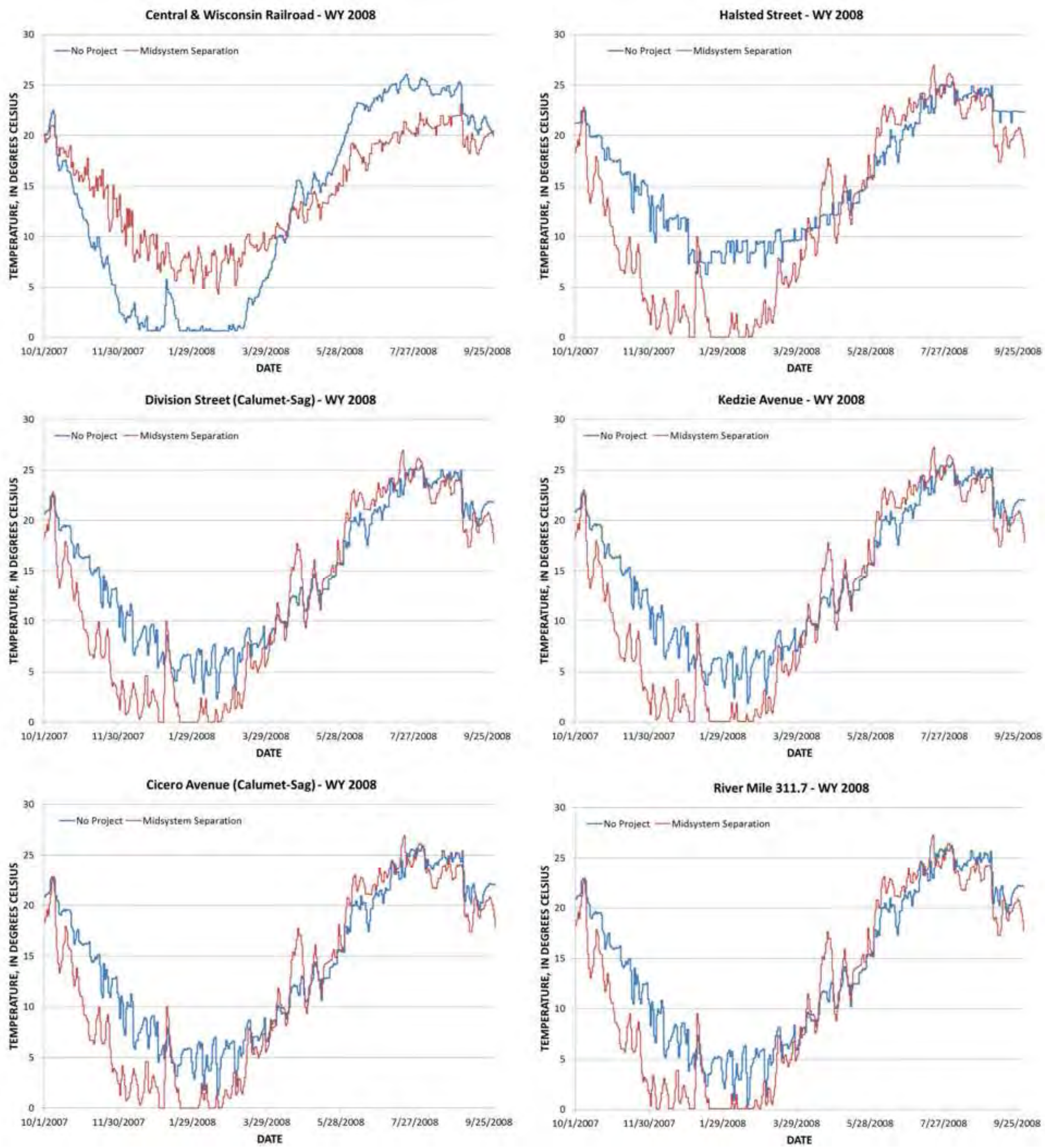
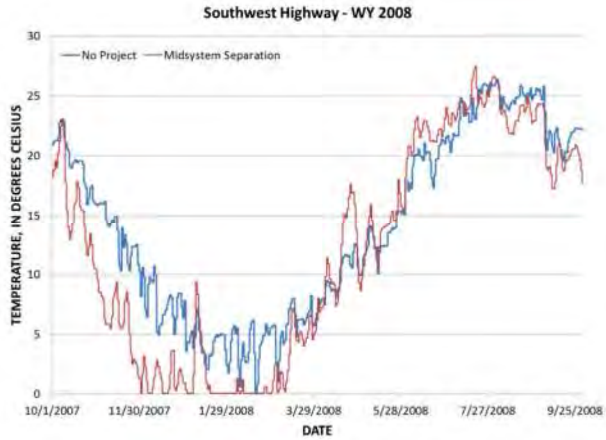


Figure K.17. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2008.



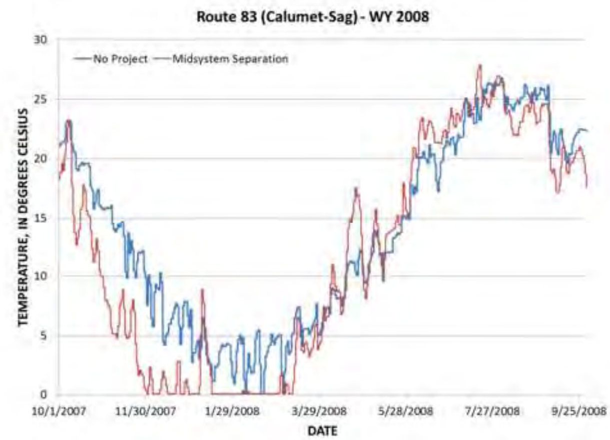


Figure K.17. (cont.) Comparison of Temperatures in the Chicago Area Waterways System for "No Project" and "Midsystem Separation" Alternatives for Baseline Conditions for Water Year 2008.

Addendum Section L: Measured Water-Surface Elevations for Lake Michigan for Water Years 2001, 2003, and 2008

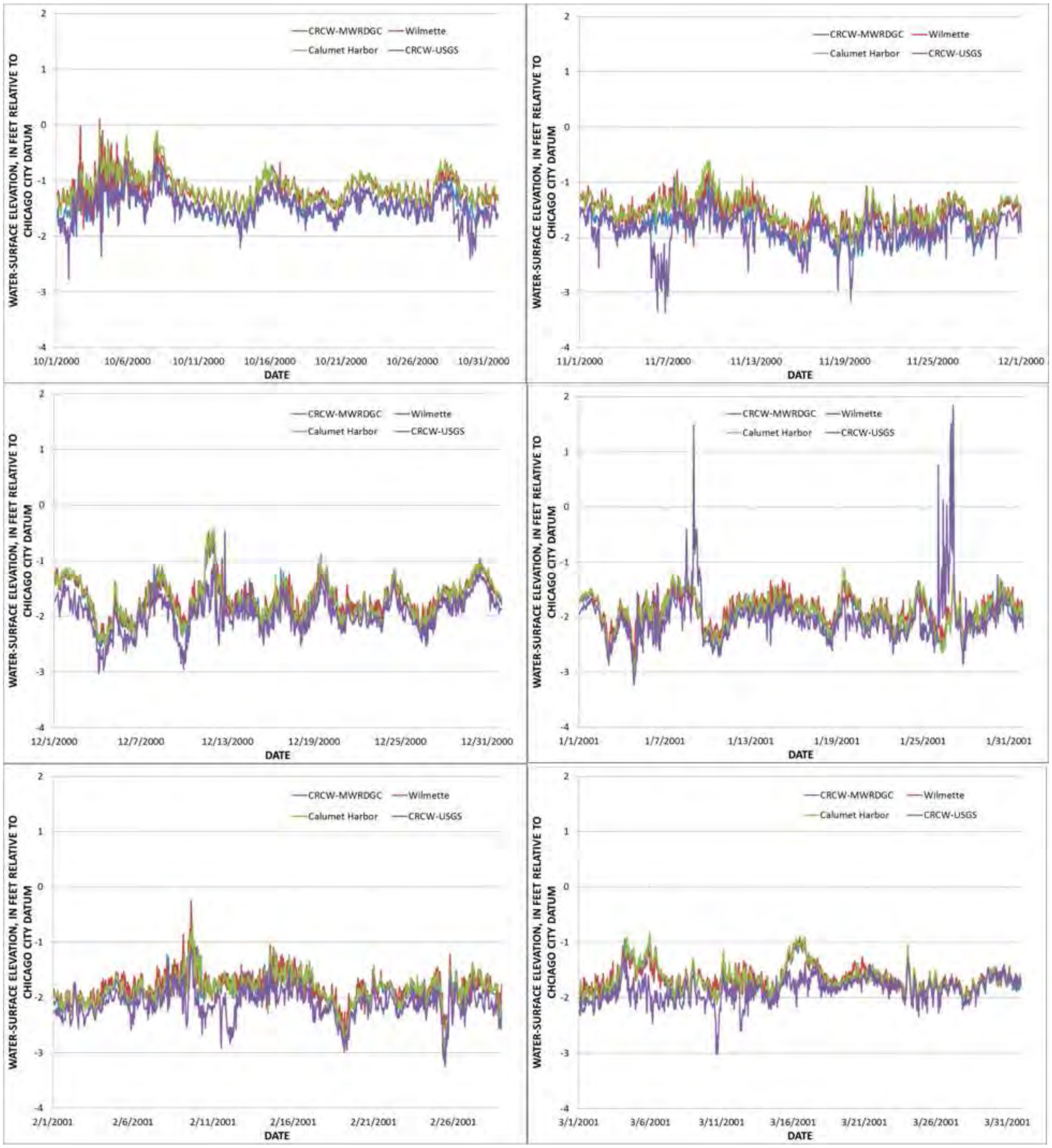


Figure L.1. Water-surface elevations for Lake Michigan measured by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) at the Wilmette Pumping Station and the Chicago River Controlling Works (CRCW), the National Oceanic and Atmospheric Administration at Calumet Harbor, and the U.S. Geological Survey (USGS) at CRCW for Water Year 2001.

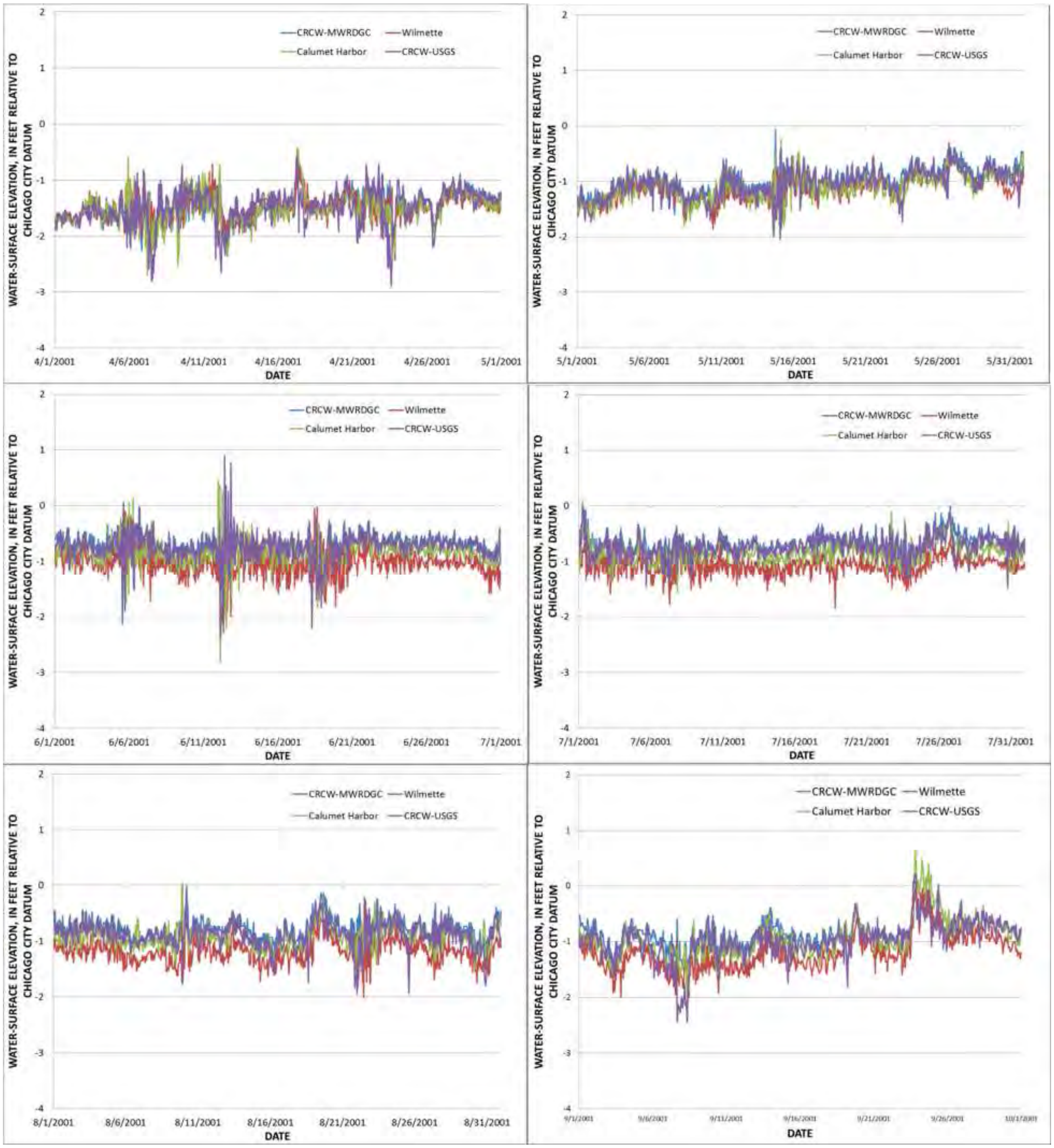


Figure L.1. (cont.) Water-surface elevations for Lake Michigan measured by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) at the Wilmette Pumping Station and the Chicago River Controlling Works (CRCW), the National Oceanic and Atmospheric Administration at Calumet Harbor, and the U.S. Geological Survey (USGS) at CRCW for Water Year 2001.

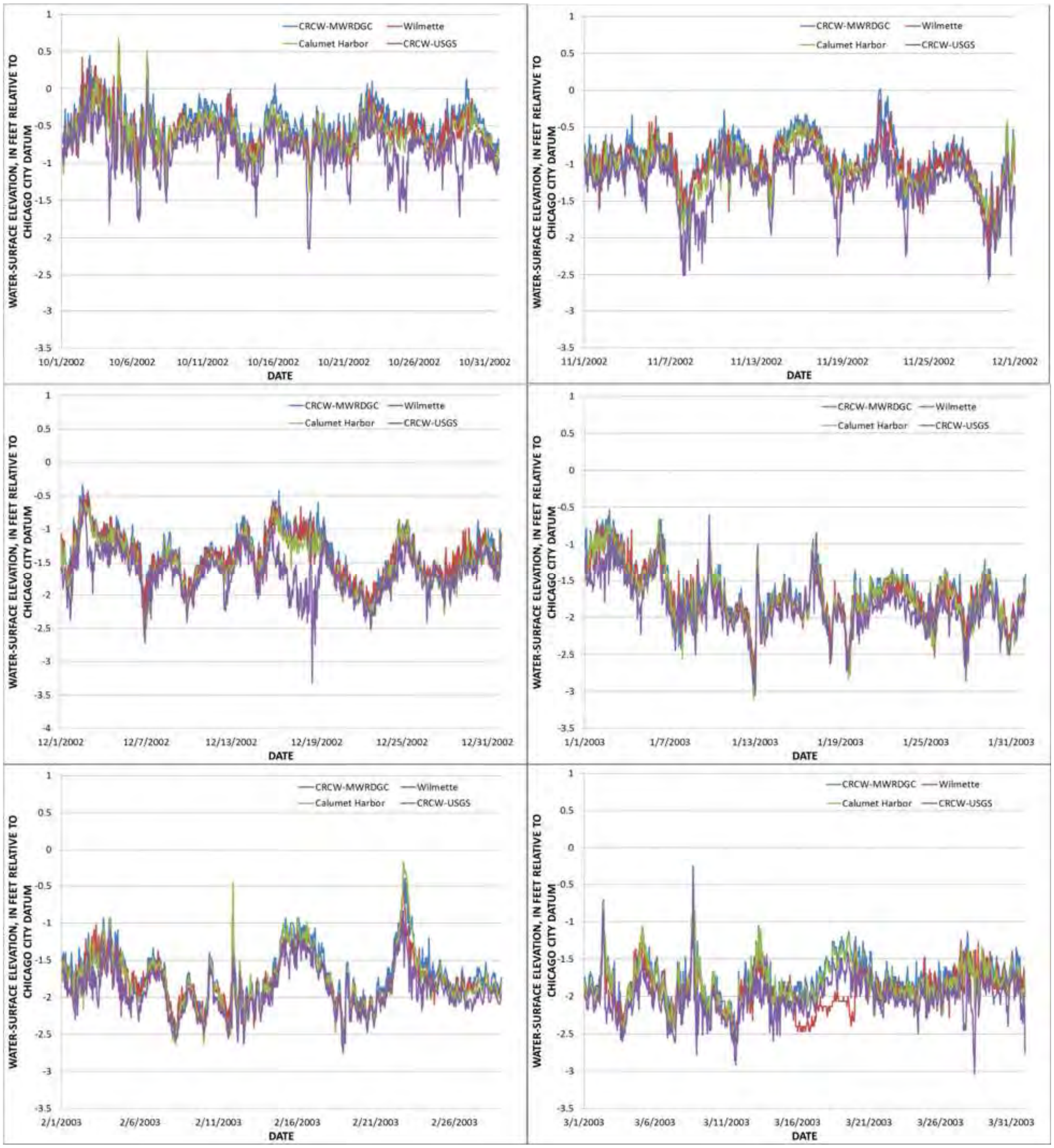


Figure L.2. Water-surface elevations for Lake Michigan measured by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) at the Wilmette Pumping Station and the Chicago River Controlling Works (CRCW), the National Oceanic and Atmospheric Administration at Calumet Harbor, and the U.S. Geological Survey (USGS) at CRCW for Water Year 2003.

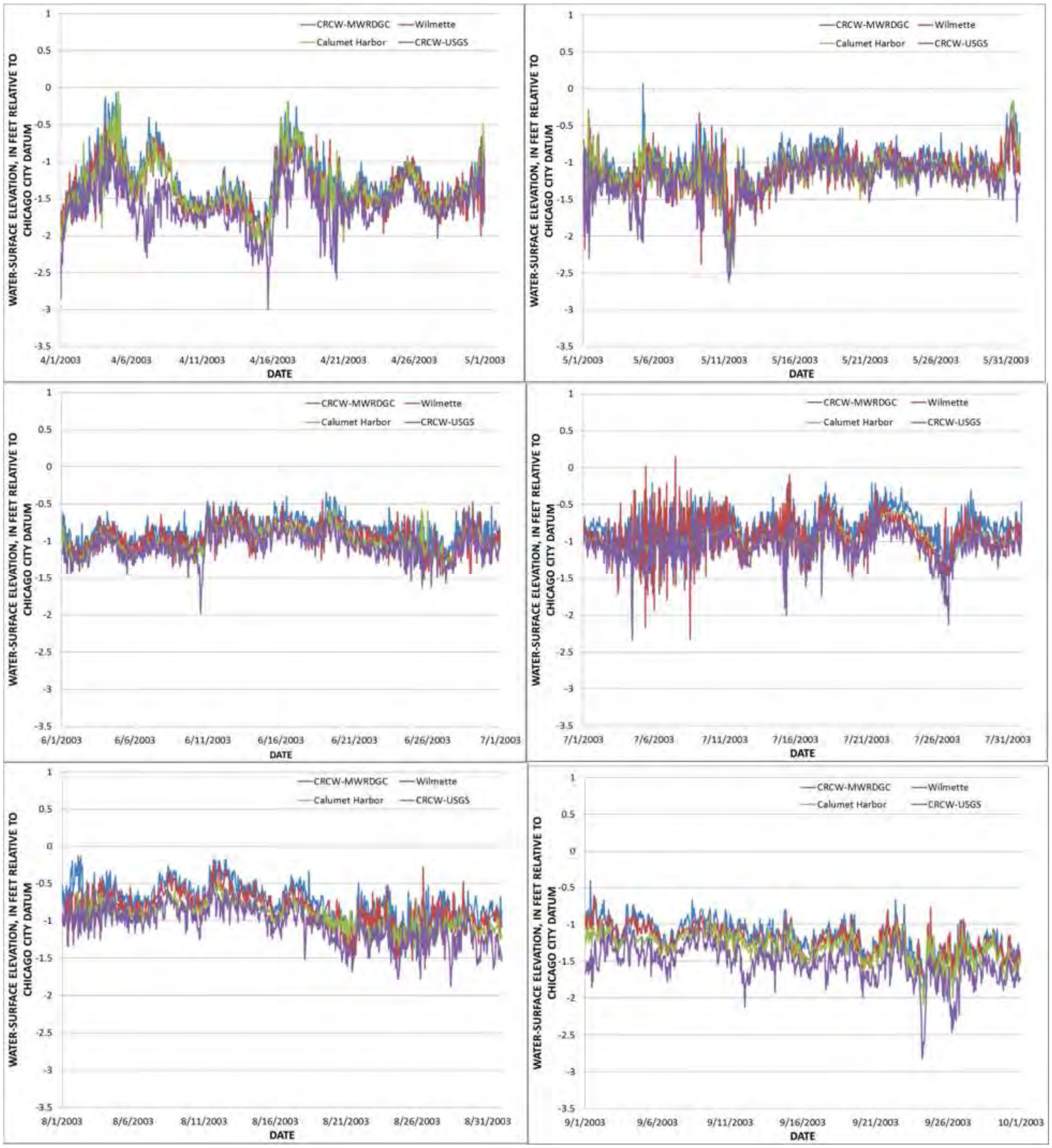


Figure L.2. (cont.) Water-surface elevations for Lake Michigan measured by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) at the Wilmette Pumping Station and the Chicago River Controlling Works (CRCW), the National Oceanic and Atmospheric Administration at Calumet Harbor, and the U.S. Geological Survey (USGS) at CRCW for Water Year 2003.

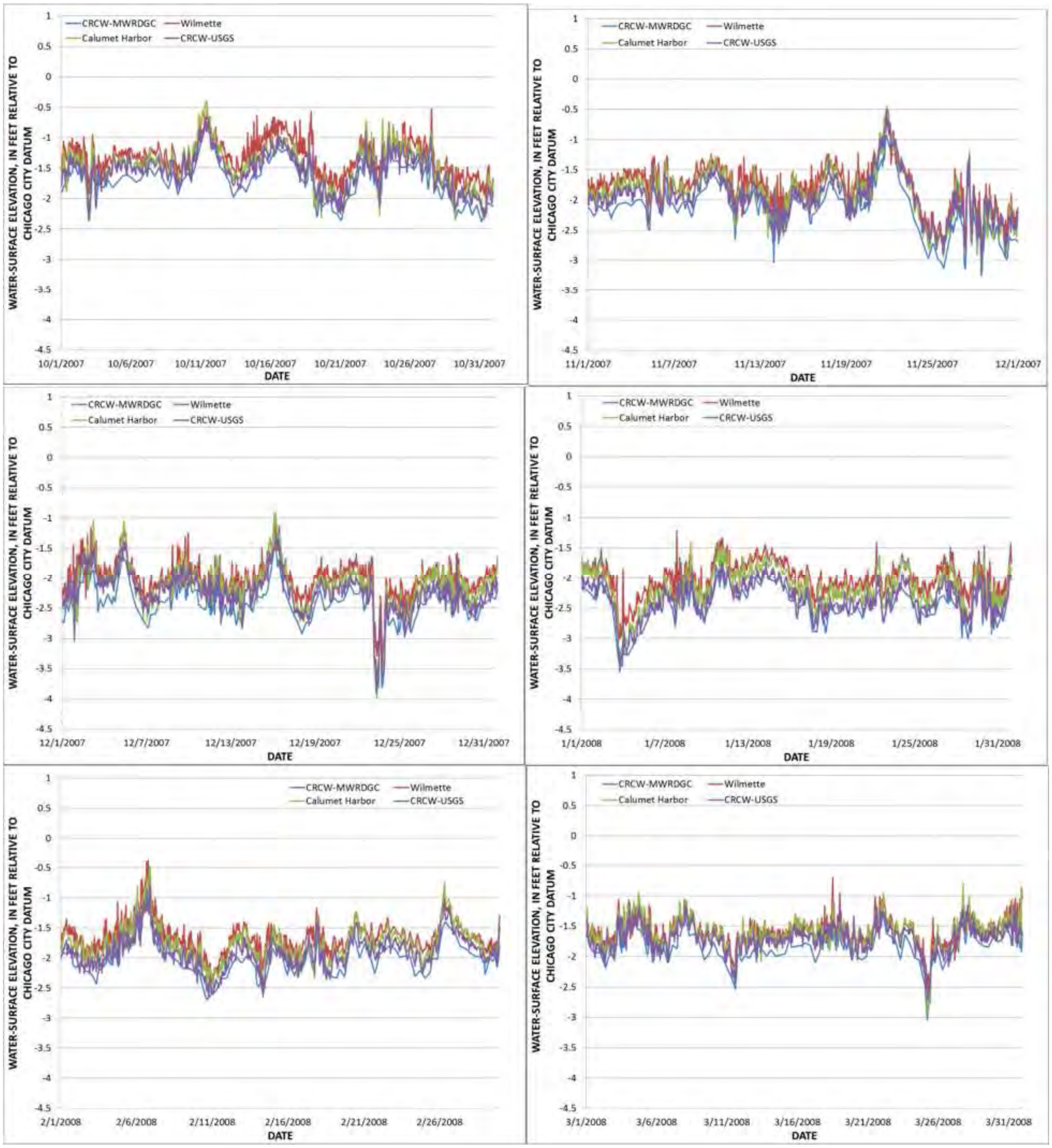


Figure L.3. Water-surface elevations for Lake Michigan measured by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) at the Wilmette Pumping Station and the Chicago River Controlling Works (CRCW), the National Oceanic and Atmospheric Administration at Calumet Harbor, and the U.S. Geological Survey (USGS) at CRCW for Water Year 2008.

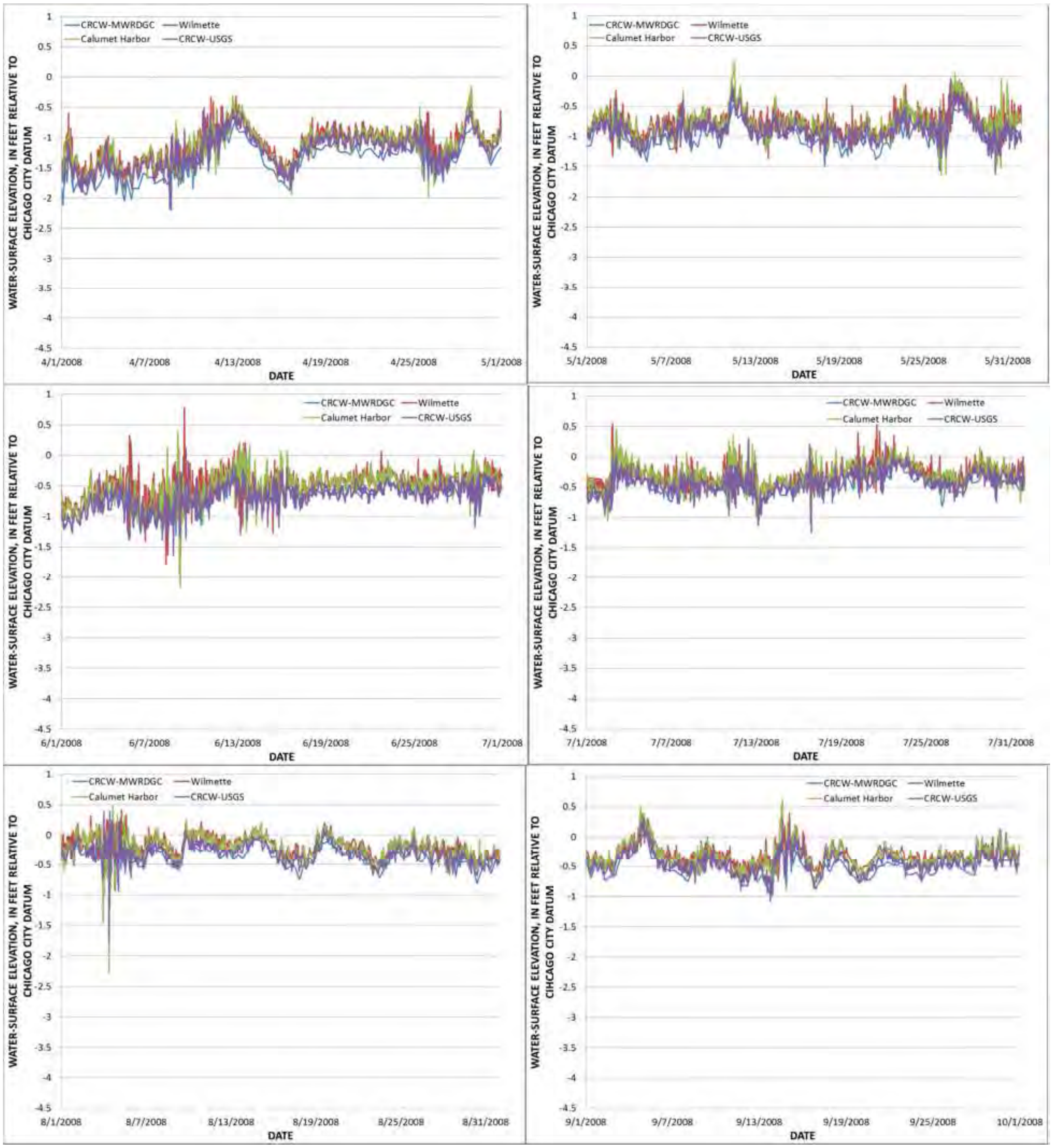
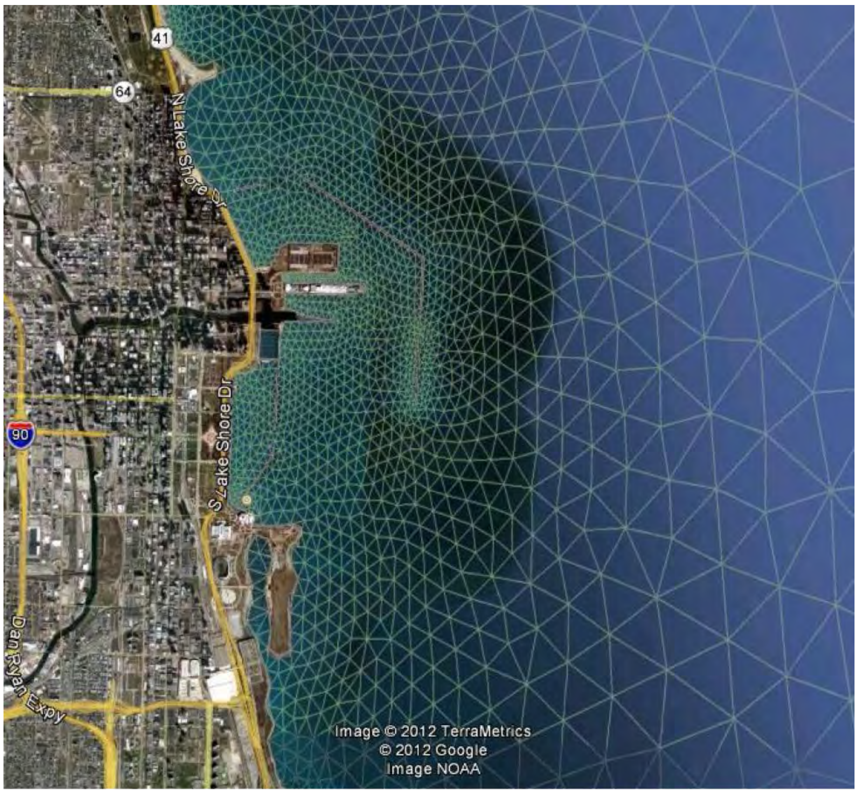


Figure L.3. (cont.) Water-surface elevations for Lake Michigan measured by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) at the Wilmette Pumping Station and the Chicago River Controlling Works (CRCW), the National Oceanic and Atmospheric Administration at Calumet Harbor, and the U.S. Geological Survey (USGS) at CRCW for Water Year 2008.

ATTACHMENT 2

MODELING THE EFFECTS OF HYDROLOGIC SEPARATION ON THE CHICAGO AREA WATERWAY SYSTEM ON WATER QUALITY IN LAKE MICHIGAN

Modeling the Effects of Hydrologic Separation on the Chicago Area Waterway System on Water Quality in Lake Michigan



Final Project Report

September, 2013

TECHNICAL REPORT

Modeling the Effects of Hydrologic Separation on the Chicago Area Waterway System on Water Quality in Lake Michigan

SUBMITTED TO

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Modeling the Effects of Hydrologic Separation on the Chicago Area Waterway System on Water Quality in Lake Michigan

Summary

In this project, we have used advanced hydrodynamic and water quality models to assess the impact of discharge from riverine sources on the nearshore water quality at locations in the southwest tip of Lake Michigan. The objectives of this project were to: 1) Simulate the coupled physical and biogeochemical processes that affect nearshore water quality off the Chicago lake-front; 2) Simulate baseline conditions and seasonal variation in the background concentrations of water quality variables lake-wide as well as in the nearshore region using a calibrated numerical model; 3) Determine the impact of removing river controls on the Chicago River and the Chicago Area Waterway System (CAWS) on nearshore water quality in Lake Michigan. The main riverine discharges (outfalls) considered in this study include the North Shore Channel, Chicago River, Calumet River, Indiana Harbor Canal, and Burns Ditch. The flow rate and concentration of water quality variables at the outfall locations were determined using a watershed model, DUFLOW, which simulated water quality conditions in the CAWS under a mid-system hydrologic separation scenario [GLMRIS Report, 2013].

Concentrations of nutrients, indicator bacteria and other water quality variables were simulated using a water quality model coupled to the FVCOM hydrodynamic model. The numerical models used an unstructured (triangular) grid with variable resolution in the nearshore

and offshore locations to resolve both small-scale and large-scale processes. In addition to simulating hydrodynamics (currents), the numerical models simulated ten water quality variables. The variables that were modeled explicitly by the water quality model were: 1) Dissolved oxygen, 2) Biochemical oxygen demand, 3) Phytoplankton, 4) Nitrate and Nitrite Nitrogen, 5) Ammonia Nitrogen, 6) Organic Nitrogen, 7) Organic Phosphorous, 8) Inorganic Phosphorous (or ortho-phosphate), 9) Fecal indicator bacteria (*E. coli*), and 10) Chloride.

We found that nutrient inputs from the outfalls that are part of the Chicago area waterway system can significantly increase the primary productivity (algal biomass) in the nearshore region. However, contaminant plumes are transported and dissipated quickly in the nearshore region by the predominantly along-shore currents and turbulent mixing with offshore waters. Simulations recreating the September, 2008 storm event indicated that concentrations of fecal indicator bacteria and ortho-phosphorous at water intakes could exceed candidate benchmarks during extreme weather events. However, the concentration of contaminants in the nearshore region reduced to background levels in about 7-10 days. As expected, the model predicted that the effect of discharge from the outfalls is more significant (in terms of persistence as well as peak values) at intakes that are closer to the major outfalls.

Table of Contents

Appendix A: Equations

Appendix B: Input

Appendix C: Statistics and water intake

Chapter 1: Introduction

1.1 Problem description

The Chicago Area Waterway System (CAWS) is composed of over 100 miles of rivers and canals which include the North Shore Channel, the North Branch of the Chicago River, the Chicago River, the South Branch of the Chicago River, the Chicago sanitary and Ship Canal, the Calumet River, the Little Calumet River, and the Grand Calumet River. The canals were constructed between 1900 and 1922 and they divert the flow away from Lake Michigan into River Mississippi. The principal purpose was to protect the drinking water supply by directing waste away from Lake Michigan and to provide a navigable waterway linking River Mississippi with the Great Lakes. However, this hydrologic link connecting the Mississippi river basin with the Great Lakes has significant ecological impacts in addition to economic benefits, as is being shown by the problem with transfer of aquatic invasive species.

Construction of hydrologic separation barriers on the Calumet-Sag Channel and the Chicago Sanitary and Ship Canal will result in the treated and untreated wastewater constantly discharging into Lake Michigan. The higher discharge from North Shore Channel, Chicago River and Calumet River into Lake Michigan is expected to increase the nutrient levels in the nearshore region of Lake Michigan. Higher nutrient inputs as a result of higher discharge from Chicago River could adversely affect the water quality at drinking water intakes for communities in the NE Illinois or NW Indiana. In this study, we have used numerical models tested against hydrodynamic and water quality data collected in the field to determine the impact that removing river controls on the Chicago River will have on water quality off the shore of the Chicago metro region.

Discharge from the CAWS enters Lake Michigan at several points. The Chicago Sanitary and Ship canal drain into the Chicago River and the North Shore Canal (Wilmette near Evanston), while the Calumet-Sag channel flows into the Calumet River. In this project, we have included the flow from the North Shore Channel, the Chicago River, the Calumet River, and the Indiana Harbor canal. In addition, we have also included the flow from the Burns Waterway (Burns Ditch) that is connected to the Little Calumet river system. The important river systems, their discharge points and the state boundaries are included in Figure 1.1 shown below.

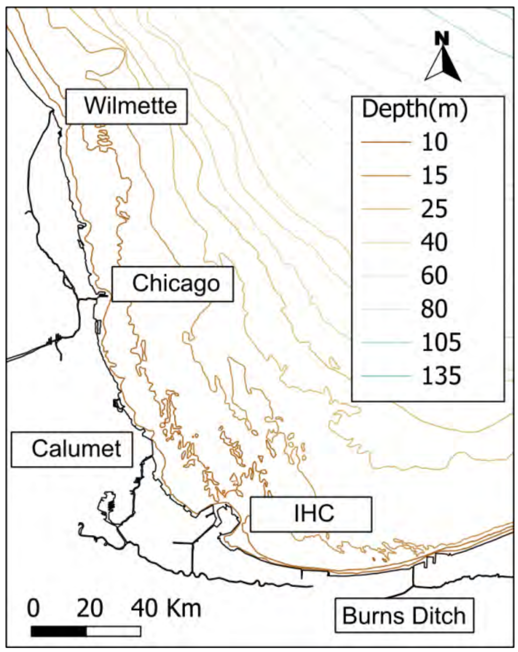

Figure 1.1 Map showing some of the major rivers and outfalls that discharge into the southern part of Lake Michigan (IHC: Indiana Harbor Canal).

Although numerous studies have examined the impact of river system redirection and its impacts on water quality in the canals and channels of the CAWS [*Melching*, 2006; *Shreshta and Melching*, 2003], this is the first study of its kind in that it examined the impact of high effluent discharge rates from the CAWS discharge points on water quality off shore of Chicago and nearby areas. The objectives of this study were to:

1. Simulate the coupled physical - biogeochemical processes that affect nearshore water quality off the Chicago lake-front.

2. Simulate baseline conditions and seasonal variations in the background concentrations of water quality variables lake-wide as well as in the nearshore region by using calibrated numerical models.

3. Evaluate the impact on nearshore water quality if the lakefront controlling works, including Wilmette Pumping Station, Chicago River Controlling Works, and the O'Brien Lock and Dam were removed and new physical barriers were constructed on the CSSC and Cal-Sag Channel to separate the Great Lakes and the Mississippi River basins.

1.2 Scope of the project

Biogeochemical processes that affect the concentrations of water quality parameters in the nearshore region of a large freshwater lake such as Lake Michigan are highly complex and involve processes occurring at multiple time and space scales. Several studies of varying complexity have attempted to study this problem in the past [*Chen et al.*, 2002, *Ji et al.*, 2002, *Luo et al.* 2012]. In this study, the principal focus was on the impact of discharge from the river outfalls on water quality in the nearshore region of Lake Michigan in NE Illinois and NW Indiana. Therefore, processes that impact the long-term variability in the water quality are beyond the scope of this study.

Some of the major assumptions/limitations that are implicit in the modeling exercise are listed below:

a. The principal sources of pollution are storm runoff and sanitary flows from watersheds that contribute to the canals and channels that form the Chicago Area Waterway System.

b. Sediment resuspension as a result of storm-generated waves is not included in the numerical model.

c. Non-point sources such as distributed sources along the beach and ground water seepage are also not considered in the model.

In addition, several simplifications to the complex interactions between different water quality variables are made and have been discussed in greater detail in the chapter describing the numerical water-quality model used in the study.

1.3 Structure of the report

The report has been divided into five chapters. The problem description, objectives and the scope of the project are covered in Chapter 1: Introduction. Chapter 2 introduces the numerical models and provides a detail description of the assumptions and simplifications made in order to arrive at the equations solved by the models. The numerical models are tested against hydrodynamic and water quality data collected during a field study conducted in August 2012. Chapter 3 presents results from these validation tests. Using results from the watershed model [*Melching*, 2006], the nearshore water quality model was used to simulate several scenarios that will be used to assess the impact of discharges from the CAWS on the nearshore region. The results from these simulations will be presented and analyzed in Chapter 4. Chapter 5 presents the concluding remarks.

Chapter 2: Materials and Methods

In this chapter, we present the details of the hydrodynamic and water quality models used in the present study and the methods used to test water samples, collected as part of a field study. The observed data are used to calibrate the numerical hydrodynamic and water quality models. The Finite-Volume Coastal Ocean Model (FVCOM, [*Chen et al.*, 2003]) formed the basis for the present modeling work. All the governing equations solved by the numerical models and the symbols are explained in Appendix-A. The hydrodynamic model was tested using observed current data measured using Acoustic Doppler Current Profilers (ADCPs) deployed in the nearshore region of Lake Michigan near Chicago. The water quality models were tested against observed concentrations for dissolved oxygen, chloride, nutrients, phytoplankton and temperature.

2.1 Computational mesh

The hydrodynamic and water quality equations are solved by the numerical model on the unstructured grid shown in Figure 2.1. The mesh is composed of 12,825 nodes and 23,757 triangular elements. In the vertical direction, the FVCOM model uses the terrain-following sigma-coordinate. Twenty-one sigma-levels were used to map the bathymetry in the lake and to resolve topographical features accurately. The principal sources of pollution and discharge for the Chicago area waterway system are Wilmette, Chicago River Controlling Works (CRCW), Calumet, IHC (Indiana Harbor Canal) and Burns Ditch. The locations of these outfalls are shown in Figure 2.2.

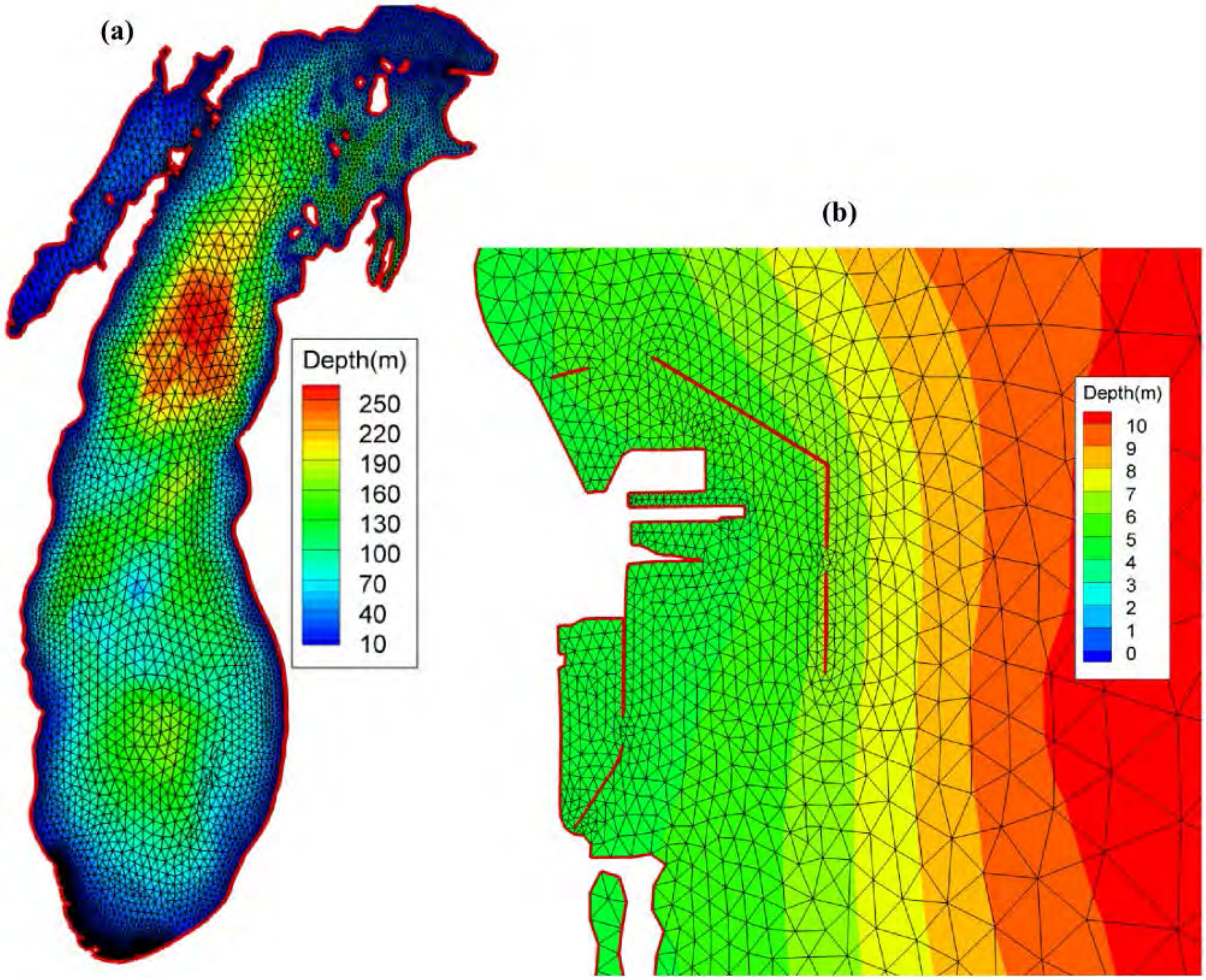

Figure 2.1 (a) The unstructured computational mesh used to resolve lake-wide circulation, (b) coastal features as described by the computational mesh near the Chicago River mouth.

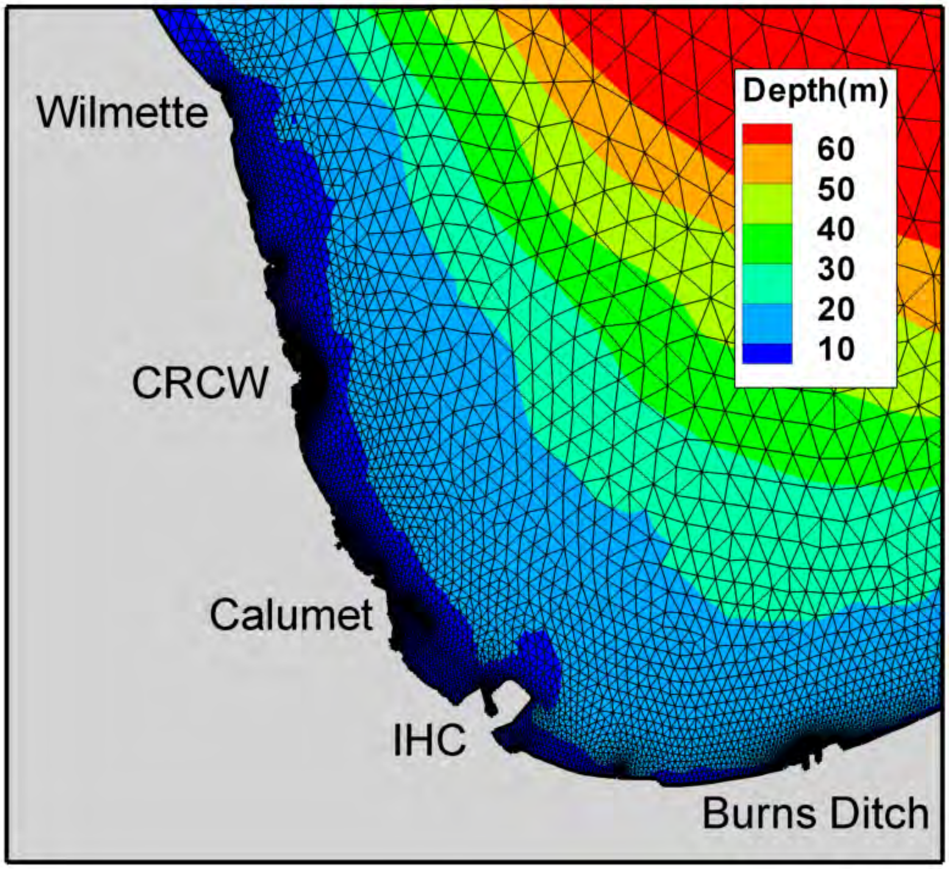

Figure 2.2 Outfalls included in the numerical model (IHC: Indiana Harbor Canal)

2.2 Field Study

A field study was conducted during the summer of 2012 to support the model testing and calibration analyses for this study. Three Acoustic Doppler Current Profilers (ADCPs) are deployed in southern Lake Michigan near Chicago. The first instrument (BBADCP in Table 2.2) is a 600 kHz Teledyne RD Instruments ADCP deployed near Chicago in approximately 20 m of water, the second instrument is a Teledyne 1000 kHz Sentinel-V ADCP and the third one is a Sontek ADCP deployed near Burns Ditch in approximately 5m of water. The laboratory methods of analysis for different water quality variables are described below. All samples were analyzed at the USGS Great Lakes Science Center (Porter, IN) and by Dr. Julie Peller, Indiana University. The approximate sampling and ADCP deployment locations are shown in Figure 2.3.

The ADCP and water sampling locations shown in Figure 2.3 are located near the southern tip of Lake Michigan and off the Chicago shoreline. Three ADCPs were deployed at location M, location S, and location V (Figure 2.3). Multiple water samples were collected in the nearshore region at multiple depths as detailed in Tables 2.1 and 2.2 and tested for Chloride, Nitrate, Sulphate, Phosphorous, Ammonia, Dissolved oxygen, Carbonaceous Biochemical Oxygen Demand (CBOD), and *E. coli* (indicator of fecal contamination in recreational waters).

2.2.1 Model testing and calibration

The numerical water quality model was tested and calibrated using data collected at the Burns Ditch outfall which is located in southern Lake Michigan. The outfall was chosen as the site for the field study due to its similarity (size and location) with the other outfalls of interest in this study (Wilmette, CRCW, Calumet, IHC). The data collected at the Burns Ditch outfall were used to provide model inputs and to test the hydrodynamic and water quality models. Background concentrations of water quality variables were estimated using samples collected at WQ2 which is in the far field of the Burns Ditch plume. It was assumed that discharge from the Burns Ditch waterway would have the greatest impact on the concentration of water quality variables at the near-field location WQ1. The comparisons at location WQ1 were used to estimate the error in model predictions and explore the parameter space for the water quality model. The final set of parameters used in the water quality model chosen provided a good estimate for all the water quality variables studied. Table 1 in Appendix A provides the parameters that were used to simulate the water quality processes. Model calibration did not include data at other water intake locations (eg. Jardine) as relevant source concentration at nearby point (riverine) and non-point sources were not adequately defined for model testing purposes.

Table 2.1 Approximate depth at which water samples were collected at locations WQ1, WQ2

Location	Surface	Mid	Bottom
Depth (ft)	2	7	13

Table 2.2 GPS location of sampling points and ADCP deployment

Name	ID	Latitude	Longitude	Apprx. depth(m)
Burns Ditch (WQ)	BD	N 41.622046	W 87.176442	NA
Plume Sampling Point (WQ)	WQ1	N 41.633164	W 87.183936	5 m
Lake Sampling Point (WQ)	WQ2	N 41.631769	W 87.193308	5 m
BBADCP (ADCP)	B	N 41.886779	W 87.542828	20m
V-ADCP (ADCP)	V	N 41.674955	W 87.196890	20 m
Sontek (ADCP)	S	N 41.631750	W 87.193308	4 m
Sentinel (ADCP, 2008)	S08	N 41.63813	W 87.18539	10 m
Monitor (ADCP,2008)	M08	N 41.71059	W 87.20996	20m
BBADCP(ADCP,2008)	B08	N 41.69717	W 87.10078	18m
NDBC Stn.	45002	N 45.3333	W 86.4297	175 m
NDBC Stn.	45007	N 42.6736	W 87.0261	160 m

TC and TOC:

Total dissolved carbon (TC) and total dissolved organic carbon (TOC) were measured using a Shimadzu Total Organic Carbon Analyzer, model TOC-5050, equipped with an ASI-550A autosampler. For the determination of dissolved organic carbon, the inorganic carbon was removed from the solution by acidification with phosphoric acid and nitrogen gas purging of the carbon dioxide that formed. The reported values were averages of 3 replicates.

Anions:

Ion analyses were performed using a Waters HPLC system, equipped with a conductivity detector. For anion separations, the IC-Pak™ Anion column was used. The mobile phase, prepared from concentrated sodium borate gluconate, was diluted with water and mixed with *n*-butanol and acetonitrile, as specified by the Waters care and use manual. A stock solution, consisting of fluoride (1 ppm), chloride (2 ppm), nitrite (4 ppm), bromide (4 ppm), nitrate (4 ppm), phosphate (6 ppm) and sulfate (4 ppm), was prepared and run prior to all the sample analyses.

Ammonia measurements (NH_3), using an ammonium ion probe:

Samples were measured either 1) within a few hours after collection, or 2) within a few days after collection (stored in the refrigerator). Water samples were treated with sodium hydroxide to raise the pH and convert the ammonium ion to ammonia gas. The probe was added to the treated water and parafilm was used to seal the container while the probe measured the ammonia gas.

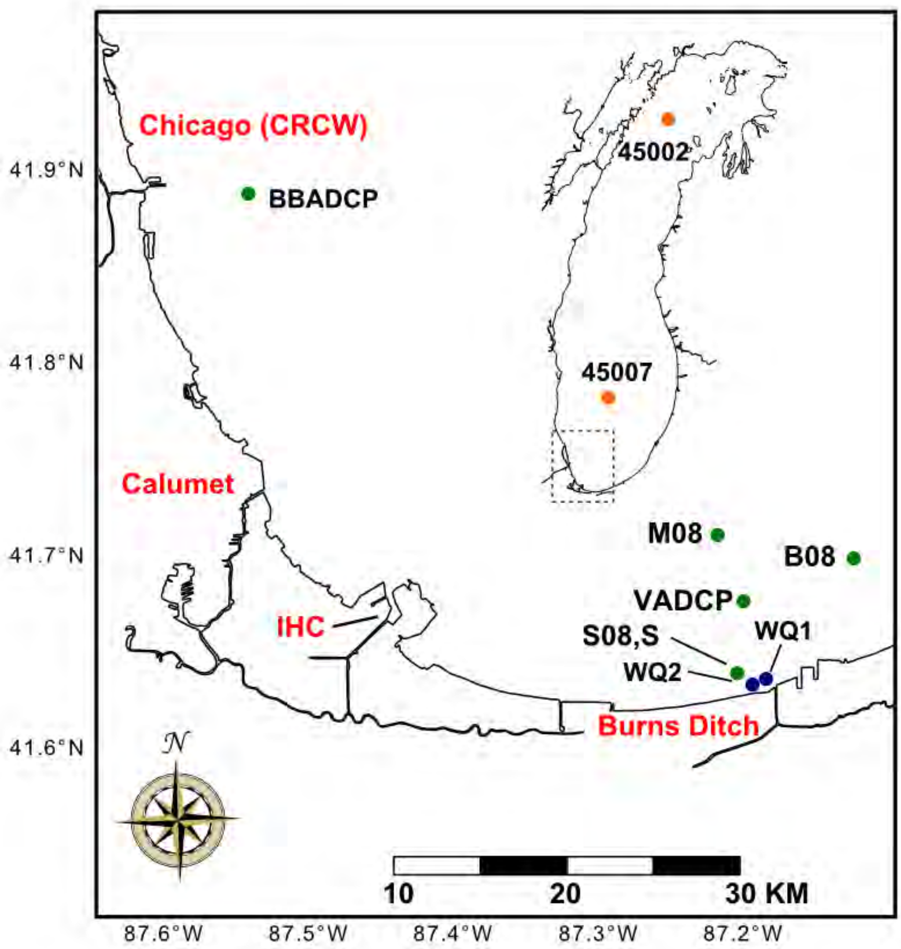

Figure 2.3 Geographical sketch showing approximate locations of sampling (WQ1 & WQ2) and ADCP deployment locations.

Chlorophyll *a*

The frozen filters were sonicated in 4 mL of 90% acetone and fine filtered in the dark. All of these solutions were run with an HPLC (High-performance liquid chromatography) method that separates the pigments, where the chlorophyll *a* elutes just before 7 minutes. Standards of chlorophyll *a* were prepared and run to quantify all the samples.

BOD analysis (5-day)

Samples were processed upon arrival to the laboratory. All samples were analyzed unseeded, lake samples were analyzed undiluted, and Burns Ditch water was analyzed undiluted and with a 2-fold dilution; distilled water (20^{o}C) was used for Burns Ditch dilution and the control. Samples and control (~325-mL) were poured into clean beakers, a crystal of Na_2SO_3 was added to each beaker, and each sample was aerated for 15 min with aeration stones connected to fish tank pumps and then allowed to rest for 30 min. After 30 min, samples were poured into 300 mL BOD bottles and analyzed for initial DO with a Pro BOD instrument (YSI incorporated, Yellow Springs, OH); care was taken to rinse the electrode between each sample. The bottles were then fitted tightly with a stopper, water sealed, and incubated at 20^{o}C in the dark for five days. After five days of incubation, the final DO of each sample was measured.

In situ analysis of DO

Dissolved oxygen for Burns Ditch was obtained from a U.S. Geological Survey gaging station (04095090) located on Burns Ditch waterway in Portage, IN (41°37'20", 87°10'33"). Dissolved oxygen for the lake samples was obtained employing a field dissolved oxygen meter (YSI incorporated, Yellow Springs, OH).

2.3 Scenarios simulated

The calibrated models were used to simulate different scenarios that are representative of current (baseline) and expected future watershed loading. The scenarios have been described in greater detail in Section 3.4. The loading from sanitary and channel discharge entering Lake Michigan in NE Indiana and NW Illinois are calculated using the DUFLOW watershed model. In all, the watershed model provided concentrations of: 1) Dissolved oxygen, 2) Biochemical Oxygen Demand (BOD), 3) Ammonia, 4) Nitrate, 5) Organic Nitrogen, 6) Inorganic Phosphorous, 7) Organic Phosphorous, 8) Fecal Coliform, and 9) Chloride. Phytoplankton concentrations were not available from the watershed model and therefore constant input concentrations of 1 mg/L were assumed at the outfalls included in the model. The concentration of fecal indicator bacteria was converted from fecal coliform to *E. coli* by assuming a 1:1 relationship [*Cude*, 2005; *Zmuda, et al.*, 2004]. The time series of the data used in the model are presented in Appendix B (Input series). The simulations were stopped and restarted during the winter months when ice-cover affects the hydrodynamics significantly. Since the hydrodynamic model did not model ice dynamics, the numerical models were stopped in October and restarted in February based on results from the simulation modeling the baseline scenario.

Chapter 3: Results

In this chapter the observations from the field study are presented along with results from the water quality and hydrodynamic numerical models. We first present the observed concentrations for the water quality variables followed by comparisons between observed and simulated results for various scenarios described in Chapter 2.Analysis and discussion of the results are presented in Chapter 4.

3.1 Observations

The observed concentrations of different water quality variables at the different water sampling locations i.e., Burns Ditch, Lake (WQ1), and Plume (WQ2) are shown in Figures 3.1 – 3.10. All concentrations are provided in mg/L which is equivalent to g/m^3.

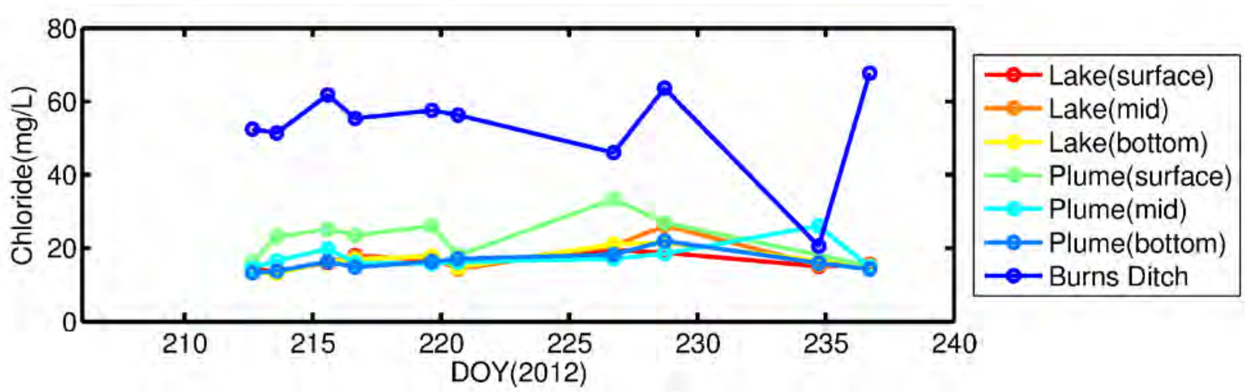

Figure 3.1 Concentration of chloride ion at water sampling locations

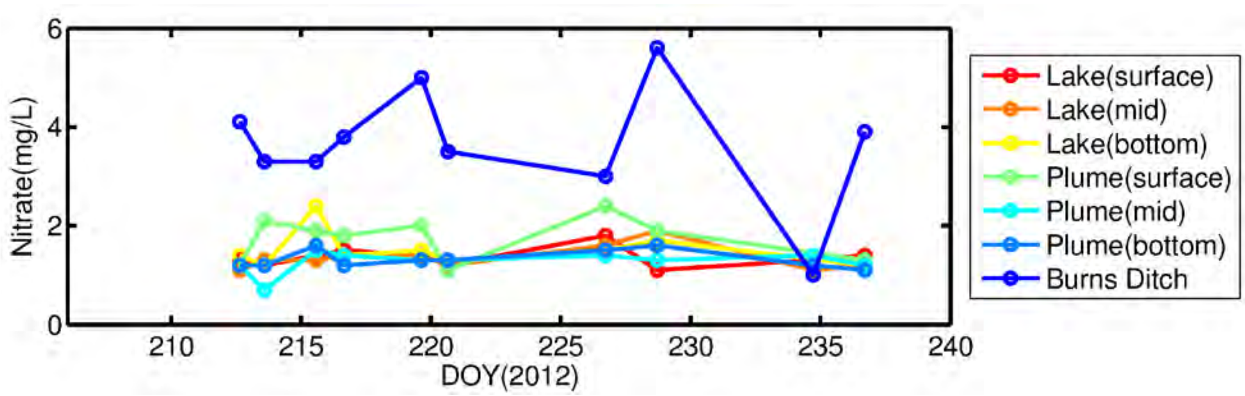

Figure 3.2 Concentration of nitrate ion at water sampling locations

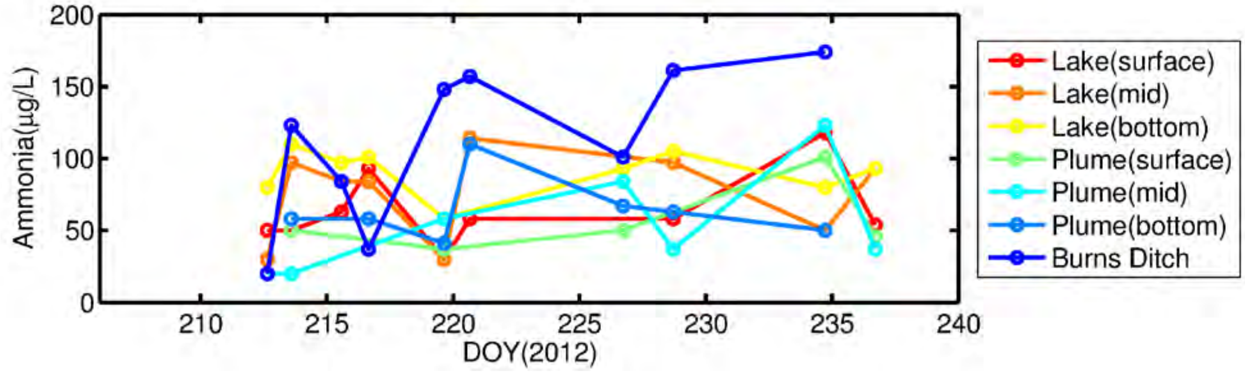

Figure 3. 3 Concentration of ammonia ion at water sampling locations

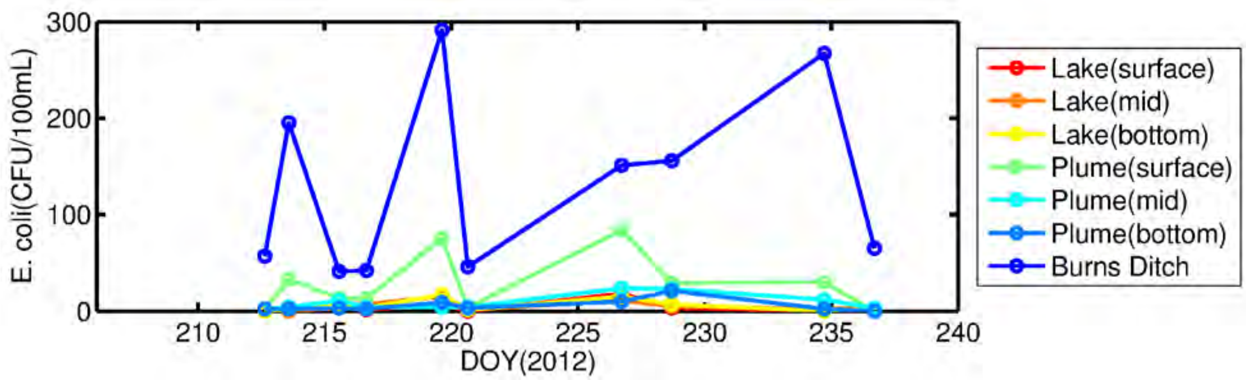

Figure 3. 4 Concentration of E. coli at water sampling locations

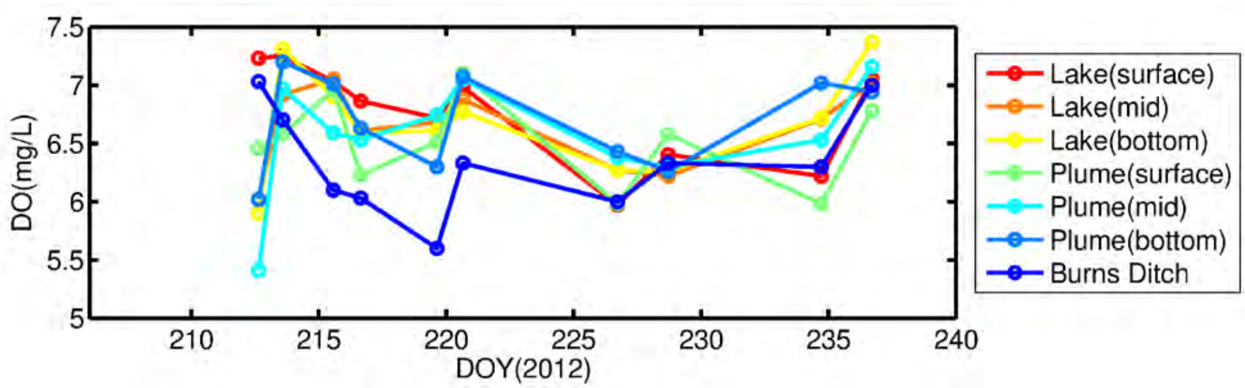

Figure 3. 5 Concentration of dissolved oxygen at water sampling locations

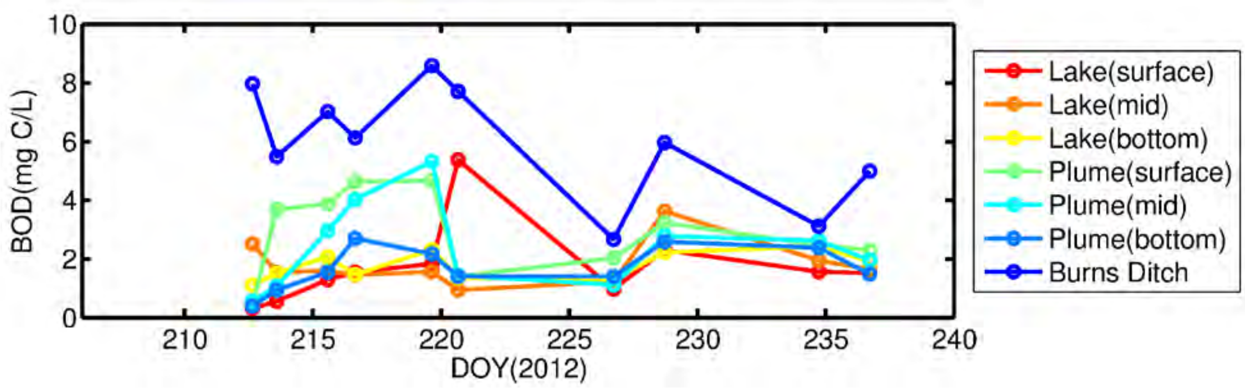

Figure 3. 6 Concentration of biological oxygen demand at water sampling locations

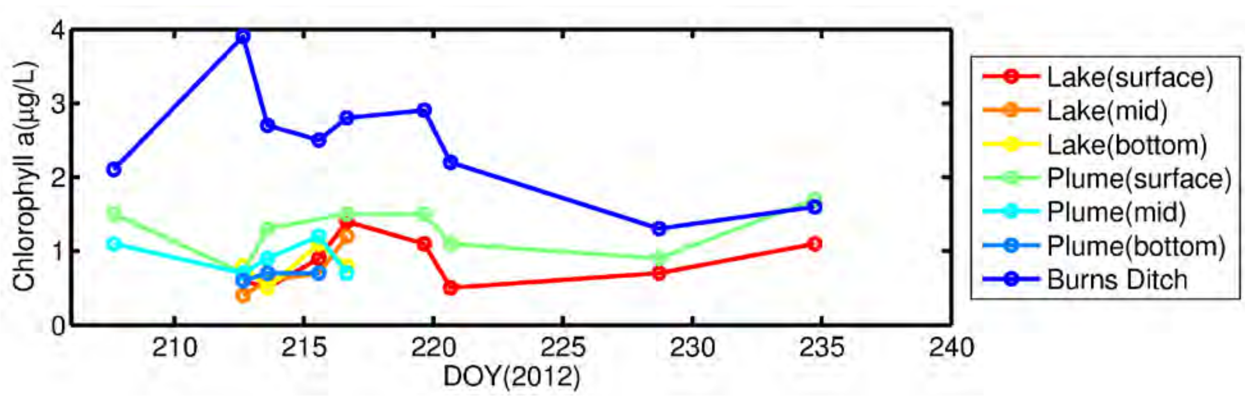

Figure 3. 7 Concentration of phytoplankton (chlorophyll a) at water sampling locations

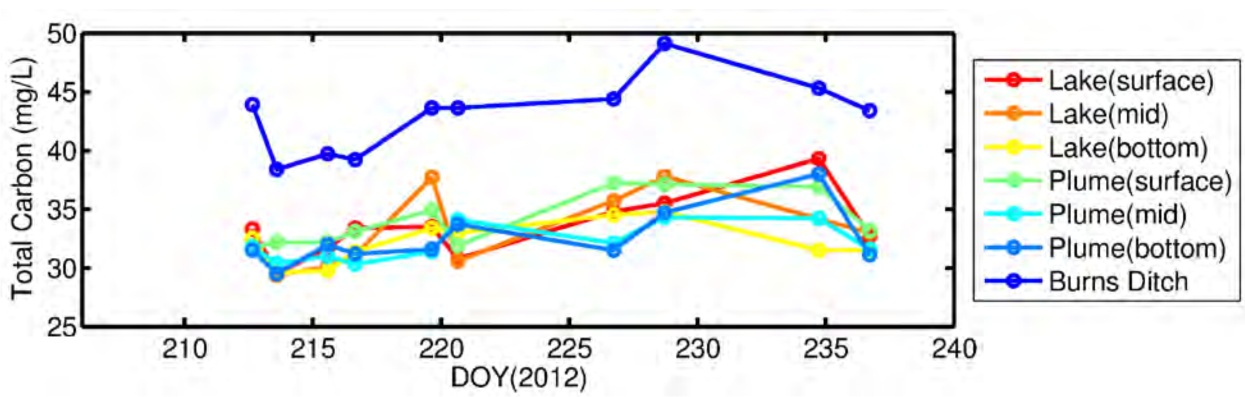

Figure 3. 8 Concentration of total carbon at water sampling locations

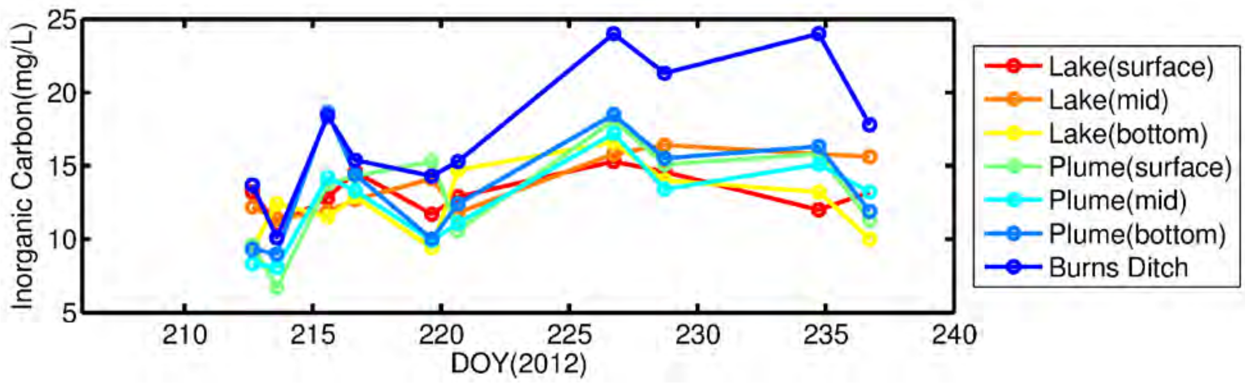

Figure 3. 9 Concentration of total inorganic carbon at water sampling locations

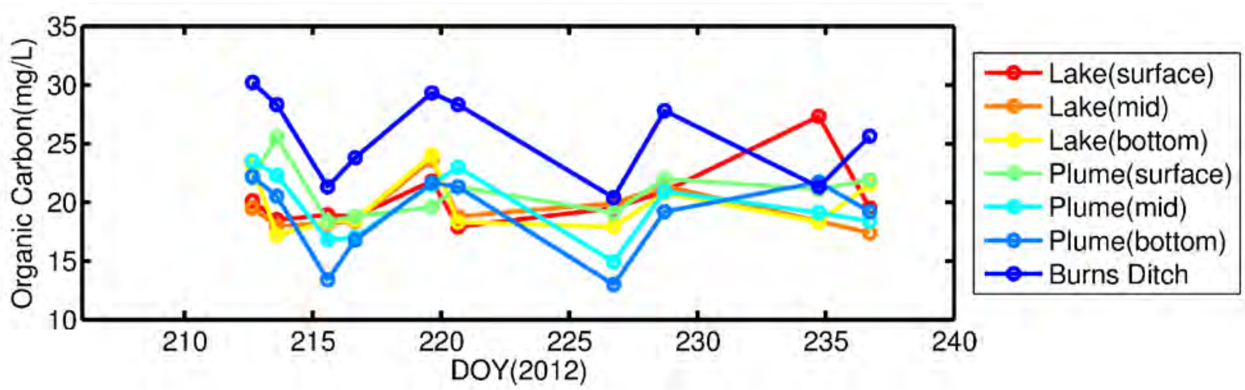

Figure 3. 10 Concentration of total organic carbon at water sampling locations

3.2 Hydrodynamic Model results

The hydrodynamic model was tested against the temperature observations from NDBC buoys moored at offshore locations in southern (#45007) and northern (#45002) Lake Michigan. Vertically-integrated velocity results from the numerical model were compared against similar ADCP observations in southern Lake Michigan collected during the 2012 field study (Figure 2.3) at locations S and B. In addition to the hydrodynamic data collected in 2012, data from an earlier study (Thupaki et al., 2010; Thupaki et al., 2013a) collected in 2008 were also compared with model results.

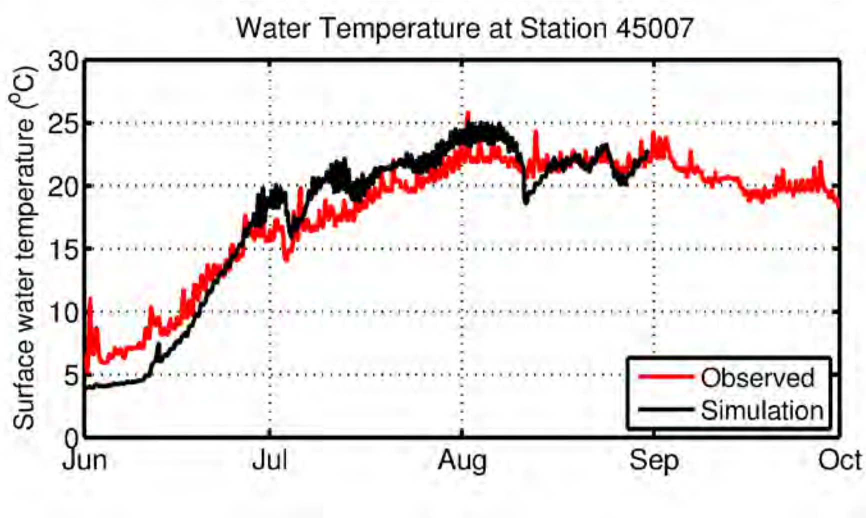

Figure 3.11 Comparison between observed surface water temperature at NDBC buoy 45007 and model results

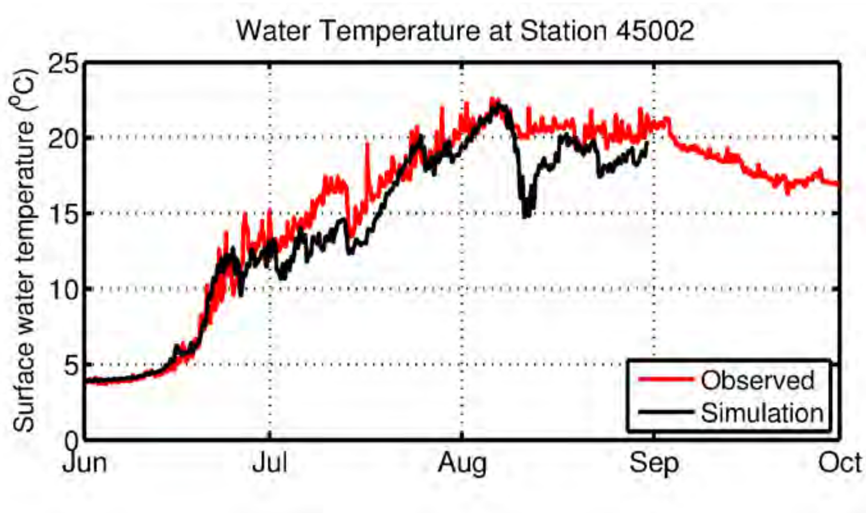

Figure 3.12 Comparison between observed surface water temperature at NDBC buoy 45002 and model results

The comparisons presented in Figures 3.11 and 3.12 show that the model is able to simulate the gradual warming of the water column during the summer months. However, some of the smaller perturbations in the surface water temperature at offshore locations are not well simulated as shown by the sudden drop in simulated temperature in mid-August.

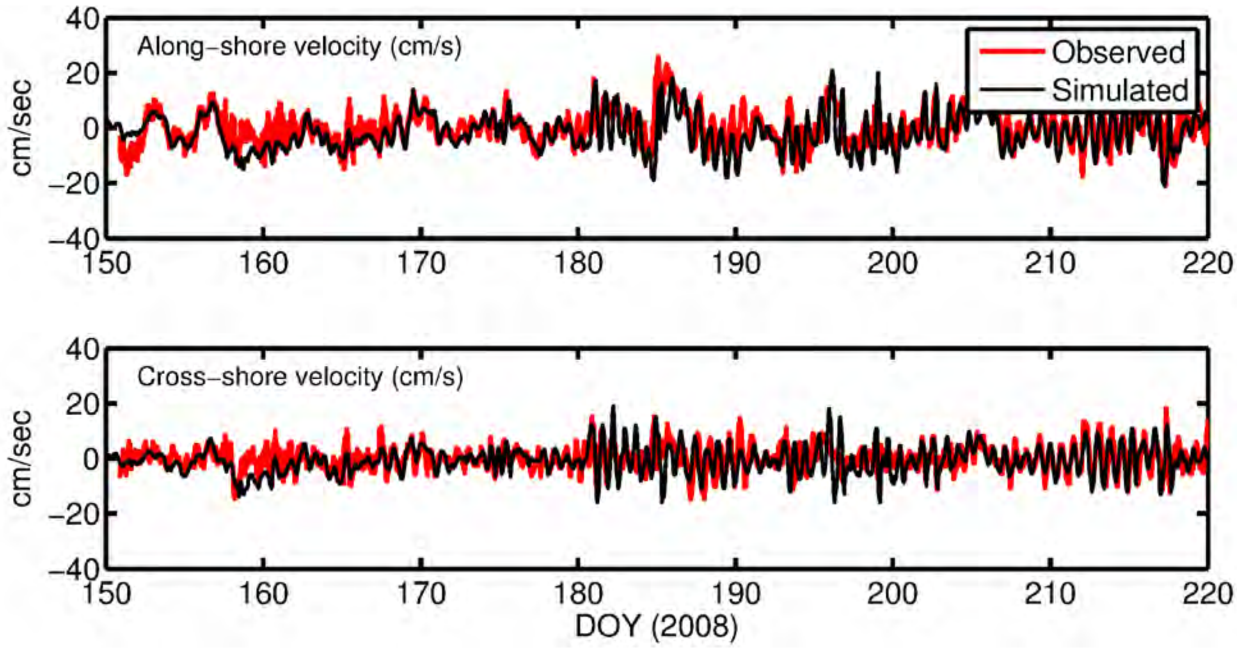

Figure 3.13 Comparisons between observed velocities in 2008 at location B08 and model results

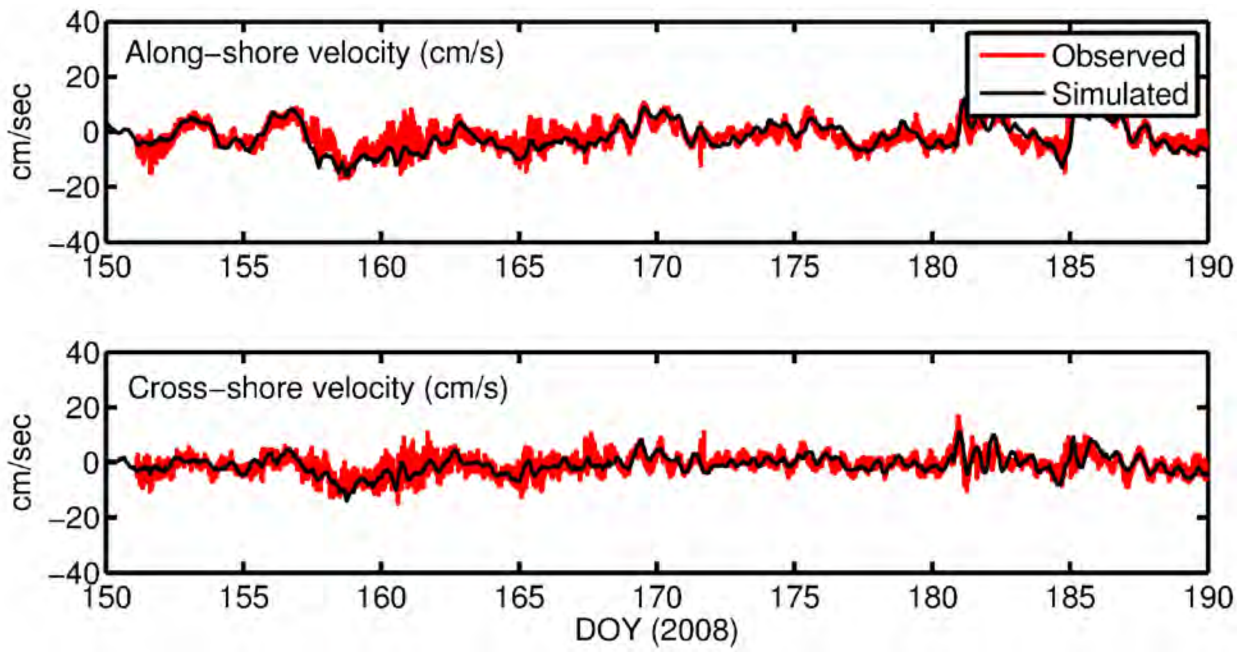

Figure 3.14 Comparisons between observed velocities in 2008 at location M08 and model results

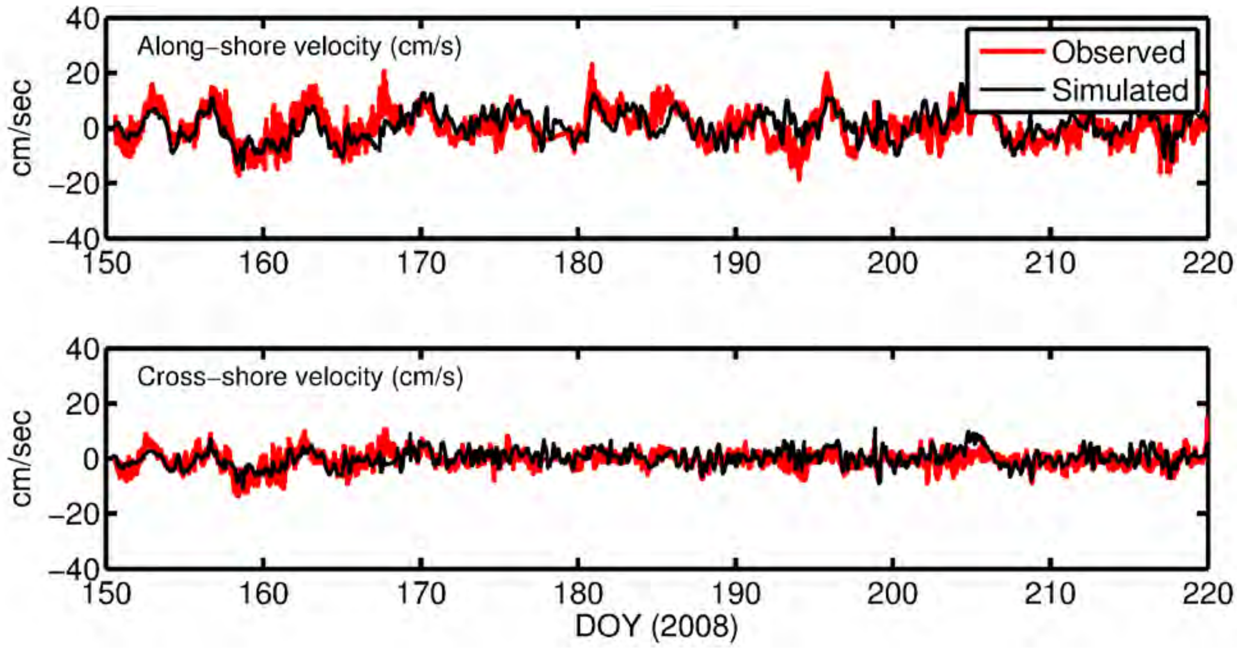

Figure 3.15 Comparisons between observed velocities in 2008 at location S08 and model results

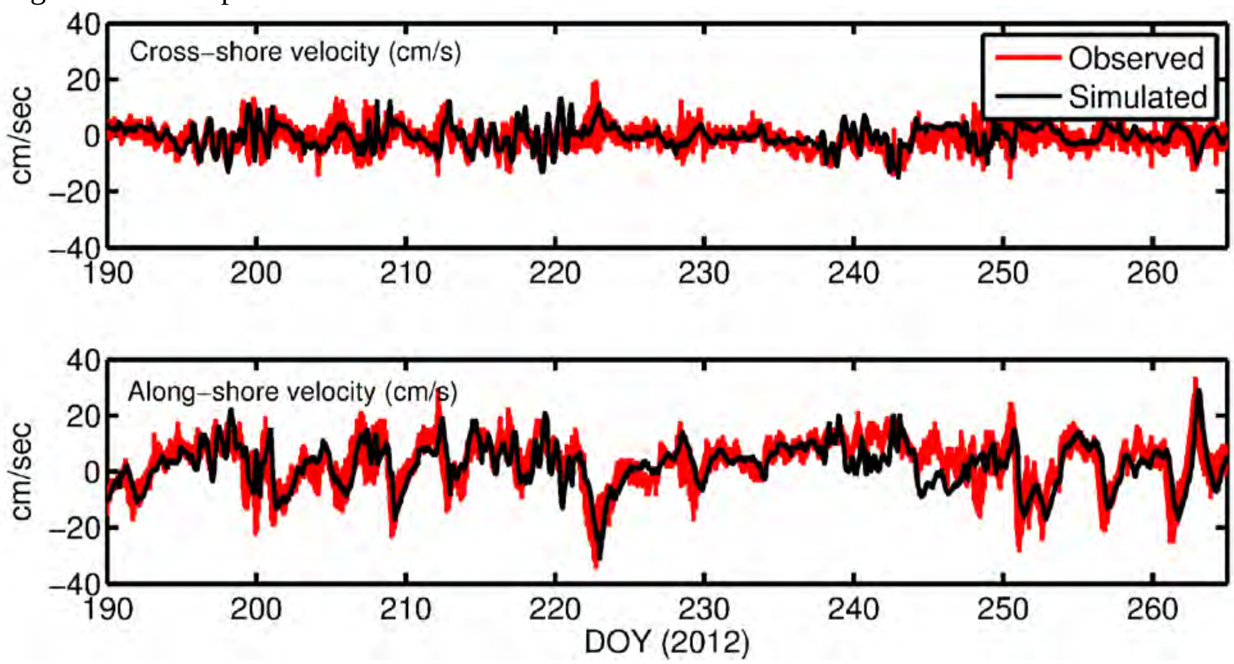

Figure 3.16 Comparisons between observed velocities in 2012 at location BBADCP and model results

3.3 Water quality model results

We calibrated the numerical water quality model using observations of Chloride, *E. coli*, Nitrate, Dissolved Oxygen, and Biochemical Oxygen Demand made during the field study in the summer of 2012. The observed (black squares) and simulated (blue solid line) values shown in the figures 17-21 are vertically averaged over the water column. Vertical variability in simulated concentrations of the water quality variables are presented by showing the maximum and minimum values in the vertical along with the vertical average. Measurements of water quality variable concentrations at location WQ2 are used to provide the background concentrations for the nearshore region. Concentrations are provided in mg/L which is equivalent to g/m^3.

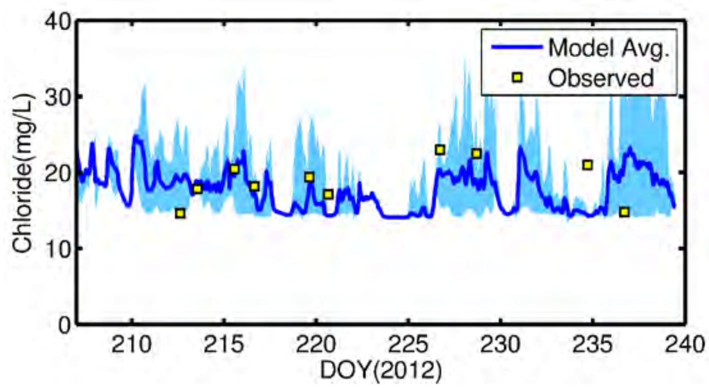

Figure 3.17 Comparison between observed and simulated values of chloride ion concentration at location WQ1

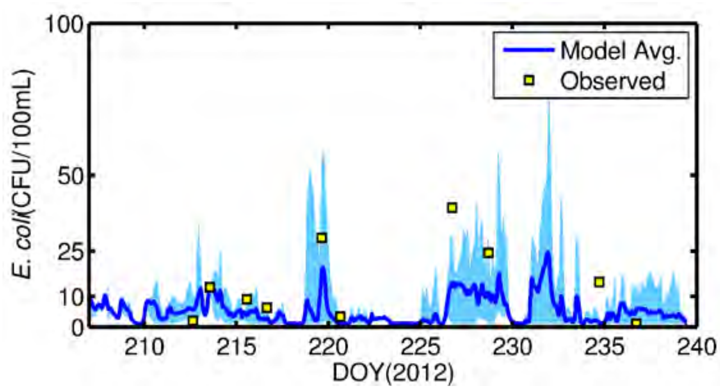

Figure 3.18 Comparison between observed and simulated values of *E. coli* concentrations at location WQ1

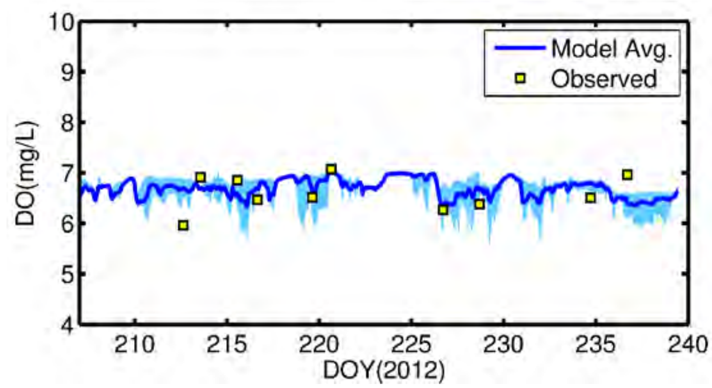

Figure 3.19 Comparison between observed and simulated values of DO concentrations at location WQ1

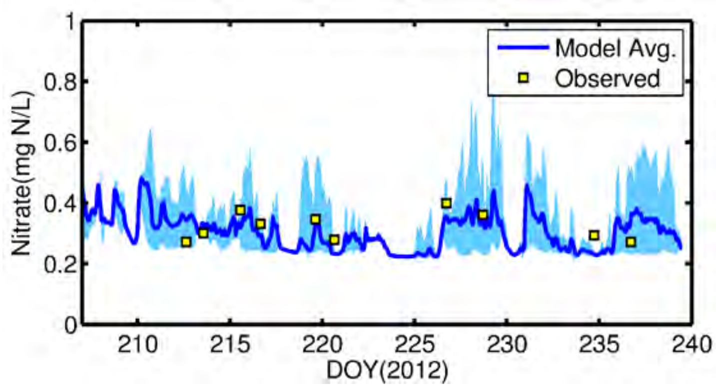

Figure 3.20 Comparison between observed and simulated values of Nitrate concentrations at location WQ1

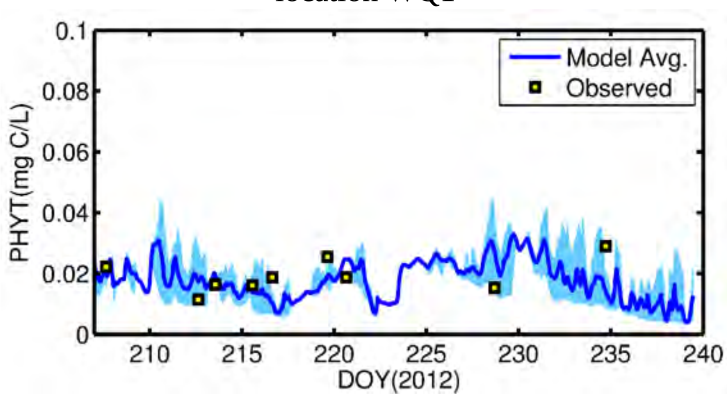

Figure 3.21 Comparison between observed and simulated values of Phytoplankton concentration at location WQ1

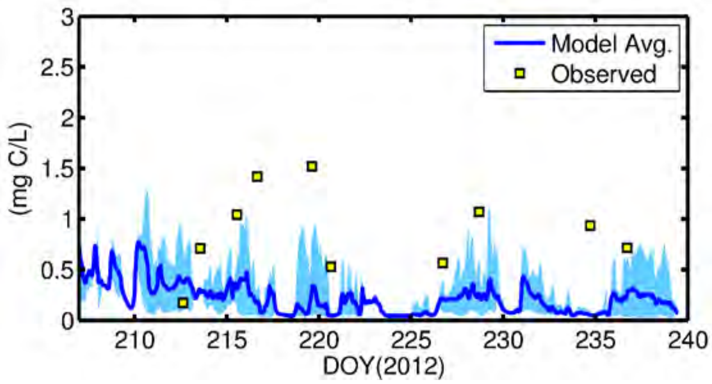

Figure 3.22 Comparison between the measured net biological oxygen demand and the model simulated carbonaceous biochemical oxygen demand. The difference between BOD and CBOD (i.e. the NBOD) is not computed by the model.

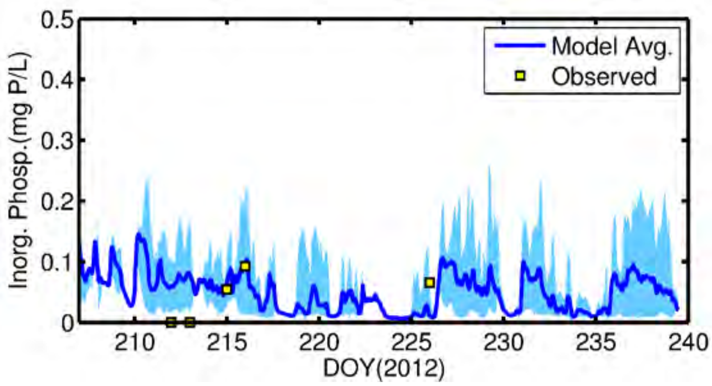

Figure 3.23 Comparison between measured and observed concentration of Inorganic Phosphorous (Phosphate ion).

The ability of the numerical model to predict transport of a tracer depends on the accuracy of the hydrodynamic model. The comparison with chloride (which acts as a tracer) shows that the model is able to simulate the mixing and transport processes that affect plume dynamics from a riverine discharge point. The models performance in the nearshore region is of particular importance since water intakes that are of importance for this study are located at or close to shore. The above comparisons with observed water quality variables provide confidence in the model's ability to describe nutrient and contaminant dynamics and allow us to test various scenarios. Table 3.1 shows where the important intakes for the City of Chicago, Gary and Evanston are located. Results, shown in figures 3.25 through 3.74, have been presented for the time series of the concentration at these locations in order to assess the impact that changes to the river control will have on water quality at the drinking water locations on the shore of Chicago.

Table 3.1 Major water intakes for this study

#	Name
1	Evanston
2	Chicago-Jardine (crib)
3	Chicago-Jardine (shore)
4	Chicago-South (crib)
5	Chicago-South (shore)
6	Hammond
7	Gary

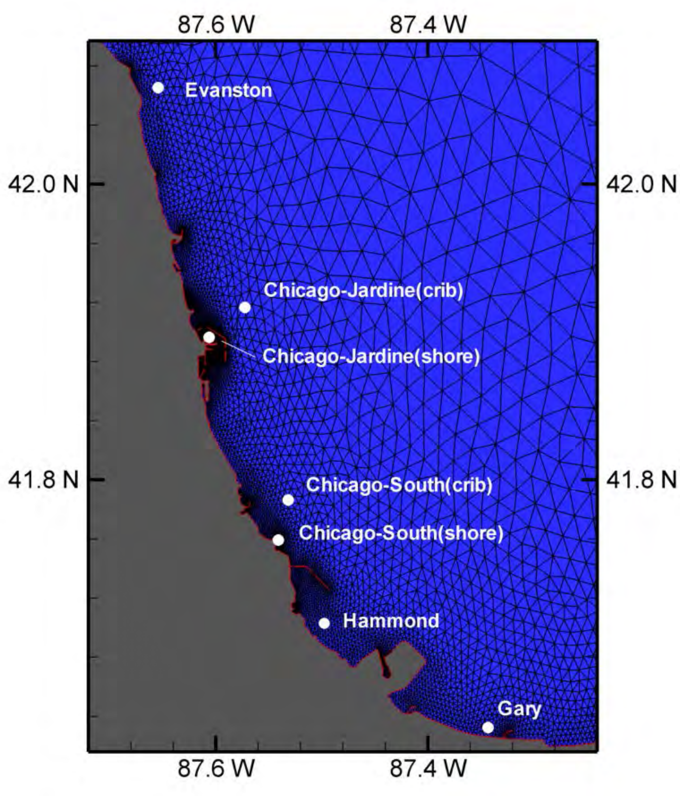

Figure 3.24 Approximate locations of major water intakes along the coastline of southern Lake Michigan

3.4 Scenario results

In this section, we present results from the numerical model for different past and potential future scenarios. In all five different scenarios have been simulated. They are:

1. **Baseline scenario**: This scenario simulates the seasonal variations in the concentrations of water quality in the nearshore region as well as over the entire lake. Meteorological forcing is based on the observations collected at the NCDC and NDBC stations located around Lake Michigan during 2008. The contaminant loadings for the Burns Ditch and Indiana Harbor Canal outfalls are based on observations. The aim of this simulation is to determine the baseline (lake-wide and nearshore) conditions in the absence of any loading from the outfalls that are part of the Chicago Area Waterway System.
2. **Continuous release (2017):** This scenario simulates the impact of year-long discharge from the outfalls on the nearshore water quality. Meteorological forcing is based on the observations collected at the NCDC and NDBC stations located around Lake Michigan during 2008. Contaminant loading for this scenario is obtained from a watershed model that simulates hydrologic processes and precipitation based on projections for 2017.
3. **Continuous release (2029):** This scenario simulates the impact of year-long discharge from the outfalls on the nearshore water quality. Meteorological forcing is based on the observations collected at the NCDC and NDBC stations located around Lake Michigan during 2008. Contaminant loading is obtained from a watershed model that simulates hydrologic conditions and precipitation based on projections for 2029.
4. **Episodic release (2017):** This scenario simulates the extreme discharge conditions based on the September storm event in 2008. The wind conditions on the lake are based on the

2008 meteorological inputs but the loading is based on the projected 2017 conditions for the watershed (e.g., precipitation)

5. **Episodic release (2029):** This scenario simulates the extreme discharge conditions based on the September storm event in 2008. As in scenario 4, the wind and other meteorological conditions on the lake are based on the 2008 data but the watershed loading is based on the projected 2029 conditions for the watershed (e.g., precipitation).

3.4.1 Scenario 1: Baseline condition

Concentrations of water quality variables at major water intake locations are shown in Figures 23-32. The results are obtained using meteorological data from 2008 to force the hydrodynamic model. Observations at Burns Ditch, Indiana harbor Canal, and Calumet are used to provide input for the water quality model.

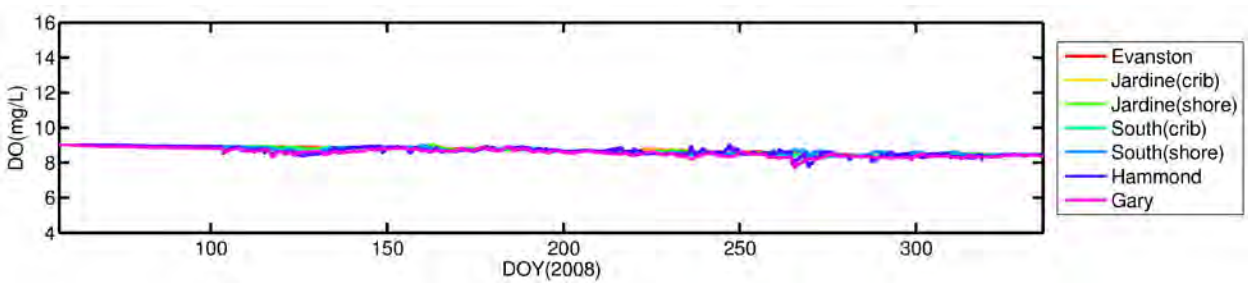

Figure 3.25 Concentration of DO at the major drinking water intake locations based on Scenario 1

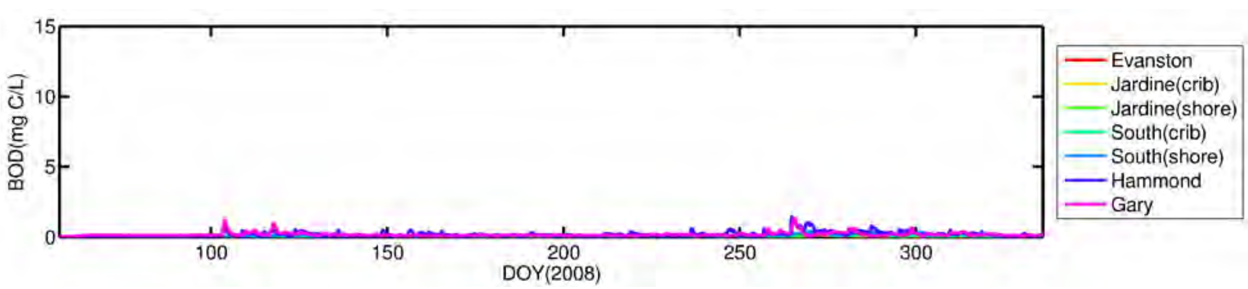

Figure 3.26 Concentration of BOD at the major drinking water intake locations based on Scenario 1

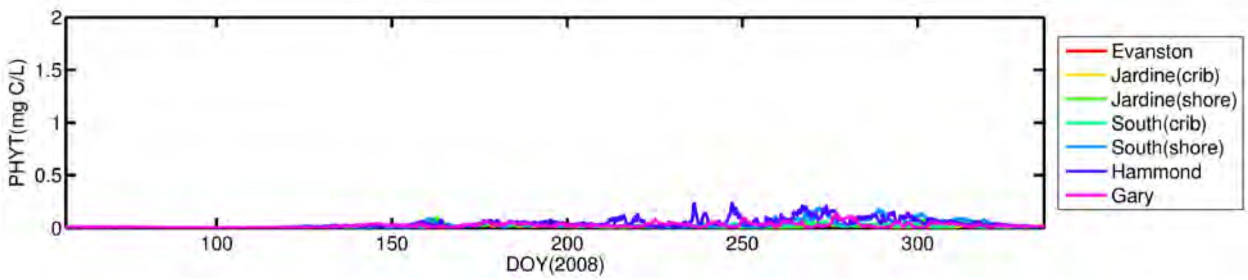

Figure 3.27 Concentration of phytoplankton at the major drinking water intake locations based on
Scenario 1

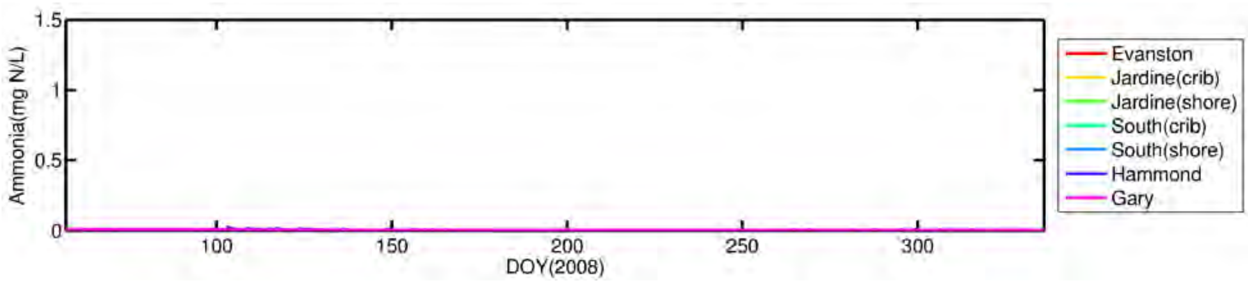

Figure 3.28 Concentration of ammonia at the major drinking water intake locations based on
Scenario 1

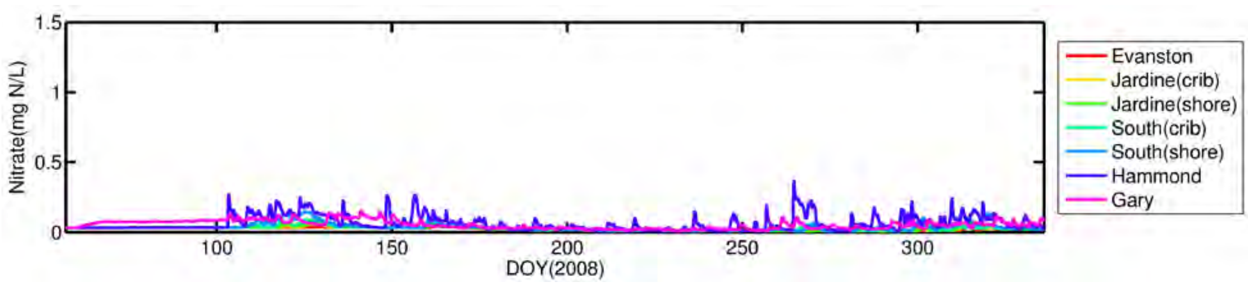

Figure 3.29 Concentration of nitrate at the major drinking water intake locations based on
Scenario 1

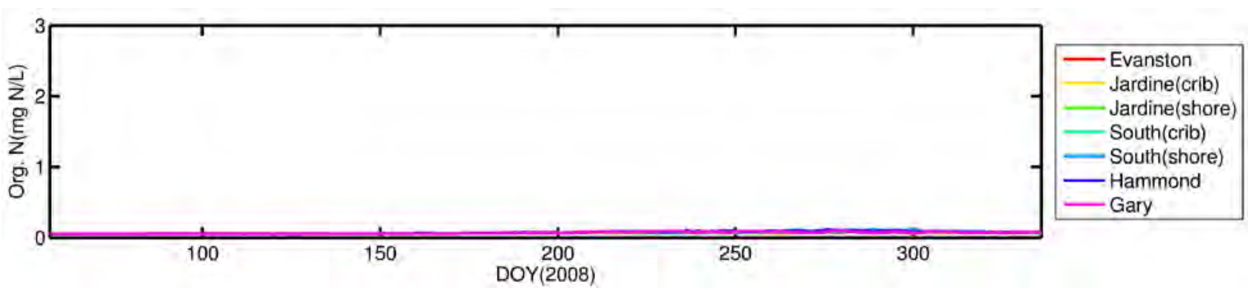

Figure 3.30 Concentration of organic nitrogen at the major drinking water intake locations based on
Scenario 1

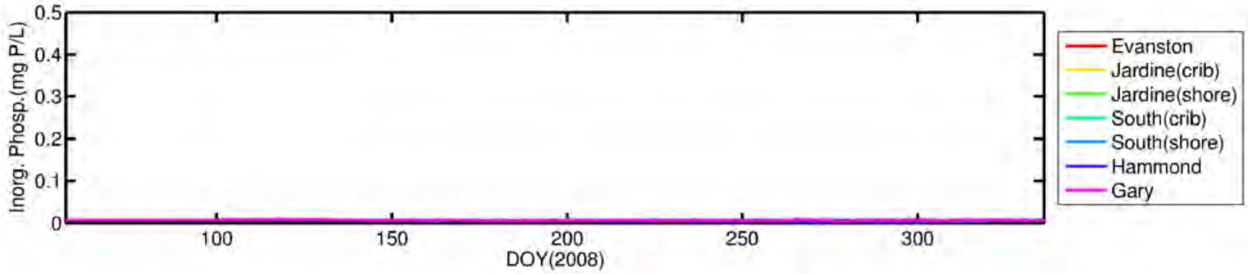

Figure 3.31 Concentration of ortho-phosphate at the major drinking water intake locations based on
Scenario 1

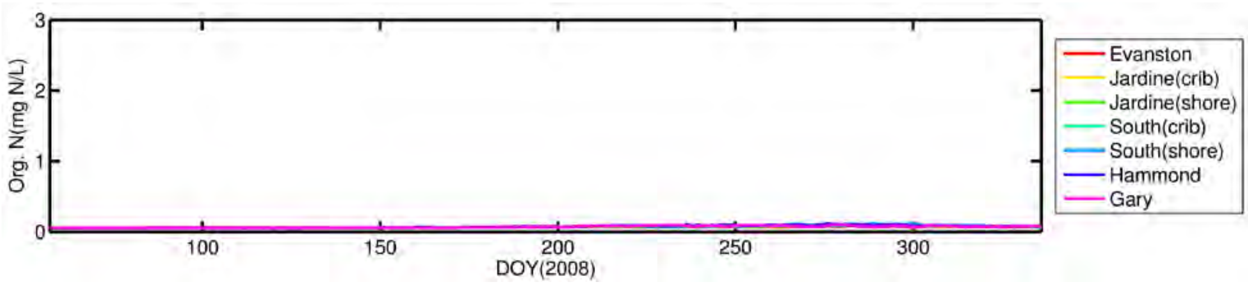

Figure 3.32 Concentration of organic phosphorous at the major drinking water intake locations based on
Scenario 1

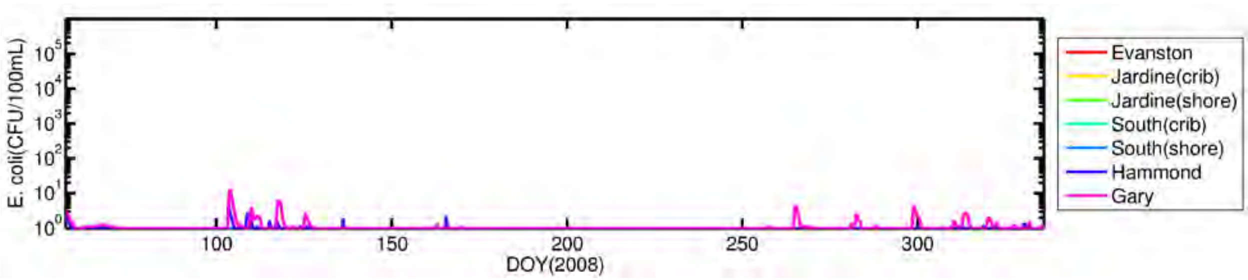

Figure 3.33 Concentration of FIB at the major drinking water intake locations based on
Scenario 1

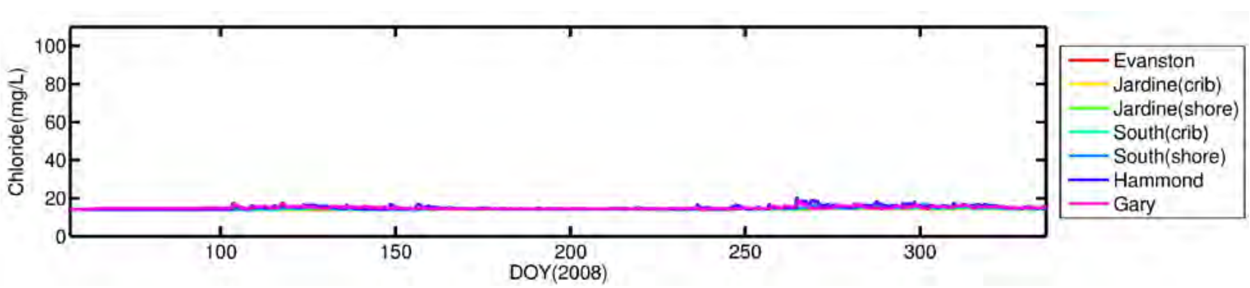

Figure 3.34 Concentration of chloride at the major drinking water intake locations based on
Scenario 1

3.4.2 Scenario 2: Continuous release (2017)

Concentrations of water quality variables at major water intake locations are shown in Figures 33-42. The results are obtained using meteorological data from water year 2008 (Sept 2007-October 2008) to force the hydrodynamic model. Watershed model results at Calumet, Indiana Harbor Canal, Calumet, Chicago, and Wilmette and observations from 2008 at Burns Ditch are used to provide input for the water quality model.

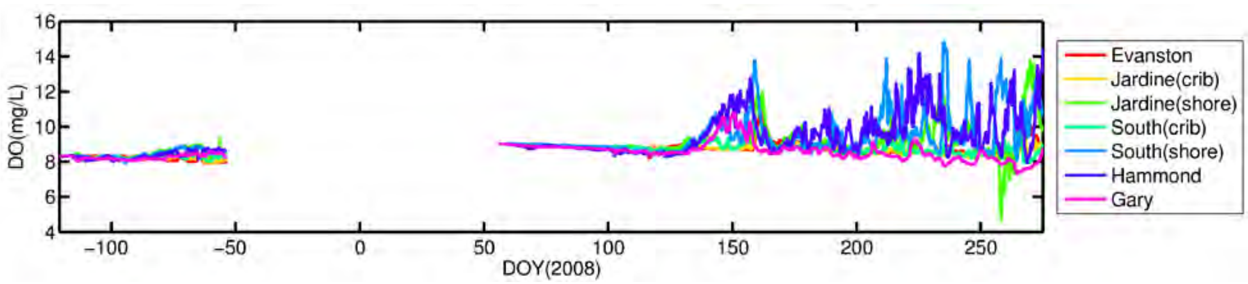

Figure 3.35 Concentration of DO at the major drinking water intake locations based on Scenario 1

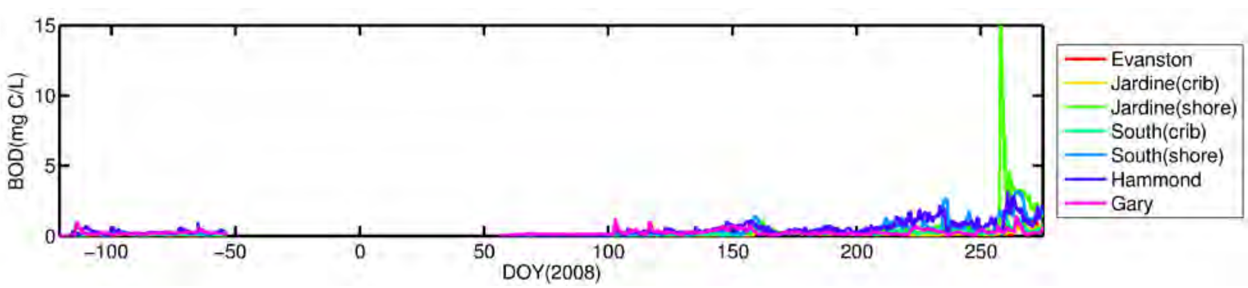

Figure 3.36 Concentration of BOD at the major drinking water intake locations

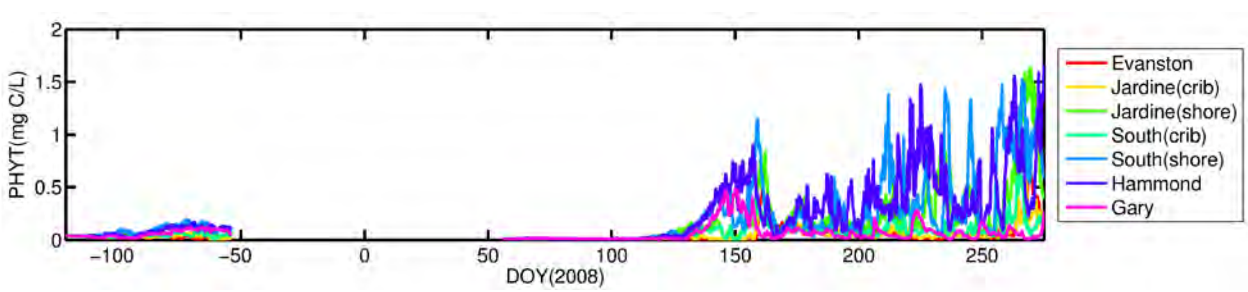

Figure 3.37 Concentration of Phytoplankton at the major drinking water intake locations

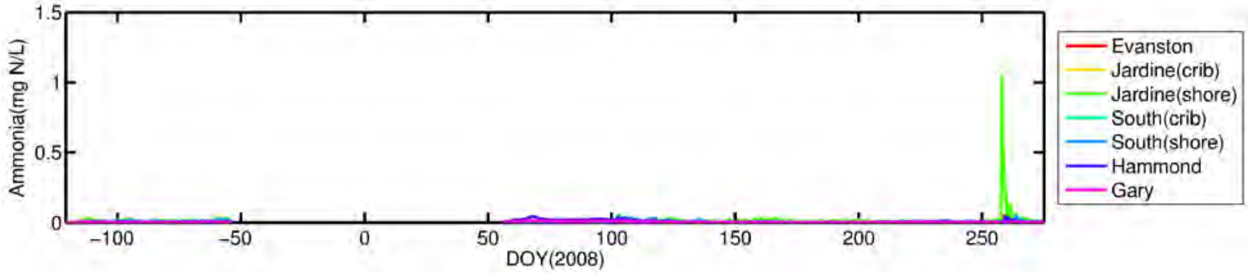

Figure 3.38 Concentration of Ammonia at the major drinking water intake locations

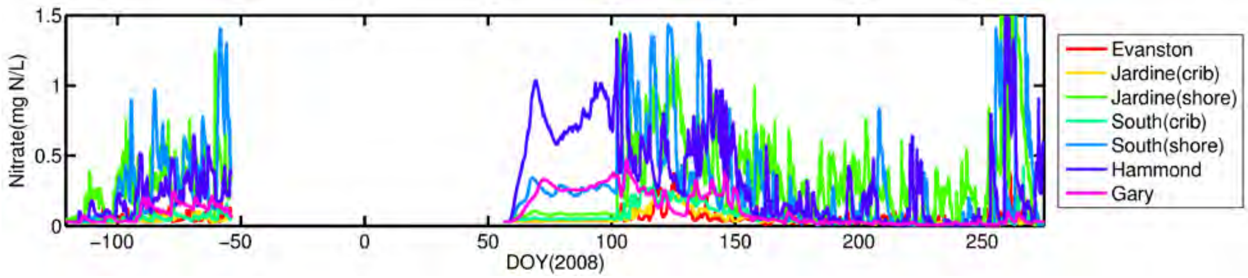

Figure 3.39 Concentration of Nitrate at the major drinking water intake locations

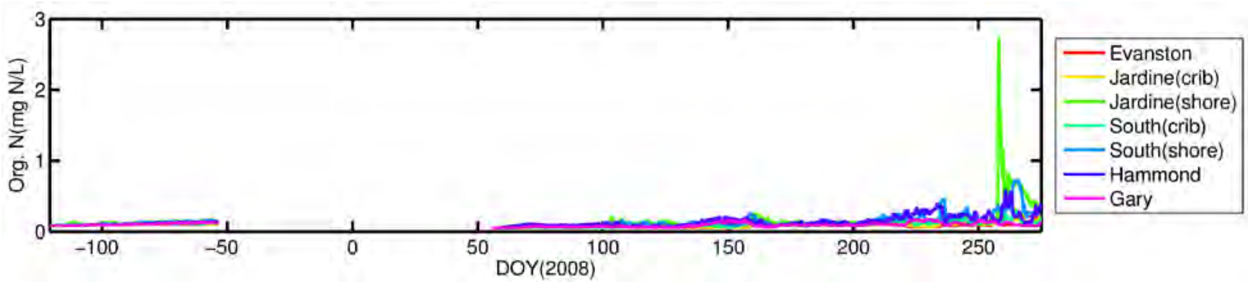

Figure 3.40 Concentration of Organic Nitrogen at the major drinking water intake locations

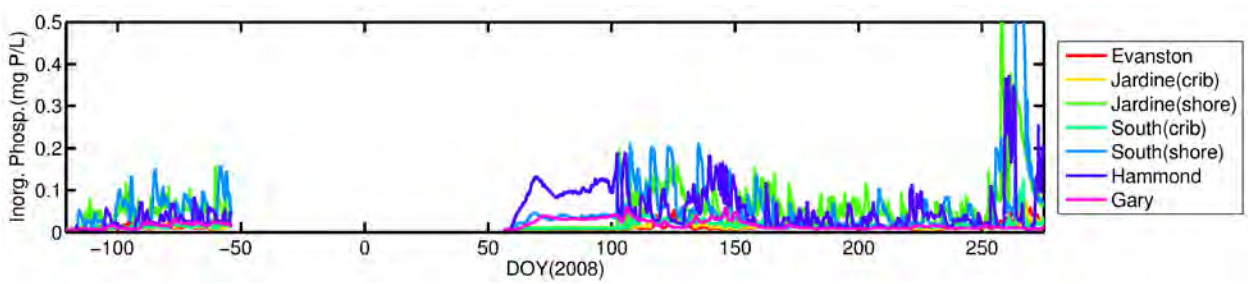

Figure 3.41 Concentration of ortho phosphate at the major drinking water intake locations

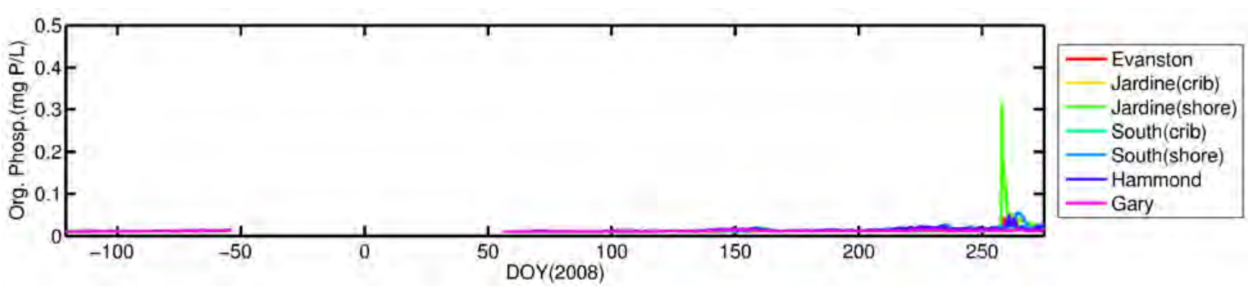

Figure 3.42 Concentration of Organic Phosphorous at the major drinking water intake locations

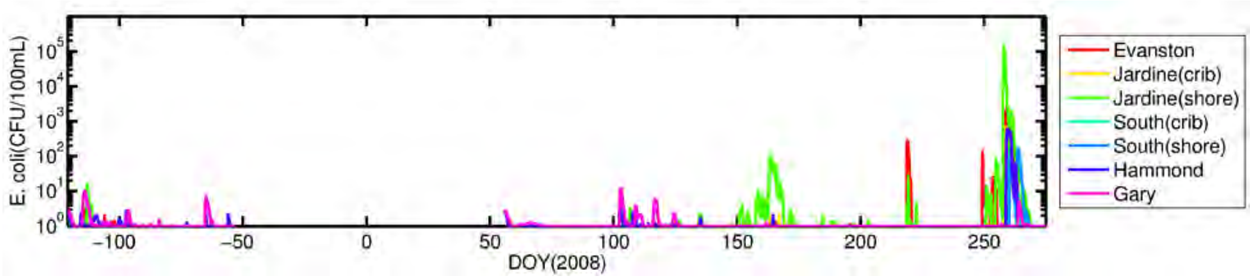

Figure 3.43 Concentration of FIB at the major drinking water intake locations

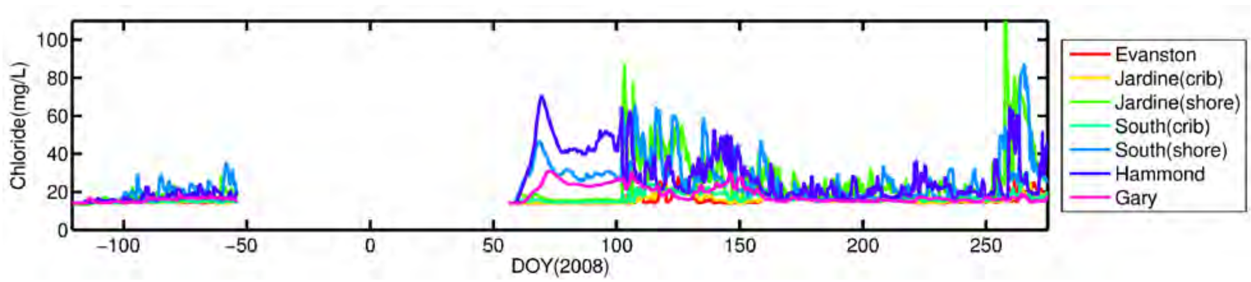

Figure 3.44 Concentration of Chloride at the major drinking water intake locations

3.4.3 Scenario 3: Continuous release (2029)

Concentrations of water quality variables at major water intake locations are shown in the Figures 43-52. The results are obtained using meteorological data from water year 2008 (Sept 2007- October 2008) to force the hydrodynamic model. Watershed model results at Calumet, Indiana Harbor Canal, Calumet, Chicago, and Wilmette and observations from 2008 at Burns Ditch are used to provide input for the water quality model.

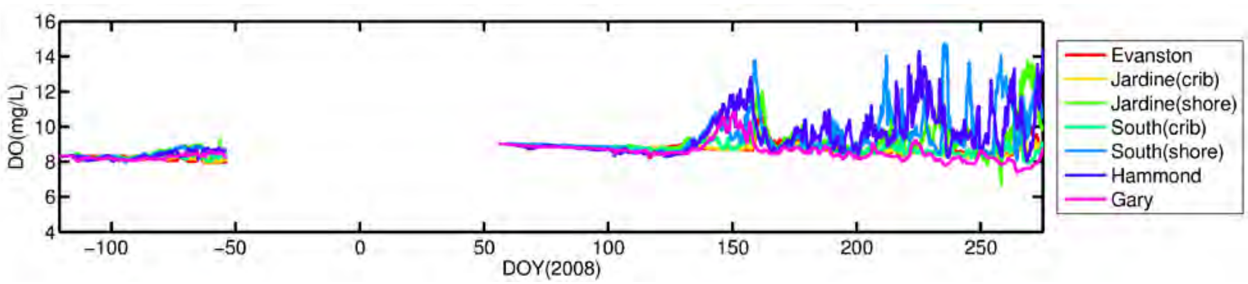

Figure 3.45 Concentration of DO at the major drinking water intake locations

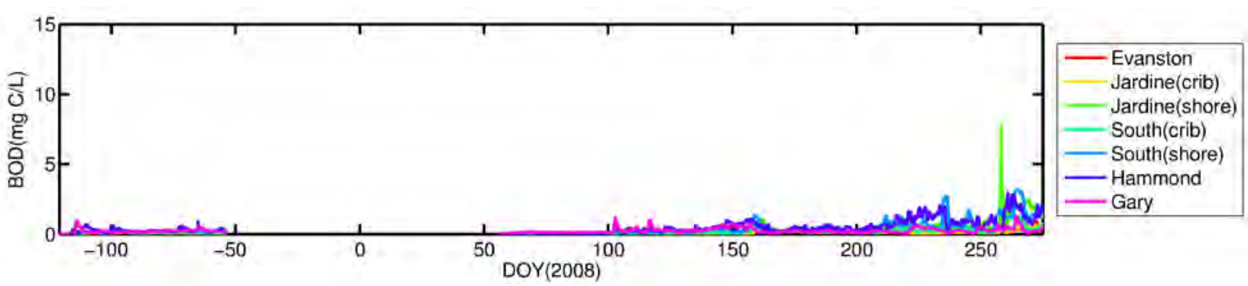

Figure 3.46 Concentration of BOD at the major drinking water intake locations

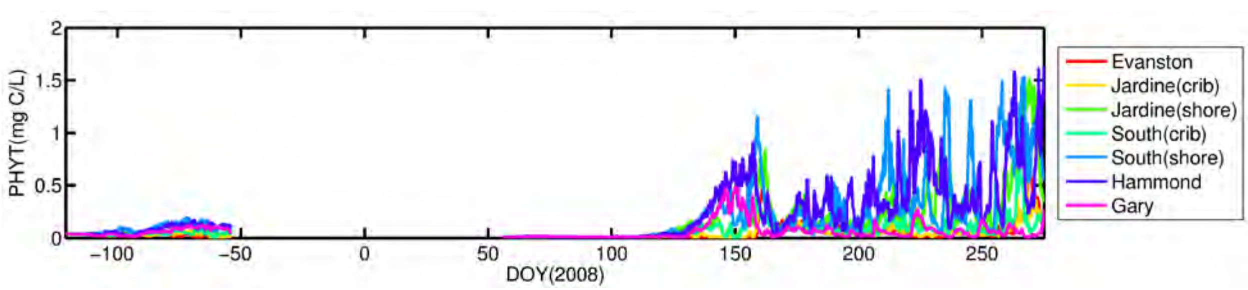

Figure 3.47 Concentration of Phytoplankton at the major drinking water intake locations

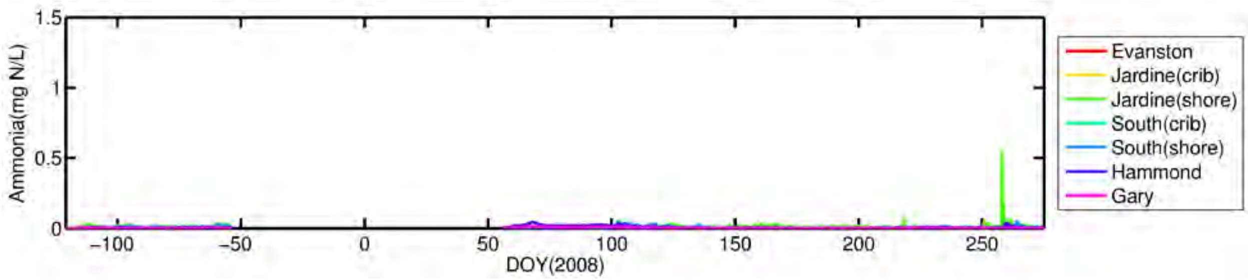

Figure 3.48 Concentration of Ammonia at the major drinking water intake locations

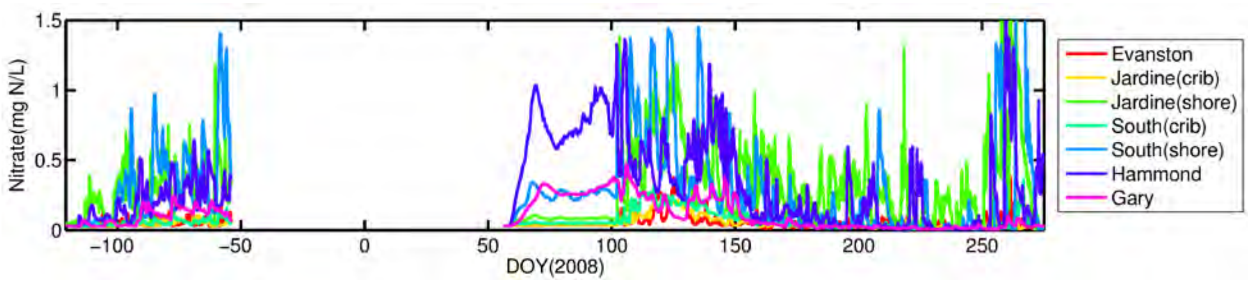

Figure 3.49 Concentration of Nitrate at the major drinking water intake locations

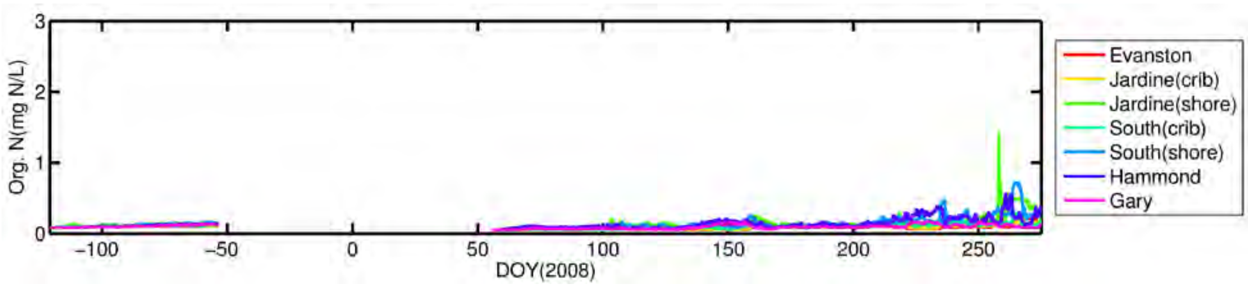

Figure 3.50 Concentration of Organic Nitrogen at the major drinking water intake locations

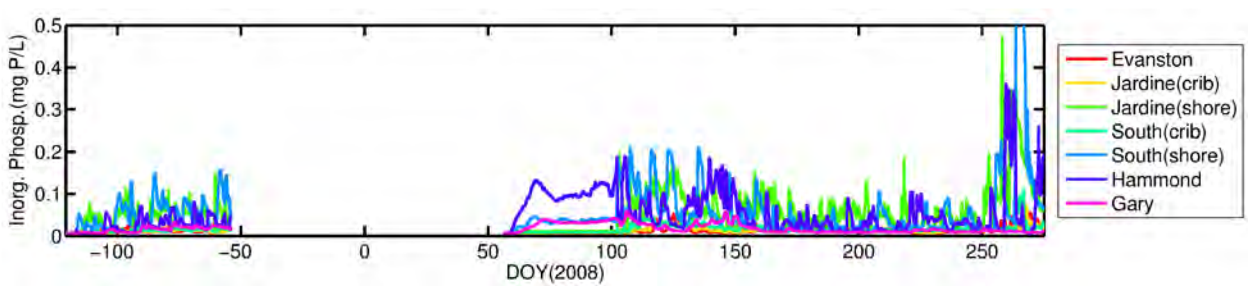

Figure 3.51 Concentration of ortho phosphate at the major drinking water intake locations

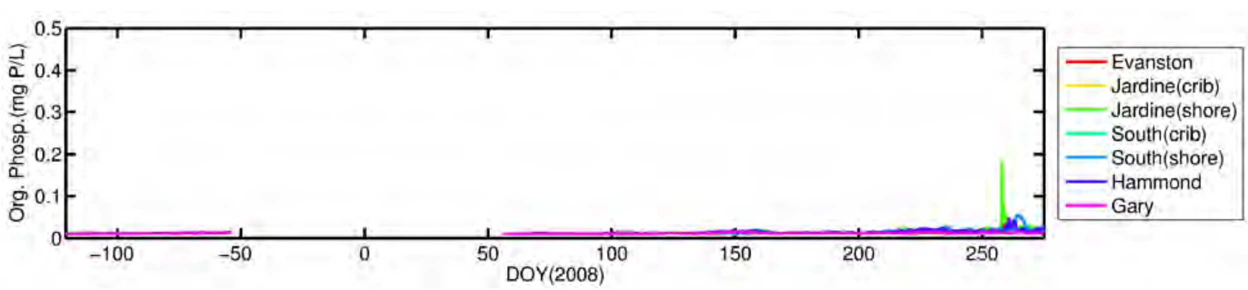

Figure 3.52 Concentration of organic phosphorous at the major drinking water intake locations

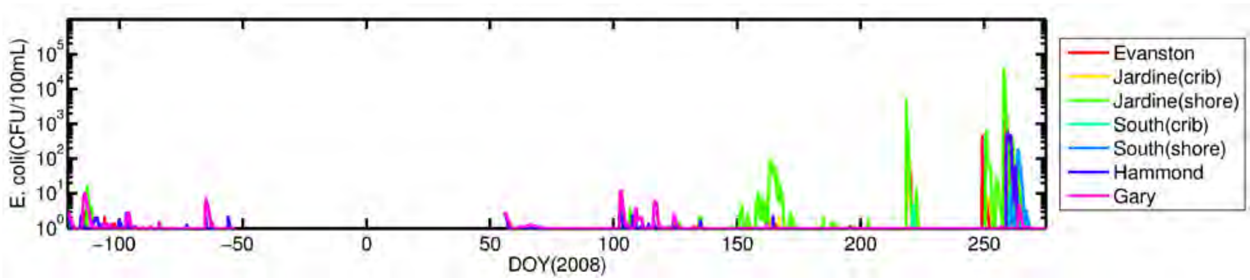

Figure 3.53 Concentration of FIB at the major drinking water intake locations

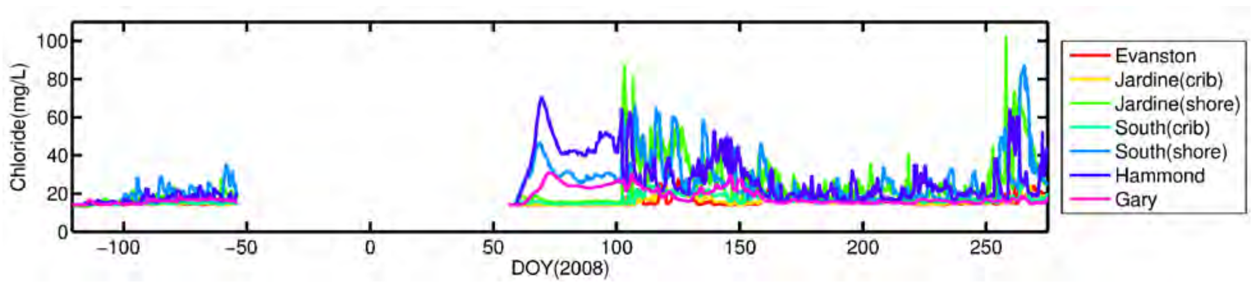

Figure 3.54 Concentration of Chloride at the major drinking water intake locations

3.4.5 Scenario 4: Episodic release (2017)

Concentrations of water quality variables at major water intake locations are shown in the Figures 53-62. The results are obtained using meteorological data from 2008 to force the hydrodynamic model. Watershed model results for the September storm event are used to provide input for the water quality model. The water quality and hydrodynamic models were run until plume (discharge) dissipation. The results for the period September 10 to October 10 are presented.

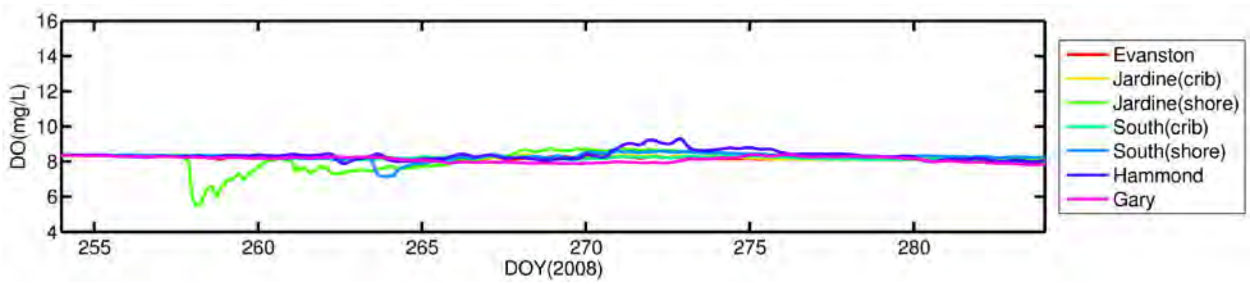

Figure 3.55 Concentration of DO at the major drinking water intake locations

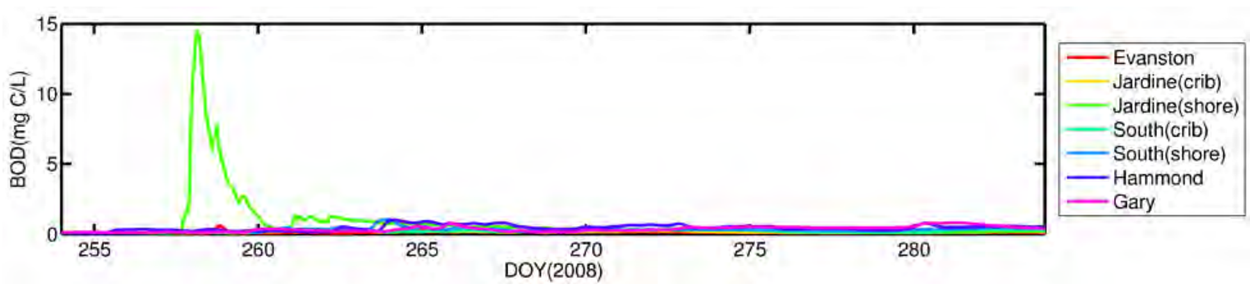

Figure 3.56 Concentration of BOD at the major drinking water intake locations

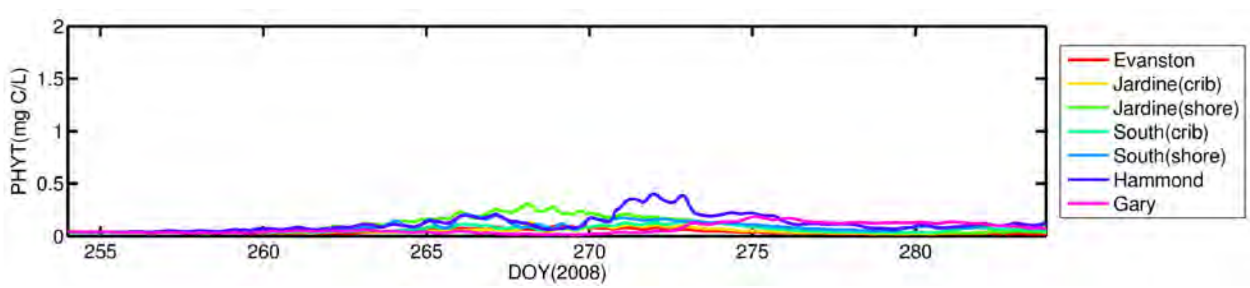

Figure 3.57 Concentration of phytoplankton at the major drinking water intake locations

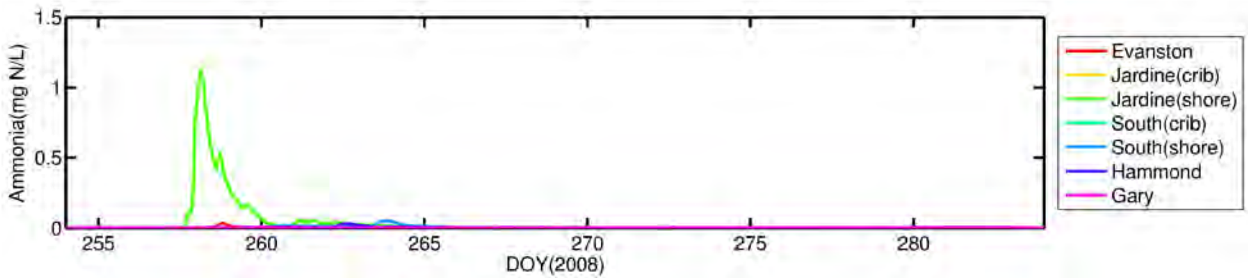

Figure 3.58 Concentration of ammonia at the major drinking water intake locations

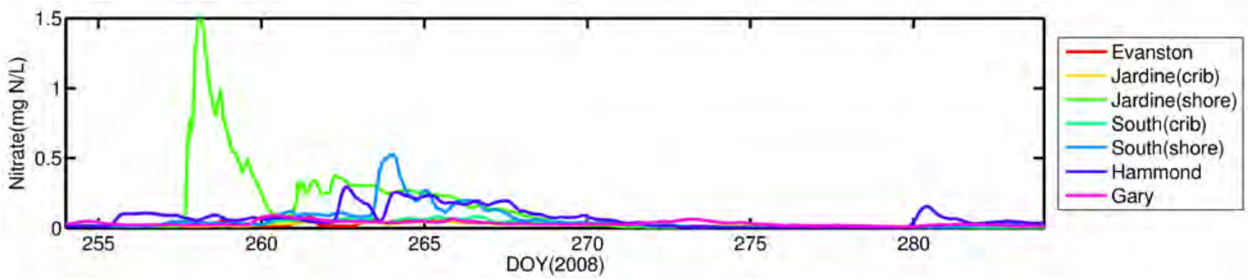

Figure 3.59 Concentration of nitrate at the major drinking water intake locations

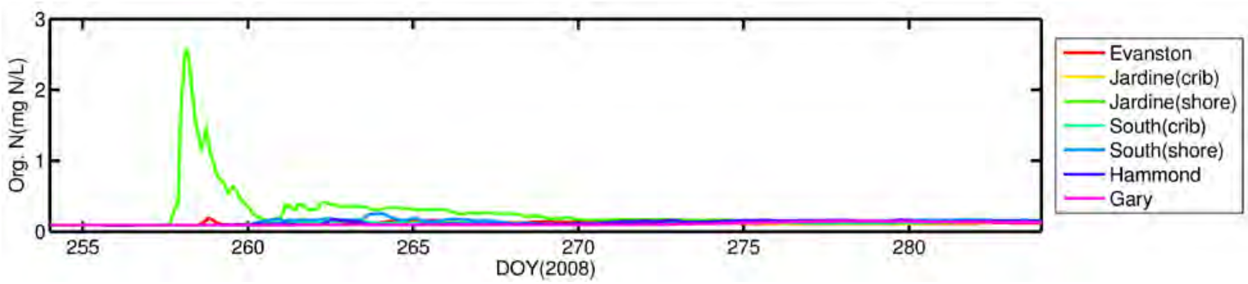

Figure 3.60 Concentration of organic nitrogen at the major drinking water intake locations

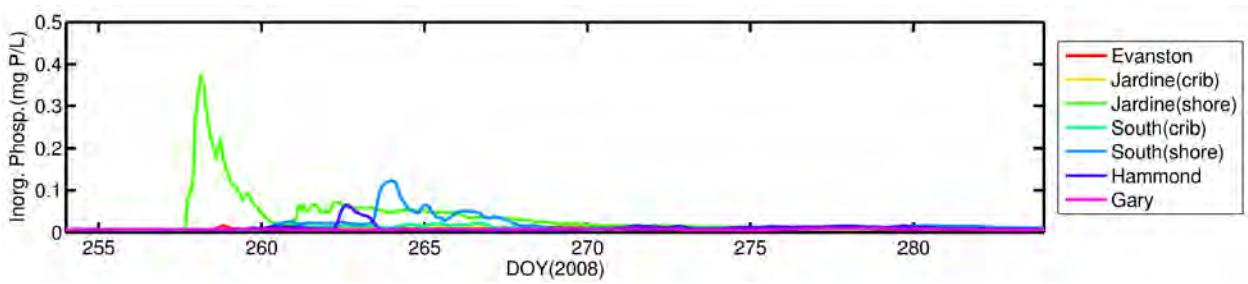

Figure 3.61 Concentration of inorganic phosphorous at the major drinking water intake locations

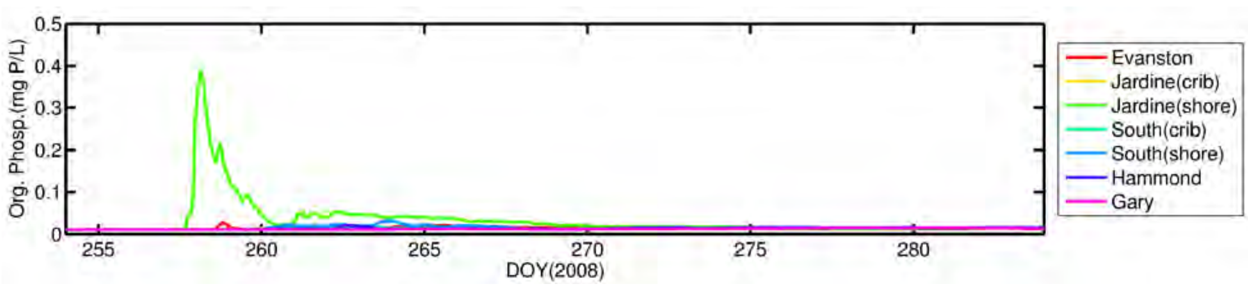

Figure 3.62 Concentration of organic phosphorous at the major drinking water intake locations

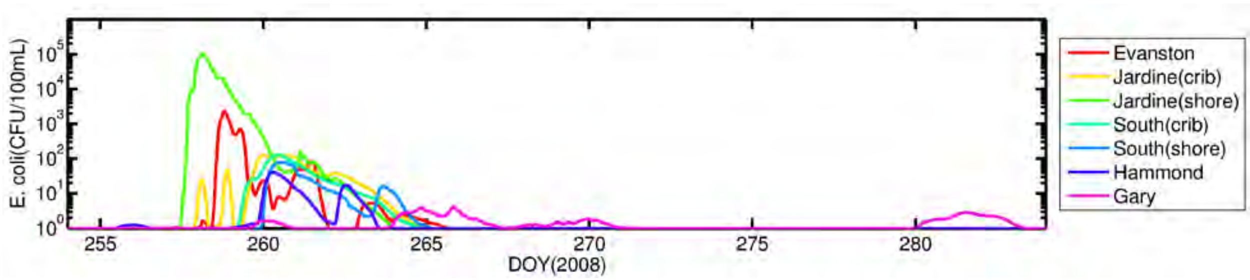

Figure 3.63 Concentration of FIB at the major drinking water intake locations

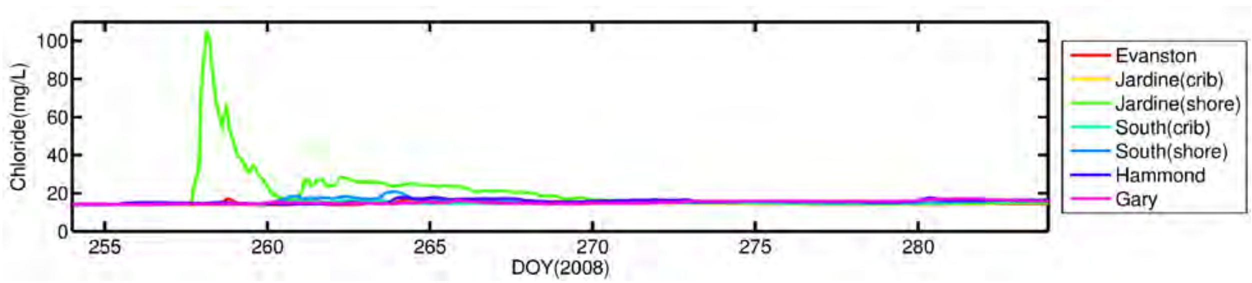

Figure 3.64 Concentration of chloride at the major drinking water intake locations

3.4.4 Scenario 5: Episodic release (2029)

Concentrations of water quality variables at major water intake locations are shown in the Figures 63-72. The results are obtained using meteorological data from 2008 to force the hydrodynamic model. Watershed model results for the September storm event are used to provide input for the water quality model. The water quality and hydrodynamic models were run until plume (discharge) dissipation. The results for the period September 10 to October 10 are presented.

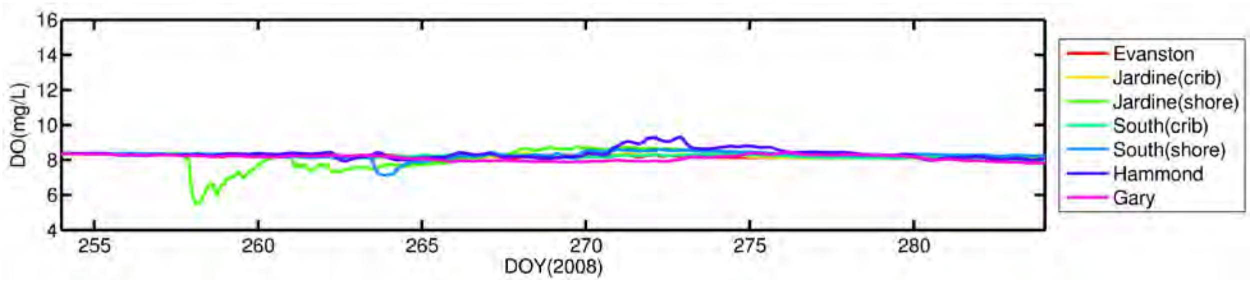

Figure 3.65 Concentration of DO at the major drinking water intake locations

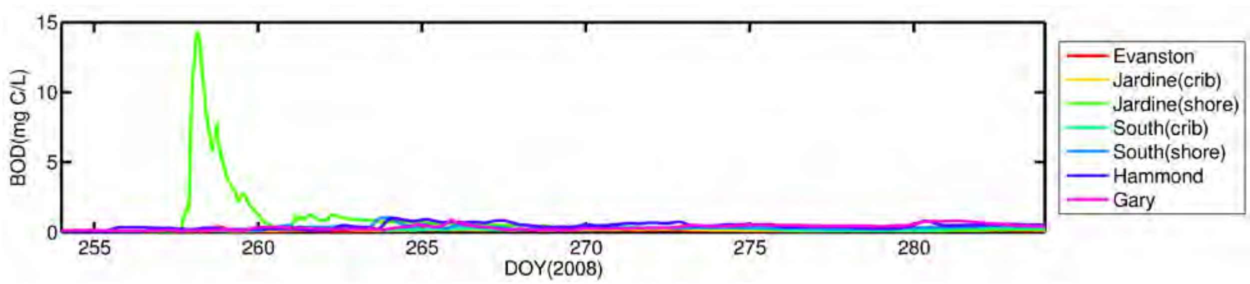

Figure 3.66 Concentration of BOD at the major drinking water intake locations

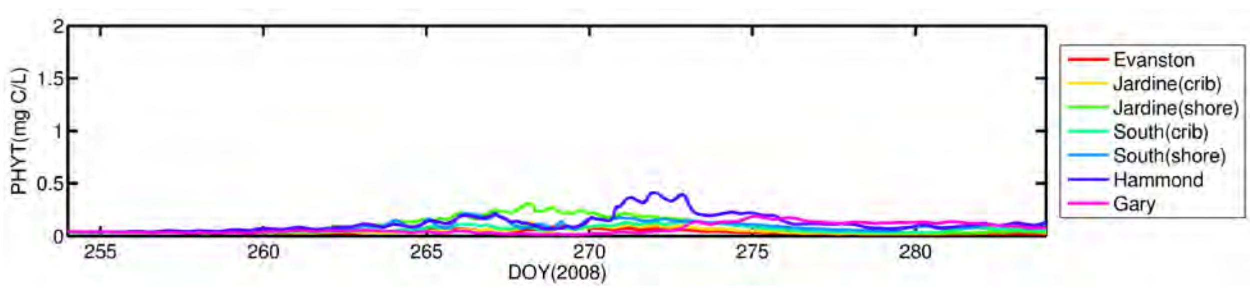

Figure 3.67 Concentration of phytoplankton at the major drinking water intake locations

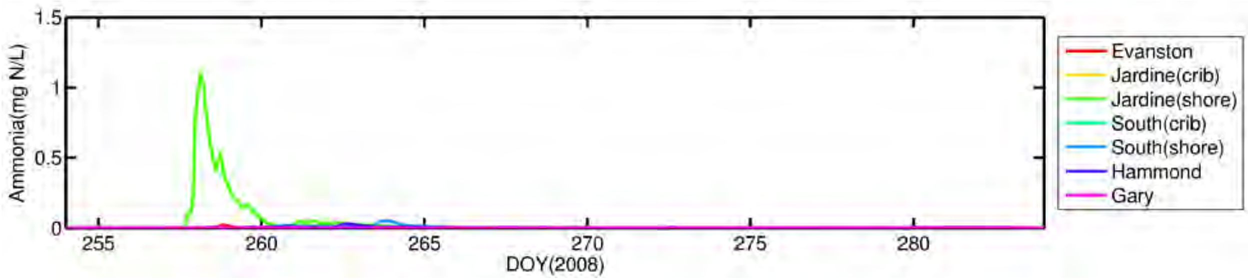

Figure 3.68 Concentration of Ammonia at the major drinking water intake locations

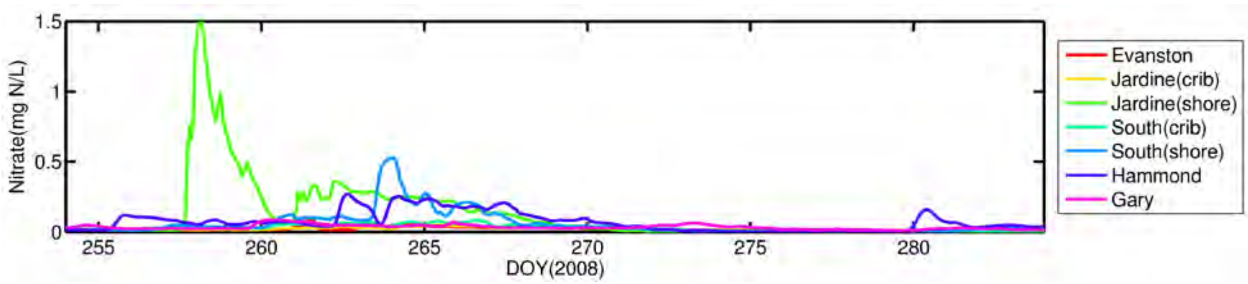

Figure 3.69 Concentration of Nitrate at the major drinking water intake locations

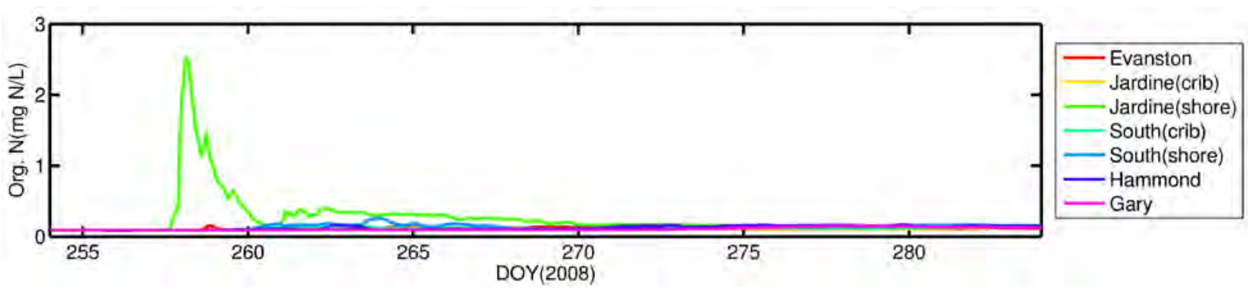

Figure 3.70 Concentration of organic nitrogen at the major drinking water intake locations

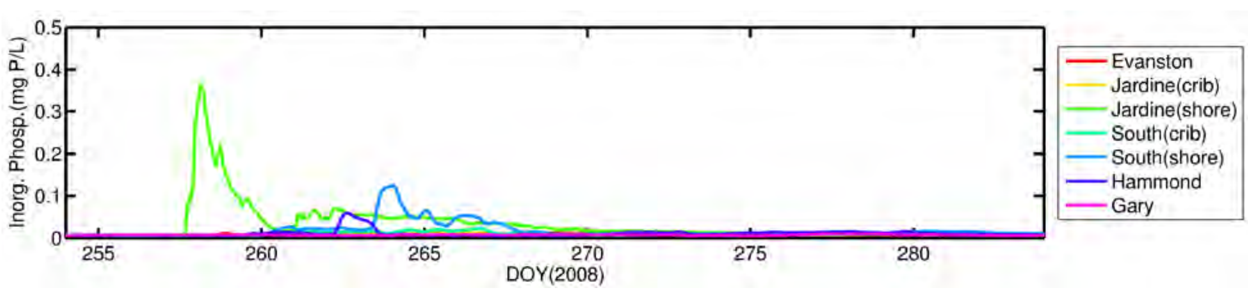

Figure 3.71 Concentration of ortho phosphate at the major drinking water intake locations

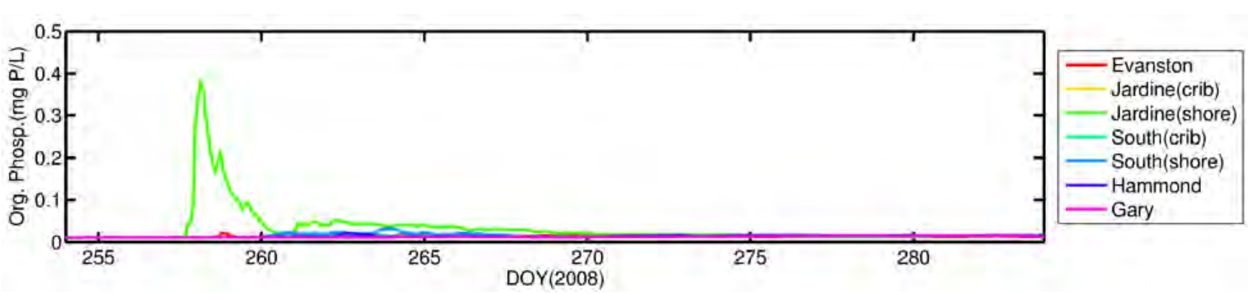

Figure 3.72 Concentration of organic phosphorous at the major drinking water intake locations

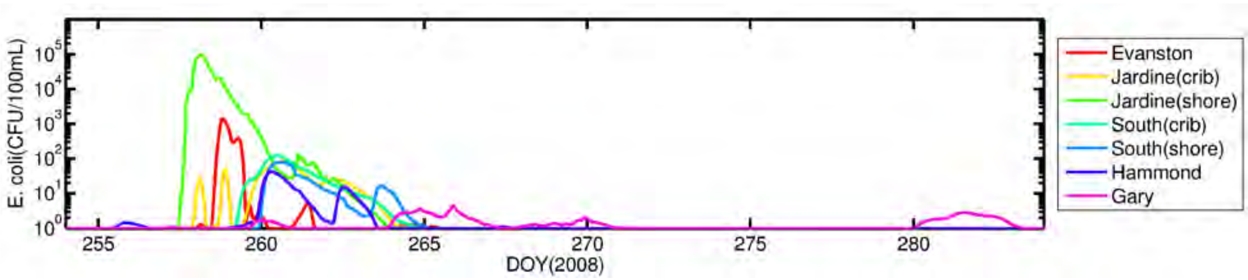

Figure 3.73 Concentration of FIB at the major drinking water intake locations

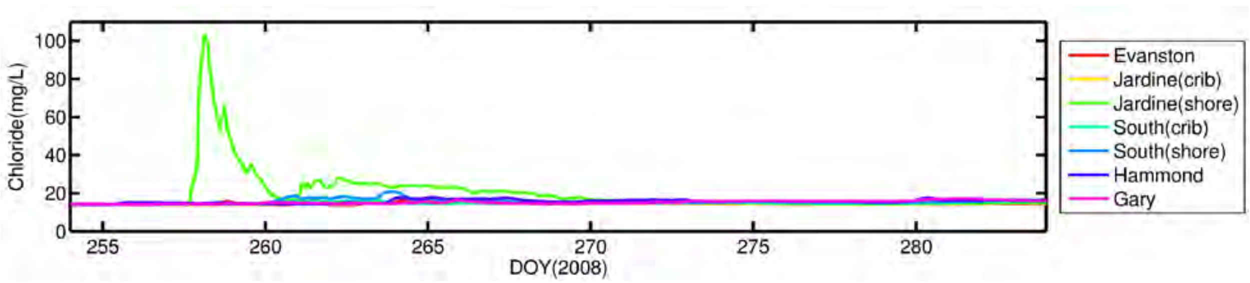

Figure 3.74 Concentration of chloride at the major drinking water intake locations

Chapter 4: Discussion

The hydrodynamic and water quality models were tested using data collected in 2008 and 2012. These data include current measurements at different locations in the nearshore region of Lake Michigan, concentrations of dissolved oxygen, biochemical oxygen demand, phytoplankton, nitrate, ammonia, *E. coli,* and chloride. The comparisons between the observed and simulated values of these water quality variables shown in Chapter 3 for the baseline conditions indicate that the model is able to simulate the mixing, transport, and the coupled physical-chemical-biological processes that affect the concentrations of water quality variables in the nearshore water column. However, a few of the peak values observed in the nearshore are not well predicted. It can also be seen that some of the variables (such as Chloride, *E. coli*, Phytoplankton, Nitrate, etc.) are better predicted by the model than other variables such as BOD, Ammonia etc.). This could be due to additional processes and/or sources that could potentially contribute to the contaminant levels in the nearshore environment. Further analysis of model sensitivity to the parameters and identifying the best (i.e., optimum) set of parameters to describe the processes in a large freshwater lake might also improve the comparisons. Identifying the optimum set of parameters in a multi-dimensional model with a large set of parameters is a computationally demanding task; therefore the parameter identification exercise in this study was limited due to lack of time.

For some scenarios (Scenario 2, Figure 3.33 in Chapter 3), the simulated dissolved oxygen levels are significantly higher than expected values. Closer examination revealed that these high DO values approaching 16 mg/L in concentration are due to surface algal blooms that occurred within the grid cell reporting the high DO value. Intense algal blooms produce high oxygen levels in the presence of sunlight due to photosynthesis and similar high DO concentrations have been measured in lakes in the past (see for example, *Batchelder and Braden*, 1976.)

As shown by the results from the different water quality model scenarios that were simulated, concentrations at different loading / discharge points have a significant impact on the nearshore water quality. The impact is more significant at locations closer to the shoreline as shown by the time-series of concentrations at the different intake locations shown in Chapter 3 (Figures 3.23 to 3.72). We find that mixing and diffusion processes quickly reduce pollutant concentrations to acceptable levels. The different candidate benchmarks for water quality in Lake Michigan (open waters) are given in Table 4.2.

Table 4.1.Candidate benchmarks for Lake Michigan open waters. Model statistics are calculated for Scenario 3 (simulating Sept 2008 storm with hydrologic separation barrier) at location Jardine (shore). Statistics are available for all locations in the Appendix.

Variable	Benchmark	Min.	Max.	Mean	Std. dev.	Days exceeded
Total Phosphorous	0.007 mg/L	0.024	0.651	0.153	0.103	30 out of 30
Ammonia	NA	0.0008	0.540	0.0211	0.055	NA
Chloride	12 mg/L	15.26	102.22	36.66	17.218	30 out of 30
DO	7.2 mg/L	6.60	13.71	9.986	1.787	0 out of 30
Nitrate	10 mg/L	0.0002	2.421	0.4984	0.491	0 out of 30
Fecal Coliform/ *E. coli*	20 CFU/100mL	1	38792	630.46	3577.3	11 out of 30
CBOD	NA	0.132	7.781	1.35	1.007	
Phytoplankton	NA	0.060	1.513	0.595	0.453	

Table 4.2.Candidate benchmarks for Lake Michigan open waters. Model statistics are calculated for Scenario 5 (simulating the September 2008 storm without hydrologic separation barrier) at location Jardine (shore). Statistics are available for all locations in the Appendix.

Variable	Benchmark	Min.	Max.	Mean	Std. dev.	Days exceeded
Total Phosphorous	0.007 mg/L	0012	0.74	0.060	0.093	30 out of 30
Ammonia	NA	0	1.09	0.034	0.130	NA
Chloride	12 mg/L	13.8	102.98	19.668	11.486	30 out of 30
DO	7.2 mg/L	5.47	8.74	8.155	0.543	1 out of 30
Nitrate	10 mg/L	0.003	1.52	0.127	0.224	0 out of 30
Fecal Coliform/ *E. coli*	20 CFU/100mL	1	95799	1728.8	9847.3	6 out of 30
CBOD	NA	0.002	14.23	0.696	1.738	NA
Phytoplankton	NA	0.022	0.307	0.096	0.074	NA

As shown by the results presented in Chapter 3 as well as in Table 4.1 and Table 4.2, the candidate benchmarks for only some of the water quality variables are exceeded at the major water intake locations even during major storm events (such as the 2008 September storm event simulated in scenarios 4 and 5). Tables 4.1 and 4.2 also show the minimum, maximum and standard deviations in the different variables of interest for monitoring water quality at intakes. These show that *E. coli*, Phosphorous exceed the benchmark values at nearshore intakes that are located close to major discharges into Lake Michigan.

4.1 Comparison between Scenario 3 and Scenario 5

The results from Scenario 3 (with hydrologic separation) and Scenario 5 (without hydrologic separation barrier) are presented in Table 4.1 and Table 4.2 respectively. The statistics and exceedance rates are calculated for a period of 30 days (Sept 1 - Sept 30) which covers the September storm event in 2008. The results suggest that in the presence of the hydrologic barrier during the storm event, the mean total phosphorous concentration is more than twice as high, but the maximum concentrations are comparable. The phytoplankton concentration is also similarly much higher in the presence of a hydrologic separation barrier due to a higher nutrient (inorganic phosphorous) availability in the water column. Other water quality variables of interest based on the benchmarks available to this study suggest similar values.

The number of days the benchmark is exceeded was also calculated for the same 30 day period (Sept 1 - Sept 30). An exceedance was reported if the prescribed water quality benchmark was exceeded at least 6 hours out of a 24 hour period. As shown by the results presented in Table 4.2, in the presence of the separation barrier, the number of exceedance of fecal indicator bacteria shows a significantly higher exceedance rate.

4.2 Vertical variability in concentrations

Concentrations of water quality variables show a lot of vertical variability in the water column. This is due to variations in temperature, sunlight intensity and the effect of sediment layer on biological and physical processes that affect process rates included in the water quality model. In order to graphically present the variability of different water quality variables within the water column, Figures 4.1-4.10 below show the concentrations at 5 ft. interval depths for September 2008 (scenario 3) model simulation. Except for the phytoplankton that shows higher growth rate at the surface and as a result shows a higher concentration at surface, most other water quality variables have a lower concentration at the surface and higher concentration at the bottom layers. In Figures 4.1-4.20, depths are shown in feet below the Chicago City Datum (CCD). The continuous release in Scenario 3 represents what would happen if hydrologic separation barriers were built on the Chicago Sanitary and Ship Canal and Cal-Sag Channel.

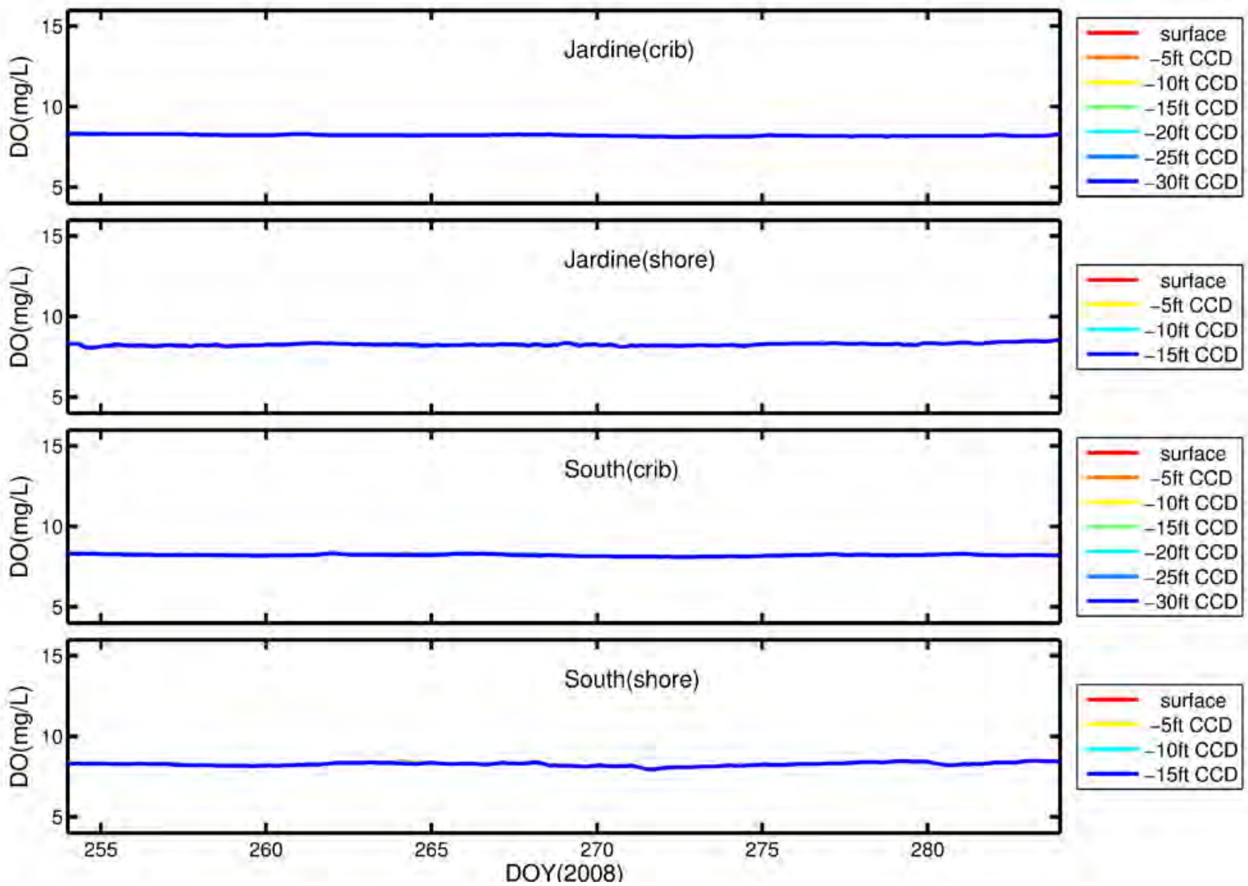

Figure 4.1 Concentration of dissolved oxygen at different depths at a few locations

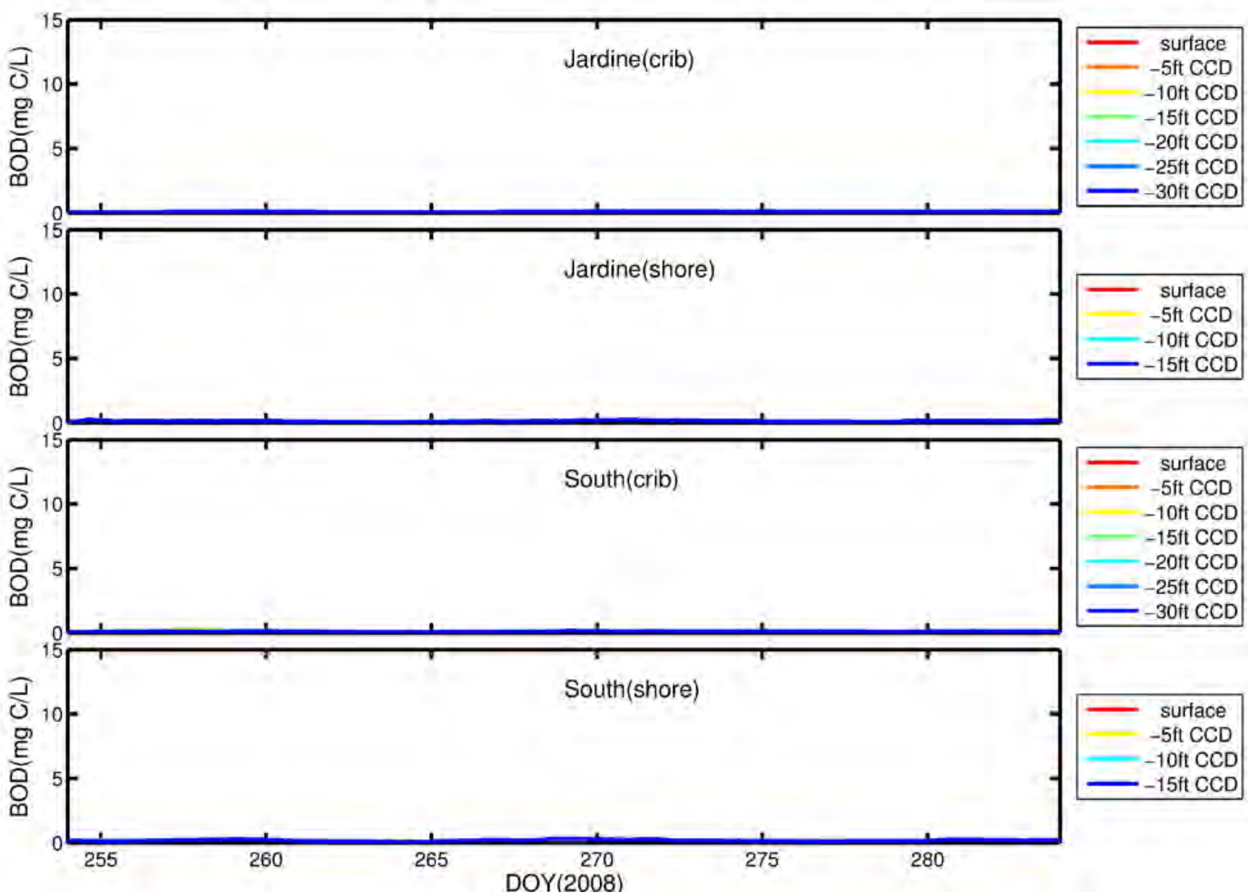

Figure 4.2 Concentration of oxygen demand at different depths at a few locations

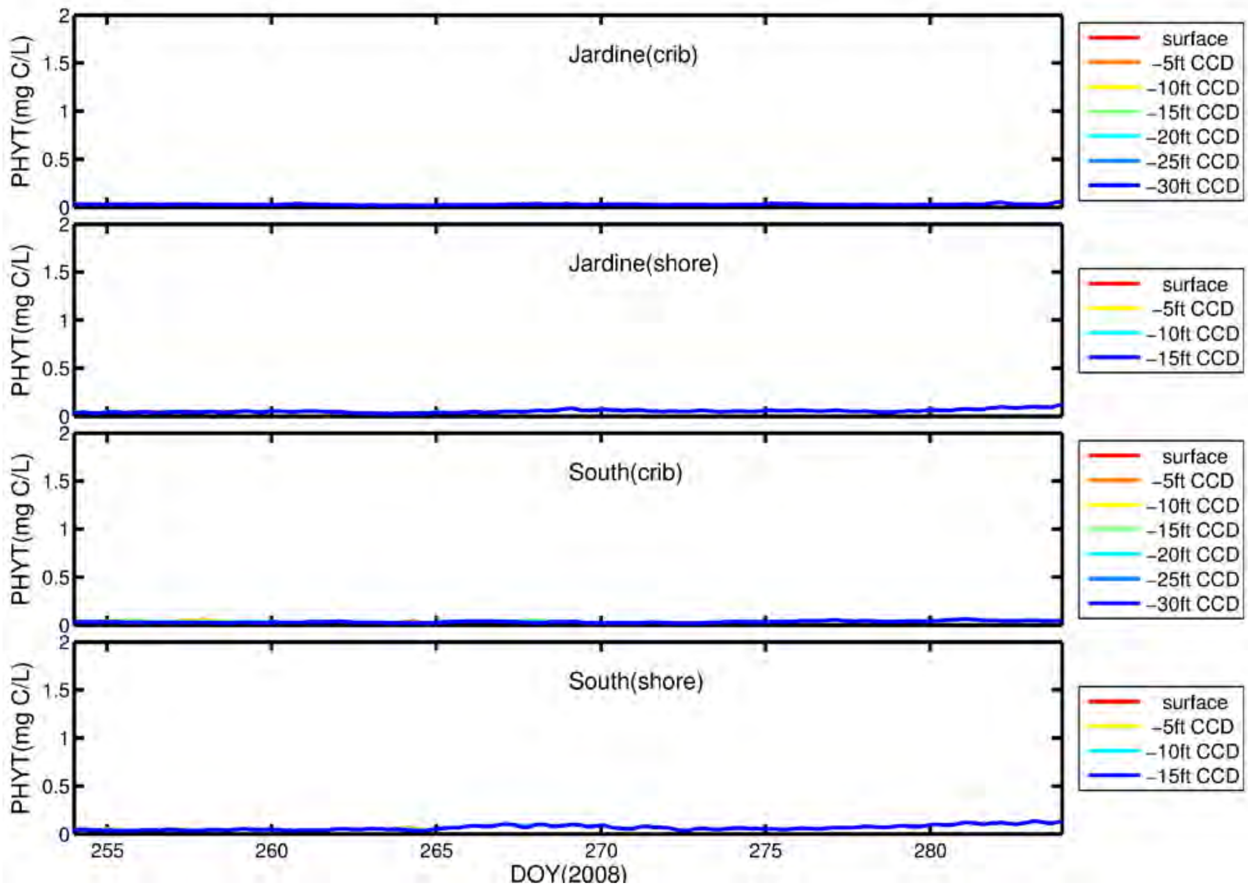

Figure 4.3 Concentration of phytoplankton at different depths at a few locations

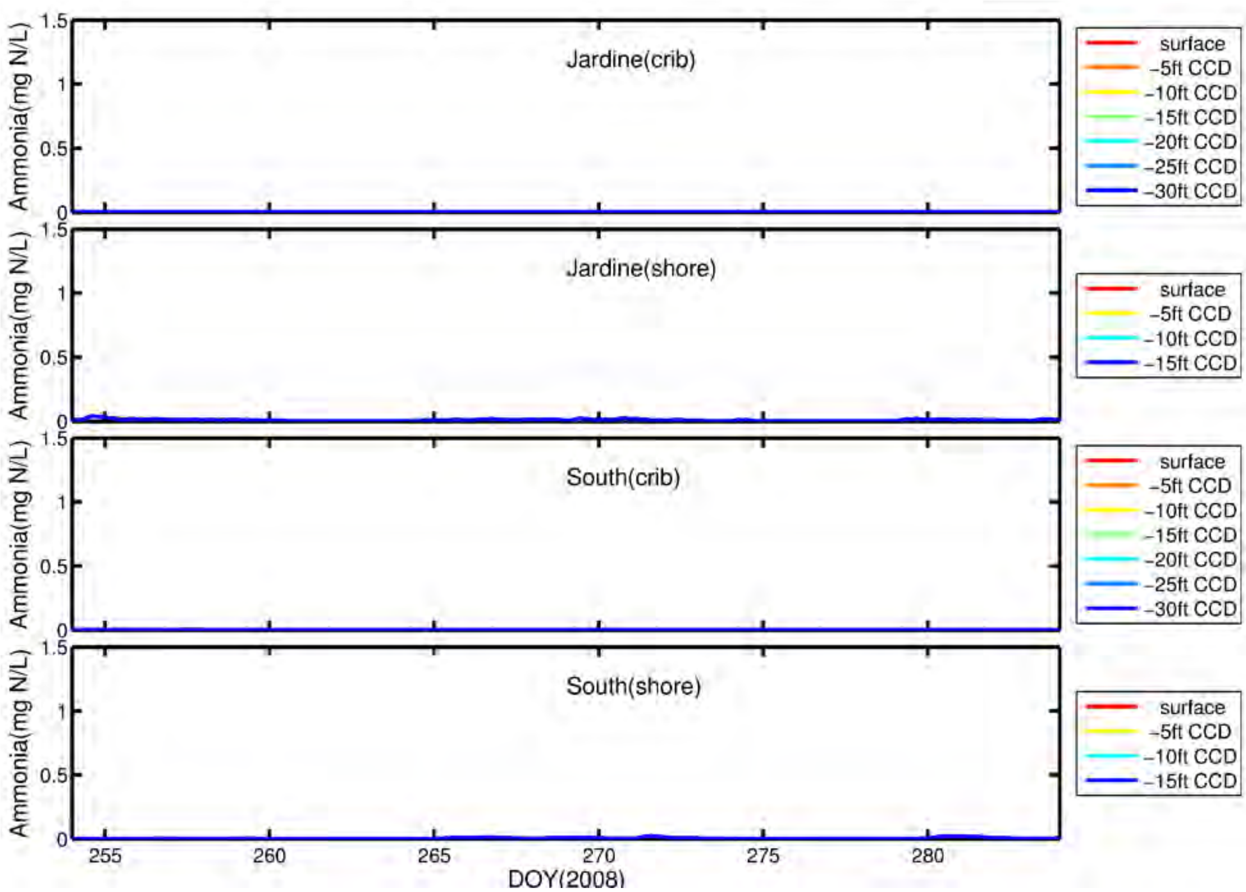

Figure 4.4 Concentration of ammonia at different depths at a few locations

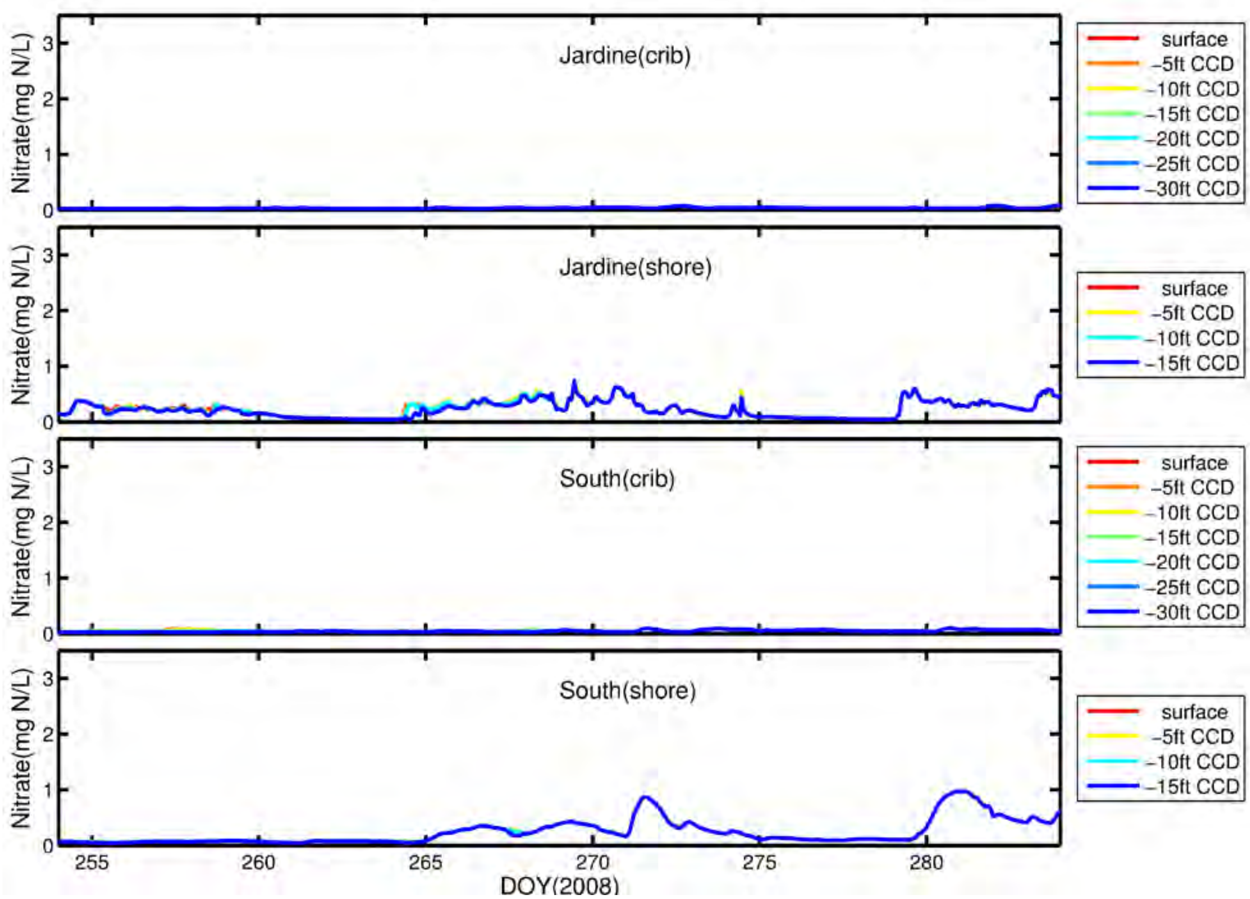

Figure 4.5 Concentration of nitrate at different depths at a few locations

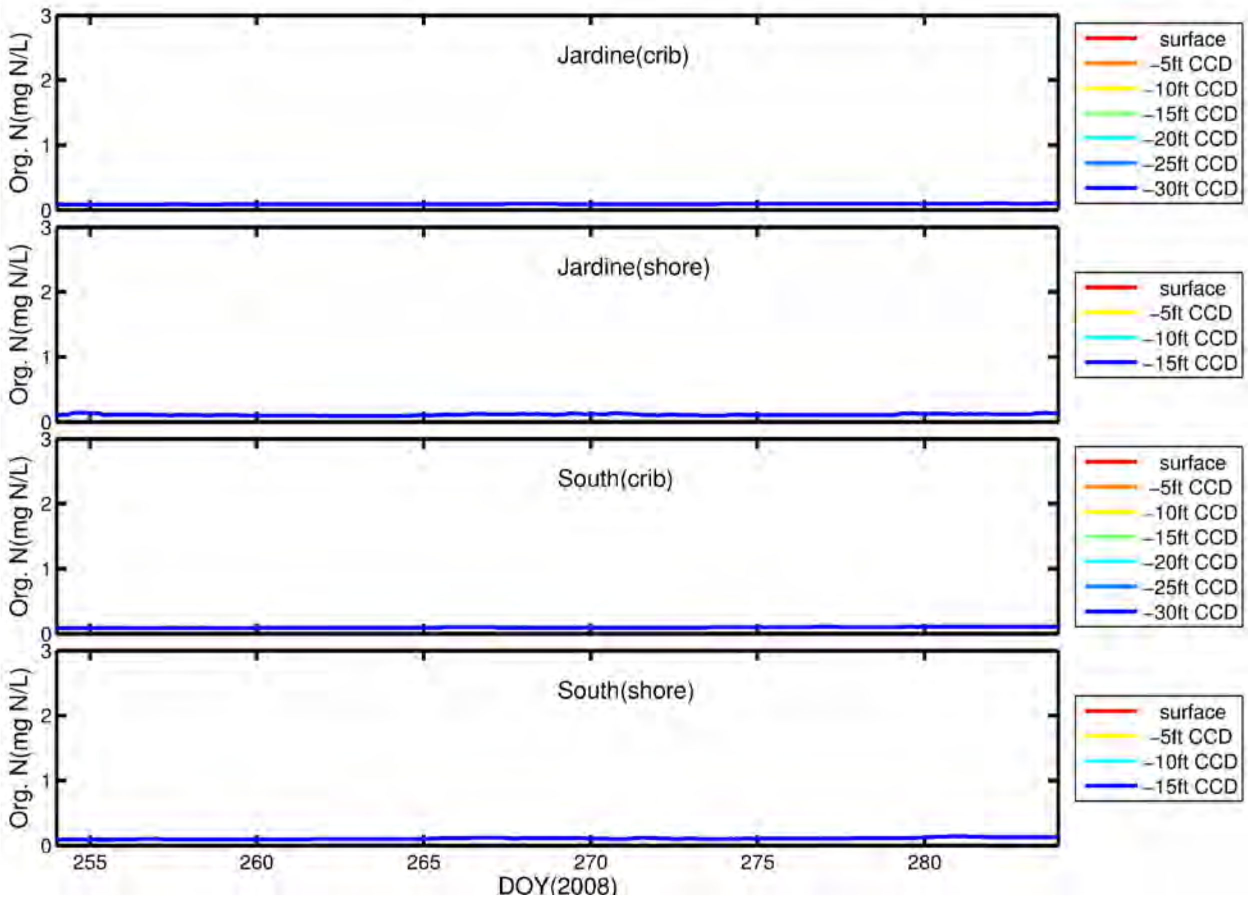

Figure 4.6 Concentration of organic nitrogen at different depths at a few locations

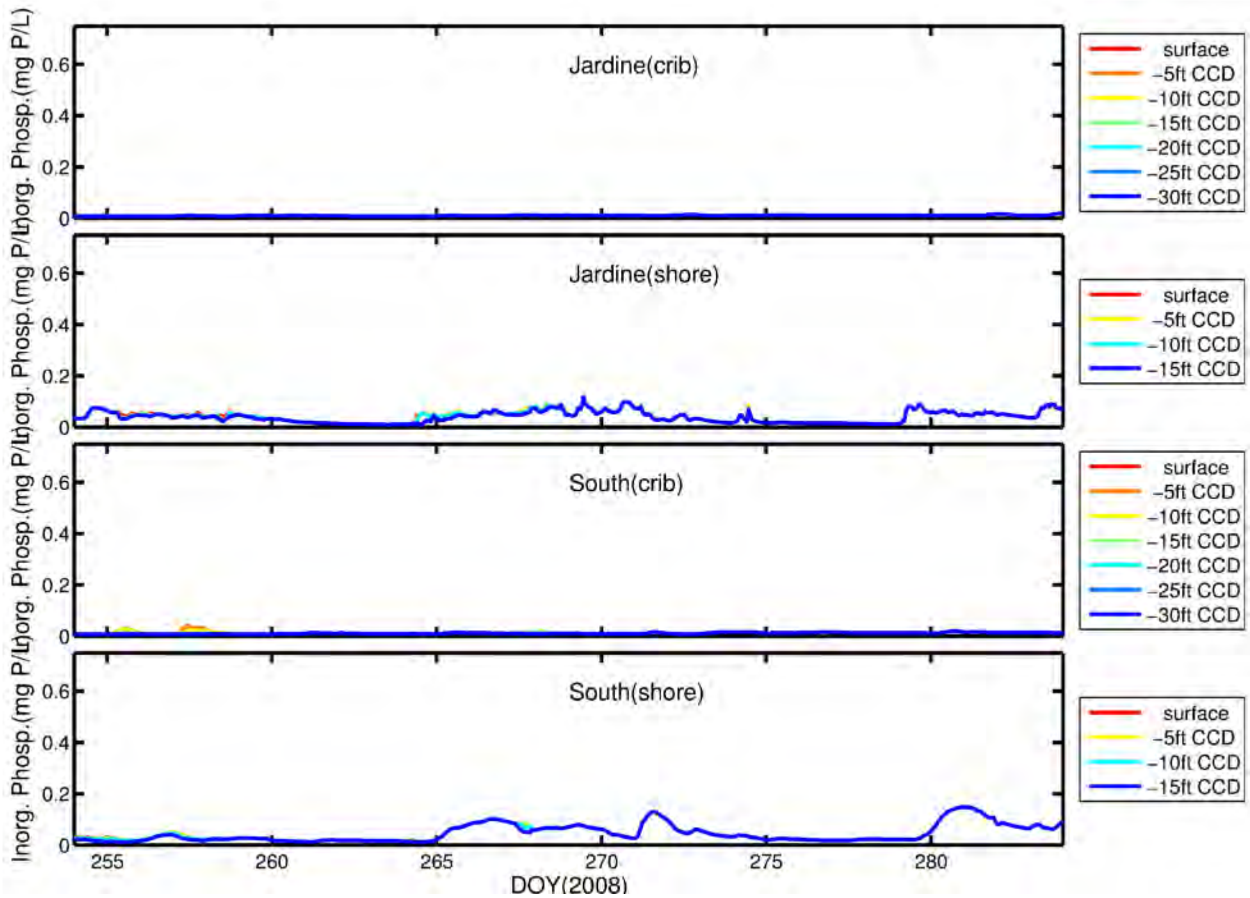

Figure 4.7 Concentration of ortho-phosphate at different depths at a few locations

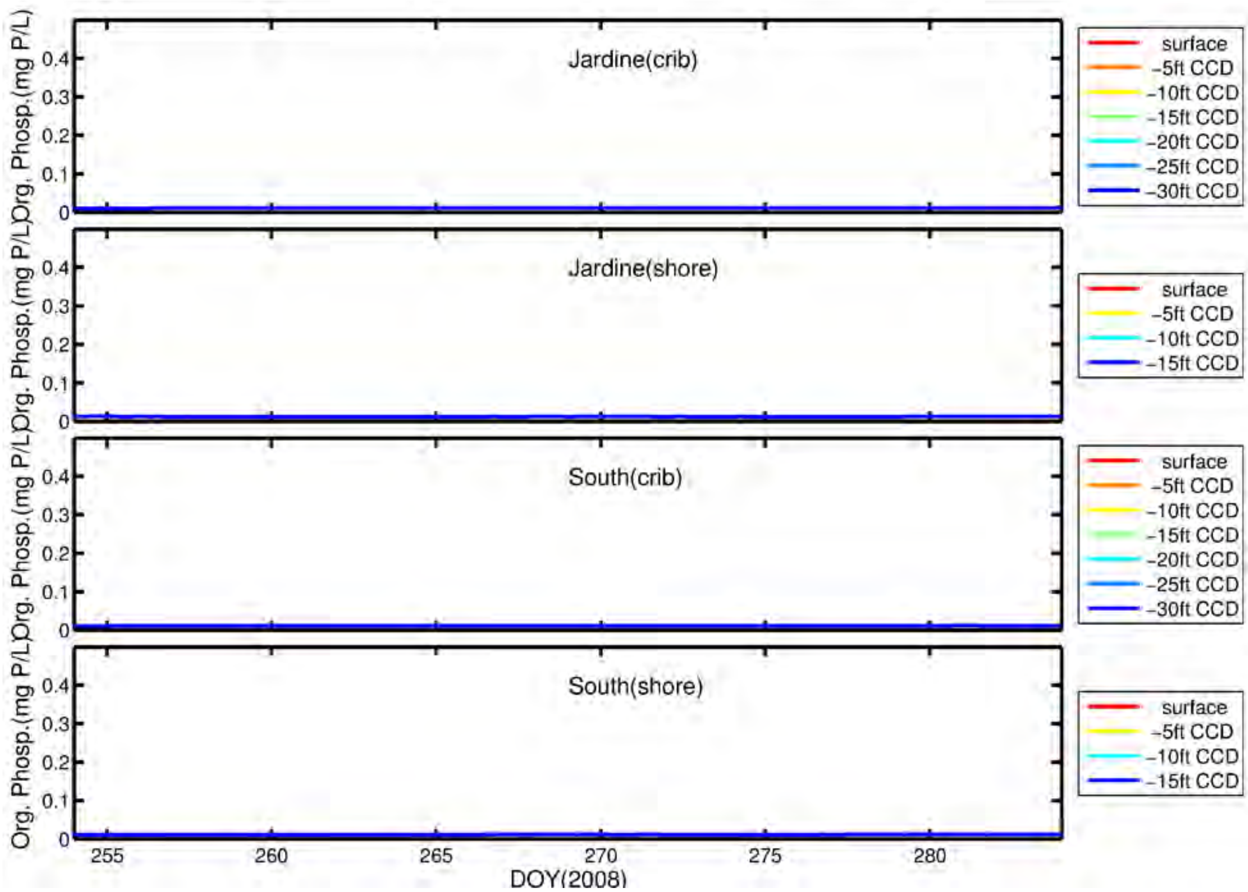

Figure 4.8 Concentration of organic phosphorous at different depths at a few locations

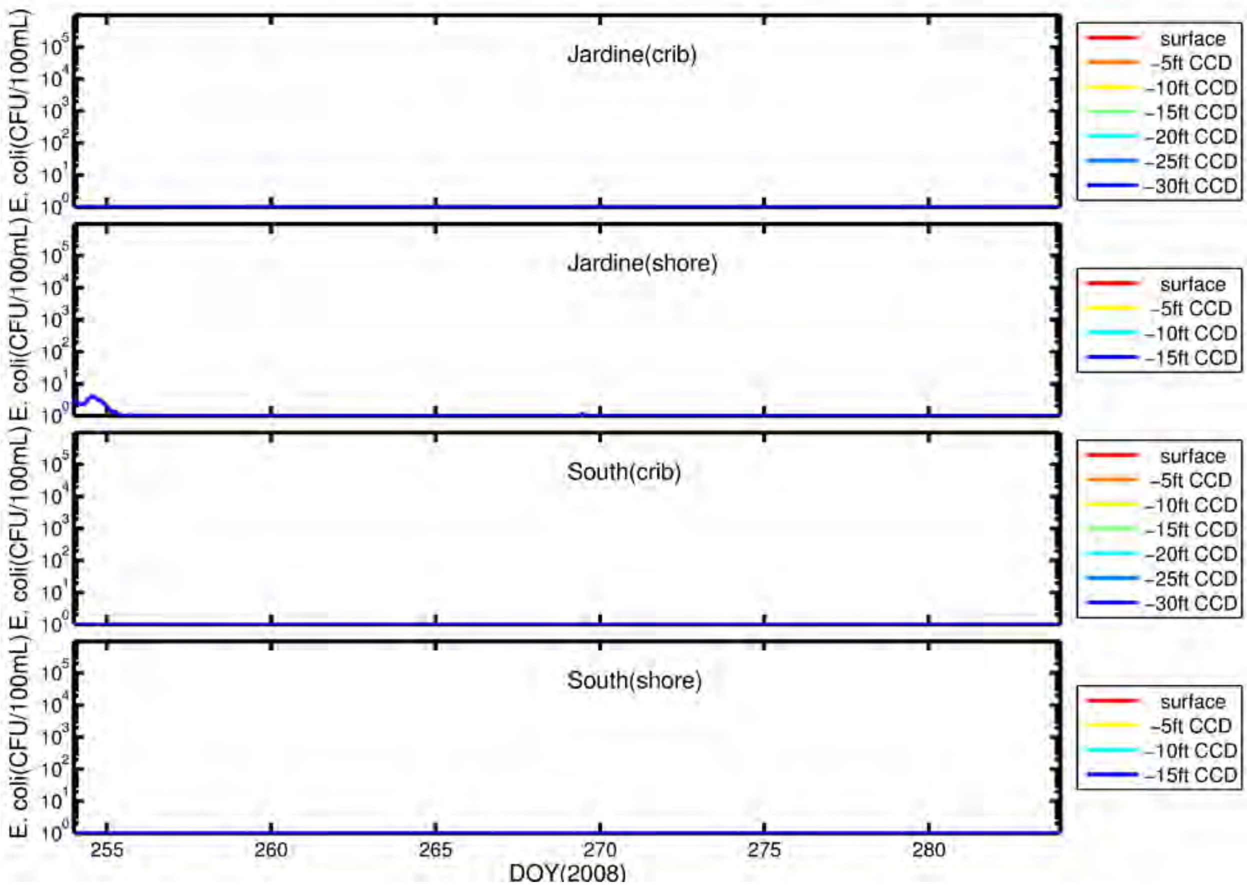

Figure 4.9 Concentration of *E. coli* at different depths at a few locations

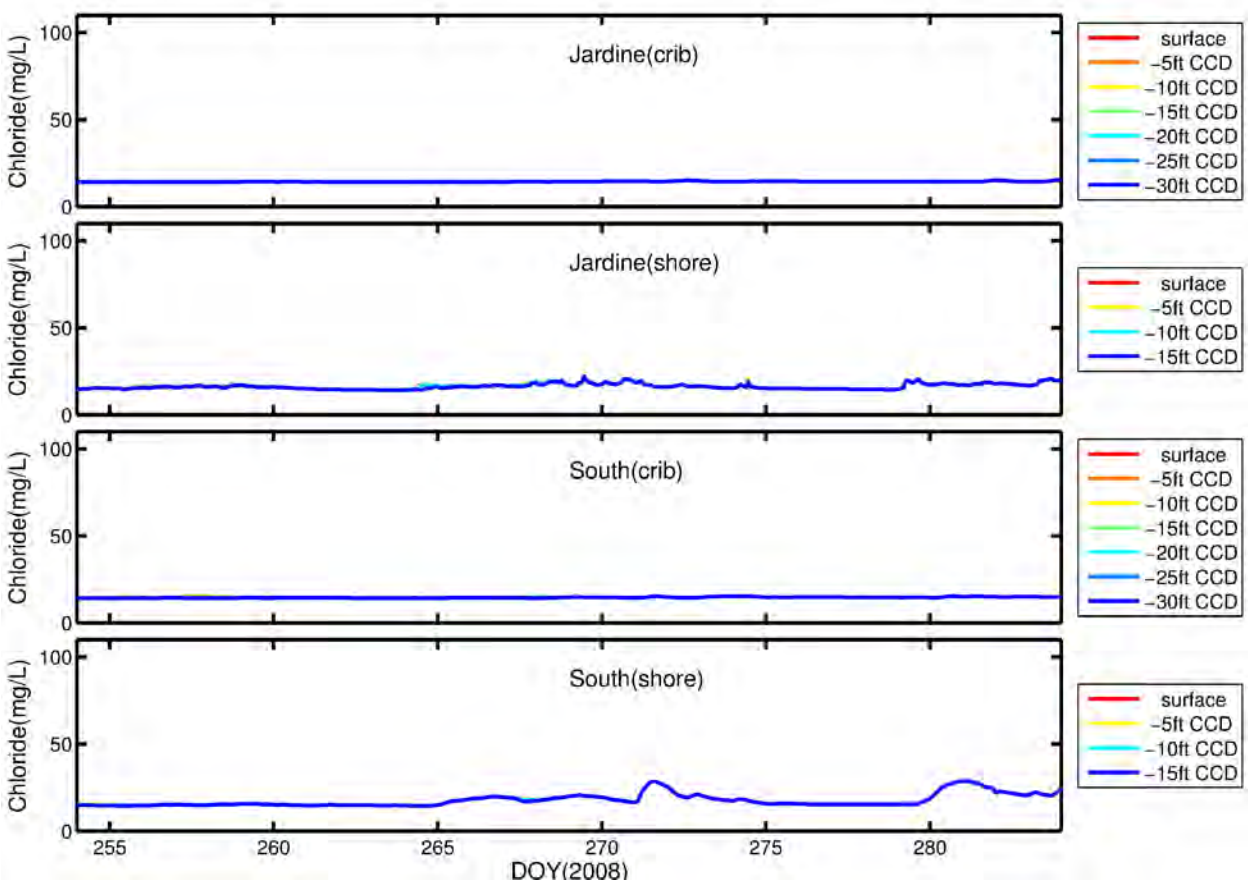

Figure 4.10 Concentration of chloride at different depths at a few locations

Figures 4.11-4.20 below show the concentrations at 5 ft. interval depths for September 2008 (scenario 5) model simulation. Except for the phytoplankton that shows higher growth rate at the surface and as a result shows a higher concentration at surface, most other water quality variables have a lower concentration at the surface and higher concentration at the bottom layers. In Figures 4.11-4.20, depths are shown in feet below the Chicago City Datum (CCD). The episodic release in Scenario 3 represents what would happen if hydrologic separation barriers were not built on the Chicago Sanitary and Ship Canal and Cal-Sag Channel and the meteorological conditions were similar to the September 2008.

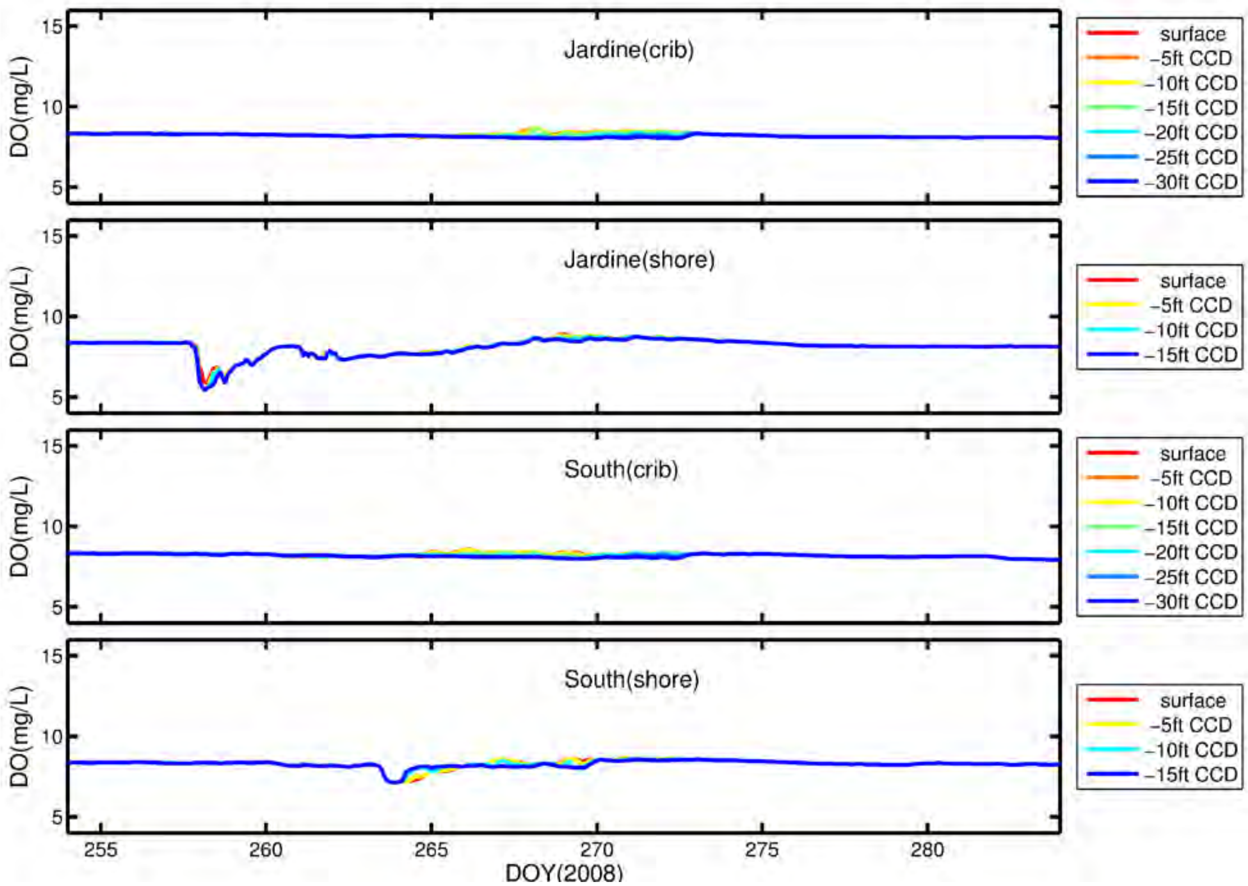

Figure 4.11 Concentration of dissolved oxygen at different depths at a few locations

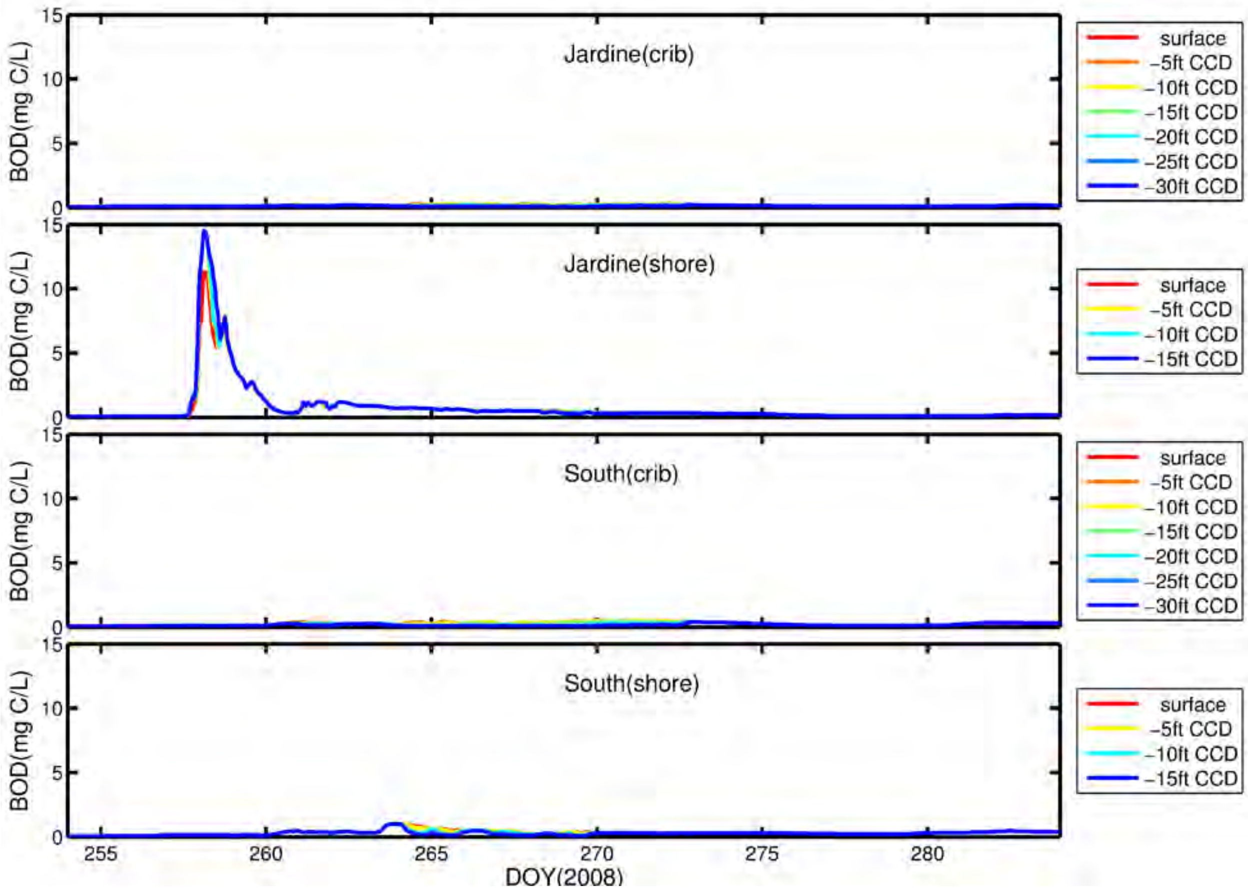

Figure 4.12 Concentration of oxygen demand at different depths at a few locations

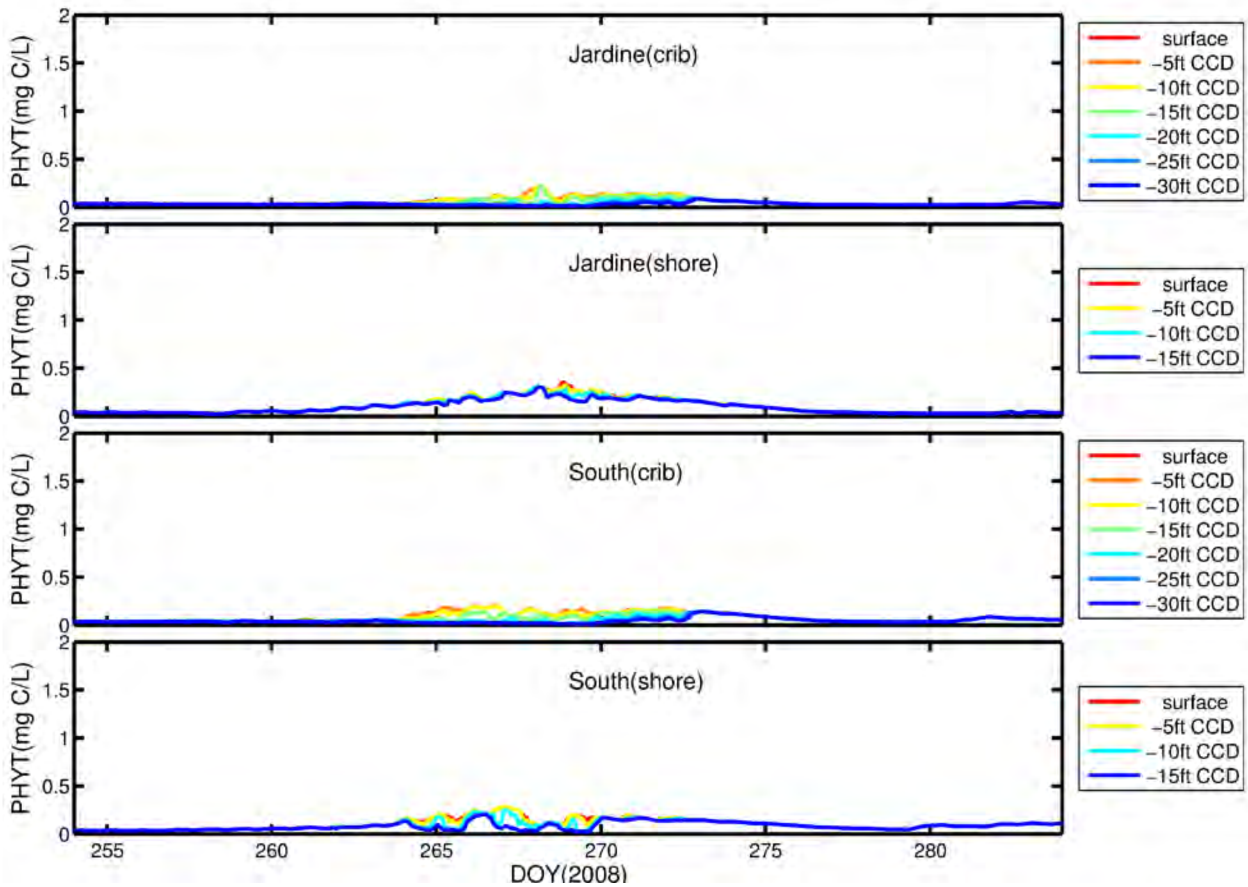

Figure 4.13 Concentration of phytoplankton at different depths at a few locations

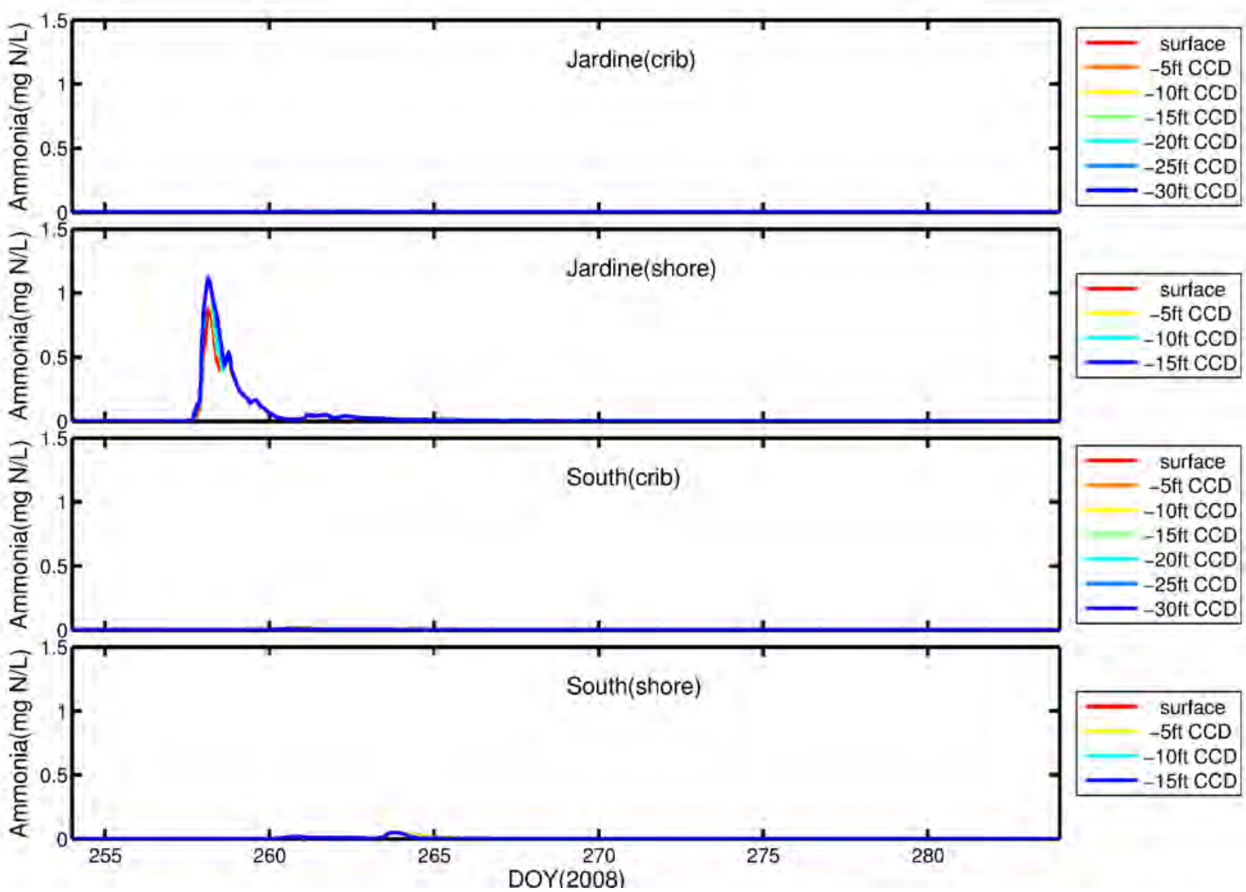

Figure 4.14 Concentration of ammonia at different depths at a few locations

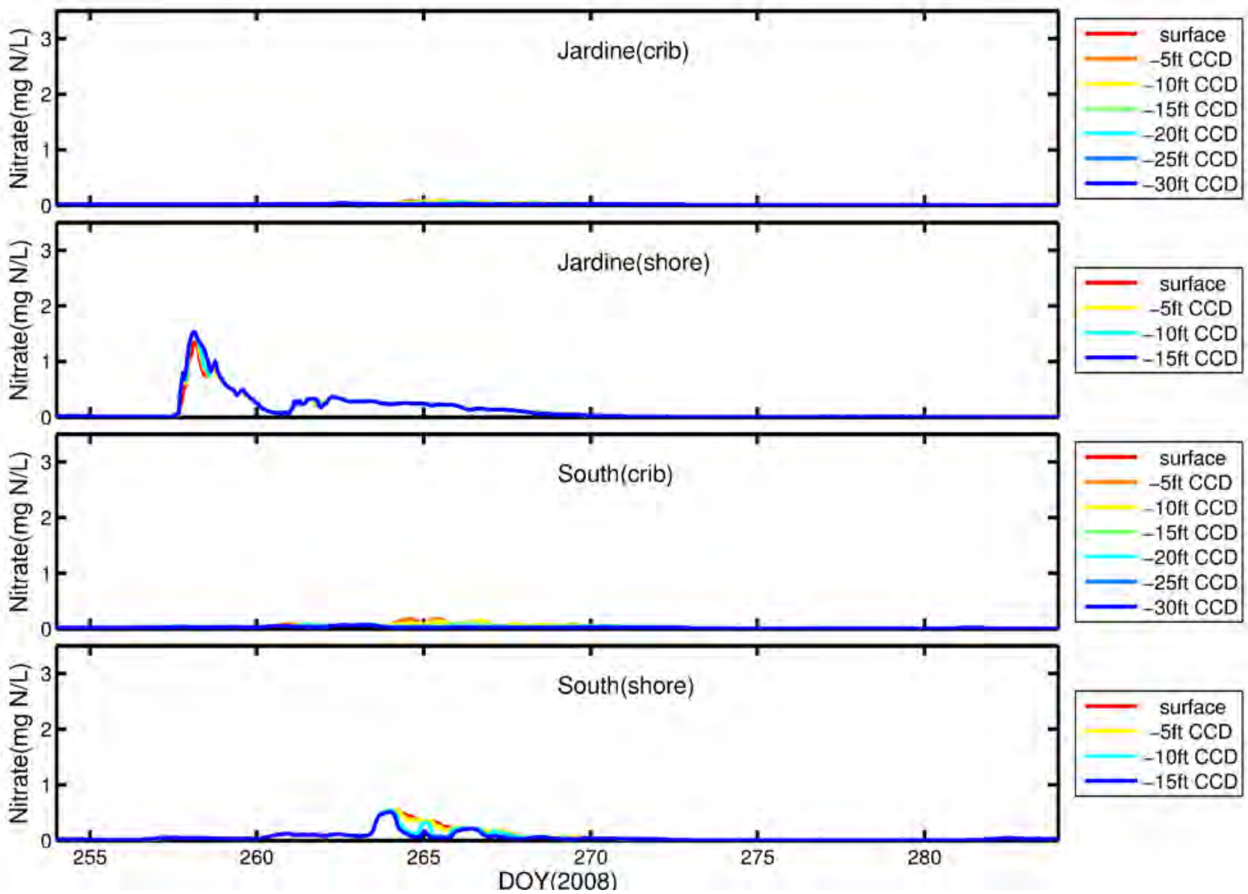

Figure 4.15 Concentration of nitrate at different depths at a few locations

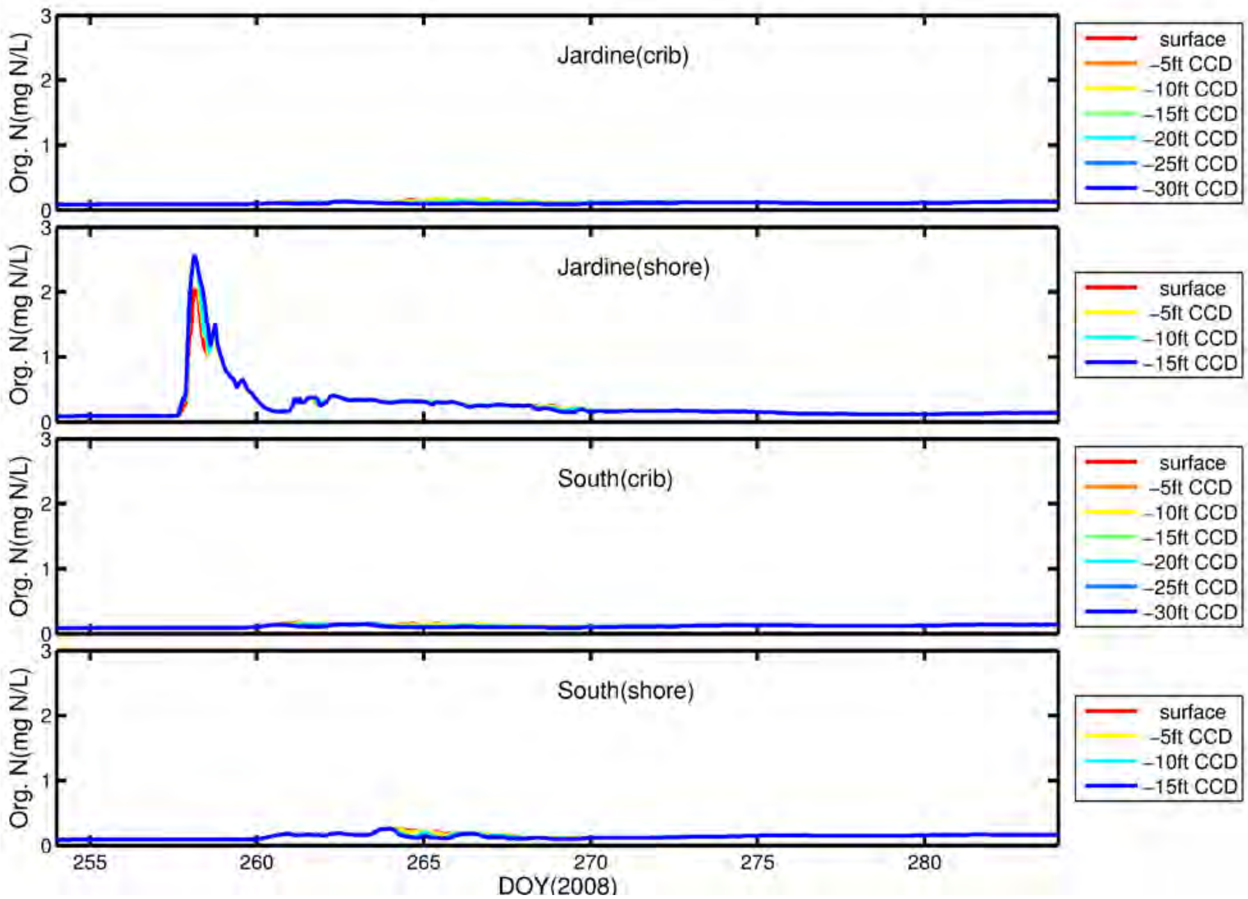

Figure 4.16 Concentration of organic nitrogen at different depths at a few locations

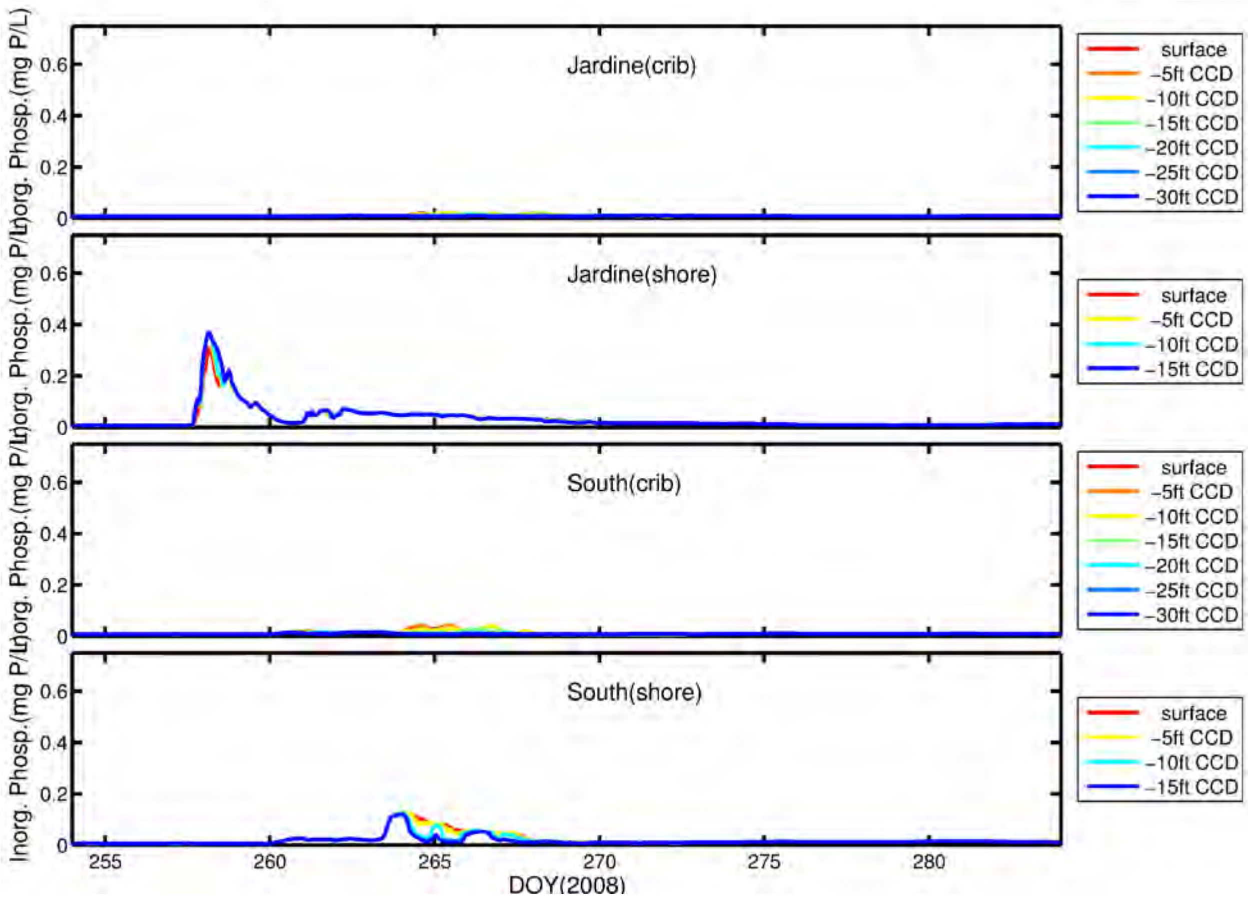

Figure 4.17 Concentration of ortho-phosphate at different depths at a few locations

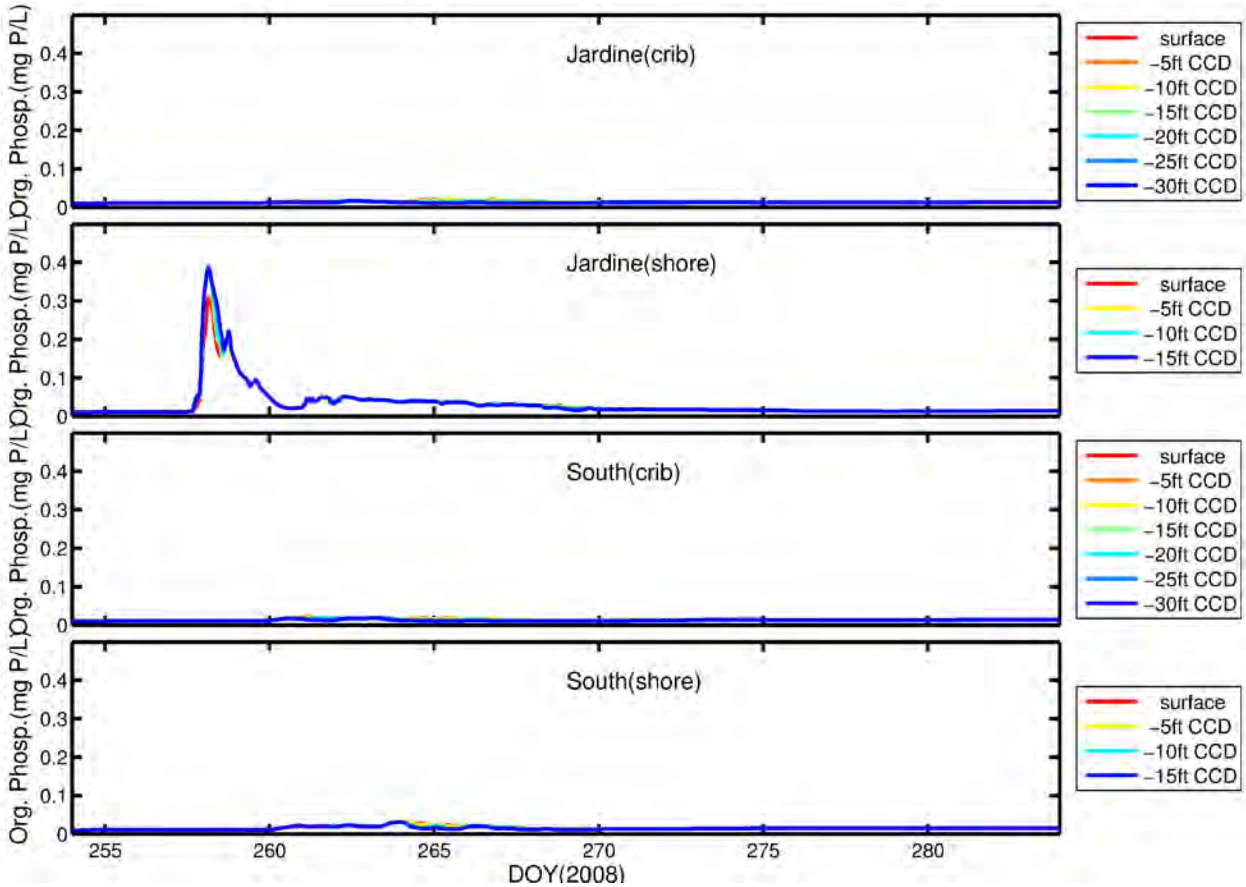

Figure 4.18 Concentration of organic phosphorous at different depths at a few locations

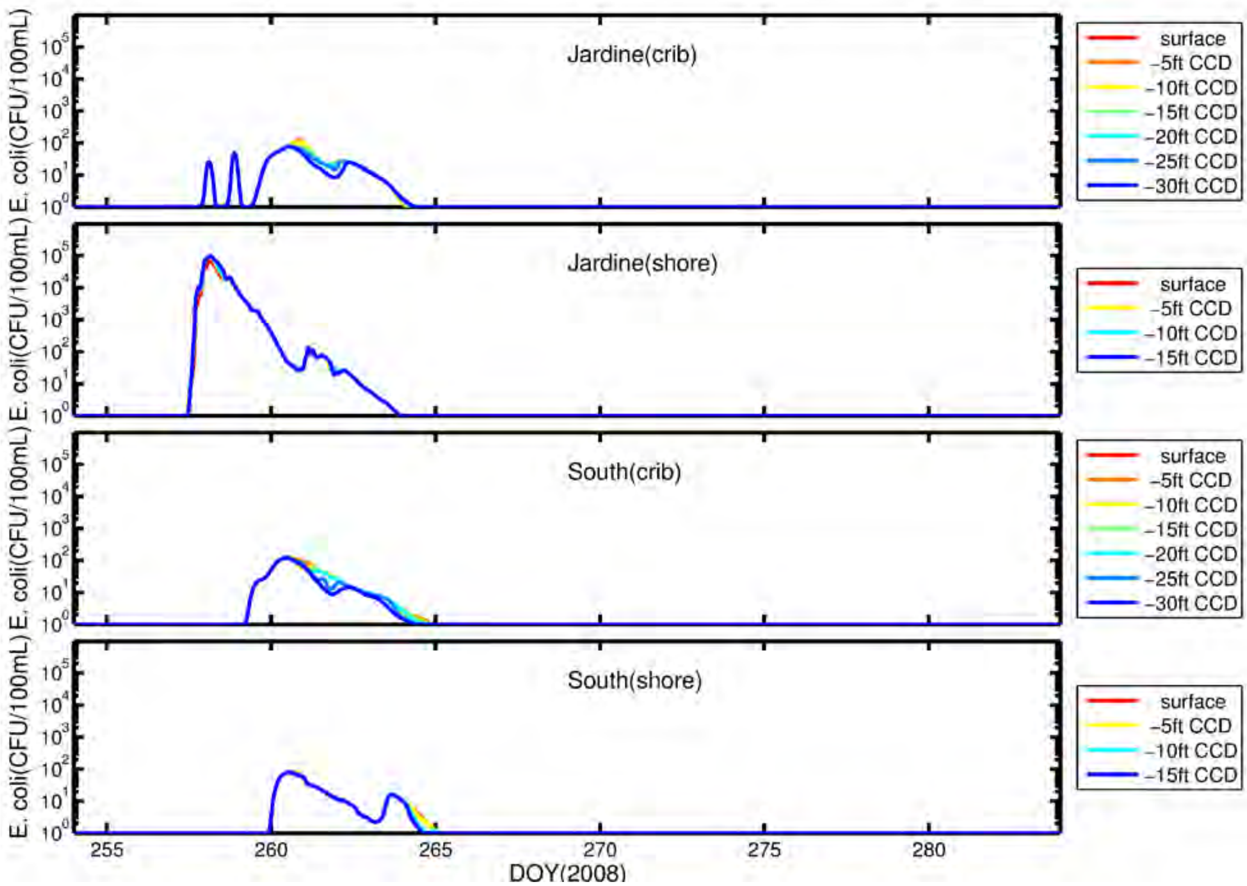

Figure 4.19 Concentration of *E. coli* at different depths at a few locations

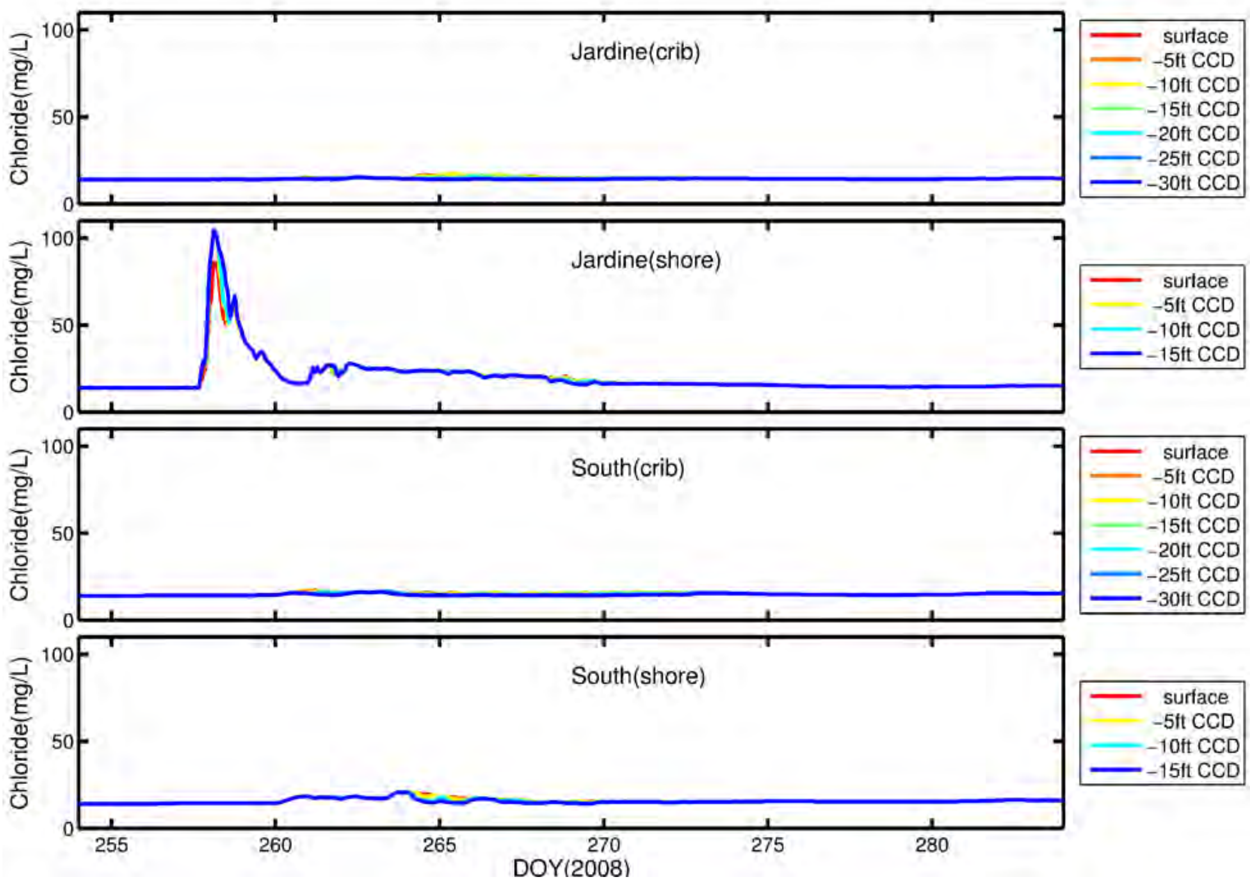

Figure 4.20 Concentration of chloride at different depths at a few locations

The mixing and transport of contaminants entering the nearshore environment in Lake Michigan is highly complex. The shape and size of the contaminant plume is determined by circulation patterns and mixing rates. The dynamic nature of these processes is not completely shown by the time-series plots presented in Chapter 3. Figure 4.11 (below) shows the spatial extent of the contaminant plumes entering southern Lake Michigan from the five outfalls (Wilmette, Chicago, Calumet, Indiana harbor Canal, Burns Ditch) during the September 2008 storm event modeled in Scenario S5 at the end of the simulation period. These plots show that the contaminants disperse very quickly and that the concentrations of contaminants in the plume reach ambient (lake background levels) within a few kilometers offshore. The spatial extent of the contaminant plumes depends on a number of factors including the volume of discharge, ratio of contaminant levels in the discharge to background levels and rate at which the contaminants are degraded/assimilated in the environment. Contour plots presented in Figure 4.11, suggest that nutrients entering the nearshore region are quickly dissipated and consumed. The concentrations of these variables therefore fall below water quality criteria for the nearshore waters very quickly. However, *E. coli* (indicative of fecal contamination of recreational waters) is significantly higher, longer and takes as much as 7 days after the discharge events to dissipate to background levels (as shown by Figure 4.9 for this scenario).

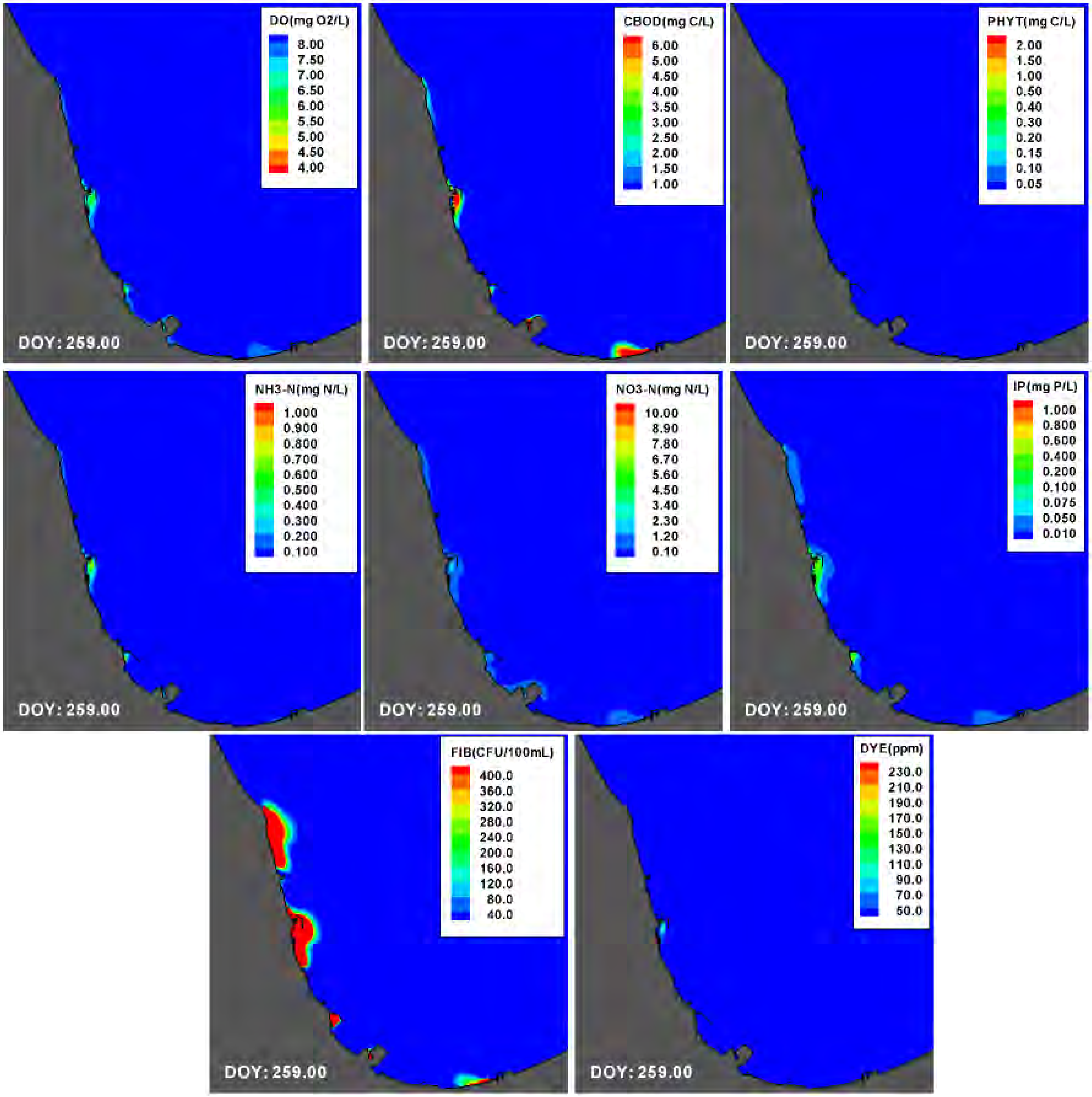

Figure 4.21 Contaminant plume shape and size on Julian Day (DOY) 259 based on Scenario 5 loading criteria

Chapter 5: Concluding Remarks

The principal objectives of this study were to assess the impacts of discharges from outfalls in southern Lake Michigan on the nearshore water quality as well as on lake-wide circulation and concentration levels. We have used a numerical water quality model coupled to a hydrodynamic model to simulate the transport, mixing and biogeochemical processes that impact the concentrations of water quality variables in the water column. The models were tested using observations from a field study conducted in Southern Lake Michigan near the Burns Ditch outfall. The results of the testing (validation) experiments presented in Chapter 3 demonstrate that the model is able to simulate temperature and currents in the nearshore with a high degree of accuracy. The model is also able to predict the variation in contaminant concentrations close to the outfalls. However, some of the peak concentrations could not be accurately resolvedby the model. This could be due to the low-resolution of observations available at the source (Burns Ditch) as well as at the sampling point (WQ1). Simulation results reveal a high degree of vertical variability in the concentrations of water quality variables modeled, however representative water sampling at three different depths in the water column might be unable to accurately estimate the average concentration at any point. In addition, several processes are not included in the numerical water quality model, including wave resuspension of nutrients from the sediment, spatially variable sediment oxygen demand, discharge from overland flow and other minor outfalls, distributed sources along the shoreline etc. All these processes are likely to add to the uncertainty in the model predictions and accounting for these processes/ sources better could improve the water quality models accuracy.

Several scenarios of interest were identified and the results of these simulations are presented in Chapter 3. The results of these simulations are presented as time-series of the concentration of water quality variables at different intake locations. Comparing the values at the intake locations with candidate benchmarks for water quality thresholds, it is clear that contaminant concentrations fall quickly to background levels due to the mixing and transport in the nearshore region. Nutrient inputs into the nearshore significantly increase the primary production and algal biomass production in the water column. This can be observed clearly by comparing the phytoplankton concentrations predicted by the baseline seasonal simulation (Scenario 1) with long-term continuous release simulations (Scenarios 2 and 3).

The severe loading conditions simulated in the episodic release scenarios (S4 and S5) reveal that the impact of a large discharges of contaminants into the nearshore – such as the one observed during the September 2008 storm – is greatest at the locations closest to where the discharges enter the nearshore. However, physical and biological processes quickly reduce the levels of contaminants in the water column to levels that are below candidate benchmark levels. On average, the impact of the storm was completely dissipated in about 7-10 days.

Model Assumptions and Limitations

The processes that determine the transport, dissipation, and degradation of contaminants in the water column are highly complex. Some of the simplifications in our modeling include the following: (a) sediment and particle processes as well as waves, wave-current interactions and their influence on particle processes and contaminant concentrations are not accounted for (b) spatially variable sediment oxygen demand and distributed sources and their impact on water quality are not described by the models. A potential impact of these simplifying assumptions is that some of the water quality variables such as Chloride or Nitrate may accumulate over time. A continuous simulation (e.g., over decades) based on a more detailed modeling that takes these processes into account may provide additional information about the long-term effect of the discharges into Lake Michigan.

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Appendix-A

1. Hydrodynamic Model

The hydrodynamic model used in this study is the Finite-Volume Coastal Ocean Model (FVCOM, [*Chen et al.*, 2003]) which solves the three-dimensional hydrodynamic equations in their primitive form. Since Lake Michigan is a large freshwater lake and density differences are not a significant driver of circulation in the lake, a model such as FVCOM that assumes hydrostatic distribution of pressure in the vertical is expected to describe the hydrodynamics well. The effect of temperature differences on momentum is included by invoking the Boussinesq approximation. Equations (1-3) below show the momentum transport equations solved by the hydrodynamic model. The continuity equation (4), and the temperature (5) equations are also given.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv = -\frac{1}{\rho_o}\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left(A_m\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_m\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right) \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu = -\frac{1}{\rho_o}\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left(A_m\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_m\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_m\frac{\partial v}{\partial z}\right) \quad (2)$$

$$\frac{\partial P}{\partial z} = -\rho g \quad (3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (4)$$

$$\frac{\partial \theta}{\partial t}+u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}+w\frac{\partial \theta}{\partial z}=\frac{\partial}{\partial x}\left(A_h\frac{\partial \theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_h\frac{\partial \theta}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_h\frac{\partial \theta}{\partial z}\right) \quad (5)$$

Here, $(u, v, w)$are the velocity components in the Cartesian (x, y, z) coordinates; f is the Coriolis component of force due to the transformation of rotating frame of reference to the inertial frame of reference; g is acceleration due to gravity; P is the fluid pressure; ρ and ρ_o are the actual and reference densities; K_h $(K_m)$and $A_h(A_m)$ are the vertical and horizontal eddy diffusivities (viscosities) that are calculated using the Mellor-Yamada and Smagorinsky models for turbulence closure respectively.

2. Numerical water quality model

The water quality module in FVCOM is based on the three-dimensional water quality analysis and simulation program (WASP5) that was originally developed by [*Ambrose et al.*, 1993]. It simulates the nitrogen and phosphorous cycles, phytoplankton dynamics as well as dissolved oxygen. In all there are eight distinct water quality variables that are solved: dissolved oxygen (DO), phytoplankton (PHYT), carbonaceous biochemical oxygen demand (CBOD), ammonium nitrogen (NH_4), nitrate and nitrite nitrogen (NO_3), ortho-phosphorous or inorganic phosphorous (OPO_4), organic nitrogen (ON), and organic phosphorous (OP). The individual water quality components were solved using the advection diffusion equation (1) with the component dependent internal source/sink (S) calculated using Equations (7-15).

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial x}\left(A_h\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_h\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_h\frac{\partial C}{\partial z}\right) + S + W_0 \qquad (6)$$

Here, C is the concentration (mass per unit volume) of the water quality component, S is the net of various internal sources and sinks depending on the component being modeled, $W_0$is the external loading from rivers, outfalls and non-point sources. u, v, w are the velocity components in the Cartesian x, y, z directions.

The equations used to calculate the internal sources and sinks for the specific water quality components are given in Equations 7-15. Chloride component is modeled as a tracer without any internal sources or sinks.

Dissolved Oxygen (DO)

$$S_1 = k_{r1}\theta_{r1}^{(T-20)}(C_s - C_1) - k_{d1}\theta_{r1}^{(T-20)}\frac{C_1C_3}{K_{BOD} + C_1} - \frac{32}{12}k_{r2}\theta_{r1}^{(T-20)}C_2$$

$$- \frac{32}{14}2k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{nitr} + C_1} + G_P\left[\frac{32}{12} + \frac{48}{14}a_{nc}\left(1 - P_{NH_4}\right)\right]C_2$$

$$- \frac{SOD}{D}\theta_{SOD}^{(T-20)} - k_{r3} \tag{7}$$

Phytoplankton (PHYT)

$$S_2 = G_PC_2 - D_PC_2 - \frac{\omega_2 S}{D}C_2 \tag{8}$$

Growth rate of phytoplankton (G_P) is a function of temperature (T) incident radiation and nutrient availability. In the model it has been calculated using:

$$G_P = k_{gr}\theta_{gr}^{(T-20)}f_1(N)f_2(I)$$

Here, the nutrient limitation factor $f_1(N)$is determined based on the calculated concentration of net available nitrogen (ammonium, nitrate, and nitrite) phosphorous (orthophosphate) assuming a Michaelis-Menten relationship based on limiting concentration being either nitrogen or phosphorous. The term $f_2(I)$ is the light limitation factor.

$$f_1(N) = \min\left(\frac{C_4 + C_5}{K_{mN} + C_4 + C_5}, \frac{C_6}{K_{mP} + C_6}\right)$$

While ammonium and nitrate are both nitrogen sources for phytoplankton growth, preference is given to the ammonium form for nitrogen. This is included in the model as the ammonium preference factor$\left(P_{NH_4}\right)$.

$$P_{NH_4} = \frac{C_4C_5}{(K_{mN} + C_4)(K_{mN} + C_5)} + \frac{C_4K_{mN}}{(C_4 + C_5)(K_{mN} + C_5)}$$

Death of phytoplankton due to viral lysis, grazing by zooplankton, and endogenous respiration is calculated using:

$$D_P = \left(k_{r2} + k_{par}k_{grz}\right)\theta_{gr}^{(T-20)}$$

Carbonaceous biochemical oxygen demand (CBOD)

$$S_3 = a_{oc}\left(k_{par} + k_{grz}\right)C_2 - k_{d1}\theta_{d1}^{(T-20)}\frac{C_1C_3}{K_{BOD} + C_1} - \frac{\omega_{3S}(1 - f_{D3})}{D}C_3 - \frac{5}{4}\times\frac{32}{12}\times\frac{12}{14}k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3} + C_1} \quad (9)$$

Ammonium nitrogen (NH_4)

$$S_4 = a_{nc}D_P(1 - f_{on})C_2 + k_{m1}\theta_{m1}^{(T-20)}\frac{C_2C_7}{K_{mPc} + C_2} - a_{nc}G_PP_{NH_4}C_2 - k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR} + C_1} + B_1 \quad (10)$$

Nitrate and nitrite nitrogen (NO_3)

$$S_5 = k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR} + C_1} - a_{nc}G_P\left(1 - P_{NH_4}\right)C_2 - k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3} + C_1} + B_2 \quad (11)$$

Ortho-phosphorous (OPO_4)

$$S_6 = a_{pc}D_P\left(1 - f_{op}\right)C_2 + k_{m2}\theta_{m2}^{(T-20)}\frac{C_2C_8}{k_{mPc} + C_2} - a_{pc}G_PC_2 + B_3 \quad (12)$$

Organic Nitrogen (ON)

$$S_7 = a_{nc} D_P f_{on} C_2 - k_{m1} \theta_{m1}^{(T-20)} \frac{C_2 C_7}{K_{mPc} + C_2} - \frac{\omega_{7S}(1 - f_{D7})}{D} C_7 \tag{13}$$

Organic Phosphorous (OP)

$$S_8 = a_{pc} D_P f_{op} C_2 - k_{m2} \theta_{m2}^{(T-20)} \frac{C_2 C_8}{K_{mPc} + C_2} - \frac{\omega_{8S}(1 - f_{D8})}{D} C_8 \tag{14}$$

Fecal Indicator bacteria (FIB)

$$S_9 = C_9 \left(k_d + k_I I + \omega_9 f_{pFIB}\right) \theta_{FIB}^{(T-20)} \tag{15}$$

All the terms used in calculating the internal sources and sinks are defined in Table 2.1

The values of parameters were chosen based on the information available in literature and adjusting them based on the validation/testing dataset collected in southern Lake Michigan during summer 2012 field study.

The oxygen reaeration rate $k_{r1}$was chosen as in the case of [*Zheng et al.*, 2004] as the maximum of flood-induced reaeration and wind-induced reaeration. The dissolved oxygen saturation concentration $C_S$for freshwater systems was determined based on temperature (T) using:

$$\ln C_S = -139.34 + (1.5757 \times 10^5) T^{-1} - (6.6423 \times 10^7) T^{-2} + (1.2438 \times 10^{10}) T^{-3} - (8.6219 \times 10^{11}) T^{-4}$$

Sediment oxygen demand (SOD)is due to various biological and chemical reactions that take place on the surface of the sediment layer and within the sediment layer. This is dependent on a number of factors including the amount of sunlight reaching the bottom sediment layer, microbiological activity, temperature, nutrient concentrations, and detritus levels in the sediment layer.

Table 1 Definition and value of the parameters used in the water quality model

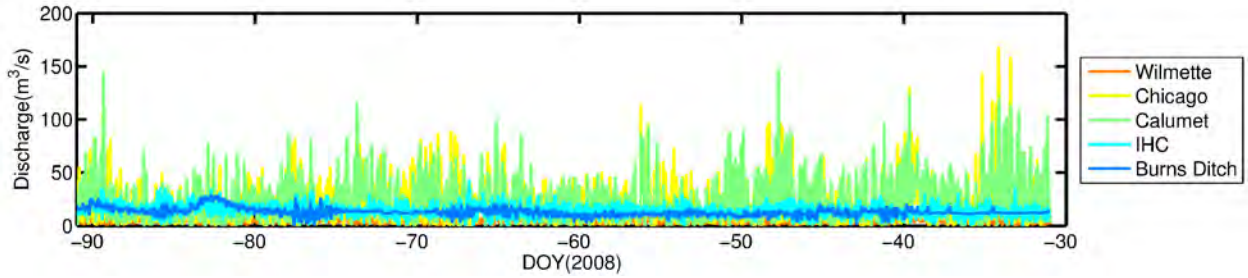
Name	Description	Value
k_{r1}	Reaeration rate (day^{-1})	$\max(k_f, k_w)$
k_f	Flow induced reaeration rate (day^{-1})	O'Connor method.
k_w	Wind-induced reaeration rate (day^{-1})	Covar method
k_{d1}	CBOD de-oxygenation rate (day^{-1})	.10
k_{ni}	Nitrification rate (day^{-1})	.09
k_{r2}	Phytoplankton respiration rate (day^{-1})	.10
k_{r3}	Bacterial respiration rate (mg O_2/day^{-1})	0.0
k_{dn}	De-nitrification rate (day^{-1})	.09
k_{gr}	Phytoplankton optimum growth rate (day^{-1})	2.5
$k_{par} + k_{grz}$	Phytoplankton basal loss rate (day^{-1})	.04
k_{m1}	Organic nitrogen mineralization rate (day^{-1})	.075
k_{m2}	Organic phosphorous mineralization rate (day^{-1})	.22
θ_{r1}	Temperature adjustment for reaeration rate	1.028
θ_{d1}	Temperature adjustment for de-oxygenation rate	1.047
θ_{ni}	Temperature adjustment for nitrification rate	1.080
θ_{r2}	Temperature adjustment for phytoplankton respiration rate	1.080
θ_{dn}	Temperature adjustment for de-nitrification rate	1.080

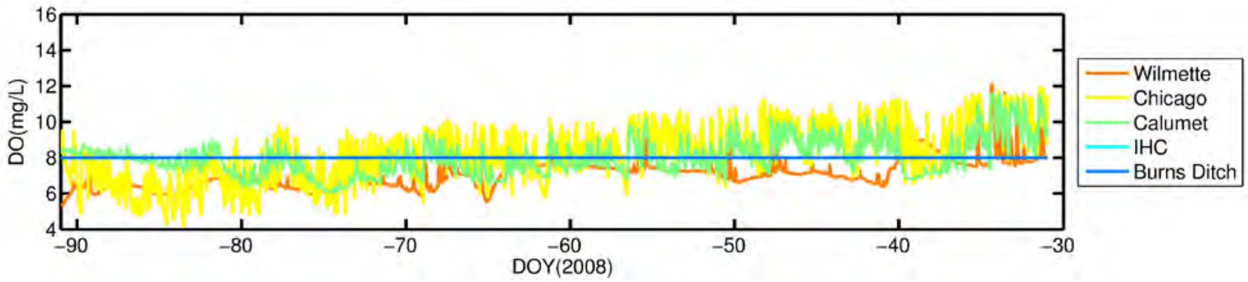
θ_{gr}	Temperature adjustment for phytoplankton growth rate	1.066
θ_{mr}	Temperature adjustment for phytoplankton death rate	1.0
θ_{m1}	Temperature adjustment for org. nitrogen mineralization rate	1.080
θ_{m2}	Temperature adjustment for org. phosphorous mineralization rate	1.080
θ_{SOD}	Temperature adjustment for SOD	1.080
SOD	Sediment oxygen demand ($gm^{-2}.day^{-1}$)	.2
K_{BOD}	Half-saturation conc. for oxygen limitation of CBOD oxidation (mg O_2 L^{-1})	.5
K_{NITR}	Half-saturation conc. for oxygen limitation of nitrification (mg O_2 L^{-1})	.5
K_{NO_3}	Half-saturation conc. for oxygen limitation of de-nitrification (mg O_2 L^{-1})	.10
K_{mN}	Half-saturation conc. for nitrogen uptake (µg N L^{-1})	25.0
K_{mP}	Half-saturation conc. for phosphorous uptake (µg P L^{-1})	1.0
k_{mPc}	Half-saturation conc. for phytoplankton limitation (mg C L^{-1})	1.0
ω_{2S}	Settling velocity for phytoplankton (m/d)	.5
ω_{2S}	Settling velocity of CBOD (m/d)	.5
ω_{2S}	Settling velocity of particulate organic nitrogen (m/d)	.5
ω_{2S}	Settling velocity for particulate organic phosphorous (m/d)	.5

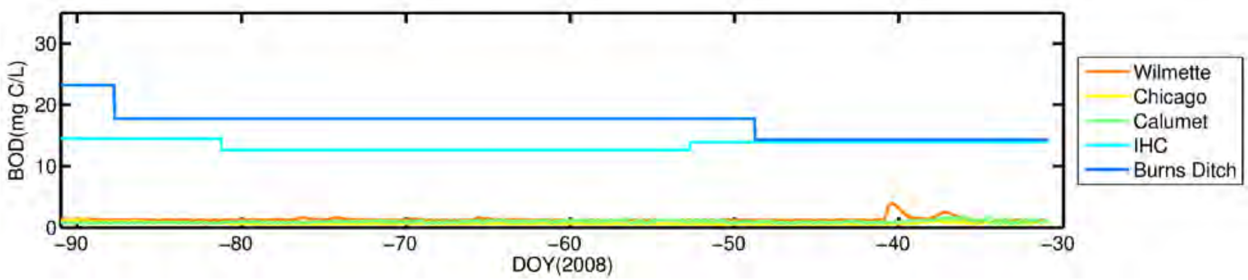
f_{D3}	Fraction of dissolved CBOD	.5
f_{D7}	Fraction of dissolved organic nitrogen	1.0
f_{D8}	Fraction of dissolved organic phosphorous	1.0
f_{on}	Fraction of dead and respired phytoplankton recycled to organic nitrogen pool	.65
f_{op}	Fraction of dead and respired phytoplankton recycled to organic phosphorous pool	.65
a_{nc}	Phytoplankton nitrogen-carbon ratio	.25
a_{pc}	Phytoplankton phosphorous-carbon ratio	.025
a_{oc}	Ratio of oxygen to carbon	32/12
k_e	Light attenuation coefficient (m^{-1})	1.0
I_S	Optimal light intensity	250.0

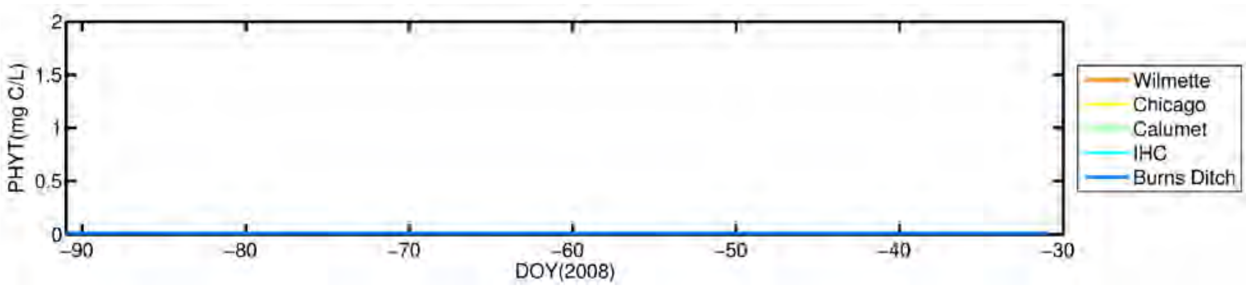
Appendix -B: Input Time Series to the Numerical Models

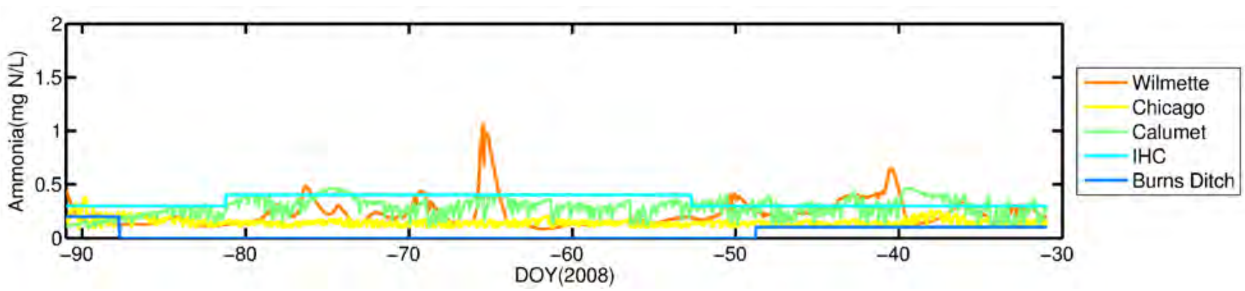
Scenario 2: Sept2007-November2007

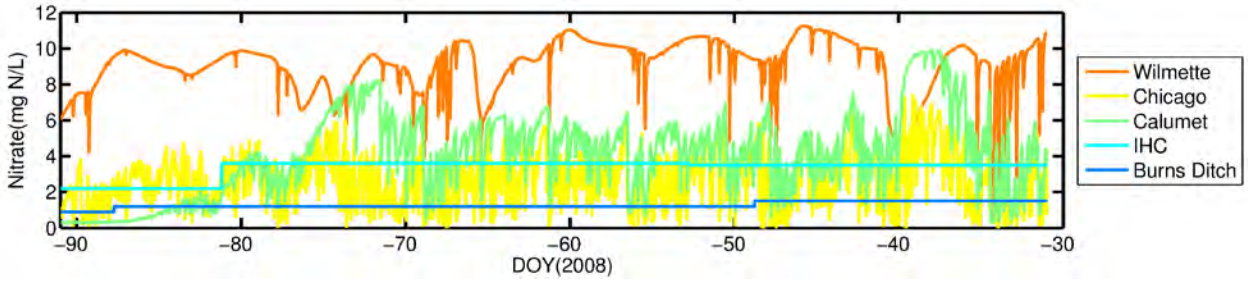


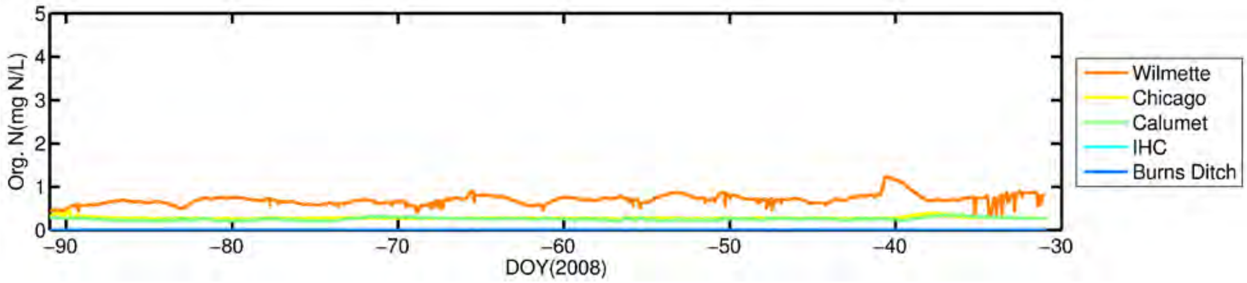









Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch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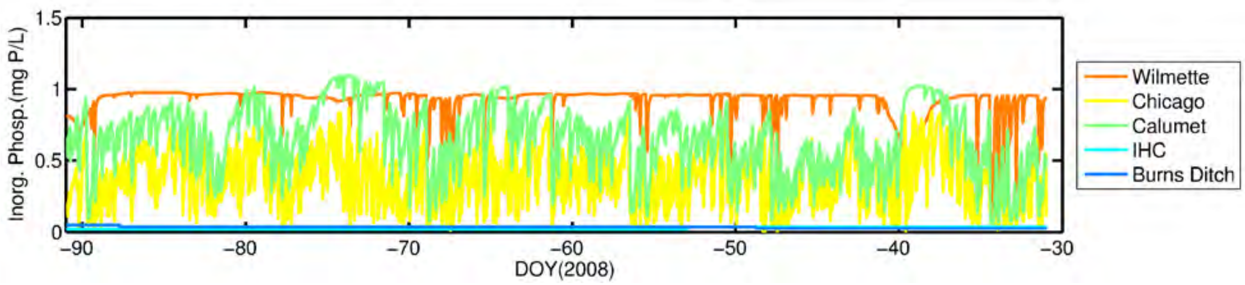
Chicago
Calumet
IHC
Burns Ditch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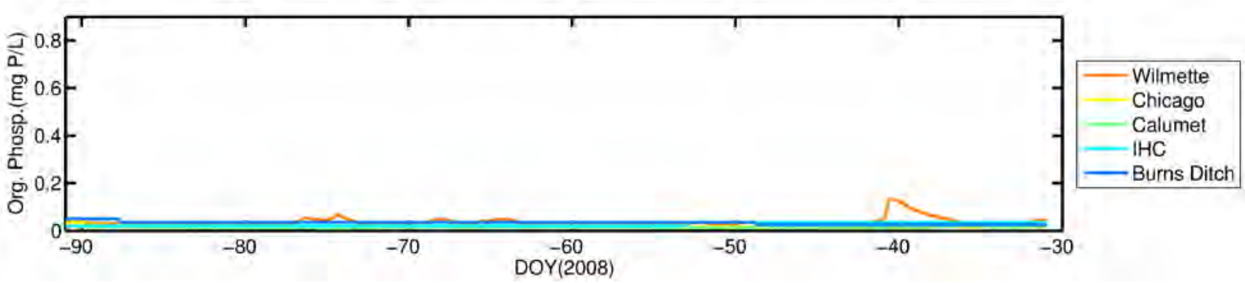
Chicago
Calumet
IHC
Burns Ditch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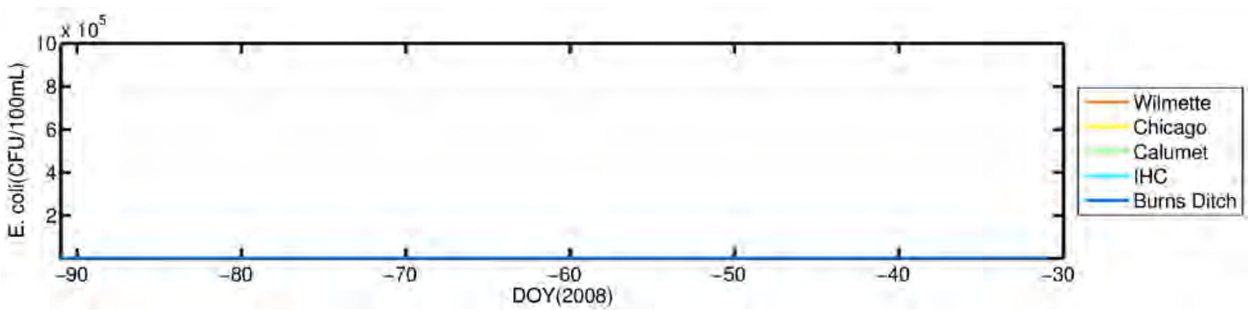
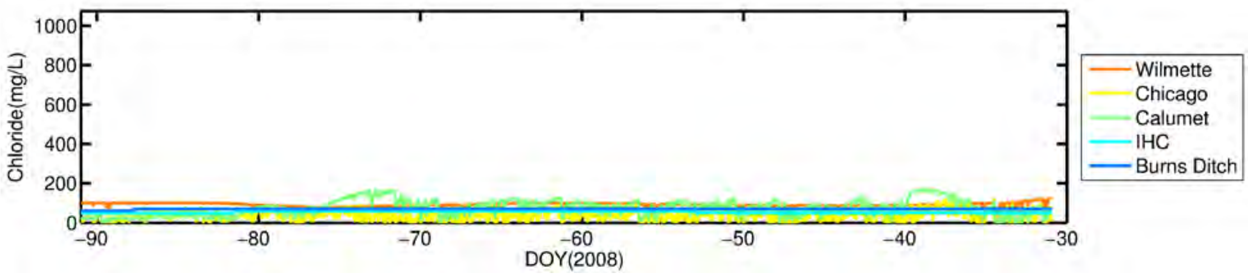
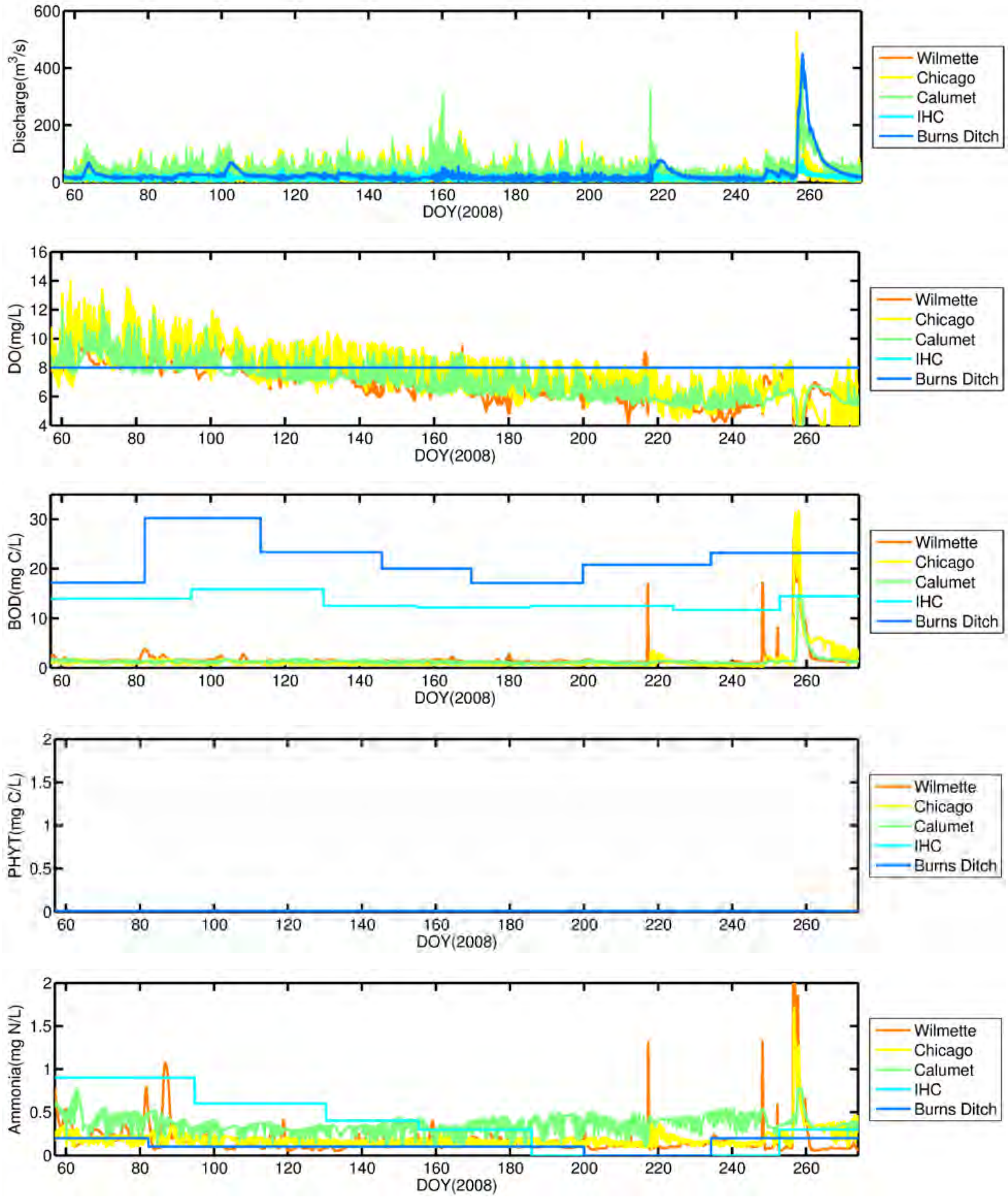
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

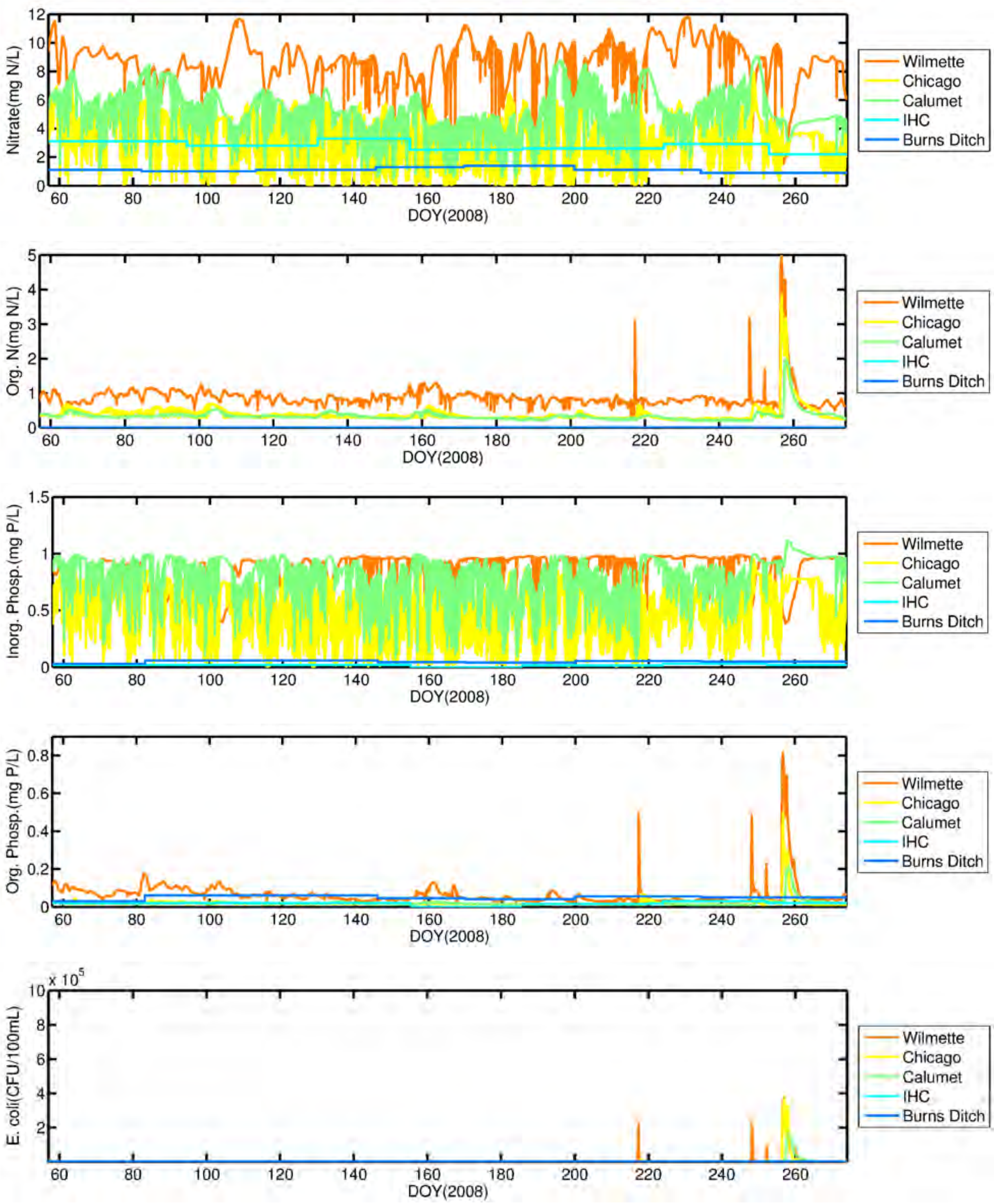

x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

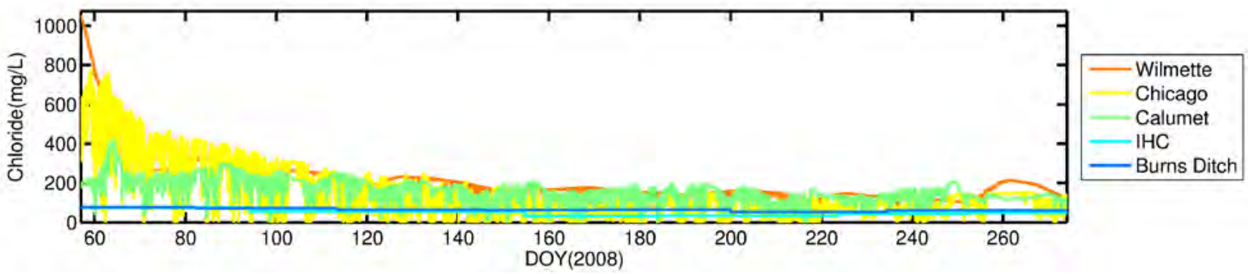


Chloride(mg/L)
1000
800
600
400
200
0
-90
-80
-70
-60
-50
-40
-30
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

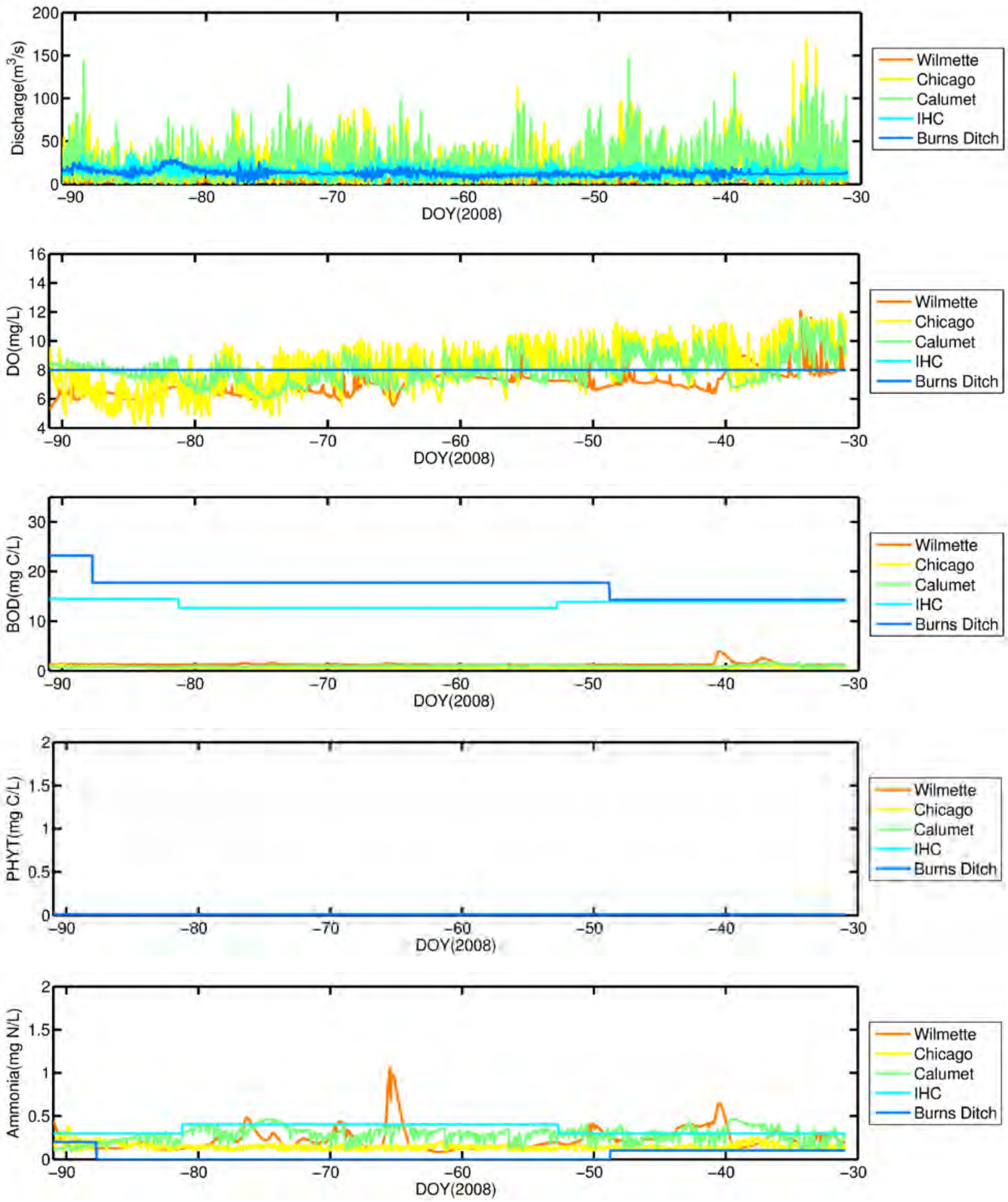
Scenario 2: March2008-September2008

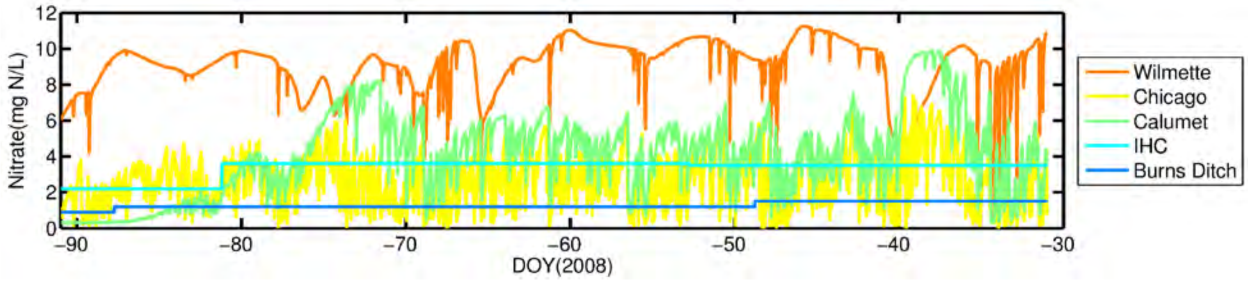



Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch
Org. N(mg N/L)
Inorg. Phosp.(mg P/L)
Org. Phosp.(mg P/L)
E. coli(CFU/100mL)
x 10^5

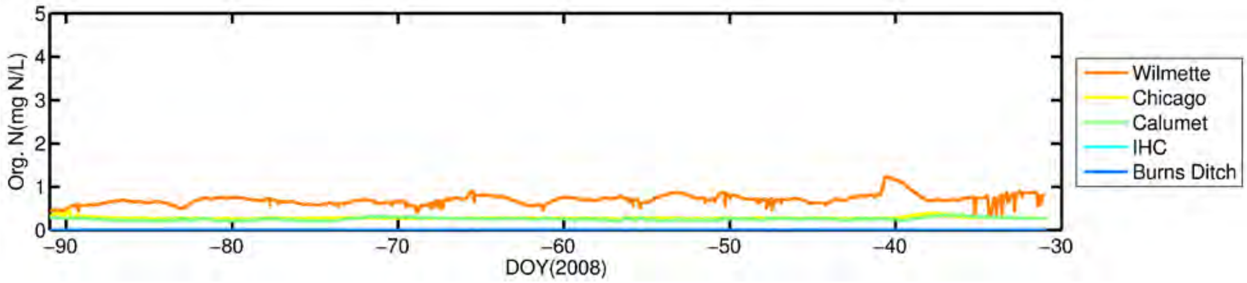

1000
800
600
400
200
0
Chloride(mg/L)
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

Scenario 3: Sept2007-November2007

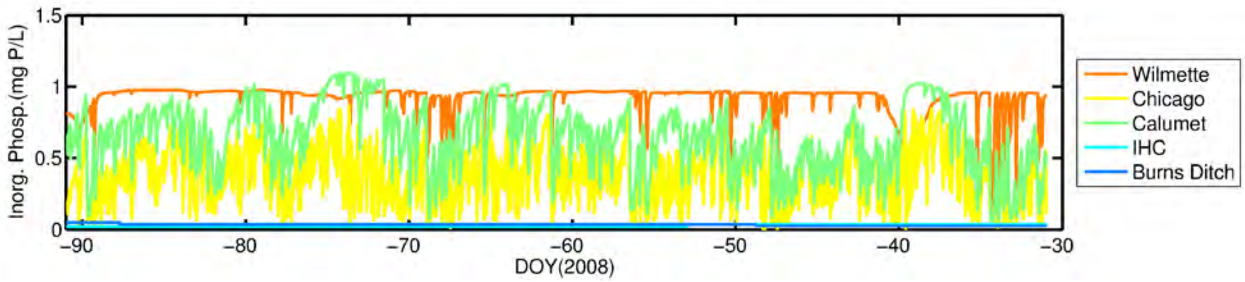




Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



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DOY(2008)
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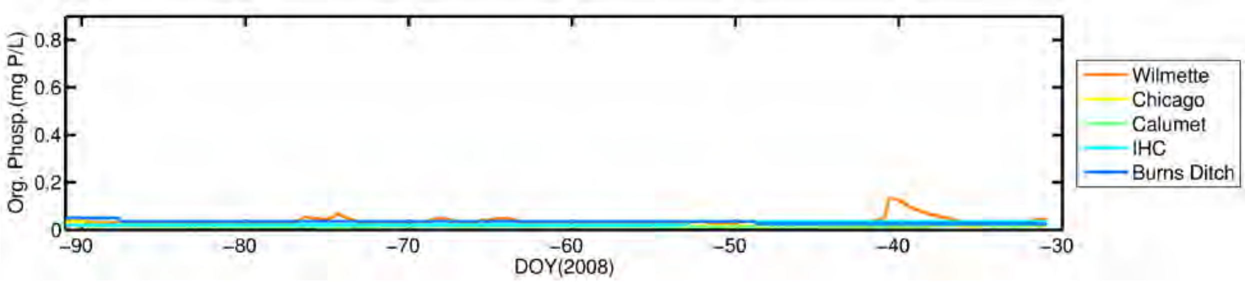
Calumet
IHC
Burns Ditch



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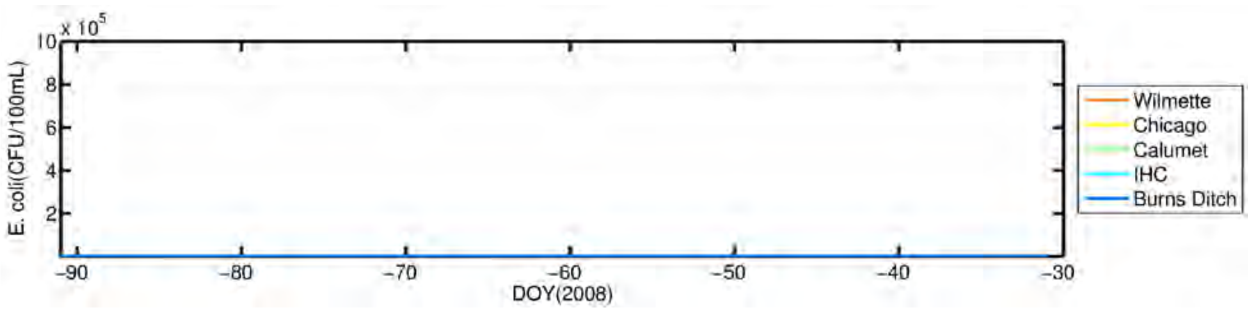
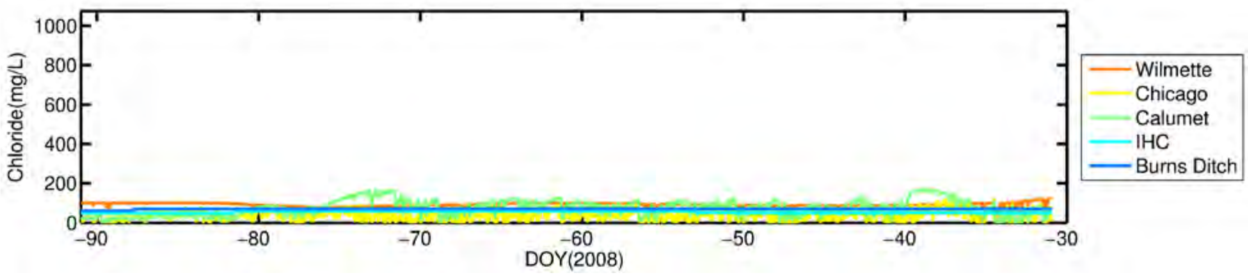
Calumet
IHC
Burns Ditch

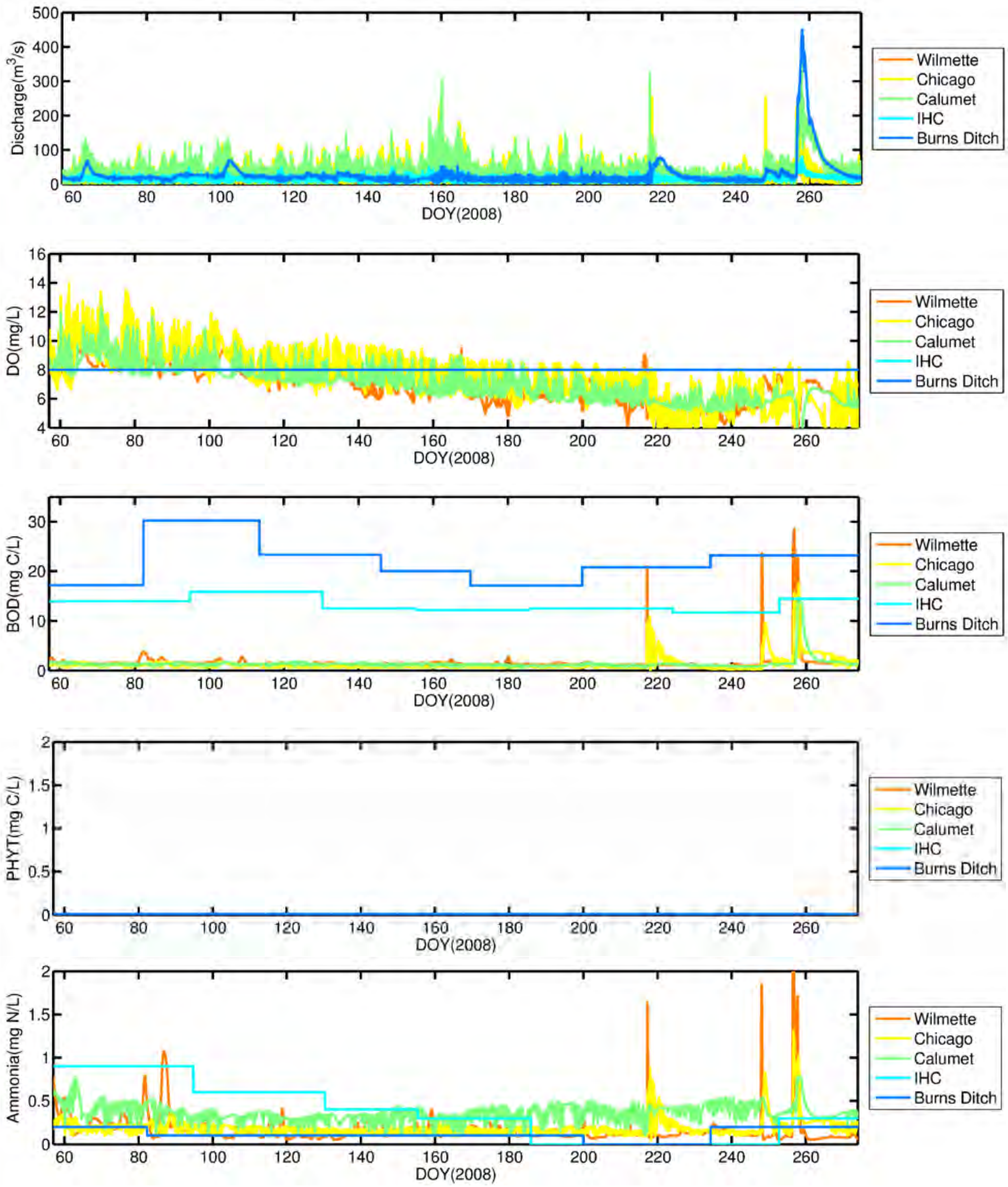


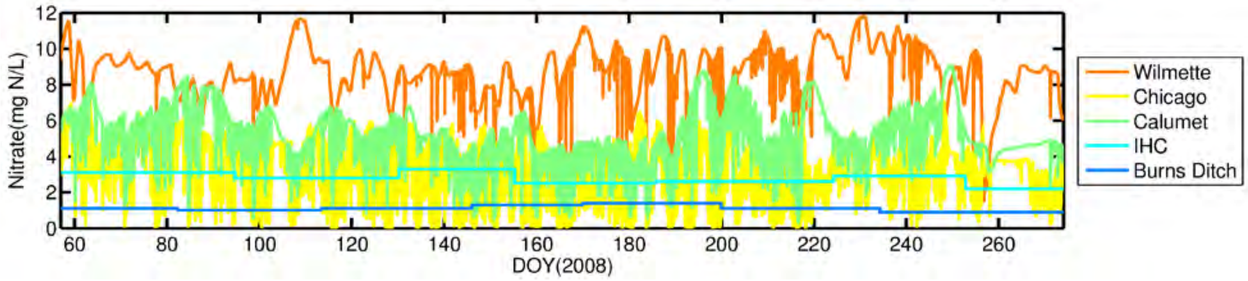
x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

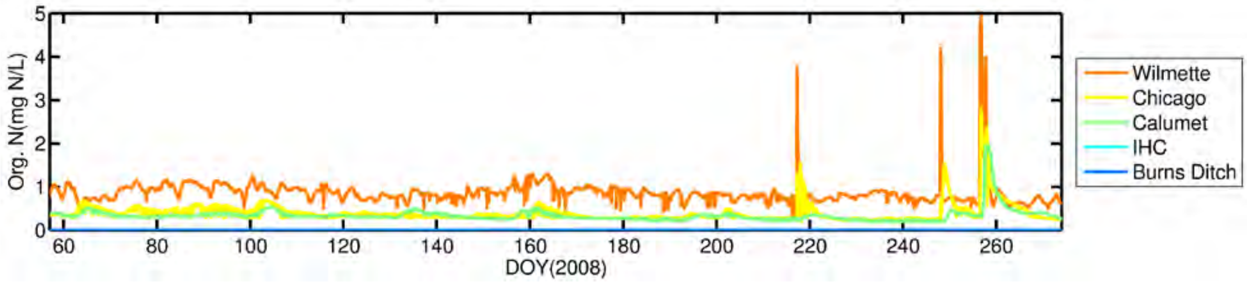


Chloride(mg/L)
1000
800
600
400
200
0
−90
−80
−70
−60
−50
−40
−30
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

Scenario 3: March2008-September2008




Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch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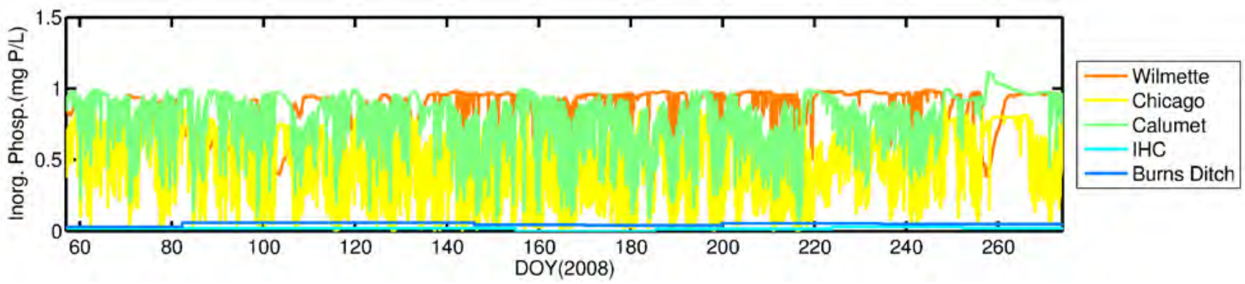
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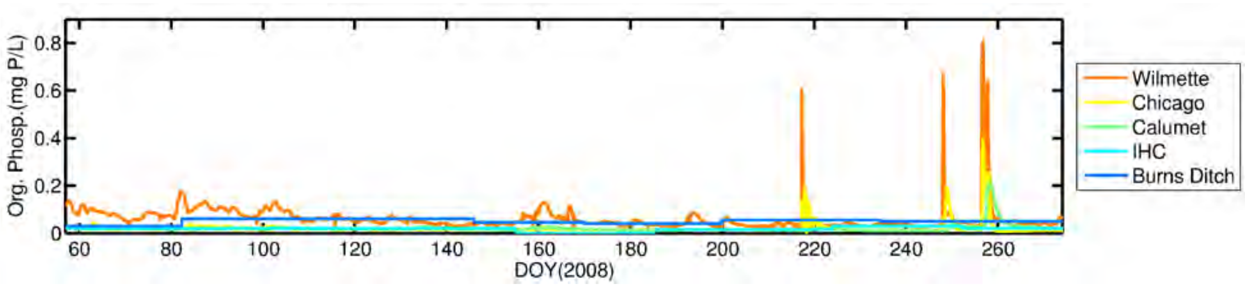
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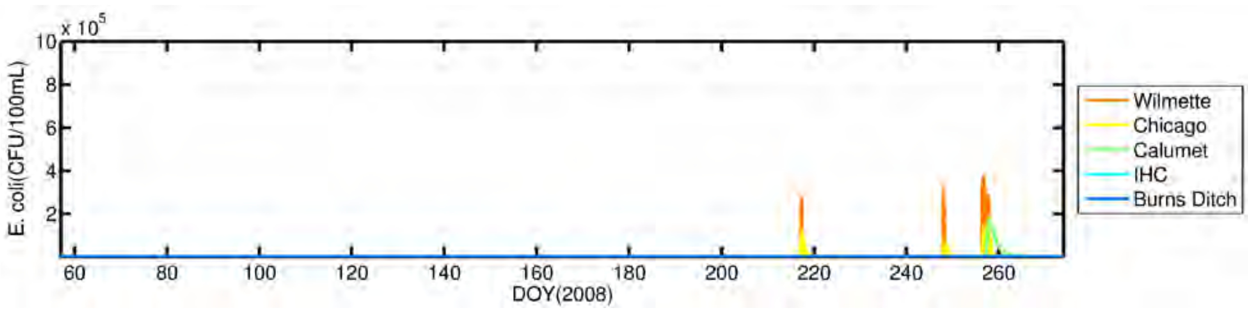
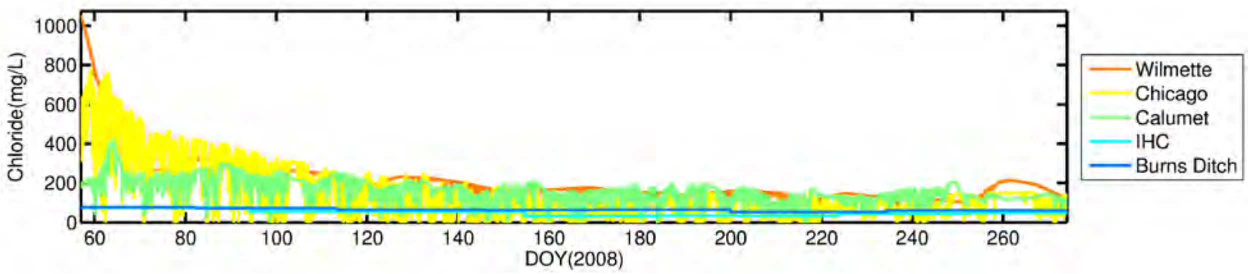
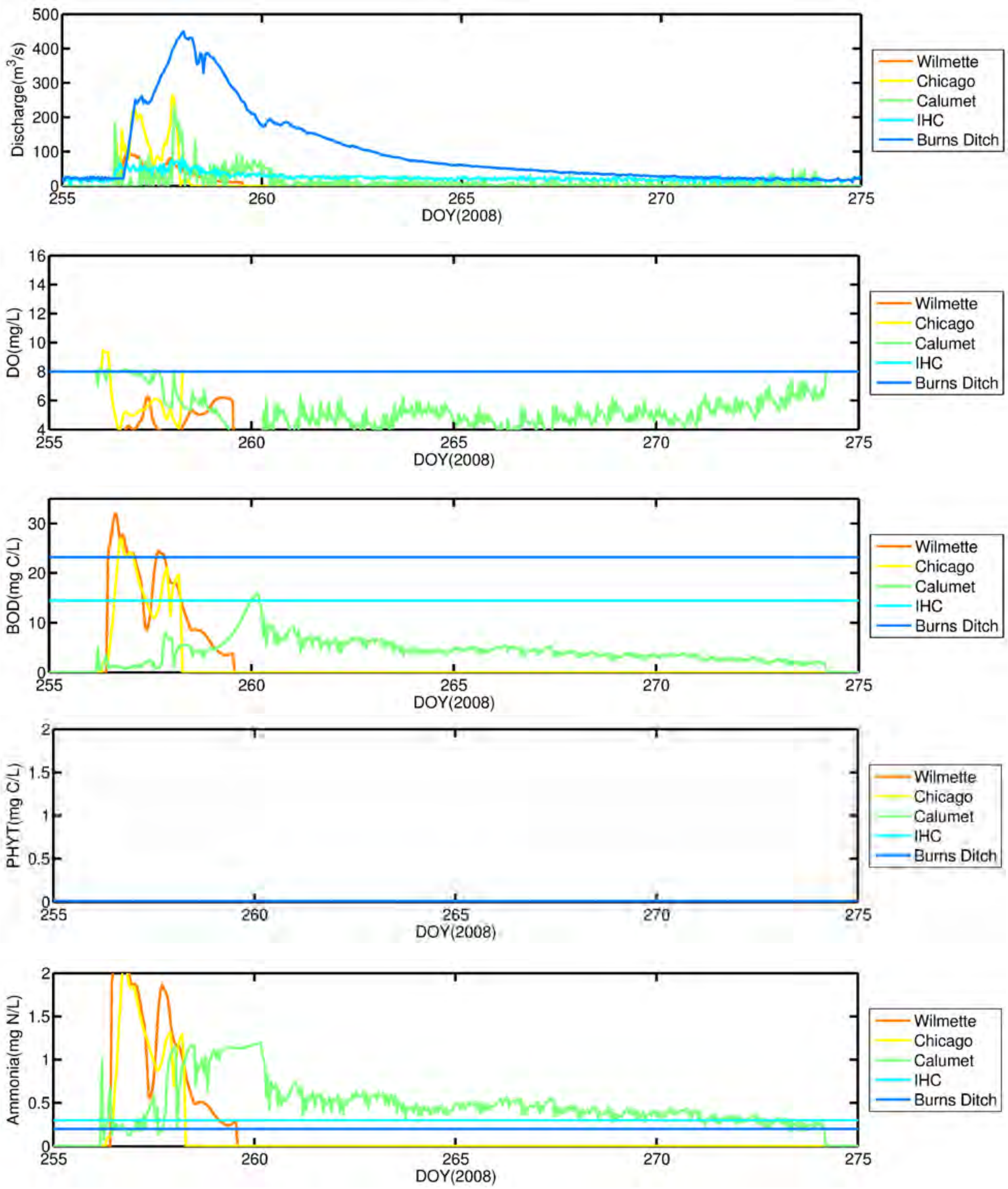
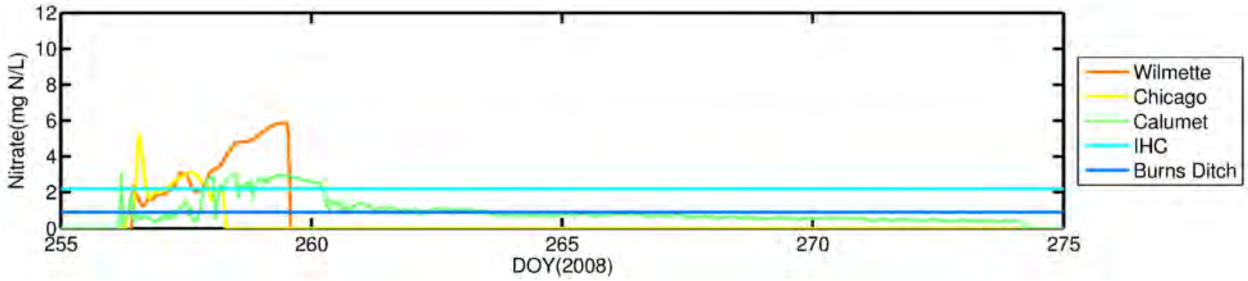
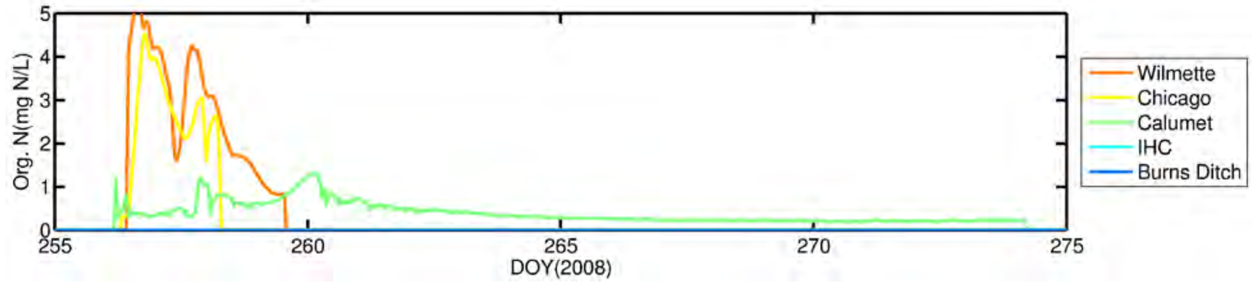

x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

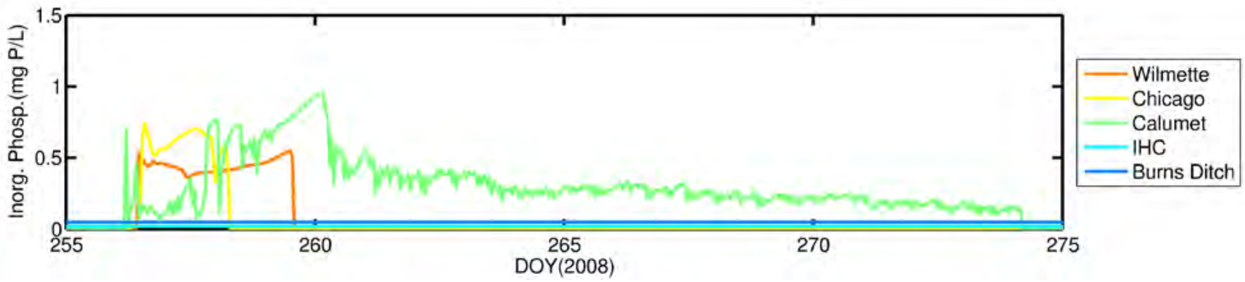

1000
800
600
400
200
0
Chloride(mg/L)
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

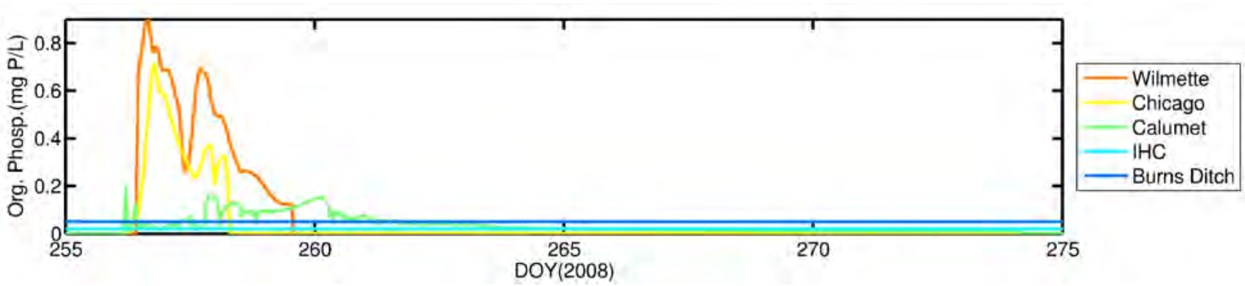
Scenario 4: September

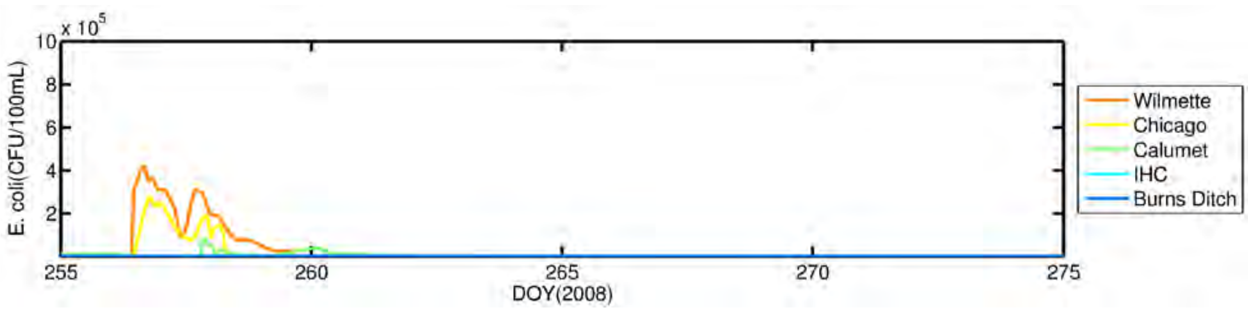


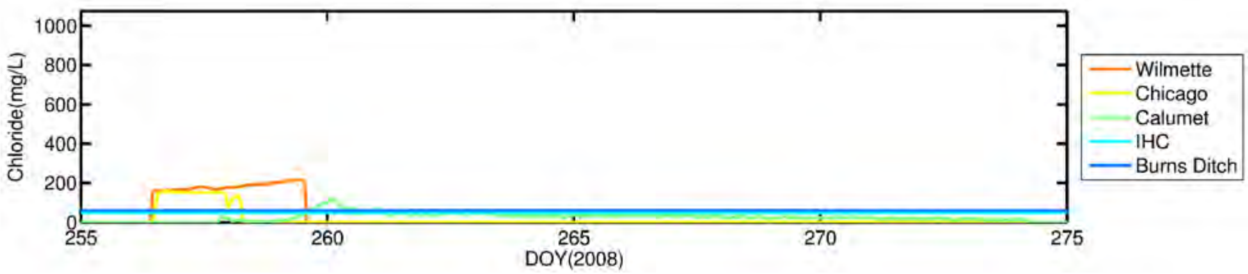

Nitrate(mg N/L)
0
2
4
6
8
10
12
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
0
1
2
3
4
5
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Inorg. Phosp.(mg P/L)
0
0.5
1
1.5
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

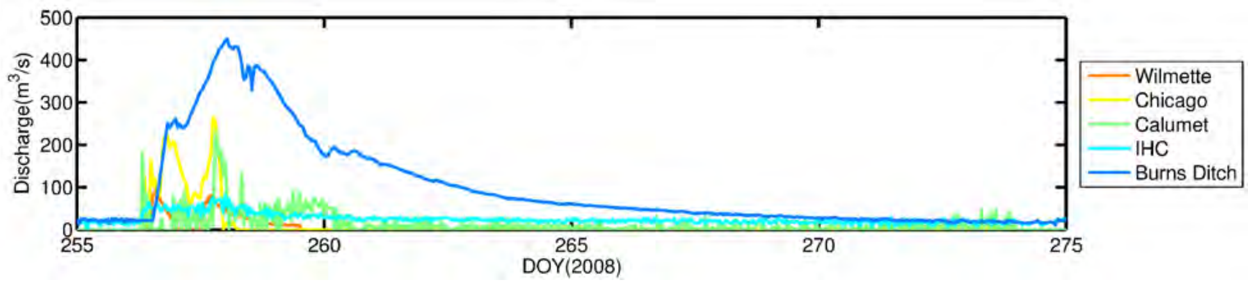

Org. Phosp.(mg P/L)
0
0.2
0.4
0.6
0.8
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

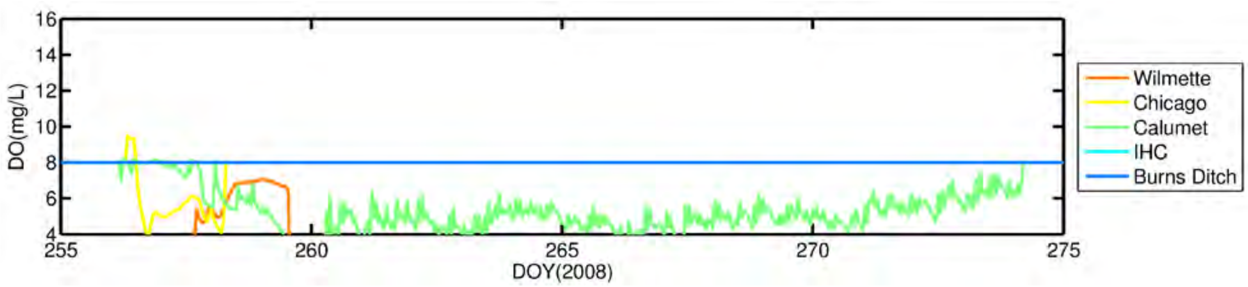

x 10^5
E. coli(CFU/100mL)
2
4
6
8
10
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

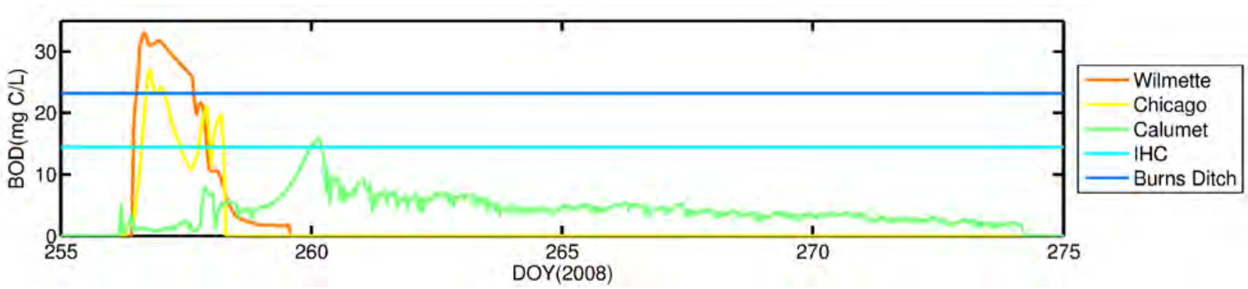


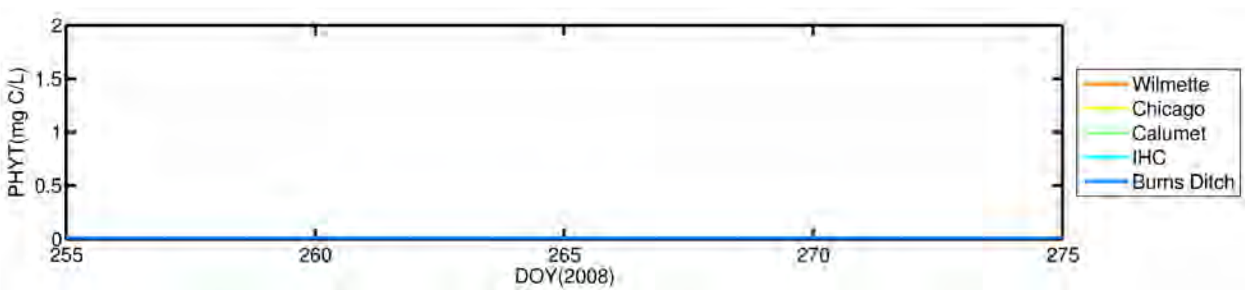
1000
800
600
400
200
0
Chloride(mg/L)
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

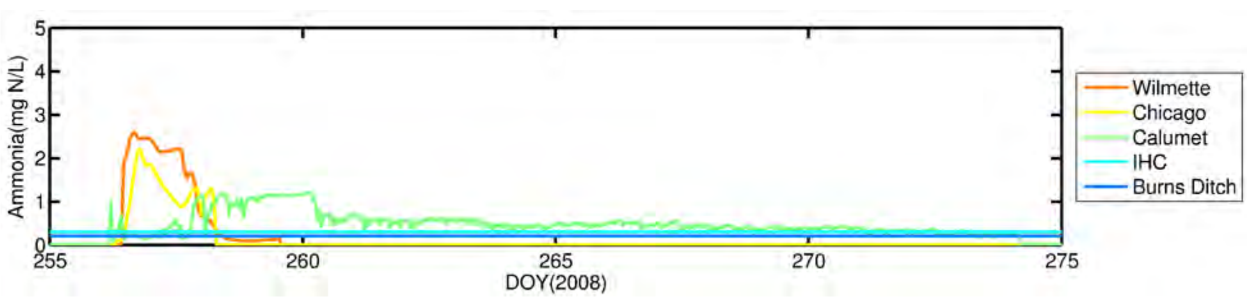
Scenario 5: September

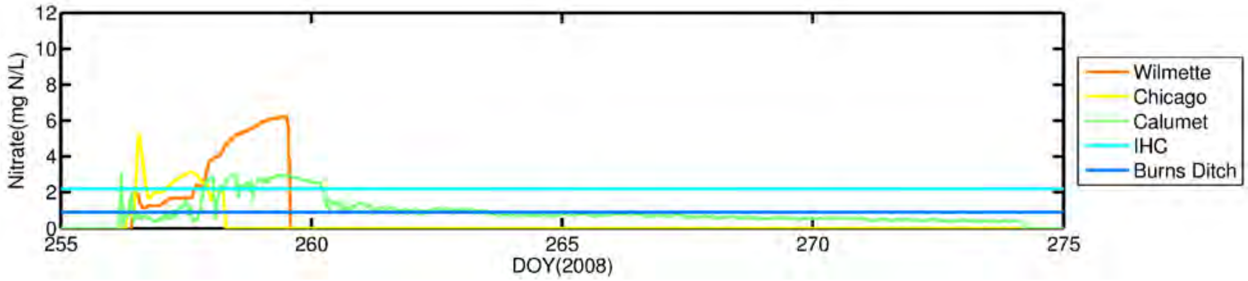




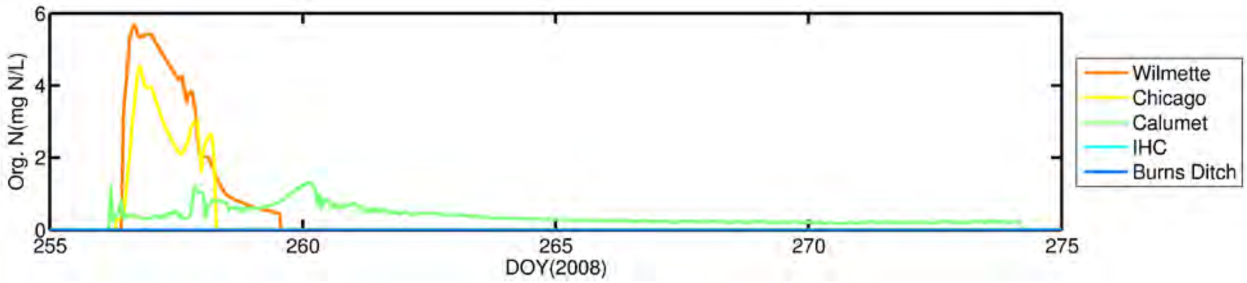




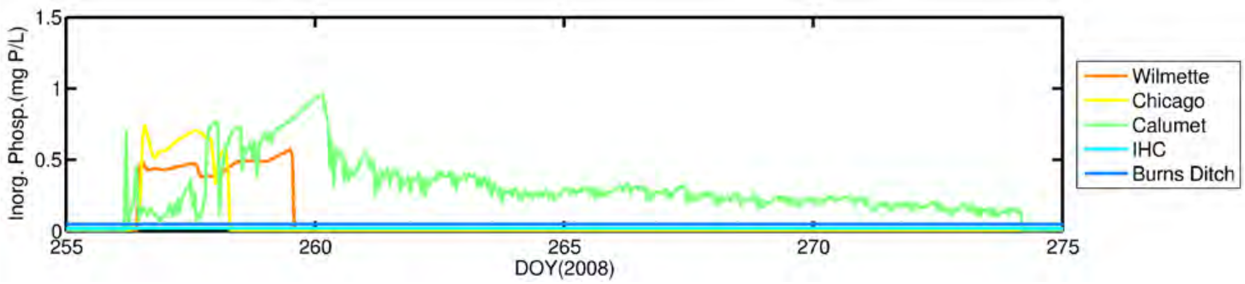




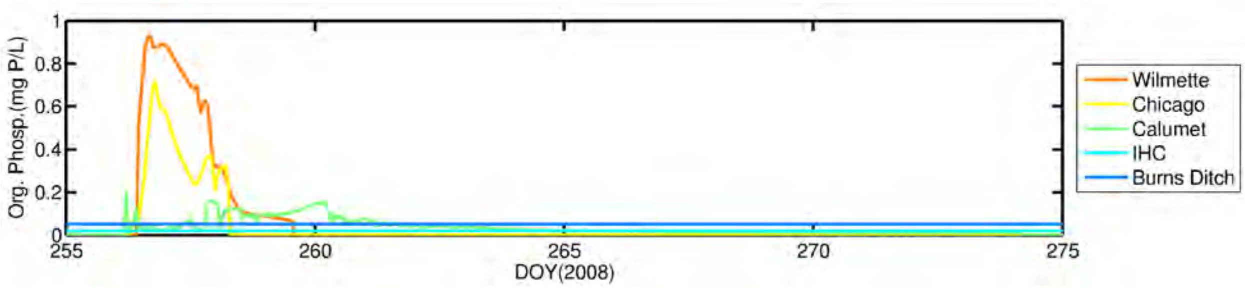
Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



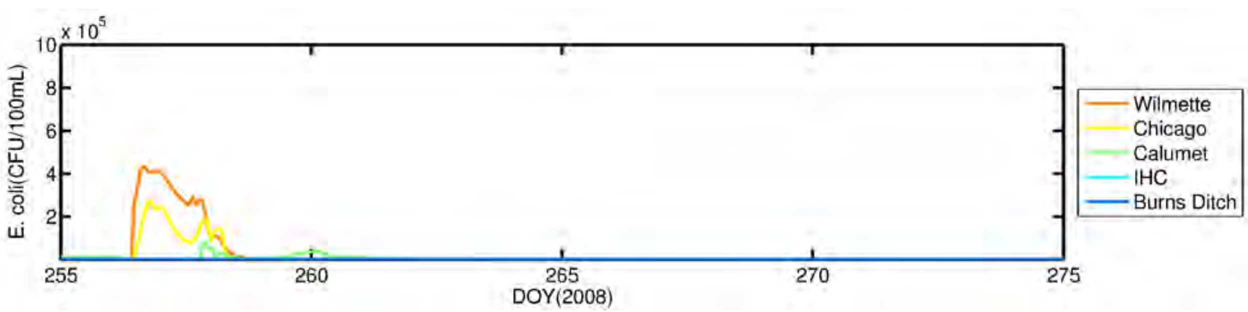
Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



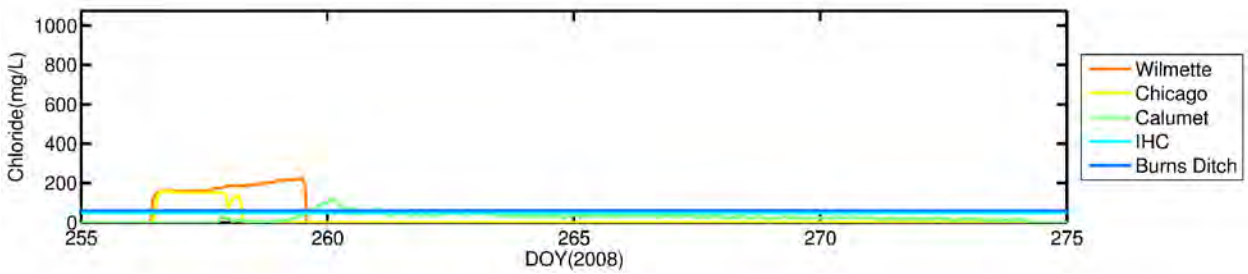
Inorg. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



Org. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



1000
800
600
400
200
0
Chloride(mg/L)
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

Appendix C

Table 1 Maximum, minimum and standard deviation of the of the vertically averaged water quality variables at major water intake locations (for Scenario 3) for 30 day period (Sept 1 - Sept 30)

Variable	Location.	Min.	Max.	Mean	Std. dev.
DO	Evanston	8.3466	10.503	8.752	0.51691
(mg/l)	Jardine(crib)	8.2082	9.7879	8.568	0.31144
	Jardine(shore)	6.6067	13.717	9.9869	1.7878
	South(crib)	7.9146	10.29	8.5942	0.47867
	South(shore)	8.1173	14.035	10.591	1.5848
	Hammond	7.994	14.249	10.154	1.3759
	Gary	7.3904	8.723	7.9808	0.30489
CBOD	Evanston	0.053343	1.0653	0.32583	0.29522
(mg C/l)	Jardine(crib)	0.090679	0.93867	0.30686	0.20438
	Jardine(shore)	0.13242	7.7814	1.3571	1.0079
	South(crib)	0.13596	1.261	0.40656	0.26144
	South(shore)	0.22573	3.1538	1.279	0.81185
	Hammond	0.32391	2.9639	1.22	0.62989
	Gary	0.051366	1.2652	0.33682	0.23244
Phytoplankton	Evanston	0.01602	0.68025	0.1604	0.16211
	Jardine(crib)	0.017239	0.53972	0.1351	0.11462
	Jardine(shore)	0.060292	1.5134	0.59557	0.45362
	South(crib)	0.0314	0.72694	0.16951	0.14725
	South(shore)	0.071253	1.5314	0.74215	0.42102
	Hammond	0.097121	1.6121	0.62889	0.3846
	Gary	0.00551	0.24791	0.058985	0.043718
Ammonia	Evanston	0.000277	0.029601	0.002112	0.003356
(mg N/l)	Jardine(crib)	0.000432	0.004474	0.001487	0.000773
	Jardine(shore)	0.000804	0.5404	0.021126	0.05578
	South(crib)	0.000682	0.005916	0.001711	0.001089
	South(shore)	0.001079	0.047672	0.005075	0.006716
	Hammond	0.001112	0.037551	0.004181	0.005095
	Gary	0.000172	0.004633	0.001212	0.000835
Nitrate	Evanston	0.002729	0.37905	0.042357	0.046515
(mg N/l)	Jardine(crib)	0.0032	0.17759	0.03013	0.026949
	Jardine(shore)	0.000262	2.4218	0.49847	0.49168
	South(crib)	0.002396	0.36367	0.041685	0.058092
	South(shore)	0.000146	2.5871	0.53085	0.75058
	Hammond	0.002555	1.7628	0.31231	0.38057
	Gary	0.004048	0.099188	0.029389	0.020797
Org. Nitrogen	Evanston	0.082719	0.2513	0.1353	0.04932
(mg N/l)	Jardine(crib)	0.096223	0.22649	0.12942	0.028403
	Jardine(shore)	0.10288	1.4191	0.33069	0.17892

	South(crib)	0.087356	0.28097	0.14068	0.042229
	South(shore)	0.13448	0.7193	0.29537	0.15824
	Hammond	0.11964	0.5558	0.23799	0.097368
	Gary	0.077409	0.15236	0.10742	0.022243
Phosphate(IP)	Evanston	0.008652	0.053683	0.021536	0.011631
(mg P/l)	Jardine(crib)	0.01055	0.073811	0.019821	0.009969
	Jardine(shore)	0.012758	0.47012	0.12919	0.092277
	South(crib)	0.009694	0.11024	0.022481	0.019291
	South(shore)	0.015251	0.6584	0.14454	0.17794
	Hammond	0.005246	0.36001	0.076771	0.092411
	Gary	0.007298	0.014838	0.010255	0.001869
Org. Phosphorous	Evanston	0.01129	0.032671	0.014307	0.003346
(mg P/l)	Jardine(crib)	0.011734	0.019322	0.013576	0.00155
	Jardine(shore)	0.011985	0.18152	0.024689	0.018088
	South(crib)	0.012314	0.022582	0.014118	0.002288
	South(shore)	0.01306	0.054409	0.022552	0.010778
	Hammond	0.013748	0.046085	0.019351	0.006348
	Gary	0.011381	0.014991	0.01284	0.000897
FIB	Evanston	1	1347.1	27.603	155.26
(CFU/100ml)	Jardine(crib)	1	23.887	2.3257	3.6983
	Jardine(shore)	1	38792	630.46	3577.3
	South(crib)	1	16.494	1.7242	2.518
	South(shore)	1	183.74	8.0284	26.992
	Hammond	1	536.36	31.818	106.03
	Gary	1	4.5224	1.1267	0.53189
Chloride	Evanston	14.453	26.236	17.423	2.6882
(mg/l)	Jardine(crib)	14.857	24.247	16.858	1.7942
	Jardine(shore)	15.263	102.22	36.668	17.218
	South(crib)	15.305	28.669	17.596	2.9142
	South(shore)	15.982	86.966	34.474	19.615
	Hammond	16.444	63.849	28.128	12.256
	Gary	14.598	18.577	15.963	0.90879

Table 2 Maximum, minimum and standard deviation of the of the vertically averaged water quality variables at major water intake locations (for the extreme event simulated in Scenario 5) for 30 day period (Sept 1 - Sept 30)

Variable	Location.	Min.	Max.	Mean	Std. dev.
DO	Evanston	8.1133	8.3457	8.2669	0.064302
(mg/l)	Jardine(crib)	8.1216	8.419	8.2681	0.060955
	Jardine(shore)	5.4783	8.7489	8.1554	0.54375
	South(crib)	8.1042	8.341	8.2669	0.066651
	South(shore)	7.1153	8.5824	8.299	0.22418
	Hammond	7.9246	9.3017	8.3778	0.24647
	Gary	7.8593	8.3707	8.1798	0.15729
CBOD	Evanston	0.002372	0.39583	0.092958	0.05834
(mg C/l)	Jardine(crib)	0.002373	0.23239	0.10527	0.062817
	Jardine(shore)	0.002371	14.232	0.69656	1.7389
	South(crib)	0.002373	0.38085	0.15809	0.11338
	South(shore)	0.002371	1.0265	0.2061	0.1863
	Hammond	0.002371	0.97997	0.31371	0.26668
	Gary	0.002373	0.92307	0.20004	0.15501
Phytoplankton	Evanston	0.025141	0.091908	0.044896	0.014732
	Jardine(crib)	0.028822	0.13251	0.047374	0.020407
	Jardine(shore)	0.022631	0.30702	0.096943	0.074416
	South(crib)	0.033354	0.13869	0.059445	0.030523
	South(shore)	0.035255	0.2159	0.079329	0.049184
	Hammond	0.036058	0.41074	0.10228	0.090059
	Gary	0.012416	0.18091	0.043664	0.026643
Ammonia	Evanston	2.43E-05	0.021925	0.000976	0.001877
(mg N/l)	Jardine(crib)	2.43E-05	0.00504	0.001089	0.001078
	Jardine(shore)	2.43E-05	1.0983	0.034349	0.13095
	South(crib)	2.43E-05	0.010663	0.001603	0.002151
	South(shore)	2.43E-05	0.050035	0.003431	0.007471
	Hammond	2.43E-05	0.030112	0.002424	0.003894
	Gary	2.43E-05	0.003489	0.001004	0.000758
Nitrate	Evanston	0.012492	0.10069	0.024658	0.011364
(mg N/l)	Jardine(crib)	0.009553	0.049393	0.023891	0.00831
	Jardine(shore)	0.002696	1.5256	0.1275	0.22414
	South(crib)	0.006085	0.080999	0.034046	0.017174
	South(shore)	0.002191	0.52805	0.061144	0.086435
	Hammond	0.00177	0.27056	0.070635	0.067251
	Gary	0.02134	0.088	0.037684	0.014346
Org. Nitrogen	Evanston	0.080031	0.15299	0.10118	0.018489
(mg N/l)	Jardine(crib)	0.080031	0.12999	0.10059	0.015926
	Jardine(shore)	0.080031	2.5225	0.23415	0.30586
	South(crib)	0.080031	0.15106	0.10211	0.019179

	South(shore)	0.080031	0.25449	0.11557	0.0376
	Hammond	0.080031	0.16208	0.10121	0.021492
	Gary	0.080031	0.12057	0.090551	0.007088
Phosphate(IP)	Evanston	0.006263	0.013853	0.00799	0.001658
(mg P/l)	Jardine(crib)	0.006449	0.014895	0.008199	0.001822
	Jardine(shore)	0.006114	0.36456	0.030412	0.047631
	South(crib)	0.006114	0.021823	0.008899	0.003871
	South(shore)	0.00566	0.12317	0.015893	0.019932
	Hammond	0.004596	0.059158	0.009143	0.00781
	Gary	0.00501	0.008279	0.006687	0.000476
Org. Phosphorous	Evanston	0.010002	0.020792	0.011995	0.002175
(mg P/l)	Jardine(crib)	0.010002	0.016652	0.011855	0.00172
	Jardine(shore)	0.010002	0.38133	0.030127	0.046069
	South(crib)	0.010002	0.018815	0.012118	0.002269
	South(shore)	0.010002	0.030894	0.013484	0.004421
	Hammond	0.010002	0.01991	0.011894	0.001854
	Gary	0.010002	0.013183	0.010988	0.000716
FIB	Evanston	1	1425.3	17.351	116.49
(CFU/100ml)	Jardine(crib)	1	85.457	5.8543	14.565
	Jardine(shore)	1	95799	1728.8	9847.3
	South(crib)	1	121.26	6.7236	19.162
	South(shore)	1	79.198	4.2513	11.922
	Hammond	1	42.243	2.456	5.5897
	Gary	1	4.4733	1.266	0.54887
Chloride	Evanston	13.969	16.918	14.502	0.62395
(mg/l)	Jardine(crib)	13.998	15.531	14.381	0.44081
	Jardine(shore)	13.775	102.98	19.668	11.486
	South(crib)	13.999	16.314	14.607	0.64265
	South(shore)	13.999	20.769	15.091	1.451
	Hammond	13.999	17.686	15.078	1.1377
	Gary	14	16.69	14.565	0.56092

Table 3: Water quality benchmarks

Variable	Benchmark
Total Phosphorous	0.007 mg/L
Chloride	12 mg/L
DO	7.2 mg/L
Nitrate	10 mg/L
Fecal Coliform/ *E. coli*	20 CFU/100mL

ATTACHMENT 3

CANDIDATE BENCHMARKS FOR CHICAGO AREA WATERWAYS

Candidate Benchmarks for Chicago Area Waterways

Nutrient: Total Phosphorus (TP)

1. MN draft eutrophication criteria for streams/rivers
   Threshold: 150 ug/l
   Regulatory status: Draft criteria
   Spatial coverage: Southern and western Minnesota
   Ecoregion: Corn Belt and Northern Great Plains (same ecoregion as Northern Illinois)
   Derivation approach: stressor-response, using change point analysis and midpoint interpolation
   Support document URL:
   http://www.pca.state.mn.us/index.php/view-document.html?gid=14947

2. OH draft trophic index criterion for streams
   Threshold: TP threshold cannot be used—Inextractably linked to DIN threshold and response variable thresholds
   Regulatory status: Draft criteria
   Spatial coverage: Statewide
   Ecoregion: Primarily Corn Belt and Northern Great Plains (same ecoregion as Northern Illinois), but also Mostly Glaciated Dairy Region and Central and Eastern Forested Uplands
   Derivation approach: stressor-response, using aquatic life protection interpolation and change point analysis
   Support document URL: http://www.epa.ohio.gov/dsw/dswrules/nutrientcriteria.aspx

3. WI eutrophication criteria for streams/rivers
   100 ug/l for non-wadeable streams
   Regulatory status: EPA approved
   Spatial coverage: Statewide
   Ecoregion: Primarily Mostly Glaciated Dairy Region (adjacent to Corn Belt and Northern Great Plains), but also Nutrient Poor Largely Glaciated Upper Midwest and Northeast
   Derivation approach: stressor-response, using change point analysis
   Support document URL: http://pubs.usgs.gov/pp/1754/

4. EPA 304(a) criteria recommendations
   Aggregate Level 3 Ecoregion = 76.25 ug/
   Level 3 Ecoregion 54 = 72.5 ug/l
   Regulatory status: Criteria recommendations published by EPA
   Coverage: Aggregate Level 3 Ecoregion: Northern Illinois, central Indiana, western Ohio, most of Iowa, southern and western Minnesota, eastern North Dakota, eastern South Dakota, eastern Nebraska
   Level 3 Ecoregion 54: Northern Illinois
   Support document URL: http://www2.epa.gov/sites/production/files/documents/rivers6.pdf

5. **TP Benchmark** = (150 ug/l + 100 ug/l + 76.25 ug/l + 72.5 ug/l) / 4 **= 100 ug/l – 870 ug/L (median CAWS concentration, 2008-2010)**

Nutrient: Total Nitrogen

TN Benchmark: 2.3 mg/L TN – 6 mg/L (median CAWS concentration, 2008-2010)

Aggregate Level 3 Ecoregion = 2.18 mg/L TN
Level 3 Ecoregion 54 = 2.461 mg/L calculated TN

Regulatory status: Criteria recommendations published by EPA

Coverage: Aggregate Level 3 Ecoregion: Northern Illinois, central Indiana, western Ohio, most of Iowa, southern and western Minnesota, eastern North Dakota, eastern South Dakota, eastern Nebraska
Level 3 Ecoregion 54: Northern Illinois

Support document URL: http://www2.epa.gov/sites/production/files/documents/rivers6.pdf

Other: Dissolved Oxygen

During the period of March through July, 5.0 mg.L at any time;
During the period of August through February,
A) 4.0 mg/L as a daily minimum averaged over 7 days, and
B) 3.5 mg/L at any time.
Regulatory Status: Recommended by Illinois EPA in CAWS UAA rulemaking

Other: TSS

None; recommend % change from current condition as metric for comparison

Other: Nitrate

10 mg/L for protection of drinking water
Regulatory Status: EPA recommended 304(a) criteria for drinking water

Other: Fecal Coliform and/or E. coli

Benchmark: E. coli (culturable) geomean of 126 cfu/100mL; 410 cfu/100mL not to be exceeded
Regulatory Status: 2012 EPA recommended 304(a) criteria for recreation

Secondary Benchmark: Fecal coliform
During the months May through October, based on a minimum of five samples taken over not more than a 30 day period, fecal coliform (STORET number 31616) shall not exceed a geometric mean of 200 per 100 ml, nor shall more than 10% of the samples during any 30 day period exceed 400 per 100 ml in protected waters. Regulatory Status: Approved General Use water quality standard

Regression between fecal coliform and E. coli: Zmuda, J.T., R. Gore, and Z. Abedin. "Estimation of the Escherichia coli to fecal coliform ratio in wastewater effluents and ambient waters of the Metropolitan Water Reclamation District of Greater Chicago." Research and Development Department Report No. 04-10. MWRDGC, July 2004.

Other: Ammonia

2013 final ammonia criteria recommendations

Other: Chloride

230 (chronic)/860 (acute)
Regulatory Status: EPA recommended 304(a) criteria for aquatic life

Other: pH

6.5-9
Regulatory Status: Recommended by Illinois EPA in CAWS UAA rulemaking

Candidate benchmarks for Lake Michigan

Nutrient: Narrative

Waters of the Lake Michigan Basin must be free from sludge or bottom deposits, floating debris, visible oil, odor, plant or algal growth, color or turbidity of other than natural origin. The allowed mixing provisions of Section 302.102 shall not be used to comply with the provisions of this Section.

Nutrient: Total Phosphorus (TP)

IL criterion for Lake Michigan: **7 ug/l TP**
Regulatory status: Approved water quality standard
Support document: Not identified

Nutrient: Total Nitrogen (TN)

No current recommendations in Lake Michigan; recommend current condition or % change from current concentration for comparison

Other: Nitrate

10mg/L for protection of drinking water
Regulatory Status: EPA recommended 304(a) criteria for drinking water

Other: Ammonia (see above)

Other: Chloride

12 mg/L must not be exceeded at any time in the Open Waters of Lake Michigan
Regulatory Status: Approved water quality standard

Other: Dissolved Oxygen

Dissolved oxygen (STORET number 00300) must not be less than 90% of saturation, except due to natural causes, in the Open Waters of Lake Michigan as defined at Section 302.501. The other waters of the Lake Michigan Basin must not be less than 6.0 mg/L during at least 16 hours of any 24 hour period, nor less than 5.0 mg/L at any time.
Regulatory Status: Approved water quality standard

Other: TSS

None; recommend % change from current condition as metric for comparison

Other: BOD

None; recommend % change from current condition as metric for comparison

Other: Bacteria

E. coli: Geomean of 126 cfu/100mL; 410 cfu/100mL not to be exceeded
Regulatory Status: EPA recommended 304(a) criteria for recreation

Fecal Coliform: Based on a minimum of five samples taken over not more than a 30-day period, fecal coliform (STORET number 31616) must not exceed a geometric mean of 20 per 100 ml in the Open Waters of Lake Michigan as defined in Section 302.501. The remaining waters of the

Lake Michigan Basin must not exceed a geometric mean of 200 per 100 ml, nor shall more than 10% of the samples during any 30 day period exceed 400 per 100 ml.
Regulatory Status: Approved water quality standard

Other: Temperature

(For existing sources) The maximum temperature rise at any time above natural temperatures shall not exceed 1.7 °C (3 °F). In addition, the water temperature shall not exceed the maximum limits indicated in the following table.

Month	°C	°F
Jan	7	45
Feb	7	45
Mar	7	45
Apr	13	55
May	16	60
June	21	70
July	27	80
August	27	80
September	27	80
October	18	65
November	16	60
December	10	50

Regulatory Status: Approved water quality standard

Other: pH

7.0 to 9.0, except for natural causes, in the Open Waters of Lake Michigan …Other waters of the Basin must be within the range of 6.5 to 9.0, except for natural causes.
Regulatory Status: Approved water quality standard