Institute of Water Research Annual Technical Report FY 2013

Introduction

The Institute of Water Research (IWR) at Michigan State University (MSU) continuously provides timely information for addressing contemporary land and water resource issues through coordinated multidisciplinary efforts using advanced information and networking systems. The IWR endeavors to strengthen MSU's efforts in nontraditional education, outreach, and interdisciplinary studies utilizing available advanced technology, and partnerships with local, state, regional, and federal organizations and individuals. Activities include coordinating education and training programs on surface and ground water protection, land use and watershed management, and many others. We also encourage accessing our web site which offers a more comprehensive resource on IWR activities, goals, and accomplishments: http://www.iwr.msu.edu.

The Institute has increasingly recognized the acute need and effort for multi-disciplinary research to achieve better water management and improved water quality. This effort involves the integration of research, data, and knowledge with the application of models and geographic information systems (GIS) to produce spatial decision support systems (SDSS). These geospatial decision support systems provide an analytical framework and research data via the web to assist individuals and local and state government agencies make wise resource decisions. The Institute has also increasingly become a catalyst for region wide decision-making support in partnership with other states in EPA Region 5 using state-of-the-art decision support systems.

The Institute works closely with the MSU Cooperative Extension Service to conduct outreach and education. USGS support of this Institute as well as others in the region enhances the Institute credibility and facilitates partnerships with other federal agencies, universities, and local and state government agencies. The Institute also provides important support to MSU-WATER, a major university initiative dealing with urban storm water issues with funding from the university Vice President for Finance. A member of the Institute's staff works half-time in facilitating MSU-WATER activities so the Institute enjoys a close linkage with this project. The following provides a more detailed explanation of the Institute's general philosophy and approach in defining its program areas and responsibilities.

General Statement

To deal successfully with the emergence of water resource issues unique to the 21st century, transformation of our knowledge and understanding of water for the protection, conservation, and management of water resources is imperative. Radically innovative approaches involving our best scientific knowledge, extensive spatial databases, and "intelligent" tools that visualize wise resource management and conservation in a single holistic system are likewise imperative. Finally, holistic system analysis and understanding requires a strong and integrated multi-disciplinary framework.

Research Program Introduction

The management of water resources, appropriate policies, and data acquisition and modeling continue to be at the forefront of the State, Regional, and National Legislatures agenda and numerous environmental and agricultural organizations. Our contribution to informing the debate involved numerous meetings, personal discussions, and most importantly, the enhancement of web-based information to aid in the informed decision-making process.

Unique Capabilities: Decision Support Systems as the Nexus

IWR, with its “extended research family,” is exceptionally well-positioned to integrate research conducted within each of the three principal water research domains: hydrologic sciences, water policy, and aquatic ecosystems. Integrated decision support both reflects and forms the nexus of these three research domains. Expanding web accessibility to the decision support system nexus (formed by the intersection of the three research domains) will facilitate broad distribution of science-based research produced in these domains. A special emphasis is being placed on facilitation of science-based natural resource state and national policy evolution. Fundamentally we are addressing the Coupled Human and Natural System (CHANS).

The Institute’s extensive experience in regional and national networking provides exceptional opportunities for assembling multi-agency funding to support interdisciplinary water research projects and multi-university partnerships.

Using a Multi-Disciplinary Framework

Using a multi-disciplinary framework facilitates dynamic applications of information to create geospatial, place-based strategies, including watershed management tools, to optimize economic benefits and assure long-term sustainability of valuable water resources. New information technologies including GIS and computational analysis, enhanced human/machine interfaces that drive better information distribution, and access to extensive real-time environmental datasets make a new “intelligent reality” possible. This is our way of addressing the "CHANS." Effective watershed management requires integration of theory, data, simulation models, and expert judgment to solve practical problems. Geospatial decision support systems meet these requirements with the capacity to assess and present information geographically, or spatially, through an interface with a geographic information system (GIS). Through the integration of databases, simulation models, and user interfaces, these systems are designed to assist decision makers in evaluating the economic and environmental impacts of various watershed management alternatives.

The ultimate goal of these new imperatives is to guide sustainable water use plus secure and protect the future of water quality and supplies in the Great Lakes Basin, across the country and the world—with management strategies based on an understanding of the uniqueness of each watershed.

Award--Modeling the Impacts of Chicago River on Lake Michigan: Dynamics of Dissolved Oxygen, BOD, Suspended Solids, Chloride and Temperature in the Nearshore Region

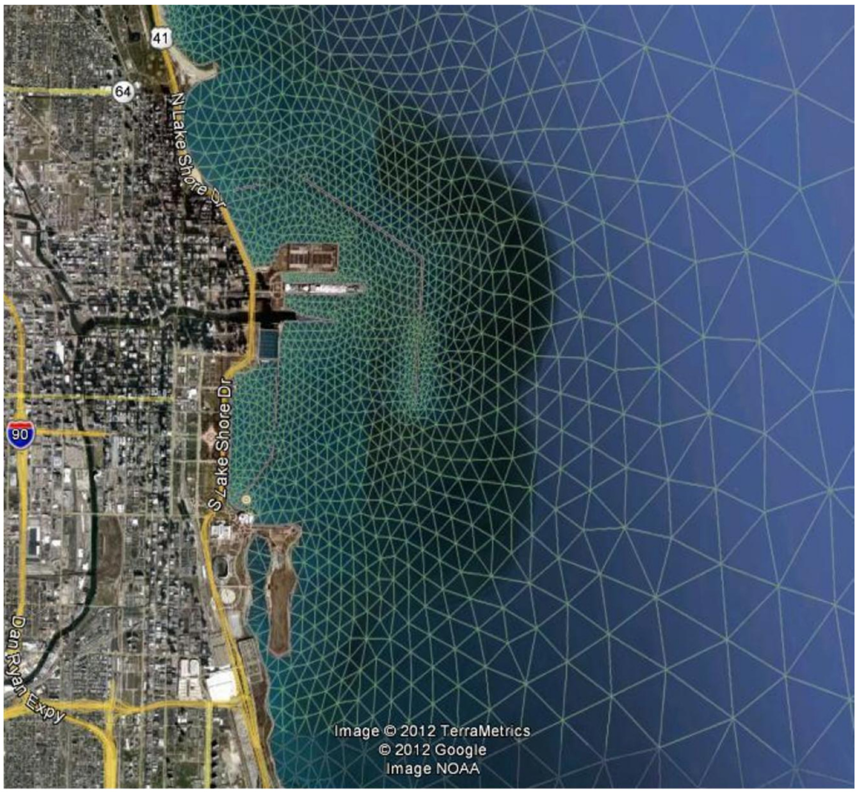
Basic Information

Title:	Award--Modeling the Impacts of Chicago River on Lake Michigan: Dynamics of Dissolved Oxygen, BOD, Suspended Solids, Chloride and Temperature in the Nearshore Region
Project Number:	2012MI219S
Start Date:	4/1/2012
End Date:	3/31/2014
Funding Source:	Supplemental
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Water Quality, Solute Transport, Nitrate Contamination
Descriptors:	Chicago River on Lake Michigan: Dynamics of Dissolved Oxygen, BOD, Suspended Solids, Chloride and Temperature
Principal Investigators:	Jon Bartholic, Phanikumar S Mantha

Publication

1. Phanikumar, Mantha S., Meredith Nevers, and Richard Whitman. 2013. Modeling The Effects Of Hydrologic Separation On The Chicago Area Waterway System On Water Quality In Lake Michigan, 105 pgs.

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

The United States Army Corps of Engineers

Dr. Pramod Thupaki
Postdoctoral Research Scholar
Department of Civil and Environmental Engineering
Michigan State University, East Lansing, MI 48824

Dr. Mantha S. Phanikumar
Associate Professor
Department of Civil and Environmental Engineering
Michigan State University, East Lansing, MI 48824

Meredith Nevers
Research Ecologist
Lake Michigan Ecological Research Station
United States Geological Survey, Porter, IN 46304

Dr. Richard Whitman
Chief, Lake Michigan Ecological Research Station
United States Geological Survey, Porter, IN 46304

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

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.

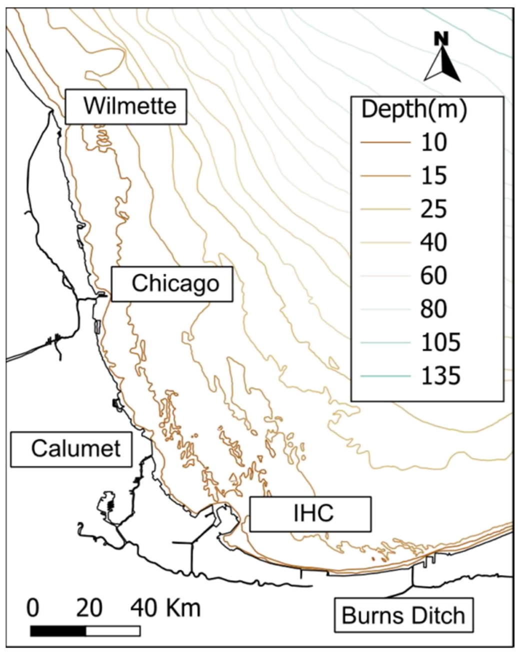


Figure 1.1 Map showing some of the major rivers and outfalls that discharge into the southern part of Lake Michigan (IHC: Indiana Harbor Canal).

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.

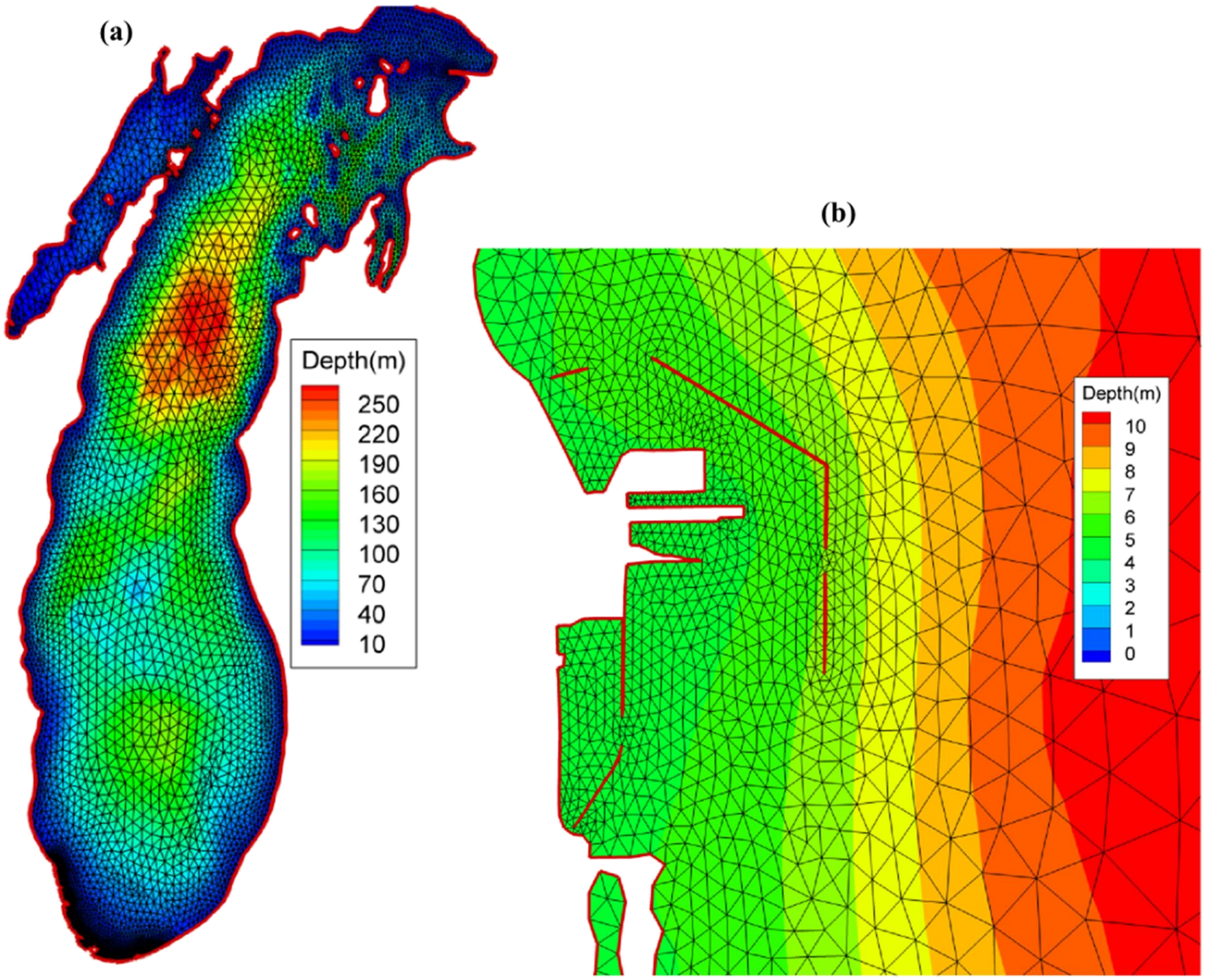


Figure 2.1 (a) The unstructured computational mesh used to resolve lake-wide circulation, (b) coastal features as described by the computational mesh near the Chicago River mouth.

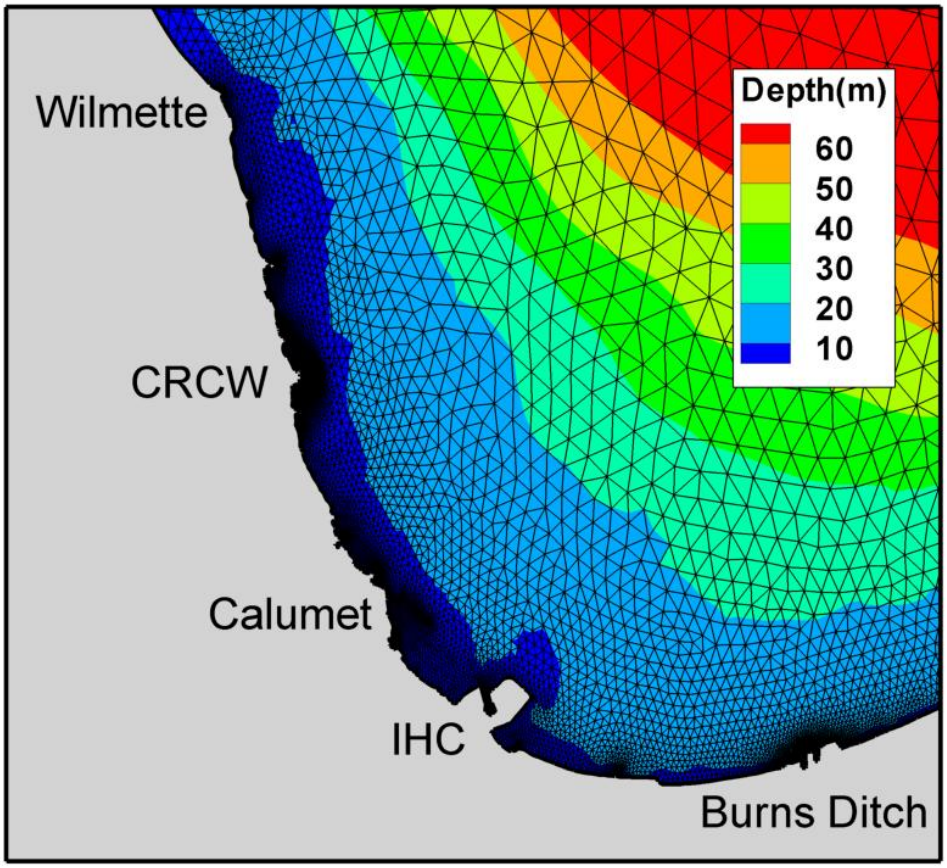


Figure 2.2 Outfalls included in the numerical model (IHC: Indiana Harbor Canal)

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.

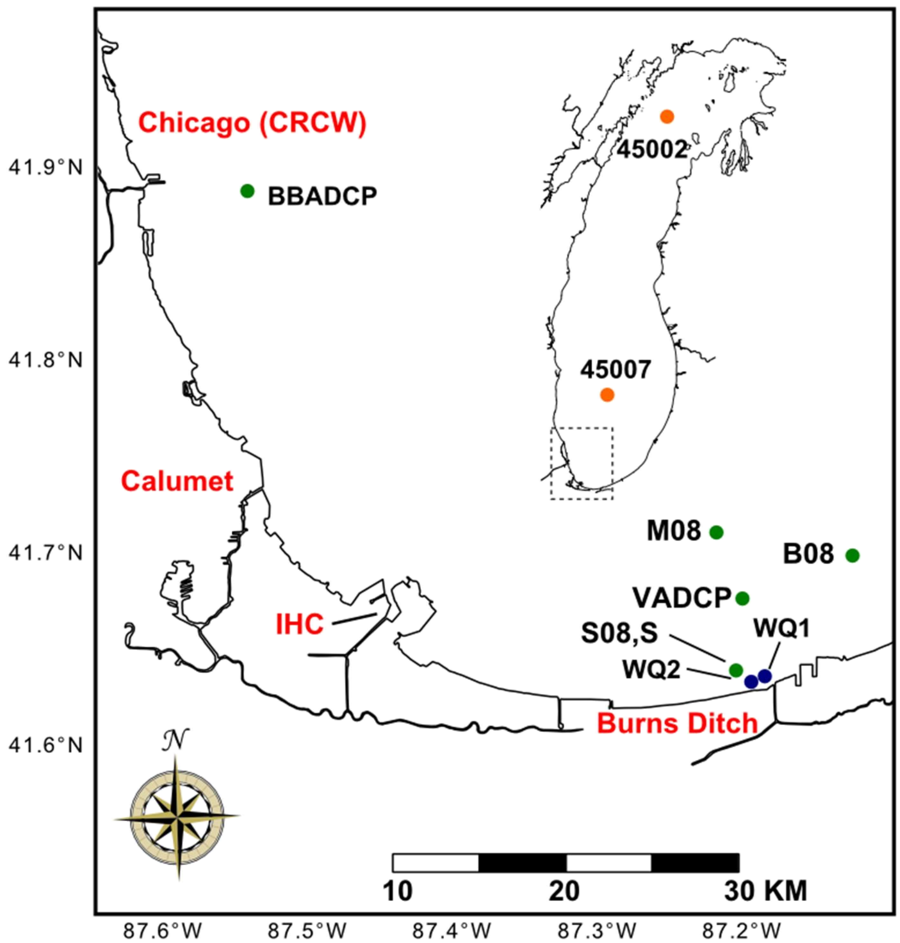


Figure 2.3 Geographical sketch showing approximate locations of sampling (WQ1 & WQ2) and ADCP deployment locations.

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.

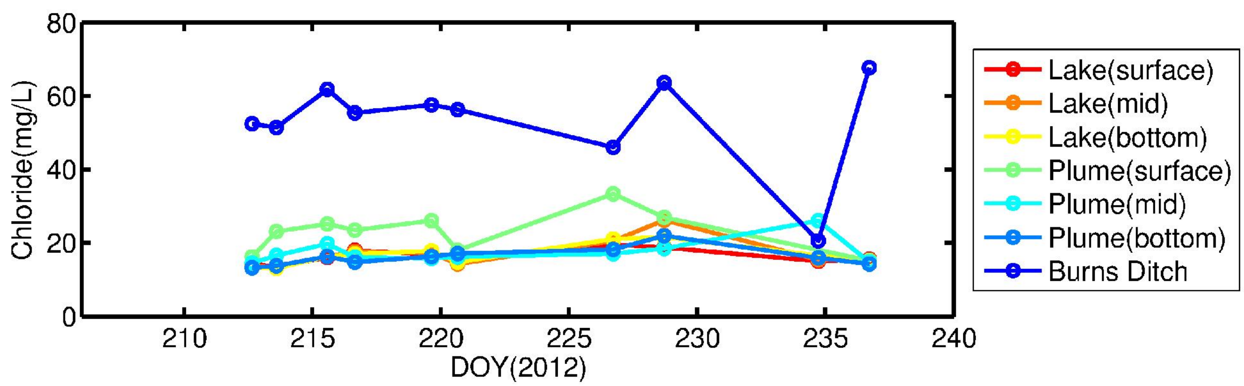


Figure 3.1 Concentration of chloride ion at water sampling locations

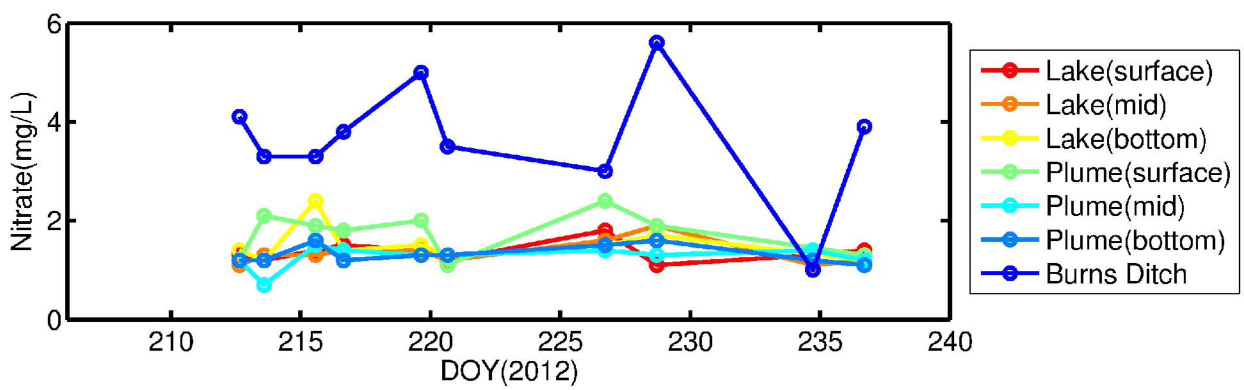


Figure 3.2 Concentration of nitrate ion at water sampling locations

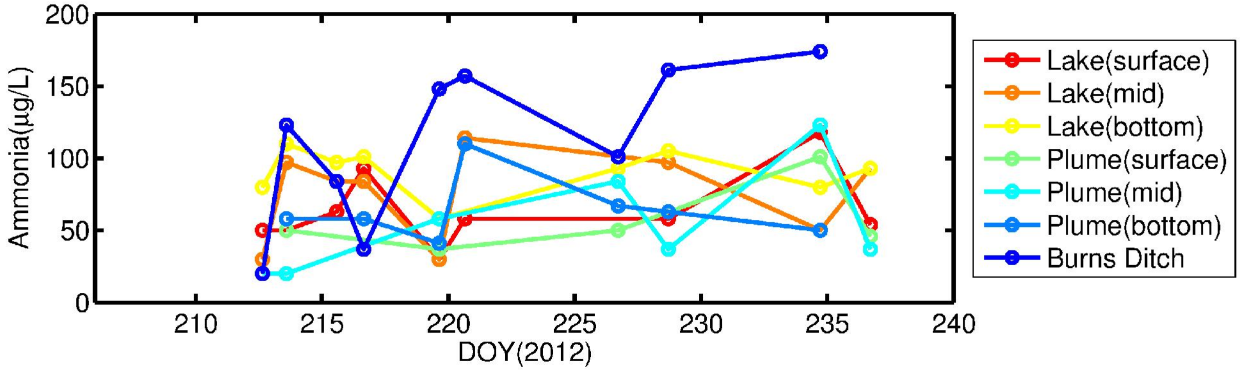


Figure 3. 3 Concentration of ammonia ion at water sampling locations

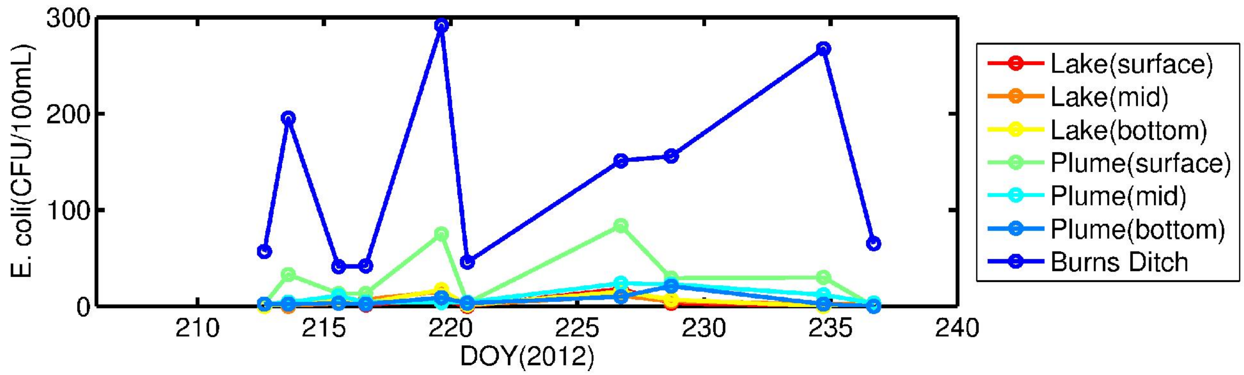


Figure 3. 4 Concentration of E. coli at water sampling locations

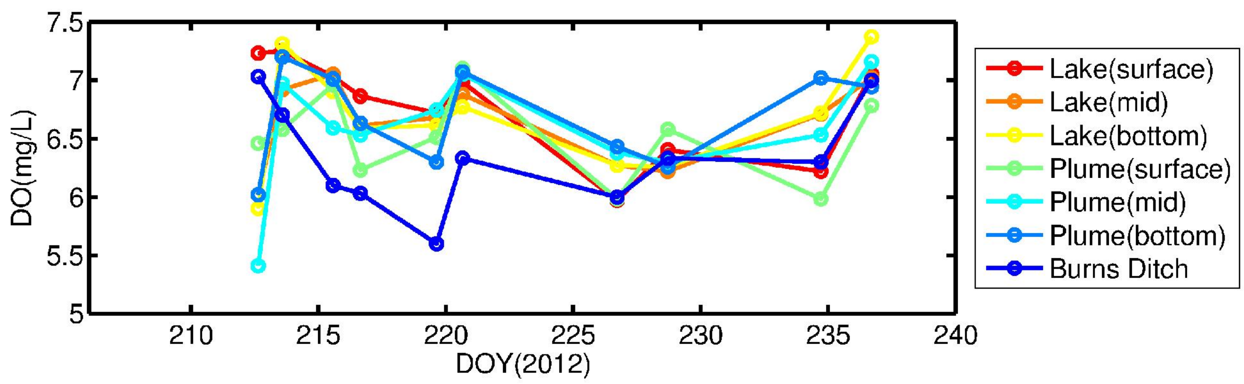


Figure 3. 5 Concentration of dissolved oxygen at water sampling locations

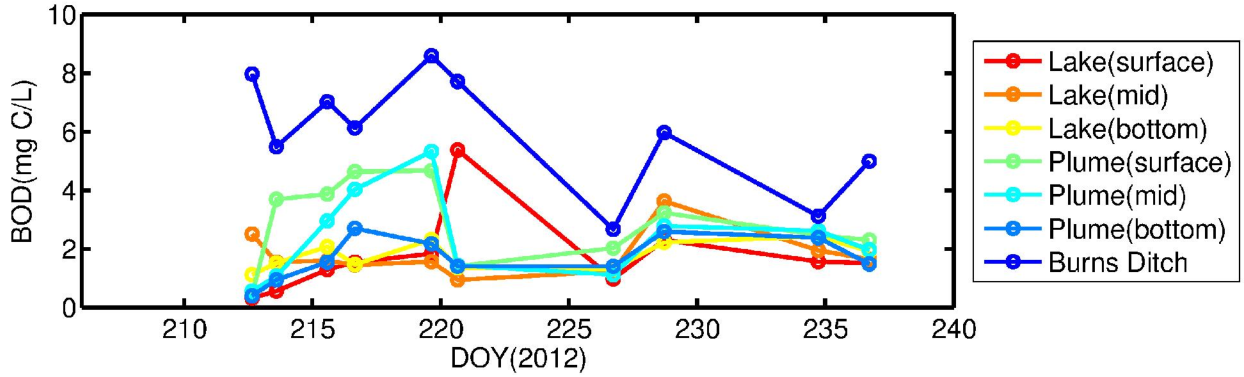


Figure 3. 6 Concentration of biological oxygen demand at water sampling locations

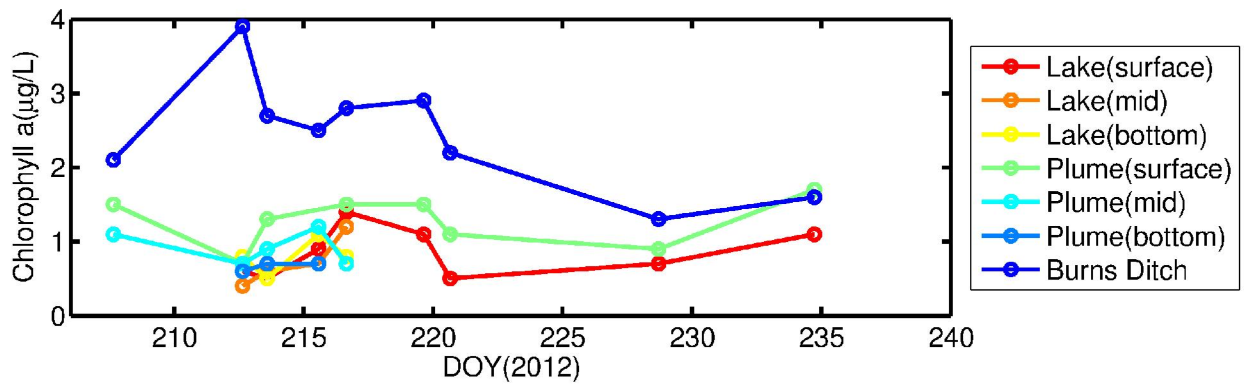


Figure 3. 7 Concentration of phytoplankton (chlorophyll a) at water sampling locations

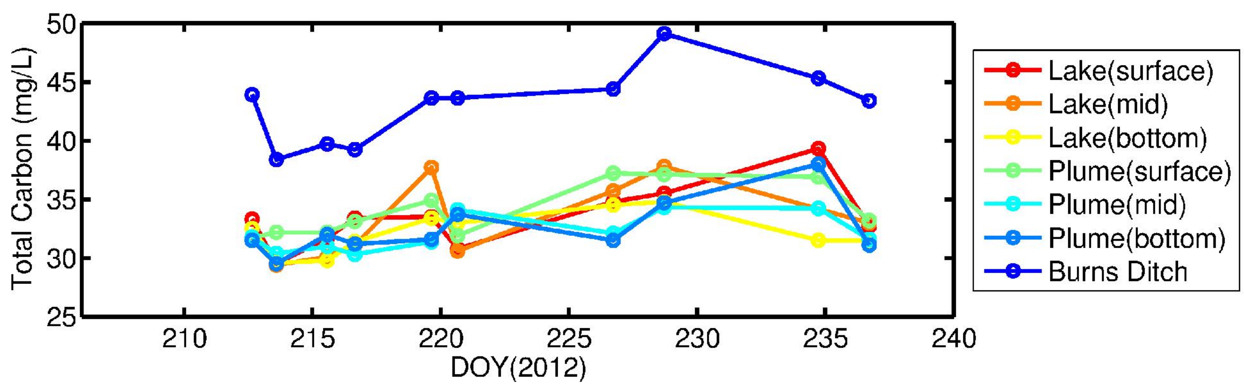


Figure 3. 8 Concentration of total carbon at water sampling locations

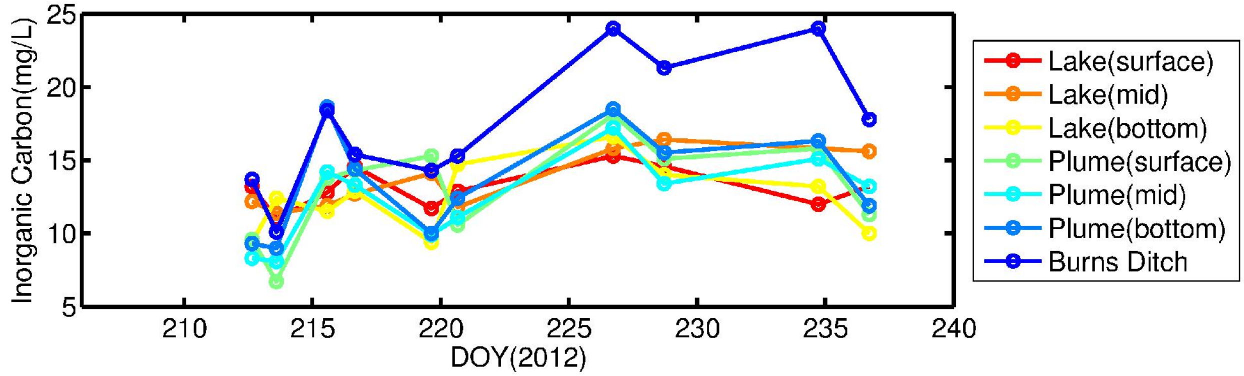


Figure 3. 9 Concentration of total inorganic carbon at water sampling locations

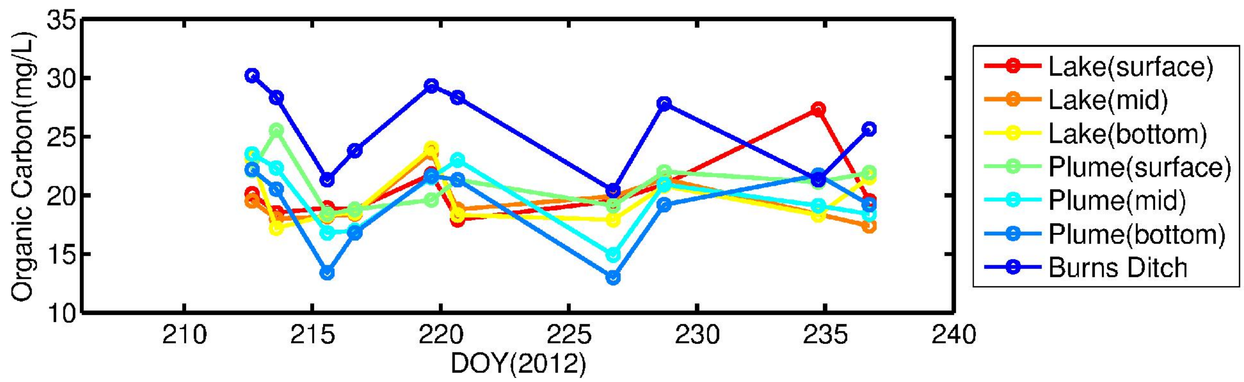


Figure 3. 10 Concentration of total organic carbon at water sampling locations

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.

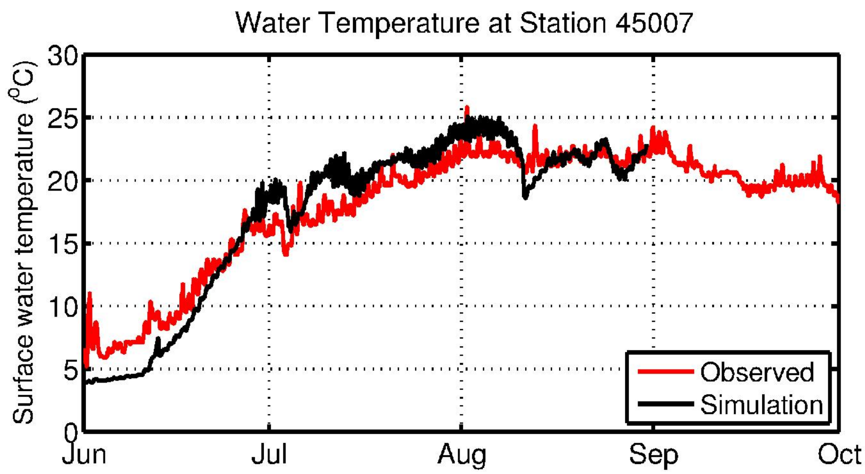


Figure 3.11 Comparison between observed surface water temperature at NDBC buoy 45007 and model results

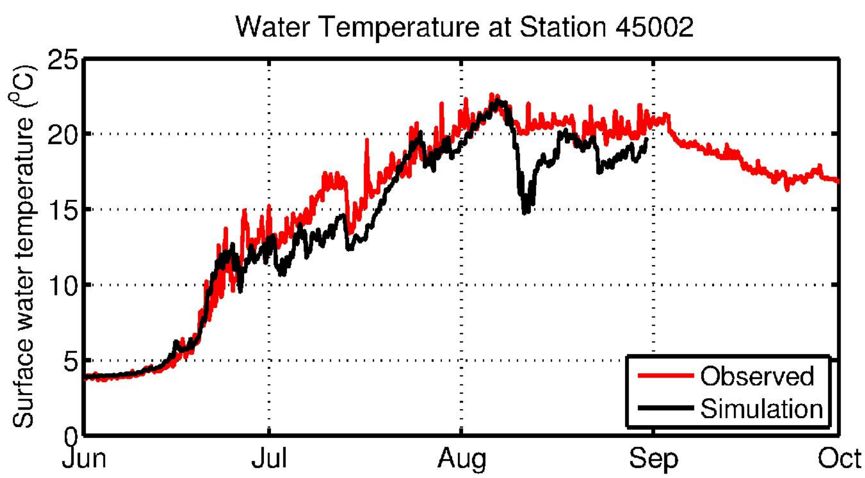


Figure 3.12 Comparison between observed surface water temperature at NDBC buoy 45002 and model results

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.

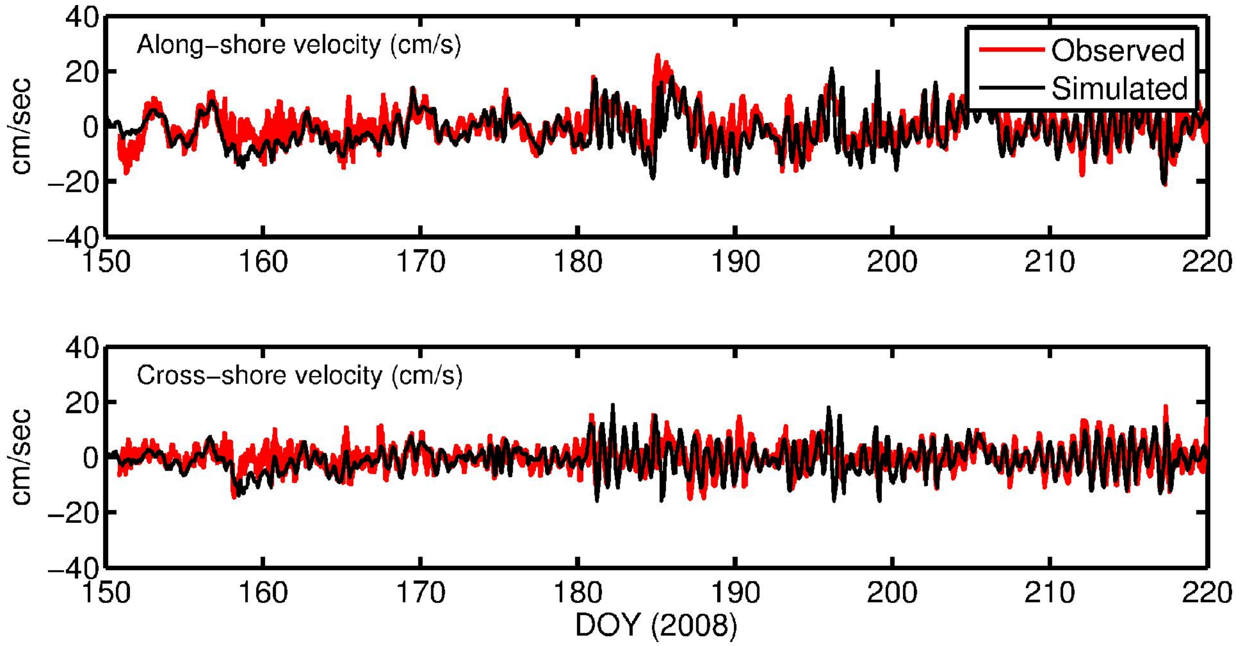


Figure 3.13 Comparisons between observed velocities in 2008 at location B08 and model results

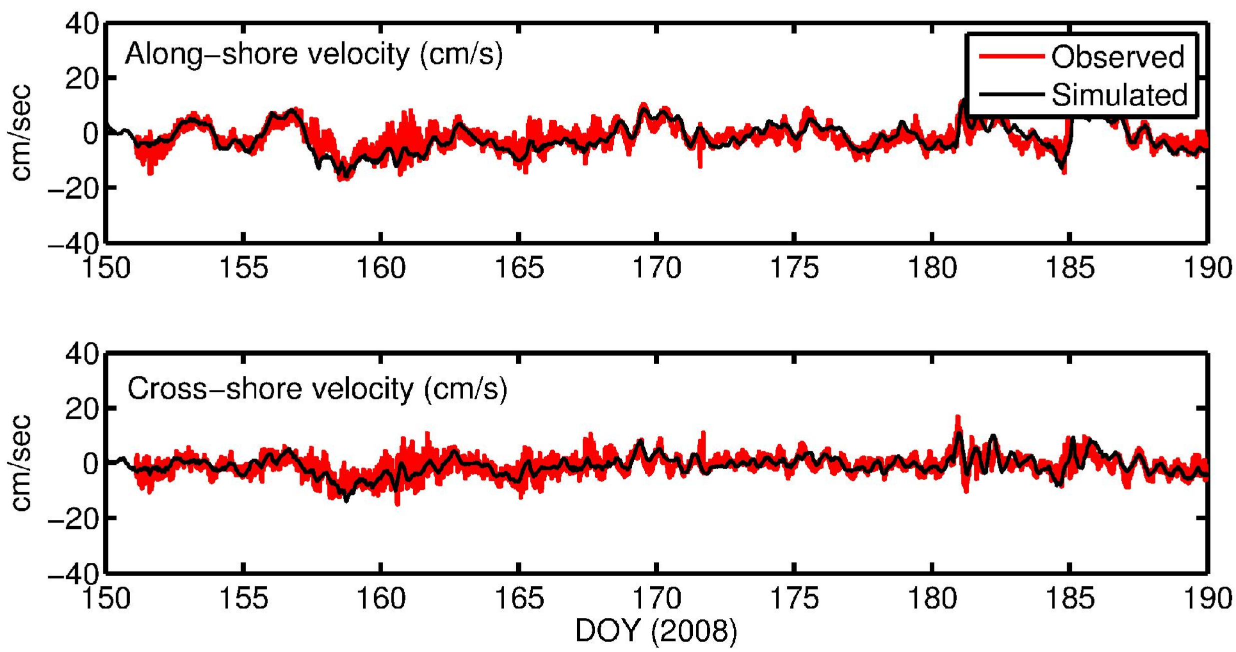


Figure 3.14 Comparisons between observed velocities in 2008 at location M08 and model results

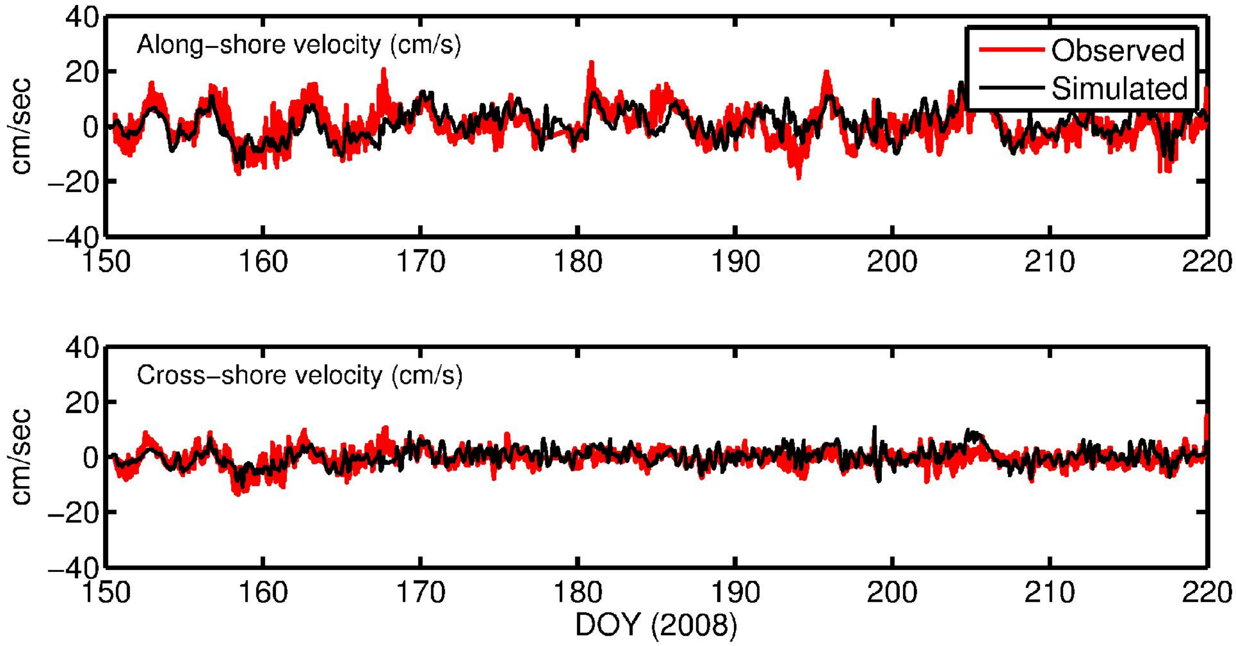


Figure 3.15 Comparisons between observed velocities in 2008 at location S08 and model results

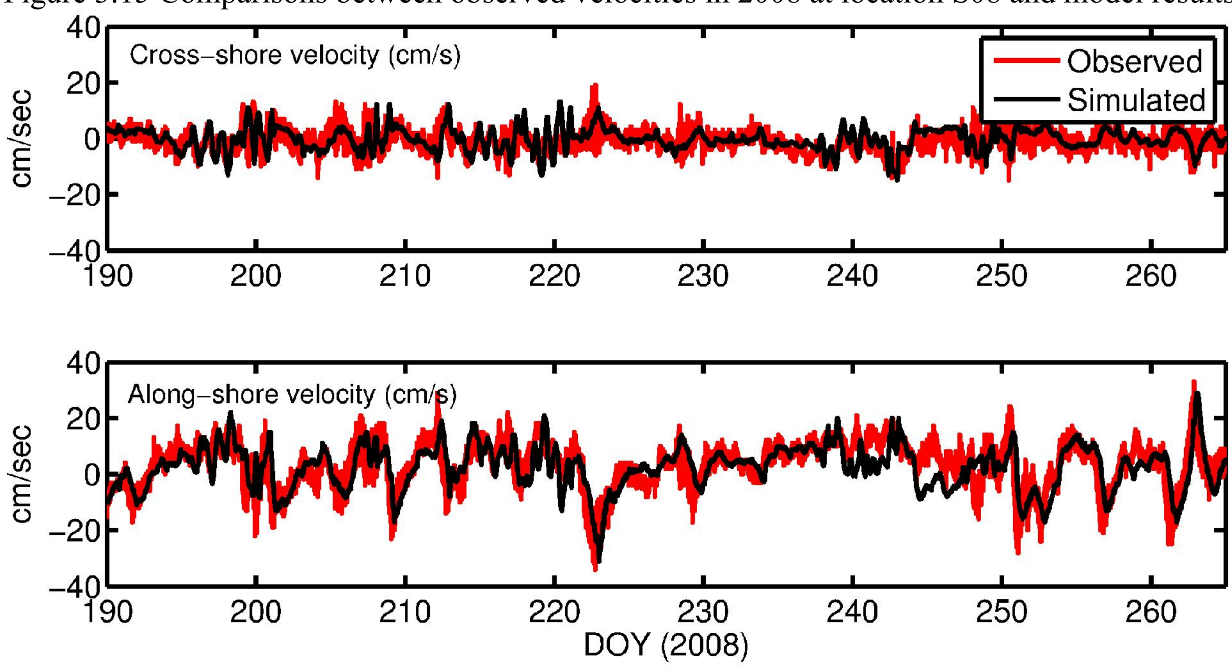


Figure 3.16 Comparisons between observed velocities in 2012 at location BBADCP and model results

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.

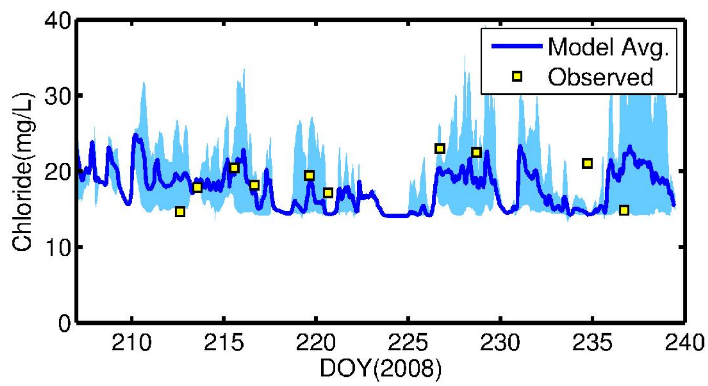


Figure 3.17 Comparison between observed and simulated values of chloride ion concentration at location WQ1

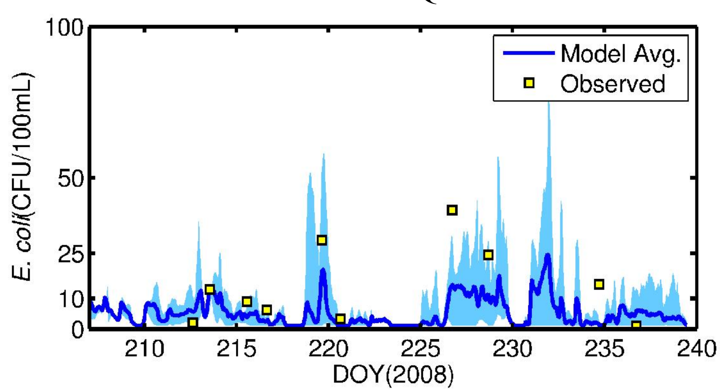


Figure 3.18 Comparison between observed and simulated values of *E. coli* concentrations at location WQ1

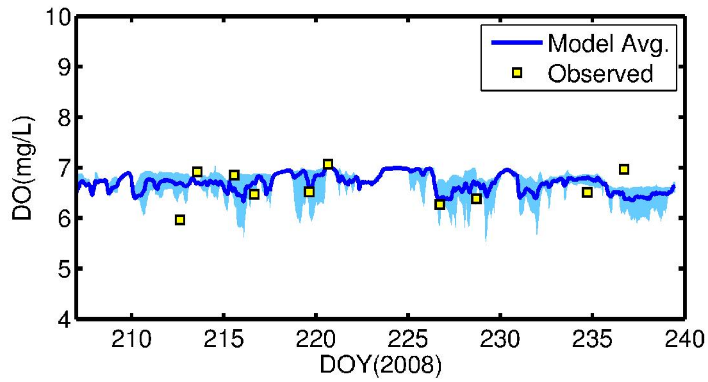


Figure 3.19 Comparison between observed and simulated values of DO concentrations at location WQ1

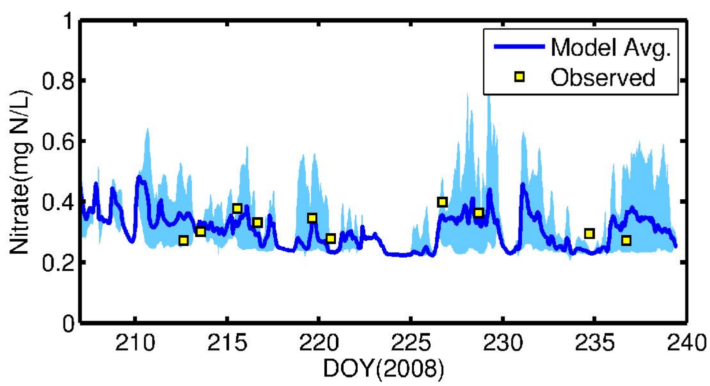


Figure 3.20 Comparison between observed and simulated values of Nitrate concentrations at location WQ1

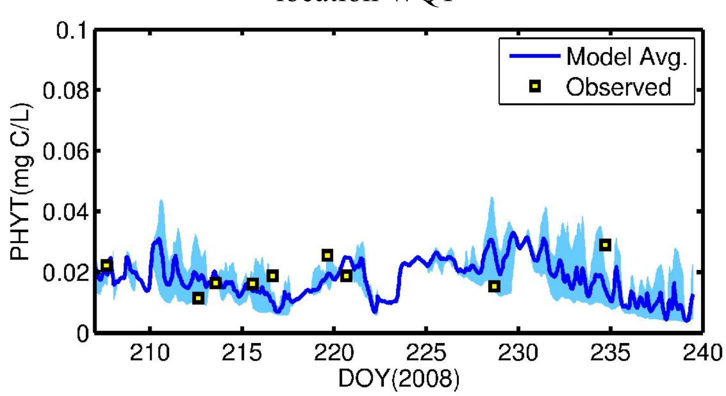


Figure 3.21 Comparison between observed and simulated values of Phytoplankton concentration at location WQ1

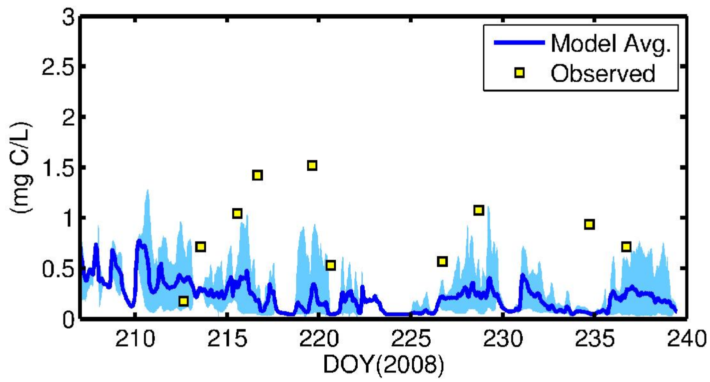


Figure 3.22 Comparison between the measured net biological oxygen demand and the model simulated carbonaceous biochemical oxygen demand. The difference between BOD and CBOD (i.e. the NBOD) is not computed by the model.

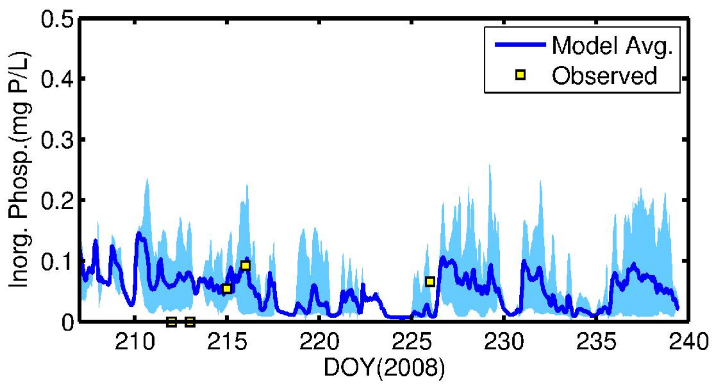


Figure 3.23 Comparison between measured and observed concentration of Inorganic Phosphorous (Phosphate ion).

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

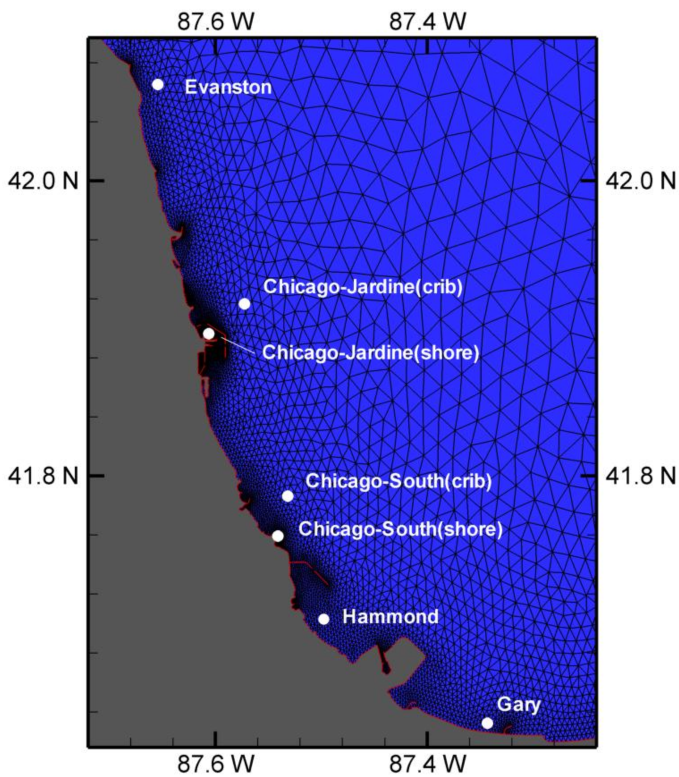


Figure 3.24 Approximate locations of major water intakes along the coastline of southern Lake Michigan

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.

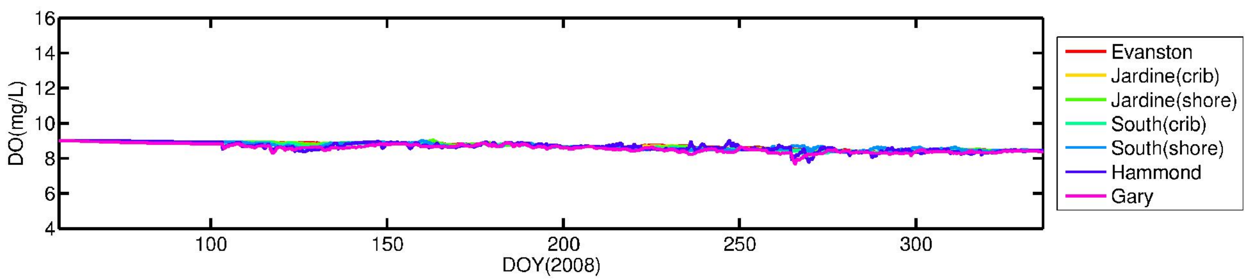


Figure 3.25 Concentration of DO at the major drinking water intake locations based on Scenario 1

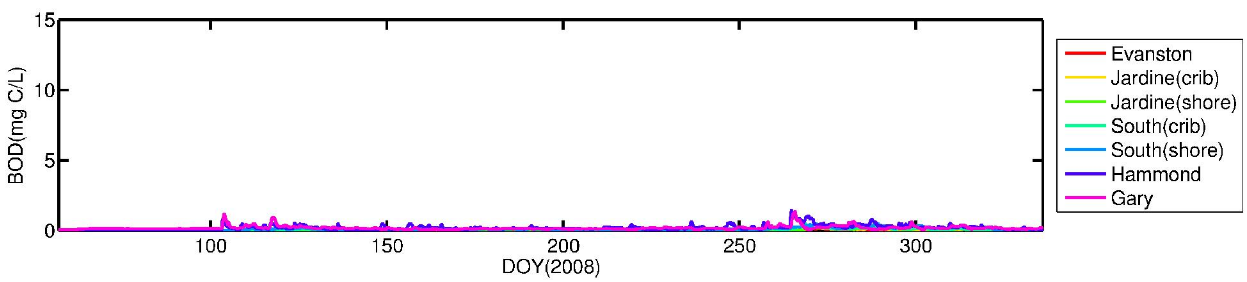


Figure 3.26 Concentration of BOD at the major drinking water intake locations based on Scenario 1

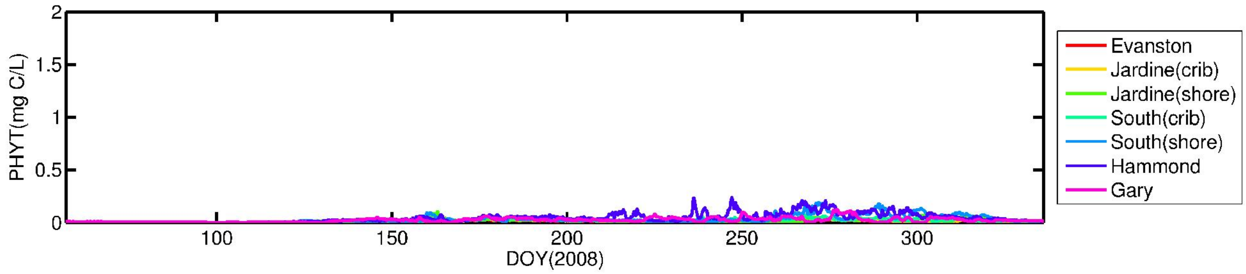


Figure 3.27 Concentration of phytoplankton at the major drinking water intake locations based on
Scenario 1

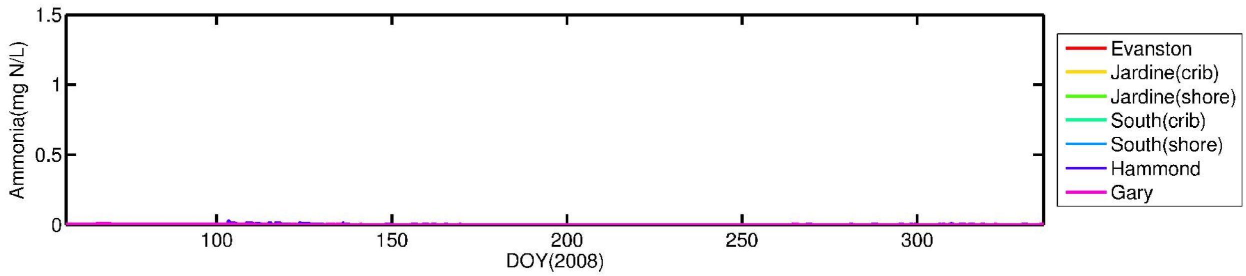


Figure 3.28 Concentration of ammonia at the major drinking water intake locations based on
Scenario 1

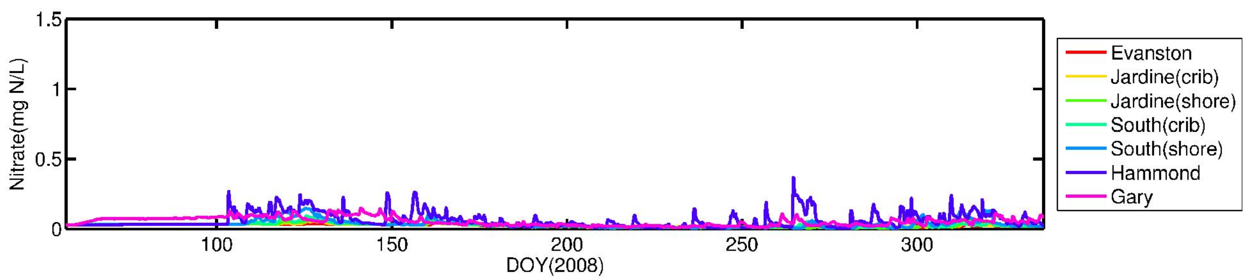


Figure 3.29 Concentration of nitrate at the major drinking water intake locations based on
Scenario 1

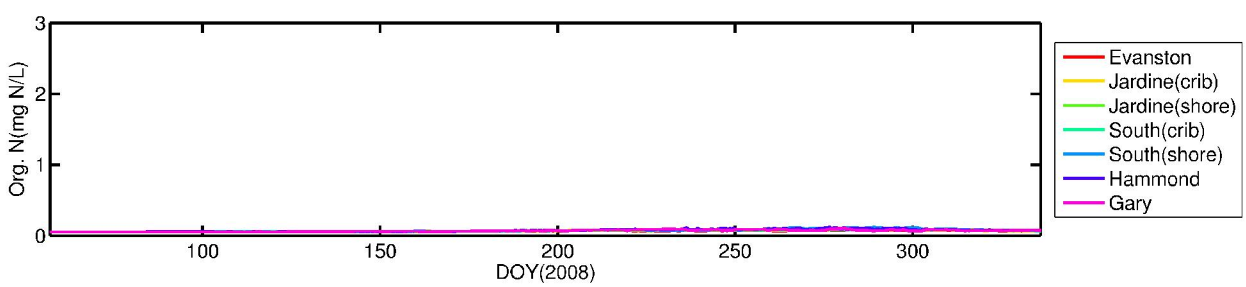


Figure 3.30 Concentration of organic nitrogen at the major drinking water intake locations based on
Scenario 1

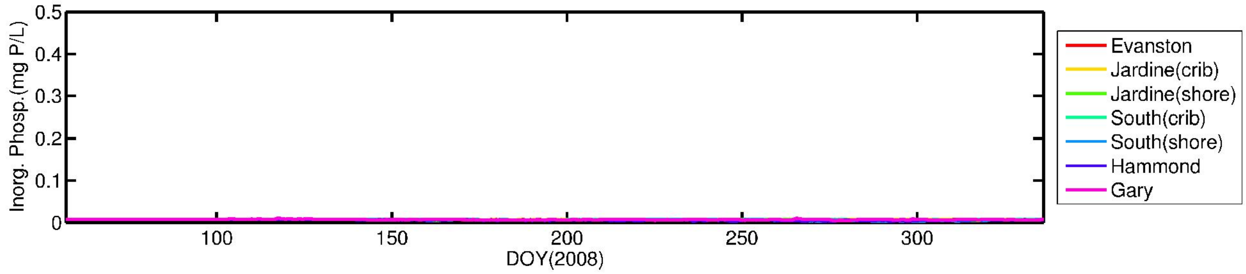


Figure 3.31 Concentration of ortho-phosphate at the major drinking water intake locations based on
Scenario 1

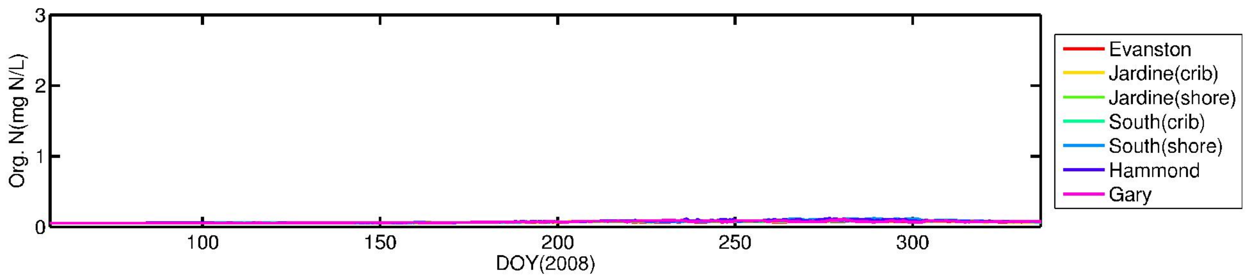


Figure 3.32 Concentration of organic phosphorous at the major drinking water intake locations based on
Scenario 1

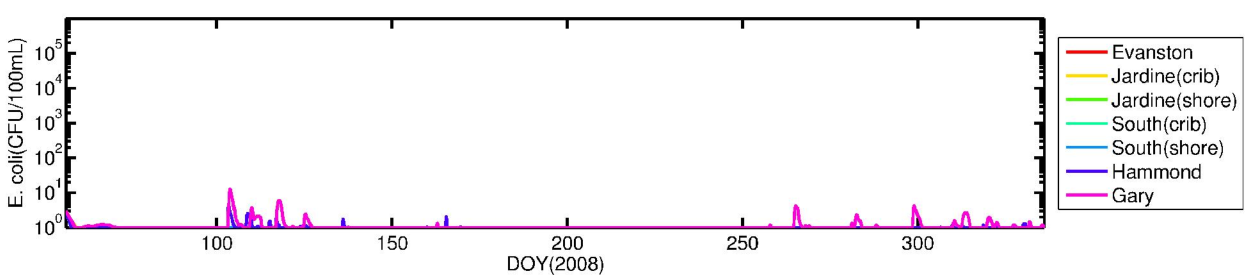


Figure 3.33 Concentration of FIB at the major drinking water intake locations based on
Scenario 1

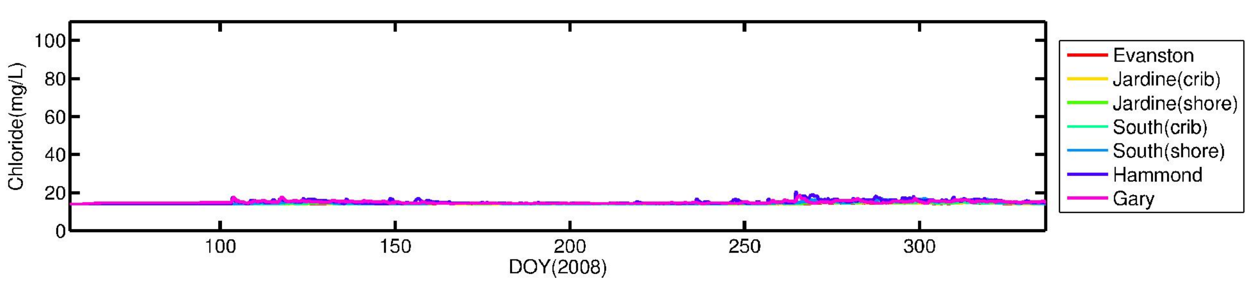


Figure 3.34 Concentration of chloride at the major drinking water intake locations based on
Scenario 1

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.

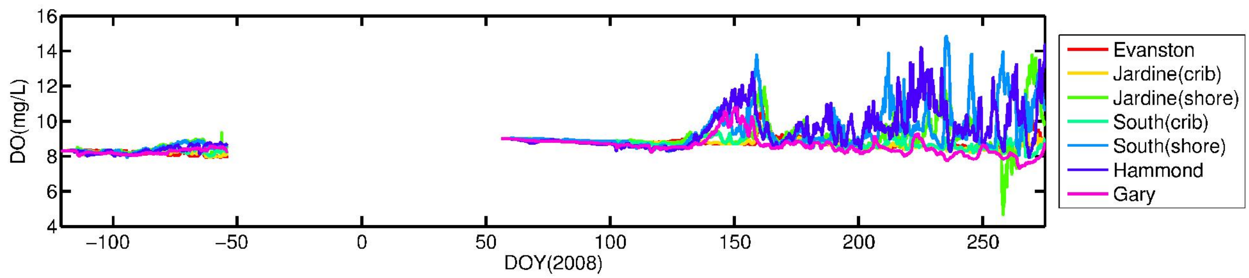


Figure 3.35 Concentration of DO at the major drinking water intake locations based on Scenario 1

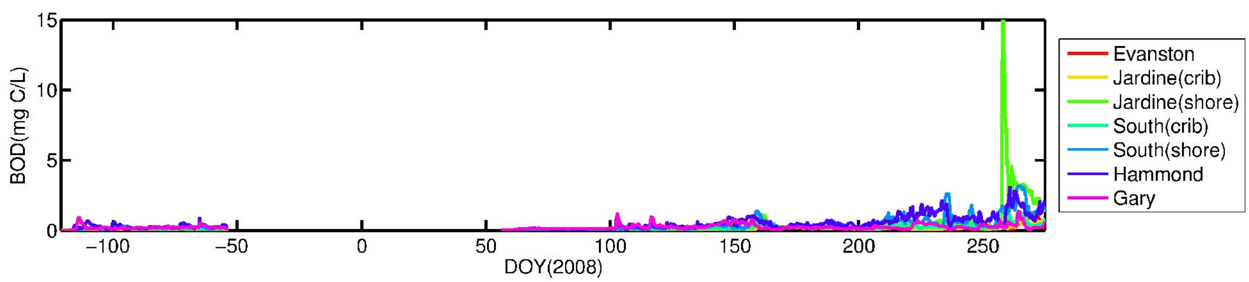


Figure 3.36 Concentration of BOD at the major drinking water intake locations

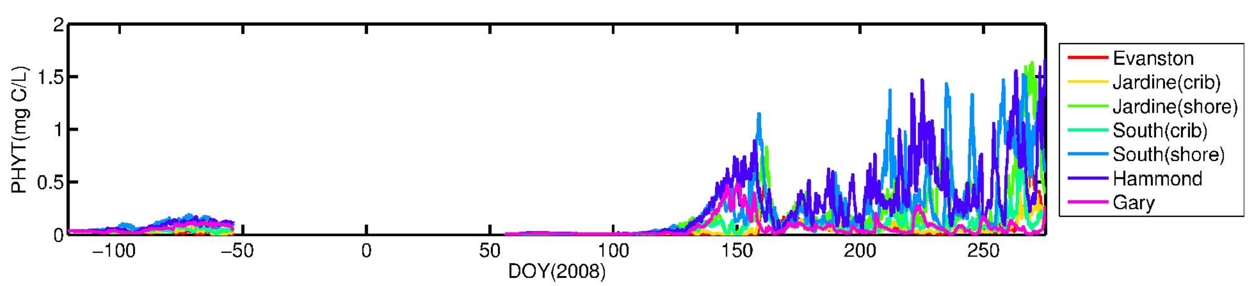


Figure 3.37 Concentration of Phytoplankton at the major drinking water intake locations

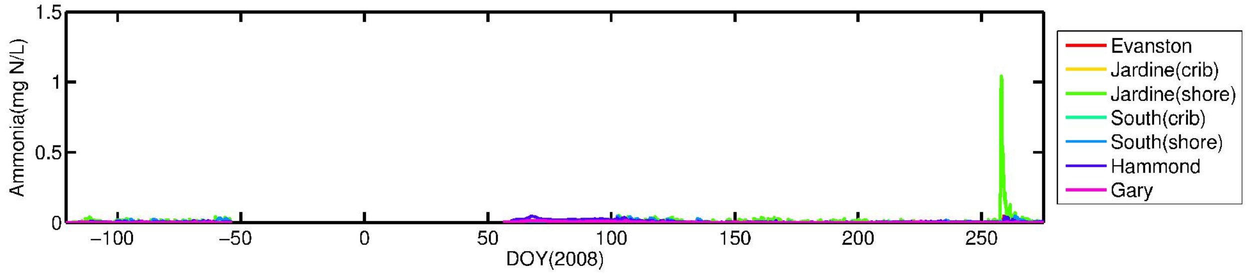


Figure 3.38 Concentration of Ammonia at the major drinking water intake locations

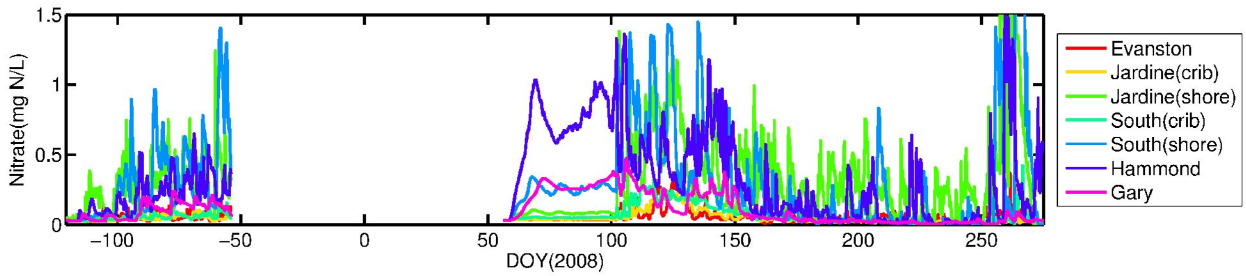


Figure 3.39 Concentration of Nitrate at the major drinking water intake locations

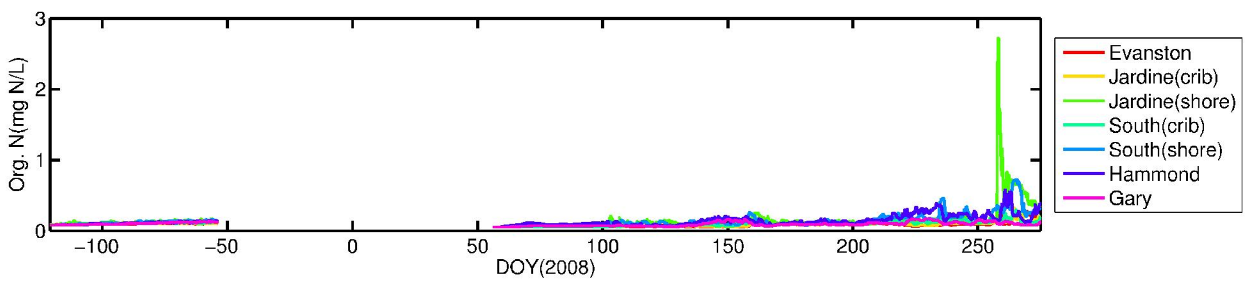


Figure 3.40 Concentration of Organic Nitrogen at the major drinking water intake locations

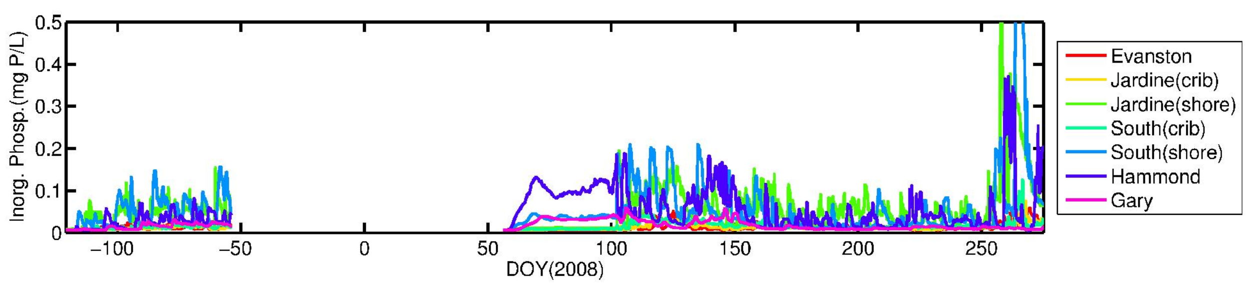


Figure 3.41 Concentration of ortho phosphate at the major drinking water intake locations

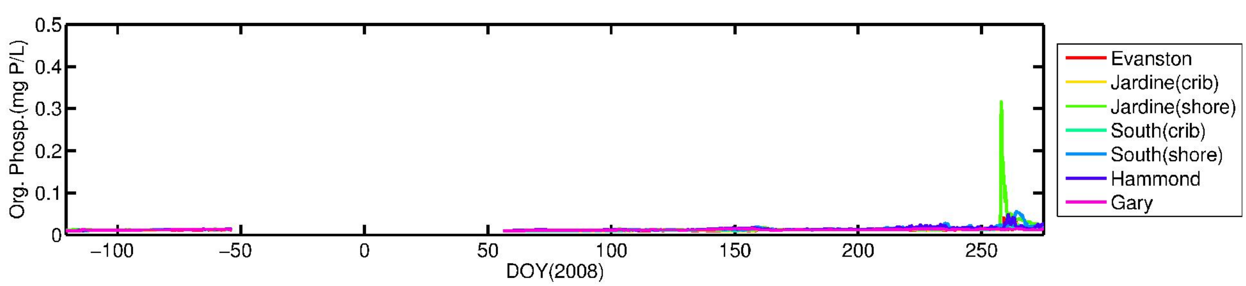


Figure 3.42 Concentration of Organic Phosphorous at the major drinking water intake locations

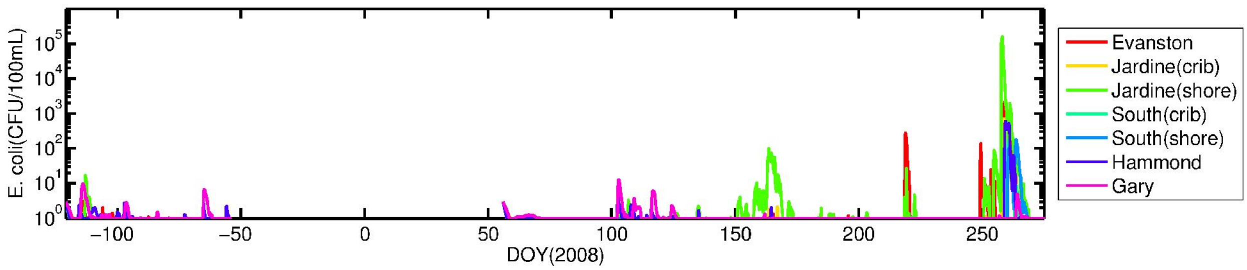


Figure 3.43 Concentration of FIB at the major drinking water intake locations

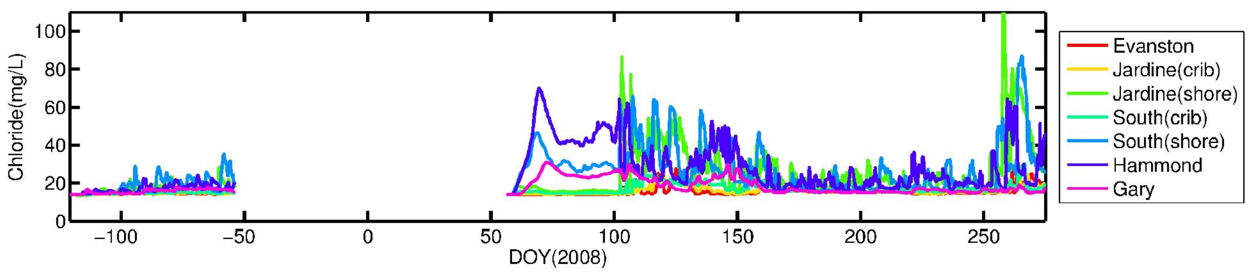


Figure 3.44 Concentration of Chloride at the major drinking water intake locations

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.

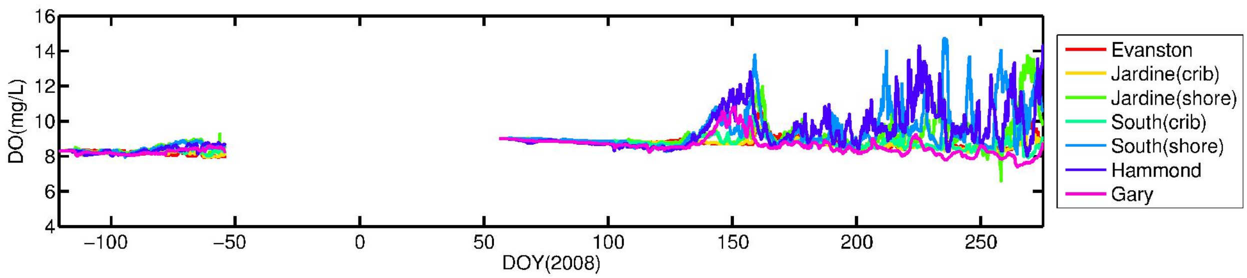


Figure 3.45 Concentration of DO at the major drinking water intake locations

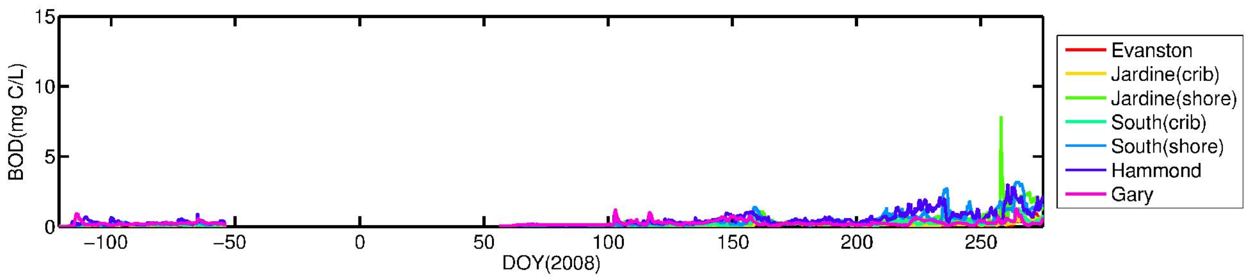


Figure 3.46 Concentration of BOD at the major drinking water intake locations

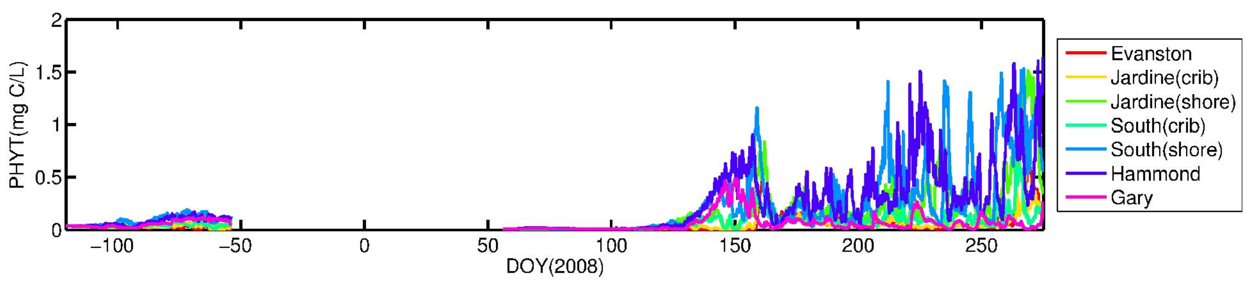


Figure 3.47 Concentration of Phytoplankton at the major drinking water intake locations

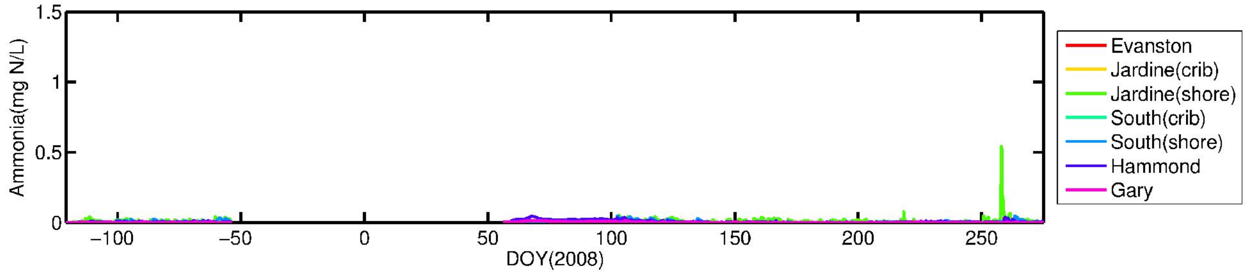


Figure 3.48 Concentration of Ammonia at the major drinking water intake locations

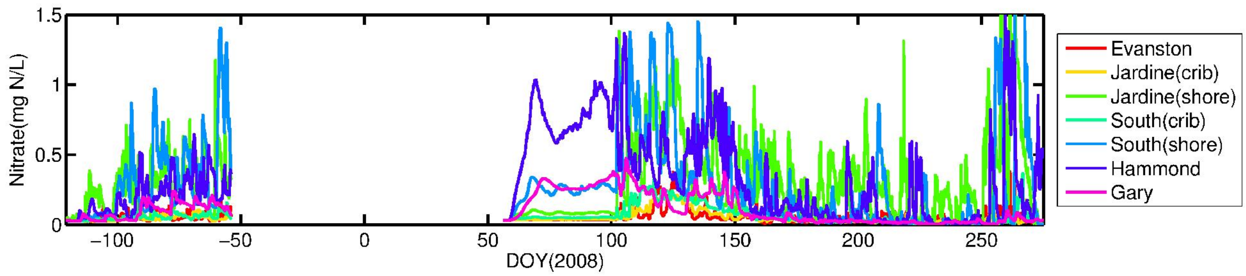


Figure 3.49 Concentration of Nitrate at the major drinking water intake locations

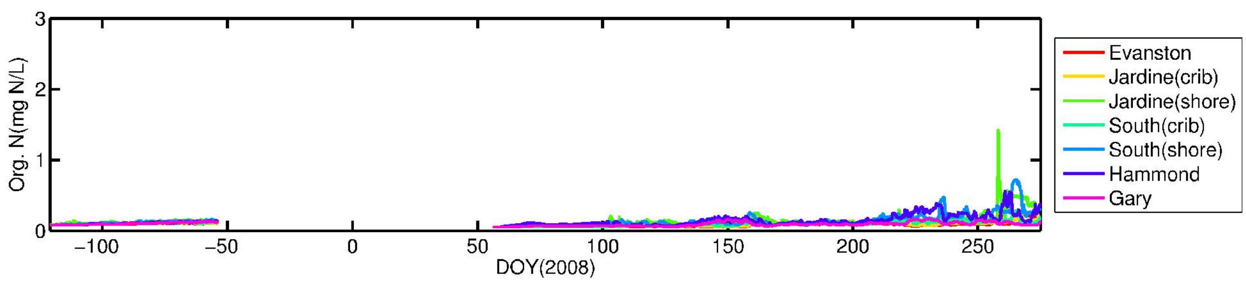


Figure 3.50 Concentration of Organic Nitrogen at the major drinking water intake locations

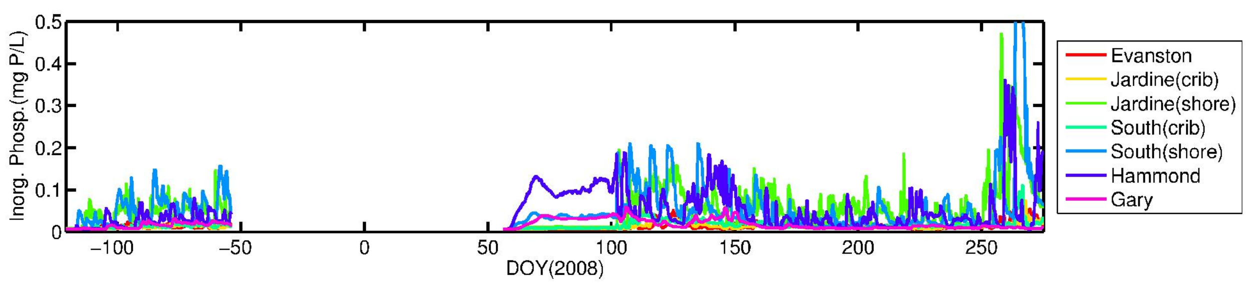


Figure 3.51 Concentration of ortho phosphate at the major drinking water intake locations

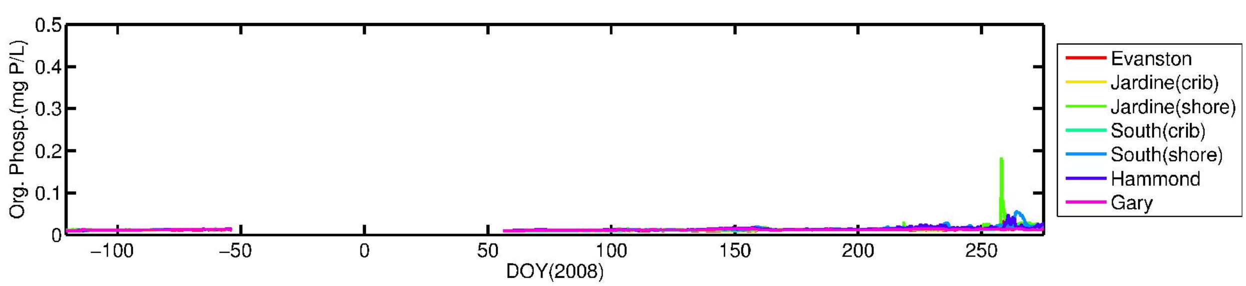


Figure 3.52 Concentration of organic phosphorous at the major drinking water intake locations

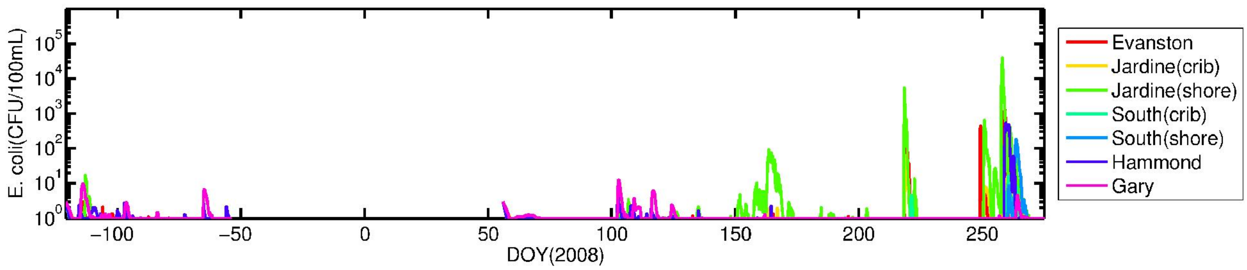


Figure 3.53 Concentration of FIB at the major drinking water intake locations

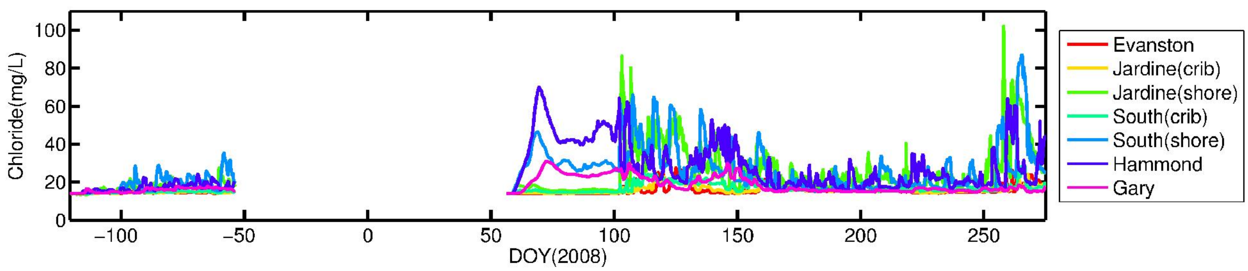


Figure 3.54 Concentration of Chloride at the major drinking water intake locations

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.

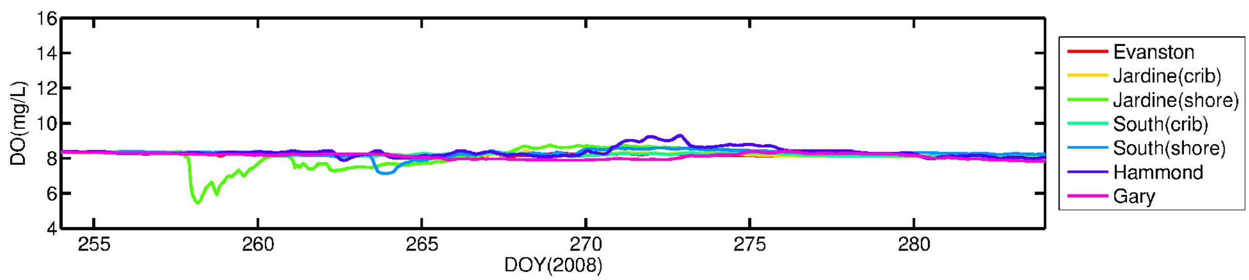


Figure 3.55 Concentration of DO at the major drinking water intake locations

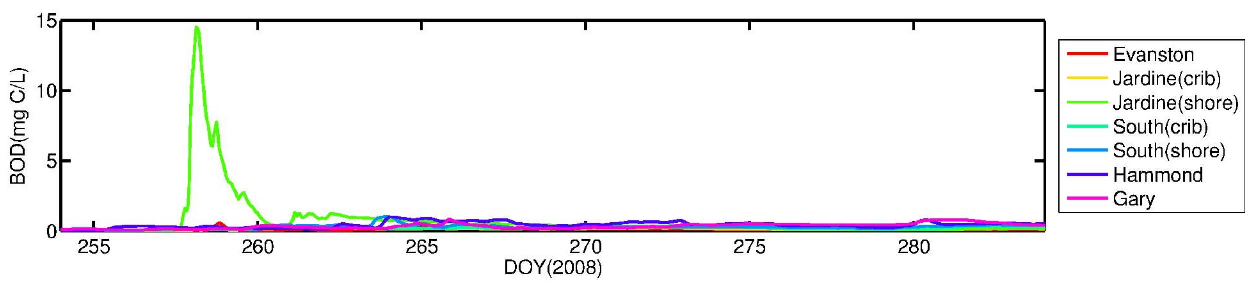


Figure 3.56 Concentration of BOD at the major drinking water intake locations

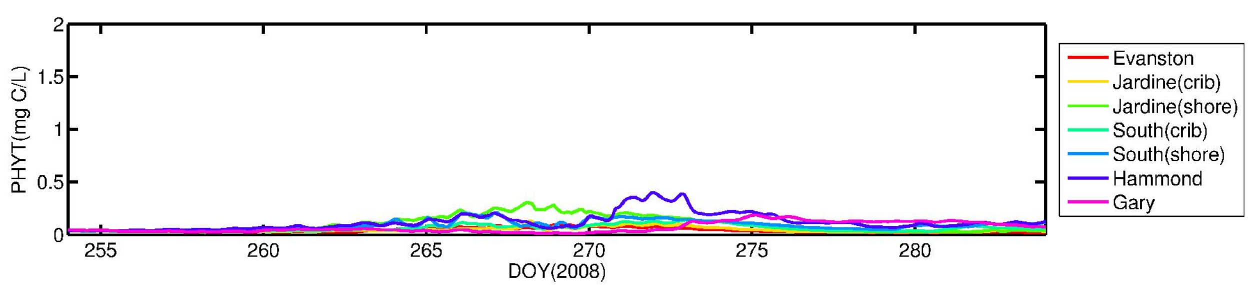


Figure 3.57 Concentration of phytoplankton at the major drinking water intake locations

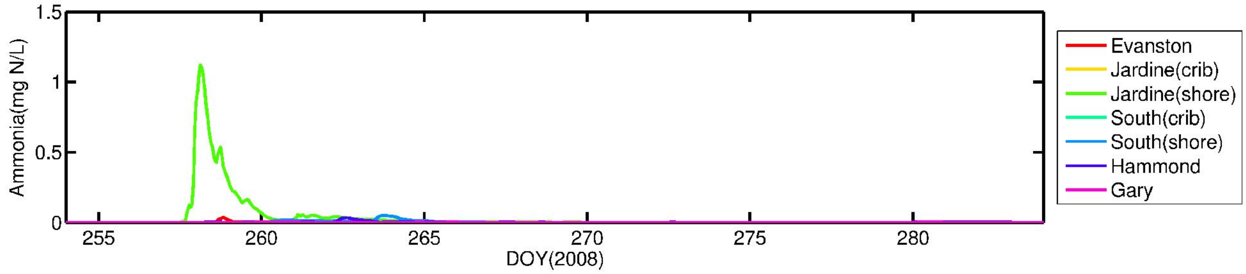


Figure 3.58 Concentration of ammonia at the major drinking water intake locations

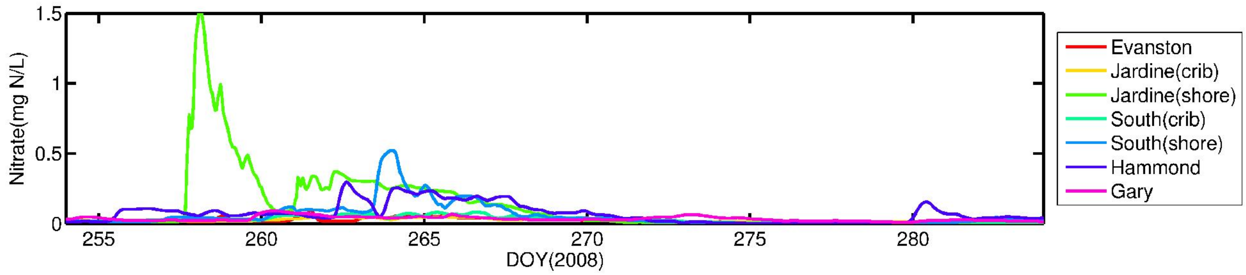


Figure 3.59 Concentration of nitrate at the major drinking water intake locations

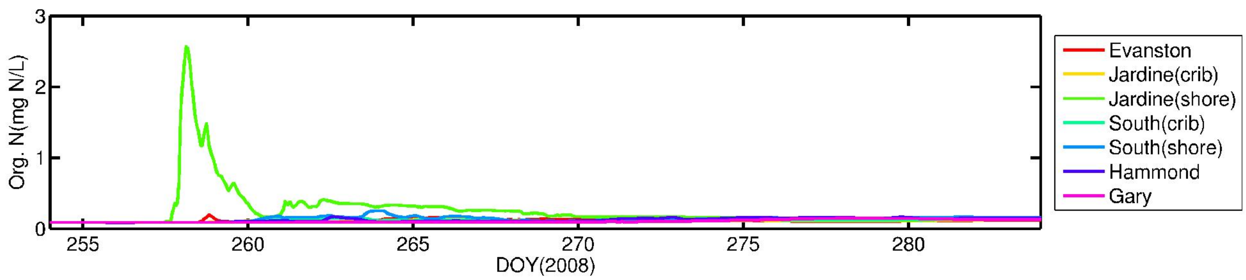


Figure 3.60 Concentration of organic nitrogen at the major drinking water intake locations

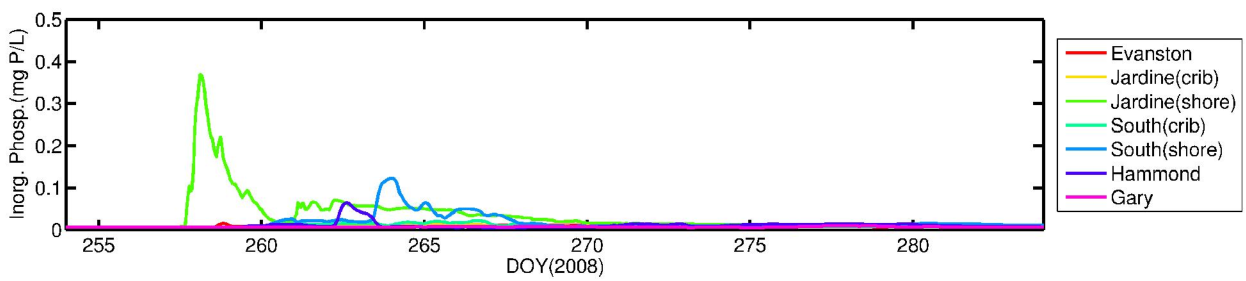


Figure 3.61 Concentration of inorganic phosphorous at the major drinking water intake locations

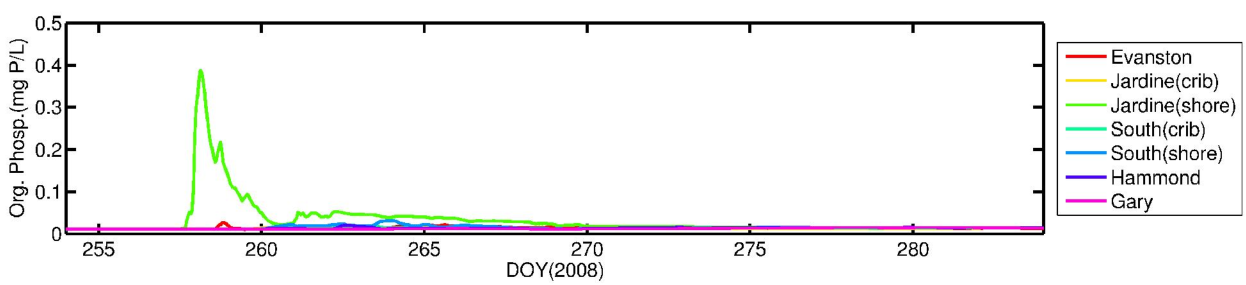


Figure 3.62 Concentration of organic phosphorous at the major drinking water intake locations

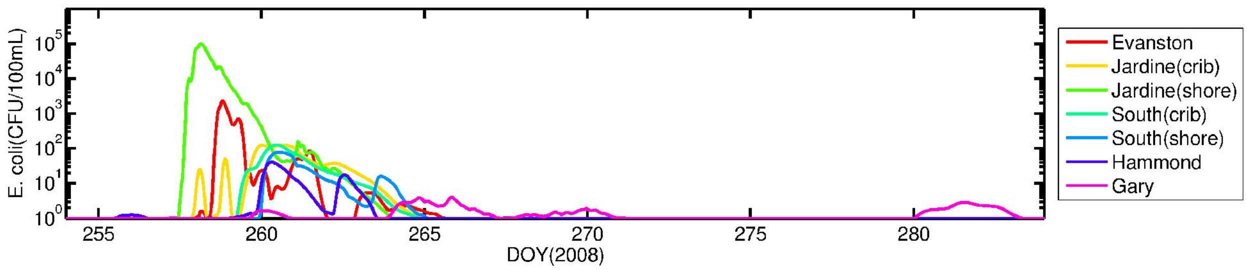


Figure 3.63 Concentration of FIB at the major drinking water intake locations

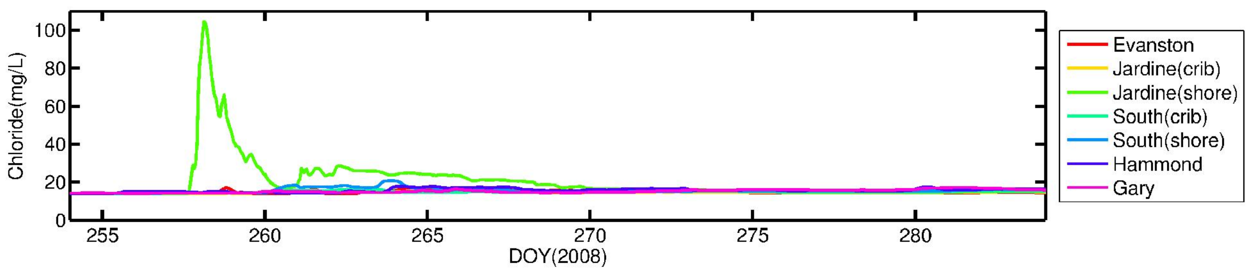


Figure 3.64 Concentration of chloride at the major drinking water intake locations

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.

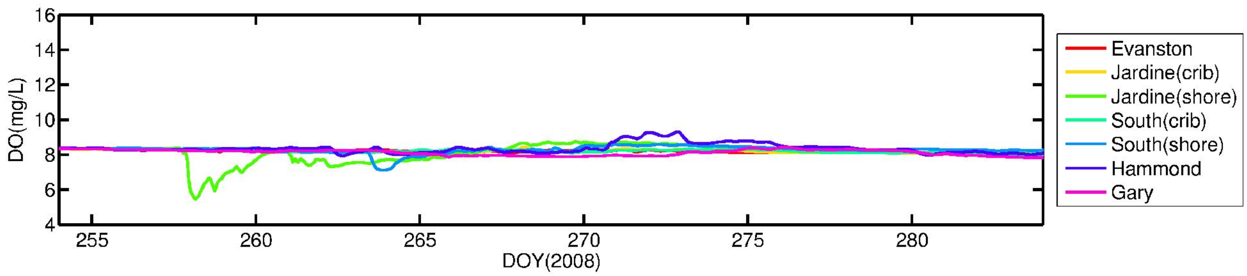


Figure 3.65 Concentration of DO at the major drinking water intake locations

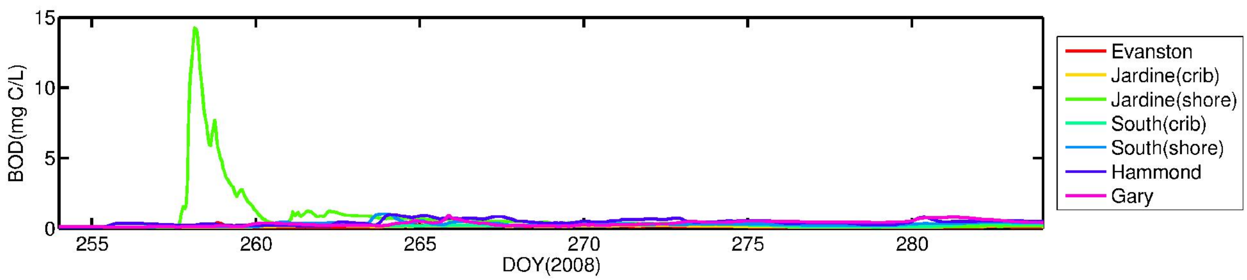


Figure 3.66 Concentration of BOD at the major drinking water intake locations

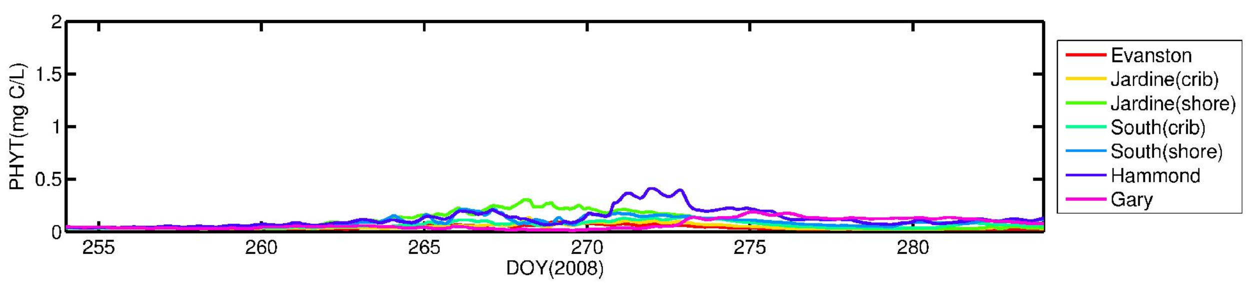


Figure 3.67 Concentration of phytoplankton at the major drinking water intake locations

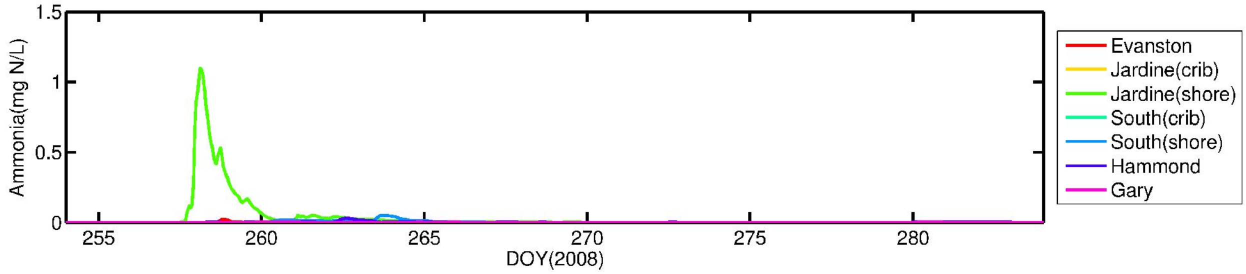


Figure 3.68 Concentration of Ammonia at the major drinking water intake locations

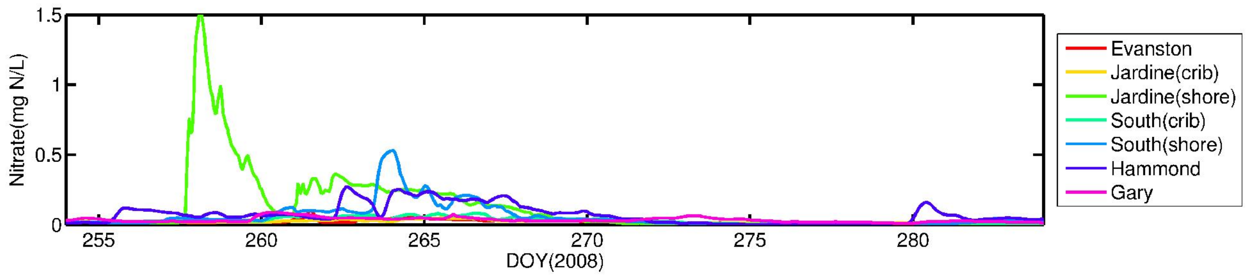


Figure 3.69 Concentration of Nitrate at the major drinking water intake locations

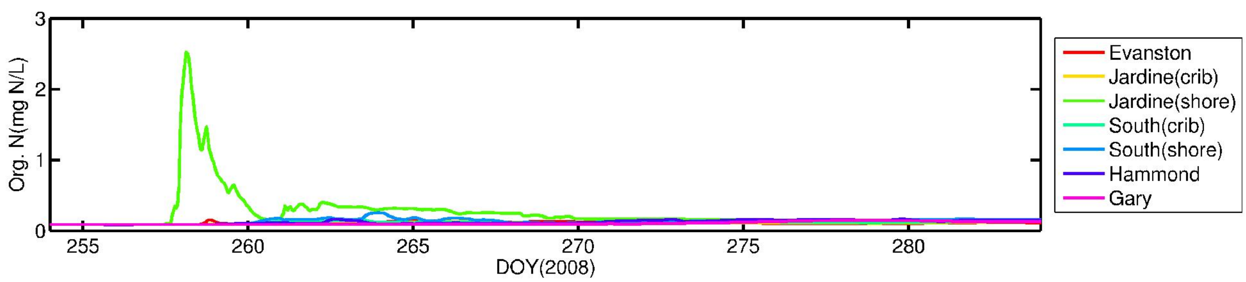


Figure 3.70 Concentration of organic nitrogen at the major drinking water intake locations

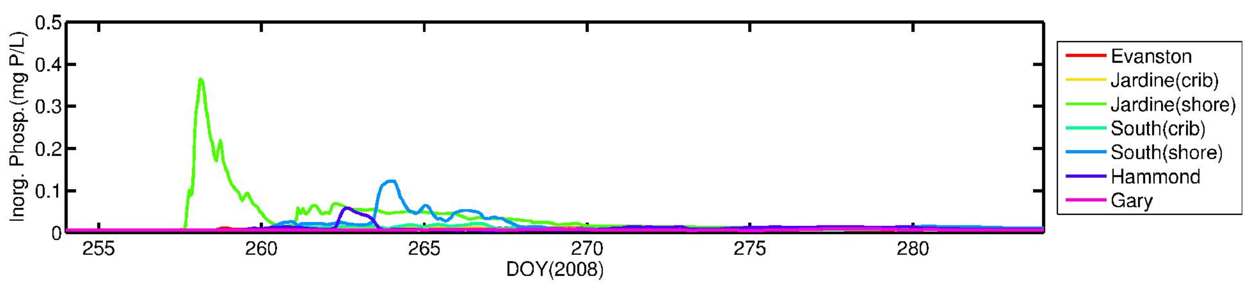


Figure 3.71 Concentration of ortho phosphate at the major drinking water intake locations

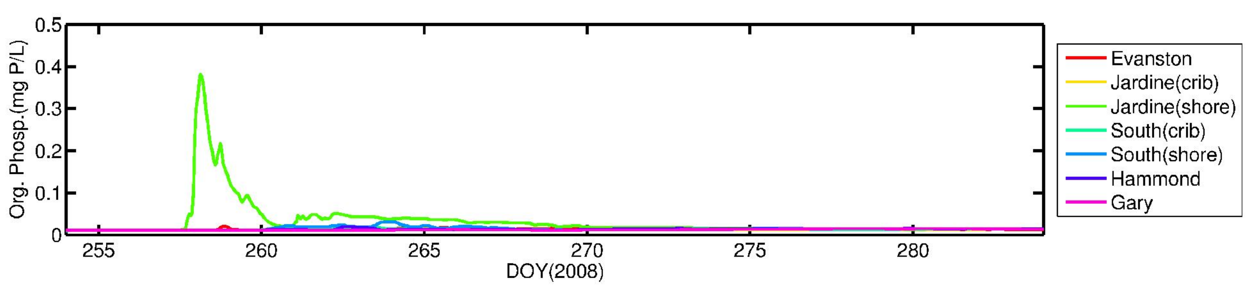


Figure 3.72 Concentration of organic phosphorous at the major drinking water intake locations

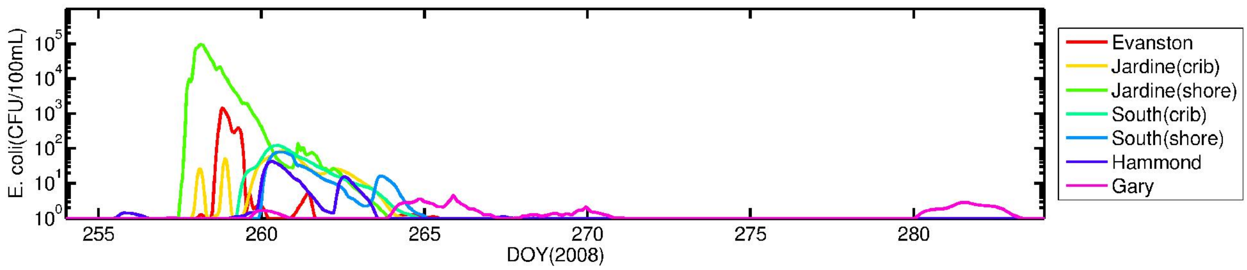


Figure 3.73 Concentration of FIB at the major drinking water intake locations

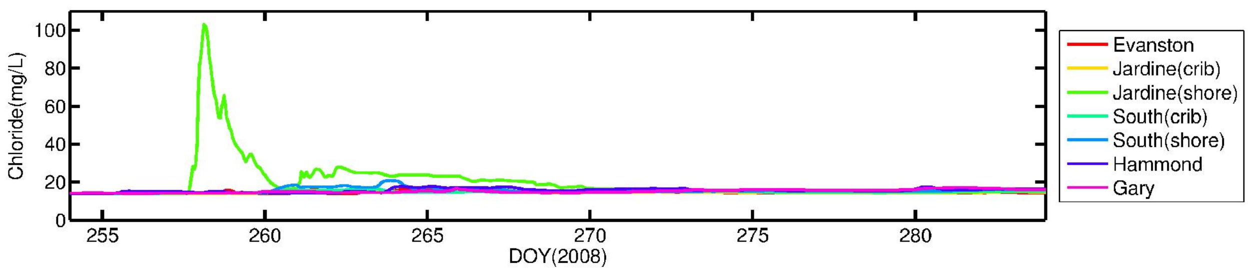


Figure 3.74 Concentration of chloride at the major drinking water intake locations

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.

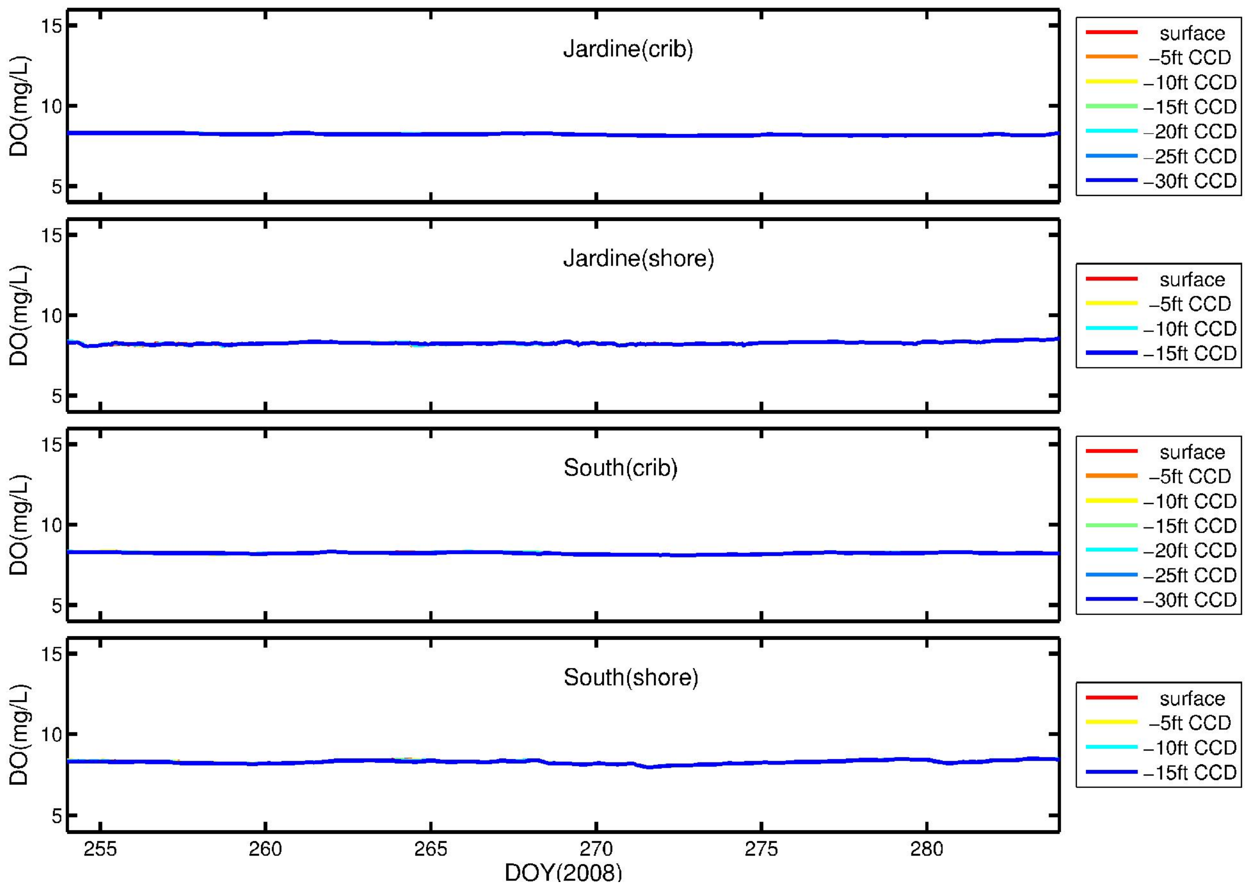


Figure 4.1 Concentration of dissolved oxygen at different depths at a few locations

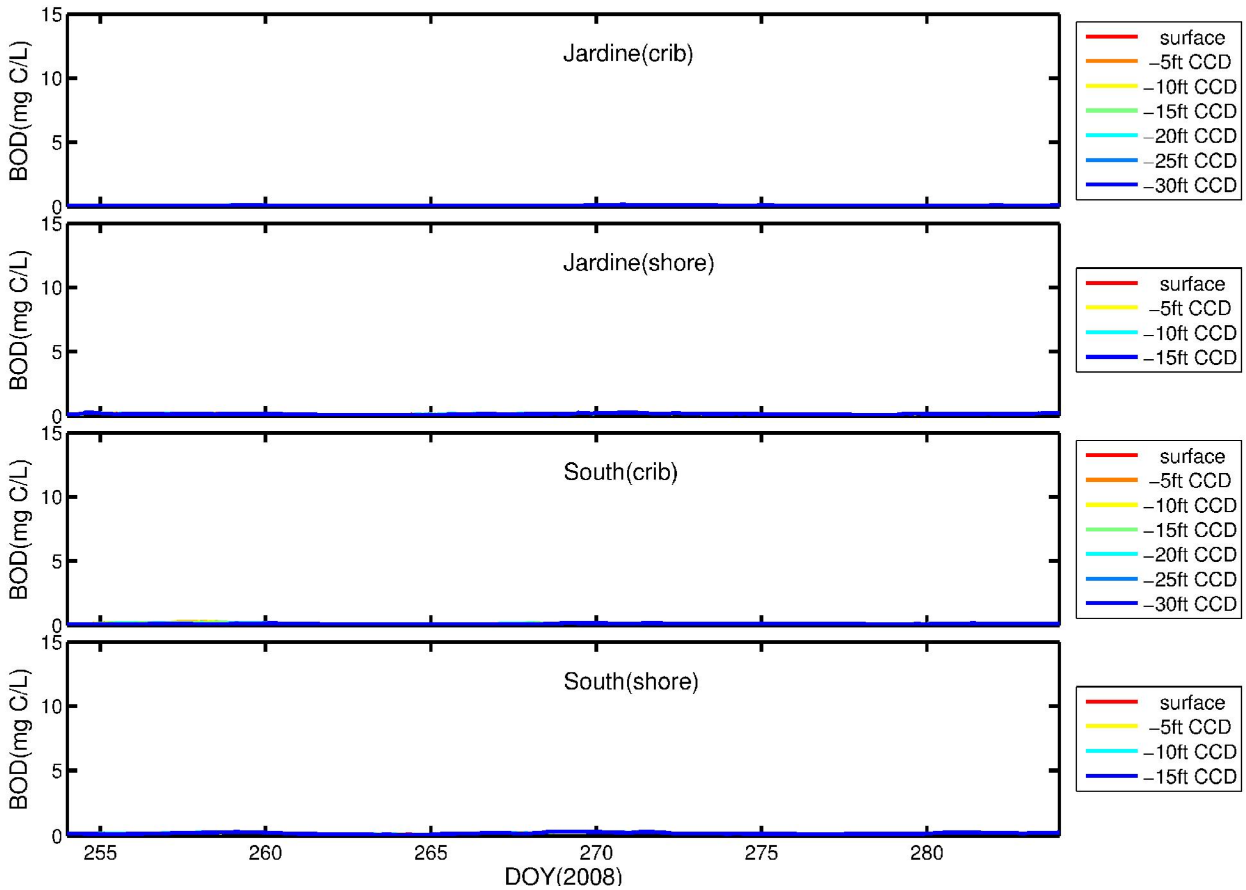


Figure 4.2 Concentration of oxygen demand at different depths at a few locations

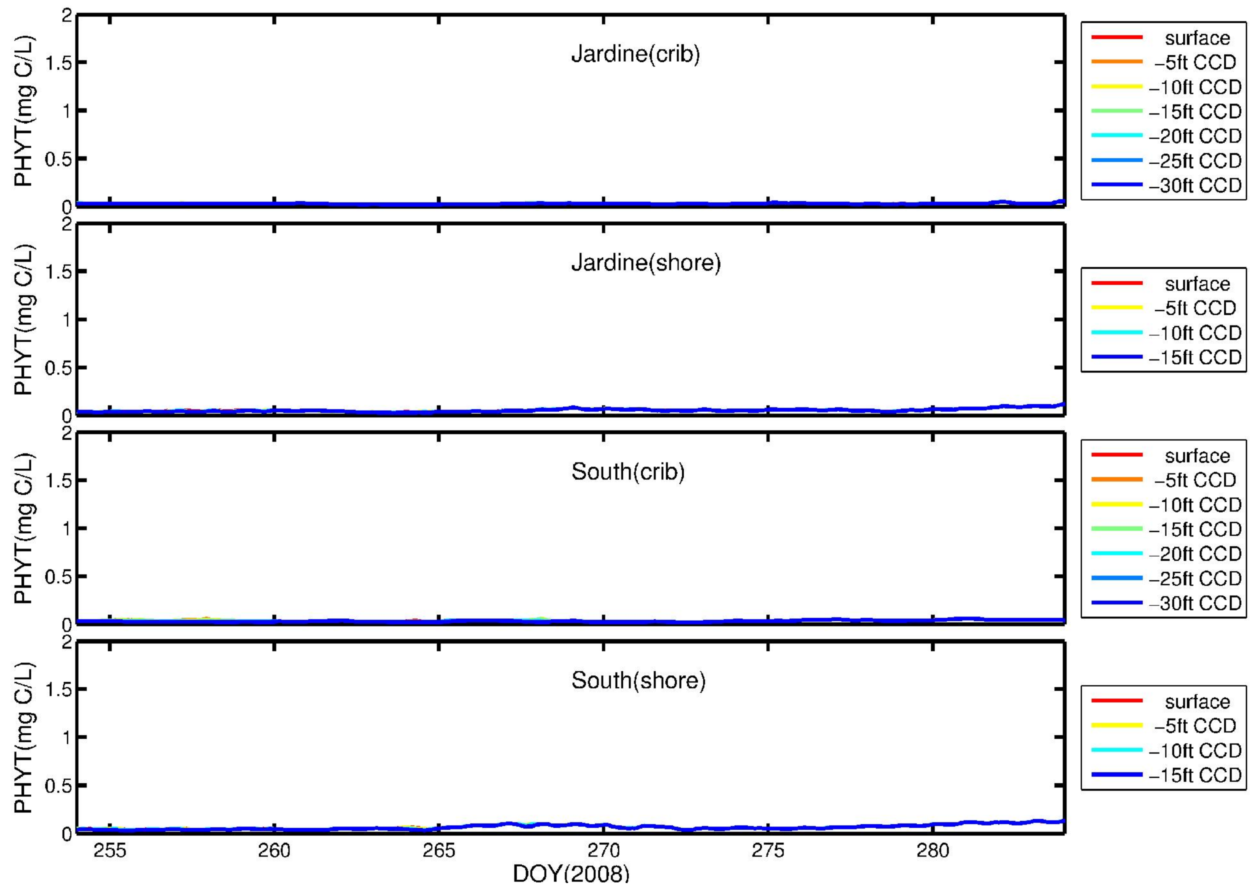


Figure 4.3 Concentration of phytoplankton at different depths at a few locations

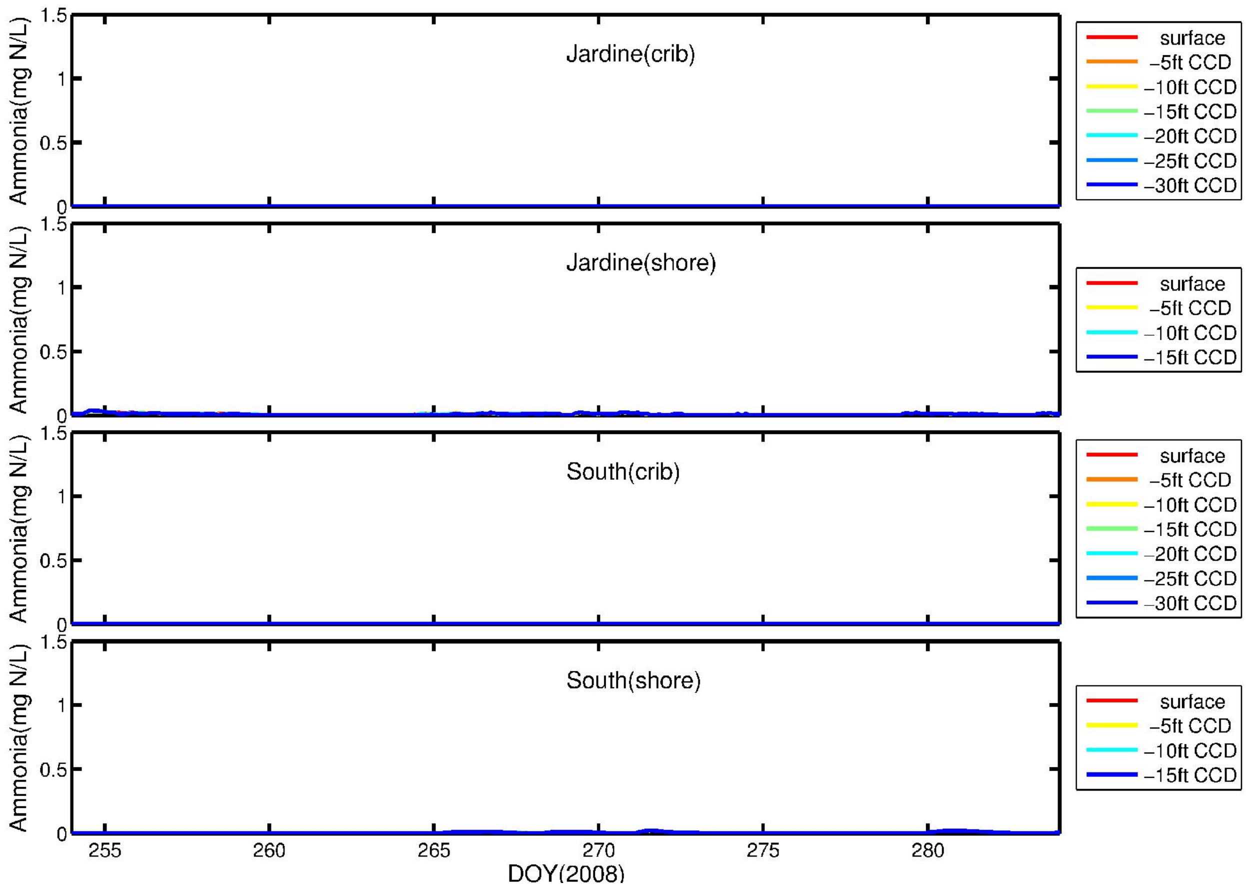


Figure 4.4 Concentration of ammonia at different depths at a few locations

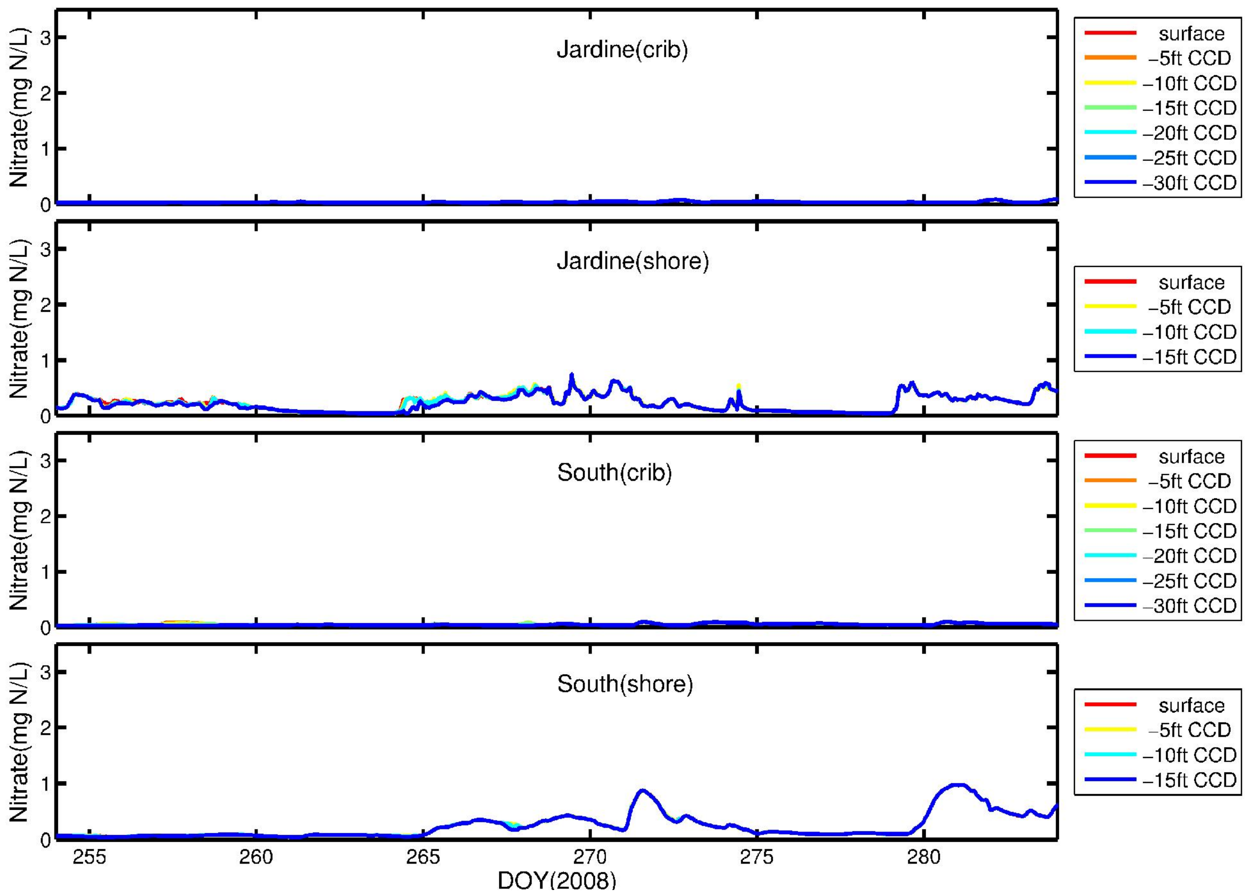


Figure 4.5 Concentration of nitrate at different depths at a few locations

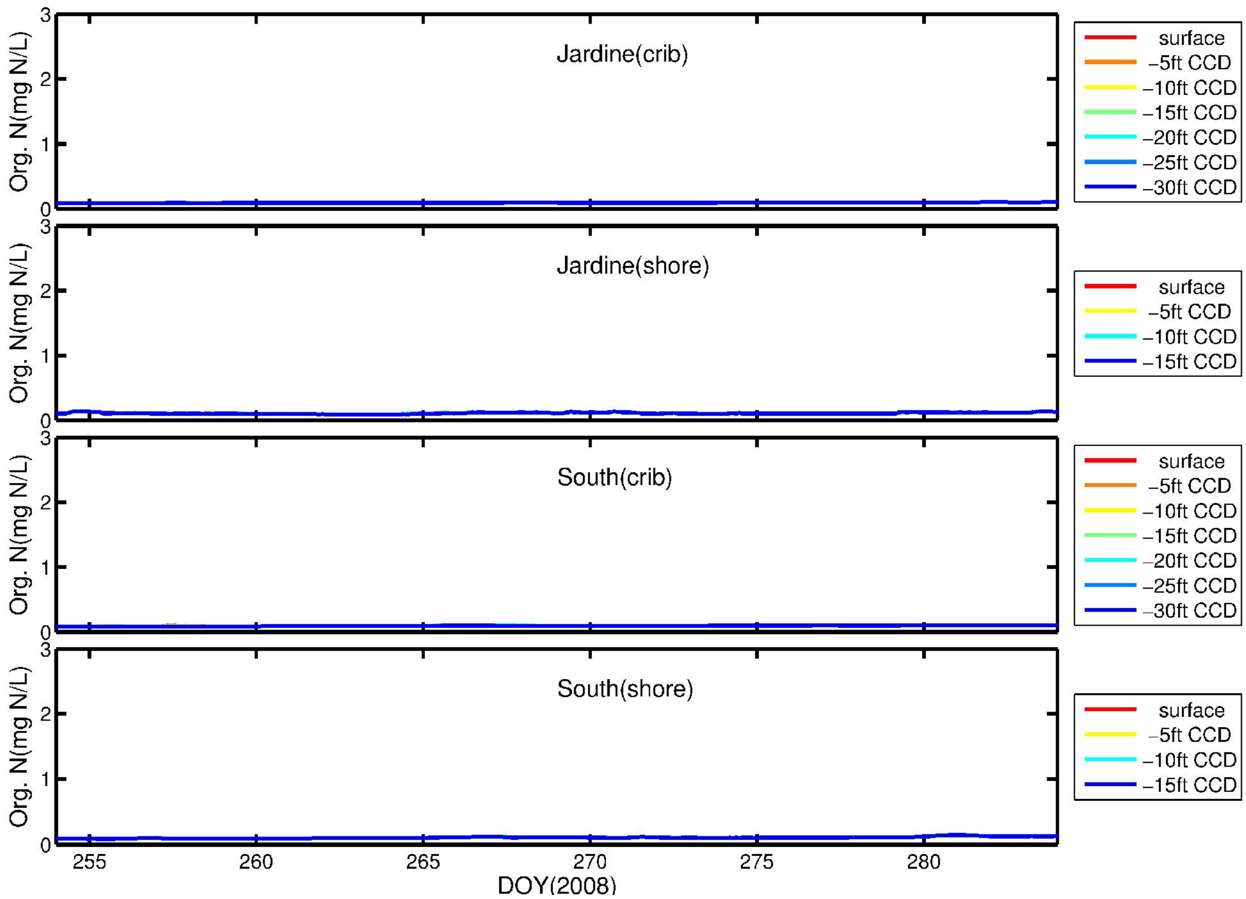


Figure 4.6 Concentration of organic nitrogen at different depths at a few locations

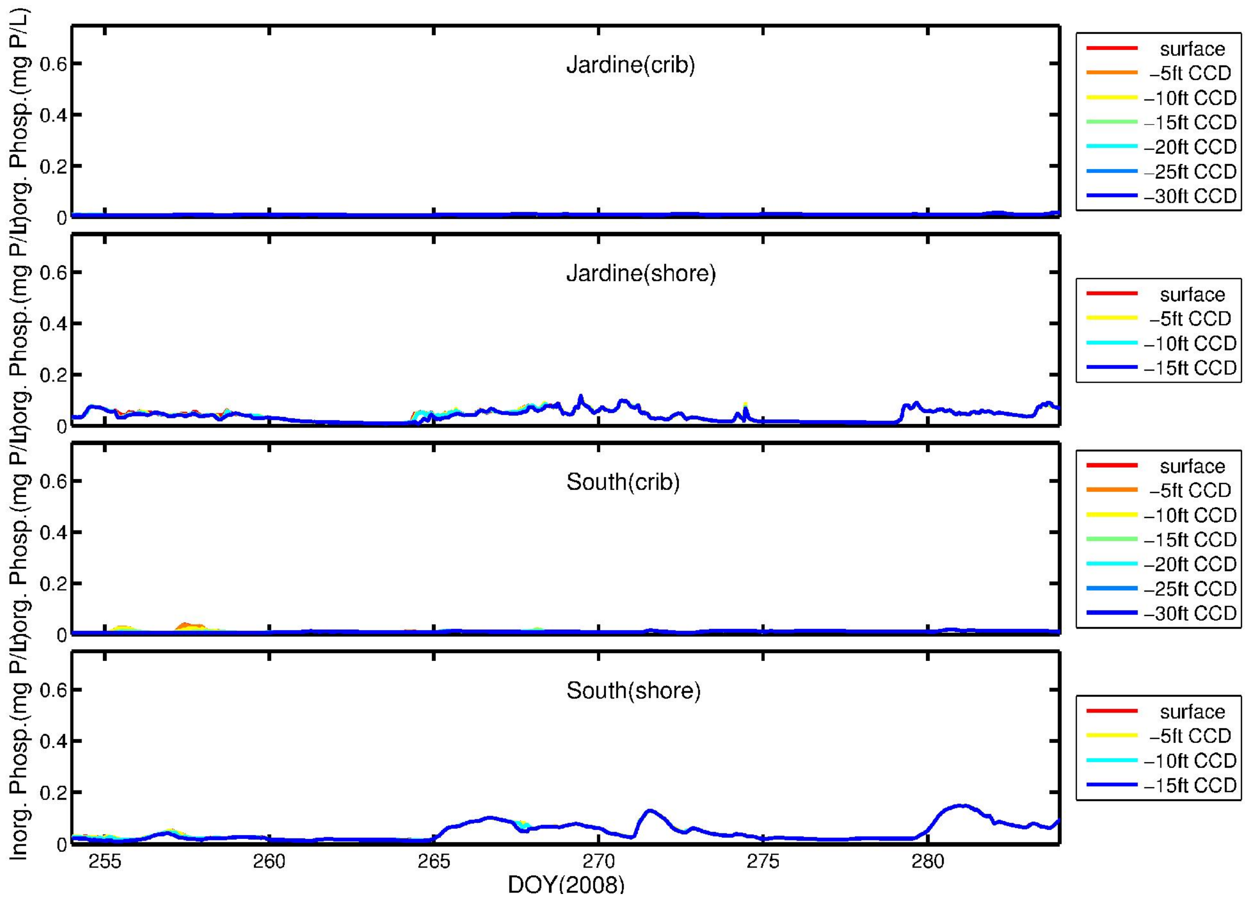


Figure 4.7 Concentration of ortho-phosphate at different depths at a few locations

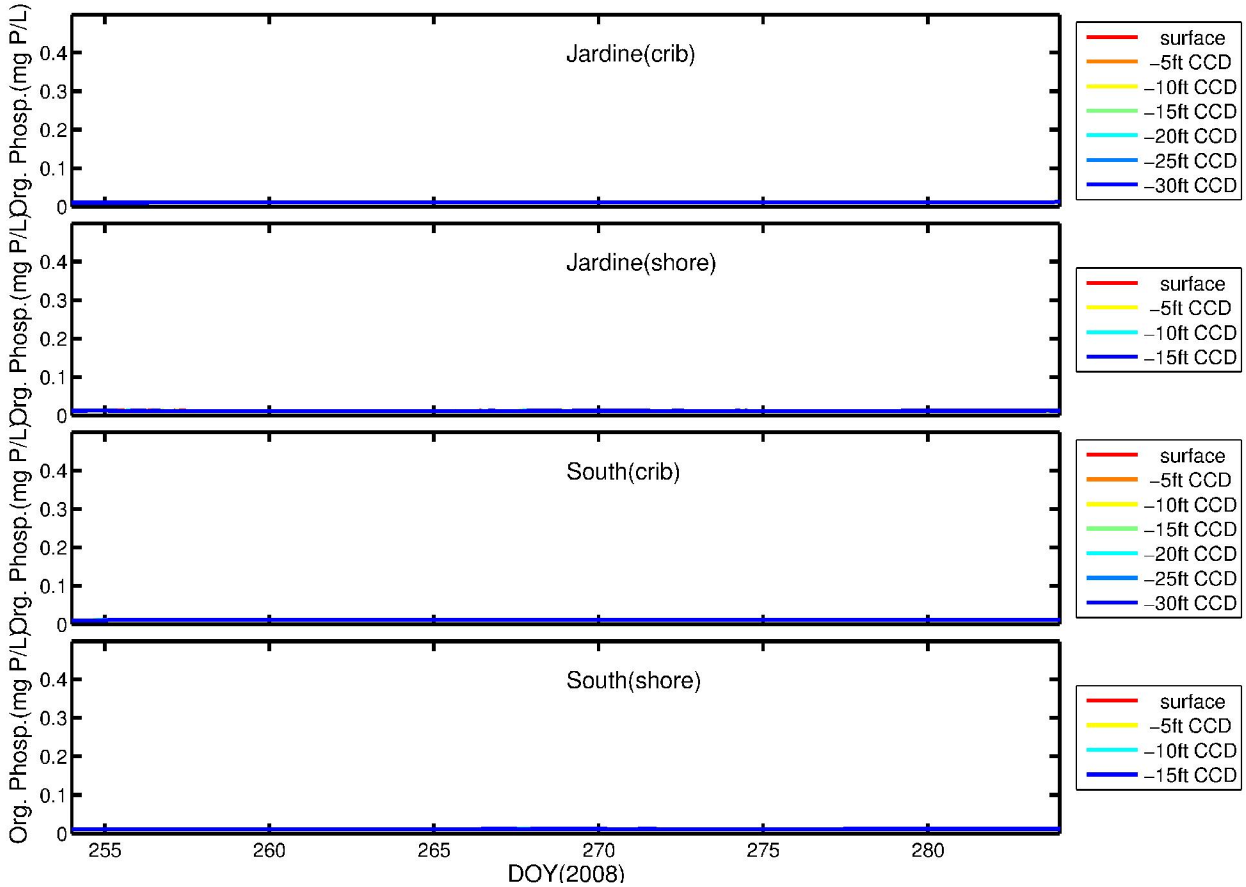


Figure 4.8 Concentration of organic phosphorous at different depths at a few locations

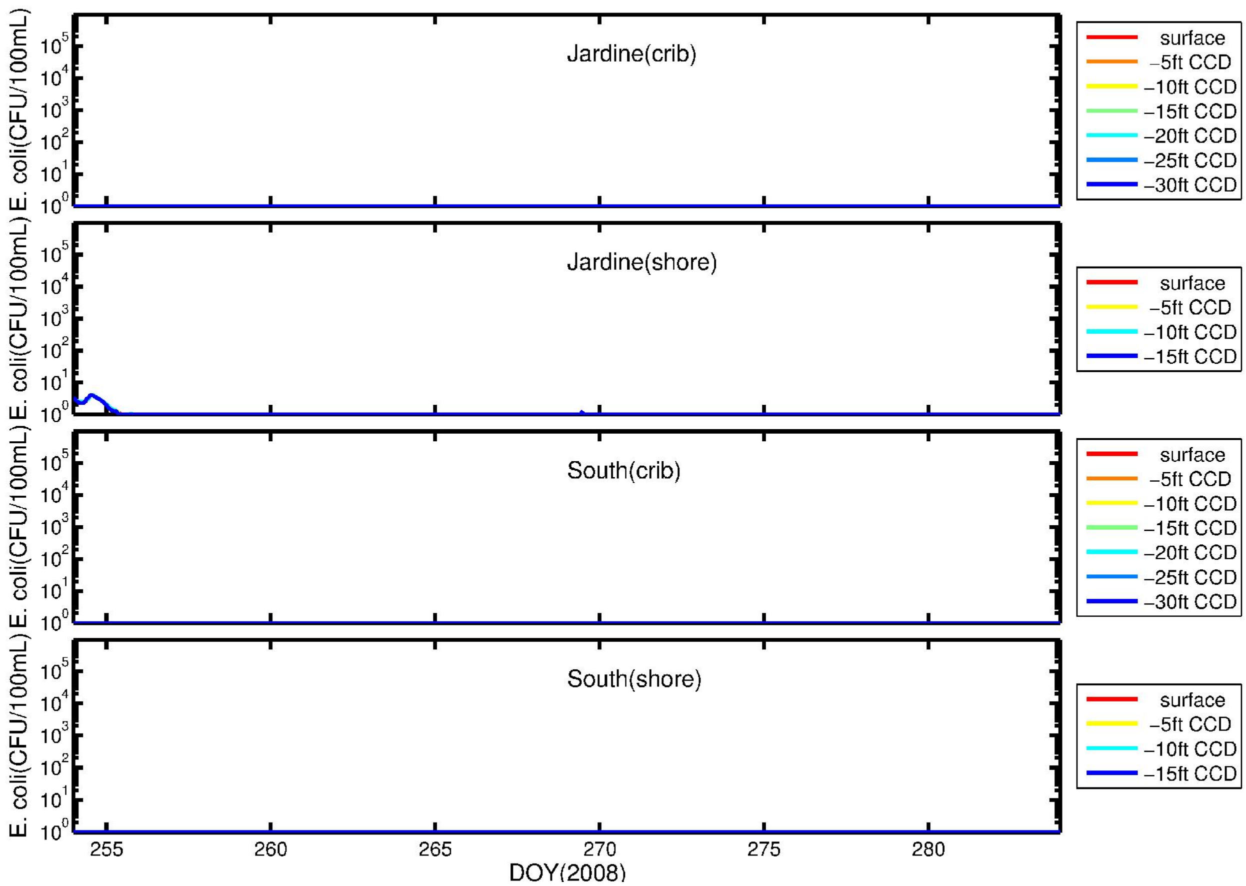


Figure 4.9 Concentration of *E. coli* at different depths at a few locations

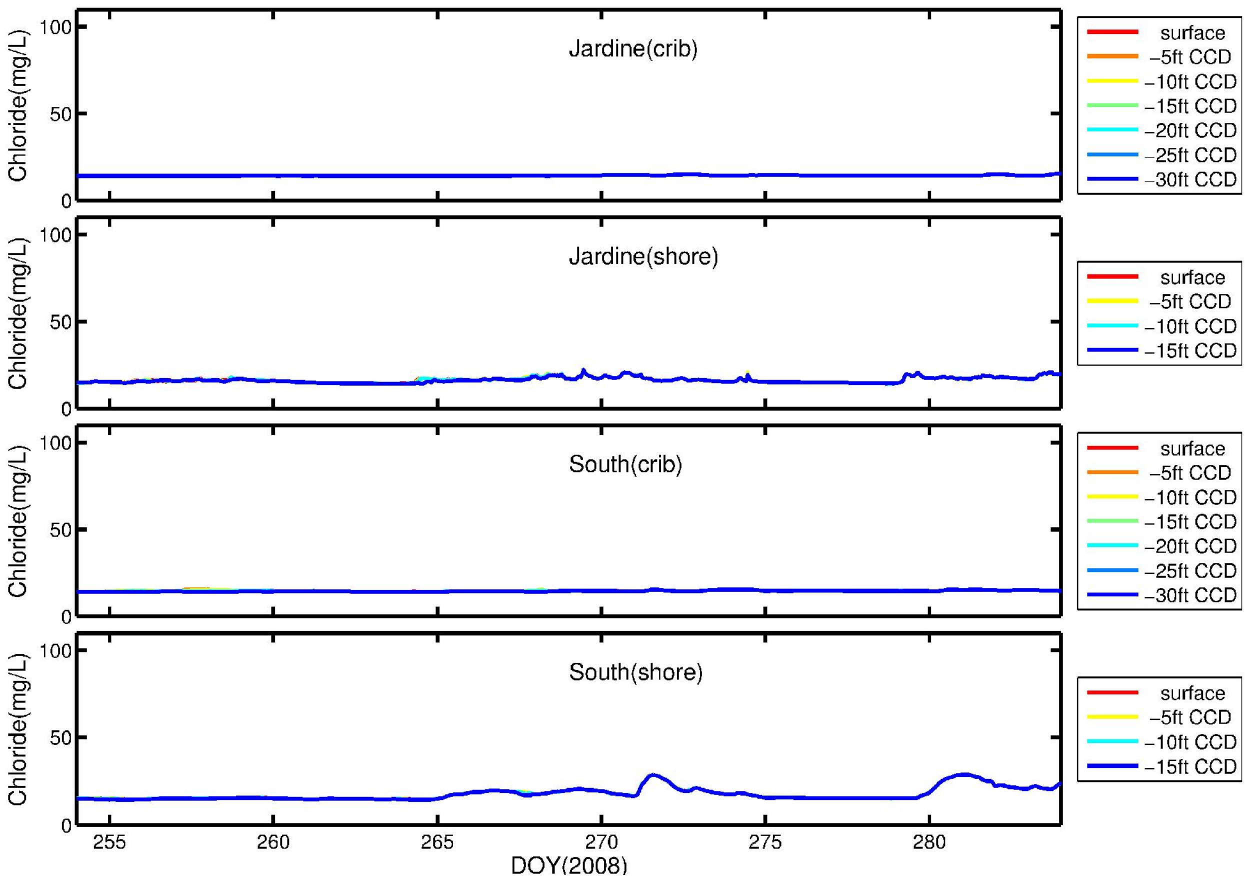


Figure 4.10 Concentration of chloride at different depths at a few locations

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.

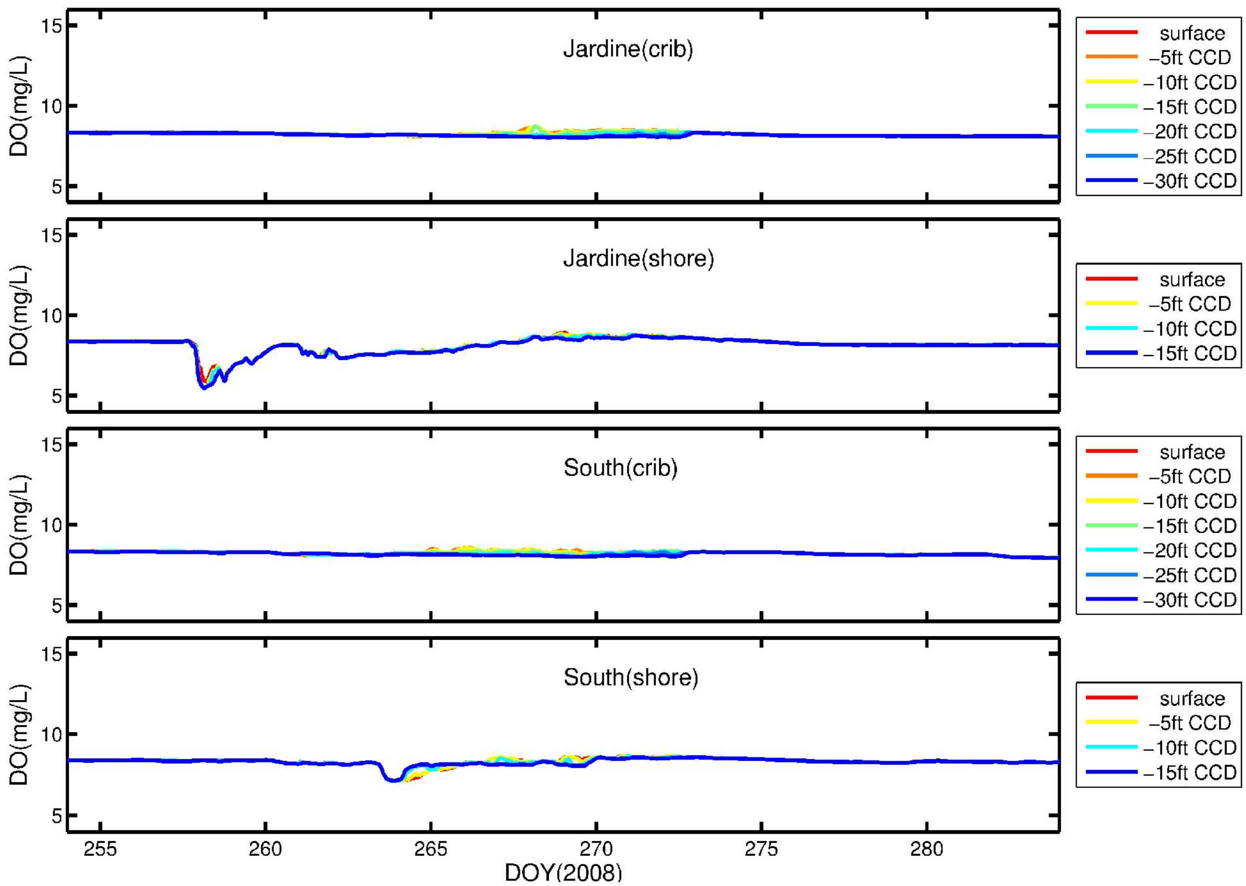


Figure 4.11 Concentration of dissolved oxygen at different depths at a few locations

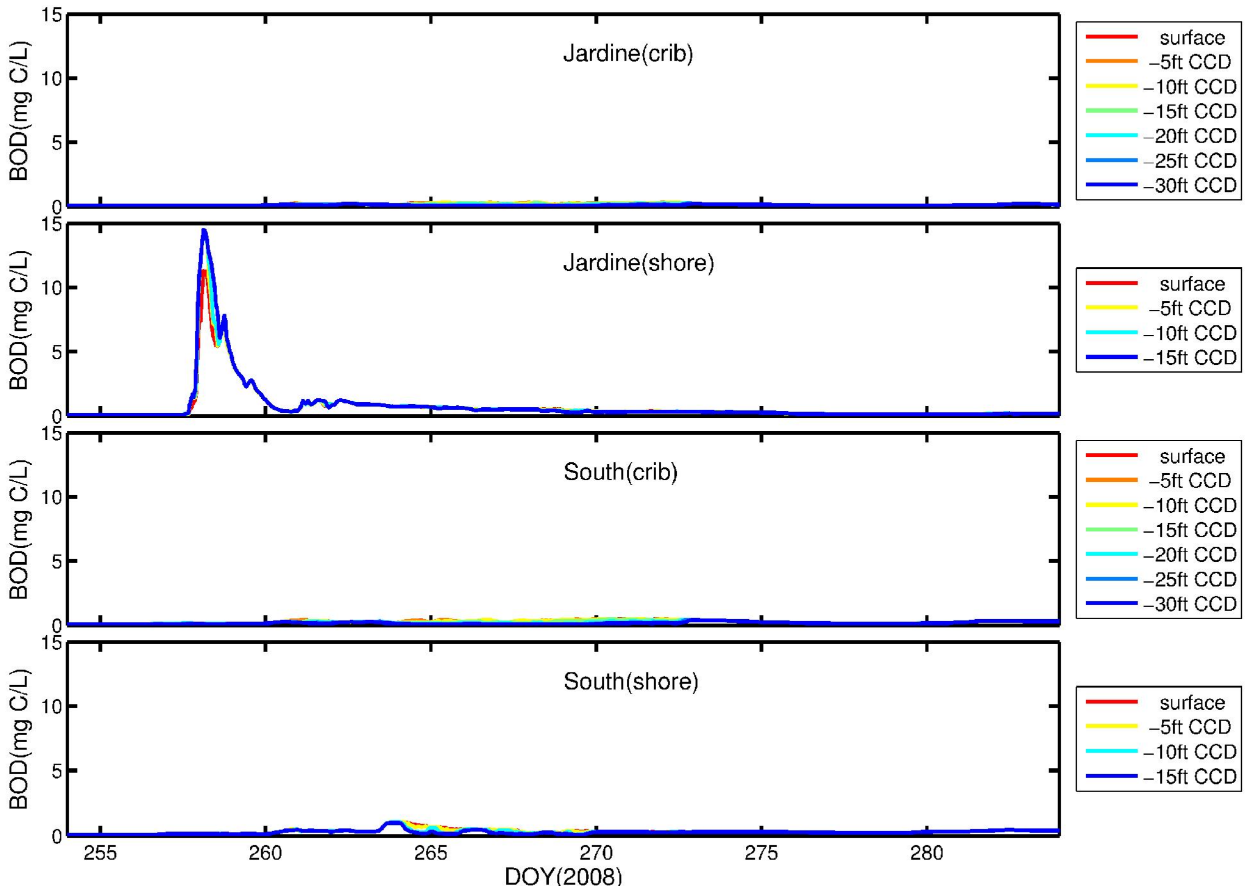


Figure 4.12 Concentration of oxygen demand at different depths at a few locations

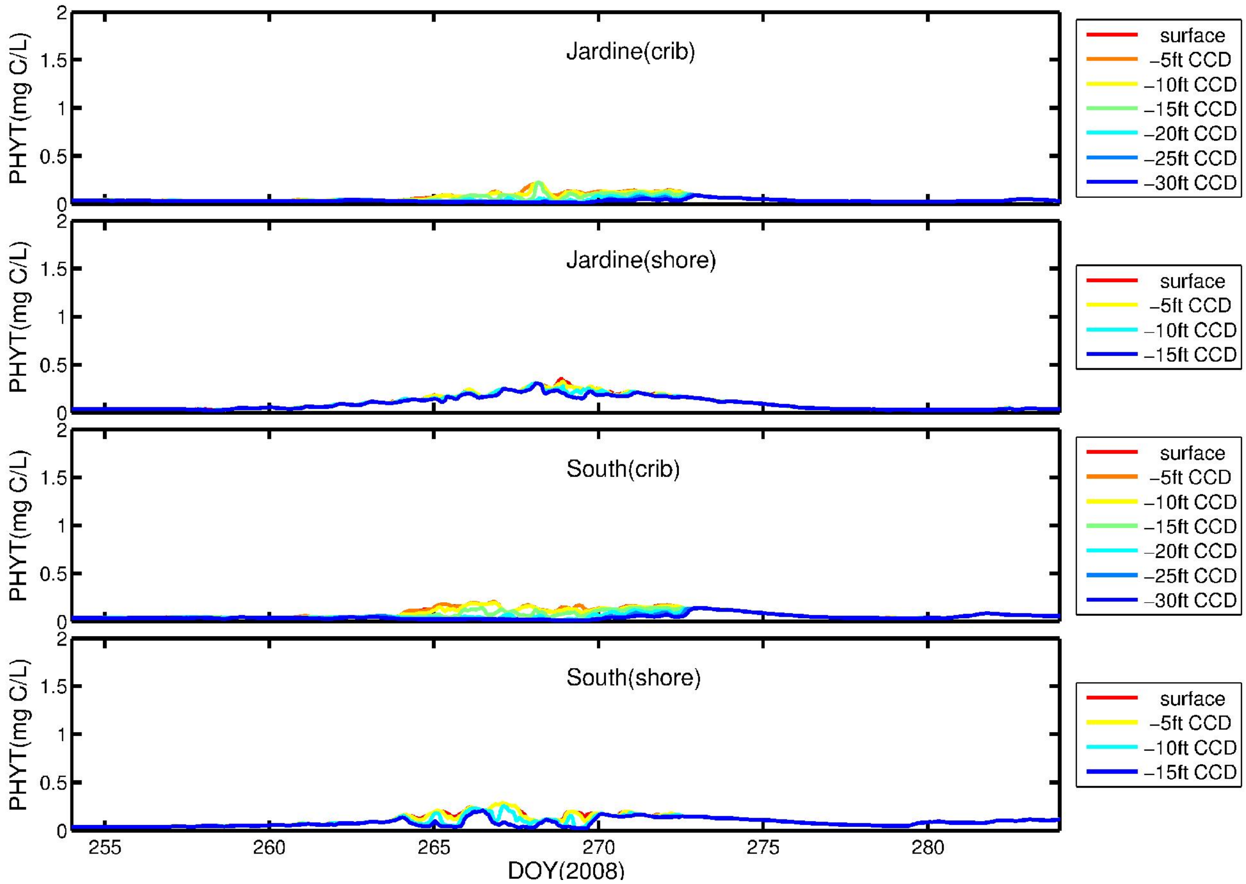


Figure 4.13 Concentration of phytoplankton at different depths at a few locations

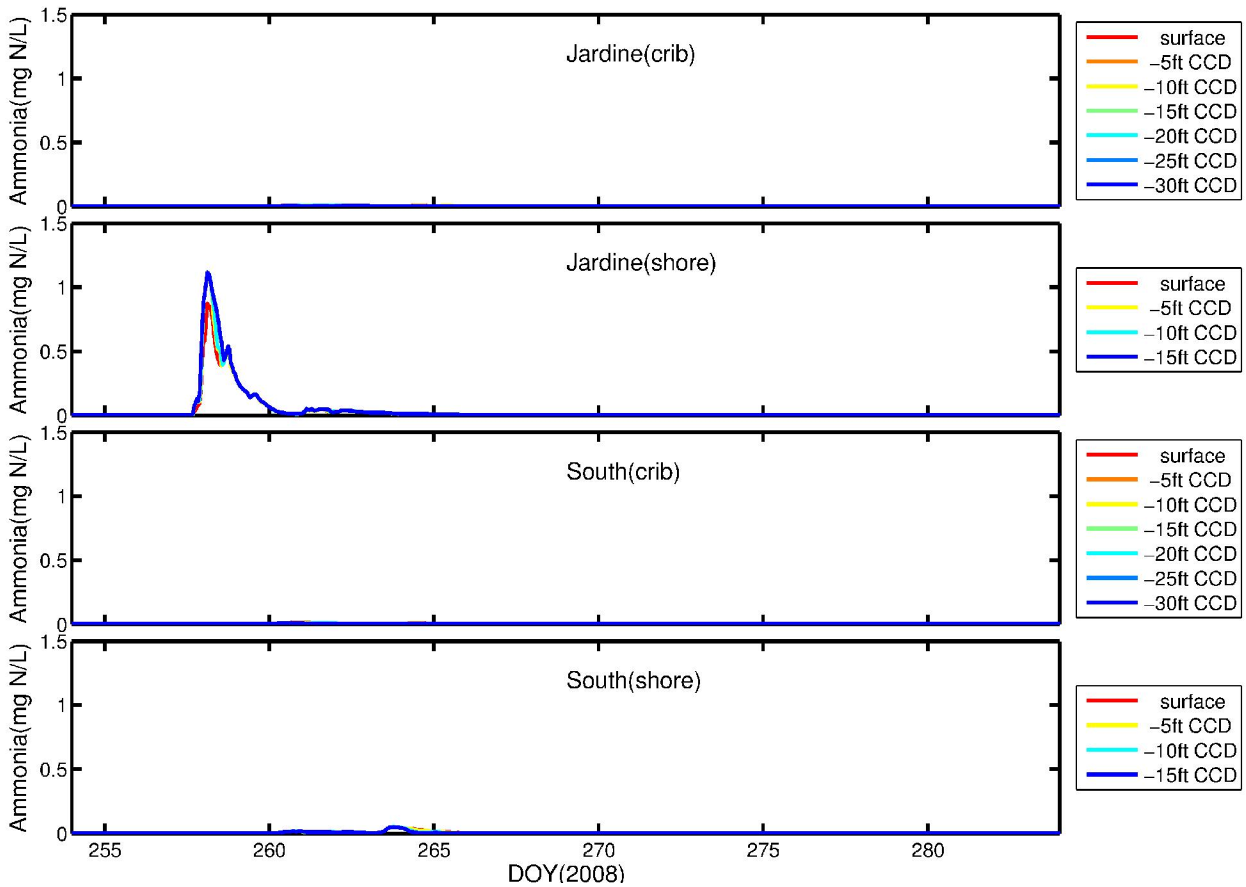


Figure 4.14 Concentration of ammonia at different depths at a few locations

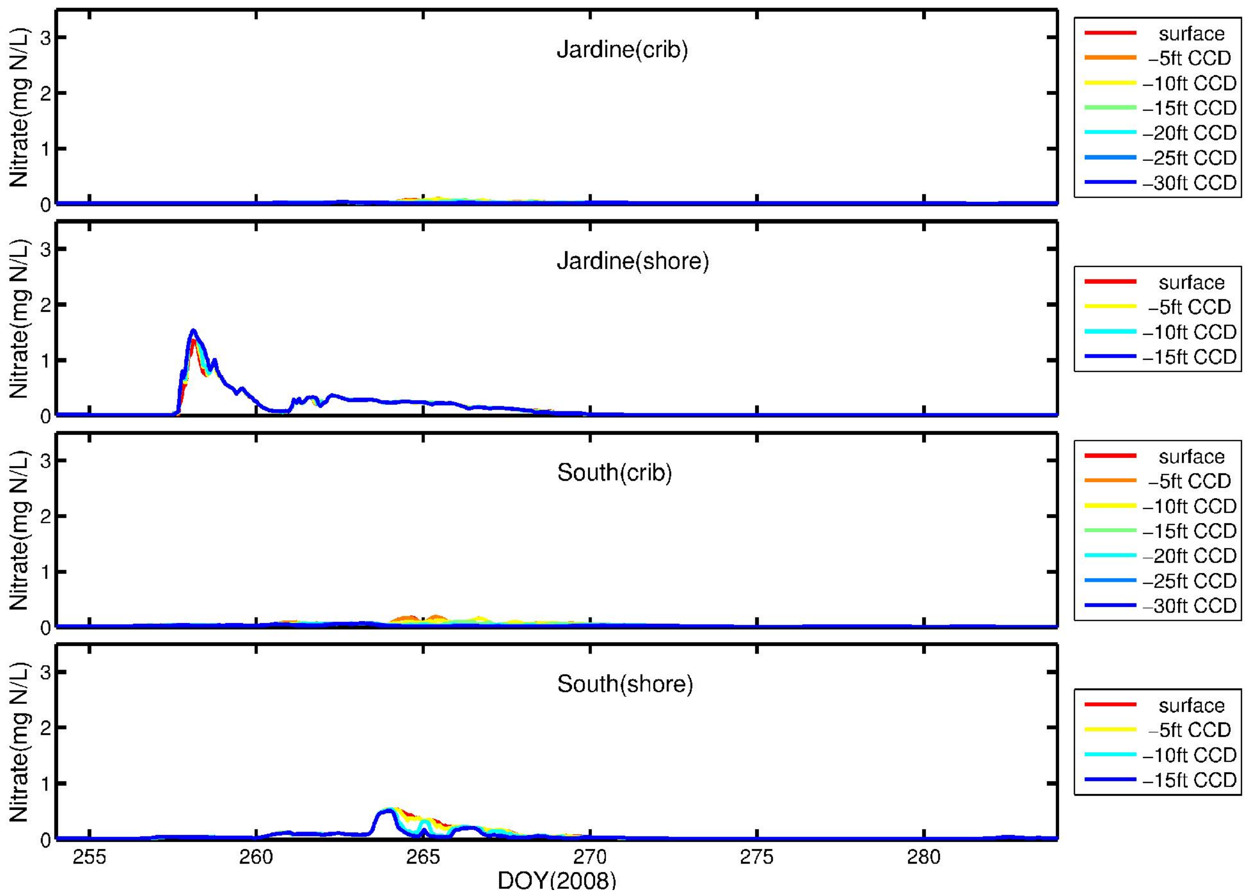


Figure 4.15 Concentration of nitrate at different depths at a few locations

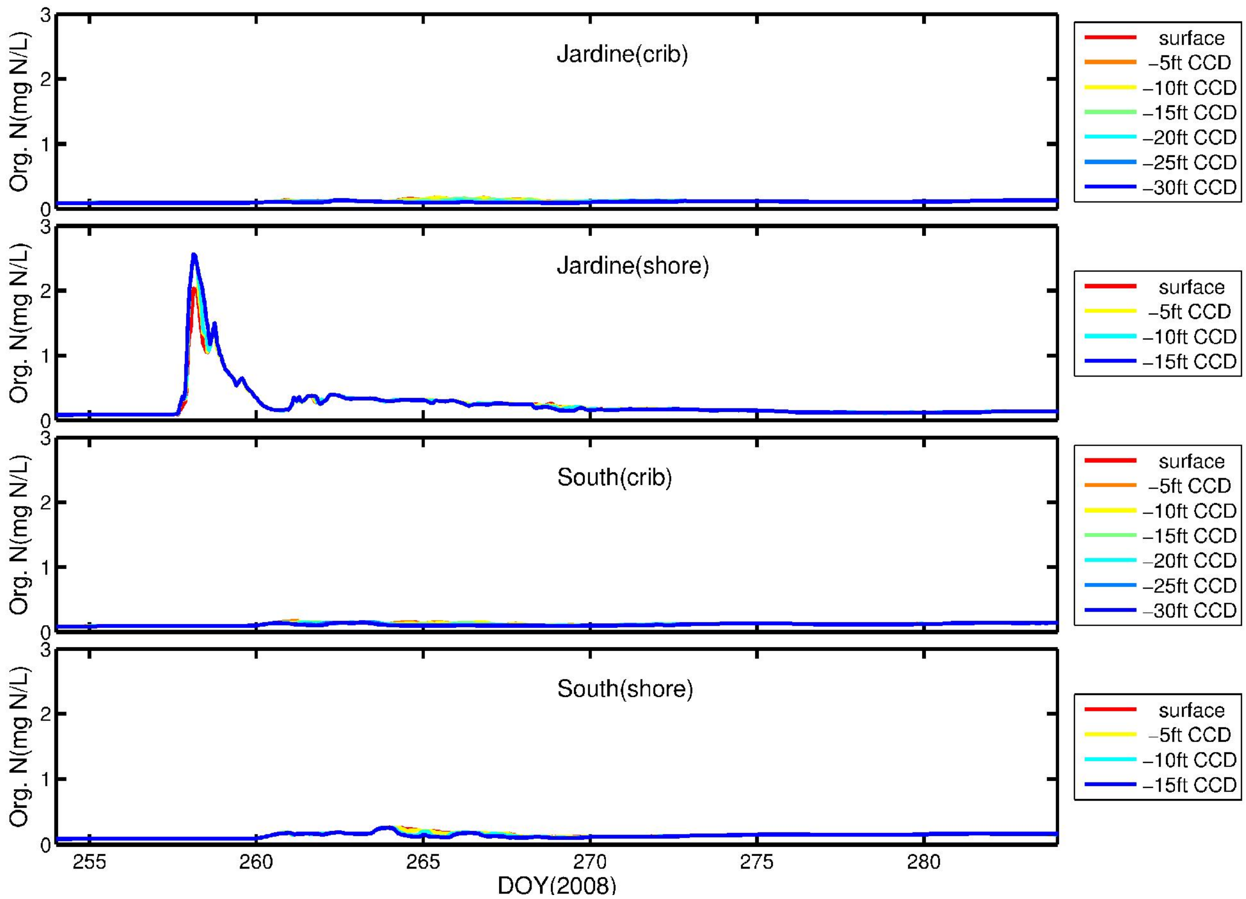


Figure 4.16 Concentration of organic nitrogen at different depths at a few locations

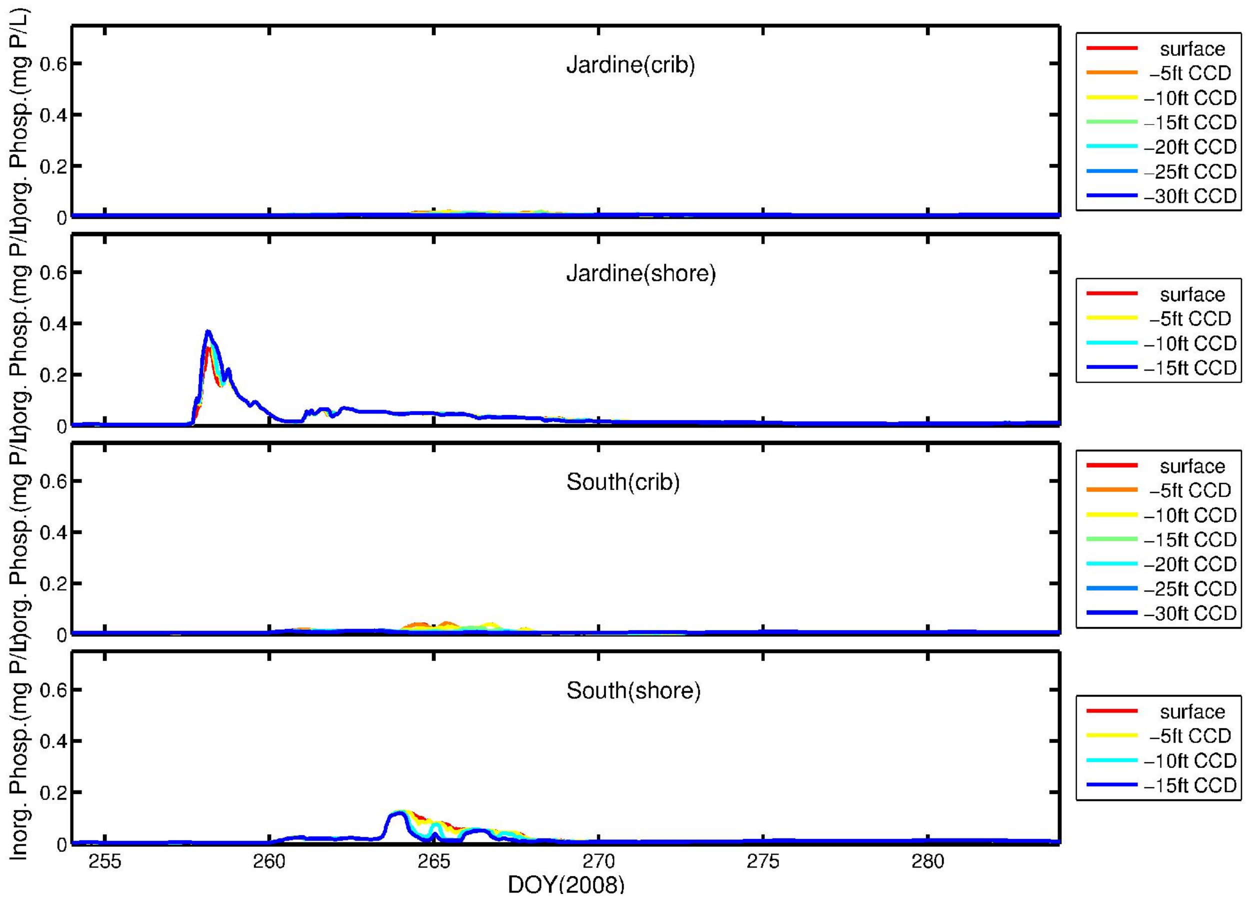


Figure 4.17 Concentration of ortho-phosphate at different depths at a few locations

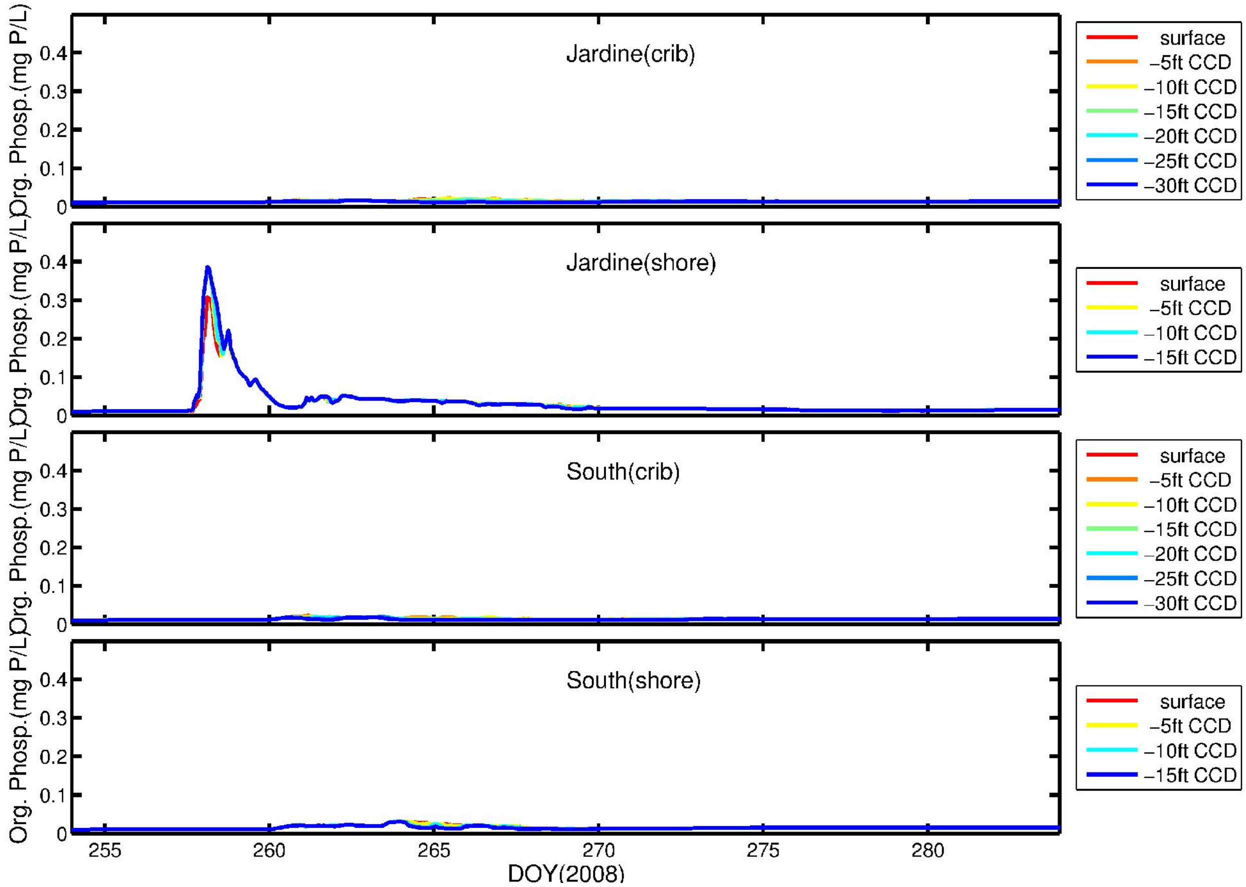


Figure 4.18 Concentration of organic phosphorous at different depths at a few locations

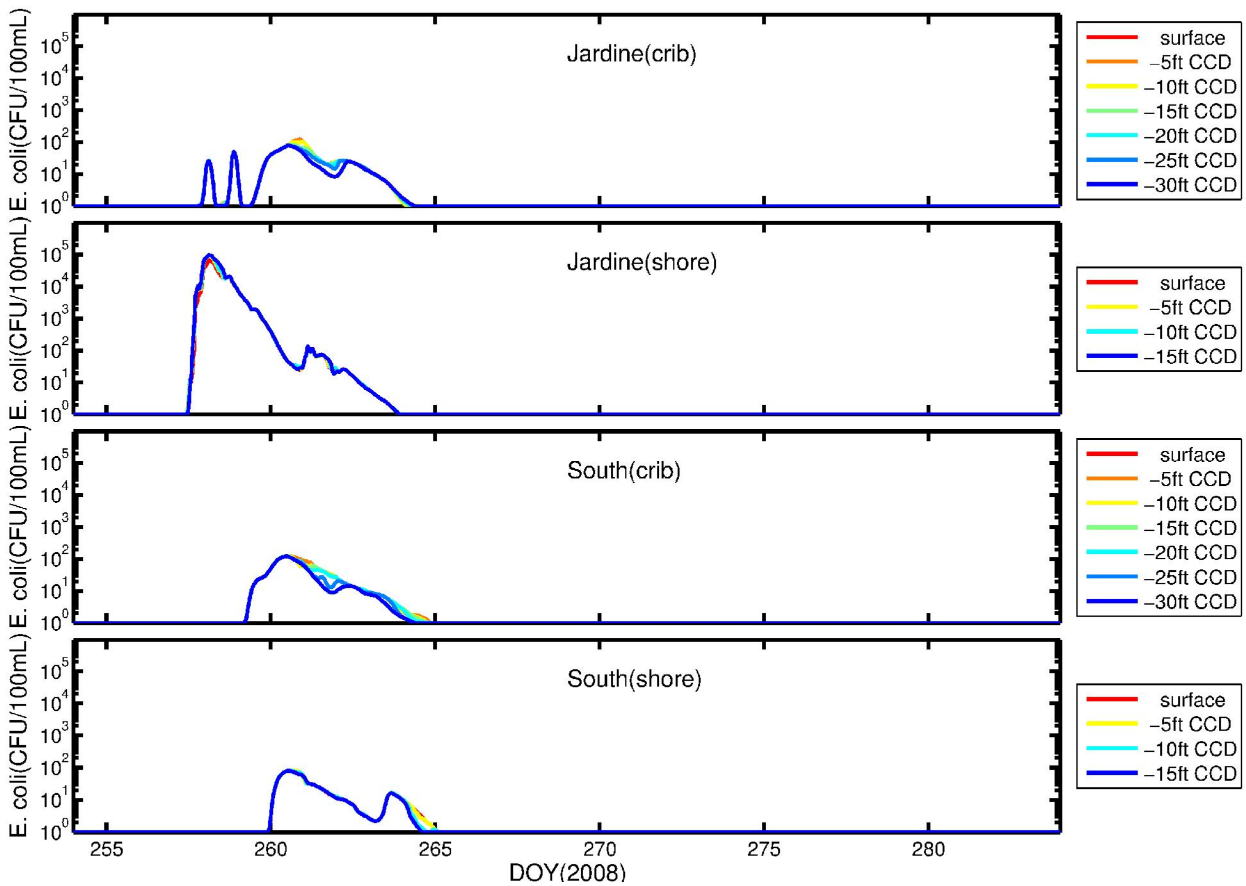


Figure 4.19 Concentration of *E. coli* at different depths at a few locations

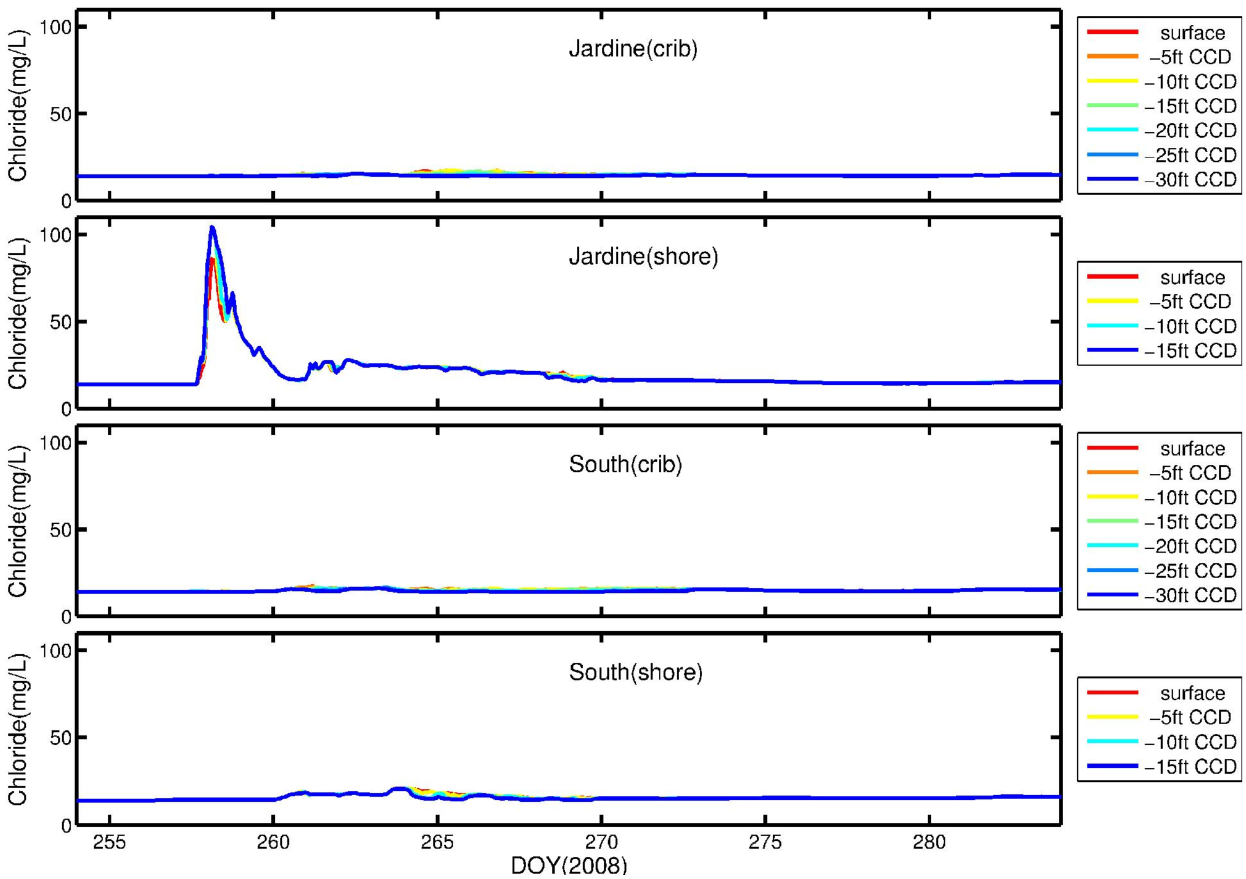


Figure 4.20 Concentration of chloride at different depths at a few locations

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).

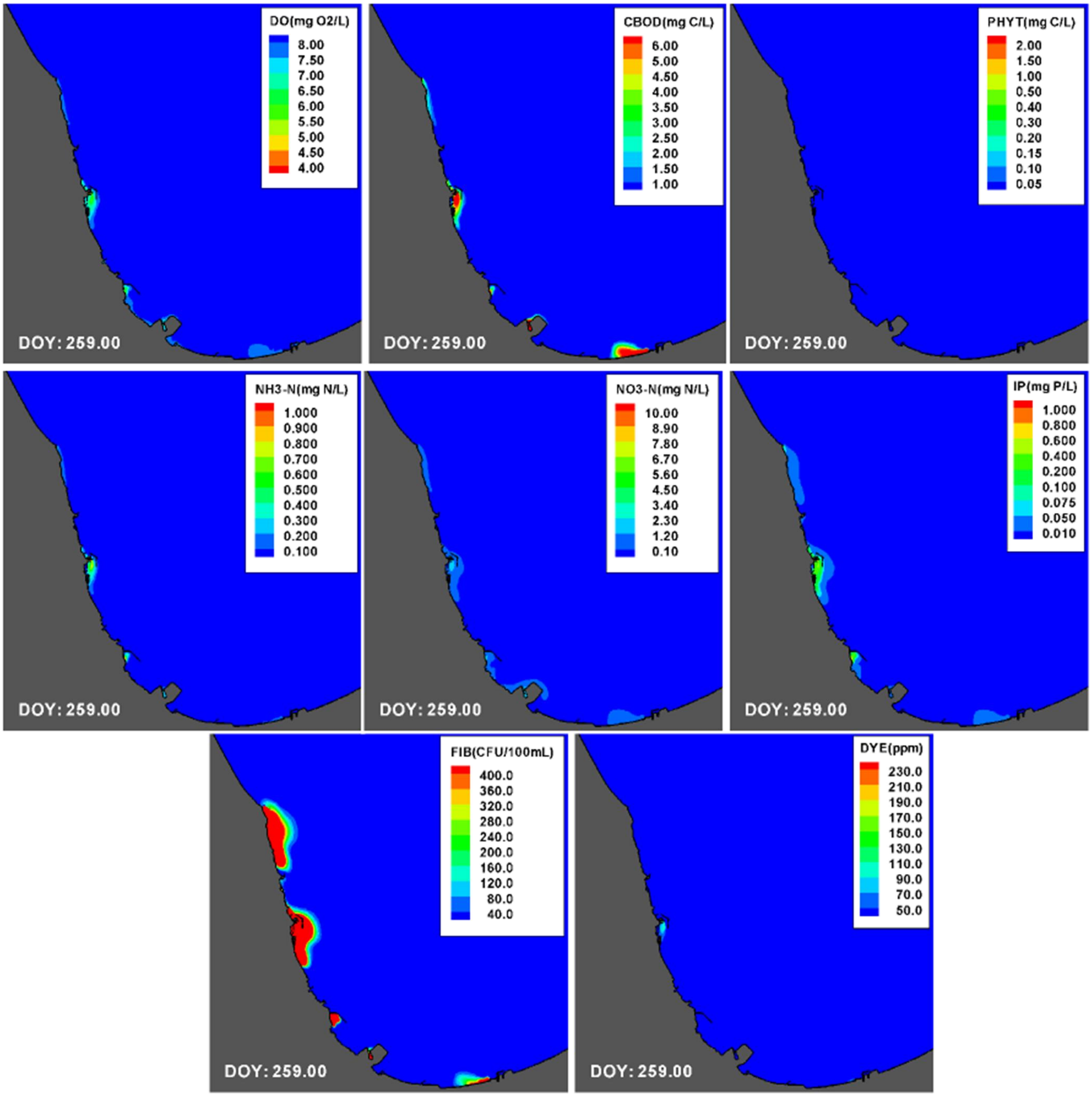


Figure 4.21 Contaminant plume shape and size on Julian Day (DOY) 259 based on Scenario 5 loading criteria

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.

References

Ambrose Jr., R.B., Wool, T.A., Martin, J.L. (1993). The Water Quality Analysis Simulation Program, WASP5, Part A: Model Documentation. U.S. Environmental Protection Agency, Athens, Georgia, 202 pp.

Batchelder, A.R. and R.A. Braden (1976). Nutrients and algae in northeast Colorado lakes, Technical Bulletin No. 1515, pp. 1-49, Agricultural Research Service, USDA in cooperation with Colorado State University Experiment Station, US Government Printing Office, Washington D.C., March 1976

Chen, C., Liu, H., Beardsley, R.C. (2003). An unstructured, finite-volume, three-dimensional, primitive equation ocean model: application to coastal ocean and estuaries. *J. Atmos. Oceanic Technol.*, 20, 159–186.

Chen, C. R. Ji, D. Schwab, D. Beletsky, D. Fahanenstial, M. Jiang, T. H. Johengen, H. Lavrentyev, B. Eadie, J. W. Budd, M. Bundy, W. Gardner, J Cotner, and P. J. Lavrentyer (2002). A coupled biological and physical model study of the ecosystem in Lake Michigan Part I: A 1-D experiment. *Ecological Modeling*, 152, 145-168.

Covar, A.P., (1976). Selecting the proper reaeration coefficient for use in water quality models. Presented at the U.S. EPA conference on Environmental Simulation Modeling, 19–22 April 1976, Cincinnati, Ohio.

Cude, C. G. (2005). Accommodating change of cacterial indicators in long-term water quality datasets, *Journal of the American Water Resources Association*, Volume 41(1):47-54

Ji, R., C. Chen,J. Budd, D. Schwab, D. Beletsky, D. Fahanenstial, T. H. Johengen, H. Lavrentyev, B. Eadies, J. Cotner, W. Gardner and M. Bundy, 2002. A coupled biological and physical model study of the ecosystem in Lake Michigan Part II: Influence of suspended sediment. *Ecological Modeling*, 152, 169-190.

O'Connor, D.J. (1983). Wind effects on gas-liquid transfer coefficients. *Journal Environ. Eng*. 109, 731–752

Melching, C. S. (2006), Simulation of fecal coliform concentrations in the Chicago waterway system under unsteady flow conditions, Technical Report 18, Institute of Urban Environmental Risk Management, Marquette University, Milwaukee, WI

Thupaki, P., M. S. Phanikumar, D. Beletsky, D. J. Schwab, M. B. Nevers, and R. L. Whitman (2010), Budget Analysis of *Escherichia coli* at a southern Lake Michigan beach, *Environmental Science & Technology*, 44(3), 1010-1016.

Thupaki, P., M.S. Phanikumar and R.L. Whitman (2013) Solute dispersion in the coastal boundary layer of southern Lake Michigan, *J. Geophysical Research - Oceans*, doi: 10.1002/jgrc.20136 (2013)

Shrestha, R.L. and Melching, C.S. (2003), Hydraulic calibration of an unsteady flow model for the Chicago waterway system, Technical Report 14, Institute of Urban Environmental Risk Management, Marquette University, Milwaukee, WI, and Metropolitan Water Reclamation District of Greater Chicago, Department of Research and Development Report No. 03-18, Chicago, IL.

Zheng, L.Y., Chen, C.S., Liu, H.D. (2003). A modeling study of the Satilla River Estuary, Georgia. Part I:flooding/drying process and water exchange over the salt marsh-estuary-shelf complex. *Estuaries* 26, 651–669.

Zmuda, J. T., R. Gore, and Z. Abedin (2004). 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.

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).

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=\frac{\partial}{\partial x}\left(A_h\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_h\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_h\frac{\partial C}{\partial z}\right)+S+W_0 \quad (6)$$

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)

$$S_3 = a_{oc}\left(k_{par} + k_{grz}\right)C_2 - k_{d1}\theta_{d1}^{(T-20)}\frac{C_1C_3}{K_{BOD} + C_1} - \frac{\omega_{3S}(1 - f_{D3})}{D}C_3$$
$$- \frac{5}{4} \times \frac{32}{12} \times \frac{12}{14} k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3} + C_1} \qquad (9)$$

Ammonium nitrogen (NH_4)

$$S_4 = a_{nc}D_P(1 - f_{on})C_2 + k_{m1}\theta_{m1}^{(T-20)}\frac{C_2C_7}{K_{mPc} + C_2} - a_{nc}G_PP_{NH_4}C_2$$
$$- k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR} + C_1} + B_1 \qquad (10)$$

Nitrate and nitrite nitrogen (NO_3)

$$S_5 = k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR} + C_1} - a_{nc}G_P\left(1 - P_{NH_4}\right)C_2$$
$$- k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3} + C_1} + B_2 \qquad (11)$$

Ortho-phosphorous (OPO_4)

$$S_6 = a_{pc}D_P\left(1 - f_{op}\right)C_2 + k_{m2}\theta_{m2}^{(T-20)}\frac{C_2C_8}{k_{mPc} + C_2} - a_{pc}G_PC_2 + B_3 \qquad (12)$$

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

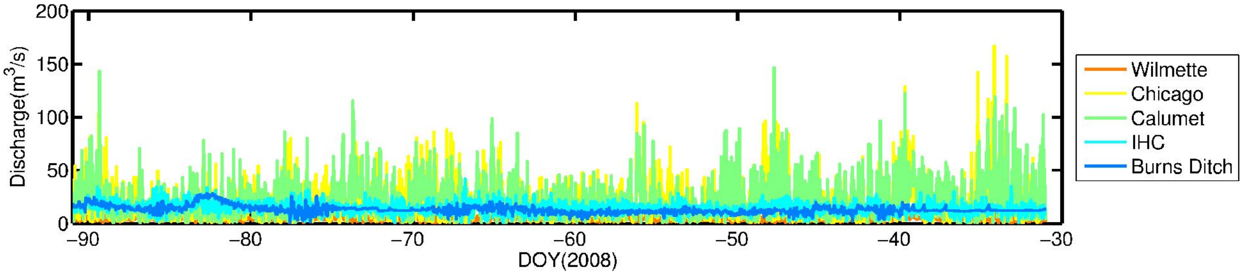
Name	Description	Value
k_{r1}	Reaeration rate (day^{-1})	$\max(k_f, k_w)$
k_f	Flow induced reaeration rate (day^{-1})	O'Connor method.
k_w	Wind-induced reaeration rate (day^{-1})	Covar method
k_{d1}	CBOD de-oxygenation rate (day^{-1})	.10
k_{ni}	Nitrification rate (day^{-1})	.09
k_{r2}	Phytoplankton 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

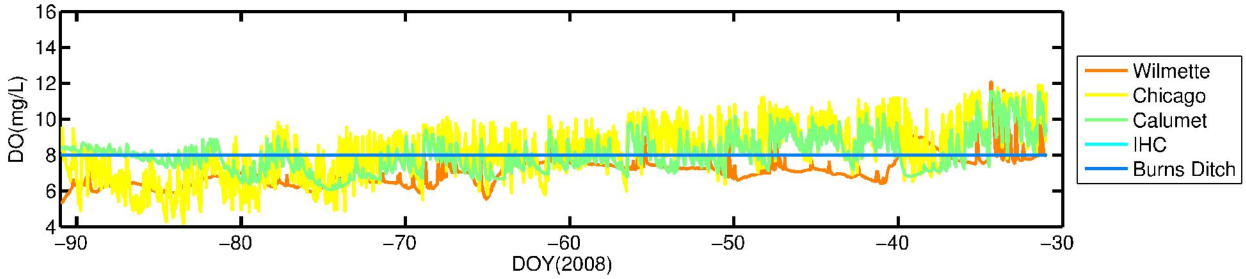
θ_{gr}	Temperature adjustment for phytoplankton growth rate	1.066
θ_{mr}	Temperature adjustment for phytoplankton death rate	1.0
θ_{m1}	Temperature adjustment for org. nitrogen mineralization rate	1.080
θ_{m2}	Temperature adjustment for org. phosphorous mineralization rate	1.080
θ_{SOD}	Temperature adjustment 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

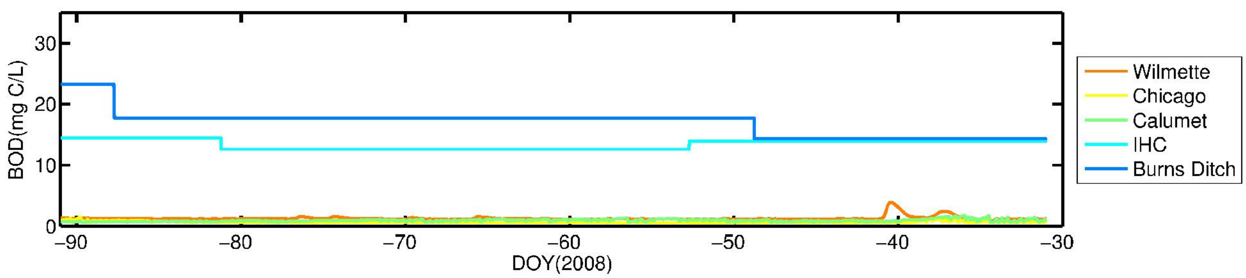
f_{D3}	Fraction of dissolved CBOD	.5
f_{D7}	Fraction of dissolved organic nitrogen	1.0
f_{D8}	Fraction of dissolved organic phosphorous	1.0
f_{on}	Fraction of dead and respired phytoplankton recycled to organic nitrogen pool	.65
f_{op}	Fraction of dead and respired phytoplankton recycled to organic phosphorous 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

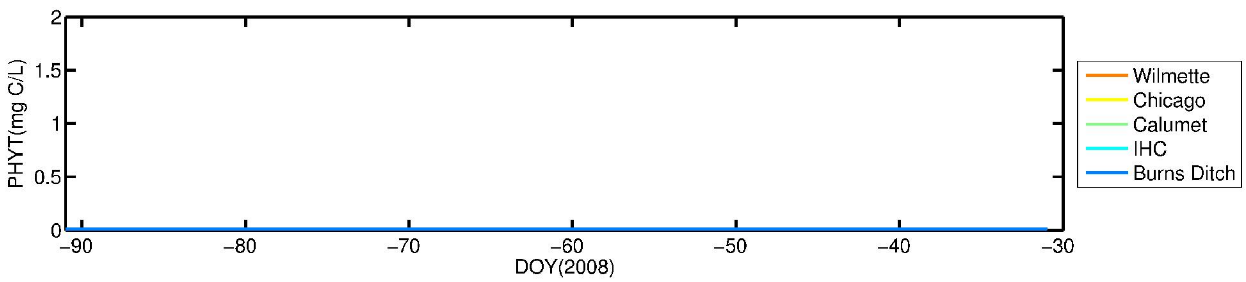
Appendix -B: Input Time Series to the Numerical Models

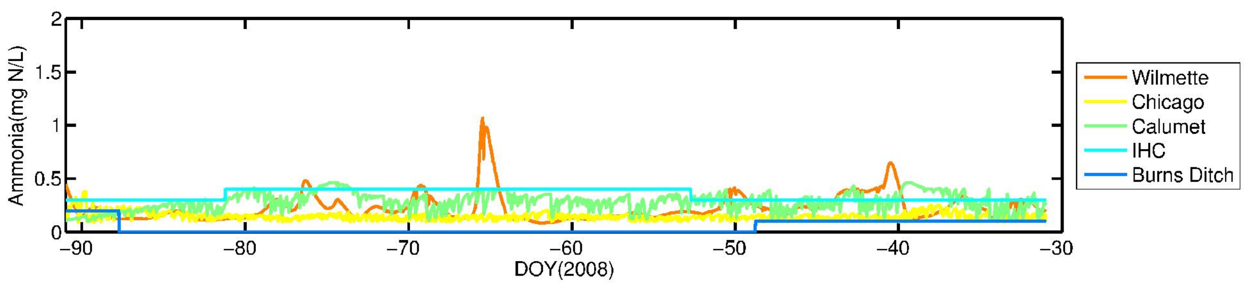
Scenario 2: Sept2007-November2007

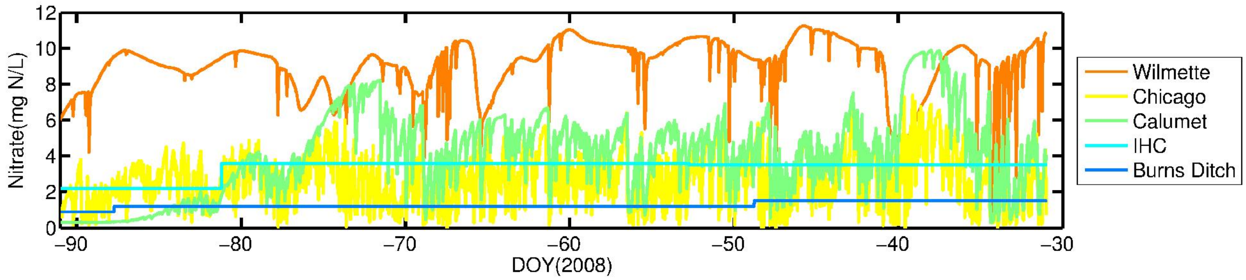


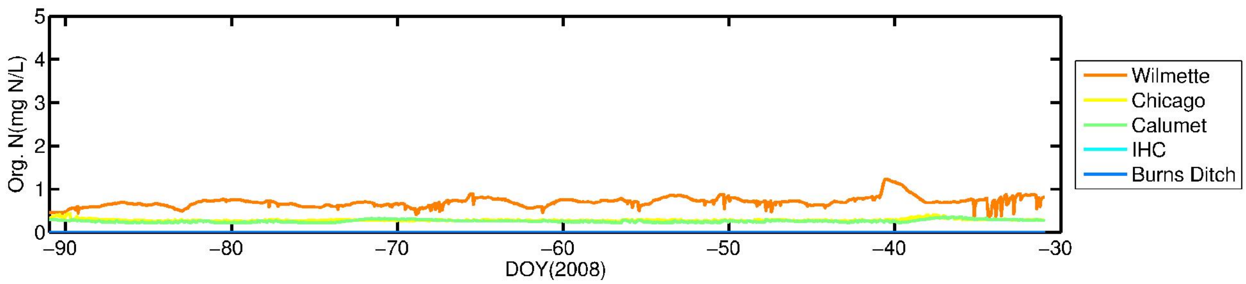


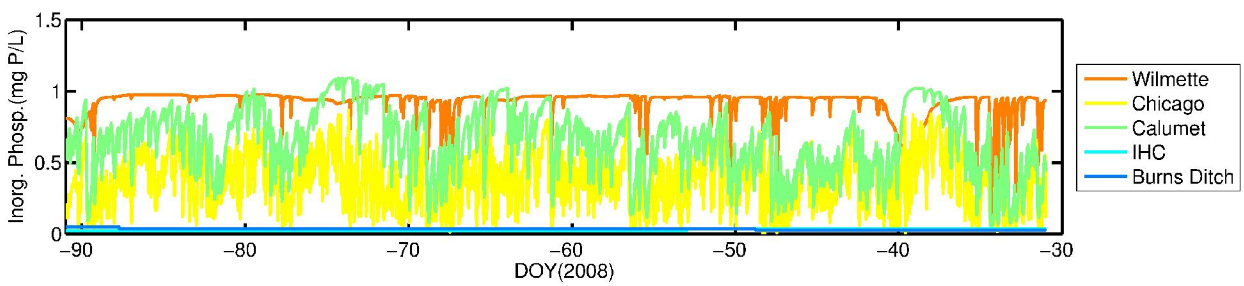


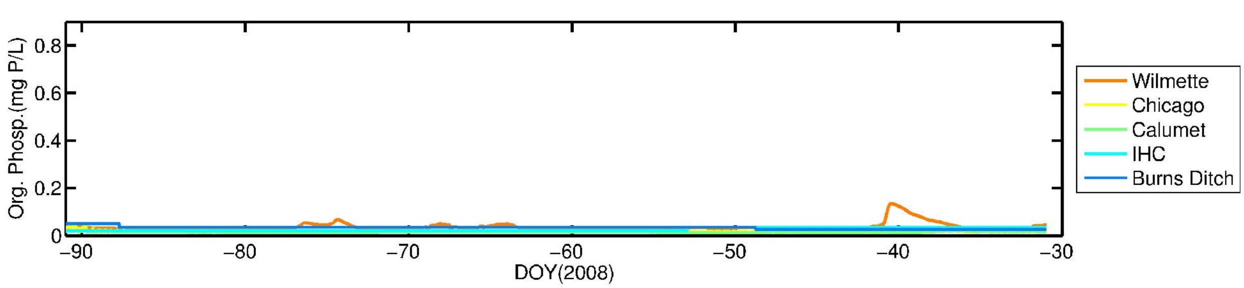


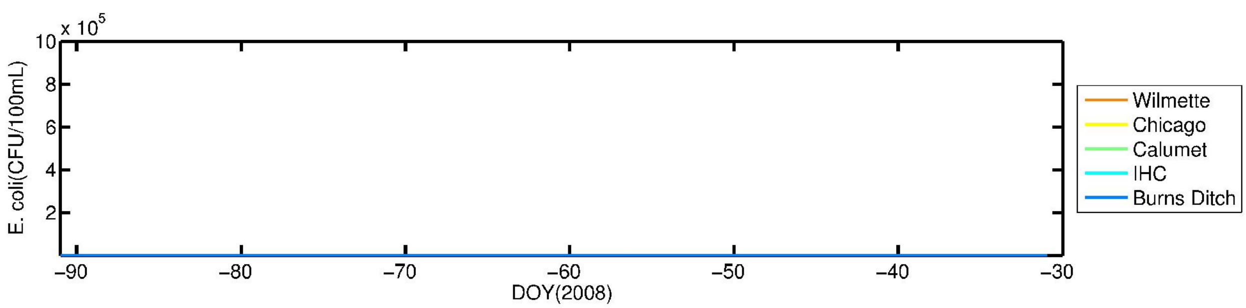


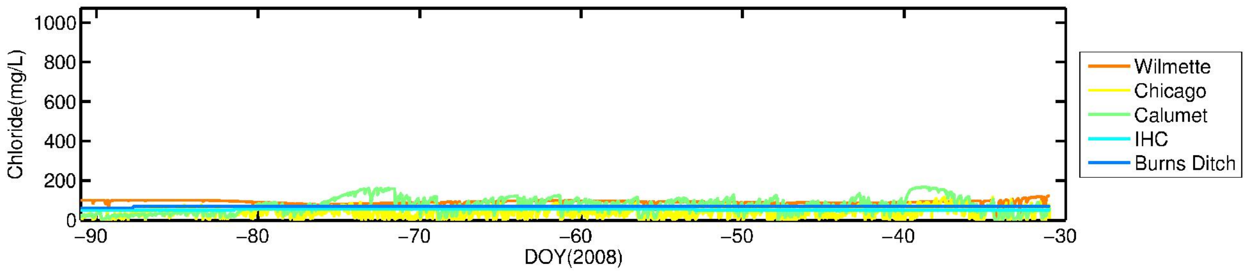

Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

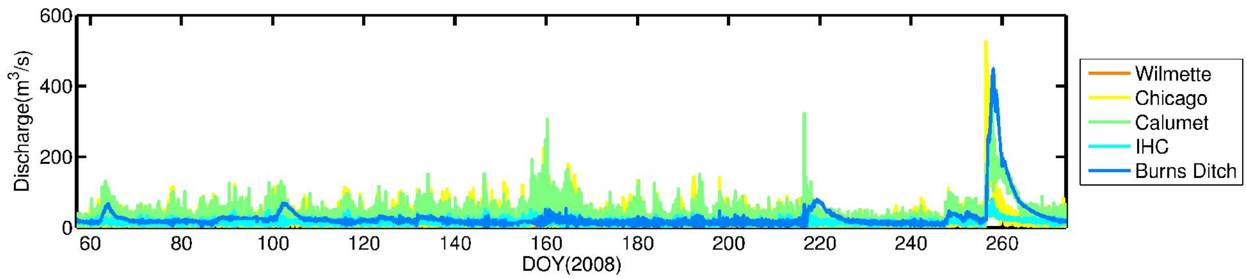

Inorg. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

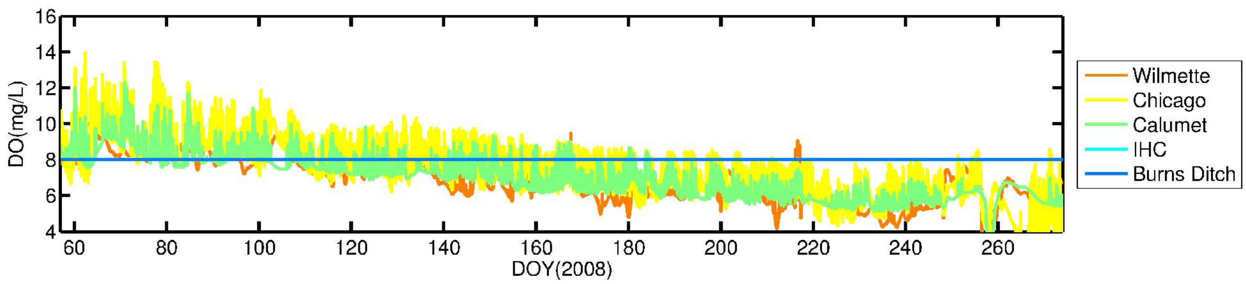

Org. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

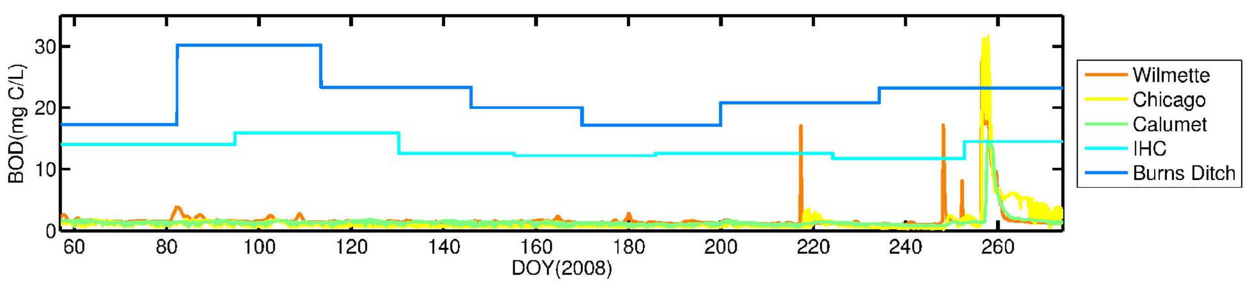

x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

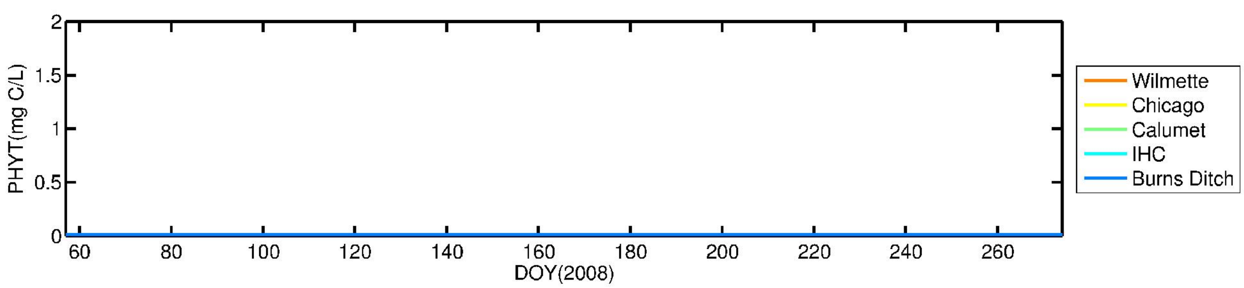

Chloride(mg/L)
1000
800
600
400
200
0
−90
−80
−70
−60
−50
−40
−30
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

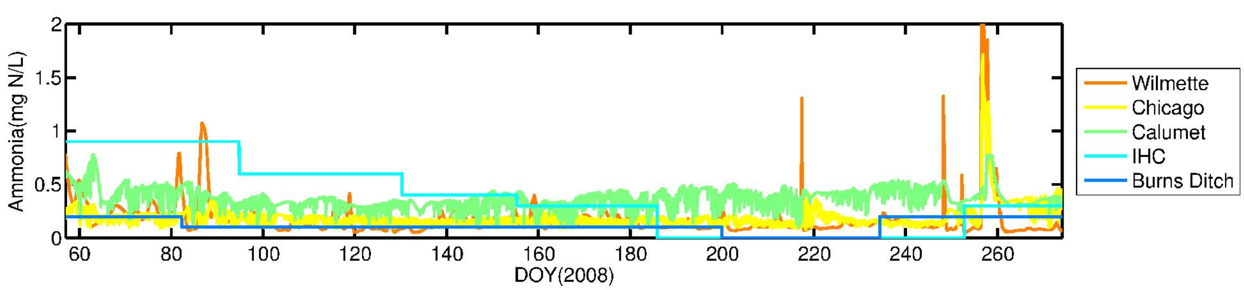
Scenario 2: March2008-September2008

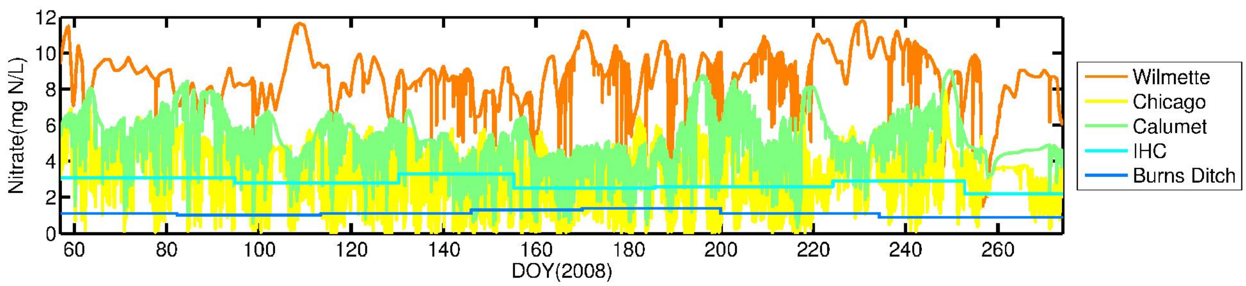


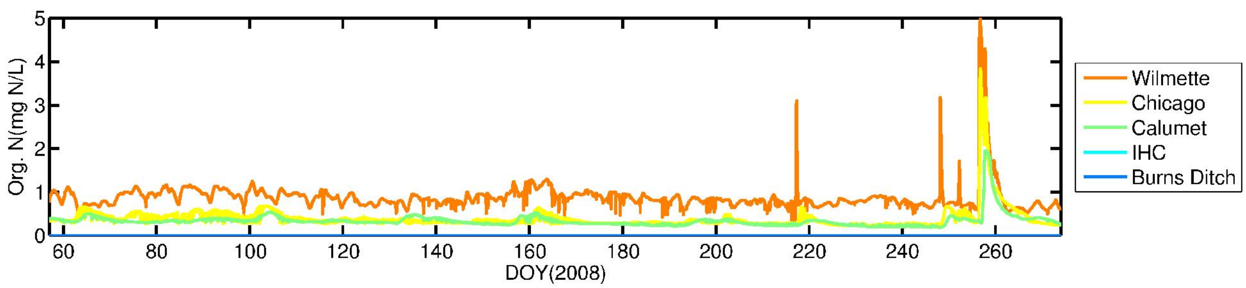


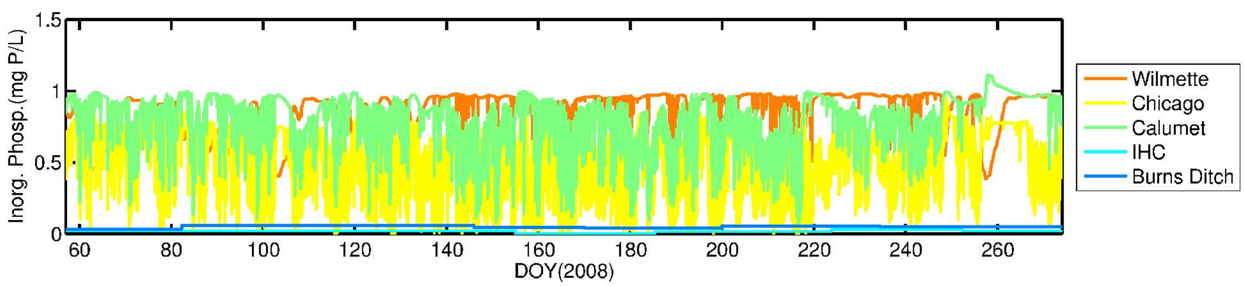


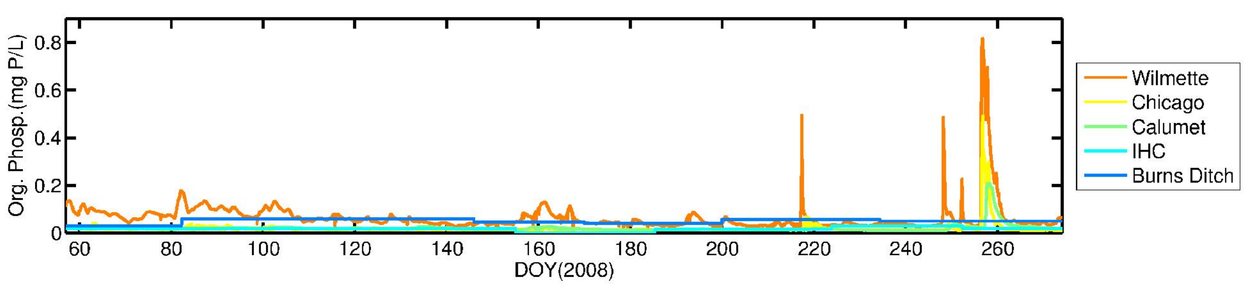


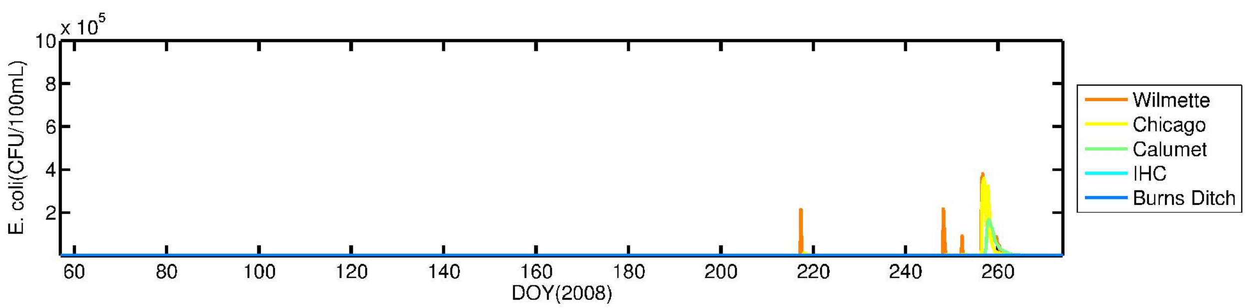


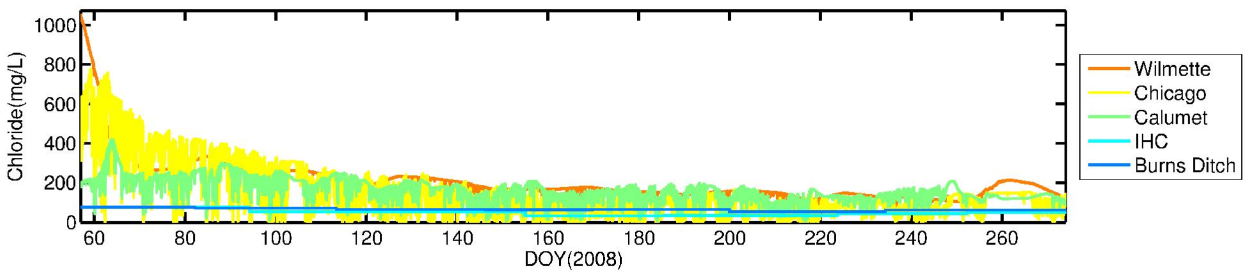

Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Inorg. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

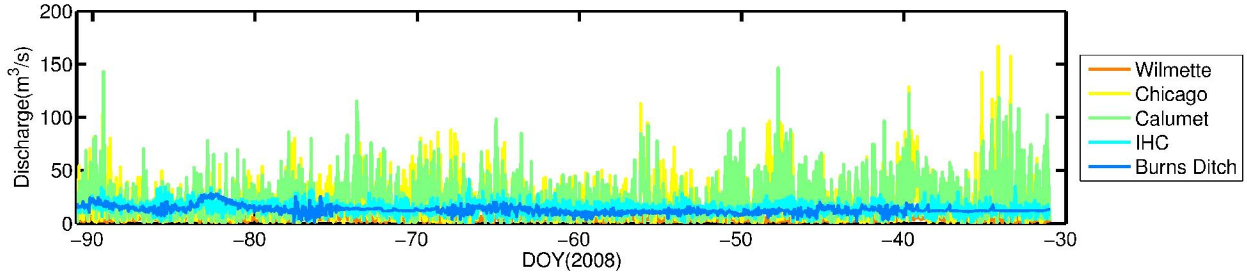

Org. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

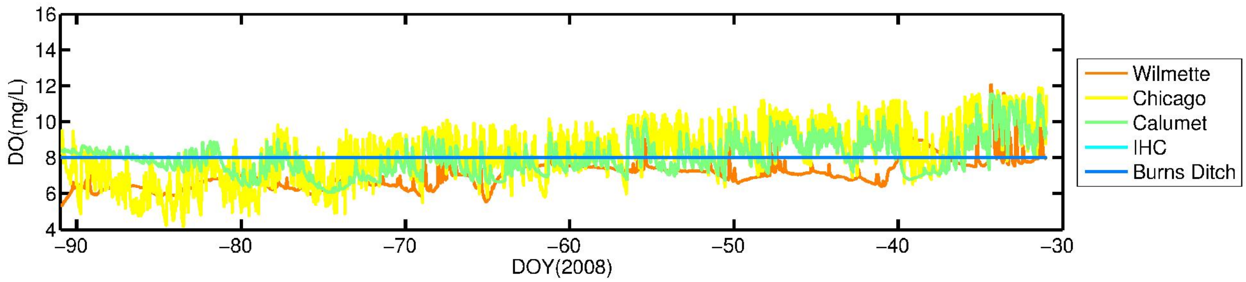

x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

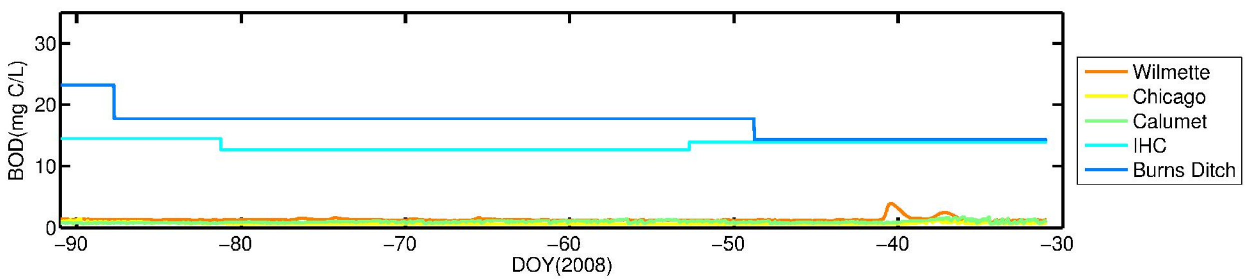


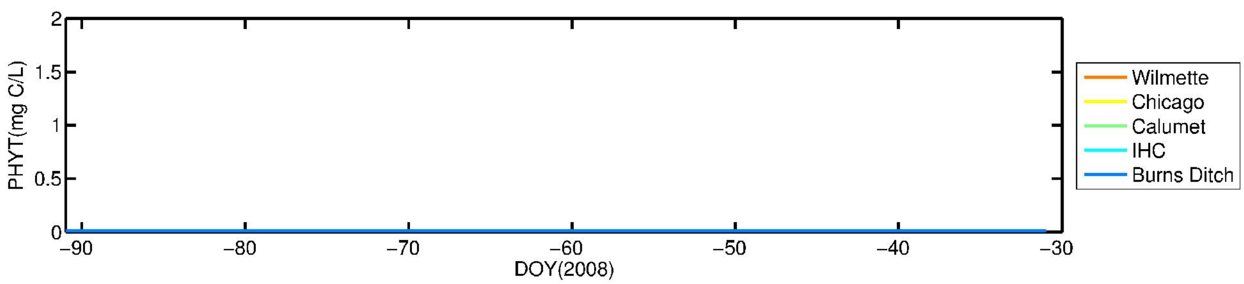
1000
800
600
400
200
0
Chloride(mg/L)
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

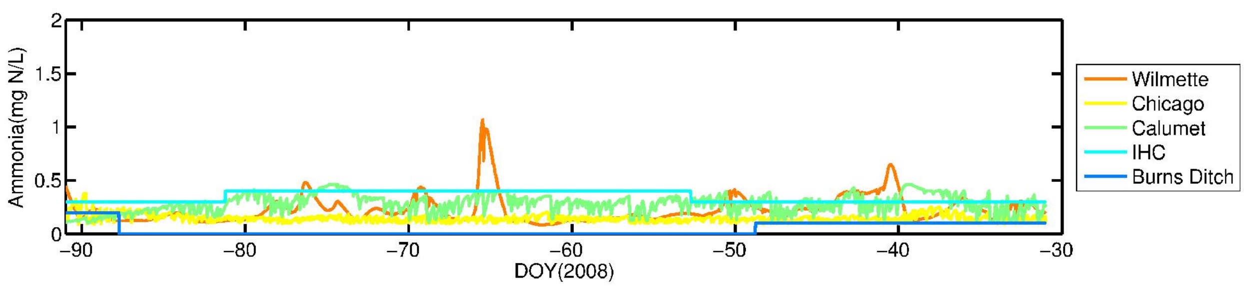
Scenario 3: Sept2007-November2007

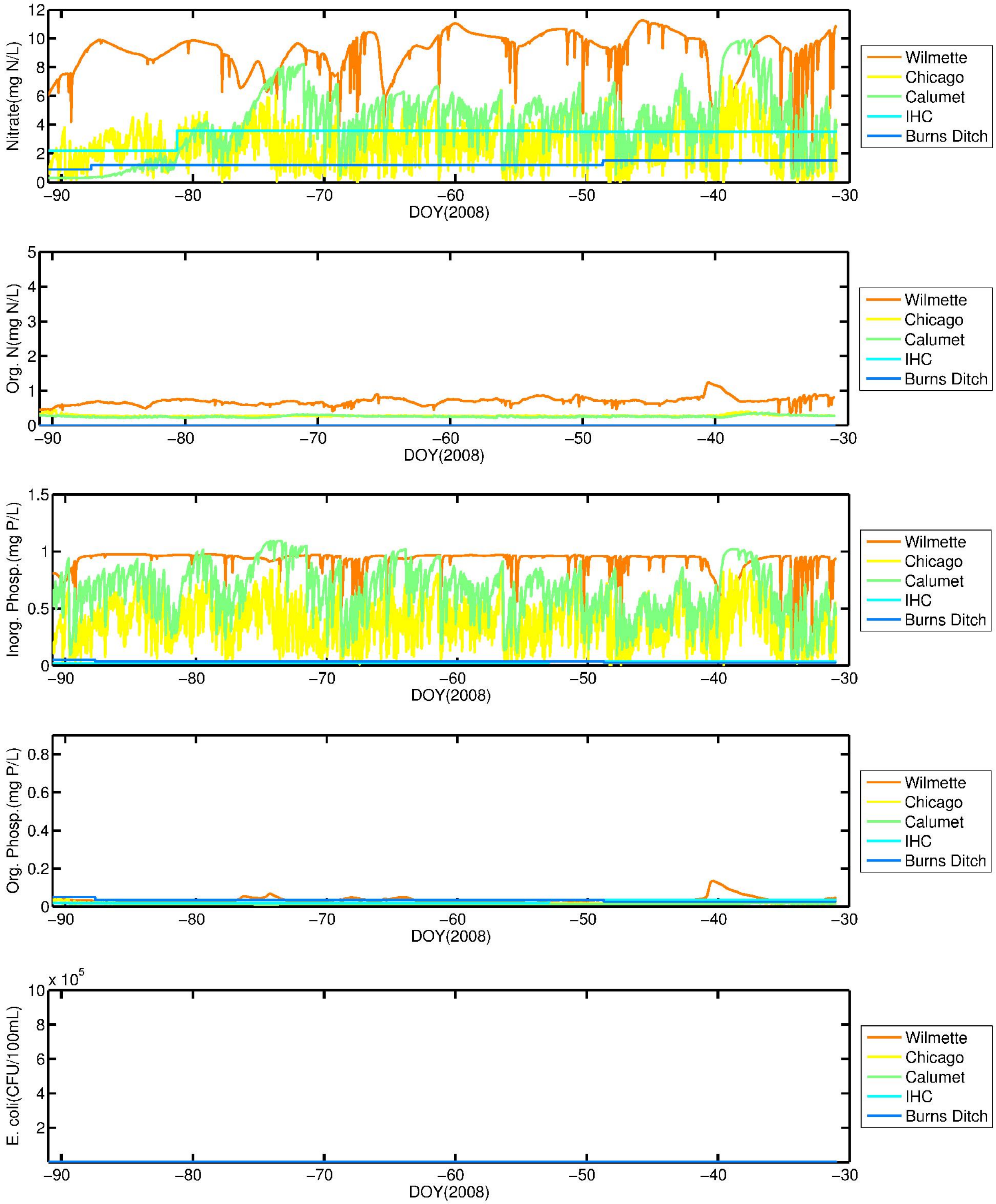


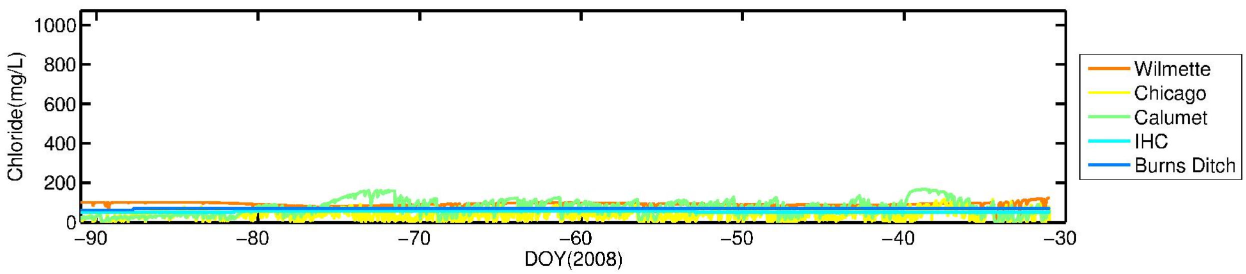






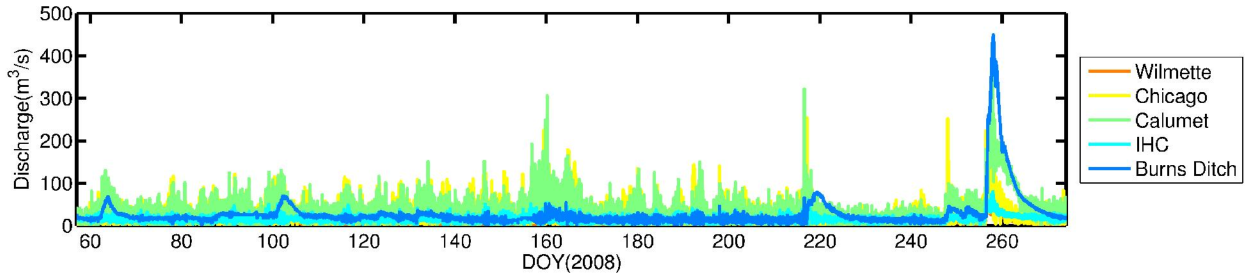


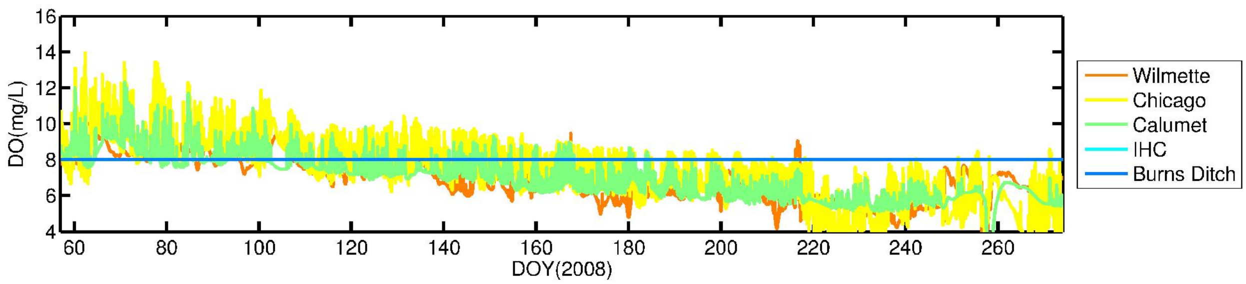

Nitrate(mg N/L)
DOY(2008)
Org. N(mg N/L)
DOY(2008)
Inorg. Phosp.(mg P/L)
DOY(2008)
Org. Phosp.(mg P/L)
DOY(2008)
x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

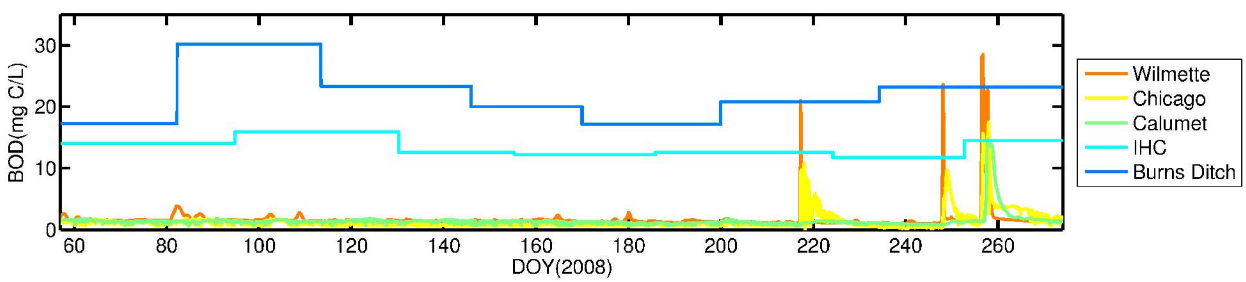


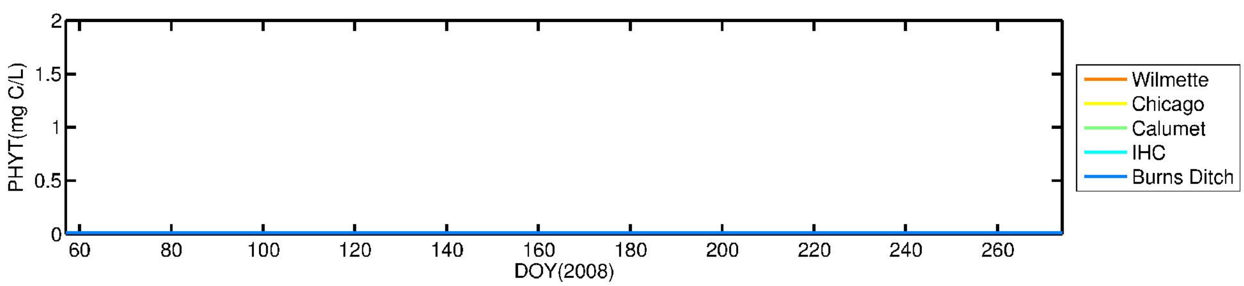
Chloride(mg/L)
1000
800
600
400
200
0
−90
−80
−70
−60
−50
−40
−30
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

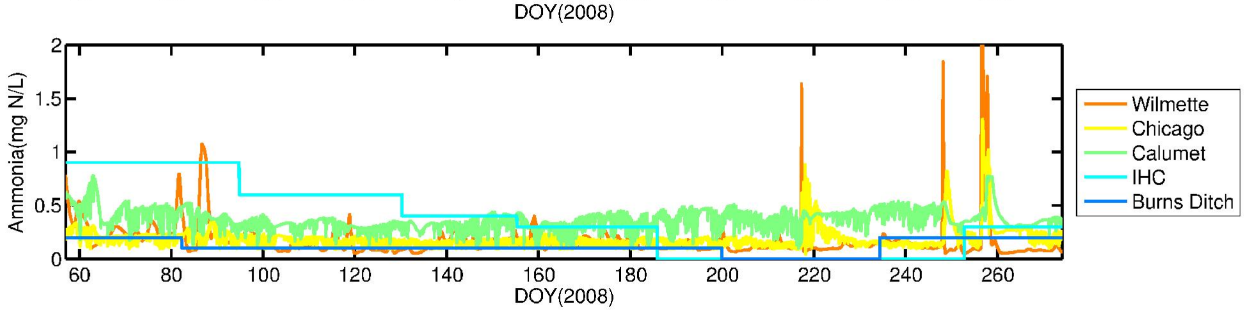
Scenario 3: March2008-September2008

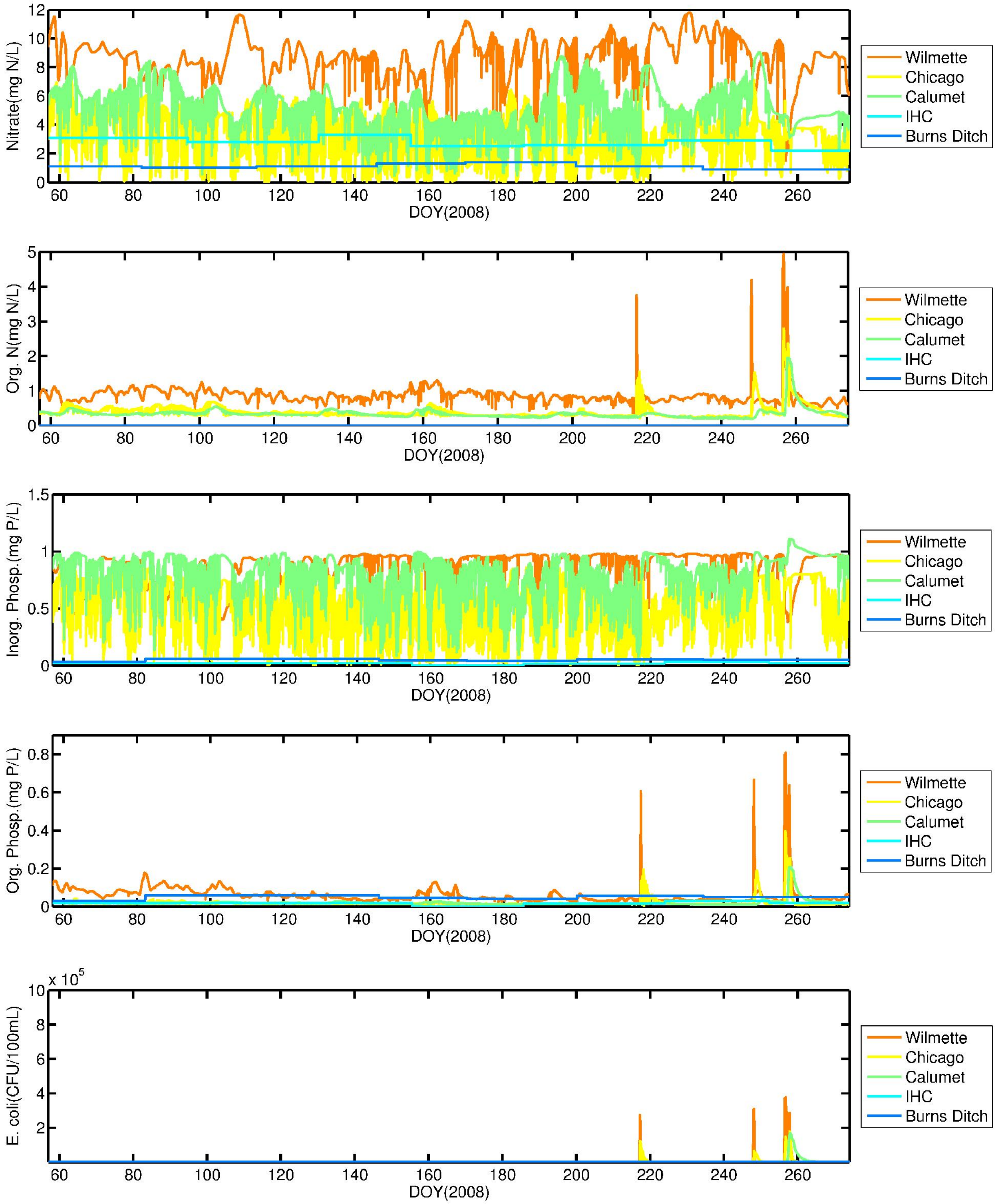


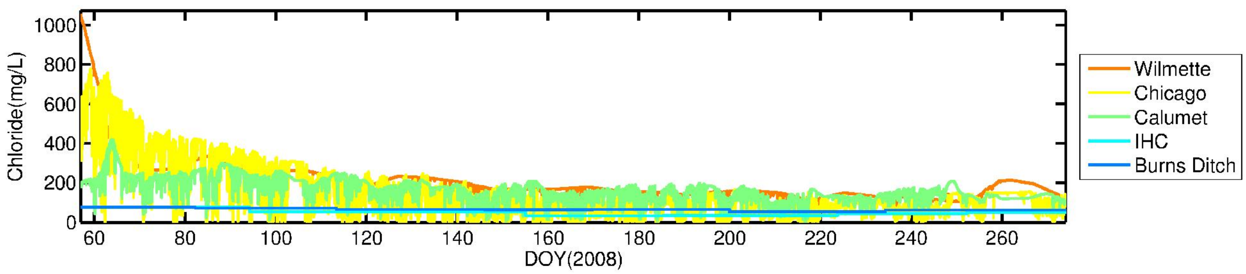






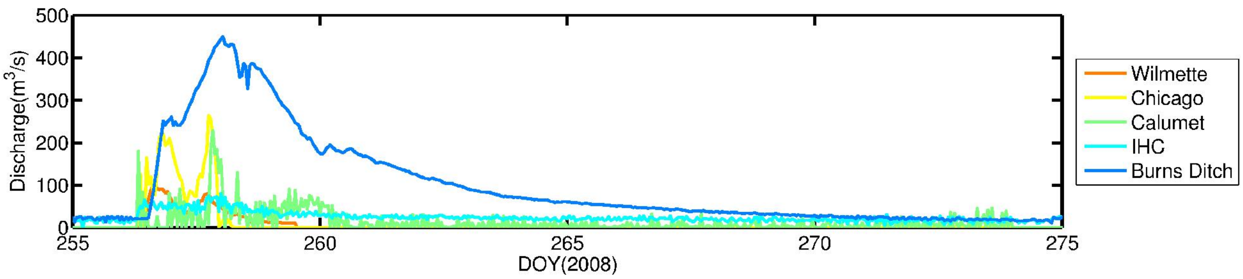


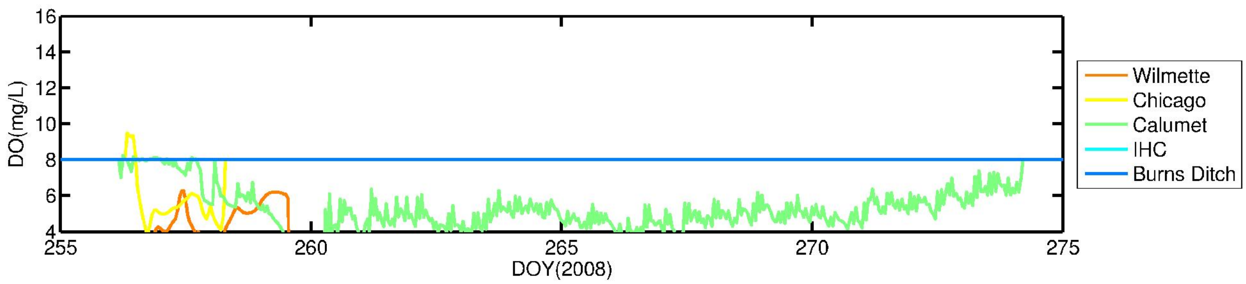

Nitrate(mg N/L)
Org. N(mg N/L)
Inorg. Phosp.(mg P/L)
Org. Phosp.(mg P/L)
E. coli(CFU/100mL)
x 10^5
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

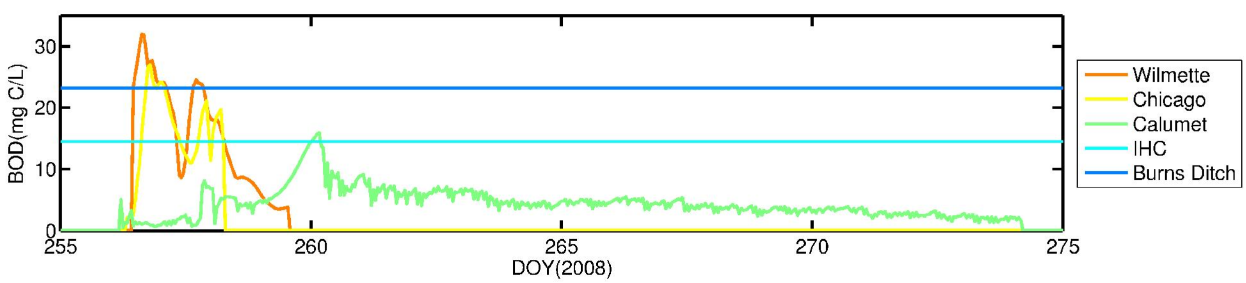


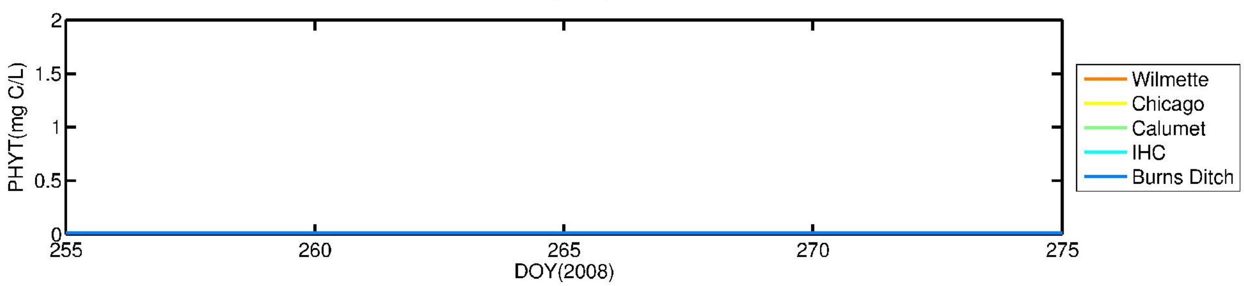
Chloride(mg/L)
1000
800
600
400
200
0
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

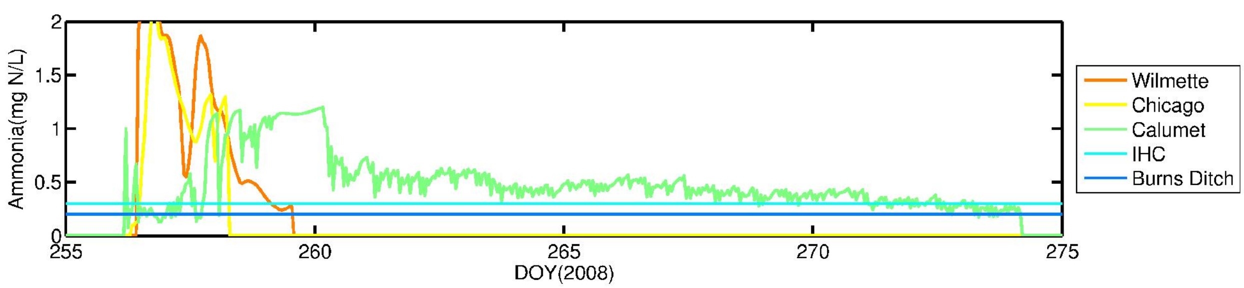
Scenario 4: September

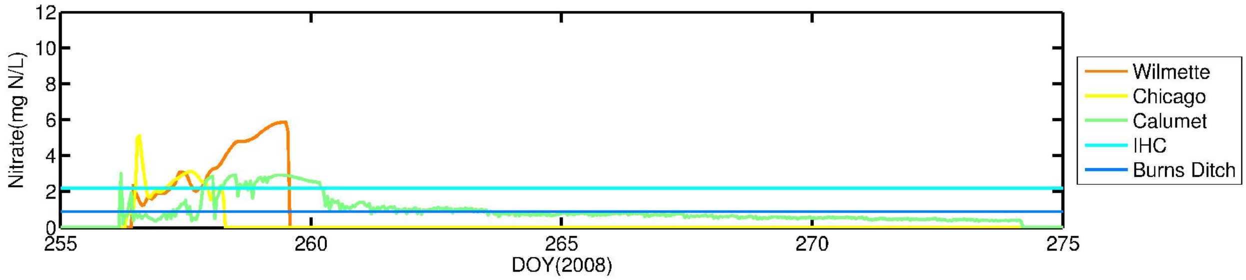


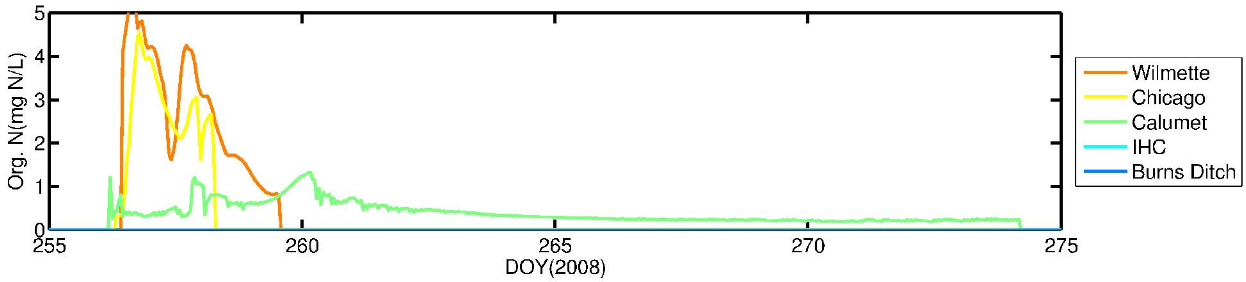


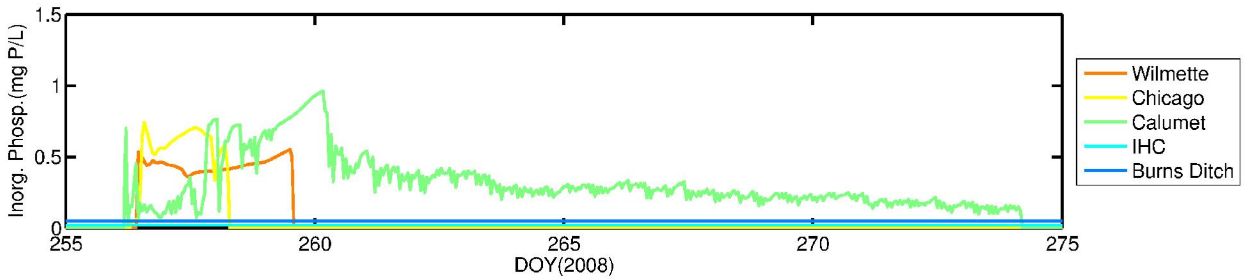


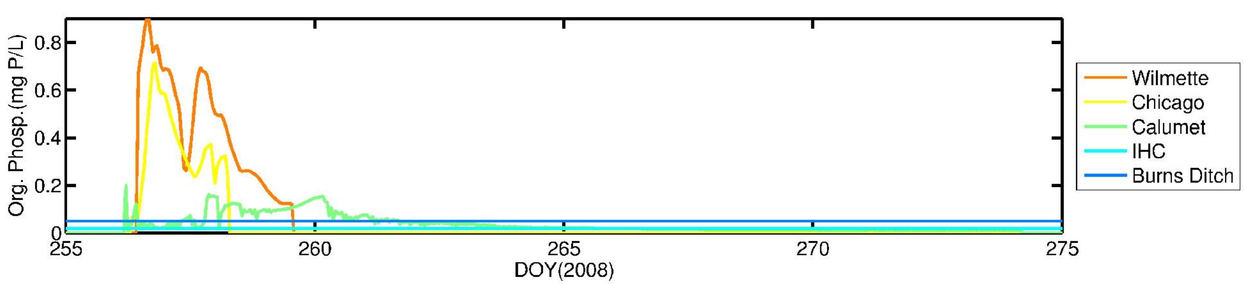




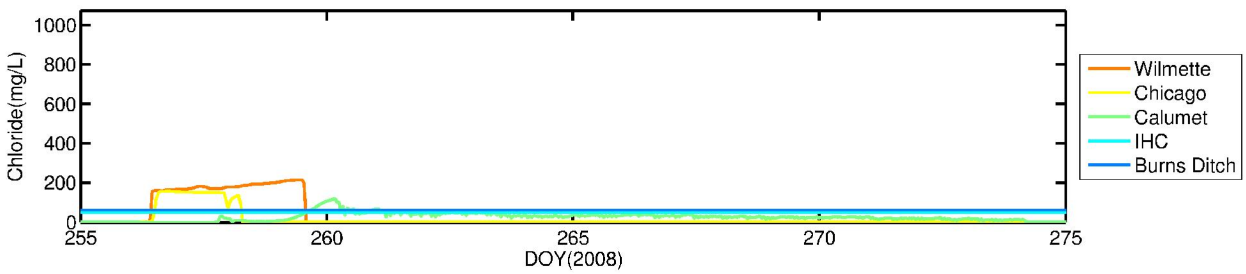

Nitrate(mg N/L)
0
2
4
6
8
10
12
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
0
1
2
3
4
5
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

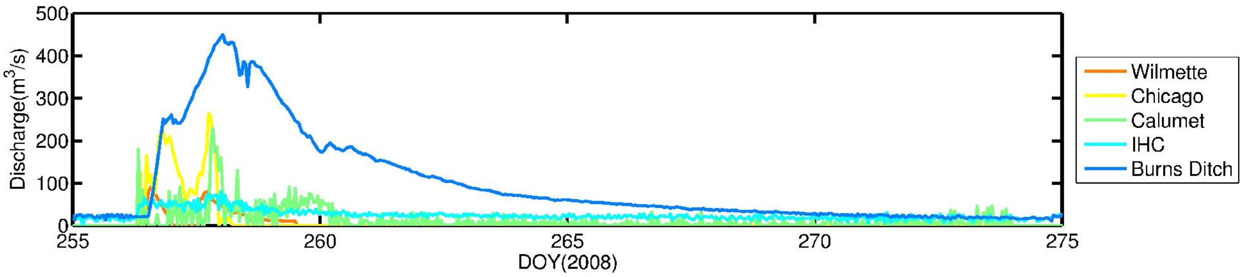

Inorg. Phosp.(mg P/L)
0
0.5
1
1.5
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

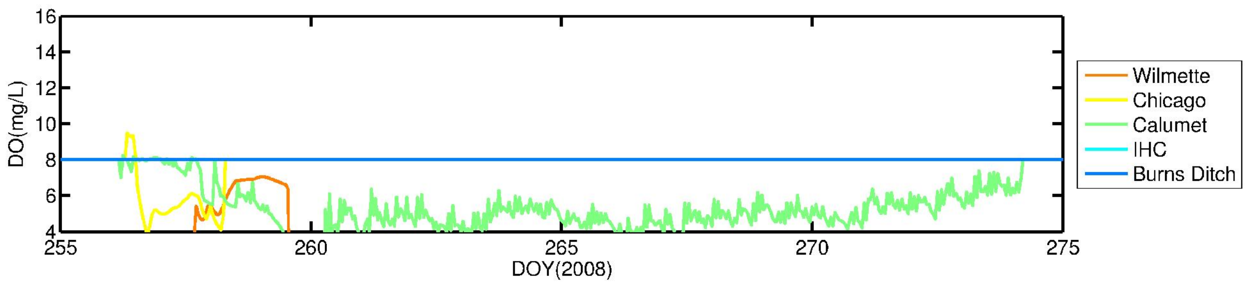

Org. Phosp.(mg P/L)
0
0.2
0.4
0.6
0.8
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

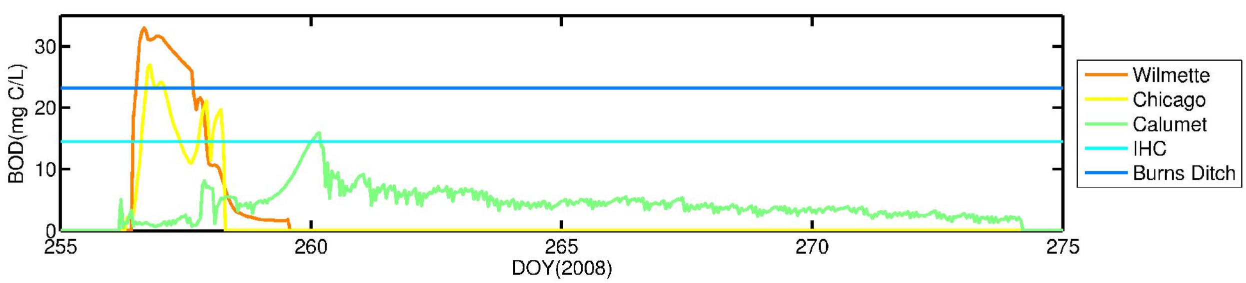

x 10^5
E. coli(CFU/100mL)
2
4
6
8
10
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

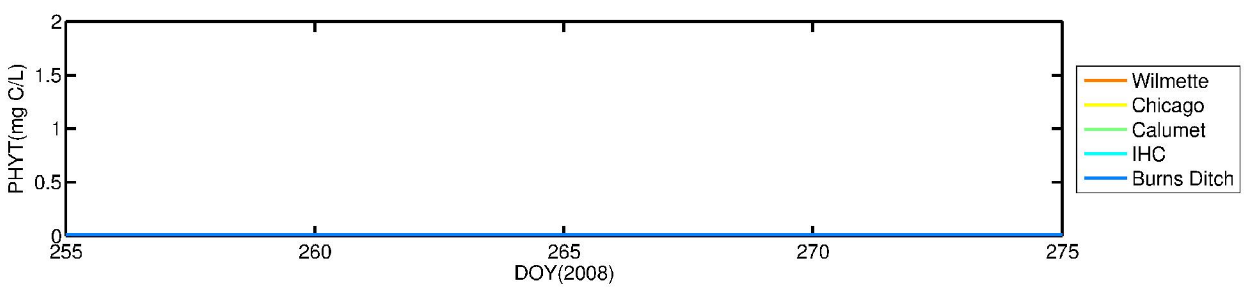

1000
800
600
400
200
0
Chloride(mg/L)
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

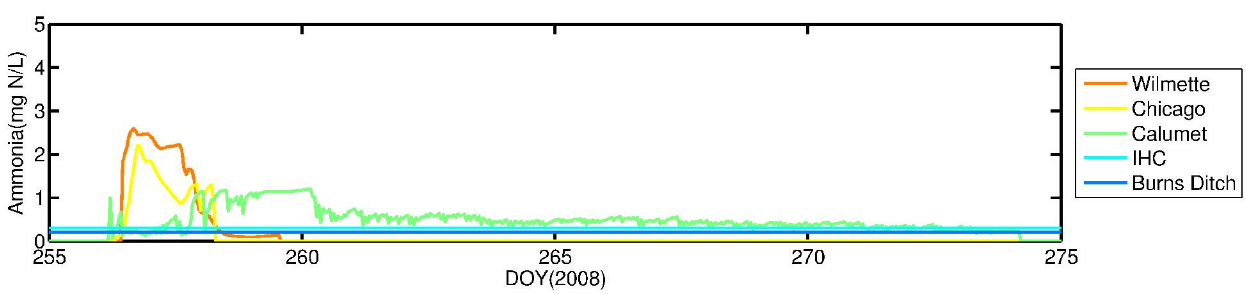
Scenario 5: September

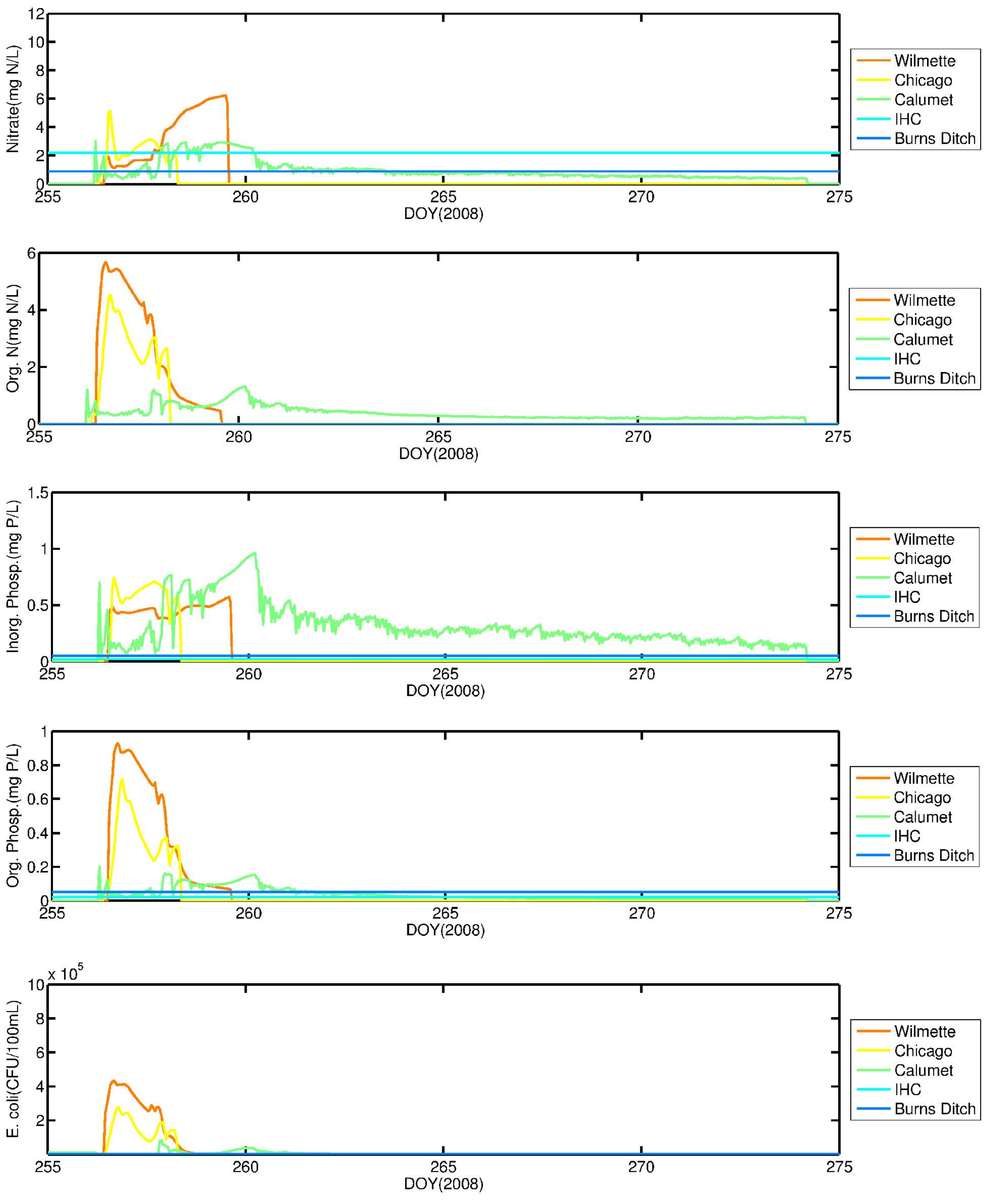


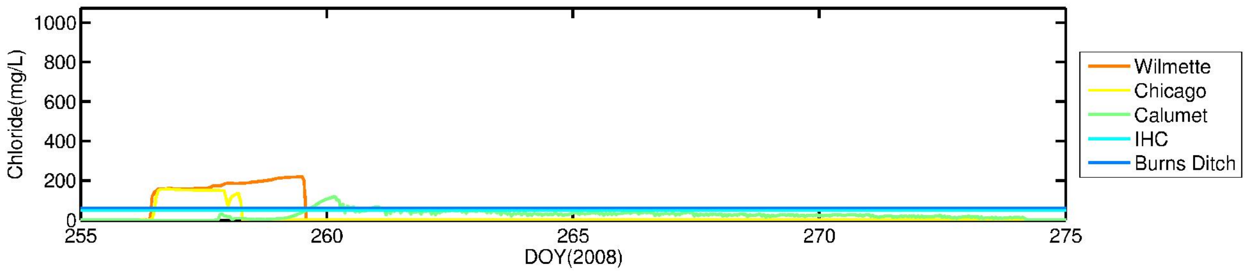









Nitrate(mg N/L)
DOY(2008)
Org. N(mg N/L)
Inorg. Phosp.(mg P/L)
Org. Phosp.(mg P/L)
E. coli(CFU/100mL)
x 10^5
Wilmette
Chicago
Calumet
IHC
Burns Ditch


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

Natural Resources Integrated Information System

Basic Information

Title:	Natural Resources Integrated Information System
Project Number:	2013MI220B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	8
Research Category:	Climate and Hydrologic Processes
Focus Category:	Management and Planning, Water Quality, Water Quantity
Descriptors:	Management and Planning, Water Quality, Water Use
Principal Investigators:	Jon Bartholic

Publications

1. Invited: Bartholic, J. 2013. Smarter Agriculture: A Dialogue on Critical Data for Agriculture workshop supported by a grant from NIFA-AFRI, Potomac, MD. Also, Lightning Round Presentation on experiences/perspectives with water resources and land management data. 10-11 Oct.
2. Bartholic, J. et al. 2013. Goal 2: Expand and Maintain Watershed Decision Support Systems - Connectivity of the Present and a Holistic Look Toward the Future. Midwest Spatial Decision Support System Partnership Conference, Chicago, IL, sponsored by U.S. EPA Region 5. 16-17 July.
3. Bartholic, J. 2013. Supporting GLRI Priorities through 516(e) Program Web-based Tools. Great Lakes Sedimentation Workshop sponsored by Great Lakes Commission, Ann Arbor, MI 14-15 May.
4. Seedang, S., P.E., Norris, S. Batie, and M.D. Kaplowitz. 2013. Michigan State University. Exploring Market-based Environmental policy for Groundwater Management and Ecosystem Protection for the Great Lakes Region: Lessons Learned. Journal of Great Lakes Research 39(3): 484-492, 23 July; on-line at http://www.sciencedirect.com/science/article/pii/S0380133013000828.
5. Bartholic, J. 2013. Spatial Decision Support Systems - Partnerships: Managing Land Use for Sustainability. Honored Invited Presenter at the 2013 International Conference on Water Sustainability in Arid Regions held at Lanzhou University in Lanzhou, Peoples Republic of China. 12-14 August, 36 pp, in Proceedings.
6. Bartholic, J. 2013. Managing Water Resources to Protect Ecologic Services with Increased Uncertainty. Invited: Presented at 2013 UCOWR/NIWR Annual Conference on Sustaining Water Resources and Ecological Functions in Changing Environments. Lake Tahoe, CA, 11-13 June. In Proceedings, Session 3: Policy for Water Supply Management.
7. Bartholic, J. 2013. Professional and Multi-generational Interdisciplinary Water Resources Education. Invited: Presented at 2013 UCOWR/NIWR Annual Conference on Sustaining Water Resources and Ecological Functions in Changing Environments. Lake Tahoe, CA, 11-13 June. In Proceedings, Plenary Session IV: Interdisciplinary Water Resources Education.
8. Bartholic, J. 2013. White Paper at the request of The Honorable Governor Snyder. Water Strategy for Michigan: Agricultural Expansion and Water Resource Protection. Submitted September, 11 pp.
9. Bartholic, J. 2013. White Paper Follow-up at the request of The Honorable Governor Snyder. The Water Cycle: Wise Use of Michigan's Water Cycle - Resources. Submitted March, 7 pp.
10. Legge, J.T., P.J. Doran, M.E. Herbert, J. Asher, G. O'Neil, S. Mysorekar, S. Sowa, and K.R. Hall. 2013. From model outputs to conservation action: Prioritizing locations for implementing agricultural best management practices in a Midwestern watershed. In Journal of Soil and Water Conservation,

68(1):22-33. www.swcs.org.

11. Bartholic, J., et al. 2013. Ottawa County Water Resource Study, Final Report. Funding provided by the Ottawa County Planning Commission, Ottawa County, Michigan and the Department of Civil and Environmental Engineering. May, 138 pp.
12. O'Neil, G., J. Bartholic, et al. 2013. Science and Technology for Environmental Solutions. Midwest Spatial Decision Support Systems Partnership (MSDSSP) Accomplishments Report. June, 46 pp.
13. O'Neil, G. J. Bartholic, et al. 2013. Development of the Great Lakes Watershed Management System. 2010-2012 Activity Report by the Institute of Water Research at Michigan State University, prepared for the U.S. Army Corps of Engineers, Great Lakes Tributary Modeling Program 516(e). May, 27 pp.
14. Bartholic, J., et al., 2013. Program Evaluation Report Fiscal Years 2008-2010. Institute of Water Research at Michigan State University prepared for the Office of External Research, Water Resources Discipline, U.S. Geological Survey. March, 66 pp.
15. Bartholic, J. 2013. Using a Decision Support System to Guide Practices and Summarize Multiple BMP Benefits in Watersheds. Annual Hatch Report Project No. MICL02236 for USDA-NIFA reporting period January-September.
16. Bartholic, J., 2013. Water Policy and Management Challenges in the West. Annual Hatch/Multi State Report Project No. MICL04064 - W2190 for USDA-NIFA reporting period January-September.
17. Bartholic, J. 2013. Modeling for TMDL Development, and Watershed Based Planning, Management and Assessment. Annual/Complete Hatch/Multi State Report Project No. MICL04053 - S1042 for USDA-NIFA reporting period October 2008-September 2013.
18. Thupaki, P., P. Mantha, M. Nevers, R. Whitman. 2013. Modeling the Effects of Hydrologic Separation on the Chicago Area Waterway System on Water Quality in Lake Michigan. Final Project Technical Report submitted to U.S. Army Corps of Engineers (ACOE). Project funded by ACOE via the USGS WRRI program through the Institute of Water Research at Michigan State University. September, 105 pp.

Institute of Water Research

Annual Technical Report - FY 20132014

Program Introduction

The Institute of Water Research (IWR) at Michigan State University (MSU) continuously provides timely information for addressing contemporary land and water resource issues through coordinated multidisciplinary efforts using advanced information and networking systems. The IWR endeavors to strengthen MSU's efforts in nontraditional education, outreach, and interdisciplinary studies utilizing available advanced technology, and partnerships with local, state, regional, and federal organizations and individuals. Activities include coordinating education and training programs on surface and ground water protection, land use and watershed management, and many others. We also encourage accessing our web site which offers a more comprehensive resource on IWR activities, goals, and accomplishments: http://www.iwr.msu.edu.

The Institute has increasingly recognized the acute need and effort for multi-disciplinary research to achieve better water management and improved water quality. This effort involves the integration of research, data, and knowledge with the application of models and geographic information systems (GIS) to produce spatial decision support systems (SDSS). These geospatial decision support systems provide an analytical framework and research data via the web to assist individuals and local and state government agencies make wise resource decisions. The Institute has also increasingly become a catalyst for region wide decision-making support in partnership with other states in EPA Region 5 using state-of-the-art decision support systems.

The Institute works closely with the MSU Cooperative Extension Service to conduct outreach and education. USGS support of this Institute as well as others in the region enhances the Institute credibility and facilitates partnerships with other federal agencies, universities, and local and state government agencies. The Institute also provides important support to MSU-WATER, a major university initiative dealing with urban storm water issues with funding from the university Vice President for Finance. A member of the Institute's staff works half-time in facilitating MSU-WATER activities so the Institute enjoys a close linkage with this project. The following provides a more detailed explanation of the Institute's general philosophy and approach in defining its program areas and responsibilities.

General Statement

To deal successfully with the emergence of water resource issues unique to the 21st century, transformation of our knowledge and understanding of water for the protection, conservation, and management of water resources is imperative. Radically innovative approaches involving our best scientific knowledge, extensive spatial databases, and "intelligent" tools that visualize wise resource management and conservation in a single holistic system are likewise imperative. Finally, holistic system analysis and understanding requires a strong and integrated multi-disciplinary framework.

Research Program

The management of water resources, appropriate policies, and data acquisition and modeling continue to be at the forefront of the State, Regional, and National Legislatures agenda and numerous environmental and agricultural organizations. Our contribution to informing the debate involved numerous meetings, personal discussions, and most importantly, the enhancement of web-based information to aid in the informed decision-making process.

Unique Capabilities: Decision Support Systems as the Nexus

IWR, with its "extended research family," is exceptionally well-positioned to integrate research conducted within each of the three principal water research domains: hydrologic sciences, water policy, and aquatic ecosystems. Integrated decision support both reflects and forms the nexus of these three research domains. Expanding web accessibility to the decision support system nexus (formed by the intersection of the three research domains) will facilitate broad distribution of science-based research produced in these domains. A special emphasis is being placed on facilitation of science-based natural resource state and national policy evolution. Fundamentally we are addressing the Coupled Human and Natural System (CHANS).

The Institute's extensive experience in regional and national networking provides exceptional opportunities for assembling multi-agency funding to support interdisciplinary water research projects and multi-university partnerships.

Using a Multi-Disciplinary Framework

Using a multi-disciplinary framework facilitates dynamic applications of information to create geospatial, place-based strategies, including watershed management tools, to optimize economic benefits and assure long-term sustainability of valuable water resources. New information technologies including GIS and computational analysis, enhanced human/machine interfaces that drive better information distribution, and access to extensive real-time environmental datasets make a new "intelligent reality" possible. This is our way of addressing the "CHANS." Effective watershed management requires integration of theory, data, simulation models, and expert judgment to solve practical problems. Geospatial decision support systems meet these requirements with the capacity to assess and present information geographically, or spatially, through an interface with a geographic information system (GIS). Through the integration of databases, simulation models, and user interfaces, these systems are designed to assist decision makers in evaluating the economic and environmental impacts of various watershed management alternatives.

The ultimate goal of these new imperatives is to guide sustainable water use plus secure and protect the future of water quality and supplies in the Great Lakes Basin, across the country and the world—with management strategies based on an understanding of the uniqueness of each watershed.

Title: Natural Resources Integrated Information System
Project Number: 2013MI220B
Start: 03/01/13 (actual)
End: 02/28/14 (actual)
Funding Source: USGS 104(B)
Congressional District: eighth
Research Category: Water Quality
Focus Categories: Management and Planning, Water Quality, Water Use
Descriptors: Management and Planning, Water Quality, Water Use
Primary PI: Jon F. Bartholic, Director, Institute of Water Research, Michigan State University, East Lansing, MI 48823, bartholi@msu.edu
Project Class: Research

Problem and Research Objectives

Nature and Importance to the Problem and Relevance to the Mission

Water is replacing oil as one of the single most important resources upon which policy and, in fact, human existence in many portions of the globe will depend. Political power, economics, and civilization's development will be critically impacted by our ability to sustainably manage and optimally utilize the planet's water resources. Because of the United States' relative advantage from a water resource standpoint, this country's role will be increasingly significant in food production and industrial production requiring significant quantities of water, and in developing sustainable approaches to maintain waters' ecological services. Specifically, the Great Lakes region will have tremendous opportunities to capitalize in numerous ways on the potential of its vast water resources. But water resources management always occurs in a social context involving multiple stakeholders. Stakeholders can have radically different perceptions of the problems and potential trade-offs associated with finding solutions because of dynamic social, economic, and political factors as well as biophysical complexities of water resources issues. This complex nature of water resource management and other related issues, such as global climate change and health care, is often referred to in the scientific community as "wicked." Research on wicked-type problems suggests that a comprehensive knowledge system sustained by a boundary organization is essential. Boundary organizations act as intermediaries between science and policy because they fulfill or possess (see Figure 1): 1) specialized roles within the organization for managing the boundary; 2) clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and 3) a forum in which information can be co-created by research and interested parties. Since its very beginning and long history of existence, the Institute of Water Research (IWR) has been functioning as a boundary organization to tackle wicked water resources management issues. Through a history of extensive knowledge generation, engagement and facilitation, and working experience with local, state, and basin-wide organizations, IWR has a solid base of success to build upon in creating innovative knowledge systems for sustainable management of water resources.

<u>Previous Work and Present Outlook</u>

- Broad Guidance: Impact Support
- Research Projects
- Spatial Decision Support Systems (SDSS)
- Building a Great Lakes Basin-Wide IT/Decision Support/Networking System

Broad Guidance: Impact Support

<u>Water Use Advisory Council Support</u>

The Michigan Department of Environmental Quality (MDEQ) convened the Water Use Advisory Council, made up of roughly 30 members, for a two-year appointment in early 2013 to advise MDEQ Director Dan Wyant on Michigan's Water Use Program. The Council meets monthly and will complete its work in December 2014. Diverse interests are represented on the Council, including those from government, non-profit organizations, and those representing agricultural, industrial, commercial, or environmental interests. The MSU-IWR has ex-officio membership on the Council and Frank Ruswick serves as a co-chair of the Water Conservation and Use Efficiency subcommittee.

Through an MOU with the MDEQ, the MSU-IWR is also providing administrative support to the Council. The Institute is responsible for preparing meeting summaries and coordinating all meeting logistics. In addition, the Institute will be compiling the Council's final report. Being intimately involved with Council activities has allowed the Institute to understand emerging needs relating to water use within the state and directly align certain project activities with major issues identified through the Council. For example, a major focus of the USDA-NIFA funded project at the Institute is the development of decision support tools to assist water users committees outlined in the legislation that dictates requirements of MDEQ's Water Use Program.

<u>White Paper Per Request from The Honorable Governor Snyder: Water Strategy for Michigan: Agricultural Expansion and Water Resource Protection - Prepared September 2013</u>

Topic Overview

Prologue: The philosophical approach that one takes in developing water strategies is extremely important. A personal note from the main author of this paper is that the title for this White Paper should be something akin to "Assuring Sustainable Water Resources." I suggest this concept as it is one upon which both users of water directly (irrigators, industry, municipality, etc.), and those who indirectly enjoy the gifts of abundant clean water can work on collaboratively. Even those who may be large users of water such as agricultural irrigators are not only interested in the possibility of new well withdrawals but they also want assurance that the tens or hundreds of thousands they've already spent on existing wells will not run dry. The public as a whole from a business perspective, or for quality-of-life also realize that sustainable management approaches are within their best interests. Thus as Michiganders, we can work together to provide a system that is fair, equitable, and assures sustainable water resources.

White Paper Follow-up - The Water Cycle: Wise Use of Michigan's Water Cycle - Resources Prepared March 2014

Wise use of Michigan's water cycle – resources! **Goal 1**: Michigan's water resources need to be maintained with a goal that optimizes community and human health, and natural, recreational, economic, and cultural uses and values. Addressing [i]**Goal 1** requires a water resource perspective that begins with an overview and understanding of Michigan's water cycle and how its components interact.

Michigan's Water Cycle: The hydrologic or water cycle is frequently divided into five major components (primary elements) - rainfall (precipitation), infiltration, evapotranspiration, runoff, and storage/groundwater. The values of these components for Michigan are relatively robust in size compared with more arid regions; e.g. the Western U.S.

The real challenge is one of scale since there is great and dynamic variability in these components across Michigan. For example, in some areas additional impervious surfaces may lead to increased runoff, less infiltration, and subsequently, greater flooding downstream. In other areas infiltration may provide inadequate recharge (storage) to keep up with withdrawals via wells from groundwater (storage) for continued urban and agricultural uses. Thus, it is critical in a Water Strategy to be well-informed about the "big" picture (basin or statewide) along with more detailed knowledge at the local watershed level. For instance, Michigan's present water withdrawal registration policy system is divided into approximately 5300 differentiated stream reaches/sub-watersheds. Additionally, since water moves vertically from the surface to groundwater but also moves laterally both above and below ground, the vertical/horizontal flux characteristics need to be included in any local water balance investigation. These broad factors along with others are required to assure *Outcome D - "Water Infrastructure is well-designed and maintained to support recreational, economic, and cultural uses and values."*

Michigan Natural Resources Working Group

Background
The Michigan Natural Resources Working Group (NRWG ~ initiated and facilitated by MSU-IWR) is a partnership of federal, state and local agencies and organizations with an interest in conserving Michigan's natural resources. Partners include the Great Lakes Commission, Michigan Department of Agriculture and Rural Development, Michigan Department of Environmental Quality, Michigan Farm Bureau, The Nature Conservancy, US Geological Survey, USDA Natural Resources Conservation Service, US Fish and Wildlife Service, Shiawassee Conservation District, Lenawee Conservation District and Michigan State University (Institute of Water Research; Department of Sociology; Michigan State Extension; Department of Community, Recreation and Resource Studies; Land Policy Institute).

The partners first met in November 2011and has been meeting regularly since then. The goal of the initial meeting was for each member organization to identify challenges and goals that they are currently facing. Two were found in common among all members of the partnership. The first was a need to measure accomplishments in terms of outcomes in addition to outputs (e.g., output of acres under conservation treatment and an outcome based on improvements in fish populations). The second was a desire to find more effective ways to get residents to make desired changes (e.g., looking at other approaches besides farm bill programs to encourage farmers to make changes in their farming practices). The partners have decided to use a "results chain" approach in order to understand the current strategies that are being used to address natural resource conservation and identify a desired future direction.

Assessment of Collaborative Capacity

IWR worked with Dr. Stephen Gasteyer (MSU Department of Sociology) to assess the motivations and causal models of NRWG members for participation in periodic meetings and coordinated actions. The rationale is that this group has the potential to provide coordinated leadership in addressing longstanding problems of surface water quality impairment in key watersheds: River Raisin; Western Lake Erie; Shiawassee/Saginaw Bay.

This research assessed the collaborative capacity of a multi-institutional collaboration to address disproportionality in water quality impairment in Michigan watersheds. The key finding was that 1) there is real interest in collaboration, 2) there is diversity in interest in collaboration, 3) the challenge of maintaining the collaboration will necessitate a continued focus modeling and intensification of voluntary approaches to land management.

Strategic Doing

In order to take action to address our common challenges and goals, the NRWG enlisted the assistance of Robert Brown, Associate Director of University-Community Partnerships, Michigan State University Outreach and Engagement. Bob led the NRWG through a process based on Strategic Doing. According to the Purdue Center for Regional Development, Strategic Doing is "a set of principles, practices and disciplines for implementing strategy in a network." (Strategic Doing: The Art and Practice of Strategic Action in Open Networks, Staff Publication 2010-1, Ed Morrison, Purdue Center for Regional Development, February 2010). The NRWG started with a framing question: *How do we use our assets and resources to develop innovative ways to change behavior on rural lands within the River Raisin and Shiawassee River watersheds resulting in improved water quality, benefiting human health and fish communities?*

After identifying assets that each member of the NRWG is willing to share, the group developed seven outcomes that should be accomplished together. These include:

1. Develop guiding system for decision making/process
2. Use results chain to determine additional data layers that would be pertinent to this analysis
3. Select, prioritize and depict specific rural geographic areas for action
4. Engage farmers and land owners as partners to change land practices
5. Increase knowledge of available sources of funding for activities at hand
6. Engage stakeholders that can either encourage or inhibit practice change (supply chain stakeholders and policy stakeholders) as partners to change land practices
7. Identify and disseminate exist and new knowledge

Current actions
The NRWG has made significant progress on Objectives 1 and 2 (process guidance system and mapping the watersheds using a results chain) and is currently implementing an Action Plan to address Objective 3 (geographic areas for action).

The NRWG has provided a means for excellent and regular communication between partners. It also fills a niche by providing a vehicle for collaboration of ongoing efforts by the partner members.

Research Projects

The following projects represent activities supported with over $2 million dollars from our partners. USGS 104b projects are covered in other sections of this report.

GLRI - Flint River Nutrient Reduction: Focusing Action

The "Flint River Nutrient Reduction: Focusing Action" Project, funded through EPA by the Great Lakes Restoration Initiative, provides for enhanced technical assistance and outreach efforts. As a result, adoption and implementation of nutrient management strategies will be accelerated. The project seeks to achieve a larger beneficial impact on agricultural non-point source (NPS) pollution than would be attained using current approaches.

Project Objectives
- **Influence** actions of landowners with education and supportive, technical and financial assistance
- **Identify** sites that have the greatest potential to lower soluble reactive phosphorus inputs to streams
- **Assist** landowners with developing an Improvement Action Plan to reduce soluble reactive phosphorus
- **Facilitate** support for implementing practices contained in the Improvement Action Plan
- **Evaluate** the environmental and economic benefits of the implemented practices
- **Support** local schools in their water quality monitoring projects by linking water quality to landscape characteristics
- **Report** the benefits to the broader community

Project Outcomes
The expected outcome of this project is a stronger, better organized network of technical experts, thus improving efficiency and effectiveness of executing programs to meet water quality improvement goals.

USDA-NIFA Grant

An Integrative Decision Support System for Managing Water Resources under Increased Climate Variability

The goal of this project is to develop and disseminate a Decision Support System that integrates a diverse set of hydrologic systems models, analytical tools and processes to create future climactic scenarios so that water resources policy-makers and managers, and agricultural producers, can consider varying climatic conditions while making water resource policy decisions, developing sustainable water strategies within communities, and planning for agricultural water uses. Significant components of this project are the assessment of water users to determine and understand their capacity to accept and make behavioral modifications regarding water use, as well as the involvement of key individuals and groups that represent the policy-makers, managers and water users during the various stages of the project.

A major outcome of the project will be to assess the implication of these scenarios on Michigan's legislated Water Withdrawal Assessment Tool and process. Furthermore, public engagement and dissemination of the knowledge gained from the project's efforts through enhanced educational programs to be develop and offered by Michigan State University and the expertise provided by Michigan State University Extension.

Red Cedar River Watershed

The IWR is leading the development of a watershed plan for the Red Cedar River Watershed, located in Ingham and Livingston Counties, Michigan. The plan emphasizes relationships among and between a diverse set of stakeholders. Participants in the watershed planning effort include drain commissioners, conservation district staff, farmland preservation boards, agricultural producers, health department staff members, and municipal officials representing townships, villages, counties and cities. A comprehensive watershed plan is being developed with these stakeholders to address bacterial loading and other pollutants of concern throughout the watershed.

Spatial Decision Support Systems (SDSS)

Decision Support System: Environmental Learning Using Computer Interactive Decisions (ELUCID)

A comprehensive, web-based interactive decision support tool was developed to assist local technicians in addressing critical areas. Using this system, technical staff are able to identify land units on which to focus limited resources and determine BMPs most effective at reducing agricultural non-point source pollution.

The tool is Environmental Learning Using Computer Interactive Decisions (ELUCID), http://elucid.iwr.msu.edu/. One of ELUCID's greatest assets is its ability to engage and inform different user groups and address multiple issues in one system. ELUCID can be linked to existing systems to enhance its analytical capabilities.

Engagement
The ELUCID system, along with water quality monitoring data, helps engage the community at large. Using the U.S. Geological Survey's (USGS) extensive, real-time monitoring data, water quality conditions before and after the project can be compared.

These results can be used as a motivator for producers and other landowners as they are able to see both the current impacts and subsequent results they may be having on water quality. The same impacts on the landscape can be incorporated into school projects that monitor water quality characteristics. The anticipated result is that students will become more responsive within their community as they see their community's effort to protect local waters and ultimately, the Great Lakes.

Great Lakes Watershed Management System (GLWMS)

With support from The Nature Conservancy and the U.S. Army Corps of Engineers, IWR has continued to enhance watershed-scale and field-scale analysis of water quality in the Great Lakes Basin. The Great Lakes Watershed Management System (GLWMS) (www.iwr.msu.edu/glwms) combines water quality model outputs from Purdue University's Long-Term Hydrologic Impact Assessment (L-THIA) tool and IWR's High Impact Targeting (HIT) system within a single mapping interface. Users can generate estimates of sediment and nutrient loading at various watershed scales, and can run field-scale scenarios of land cover change and best management practices (BMPs). Users can digitize areas of change or BMPs, view upland contributing areas, estimate loading changes, and save results within an on-line database. They can also generate reports showing cumulative loadings/savings over time across projects. The GLWMS is currently available for the Fox River Basin in Wisconsin, the Saginaw River Basin in Michigan, the Maumee River Basin in Ohio, and the Genesee River Basin of New York. Additional support from The Nature Conservancy will allow for the addition of a ground-water recharge scenario modeling within the Saginaw River Basin in the coming months.

Train the Trainer - High Impact Targeting (HIT)

In 2012, the US Army Corps of Engineers (USACE) worked with the IWR and Purdue University to develop training materials for the High Impact Targeting (HIT) and Long-term Hydrologic Impact Analysis (L-THIA) online systems. These systems were originally developed by the Institute and Purdue University for the USACE Great Lakes Tributary Modeling 516e Program. This train-the-trainer effort consisted of preparing written materials including manuals, tutorials and fact sheets, a 10-part online video tutorial series, and powerpoint presentations. A workshop was conducted with the USACE to review all of the materials and discuss strategies for conducting trainings in their districts. This collaboration was a effective and efficient method to further disseminate the online tools throughout the Great Lakes and educate end users. The USACE is currently offering free trainings utilizing the materials prepared as part of the train-the-trainer project. This effort also fostered expertise within the Institute to develop online video tutorials for other IWR web-based tools, including a 10-part video series for the Social Indicators Data Management and Analysis (SIDMA) system and a video tutorial for the Water Use Reporting System for the State of Michigan.

Building a Great Lakes Basin-Wide IT/Decision Support/Networking System

Great Lakes Clean Communities Network (GLCCN) www.iwr.msu.edu/glccn

The Great Lakes Clean Communities Network (GLCCN) seeks to empower and connect communities and organizations around the Great Lakes to more effectively implement programs to improve ecological health in their watersheds, community, and the Great Lakes Basin. This network is funded by the Great Lakes Protection Fund and being developed by the Institute of Water Research (IWR) at Michigan State University (MSU).

The GLCCN will connect Great Lakes environmental practitioners (e.g., sustainability managers, watershed groups, state and local government) and equip them with the latest innovations to improve or sustain ecological health in their communities. The overall goal is to provide a platform where practitioners can share tools, ideas, and techniques to learn from one another and more efficiently address their environmental concerns such as storm water runoff, nutrient loading, water conservation, or beach closure. The Network will feature a central online hub which will provide easy access to environmental tools, measures for gauging ecological impact, and social media communication strategies. With these enhanced capabilities, communities and groups may be better equipped to implement practices and evaluate their effectiveness. Several partners will contribute to the development and deployment of the GLCCN, including the Great Lakes and St. Lawrence Cities Initiative (GLSLCI), The Nature Conservancy (TNC), and University of Michigan School of Information. The central portal for the GLCCN is currently in-development. It is expected that the Network will launch in late 2014.

Our vision is to create an institute that effectively links science and technology for the sustainable management of water resources. There is a great need for local, state, national and international water resources management decisions and policies to be based on thorough scientific research and multidisciplinary expertise. IWR works across multiple units within the University and with numerous external partners. As water resource issues become more complex, IWR will embrace and strive to enhance its service as a boundary organization by advancing the understanding of wicked problems related to water issues among academia, state partners, NGOs, citizens of Michigan and the global community, and through the research and development of new decision support systems that help address these complex problems.

Methodology

Research Methods/Experimental Procedures

The manner in which we have engaged in team efforts with the scientific community from across campus, the state and region has been effective and provides an approach upon which we can build. As previously mentioned, we have an evolving process which will help us to transform our institute to more effectively address "wicked" problems. The advisory body will be critical in guiding the re-creation of our activities, which will lead to more holistic and effective approaches to addressing "wicked" problems. This transformation may be aided through support and input from various internal individuals and entities, including departments and units within CANR such as the proposed new Department of Natural Resources Ecology and Management, Department or focal area of Sustainable Studies and Biosystems Engineering. In addition, Dr.

Hiram Fitzgerald, Director of University Outreach and Engagement, and colleagues, are refining a community-based systems approach for affecting change in social systems, which IWR may incorporate as a component of this new strategy. These various inputs will guide our initial activities. In addition to its staff members who have expertise in a broad array of water resources management topics, including database development and information systems, GIS, aquatic ecology and community-based water management programming, IWR has historically worked with many diverse faculty members representing a broad cross section of water resources expertise across MSU colleges. A listing of the faculty members and students who have recently worked with and received support from IWR on various water resources management projects was included in a recent report compiled for the Water Resources Partnership, a jointly funded agreement with the Michigan Department of Environmental Quality and MSU.

Our first achievement strategy is to build on and transform current IWR strengths, partnerships, and reputation. By working in a co-creative framework with individuals, policymakers and organizations to integrate the science and knowledge base, IWR is generating adaptive and dynamic systems for management of critical water resources that includes ecological, social and economic components.

(1) Reorganize IWR to more effectively link knowledge with action, i.e., connecting knowledge generation and local applications by becoming an appropriately structured boundary organization. The structure depicted in Figure 1 shows that IWR will not only serve as a critical link between the research and knowledge generated by the scientific community (i.e., entities at the University) and the user community, but will also serve to facilitate the co-creation of knowledge (middle column, Figure 1) by working with the end users (right column) and the scientific community (left column).

(2) Actively be involved in facilitating, leading, demonstrating and evaluating the co-creation process through numerous specific activities involving “wicked” problems. Water resources management with consideration for economic development is a complex or "wicked" problem because it often demands organizations/stakeholders at all levels to come together and find acceptable solutions to issues. Such solutions may also evolve over time when agreed upon by the parties involved. Integrating sciences into this dynamic social process and utilize modern technologies to facilitate communications and problem solving is the grand challenge we face as university researchers and technology transfer professionals. As a boundary organization, our objective is to be uniquely positioned to work across disciplinary boundaries and bring advanced sciences and technologies into decision makers' hands. Since there is a large gap between academic research and real world operational applications, bridging this gap and streamlining research and the technology transfer process is a major task for IWR as a boundary organization. The efficient and effective utilization of modern technologies such as advanced Information and Communication Technology (ICT), GIS and numerical modeling is the key to achieve this objective.

(3) Develop decision support systems that provide support for knowledge users to make more informed decisions based on input from the knowledge generators. As we move from traditional PC-based computing era to a new Internet-based cloud computing age with millions of mobile computing devices coming online at an accelerated rate, we need to conduct further detailed research on how we can develop a new generation of water resources decision support and knowledge systems that can take advantage of recent advances in cyber infrastructure, social networking, geospatial technologies and

numerical modeling and associated scientific visualization technologies. To implement this new generation of systems, we need to analyze the needs of different target audiences such as federal, state and local government agencies, NGOs, various environmental organizations and the general public. As a boundary organization, it's critically important that we bring environmental knowledge producers and consumers together under the same overarching umbrella and provide tools for them to work together in a mutually beneficial manner. We need to understand their needs and concerns and address them appropriately.

(4) Guide development of this new bridging structure through an external advisory body, representing a cross-section of users and scientific groups. This advisory body will have integrative and dynamic roles in providing guidance and ideas to communities of users. The scientists involved will provide connections to clusters of water expertise from the following: multiple units within CANR, such as the Center for Water Sciences and Department of Biosystems and Ag Engineering; other colleges, such as Natural Science and Civil and Environmental Engineering; and, external partners including the USGS Great Lakes Science Center, the Nature Conservancy and others.

(5) Provide an inclusive environment to facilitate a sense of trust among the knowledge users so they can effectively interact with the knowledge generators, creating an atmosphere and functionality where there is successful communication, translation, mediation, and adaptive process outcomes.

(6) Actively inform and partner with NGOs (with emphasis on TNC) and other funding agencies such as EPA, GLPF (Great Lakes Protection Fund), US Army Corps of Engineers, etc., to aid in acquiring support of IWR activities. These partnerships will help to add new funding sources to IWR's existing broad portfolio of funders to facilitate an expanding base of fiscal support.

Literature Review

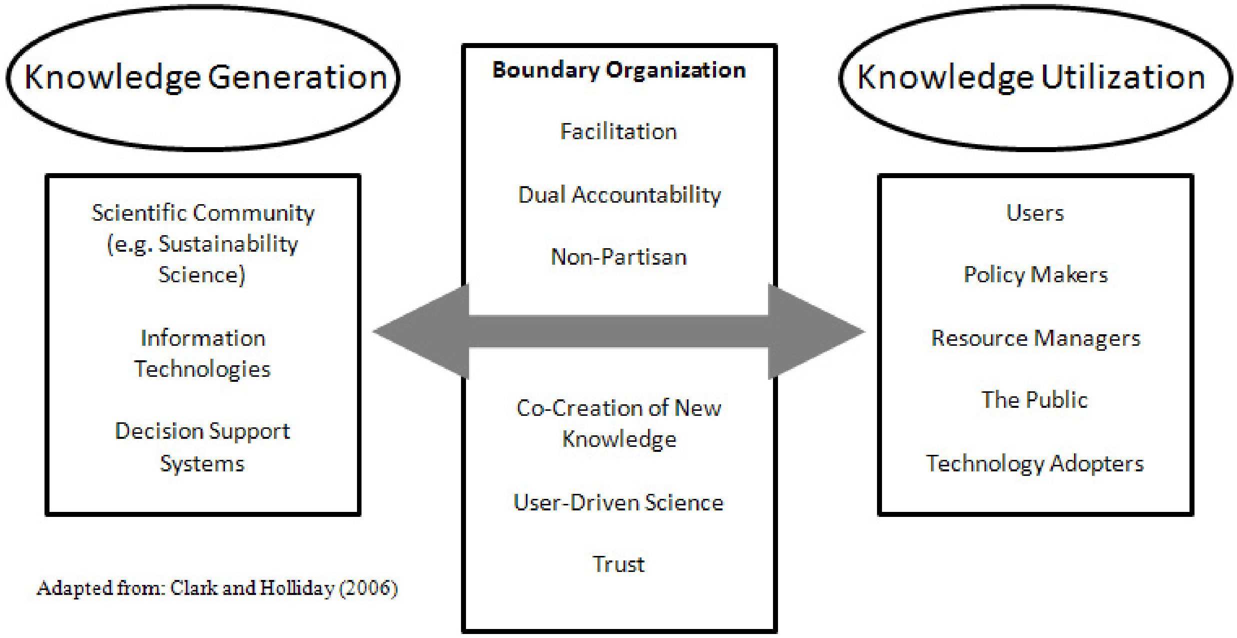


Figure 1. Boundary organization: Linking knowledge with action

All social, economic and environmental factors in a watershed need to be considered in a holistic approach to determine proper actions to manage water resources (Heathcote 1998; Gregersen et al., 2008). Watershed management often involves multiple stakeholders with conflicting interests. These stakeholders can have radically different perceptions of the problems and potential trade-offs associated with finding solutions because of dynamic social, economic, and political factors as well as biophysical complexities of water resources issues. This complex nature of water resource management and other related issues, such as global climate change or health issues, is often referred to in the scientific community as wicked problems (Batie 2008). These types of problems are so named because they are usually difficult to solve due to their complexities and changing nature and often may create other problems as the initial ones are being addressed.

Research on wicked-type problems suggests that a comprehensive knowledge system sustained by a boundary organization is essential (Cash et al., 2003). Boundary organizations act as intermediaries between science and policy because they fulfill or possess: 1) specialized roles within the organization for managing the boundary; 2) clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and 3) a forum in which information can be co-created by interested parties (Cash et al., 2003). Ingram and Bradley (2006) define boundary organizations as those situated between different social and organizational worlds, such as science and policy. Guston (2001) list three conditions often attributed to successful boundary organizations. "First, they must provide incentives to produce boundary objects, such as decisions or products that reflect the input of different perspectives. Second, they involve participation from actors across boundaries. Third, they have lines of accountability to the various organizations spanned by the boundary organization." According to Batie (2008), adaptive and inclusive management practices are essential to the functioning of boundary organizations, and Ruttan et al. (1991) suggests that boundary organizations serve as a bridging institution and help to link suppliers and users of knowledge.

One way to further the efforts of boundary organizations, particularly with wicked problems, is to provide tools to assist with good decision-making using science-based data. Spatial Decision Support Systems (SDSS) are a type of computer system that combine the technologies of Geographic Information Systems (GIS) and DSS to assist decision-makers with problems that have spatial dimensions (Walsh 1993). SDSS are developed to integrate data, knowledge, and modeling results to identify, evaluate, and recommend alternative solutions to spatially distributed problems (Djokic, 1996; Prato and Hajkowicz, 1999). A SDSS focuses on a limited problem domain, utilizes a variety of data, and brings analytical and statistical modeling capabilities to solve the problems. It further depends on graphical displays to convey information to the users. It can be adapted to decision-maker's style of problem solving, and can easily be extended to include new capabilities as needed (Densham et al. 1989, Armstrong et al. 1990).

In natural resource management, SDSS have proven to be effective in a variety of applications such as flood prediction (Al-Sabhan et al., 2003) and conservation program management and best management practices assessment (Rao et al., 2007). Al-Sabhan et al. (2003) argued that a web-based hydrologic modeling SDSS can help solve problems such as limited accessibility by non-experts and the public; lack of collaboration support; and costly data acquisition and communications. They further indicated such system can offer openness, user friendly interface, transparency, interactivity, flexibility, and fast communication and be directly accessible to a broad audience including decision makers, stakeholders and the general public.

Objectives

(1) Reorganize IWR to more effectively link knowledge with action, i.e., connecting knowledge generation and local applications by becoming an appropriately structured boundary organization.
(2) Actively be involved in leading, demonstrating and evaluating the co-creation process through numerous specific activities involving "wicked" problems.
(3) Develop decision support systems that provide support for knowledge users to make more informed decisions based on input from the knowledge generators.
(4) Guide development of this new bridging structure through an external advisory body, representing a cross-section of users and scientific groups.
(5) Provide an inclusive environment to facilitate a sense of trust among the knowledge users so they can effectively interact with the knowledge generators, creating an atmosphere and functionality where there is successful communication, translation, mediation, and adaptive process outcomes.
(6) Actively inform and partner with NGOs and other funding agencies to aid in acquiring support of IWR activities. These partnerships will help to add new funding sources to IWR's existing broad portfolio of funders to facilitate an expanding base of fiscal support.

Plans to Disseminate Information from Stated Research

IWR has effectively worked with a variety of organizations and audiences. This has allowed IWR to build a diverse network of partners. As a complicated and wicked problem, effective water resource management requires solutions from the broad economic sectors it affects. With partners from the university, government, non-government, and private sectors, IWR will receive the input needed to reorganize itself as a boundary organization, bridging the gaps between each of the sectors. IWR will work with its partners and internally to co-create solutions to the complex problems posed by water resource management and disseminate this information through its well established technology transfer program, as well as through its decision support systems, regional networking, social networks and facilitation capabilities. Advisory body inputs will be critically important in defining targets, timelines, and expected impacts. This reorganization can evolve largely within our existing financial and personnel structures.

References

Al-Sabhan W., M. Mulligan and G. A. Blackburn. 2003. A real-time hydrological model for flood prediction using GIS and the WWW. Computers, Environment and Urban Systems, 27(1): 9-32.

Armstrong, M. P., and Densham, P. J. 1990. Database Organization Strategies for Spatial Decision Support Systems. International Journal of Geographical Information Systems, 4(1): 3-20.

Bartholic, J., Y. Shi, K. Maredia, S. Seedang, J. MacDonagh-Dumler. 2010. Institute of Water Research and Institute of International Agriculture, Michigan State University, "Characteristics of an Action Plan for Addressing Emerging Issues in Water Management for Sustainable Agriculture in South Asia Region." Submitted to the Central Soil & Water Conservation Research & Training Institute Research Centre, India for inclusion in Proceedings from the Indo-US Workshop on Emerging Issues in Water Management for Sustainable Agriculture in South Asia Region, December 10-12, 2009, in Udhagamandalam, Tamil Nadu, India. In Press.

Batie, Sandra. 2008. Wicked Problems and Applied Economics. Amer. J. Agr. Econ., 90 (5): 1176–1191, DOI: 10.1111/j.1467-8276.2008.01202.x

Cash, D.W., W.C. Clark, F. Alcock, N.M. Dickson, N. Eckley, D.H. Guston, J. Jäger and R. B. Mitchell. 2003. Knowledge systems for sustainable development. PNAS, 100 (14): 8086–8091.

Clark, W. and L. Holliday. 2006. Linking Knowledge with Action for Sustainable Development. The Role of Program Management. Workshop Summary, Roundtable on Science and Technology for Sustainability, Policy and Global Affairs. National Research Council of the National Academies. Washington, DC; National Academies Press.

Densham, P. J., Goodchild, M. F. 1989. Spatial Decision Support System: A Research Agenda. Proceedings of GIS/LIS '89, Florida, pp. 707-716.

Djokic, D. 1996. Towards general purpose spatial decision support system using existing technologies. In: GIS and Environmental Modeling: Progress and Research Issues. GIS World Books, Ft. Collins, CO.

Gregersen, H., Folliott, P., Brookes, K. 2008. Integrated Watershed Management: Connecting People to their Land and Water. Cabi Publishing. 2008.

Guston, D.H. 2001. "Boundary Organizations in Environmental Policy and Science." *Science, Technology and Human Values,* 26(4): 399–408.

Heathcote I. 1998. Integrated Watershed Management: Principles and Practice. Wiley. 1998.

Ingram H., and B. Bradley. 2006. "Water Sustainability: Policy Innovation and Conditions for Adaptive Learning." Paper presented at the Michigan State University Sustainable Michigan Endowed Project Academy, Dearborn, MI, 18–19 November.

O'Neil, G., J. Bartholic, Y. Shi. 2010. Institute of Water Research, Michigan State University. "High Impact Targeting Decision Support System for BMPs to Most Effectively Reduce NPS Pollution" presented at the 18th National Nonpoint Source Monitoring Workshop held in Milwaukee, Wisconsin November 16-18. Nov. 17, Session 5-03, In Proceedings on CD, 33 pp.

O'Neil, G., L. Theller, Y. Shi, J. Bartholic, B. Engel. 2010. The Swan Creek Watershed Management System," presented by O'Neil at the TMDL 2010: Watershed Management to Improve Water Quality ASABE Conference, Nov. 14-17 in Baltimore, MD. In Press

Prato, T. and S. Hajkowicz. 1999. Selection and sustainability of land and water resource management systems. Journal of the American Water Resources Association, 35(4): 739-752.

Rao, M., Guoliang Fan, J. Thomas, G. Cherian, V. Chudiwale and M. Awawdeh. 2007. A web-based GIS Decision Support System for managing and planning USDA's Conservation Reserve Program (CRP). Environmental Modelling & Software, 22(9):1270-1280.

Ruttan, V.W., D.E. Bell, and W.C. Clark. 1994. "Climate-Change and Food Security—Agriculture, Health and Environmental Research." *Global Environmental Change-Human and Policy Dimensions,* 4(1):63–77.

Steinman, A.D., J.R. Nicholas, P. Seelbach, J. Allan, and F. Ruswick. 2010. The role of science in developing policy for the use of groundwater in the state of Michigan. Water Policy. DOI:10.2166/wp.2010.047.

Walsh, M. R. 1993. Towards Spatial Decision Support Systems in Water Resources. Journal of Water Resource Planning and Management, 119(2): 158-169.

[i] The Water Strategy Proposed Goals and Outcomes are referenced frequently in this paper to highlight water cycle characteristics connections to specific Goals and Outcomes.

Information Transfer Program Introduction

The state of Michigan is fortunate to have an abundant and widespread supply of water due in large part to its geographical location within the Upper Great Lakes Region. The state's many rivers, lakes, and wetlands as well as the Great Lakes support critical habitat, a world class fisheries, and high quality waters. Multiple users utilize these resources for drinking water, recreation, industrial processes, irrigation, and numerous other activities. As these uses continue to grow, the waters of the state become more susceptible to degradation, ecosystem changes, and conflicts with water users. Problems associated with nonpoint source pollutants, invasive species, habitat degradation, climate change, and wetland loss are just a few of the many challenges that Michigan residents and decision makers face. Additionally, water withdrawals from both surface water and groundwater can result in decreased stream flow or reduced lake levels and lead to ecological and human-related problems. Conflicts between irrigators and domestic users may also increase as withdrawals affect well water. These issues are exceedingly complex and sometimes contentious. They require people working together to address these issues with access to good data, human resources, and good science-based knowledge of the situations.

Dissemination, Technology Transfer Training and Program Development

Basic Information

Title:	Dissemination, Technology Transfer Training and Program Development
Project Number:	2013MI221B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Surface Water, Water Quality, Acid Deposition
Descriptors:	Water Quality; Natural Shorelines, Great Lakes, Watershed Management; Invasive Species; Lake and Stream Monitoring; Interactive Web-based Decision Support Systems; Climate Outreach
Principal Investigators:	Lois G Wolfson

Publications

1. Wolfson, Lois and Jane Herbert. 2013. A Michigan Boater's Guide to Selected Invasive Aquatic Plants. MSU Extension Bulletin E-3189. Michigan State University, East Lansing, MI. 28pp.
2. Wolfson, Lois. 2013. Lessons Shared – the Michigan Shoreline Conference, Michigan Natural Shoreline Partnership Newsletter, Vol 3(2): 5-6.
3. Kline-Robach, Ruth. 2013. Michigan State University NPDES Phase II Storm Water Regulations Progress Report for 2011-2013. Submitted to the Michigan Department of Environmental Quality.
4. Kline-Robach, Ruth. 2013.Michigan State University Stormwater Management Program. Submitted to the Michigan Department of Environmental Quality.
5. Fortin, Connie and N. Mulhern. 2013. Michigan's Winter Maintenance Manual: Promoting Safe Roads and Clean Water. Edited by Lois Wolfson. MSU Extension, Michigan State University, East Lansing, MI. 45pp.

General Statement

Problem and Research Objectives

Universities have a positive reputation for providing dependable, accurate and unbiased information to its clientele and partners, by providing science-based data and research results. But, as information from multiple and unverified sources becomes increasingly accessible over the internet, it is critical that Universities continue to provide current, reliable, and readily transferable information to multiple audiences in a variety of formats that are easily understood and easily accessible. It is also essential to work together with these user groups from the initial stages to help move them to effective outcomes. An effective information dissemination program encompasses the transfer of research-based information to a wide and often diverse audience and a variety of alternative solutions, where available, to problems being assessed. It also provides a two-way interaction so that users have a sense of ownership in solving problems within their communities, businesses, schools, or in their livelihood to improve and accelerate innovative solutions to difficult problems. The Institute of Water Research (IWR) at Michigan State University has developed and expanded upon its information dissemination and training program to address the needs of multiple groups and individuals. The objectives of the program are to develop and present educational programs, trainings, and decision support systems designed to not only increase the public's awareness, knowledge and appreciation of the water quality and quantity problems in Michigan but to provide tools, data, and information to address multiple and often complex problems; to stress the environmental and economic trade-offs required to solve real world water related problems; and to promote transformational education that will lead to positive changes for the environment and people of the state.

Methodology

The IWR is able to make its information available to multiple groups, some of who are more comfortable with traditional modes of communications and others who desire the latest available technology. Formats that were used in the offering of programs included computer-based systems, on-site demonstrations, trainings and workshops, conferences, written materials and group presentations. Specifically, modes of delivery included: (1) developing training sessions and workshops to help users understand aquatic ecosystems and water quality issues; (2) creating and delivering lectures/demonstrations and power point presentations (3) developing, organizing and co-coordinating technical and non-technical conferences; (4) developing web-based interactive programs to assess and address potential problems and visualize areas within watersheds; (5) developing webinars and web based self-help tutorials (6) compiling, interpreting, and distributing water related information to appropriate sources of expertise and information; (7) partnering with Michigan State University Extension field and campus educators; and (8) interacting with researchers, agency personnel, other states, and professionals on multidisciplinary.

Principal Findings and Significance

Conferences

Several conferences are held yearly to address key state environmental issues. These conferences reach large audiences and often address multiple issues. Now in its 24th year, the Great Lakes conference presented current research and discussed emerging issues relating to the management and protection of the Great Lakes. The 2013 conference was titled, "The Great Lakes: Science and Stewardship" and addressed water use; walleye resurgence and implications; sturgeon rehabilitation; agricultural practices, public policy, and effects in Lake Erie; changing water levels and infrastructure; the Great Lakes Stewardship initiative; Asian carp, and the muck and multi-stressor problems in Saginaw Bay. Partners with the IWR included Michigan Sea Grant Extension, MSU Department of Fisheries and Wildlife, and the Office of the Great Lakes, Michigan Department of Environmental Quality (MDEQ). Conference evaluations indicated that many attendees were returning participants who have direct connections with the Great Lakes, either through their work or through teaching. The conference was attended by nearly 200 people and included state and local agency personnel, researchers and educators, environmental organizations, and interested citizens. About 94% of the evaluations rated the conference as high or very high in terms of what it offered, and many participants indicated that they would use the information gained at the conference in their classrooms or in their work.

The IWR co-sponsored the Michigan Shoreline and Shallows conference focusing on Natural Shorelines and the Habitat Connection. The conference featured examples of work being done at the Chicago Botanical Gardens on natural shorelines and provided presentations on Quantifying the Ecological Benefits of Shore land Restoration; High Energy Sites, Vegetation and Stabilization; and Balancing Native Plant Selection and Design with Fluctuating Lake Levels. The conference is jointly sponsored and led by the Michigan Natural Shoreline Partnership, IWR, and Michigan Department of Environmental Quality. Several other NGOs are contributors. By offering CEU units to certified shoreline professionals attending the meeting, the conference helps keep contractors up to date on new and improved methods for bioengineering. Nearly 100 people took part in the conference.

Lake and Stream Leaders Institute

A newly revised Lake and Stream Leaders Institute took place in 2013 and included in-classroom lectures, homework, field experiences, and a project completed by the students. The Institute has been in existence for over 12 years and consists of intensive on-site training on leadership and water issues. IWR has maintained a significant role in both the development and implementation of this program and provided key resources this year. This year, 92% of participants rated combined the field and lectures sessions during the multi-day session as very or extremely helpful. One participant wrote, "Because of the hands on activities and shoreline tour, this is the most beneficial session so far. The morning speakers/presentations were all very informative and easy to comprehend."

A new program initiated with the main funding coming through another grant was the development of three on-line modules that will be incorporated into the Lake and Stream Leaders Institute and other Great Lakes states' Watershed Academies. Use of the module by other states will increase visibility of MSU while the free interchange of modules with other states will broaden the scope of the individual programs. IWR's contribution was an online module on Developing a Volunteer Monitoring Program (http://volunteermonitoringprograms.weebly.com/)

Aquatic Ecology Training

The IWR took part in a number of trainings to assist local decision makers, agency personnel, riparians and other interested citizens with tools and information concerning land and water ecosystems. These included: the Michigan Conservation Stewards Program, Kalamazoo Ag Action Day, and the Oakland County parks lakes program. The MSU Extension Inland Lakes Program was revamped and recorded for future use. IWR staff took the lead on the Aquatic Plants Module.

Internet-Based Programs Using Decision Support Tools
The IWR continues to be a leader in the development of decision support tools to assist users with making more informed science based decisions through the aid of computer models, GIS, extensive data, and visual programs. Multiple funding sources have contributed to their development, updating, and maintenance. Ongoing projects with decision support include: Flint River Nutrient Reduction: Focusing Action: http://elucid.iwr.msu.edu/; the Great Lakes Clean Communities Network: http://greatlakescleancommunities.weebly.com/; the Mid-Michigan Health Impact Assessment Toolkit: http://35.8.121.111/hia/ and the Great Lakes Water Management System: http://35.8.121.111/glwms/Map.aspx. Staff employees are continually upgrading the software, incorporating new models, and writing code to enable seamless entry to other web programs such as Bing maps, Google Earth, and social networks. IWR staff members are also in the process of creating "apps" for use by agricultural producers and technicians in the field. The IWR also produces and maintains an on-line newsletter, *The Watershed Post*. This electronic newsletter provides current information on Institute activities as well as general articles of interest. Contributions are made by faculty, staff, and students.

Climate Outreach and Water
The IWR assisted in the planning, production, and presentation of a webinar that featured web-based computer programs and models that can be used in helping to address water and climate change in urban settings and the other focusing on sustainable communities and water issues relating to climate change. Overall 240 registrants took part in the Climate Tools Café 2 Webinar. Of those submitting evaluations, 84% agreed or strongly agreed with the statement: Because of the webinar, I gained information that will help me do my job better and 88% agreed or strongly agreed with the statement: Because of the webinar, I learned something I will share with others. IWR also played a major role in the development of a short course on Climate Change and Sustainability. Fifty attendees completed the 40 hour web-based course.

Invasive Aquatic Plant Species Guide
IWR staff co-authored a booklet on a boater's guide to selected invasive aquatic plants. In coordination with MSU Extension, the boater's guide identified key invasive species, provided illustrations, location information and possible treatments. Plants featured were either already in Michigan or had the potential to invade Michigan waters. About 700 copies of the booklet were purchased by the MDEQ and distributed as part of the State's Cooperative Lakes Management Program. Another 200 were distributed at a Lakes Convention. The remaining copies were placed in the MSU Extension bookstore.

Exhibits and Demonstrations
The IWR takes part in a variety of University sponsored events along with several nonprofit campus events. Each year the IWR features an educational exhibit that highlights one or more areas of water quality protection during the University's Ag Expo. The event draws over 20,000 people during the 3-day event, and about 20% pass through the tent where IWR is housed. The

IWR also participated in events that showcased the University's role in science based education. These included: Michigan Science Olympiad's Water Quality State Finals, Children's Water Festival, Grandparents' University, Autumn Fest, and the annual FFA competition event. The IWR also took part in MSU's Science Festival, a 10-day celebration that featured a variety of science subject areas. The goal of the event was to bring mid-Michigan communities together with MSU scientists to explore science and how it affects everyday life.

Lectures and Seminars

Lectures in the classroom, presentations at other conferences, and seminars were provided by IWR staff members throughout the year to outside groups on issues relating to IWR Decision Support Systems including a presentation on Co-Creation and Adaptation of Tools for New Purposes & Audiences: Great Lakes, Gulf, Upper Mississippi, at the Midwest Spatial Decision Support System Partnership Conference in Chicago; Invasive aquatic species presented to an MSU class on Water Resources Management; Protecting Public Groundwater Using the Michigan Groundwater Management Tool presented at the Michigan Water Environment Association Annual Meeting and other topics such as volunteer stream monitoring, lake and stream ecology, and pond management. Audience or class participation ranged from approximately 25 to over 100 for each presentation.

Building Capacity within Township Planning Commissions to Facilitate Water User Committees in the context of Michigan's Water Withdrawal Assessment Program

Basic Information

Title:	Building Capacity within Township Planning Commissions to Facilitate Water User Committees in the context of Michigan's Water Withdrawal Assessment Program
Project Number:	2013MI223B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	8
Research Category:	Social Sciences
Focus Category:	Groundwater, Water Use, Management and Planning
Descriptors:	groundwater management, yield estimation, irrigation potential mapping, local planning
Principal Investigators:	David Lusch

Publications

There are no publications.

Title: **Revised –** Statewide Groundwater Yield Estimates for Improved Mapping of Agricultural Irrigation Potential. OLD - ~~Building Capacity within Township Planning Commissions to Facilitate Water User Committees in the context of Michigan's Water Withdrawal Assessment Program~~
Project Number: 2013MI223B
Start: 03/1/2013
End: 02/28/14 (actual)
Funding Source: USGS ("104B")
Congressional District: eighth
Research Category: Information Transfer
Focus Categories: Groundwater, Water Use, Management and Planning
Descriptors: groundwater management, yield estimation, irrigation potential mapping, local planning
Primary PI: Dr. David Lusch, Senior Research Specialist, Michigan State University, lusch@msu.edu, 517-355-8497

Project Class: Information Transfer

Introduction

Michigan statutes passed in 2006 developed the Water Withdrawal Assessment Program which regulates large-quantity groundwater withdrawals by assessing their potential impact on streamflows. The 2006 statutes (enacted as Part 327 of Act 451) also recommended the creation of community water user committees to evaluate the status of local current water use and water resources and to assist in long-term water resource planning. To date, however, no water user committees have been established and it is unclear just how to set these committees up, let alone facilitate their functioning. However, during the early phase of this project, a major study of agricultural irrigation potential in Michigan was released and its results strongly suggest that capacity building for township planning commissions need to follow a revision of the groundwater yield map. In light of this irrigation potential report, **this USGS 104B project is being redirected to a new, more critical objective.**

General Statement

Problem and Research Objectives

Subsequent to the development of the original project scope, a new study was completed by a colleague in the Agricultural and Biosystems Engineering Department at Michigan State University. Using GIS, Steve Miller, PE, analyzed hydrologic soil groups, surface slopes and estimated groundwater yields within existing croplands to map the potential for new agricultural irrigation systems throughout Michigan. However, when irrigators from key areas of the State reviewed the draft results of this first-of-its-kind irrigation potential study, they consistently pointed out local areas were the groundwater yield data were erroneous and needed to be updated to reflect actual aquifer conditions. New well data are available now that were not in the MDEQ *Wellogic* database when the original groundwater yield estimates were completed.

This revised project will process the existing, Enhanced *Wellogic* data set to reconstruct transmissivity and yield map products for the glacial and bedrock aquifer systems of

Michigan using the general processing approach originally developed in 2005 as part of the MDEQ Groundwater Inventory and Mapping (GWIM) Project. The digital water well database used in the GWIM Project contained about 283,000 records. The current *Wellogic* database contains more than 530,000 records, all of which have improved lat/lon locations as the result of a geocoding project completed by the State of Michigan.

As a result of the increased amount of better-located data, the revised maps of the estimated aquifer yield for both the bedrock and glacial aquifer systems in Michigan will be much more accurate than the first versions. To ensure the best practices are employed, MSU project staff will meet with personnel from the MDEQ, Office of Drinking Water and Municipal Assistance and the USGS Water Science Center in Lansing to review and finalize the processing protocol. The resulting map products will be in a standard GIS format (ESRI shapefile) and made available to the public through the State of Michigan Geographic Information Library.

The GIS model developed by Steve Miller is available and the improved groundwater yield map can be easily incorporated into it. Mr. Miller has committed a portion of his MSU Extension appointment to re-running the Irrigation Potential model after the updated groundwater yield data are incorporated. Re-mapping the aquifer yields will significantly improve the GIS estimates of irrigation demand, thus providing potential large volume water users, local governments, planners and regulators with much better information upon which to base their decisions.

<u>Methodology</u>

In the Enhanced *Wellogic* dataset, effective hydraulic conductivity (K) values are assigned to each water well record through a recently improved automated process that was originally developed during the GWIM Project. The revised process uses the K value assigned to each lithologic layer described on the water well record by table look-up based on the surficial glacial landsystem for the area, the primary lithologic description for each interval, and the lithologic modifier, if present. By summing the individual strata K values and dividing by the summed thickness, an equivalent horizontal hydraulic conductivity (K_h) for each well is calculated. Once K_h values are obtained, the saturated thickness described on the water well record is used to calculate an aquifer transmissivity (T) for the well. For glacial wells, T values are calculated by two methods – one based on the saturated thickness from the bottom of the well up to the static water level and the other based on the saturated thickness from the bottom of the well to the bottom of the first, significant confining unit described on the water well record. For bedrock wells, T values are calculated on the basis of a saturated thickness measured from the bottom of the well up to the top of bedrock.

A simple analytical equation (the Theis solution) will be used to estimate the pumping rate that would be required to lower the hydraulic head at each well to fifty percent of the available drawdown after 100 days of pumping. This estimated yield is computed using the transmissivity and saturated thickness values for each well point and a fixed storativity value of 0.0016 (typical of a leaky-confined aquifer). Ordinary Kriging will be employed to interpolate these estimated yield point values to 1000 m x 1000 m grids.

Principle Findings and Significance

No findings to date. The project scope and methodology has been significantly revised to respond to new opportunities.

The current Enhanced *Wellogic* data set contains about 33% more data which is more accurately located than the *Wellogic* data set used by the GWIM Project. The availability of these data will significantly improve the GIS estimates of irrigation demand, thus providing potential large volume water users, local governments, planners and regulators with much better information upon which to base their decisions.

Mr. Miller has committed a portion of his MSU Extension appointment to re-running the Irrigation Potential model after the updated groundwater yield data are incorporated. In addition, he will be responsible for outreach dissemination of the results of the revised irrigation potential mapping as part of his planned Extension work in the upcoming fiscal year.

Notable Achievements

Re-scoping the project. Securing a commitment for additional funding through the Michigan State University AgBioResearch.

Publications

None to date.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	3	0	0	1	4
Ph.D.	2	0	0	4	6
Post-Doc.	0	0	0	0	0
Total	7	0	0	5	12

Notable Awards and Achievements

Title: Winter Maintenance of Roads Training Workshop: Best Practices to Ensure Safe Roads and Reduce Environmental Impacts

Brief: The Winter Maintenance training program was a multi-state program, where we utilized what had been developed in another state (Minnesota) as a base for developing a program and training manual in Michigan. The program was endorsed and supported by the Michigan Department of Transportation (MDOT). They helped in the trainings, provided input to “Michiganize” the Minnesota Road Maintenance Manual, and supported the water quality sections within the manual. When completed, the Manual was adopted for use by MDOT and 200 copies were distributed to personnel. Road Commission staff, private contractors, and public works personnel indicated that they would be incorporating a portion of what they learned during the training in their daily operations.

Funding Agency: USDA National Institute of Food and Agriculture

Jon Bartholic and IWR received an Education & Public Service Award 2013, presented by The Board of Directors of the Universities Council on Water Resources acknowledging the vision and leadership in advancement of water resources education and public service. 12 June, 2013.

Ruth Kline-Robach, Outreach Specialist in the Department of Community Sustainability and Institute of Water Research, received the 2013 Groundwater Management Professional of the Year award from the Michigan Water Environment Association at its annual conference this past summer. The award recognizes individuals for efforts in promoting activities and professionalism in groundwater management and groundwater protection issues.

Publications from Prior Years