BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
WATER QUALITY STANDARDS AND	)	
EFFLUENT LIMITATIONS FOR THE	)	R08-9
CHICAGO AREA WATERWAY SYSTEM	)	(Rulemaking - Water)
AND THE LOWER DES PLAINES RIVER:	)	
PROPOSED AMENDMENTS TO 35 Ill.	)	
Adm. Code Parts 301, 302, 303 and 304	)	

PRE-FILED TESTIMONY OF ADRIENNE D. NEMURA

This report presents the opinions that I, Adrienne D. Nemura, P.E., am submitting to the Illinois Pollution Control Board related to the comprehensive water quality standards proposal by the Illinois Environmental Protection Agency (IEPA). IEPA is proposing to update the designated uses and criteria for the Chicago Area Waterway System (CAWS). My opinions address IEPA's failure to consider the need for wet weather water quality standards for the CAWS in the agency's proposal.

I am a Vice President and an Owner of LimnoTech, an environmental consulting firm with headquarters in Ann Arbor, Michigan. I am a licensed Civil Engineer and have 24 years of experience evaluating impacts of pollutant sources on watersheds and waterways. Specifically, I have focused the last 11 years on evaluating the impacts of sewer overflows on water quality and development of appropriate control measures to meet water quality standards. I have worked for numerous municipalities on combined sewer overflow (CSO) control plans and have supported the United States Environmental Protection Agency (US EPA) in developing guidance documents, training materials, and Reports to Congress on these issues. This work has included assessment of CSO impacts, evaluation of CSO control alternatives, preparation of long-term control plans, and review and revision of water quality standards, including use attainability analyses (UAAs).

My education, registrations, professional appointments, professional affiliations, and specific projects and publications are included in Attachment 1. My experience includes chairing a scheduled workshop at WEFTEC 2008 in Chicago on development of new "pathogen" criteria and expert assistance to the National Association of Clean Water Agencies in the Beach Act case.

Overview

It is my professional opinion that IEPA improperly established standards for aquatic life and recreational uses in the CAWS because the agency did not demonstrate that the uses are attainable when the system is impacted by wet weather discharges. The CAWS is unique as the system was designed and is operated to receive and transport wet weather discharges including runoff from tributaries, CSOs, pump station bypasses, and stormwater runoff to prevent flooding and other impacts in the Chicago metropolitan area.

IEPA failed to demonstrate that the proposed standards can be met despite wet weather discharges today and in the future, even if additional treatment is provided. The proposed standards are therefore premature and if adopted, should include a provision for exemptions to the standards due to wet weather conditions. In particular, a provision is needed to inform the public that the waterways should not be used for recreation when impacted by wet weather discharges. Furthermore, the agency should address the impacts of these discharges on attainability of the proposed aquatic life standards. Specific opinions are provided below.

1. By deferring promulgation of criteria for recreational uses, Illinois EPA has not established that the recreational uses will be attained when wet weather discharges occur.

Section 101(a)(2) of the Clean Water Act establishes a national goal that "wherever attainable", water quality standards shall be set to protect aquatic life and recreational uses. Section 303(c)(2)(A) directs that new or revised standards "shall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses." The criteria are used for decisions about identifying impairments, notification of beach closures, NPDES permitting, and development of Total Maximum Daily Loads.

The agency did not include "a numeric bacteria standard to protect recreational activity" (IEPA, 2007, p. 24) and "defer setting numerical standard for bacterial parameters for all three of the proposed recreational use designations" (IEPA, 2007, p. 42). IEPA instead proposed a technology-based effluent disinfection requirement to "assure that disinfection technologies are functioning properly" at wastewater treatment facilities so that the recreational uses can be met (IEPA, 2007, p. 92). IEPA states, however, that:

> "it is clear that as a result of CSOs during wet weather, any level of recreational activity in the waterway is unhealthy during periods when raw sewage is present. Until completion and operability of the reservoir phase of the Tunnel and Reservoir Project system, numerous CSO discharges will continue to produce highly elevated bacterial levels that likely create an unacceptably high health risk for recreational activity during and immediately following these periods. While there may be an argument that most of the current recreational activity may be reasonably attained during dry weather, conditions under wet weather are clearly incompatible with recreational activity and the recreational use is not being attained during those conditions at any reasonably acceptable risk level" (IEPA, 2007, p. 45).

IEPA has failed to define "dry weather" or what recreational activity can be attained at different locations or different times along the CAWS. The agency has not demonstrated that it assessed how CSOs and other wet weather discharges prevent attainment of the designated uses along the waterways, during or after a wet weather event. Attachment 2 provides a description of the impact of the CSOs, pump station bypasses, and tributary runoff on bacteria levels in the CAWS. This information shows that the magnitude, frequency and duration of the CSO impact on bacteria levels vary from location to location and from storm to storm. In some instances, these impacts are calculated to last several days after wet weather discharges have ceased.

It should be noted that there has been long-standing concern (as well as confusion) over the validity and implementation of US EPA's 1986 bacteria criteria (ASIWPCA, 2005). Nevertheless, States have adopted, with US EPA approval, numeric water quality criteria for both primary and secondary contact recreation. Several states have retained numeric criteria for recreational uses while recognizing the need for wet weather exemptions due to CSOs. Examples are provided in Attachment 3. If no regulatory target is provided to address wet weather conditions, the public will not know when the water is safe for recreation and when it is not, and decisions about appropriate levels of control for sources other than wastewater treatment facilities will be arbitrary. The District has completed a human health risk assessment for conditions during dry and wet weather and is in the process of completing an epidemiological study of the waterways. These results should be considered by the agency in any proposed revisions to the designated uses so that the standards reflect the potential health risks associated with recreation in the waterways.

2. IEPA did not evaluate the impact of wet weather discharges on aquatic life or whether the proposed standards could be met when the CAWS are impacted by wet weather.

IEPA established two new aquatic life uses (A and B) for the CAWS to maintain populations "that are adaptive to the unique physical conditions, flow patterns, and operational controls necessary to maintain navigational use, flood control, and drainage functions of the waterway system" (IEPA, 2007, p. 46). The distinction between the two definitions is that Use A waters include "tolerant and intermediately tolerant types" and Use B waters include "tolerant" types that have adapted to "deep-draft, steep-walled shipping channels." For both uses, a daily minimum dissolved oxygen of 3.5 mg/l and a 7-day mean of daily minima of 4.0 mg/l is proposed for when early life stages are absent. For Use A, a daily minimum of 5.0 mg/l is proposed as necessary to protect early life stages from March to July.

In establishing these uses and the associated criteria, IEPA (and the UAA upon which the standards are presumably based) did not address the effects of intermittent low dissolved oxygen as a result of wet weather discharges, even though these effects were recognized as being present in the UAA (CDM, 2007). Ample continuous monitoring data and receiving water quality modeling information exists that shows that wet weather discharges will cause the dissolved oxygen to drop below the proposed criteria. Alp and Melching (in press) identified that precipitation and duration of storm effects on low dissolved oxygen levels in the CAWS are well correlated. The magnitude, frequency and duration of these low dissolved oxygen conditions varies from location to location and storm to storm as shown in Attachment 4.

IEPA did not identify the species of fish or benthic organisms that will benefit from the proposed changes nor did the agency identify whether these species are adversely impacted by periodic wet weather events. Furthermore, IEPA did not identify the magnitude, frequency or duration of low dissolved oxygen events that could be tolerated by these species. Data from the District's continuous dissolved oxygen monitoring network shows that the magnitude, frequency, and duration of the CSO impacts varies from location to location and from storm to storm. These data show that the dissolved oxygen can get very low (zero to two milligrams per liter) at times and these impacts can last several days to a week at some locations.

As stated in testimony of Samuel Dennison, the ability of fish to avoid the low dissolved oxygen segments may explain the lack of frequent fish kills throughout the system in spite of dissolved oxygen levels that routinely drop below IEPA's proposed minimum criteria of 3.5 mg/l. These conditions are likely to remain as long as there are wet weather sources. For example, as shown in Attachment 4, low dissolved oxygen levels are likely to remain even if the gravity CSOs could be eliminated due to pump station discharges, sediment resuspension, stormwater runoff, and tributary loads.

3. IEPA did not evaluate whether provisions could be designed to protect the proposed aquatic life and recreational uses when the CAWs are impacted by wet weather.

In research on UAAs, Freedman et al (2007, p. 1-4) notes that wet weather sources "create unique issues in the context of meeting water quality standards because of the difficulty of tracking these sources and the expenses associated with controlling them…therefore, having realistic attainable standards as the regulatory target is critical." US EPA's guidance on using flow duration curves in Total Maximum Daily Loads, for example, specifically mentions that criteria could explicitly state applicability under certain conditions (e.g., dry weather or 7Q10 flow) to reduce the importance of the criteria during conditions such as wet weather (US EPA, 2007, p. 12). IEPA did not document that it considered the need to establish realistic attainable targets for wet weather conditions in its proposed rulemaking.

Furthermore, a key principle of the 1994 CSO Policy is "[r]eview and revision, as appropriate, of water quality standards and their implementation procedures when developing CSO control plans to reflect site-specific wet weather impacts of CSOs" (59 FR 18688). In response to directives from Congress, US EPA developed guidance in 2001 for coordinating water quality standards reviews for water bodies where long-term CSO control plans will be implemented because "implementation of this principle has not progressed as quickly as expected" (US EPA, 2001, p. i).

IEPA indicates that the proposed dissolved oxygen criteria cannot be met during wet weather. IEPA states:

> "The existing Secondary Contact and Indigenous Aquatic Life dissolved oxygen standards applicable to these waters are 3.0 mg/L in the Calumet-Sag Channel and 4.0 m/l in the rest of the waters, and are frequently violated during wet weather periods. During periods when wet weather causes CSO discharges to impact the CAWS and Lower Des Plaines River, dissolved oxygen levels can drop to zero. Similarly, at least until the Tunnel and Reservoir Project is complete in 2016, it is highly likely the proposed dissolved oxygen standards will be violated" (IEPA, 2007, p. 61).

IEPA should have considered the wet weather discharges in this standards review given that the District has an approved plan —the Tunnel and Reservoir Project – for controlling CSOs. As described in US EPA (2001), one of US EPA's goals in developing the water quality standards' review guidance was "for states to review and revise water quality standards as appropriate to ensure they are attainable." US EPA identifies a number of options that states can pursue in adopting standards that recognize the impact of wet weather discharges. These approaches include segmenting the water body; adopting subclasses to recognize intermittent exceedances of criteria or physical characteristics and/or ecological systems; and high flow cutoffs.

Several states have modified their water quality standards to reflect the challenges associated with attaining uses during wet weather (Freedman, 2007, p. ES-5). Examples include state legislation in Indiana, Maine, and Massachusetts as described in Attachment 3. Indiana allows for a temporary suspension of the recreational uses if CSO discharges are in accordance with an approved long-term control plan and a UAA. Massachusetts allows for a partial use designation for recreational or aquatic life uses with a UAA or a variance. Maine allows for a CSO subcategory where recreational and aquatic life uses may be temporarily suspended.

Several UAAs have also been conducted that allow for suspension of recreational uses due to wet weather discharges (Attachment 3).

The District has made a significant investment in developing a water quality model that can be used to assess the attainability of both proposed recreational uses and aquatic life uses, and this could readily be applied to ascertain the conditions that are caused by wet weather. The appropriate path for establishing attainable uses for the CAWS would be to apply this model to distinguish the effects of dry and wet weather sources; use the results of the human health risk assessment and epidemiological study; assess information from ongoing aquatic life and habitat research; and assess the economic and social impact to identify the controls necessary to attain the proposed standards.

Respectfully submitted,

By: Adrienne Nemura

Testimony Attachments

1. Adrienne D. Nemura curriculum vita
2. Description of the impact of the CSOs, pump station bypasses, and tributary runoff on bacteria levels in the CAWS
3. Examples of wet weather water quality standards
4. Description of the impact of gravity CSOs and other wet weather discharges on dissolved oxygen levels in the CAWS
5. Alp, E. (2006)

REFERENCES

Alp, E. (2006). "A method to evaluate duration of the storm effects on in-stream water quality." Ph.D. Thesis, Department of Civil and Environmental Engineering, Marquette University, Milwaukee, WI.

Association of State and Interstate Water Pollution Control Agencies (ASIWPCA) (2005). Pathogen Criteria White Paper. ASIWPCA Water Quality Standards Taskforce. Nov. 4.

CDM. (2007). Chicago Area Waterway System Use Attainability Analysis. 8-01-07 edits version. http://www.ipcb.state.il.us/documents/dsweb/Get/Document-59252/ Accessed Jan. 2008.

Freedman, P. and T. Dupuis, et al (2007). Factors for Success in Developing Use Attainability Analyses. Water Environment Research Federation. 04-WEM-1.

IEPA. (2007). Statement of Reasons in the Matter of Water Quality Standards and Effluent Limitations for the Chicago Area Waterway System and the Lower Des Plaines River: Proposed Amendments to 35 Ill Adm. Code Parts 301, 302, 303, and 304.

US EPA (2001) Guidance: Coordinating CSO Long-Term Planning With Water Quality Standards Reviews. EPA-833-R-01-002. http://www.epa.gov/npdes/pubs/wqs_guide_final.pdf

US EPA (2007) An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. August.

Attachment 1

Adrienne D. Nemura, P.E.

Vice President
LimnoTech

Principal Expertise

- Tackling Wet Weather Problems (CSO, SSO, Stormwater, Peak Municipal Treatment Plant Flows)
- Expert Monitoring and Modeling for Water Resource Decisions
- Developing and Reviewing TMDLs and Use Attainability Analyses
- Negotiating Fair & Effective NPDES Permits
- Expert Support for Litigation and Consent Decrees
- Technical & Policy Support to Local Governments

Education

MS	Civil Engineering Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1986
BS	Civil Engineering Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1984

Registration/Certification

Professional Engineer, Michigan, 1999 (#46150)

National Council of Examiners for Engineering and Surveying (#24958)

Experience Summary

Ms. Nemura manages LimnoTech's services for providing creative solutions for permits and water quality regulations. She has 24 years of experience evaluating impacts of pollutant sources on watersheds and waterways, is active in several national organizations, and is a routine speaker at national conferences on water quality issues.

Ms. Nemura works for municipalities, industries, state and federal regulatory agencies, and attorneys on a wide variety of environmental engineering projects. For example, she has:

- Assisted a utility in implementing the country's first wet weather Consent Decree based on the principles of watershed management;
- Provided training for US EPA, States, and municipalities on the national Combined Sewer Overflow (CSO) Policy and provided expert assistance to numerous municipalities in complying with the Policy;
- Directed water quality strategy discussions and monitoring and modeling programs for a significant number of wastewater treatment plants and CSO communities; and
- Assisted municipal and industrial clients in reviewing TMDLs, assessing water quality standards compliance, obtaining fair and cost-effective permit limits, and serving as an expert witness in litigation.

While at the Virginia Water Control Board, Ms. Nemura was responsible for pollution control for the James and Appomattox Rivers. At the Metropolitan Washington Council of Governments, she represented a large constituency of regulated parties and directed the region's water resource programs.

Professional and Academic Appointments

Vice President Apr. 2007 – Present	LimnoTech Ann Arbor, Michigan
Senior Manager Jul. 2003 – Apr. 2007	LimnoTech Ann Arbor, Michigan
Senior Environmental Engineer Aug. 1997 – Jun. 2003	Limno-Tech, Inc. Ann Arbor, Michigan
Water Resources Program Director Jan. 1997 - Aug. 1997	Metropolitan Washington Council of Governments Washington, DC
Chief, Water Quality Management & Administrative & Technical Services 1992 - 1996	Metropolitan Washington Council of Governments Washington, DC
Section Manager, Water Quality Modeling and Technical Support 1991-1992	Metropolitan Washington Council of Governments Washington, DC
Senior Environmental Engineer 1990-1991	Metropolitan Washington Council of Governments Washington, DC
Environmental Engineer 1988-1990	Metropolitan Washington Council of Governments Washington, DC
Water Resources Engineer 1986-1988	Virginia Water Control Board Richmond, Virginia
Cooperative Education Student 1981-1984	GKY and Associates, Inc. Roanoke and Springfield, Virginia

Professional and Service Organization Affiliations

National Association of Clean Water Agencies (NACWA), 2002 – Present.

NACWA Emerging Contaminants Workgroup, 2006 – Present.

Water Environment Federation (WEF), 1998 – Present.

WEF Secondary Treatment Water Quality Workgroup, 2008 – Present.

American Society of Civil Engineers, 1984 – Present.

Chi Epsilon, 1980 – Present.

Charter Member. Avis Farms Toastmasters, 2001 - Present.

Board Member. Therapeutic Riding, Inc. 2004 - Present.

Selected Experience

Regulatory Support

Water Quality Regulations Support for the Chairman of the ORSANCO POTW Committee. Expert review of proposed revisions to water quality standards and development of a bacterial TMDL for the Ohio River. (Apr. 2008 - Present, <5%).

Advisory Panel for National Association of Clean Water Agencies v. EPA in the BEACH Act Case. 2:2006cv04843. Assist NACWA's counsel and expert witness in preparing testimony and negotiating a multi-party settlement agreement (Jul. 2007 – Present, <5%).

Member, Strategic Advisory Team for Sanitation District No. 1 of Northern Kentucky. Provide strategic advice to the District on development of watershed plans to meet the requirements of the country's first consent decree for CSOs and SSOs that is based on the watershed approach (Jun. 2006 – Present, <5%).

Expert Witness for Northeast Ohio Regional Sewer District. Successfully represented the client in demonstrating that an extensive data collection program proposed by EPA was not needed for making decisions about the adequacy of the District's CSO long-term control plans. Case No. 1:07 CV 23(Feb. to Mar. 2007, <5%).

Factors for Success in Developing Use Attainability Analyses. Senior engineer on research for the Water Environment Research Federation on successes and failures associated with UAAs, particularly for wet weather, urban, effluent dependent and effluent dominated water bodies. (Feb. to Nov. 2006, <5%).

Expert Witness for Colorado Springs Utilities. Analyzed information to assess water quality impacts associated with SSOs and spills of reclaimed water. (Jun. 2006 – Feb. 2008, <5%).

Review of Proposed Revisions to the District of Columbia's Water Quality Standards. Senior Manager for review and comment on the proposed changes to water quality standards that address Federal criteria for bacteria, dissolved oxygen, clarity, and chlorophyll *a*. (Jan. 2005 to Oct. 2005, <5%)

National Combined Sewer Overflow Policy Support 1999 to Mar. 2007. Senior Engineer involved in the development of **guidance manuals and training** for the combined sewer overflow policy. Assisted in the development of the guidance manual **Review of Long-Term Control Plans** (10/01-2/02, 2%) to assist federal and state regulatory agencies in approving long-term control plans. Conducted training for EPA and state water quality agencies in Indianapolis, IN (2/02), Harrisburg, PA (3/02), Chicago, IL (7/03), Buffalo, NY (10/04), Albany, NY (11/04), Philadelphia (12/04), and Covington, KY (9/05) on developing and reviewing LTCPs. **Reviewed two LTCPs for state regulatory agencies** in Ohio (8-9/06) and one for Illinois (3/07). Member of a senior technical team responsible for reviewing development of the EPA guidance document for **Coordinating CSO Long-term Control Planning with Water Quality Standards Reviews** (5/00-6/01, 2%). Presented the receiving water monitoring and modeling chapters of the EPA guidance manual on **CSO Monitoring and Modeling** in Washington, PA (9/99). Provided training on conducting CSO and SSO inspections in Chicago, IL (11/03). Author of a chapter on the resources spent on sewer overflows for the **2004 Report to Congress on the Impacts of CSOs and SSOs** and senior reviewer of remaining chapters (3/03 – 7/04). Provided senior review of development of case studies for the EPA **Report to Congress on the Status of Long-term Control Plans** (4/01-6/01, 2%).

Administrative Record Review for a Draft NPDES Permit for the Washington Aqueduct Water Treatment Plant in Washington, D.C. Project manager supporting EPA Region 3 in a confidential administrative project for establishing permit conditions for the Aqueduct for total suspended solids and aluminum. Managed potential conflict-of-interest issues for LTI. Co-authored a report summarizing EPA's best professional judgment for establishing permit limits and assisted EPA in responding to comments. (Oct. 2002 – May 2003, 4%)

Mica Bay, Idaho – NPDES Storm Water Case Development Support. Project manager supporting EPA Region 10 in a confidential enforcement case against the Idaho Transportation Department and its contractor. Developed an efficient work plan to accommodate limited time and resources, directed work, and provided senior review of the report. (Nov. 2002 – Jan. 2003, 15%)

Preparation of SSO Case Studies for EPA to Assess the Effectiveness of Abatement Efforts and Regulatory Programs. Provided senior review and guidance on the development of three case studies on sanitary sewer overflow (SSO) abatement across the United States. EPA is using the results of the case studies to formulate an SSO control policy (Oct. 1997 – May 1998, <2%).

Virginia State Water Control Board Pollution Response Team. 1986-1988. Team member responding to a variety of water pollution problems ranging from investigation and remediation of oil spills, leaking underground storage tanks, and fish kills.

Combined Sewer Overflow and Collection System Studies

Development of a CSO LTCP for the City of Ottawa, IL. Senior manager assisting a small city and their engineer in updating their LTCP to respond to changing regulatory requirements. Assisting in regulatory negotiations, development of a receiving water monitoring program, water quality assessment, collection system model, and LTCP development for a community of 18,000 people. (Nov. 2007 to present, <5%).

Water Quality Assessment Services for Updating the CSO LTCP for the Louisville Jefferson County Metropolitan Sewer District. Project manager for development of a water quality data report, Ohio River model update, and development of a water quality compliance strategy. Provide critical review of a proposed TMDL for a watershed impacted by CSOs and SSOs and lying entirely within a Phase II municipal separate storm sewer system (MS4) area (Feb. 2007 to present, <5%).

Watershed Characterization and Planning Services for Northern Kentucky in Support of Consent Decree Requirements. Project manager for adaptive watershed planning activities for the Sanitation District No. 1 to support requirements associated with a draft Consent Decree for combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs). Oversee development of a framework for complying with the Consent Decree. Also oversee watershed planning including development of integrated databases, a Watershed Assessment Tool for assessing pollutant loading potential from all sources, development of 16 watershed characterization reports, quality assurance of ongoing receiving water and outfall sampling, and development of more detailed water quality modeling tools to support the long-term control plans. (Sep. 2006 – Present, 15%).

Strategic Advisory Team for the Sanitation District No. 1. Selected as one of four members of a team providing strategic advice to the District on issues and approaches associated with implementing the adaptive watershed approach for infrastructure and watershed management. (May 2006 – Present, <5%).

Update of a Facilities Plan for the North Side Water Reclamation Plant for the Metropolitan Water Reclamation District of Greater Chicago. Senior project manager for application of a water quality model for evaluating decisions associated with disinfection, flow augmentation, supplemental aeration, and additional CSO control to meet future water quality standards for the Chicago Area Waterways (Dec. 2004 – Feb. 2007, 10%).

Update of the CSO Long-term Control Plan for the St. Louis Metropolitan Sewer District. Expert advisor for response to a Federal 308 letter requiring additional activities for a long-term control plan (LTCP), development of an integrated watershed monitoring program and receiving water modeling, and updates of the LTCP. Also assist the utility in reviewing and finalizing Use Attainability Analyses for CSO-impacted waters (Sep. 2004 – Present, 10%)

Update of the CSO Long-term Control Plans for New York City. Expert advisor for review of draft CSO LTCPs for NYC DEP. (Sep. 2005 – Nov. 2006, <5%)

Water Quality and Regulatory Support for the City of Kansas City, Missouri. Senior staff member providing assistance in selection of performance measures and review of water quality regulations and programs for CSOs, SSOs, and stormwater for the Kansas City Water Services Department. (Nov. 2003 – Oct. 2005, 1%)

Technical Support on the 2020 Facilities Plan for MMSD. Project manager and senior reviewer for review of water quality reports associated with CSO long-term control plan development for the Milwaukee Metropolitan Sewer District. (Jun. 2004 – Dec. 2005, 1%)

Development of a Combined Sewer Collection System Model for St. Louis, Missouri. Project Manager for development of a detailed collection system model using XP-SWMM of a 2.5-square-mile sewershed. (Apr. 2004 – Present, 5%)

Wet Weather Water Quality Standards for the Ohio River. Assisted the Ohio River Valley Water Sanitation Commission's POTW Committee in formulating options for pursuing revision of water quality standards to address wet weather flows and establishing a process that could be used by an Advisory Committee to identify and select options. Analyzed Ohio River data and compiled a list of various approaches that could be used. Co-authored a report on the regulatory options associated with review and revision of water quality standards for water bodies impacted by wet weather discharges. (Apr. 2003 – Sep. 2005, <5%).

Update of a Long-term Control Plan for Combined Sewer Overflows for the City of South Bend, IN. Project Manager for development of an update to South Bend's CSO long-term control plan. This includes customization of a watershed model for the St. Joseph River and pre- and post-processing software. Oversaw results of several control alternatives and presentation of alternative water quality standards for *E. coli*. Assisted the City in discussions with EPA, IDEM, and MDEQ regarding updates to the LTCP. (Oct. 2004 – Present, 10%)

Expert Assistance in Implementation of the CSO Policy for South Bend, IN. Senior advisor to the City of South Bend and its engineer at meetings with EPA on water quality issues associated with the City of South Bend's CSOs. Directed the development of a methodology to select a "typical year" and development of several chapters of the long-term control and subsequent updates (Sep. 2002 – Sep. 2002, <5%)

Receiving Water Modeling Program for the West Fork of the White River, Indiana. Senior manager for the City of Anderson in developing a receiving water characterization and model for the White River in the vicinity of the City's combined sewer overflows (CSOs) as part of a Consent Decree agreement. Provided oversight of the data review, design of the sampling program, and development and application of the model and review of the chapters for the various reports and workplans. Participated in meetings with EPA and the Indiana Department of Environmental Management on meeting requirements of the Consent Decree. (Aug. 2002 – present, 5%)

Water Quality Assessment for the Southerly, Easterly, and Westerly Districts' CSO Phase II Facilities Plans in Cleveland, Ohio. Project Manager for the receiving water assessment portions of three CSO Phase II facilities plans for the Northeast Ohio Regional Sewer District. Developed receiving water monitoring and modeling approaches; evaluated existing data; and provided senior review of the development and application of the receiving water models, include watershed, creek, culverts, two rivers, and Lake Erie. Project involved monitoring for biological and conventional pollutants and detailed velocity and temperature monitoring of the harbor, and use of SWMM, WASP, and POM models. Authored or co-authored several report chapters for the long-term control plans and assisted the District in preparing their summary report of the three LTCPs. (Sep. 1997 to Mar. 2005, 15%)

CSO Water Quality Monitoring and Assessment for Three Counties in Northern Kentucky: Evaluation of CSO Control Alternatives. Project Manager of the water quality analysis that is supporting the development of a long-term control plan for the Sanitation District No. 1 in Fort Wright, KY. Co-authored a major report evaluating the water quality impacts of CSOs on Banklick Creek and the Licking River using data analysis and receiving water models. Facilitated a workshop on preliminary screening of CSO control technologies, developed water quality objectives, and provided technical direction in the development of a screening/ranking system for selection of CSO control technologies. Coordinating application of receiving water models on a continuous basis to project the benefits of Long-term Control Plan alternatives. Developed a proposed scope of work for a process for ORSANCO to achieve a revision to the recreational water quality standards for the Ohio River. (Mar. 1998 – Aug. 2006, <25%).

Water Quality Model of *E. Coli* Bacteria for the St. Joseph and Elkhart Rivers for the Cities of Elkhart, Mishawaka, and South Bend, Indiana. Project Manager for a development of a regional watershed model for three communities with combined sewer overflows (CSOs) in EPA Region 5. She assisted the communities in obtaining two grants to conduct monitoring and develop and refine the model, which includes a watershed model, hydraulic model, and water quality model of the St. Joseph and Elkhart Rivers. (Oct. 2002 – Jan. 2006, 5%)

Combined Sewer Overflow Control for the City of Lafayette, IN. Provided senior oversight of the development of a Lagrangian transport model to characterize the impacts of CSO and storm water discharges from two communities on the Wabash River. (Nov. 2001-May 2005, 5%)

Combined Sewer Overflow Control for the City of Terre Haute, IN. Provided senior oversight of the development of a receiving water sampling program and a Lagrangian transport model to characterize the impacts of CSO and storm water discharges on the Wabash River. Evaluated monitoring data, sewer model results, and receiving water modeling results, and provided senior review of the entire long-term control plan document and development of the use attainability analysis. Provided presentations at public meetings. (Nov. 2001-Present, 5%)

Receiving Water Modeling of Combined Sewer Overflow Long Term Control Plan for the City of Elkhart, IN. Provided senior oversight of the development and application of a Lagrangian transport model to characterize the impacts of CSO and storm water discharges on the Elkhart and St. Joseph Rivers. Evaluated receiving water modeling results and development of the long-term control plan and subsequent update (May 2001 – Present, <5%).

Engineering Program Management Consultant for Development and Implementation of a Long-Term Control Plan for the District of Columbia's Combined Sewer System. Task Leader for the development of receiving water models and post-processors for assessing combined sewer overflow (CSO) impacts on the Anacostia River, the Potomac River, and Rock Creek. Reviewing past modeling efforts and known receiving water impacts, and recommending a modeling strategy to assist in the development of a long-term control plan. Providing coordination with other agencies in receiving water and source monitoring, and development of a Total Maximum Daily Load for the Anacostia River (Aug. 1998-Apr. 2002, 10%).

Water Quality Benefits of Combined Sewer Overflow Abatement in the Tidal Anacostia River. Final Report and Data Report. Project Manager and Engineer of a wet weather monitoring program and water quality assessment of the benefits to the tidal Anacostia of the District of Columbia's Phase I CSO Control Plan. Project included wet weather and continuous monitoring, and evaluation of pollutant loads and sediment oxygen demand to assist the District in making an $82.4 million decision regarding benefits of proposed future controls (1987-1991).

Eutrophication Studies

Spatial Data Analysis for Developing Lake Nutrient Standards for the State of Indiana. Project manager for assisting the Indiana Department of Environmental Management with reviewing water quality, geomorphometric, and biological data to establish proposed nutrient criteria for 2,000 lakes in Indiana. (Nov. 2005 – Jan. 2007, 2%).

Maryland Nutrient Trading Strategy. Project Manager and senior engineer to provide assistance to the prime contractor developing a nutrient trading strategy for the State of Maryland, under a Water Environment Research Federation grant. Provided comments on the potential impacts on drinking water and defined cross-basin trading issues (Feb. 1999-Sep. 2000).

Review of Chesapeake Bay Criteria and Water Quality Modeling for the Potomac Estuary near Washington, D.C. Project Manager of the review and application of proposed designated uses and criteria for dissolved oxygen, chlorophyll *a*, and clarity for the Chesapeake Bay system to develop load allocations for nutrients and solids. Providing assistance to the Metropolitan Washington Council of Governments in evaluating appropriateness of criteria and the calibration and application of the water quality model for determining use attainability and load reductions necessary to meet the criteria. (5%, Sep. 2001 to Jun. 2006, <5%)

Member, Maryland Middle Potomac Tributary Team. Team member, appointed by the Governor of Maryland, to oversee implementation of Maryland's Middle Potomac Tributary Strategy to meet Chesapeake Bay Nutrient Reduction Goals. Provided regional and inter-governmental coordination between local and state agencies, as well as technical support on wastewater issues (1995-1997).

Expert Assistance on Potomac River Nutrient Reduction Strategy. Project Manager and Engineer providing expert assistance to local governments in reviewing the revised Chesapeake Bay Water Quality and Watershed Models to support development of a tributary nutrient reduction strategy for the District of Columbia, Maryland, and Virginia (1994-1997).

Regional Pilot Program for Wastewater Treatment Plants in the Metropolitan Washington Region to Meet Chesapeake Bay Restoration Goals. As Project Manager, assisted in development of an innovative agreement between local governments to maximize aggregate nitrogen reductions from wastewater treatment plants in a facilitated environment without unnecessary regulatory burdens (1995-1996).

Member, Potomac River Basin National Water Quality Assessment Team. Represented local government members in the Washington metropolitan region on the USGS river basin team. Provided presentations and analysis of water quality conditions within the region, assisted in the design of a basin-wide monitoring network, and evaluation of the sources and impacts of nutrients, pesticides, and metals throughout the basin for surface water and groundwater (1990-1992).

Chain Bridge Automated Storm flow Monitor. Project Manager providing oversight of automated storm flow monitoring of the Potomac River, calculation of daily loads, and trend analyses (1987-1997).

Kingman Lake. Provided water quality modeling of Kingman Lake using WASP5 to evaluate the water quality impacts of constructed wetlands (1996).

Evaluation of Potential Impacts of Nitrogen Removal on Eutrophication in the Potomac Estuary. As Project Manager and Engineer, provided consultant oversight, prepared estuarine loads and environmental conditions, performed water quality model simulations, and committee presentations. Evaluated the development of a hybrid empirical and deterministic model to evaluate the potential risk of nuisance bluegreen algal blooms in the Potomac Estuary (1991-1992).

Evaluation of Sediment Oxygen Demand and Nutrient Flux in the Tidal Anacostia River. Project Manager and Engineer overseeing field and laboratory experiments to determine the magnitude of sediment oxygen demand (SOD) and nutrient fluxes, development of an SOD and nutrient flux model which is linked to a coupled hydrodynamic and water quality model, and application of the model to determine sediment response to CSO abatement (1991-1992).

Development and Calibration of a Two-Functional Algal Group Model of the Potomac Estuary. Project Manager and contributor to expansion of the Potomac Eutrophication Model to include phosphorus sorption modeling and effect of wind speed on net Microcystis growth rate. Compiled, organized, and summarized water quality data and model inputs. Reviewed development of model and tested sensitivity of model to key parameters. Evaluated alternative treatment scenarios, forecasted water quality effects, and presented results to wastewater agencies, regulatory agencies, and elected officials (1989-1992).

NPDES and Special Studies

Review of Permit Limits for Unified Government of Kansas City and Wyandotte County, KS. Project manager for applying CORMIX and calculating appropriate seasonal ammonia discharge limits, and providing comments on proposed permit conditions associated with WET testing, CSO LTCP development, and nitrogen removal studies. (Feb. to Nov. 2006, <5%).

Development of Water Quality Based Effluent Limits for the Chicago O'Hare International Airport. Project manager for the development of a monitoring and modeling program to establish NPDES limits for O'Hare's discharge basins to a creek and the Des Plaines River. (May to Jun. 2004, 1%)

Development of a Dissolved Oxygen Model for the Lower Black River from Elyria, Ohio, to Lake Erie. Project manager responsible for the design of a modeling and monitoring program for the Black River to develop an understanding of the causes of low dissolved oxygen. Coordinated development of a monitoring program between Ohio EPA, LTI, USGS, two laboratories, and four clients. Prepared database of existing data, reviewed earlier studies, and co-authored the Phase 1 report, which addressed existing data, development and application of a screening level model, and the recommended monitoring program. Directed the implementation of the coordinated monitoring program, and provided QA/QC of the data, and senior oversight of the Phase 2 Data Report. For Phase 3, providing senior oversight in the development of a linked UNET/WASP model of the Black River, and refinement of a hydrodynamic/water quality model of the navigation channel. Under Phase 4, directed the evaluation of controls and assimilative capacity of the navigation channel, which showed that increases in WWTP loads would not adversely affect the dissolved oxygen problem. (Oct. 2000 to Feb. 2004, 10%)

Blue Plains Regional Wastewater Treatment Plant NPDES Permit Support. Project Manager providing specialized technical and legal support in the District of Columbia's negotiations with the US EPA Region 3 over permit conditions. Major issues included nitrogen removal, mercury, and combined sewer overflow requirements. Designed sampling program for before and after testing of receiving water response to a pilot (half plant) test of nitrogen removal (1995-1997).

Metropolitan Washington Regional Monitoring Program. Program administrator overseeing coordination of Federal, state and local monitoring of the Potomac and Anacostia Rivers in the Washington metropolitan region (1986-1997).

Administrative and Technical Support to the Blue Plains Regional Committee (District of Columbia; Fairfax County, Virginia; and Montgomery and Prince George's Counties, Maryland). Project manager overseeing staff administrative, technical, and secretarial support to the Blue Plains Regional and Technical Committees which coordinated technical and policy issues for a 370 mgd regional wastewater plant and a regional composting facility. Provided support to the Blue Plains Chief Administrative Officers. Blue Plains IMA of 1985 and renegotiation of a MOU on biosolids management (1995-1997).

Development of an Environmental Geographic Information System for the District of Columbia Environmental Regulatory Administration. Co-Project Manager conducting a user requirements analysis, including the design and implementation of a customized GIS.

Blue Plains Flow Forecast Model. Provided project management of the development of a GIS-based sewershed model to generate flow forecasts for a 370 mgd regional wastewater treatment plant in Washington, D.C. Provided training of local government staff in operation of the model.

GIS Assistance to MWCOG in the Development of Model Inputs for, and Mapping of the Potomac Interceptor to the Blue Plains Wastewater Treatment Plant. Project Engineer overseeing consultant development of an engineering study of the monitoring and capacity of a regional wastewater interceptor in Washington, D.C. (1992-1994).

Water Quality Analysis and Modeling in Support of NPDES Requirements for the Expansion of the Lower Potomac Pollution Control Plant, Fairfax Co., Virginia. Project Manager and Engineer providing assistance on defining and modeling steady-state summer boundary conditions in the Potomac Estuary with various assumed levels of nitrogen control for the Washington region's municipal wastewater treatment plants (1992-1993).

Selected Trace-Element and Organic Contaminants in Streambed Sediments of the Potomac River Basin. As part of the report team for this task of the Potomac National Water Quality Assessment being conducted by the USGS, provided senior level review and input into the assessment of sediment contamination in the Potomac River (1991-1992).

Fall-Line Toxics Monitoring. Provided oversight of monitoring of the Potomac River fall line for storm and baseflow monitoring of pesticides, herbicides, and toxic contaminants. Key member of project team in analysis of the water quality data, generation of annual pollutant load estimates, and comparison with other tributaries (1991-1992).

TMDL and Watershed Experience

Critique of a Draft Nutrient TMDL. Expert review of a draft phosphorus TMDL for an industrial discharger to an oxbow lake of the Mississippi River (Apr. 2008 - Present, <5%).

Support for a Category 4b Demonstration for the Shawsheen River Headwaters. Senior advisor for evaluating biological impairments to the Shawsheen River for the Massachusetts Port Authority. The purpose of the evaluation is to support a category 4b demonstration to replace a high-flow TMDL so that the authority can address biological impairments in an adaptive manner as part of the Stormwater Pollution Prevention Plan (SWPP). (Dec. 2007 - Present, <5%).

Support to the Yadkin Pee Dee River Basin Association for Active Review of the High Rock Lake TMDL. Project Manager for expert review of NCDEP's plans to develop a water quality model of High Rock Lake to address turbidity, dissolved oxygen, and eutrophication problems. Assisted the Basin Association in identifying data collection, watershed, and water quality model needs and secure a grant for conducting the monitoring to support model development. (Jul. 2005 to Dec. 2006, <5%).

Expert Review of Dissolved Oxygen TMDLs along the East Coast of the United States. Senior manager providing expert review of example TMDLs dealing with standards revisions for dissolved oxygen for an attorney (Jan. 2006, <5%).**Environmental and Regulatory Review of Wastewater Facility Plan for New Castle County, Delaware.** Project manager and senior engineer evaluating various disposal and recharge options for treated wastewater in southern New Castle County, DE. (Dec. 2004 to Sep. 2005, 2%).

Expert Review of the Cooper River Water Quality Model in South Carolina. Project Manager for expert review of development of a water quality model for the Charleston Harbor and advice to the North

Charleston Sewer District on application of model to assess compliance with dissolved oxygen standards. (May 2005 – Present, 5%).

Expert Review of TMDL Development for the Reedy River in South Carolina. Project Manager for expert review of development of a water quality model of the Reedy River and the Reedy River arm of Lake Greenville and development of TMDLs for Greenville County, South Carolina (Apr. 2005 – Present, 5%).

Analysis, Identification, and Strategies for Urban Wildlife Contamination to Support TMDL Implementation in Washtenaw County, Michigan. Project Manager for a sampling program to investigate the sources of fecal contamination in storm sewers draining to the Huron River. Development of a quality assurance project plan, monitoring plan including storm sewer and scat sampling for *E. coli* and bacteria source tracking. (Oct. 2004 – Dec. 2006, 5%)

Development of a Watershed Monitoring Plan for Clean Water Services in Oregon. Senior staff developing a monitoring plan to provide a comprehensive characterization of environmental conditions, and the impacts of a wide range of environmental programs and projects in the Tualatin River watershed. (Aug. 2004 – Jun. 2006, <5%)

Creating Successful Total Maximum Daily Loads: An AMSA Handbook. Working group member for review of the handbook and contributor to the modeling section. (Dec. 2003 – Apr. 2004, <1%).

Review of Nearshore Lake Michigan *E. coli* TMDL for the Gary Sanitary District, Indiana. Project Manager and senior staff reviewing the TMDL which includes water quality model development and application of an EFDC model of nearshore Lake Michigan for northern Indiana. (Nov. 2003 – Sep. 2004, 5%)

Navigating the TMDL Process: Evaluation and Design. Co-author of a section on adaptive watershed management of a Water Environment Research Federation investigation on a comprehensive study of the Total Maximum Daily Load (TMDL) program. Researched where adaptive management is currently being used in developing TMDLs and watershed plans. Identified the necessary components of adaptive management. (Apr. 2002 – Oct. 2002, 1%)

TMDL Support Activities for Metals and Organics in the Anacostia River, District of Columbia. Project manager providing peer review and expert assistance in hydrodynamic and water/sediment quality modeling for development of TMDLs for metals and organics in the Anacostia River as part of an EPA support contract. This project is on a tight timeframe caused by a court-ordered deadline, and requires that LTI assist the District of Columbia in producing an approvable TMDL. Facilitated discussions between the District of Columbia and EPA, reviewed model results and 303(d) listing justification, and directed technical investigations and peer review of product. (Jul. 2002 – Mar. 2003, 5%)

Review of Maryland's Decision Criteria and Draft 303(d) List for the Washington Suburban Sanitary Commission. Senior engineer assisting in reviewing Maryland's draft 2001 303(d) list for the Washington Suburban Sanitary Commission. This includes review of the listing methodology and water quality analysis for dissolved oxygen, pathogens, nutrients, and sedimentation. (May 2002 – Jul. 2002, 2%)

Action Plan for the Columbia Slough Watershed, Oregon. Project manager and senior reviewer of a project to assist the Columbia Slough Watershed Council in developing a 5-year watershed action plan for the 40,000-acre watershed. The plan recommends projects to improve the health of the watershed and educational programs to increase awareness of watershed pollution. (May 2002 – Apr. 2003, 3%)

Development and Implementation of a Watershed Protocol for Northern Kentucky. Reviewed applicable state and federal CSO requirements and integrated these requirements for watershed planning into the draft protocol (Apr. 2002, 1%).

Review of draft TMDLs for the Mountain Run Watershed in Culpepper County, Virginia and the Manokin River, Somerset County, Maryland. Project manager and senior engineer responsible for providing comments to municipalities on two draft Total Maximum Daily Loads, one in Virginia for bacteria based on an HSPF model, and one in Maryland for dissolved oxygen and nutrients based on a WASP5 model. Identified problems in scarcity of data, inappropriate or incomplete calibration of model, and implementation issues (Jun.-Jul. 2000, <5%).

Anacostia Restoration Plan. Provided technical review and direction for evaluation of baseline water quality, identification of pollutant loads on a subwatershed basis, tracking restoration project development and costs, and determination of environmental indicators to be used in evaluating water quality benefits (1996-1997).

Richmond-Crater Interim Water Quality Management Plan: Technical Support Information. As Project Engineer provided tidally averaged water quality modeling of the James and Appomattox Rivers near Richmond, Virginia, to develop a two-tiered wasteload allocation under steady-state, low flow conditions. Results were used to set permit limits for major municipal and industrial wastewater dischargers. Developed water quality and point source database for the Piedmont Regional Office of the State Water Control Board (1986-1988).

Metropolitan Washington Regional Drinking Water Summit. Provided staff support to over 100 drinking water professionals to examine the monitoring needs and watershed protection and public health strategies needed to address drinking water contamination by cryptosporidium and other bacteria/protozoa/viruses (Jan. 1994)

Metropolitan Washington Water Supply Emergency Plan. Provided staff support on development of a Federal/state/local government coordination plan for water supply emergencies in the Washington metropolitan region (1994).

Database and Model Development Support

Development of TMDLs for Nine Watersheds in Illinois. Senior staff member in the development of a database of water quality data for use in evaluating listing decisions and development of TMDLs for Illinois EPA for nine watersheds in southern Illinois (Jun. – Jul. 2004).

Ottawa River Hot Spot Delineation & Risk Assessment. Senior engineer providing a database design for a human health and ecological risk assessment for the Ottawa River in Toledo, Ohio (Feb. 2000-Mar. 2000, <5%).

Data Management for the Fox River PCB Investigation. Senior oversight of the extraction of PCB congener data for water, sediments, and fish for use in calibration of a fate and transport model of the Fox River (1999).

Development of a Database to Manage Sewer Information for the City of Toledo, Ohio. Expert advisor on water quality and CSO compliance issues. Technical Manager developing a menu-driven data entry tool for combined sewered areas in Toledo. The tool will be used by the city for future data management and linked with a hydraulic model of the system (Apr. 1999 – Apr. 2005, <5%).

Linked Database and Visualization Tool for Lower Fox River and Green Bay. Technical Manager overseeing the development of a large (1.8 million results) ACCESS database of water quality, sediment, and biota data for the Green Bay watershed in Michigan and Wisconsin. Refined database design, developed data dictionaries, oversaw processing of data for entry, conducted quality assurance/quality control checks, and investigated discrepancies and missing information. Provided senior oversight of the development of a menu system for processing data. Developed the documentation of the database and record of updates. (Apr. 1998- Apr. 2006, <15%)

Technical Advisor to the Milwaukee Metropolitan Sewer District (MMSD) on a Comprehensive Modeling Strategy. Senior technical advisor as part of an MMSD team. Participated in a strategy workshop and review of a modeling strategy document. (May to Oct. 2002, 1%)

Selected Publications

Publications

The Role of Receiving Water Models in CSO Long-Term Control Plan Decision-Making and Water Quality Standard Revisions. WEFTEC 2008 with C.L. Turner. Chicago, IL. Scheduled for Oct. 18-22, 2008.

Implementing a Sewer Overflow Consent Decree through Watershed Management. WEFTEC 2008 with C.L. Turner, J.P. Gibson, Jr., J. Turner, B. Vatter, D. Zettler, G.M. Grant, S. Fitzgerald, J. Lyons. Chicago, IL. Scheduled for Oct. 18-22, 2008.

The Role of Adaptive Watershed Management Concepts in Wet Weather Consent Decrees. WEFTEC 2007 with P.L. Freedman, J.A. Eger, J.P. Gibson Jr., and N. Clements. San Diego, CA. Oct. 13-17, 2007.

A Spatial Tool for Watershed Characterization and Assessment in Northern Kentucky. WEFTEC 2007 with J.P. Gibson, Jr., T.A.D. Slawecki, and D.K. Rucinski. San Diego, CA. Scheduled for Oct. 13-17, 2007.

Maximum Extent Practicable Meets TMDL for Municipal Stormwater Permits: Which Will Prevail? StormCon 2006 with E. Powers. Denver, CO. Jul. 24-27, 2006.

Making a Case for Site-Specific, Performance-Based Water Quality Standards for Pathogens. 2005 TMDL Conference with H.P. Holmberg. WEF Specialty Conference, Philadelphia, PA, Jun. 26-29, 2005.

Emerging Wet Weather Issues for Municipal Permits with J.S. Moore. Collection Systems 2004: Innovative Approaches to Collection Systems Management. WEF 2004 Specialty Conference Series, Milwaukee, WI, Aug. 8-11, 2004.

Tools for the St. Joseph River, Indiana Watershed Initiative for a Safer Environment (WISE) with C.L. Turner, M.A. Salee, and A.K. Umble. Watershed 2004. WEF 2004 Specialty Conference Series, Dearborn, MI, Jul. 11-14, 2004.

Approaching TMDLs Using Aristotle as a Teacher: An Adaptive Watershed Management Approach with P.L. Freedman and D.W. Dilks. National TMDL Science and Policy 2002 Specialty Conference; Phoenix, AZ, Nov. 13-16, 2002.

Evolving Wet Weather and Water Quality Standards Issues for CSO Communities with J. J. Slack, WEFTEC 2000: The 73rd Annual Conference & Exposition on Water Quality and Wastewater Treatment, WEF, Anaheim, CA, Oct. 14-18, 2000.

The Chesapeake Bay Program: Meeting an "Unfunded Non-mandate" with S.A. Freudberg and K.W. Berger, WEFTEC 1995: The 68th Annual Program for Technical Professional Development, WEF, Miami Beach, FL, Oct. 21-25, 1995.

An Alternative to the NPDES "Command and Control" Approach to Achieve Nitrogen Reductions at Wastewater Plants with T.T. Spano and S.A. Freudberg, Management of Environmental Problems for Elected and Public Officials, WEF Specialty Conference Series, Richmond, VA, Nov 13-16, 1994.

Presentations and Symposiums

Déjà vu: New Recreational Use Criteria. Panel Presentation with M. Tate and M. Pla. NACWA Summer Conference. Anchorage, AK. Jul. 15-18, 2008.

How to Address Daily Load Issues in TMDLs with F.P. Andes and L.H. Weintraub. Barnes & Thornburg Clean Water Workshop. Chicago, IL. Sep. 26-28, 2007.

Use Attainability Analysis (UAA) as a Tool to Meet Clean Water Act Requirements. Panel on UAAs with F.P. Andes, J.Perras, and J. Rexhausen. Indiana Water Environment Association Government Affairs Committee CSO Workshop. Indianapolis, IN. Aug. 15, 2007.

The Link between Appropriate Water Quality Standards and Reasonable Total Maximum Daily Loads. Indiana Water Environment Association. Indianapolis, IN. Nov. 13-15, 2006.

Spatial Data Analysis for Developing Lake Nutrient Standards for the State of Indiana. 26th International Symposium, North American Lake Management Association (NALMS) with Carol Newhouse, Indiana Department of Environmental Management. Indianapolis, IN. Nov. 8-10, 2006.

Challenges Associated with Watershed Management for Bacteria. NOAA Great Lakes Environmental Research Laboratory Seminar, Ann Arbor, MI. Mar. 17, 2006.

Challenges Associated with Developing Nutrient and Sediment TMDLs for Impoundments in the Southeastern United States. NALMS: 15th Annual Southeastern Lake and Watershed Management Conference with J.V. DePinto and V.J. Bierman. Columbus, GA. Mar. 8-11, 2006.

The Not So Ready for Prime Time Players Visit Indiana —Is the Price Right for Clean Water? Indiana WEA 2005 Conference with J. Rexhausen and R. Hamilton., Indianapolis, IN. Nov. 14-16, 2005

Application of Modeling Tools for the St. Joseph River to Evaluate Bacteria Source Impacts on Water Quality. Indiana WEA 2005 Conference with C.L. Turner and M. Salee., Indianapolis, IN. Nov. 14-16, 2005

Sustainable or In-Saneable? The Wheel of Water Fortune — Debunking the Myths Associated with Sustainable Water Resources. Skit at the AMSA 2005 Winter Conference, San Antonio, TX. Feb. 2-4, 2005.

Making a Case for Site-Specific, Performance-Based Water Quality Standards for Pathogens. 2005 TMDL Conference with H.P. Holmberg. Indiana WEA 68th Anniversary Conference, Indianapolis, IN, Nov. 15-17, 2004.

Tackling the Challenge of Funding Wastewater and Water Supply Infrastructure in the 21st Century. 2004 Annual Conference of the Michigan Water Environment Federation and American Water Works Association. Grand Rapids, MI. Aug. 11, 2004.

Water Quality Standards and the Use Impasse. Skit at the AMSA 2004 Summer Conference, Denver, CO. Jul. 21, 2004.

Using Modeling Tools to Present Data to Gain EPA and IDEM Acceptance of Combined Sewer Overflow Long-Term Control Plans. Indiana Water Environment Association, 67th Annual Conference. Indianapolis, IN. Nov. 19, 2003.

Emerging Wet Weather Issues for Municipal Permits with J.S. Moore. Three Rivers Wet Weather Demonstration Project. Fifth Anniversary Sewer Conference. Four Points Sheraton North. Mars, PA. Sep. 11, 2003.

Case Studies in the Use of Adaptive Watershed Management for Total Maximum Daily Loads with P.L. Freedman and D.W. Dilks. TMDL 2003 Specialty Conference. Water Environment Federation. The Westin Michigan Avenue. Chicago, IL. Nov. 16-19, 2003.

Emerging Wet Weather Issues for Municipal Permits with J.S. Moore. Louisiana Water Environment Association's Spring Technical Conference & Crawfish Boil. Gonzales, LA. Apr. 24, 2003

Review Criteria for Combined Sewer Overflow Long-Term Control Plans with J.S. Moore. 66th Annual IWPCA Conference, Indianapolis, IN. Nov. 18-20, 2002

Evolution of Wet Weather Water Quality Standards for Urban Communities. Presentation to the 3 Rivers Wet Weather Fourth Annual Sewer Conference, Pittsburgh, PA. Sep. 16-17, 2002.

Presentation to the Virginia Association of Metropolitan Wastewater Agencies on Chesapeake Bay Water Quality and Watershed Modeling. 1996. Richmond, VA.

Fall-Line Toxics Monitoring to the Potomac National Water Quality Assessment Committee. 1993. Harrisburg, VA.

Workshops/Short Courses

Getting Prepared for "New" Pathogen Standards. Workshop Chair and Presenter on Recreational Use Attainability Analyses: Need For UAAs and Factors for Success. WEFTEC 2008. Chicago, IL. Scheduled for Oct 19, 2008.

"Doing Successful Use Attainability Analyses (UAAs)". Panel Symposium with F. Andes, D.Pfeifer, J. Perras, and J. Rexhausen. Keeping Your Head Above Water in the Regulatory World. Indiana Water Environment Association. Marriott Indianapolis East. Aug. 15, 2007.

"Long Term Control Plan Issues". Panel Symposium with F. Andes, L. Benfield, and D. Markowitz at the CSO Control Strategies and Key Developments Among Leading CSO Communities. The Drake Hotel, Chicago, IL. Apr. 26-27, 2007.

How to be "Passionate about Pathogens" with Water Quality Modeling. 2006 Developments in Clean Water Law: A Seminar for Public Agency Attorneys & Managers. Boston, MA. Nov. 15-17, 2006

"Getting Nutrient Limits Right." Presentation at the 2004 Barnes & Thornburg Clean Water Workshop, The Standard Club, Chicago, IL. Jun. 9-11, 2004.

"It's Time to Start Talking TMDLs" with D.W. Dilks. TMDL Informational Seminar. Greenville Soil and Water Conservation District, et. al. Greenville, SC. May 25, 2004.

EPA CSO / SSO Inspector Training with M.P. Sullivan and B.K. Hazelwood. EPA Region 5. Chicago, IL. Nov. 12-14, 2003.

Presented at the training workshop for US EPA for the CSO LTCP Review Training for Permit Writers and EPA Regional Staff. Indianapolis, IN. Feb. 6-7, 2002 and Harrisburg, PA. Mar. 2002.

Presented the receiving water monitoring and modeling chapters of the EPA Guidance Manual on CSO Modeling and Modeling. Washington, PA. Sep. 9-10, 1999.

Facilitation of a workshop to define water quality management objectives and evaluate/screen CSO control technologies for preliminary facilities planning.

Series of workshops on Development of the Chesapeake Bay Water Quality and Watershed Models for Washington metropolitan region's wastewater treatment plants.

Coordinated workshop on ultra-clean sampling techniques for metals and pesticides.

Client Reports and Unpublished Papers

Spatial Data Analysis for Developing Nutrient Standards for Indiana Lakes. Prepared for the Indiana Department of Environmental Management. Jan. 29, 2007.

Effects of Disinfection at the North Side, Stickney, and Calumet Water Reclamation Plants on Bacteria Levels in the Chicago Area Waterways. Prepared for the Metropolitan Water Reclamation District of Greater Chicago under subcontract to Consoer Townsend Envirodyne Engineers, Inc. Dec. 7, 2005.

Nationwide Review of Wet Weather Water Quality Standards. Prepared for the Sanitation District No. 1 of Northern Kentucky. Sep. 2005.

Technical Review of the Katonak-Rose Report on Public Health Risks Associated with Wastewater Blending (Nov. 17, 2003). Prepared for the National Association of Wastewater Agencies. Mar. 7, 2005.

Interim Water Quality Study Report: CSO Long-Term Control Plan Update. Prepared for Metropolitan St. Louis Sewer District. Sep. 28, 2005.

Management Applications of the Lower Black River Water Quality Model, Phase 4 Report. Prepared for the Black River Cooperative Parties under contract to the City of Elyria, Ohio. Feb. 27, 2004.

Draft Lower Black River Water Quality Model, Phase 3 Report. Prepared for the Black River Cooperative Parties under contract to the City of Elyria, Ohio. Sep. 29, 2003.

Summary of Background Information for the Washington Aqueduct BPJ. Dec. 16, 2002.

2001 Monitoring Data for the Lower Black River Water Quality Model, Phase 2 Report. Prepared for the Black River Cooperative Parties under contract to the City of Elyria, Ohio. Apr. 2002.

Southerly District Combined Sewer Overflow Phase II Facilities Plan. Submitted by Metcalf & Eddy in association with CH2MHill. Prepared for the Northeast Ohio Regional Sewer District. Mar. 2002.

Easterly District Combined Sewer Overflow Phase II Facilities Plan. Submitted by Metcalf & Eddy in association with CH2MHill. Prepared for the Northeast Ohio Regional Sewer District. Mar. 2002.

Design of the Modeling and Monitoring Programs for the Lower Black River Water Quality Model (LBRWQM) Project. Prepared for the Black River Cooperative Parties under contract to the City of Elyria, Ohio. Feb. 2001.

Study Memorandum LTCP-6-3: Receiving Water Model Selection. Prepared for District of Columbia Water and Sewer Authority EPMC III - Sewer Systems. Draft. Dec. 1999.

Study Memorandum LTCP-6-1: Receiving Water - Existing Information. Prepared for District of Columbia Water and Sewer Authority EPMC III - Sewer Systems. Draft. Dec. 1999.

Northeast Ohio Regional Sewer District Westerly CSO Phase II Facilities Plan: Chapters 4 and 7. Water Quality Analysis. Final Report, Dec. 1999.

Database for Lower Fox River and Green Bay: Database Report, Versions 1.0 to 3.0, Apr. 30, 1999.

Preliminary Control Alternatives Workshop, May 20, 1998.

Water Quality Assessment of Banklick Creek and the Lower Licking River, Mar. 1998.

Northeast Ohio Regional Sewer District Westerly CSO Phase II Facilities Plan: Water Quality Analysis Interim Draft Report, Oct. 1997.

Wastewater Treatment Plants in the Washington Metropolitan Region, 1993-1994.

Potomac and Anacostia Rivers Water Quality Data Report 1990, Dec. 1992.

Modeling Sediment Oxygen Demand and Nutrient Fluxes in the Tidal Anacostia River, Dec. 1992.

Water Quality Benefits of Combined Sewer Overflow Abatement in the Tidal Anacostia River, Nov. 1 1991.

Richmond-Crater Interim Water Quality Management Plan Technical Support Information. Mar. 1988.

Specialized Training and Coursework

Institute on Mathematical Modeling of Water Quality, Manhattan College, New York, 1989.

Workshop on Group Facilitation Training for the "Partnership for Regional Excellence" by Whorton and Youngquist, Inc. Atlanta, GA. Nov. 1992.

Attachment 2

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
WATER QUALITY STANDARDS AND	)	
EFFLUENT LIMITATIONS FOR THE	)	R08-9
CHICAGO AREA WATERWAY SYSTEM	)	(Rulemaking - Water)
AND THE LOWER DES PLAINES RIVER:	)	
PROPOSED AMENDMENTS TO 35 Ill.	)	
Adm. Code Parts 301, 302, 303 and 304	)	

ATTACHMENT 2 TO

PRE-FILED TESTIMONY OF ADRIENNE D. NEMURA

This attachment provides a description of the impact of combined sewer overflows (CSOs), pump station bypasses, and tributary runoff on bacteria levels in the Chicago Area Waterway System (CAWS). The information presents fecal coliform results of the District's water quality model for a simulation from July 12, 2001 to November 10, 2001 for the following scenarios: (1) Existing Conditions with assumed CSO and pump station bypass concentrations of 1,100,000 colony forming units per 100 milliliters (cfu/100ml); (2) Existing Conditions with assumed CSO and pump station bypass concentrations of 170,000 cfu/100ml; (3) Elimination of bacteria in the CSO and pump station bypass discharges (concentration set at 0 cfu/100ml); and (4) Disinfection of the Water Reclamation Plants (WRPs). For the WRP disinfection scenario, the following concentrations were assumed: 1,030 cfu/100ml at the North Side and Calumet WRPs and 2,740 cfu/100ml at the Stickney WRP. These scenarios were conducted in the summer of 2005 for the North Side WRP Facility Planning effort.

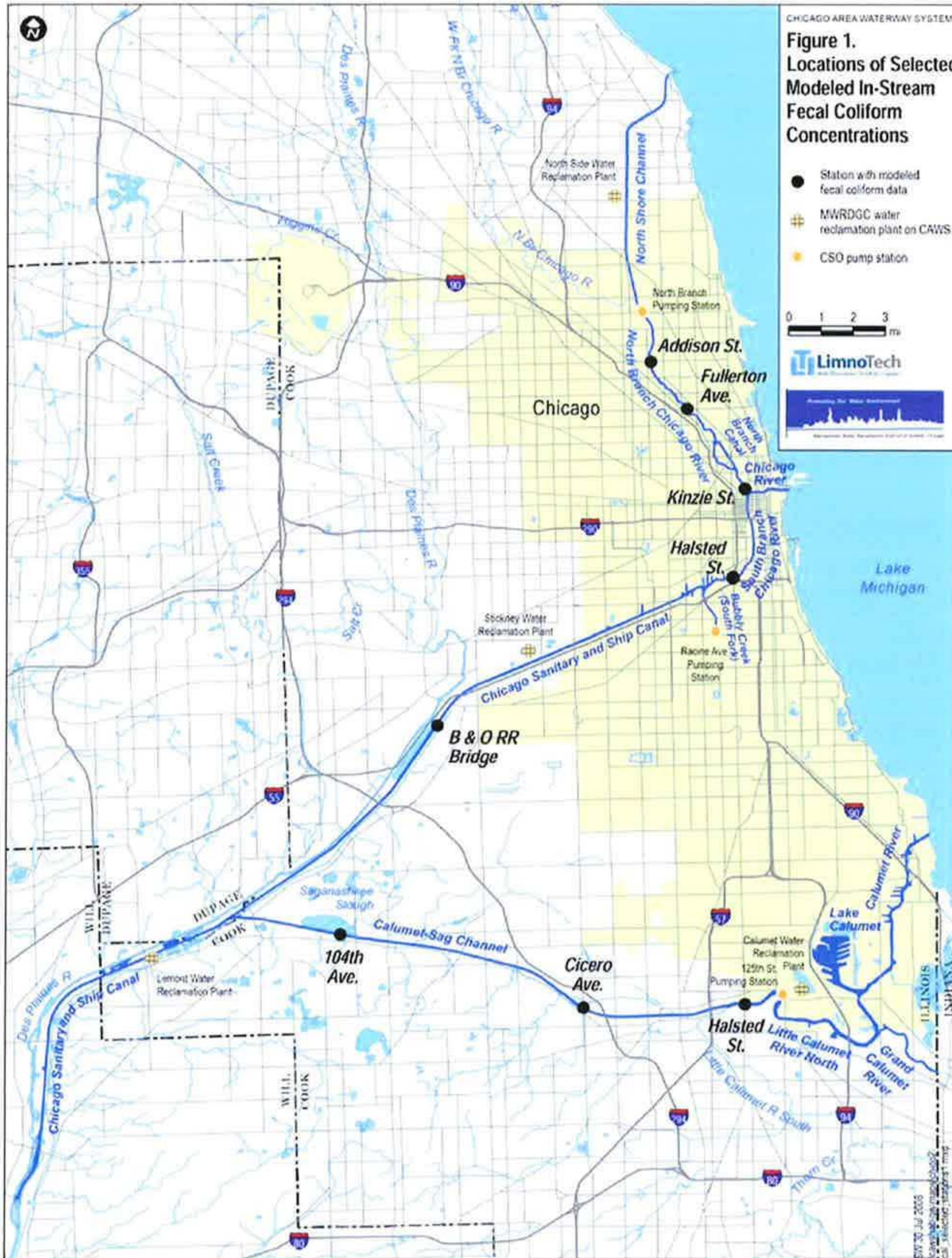
In summary, the results presented in this attachment (based on two representative storms) show that:

- The effect of CSO and pump station discharges can increase in-stream fecal coliform concentrations by 15,000 to 230,000 cfu/100ml depending on the discharge concentration and location;
- The effect of these discharges can persist for at least three to five days depending on location; and
- These effects will remain even if disinfection is provided at the WRPs.

Model results for these scenarios are provided for eight representative locations shown in Figure 1. These locations include three locations (Addison Street, Fullerton Avenue, and Kinzie Street) on the North Branch Chicago River (NBCR); Halsted Street on the South Branch Chicago River (SBCR); the B&O Railroad Bridge on the Chicago Sanitary Ship Canal (CSSC); Halsted Street on the Little Calumet River (LCR); and two locations (Cicero Avenue, and 104^{th} Avenue) on the Calumet-Sag Channel (CSC). Results are presented for two CSO events shown in Table 1: July 25, 2001and August 2-3, 2001. These results are representative of the range of the 15 CSO events for the portions of 2001 and 2002 that were modeled.

Table 1. Representative CSO Events for Model Simulation Periods in 2001 and 2002

Date(s) of CSO Event	Total Gravity CSO (million gallons)	Total Pump Station Bypass (million gallons)	Total Discharge (million gallons)
July 25, 2001	585	963	1,548
August 2-3, 2001	3,136	1,118	4,254
Range for Portions of 2001 and 2002 that were Modeled	0 to 11,417	0 to 2,347	409 to 12,982


CHICAGO AREA WATERWAY SYSTEM
Figure 1.
Locations of Selected Modeled In-Stream Fecal Coliform Concentrations
Station with modeled fecal coliform data
MWRDGC water reclamation plant on CAWS
CSO pump station
0 1 2 3 mi
LimnoTech
North Side Water Reclamation Plant
North Shore Channel
North Branch Pumping Station
Addison St.
Fullerton Ave.
Chicago
North Branch Chicago River
North Branch Canal
Chicago River
Kinzie St.
Halsted St.
South Branch Chicago River
Lake Michigan
Stickney Water Reclamation Plant
Chicago Sanitary and Ship Canal
Bubbly Creek (South Fork)
Racine Ave Pumping Station
B & O RR Bridge
Calumet-Sag Channel
104th Ave.
Cicero Ave.
Lemont Water Reclamation Plant
Calumet Water Reclamation Plant
125th St. Pumping Station
Halsted St.
Little Calumet River North
Grand Calumet River
Lake Calumet
Calumet River
Des Plaines R
Salt Creek
DUPAGE
COOK
WILL
ILLINOIS
INDIANA

Figures 2 through 9 provide plots of the fecal coliform levels the eight locations for July 24 to August 10, 2001 which includes the two CSO events in Table 1. Results are presented for existing conditions with the CSO and pump station discharge concentrations set at 1,100,000 cfu/100ml (green line) and 170,000 cfu/100 ml (blue line). This represents the hypothetical range of CSO impacts as documented by Marquette University (Manache and Melching, 2005). Bacteria concentrations in these discharges are likely to vary from event to event. The dashed brown line shows the effect of zeroing out the CSO and pump station discharge concentrations. This line represents lower concentrations than would be calculated with a scenario of actual treatment or elimination of CSO because the associated "clean" flow from the CSO discharges is still entering the CAWS in the simulation and diluting the calculated in-stream concentrations.

The effects of the bacteria loads from the North Side WRP, North Branch Pumping Station, and the NBCR tributary (which includes storm water runoff and CSOs) can be seen at Addison Road. If the assumed concentrations for the CSOs and pump station discharges are 1,100,000 cfu/100ml, the maximum difference in in-stream concentration with the scenario where the fecal coliform is zero is approximately 100,000 cfu/100ml for the first event and 230,000 cfu/100ml for the second event. If the assumed concentrations for the CSOs and pump station discharges are 170,000 cfu/100ml, then the maximum in-stream difference is reduced to 16,000 cfu/100ml and 35,000 cfu/100ml respectively. The effect of the wet weather discharges lasts approximately three days for the first event and four days for the second event.

The effect of wet weather discharges is similar, and more pronounced, at Fullerton Avenue and Kinzie Street on the NBCR (Figures 3 and 4). The higher peak concentrations in these figures show the effect of the additional bacteria load from the CSOs located upstream of these locations. The effect of the wet weather discharges lasts approximately three to five days at these locations.

Figure 5 shows the effect of the CSO and pump station discharges at Halsted Street on the SBCR. Again, the higher peak concentrations and longer duration of the wet weather impacts resulting from additional CSO is shown. The second event in Figure 5 also shows the effect of flow reversals caused by the Racine Avenue Pump Station discharge where in-stream bacteria concentrations increase on August 7 and 8, 2001. A similar effect is seen at the B&O Railroad Bridge on the CSSC, as shown in Figure 6.

Figure 7 shows the effect of the CSOs, Calumet WRP, 125th Street Pump Station, and other wet weather discharges on in-stream concentrations at Halsted Street on the Little Calumet River. For the first event, the difference between the existing situation (with an assumed discharge concentration of 1,100,000 cfu/100ml in the CSOs and pump stations) is 100,000 cfu/100ml and 150,000 cfu/100ml for the second event. If the assumed discharge concentration is 170,000 cfu/100ml, the impact of the CSOs and pump station discharges on in-stream concentrations is 15,000 cfu/100ml and 23,000 cfu/100ml respectively. The duration of the wet weather impacts at this location is four to five days.

As shown in Figures 8 and 9, the wet weather effects become more pronounced in the CSC both in terms of peak concentrations and duration of impact of the wet weather discharges. This is because of increased wet weather loads along the CSC and longer travel times.

Figure 2. Comparison of Fecal Coliform Levels at Addison Road, NBCR for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)

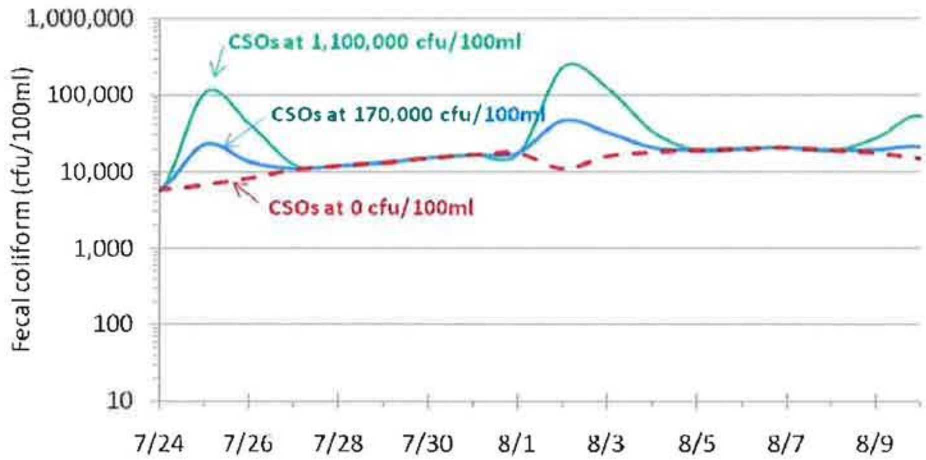


Figure 3. Comparison of Fecal Coliform Levels at Fullerton Avenue, NBCR for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)

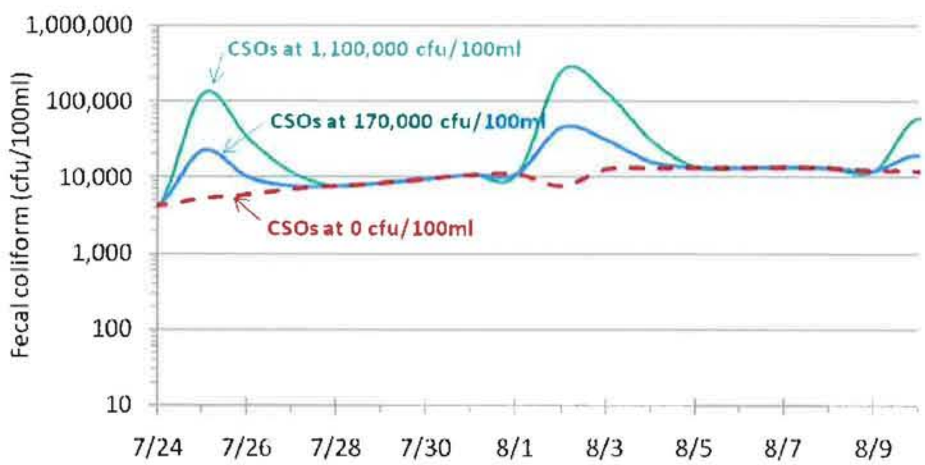


Figure 4. Comparison of Fecal Coliform Levels at Kinzie Street, NBCR for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)

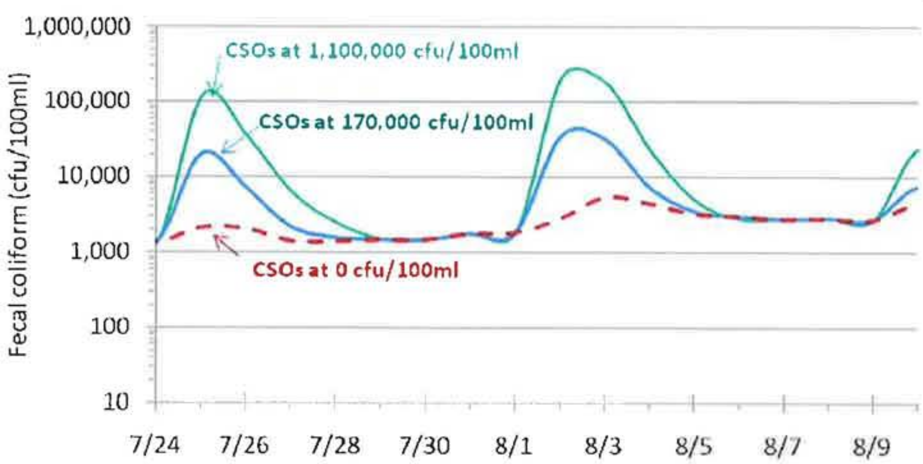


Figure 5. Comparison of Fecal Coliform Levels at Halsted Street, SBCR for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)

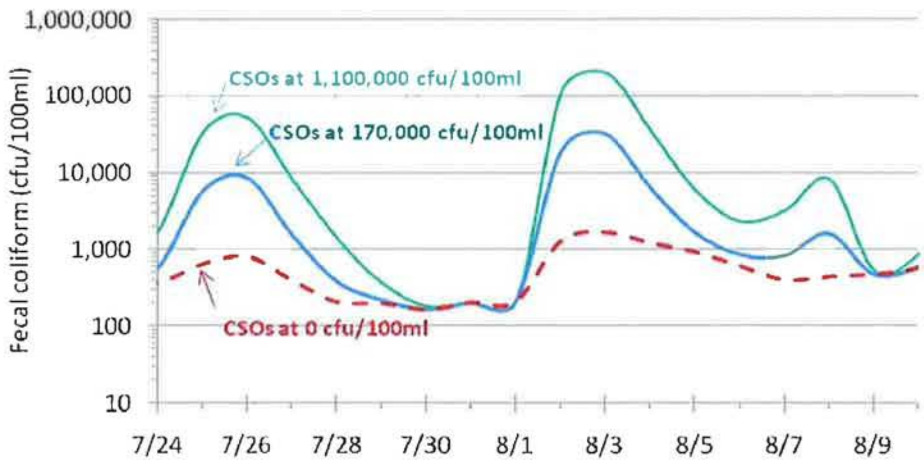


Figure 6. Comparison of Fecal Coliform Levels at B&O Railroad Bridge, CSSC for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)

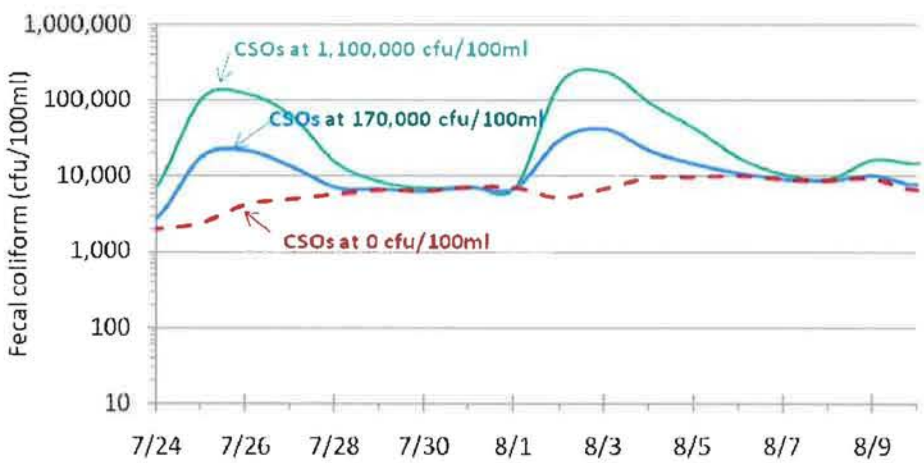


Figure 7. Comparison of Fecal Coliform Levels at Halsted Street, LCR for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)

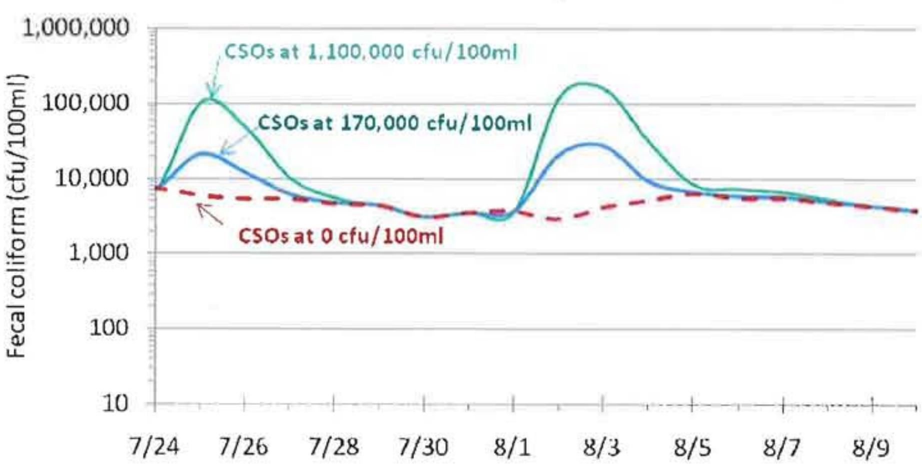


Figure 8. Comparison of Fecal Coliform Levels at Cicero Avenue, CSC for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)

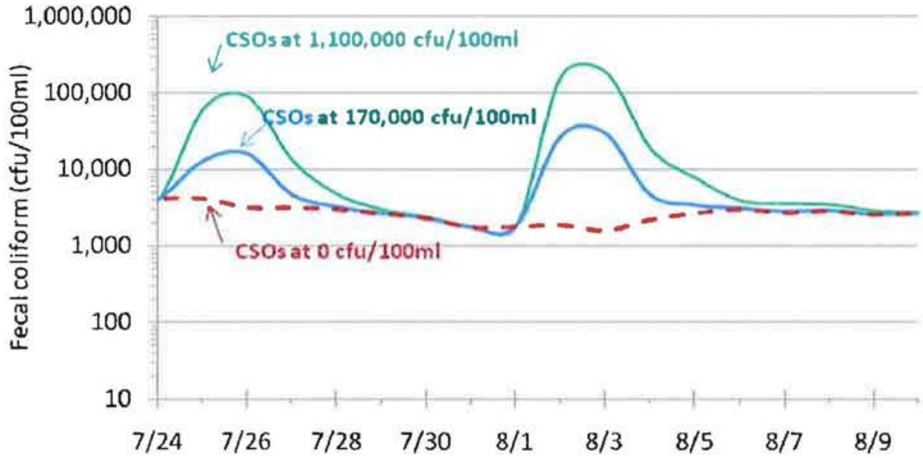
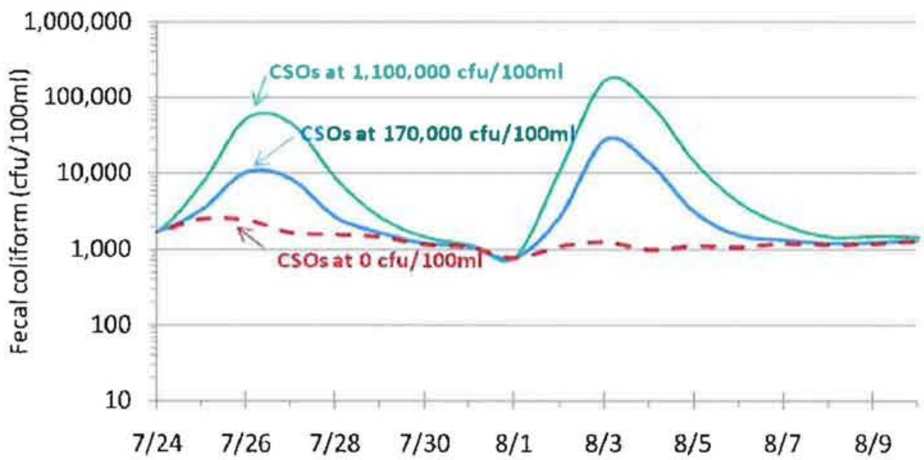


Figure 9. Comparison of Fecal Coliform Levels at 104th Avenue, CSC for Existing Conditions and Elimination of CSO/Pump Station Bacteria Concentration (2001)



Figures 10 to 17 provide a comparison of the existing condition (with an assumed CSO and pump station discharge concentration of 170,000 cfu/100ml) to a scenario where the WRP effluents are disinfected. Along the NBCR (Addison Street, Fullerton Avenue, and Kinzie Street) there is a slight reduction in peak concentrations during the wet weather events due to disinfection at the North Side WRP. Concentrations, however, are still in excess of 10,000 cfu/100ml. At the other locations, WRP disinfection does not reduce the peak concentrations during the wet weather events.

Figure 10. Wet Weather Impacts at Addison Road, NBCR (2001)

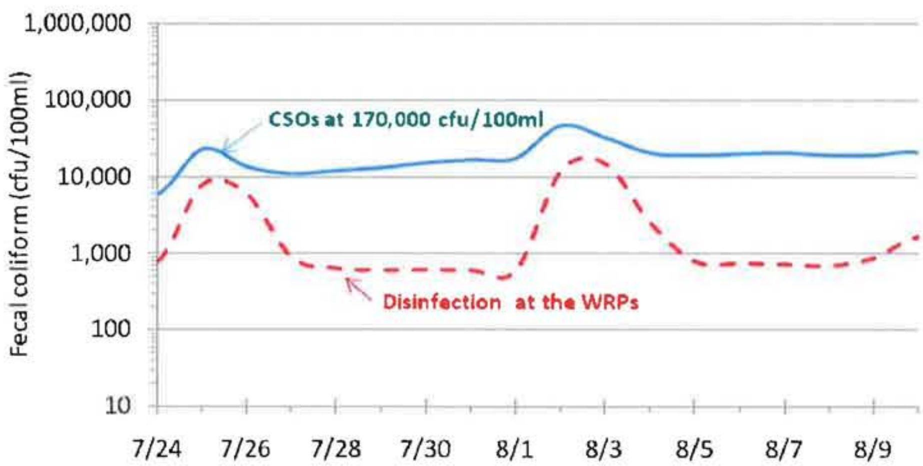


Figure 11. Wet Weather Impacts at Fullerton Avenue, NBCR (2001)

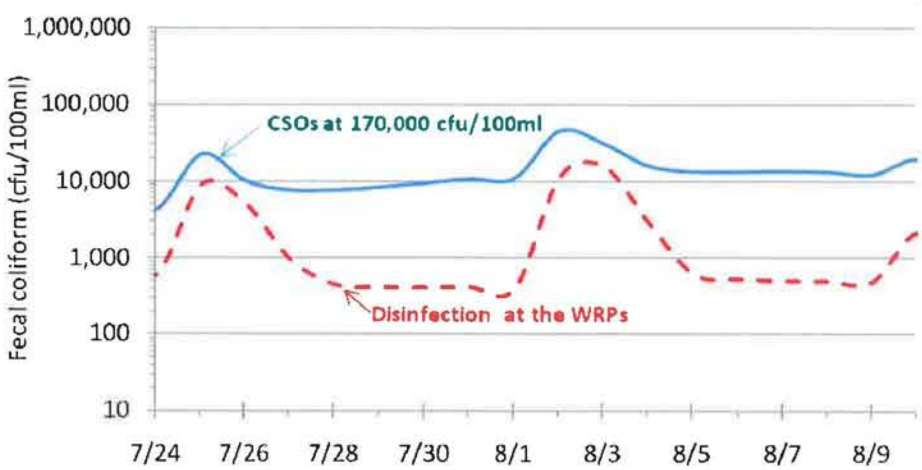


Figure 12. Wet Weather Impacts at Kinzie Street, NBCR (2001)

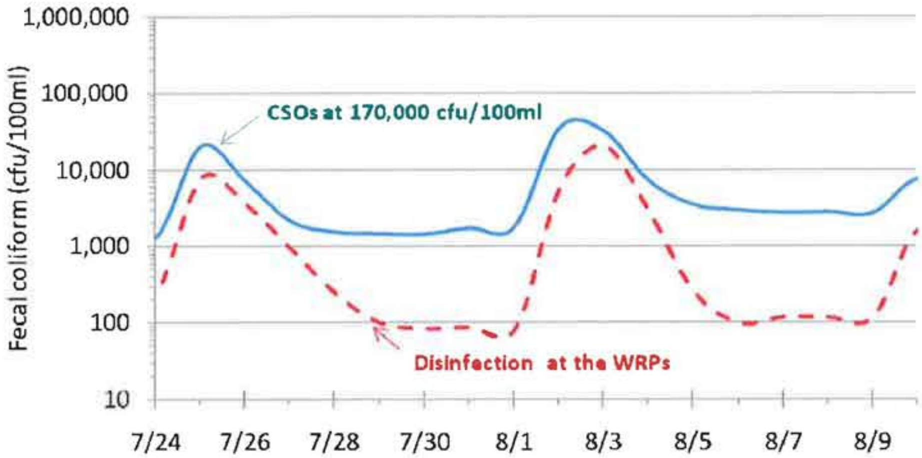


Figure 13. Wet Weather Impacts at Halsted Street, SBCR (2001)

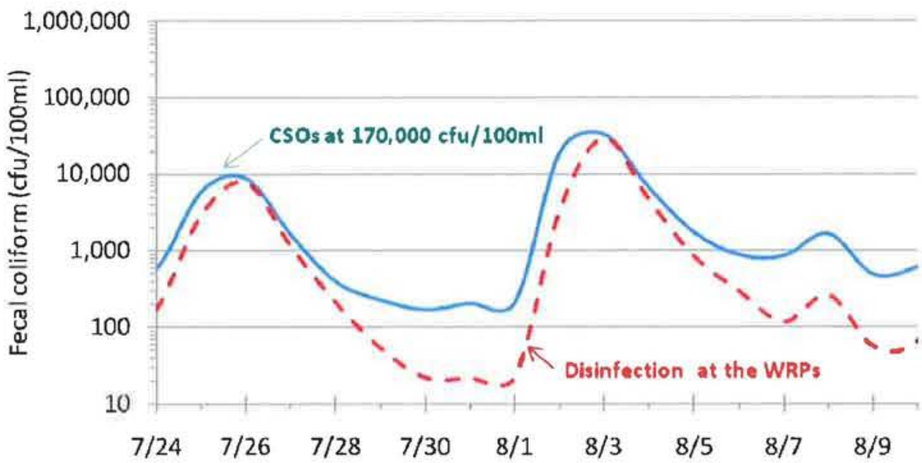


Figure 14. Wet Weather Impacts at B&O Railroad Bridge, CSSC (2001)

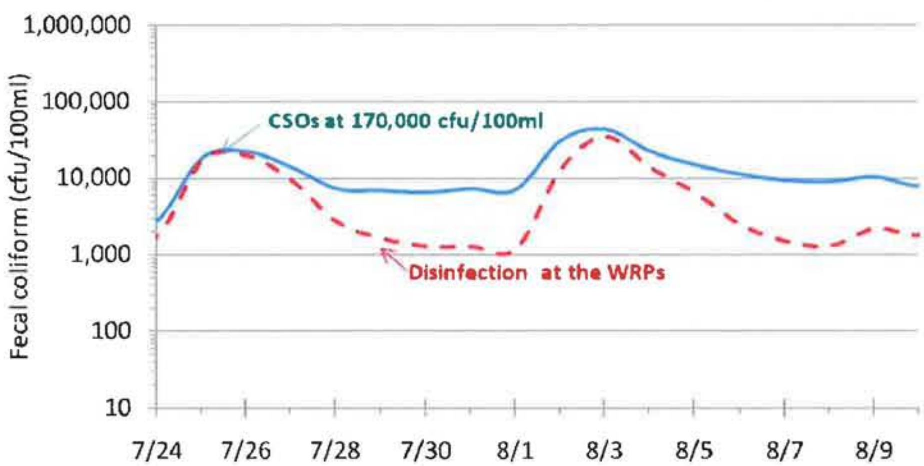


Figure 15. Wet Weather Impacts at Halsted Street, LCR (2001)

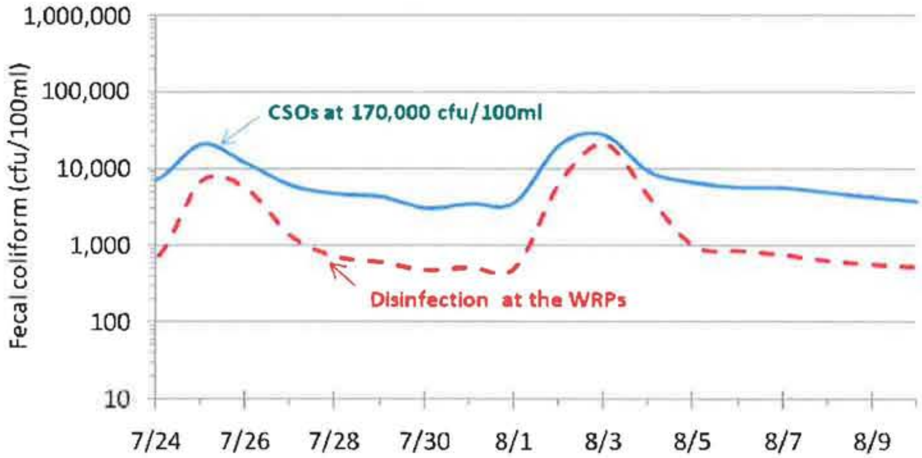


Figure 16. Wet Weather Impacts at Cicero Avenue, CSC (2001)

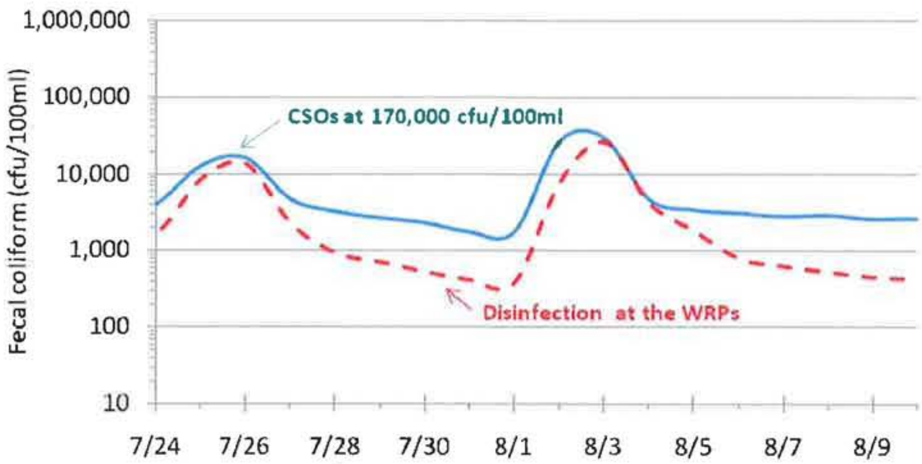
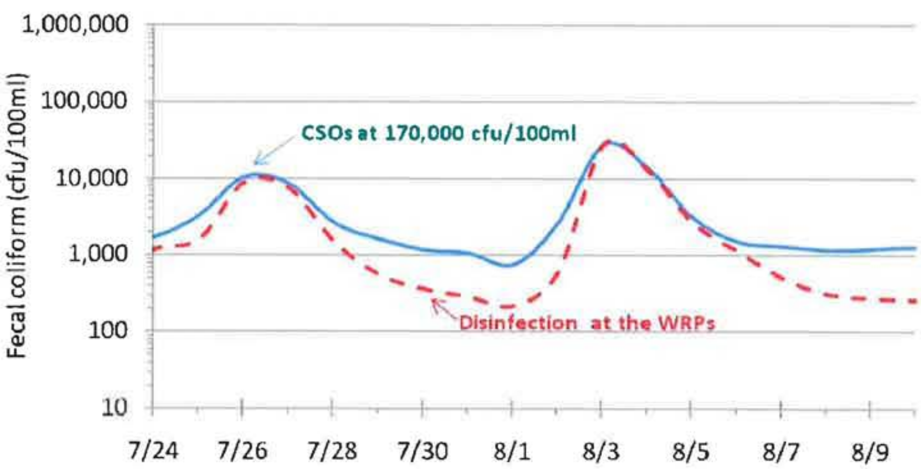


Figure 17. Wet Weather Impacts at 104th Avenue, CSC (2001)



REFERENCES

Manache, G. and Melching, C.S. (2005) Simulation of fecal coliform concentrations in the Chicago Waterway System under unsteady flow conditions, Technical Report 16, 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. 2005-9, Chicago, IL.

Attachment 3

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
WATER QUALITY STANDARDS AND	)	
EFFLUENT LIMITATIONS FOR THE	)	R08-9
CHICAGO AREA WATERWAY SYSTEM	)	(Rulemaking - Water)
AND THE LOWER DES PLAINES RIVER:	)	
PROPOSED AMENDMENTS TO 35 Ill.	)	
Adm. Code Parts 301, 302, 303 and 304	)	

ATTACHMENT 3 TO

PRE-FILED TESTIMONY OF ADRIENNE D. NEMURA

This attachment provides examples of wet weather water quality standards for three states, and an interstate commission that recognized the potential need for wet weather standards, because of the impact of wet weather discharges, primarily combined sewer overflows (CSOs). The states of Indiana, Massachusetts, and Maine and the Ohio River Valley Water Sanitation Commission (ORSANCO) have adopted provisions within their water quality standards to reflect the challenges associated with meeting water quality standards due to CSOs or stormwater discharges. Information is also presented on relevant Use Attainability Analyses (UAAs) that have been conducted with respect to wet weather discharges.

Indiana

The State of Indiana revised its water quality standards to include a CSO wet weather limited use designation that allows for temporary suspension of the recreational use criteria for up to four days following a CSO event. This revision also allows the state to incorporate long-term compliance schedules into NPDES permits for CSO communities. US EPA approved these revisions on June 9, 2008 (US EPA, 2008). To obtain the limited use designation, CSO communities must have completed a US EPA- approved UAA and have implemented a long-term control plan. The state incorporates the long-term control plan into the NPDES permit (before the long-term control plan is fully implemented) and specifies the water quality based requirements that apply to the remaining CSO discharges during and immediately following the CSO events. US EPA indicated that these requirements "should be based upon the engineering and modeling analyses and assumptions that were used in developing the LTCP and UAA, and could be expressed in a number of different ways" (US EPA, 2008, p. 2). This includes, but is not limited to, number of overflows per typical-year, percent capture, or a design-storm event.

Massachusetts

The State of Massachusetts has provisions in its water quality standards to provide for partial designated use of CSO- or stormwater-impacted waters. Communities can also obtain a variance, if needed. The partial use designation indicates that the "criteria may depart from the criteria assigned to the Class only to the extent necessary to accommodate the technology based treatment limitations of the CSO or stormwater discharges" (MassDEP, 2007).

Maine

The State of Maine has adopted a variance approach to address CSO conditions during implementation of an approved long-term control plan (MDEP, 2003). A temporary CSO subcategory is established after the community submits a long-term control plan, implementation schedule, and a UAA. A Citizen Board may then temporarily suspend or modify the water quality standards associated with the use (including the extent and duration) for CSO events beyond a rainfall-selected event size.

ORSANCO

ORSANCO adopted provision in its water quality standards for the Ohio River allowing for development and application of alternative criteria if CSO communities have submitted a long-term CSO control plan and a UAA (ORSANCO, 2006). Several CSO communities along the Ohio are in the process of developing or updating their long-term control plans, although none have submitted UAAs to date.

City of Indianapolis UAA

The City of Indianapolis incorporated a UAA into its long-term CSO control plan in accordance with the State's provision for a CSO wet weather limited use designation. On May 7, 2008, the State submitted a proposed rule for public hearing to designate the receiving waters affected by the City's CSOs for the wet weather limited use designation (IDEM, 2008).

Massachusetts Water Resources Authority (Boston)

On March 16, 2006, agreement was reached between the US EPA, Massachusetts Department of Environmental Protection (MassDEP), the Conservation Law Foundation of New England, Inc., and the Massachusetts Water Resources Authority (MWRA) on long-term (through the year 2020) variances for the Charles River, Alewife Brook and East Boston (US EPA, 2006). This allows MWRA to implement its long-term control plan and conduct post-construction monitoring in 2018 to 2021 to demonstrate that it has achieved compliance with its long-term control plan.

Santa Ana River UAA, California

A Stormwater Quality Standards Task Force has been meeting monthly since May 2004 to establish appropriate recreational uses for the Santa Ana River. A work plan was established in 2003 to review the beneficial use classifications and assess existing conditions (Phase I); review and update the water quality objectives (Phase II); and develop permit implementation and monitoring strategies (Phase III). The workgroup has completed Phase I and is in the process of completing Phase II. Under Phase I, it was determined that a high flow suspension of recreational uses was appropriate along with re-designation of certain segments to Limited Rec-1 or a lack of Rec-1 uses, along with revision of the numeric criteria (Bounds, 2008). Phase II includes completion of a UAA.

Engineered Flood Channels UAA in Ballona Creek, California

The Los Angeles Regional Water Quality Control Board in California adopted a high flow suspension of recreational uses for Ballona Creek, which is a straightened, concrete-lined channel designed to move floodwaters from urban areas to the ocean (SWRCB, 2003). This suspension was based on information showing that it is not safe to be in the modified channels for this waterbody and therefore bacteria criteria for protection of recreational uses do not need to be met. The suspension applies under the rainfall conditions that trigger swift-water protocols (i.e., rescue squads are on alert if someone should happen to enter the water).

REFERENCES

Bounds, D. "Science Surrounding Effluent Disinfection and Pathogens in the Environment." Presentation to the IAWA Technical Committee. Starved Rock Lodge, Utica, IL. Jul. 11, 2008.

Indiana Department of Environmental Management (IDEM) (2008). TITLE 327 WATER POLLUTION CONTROL BOARD Proposed Rule LSA Document #08-324. May 7, 2008. (3 pp.)

Maine Department of Environmental Protection (MDEP). 2003. 38 MRSA Section 464. November 10, 2003.

Massachusetts Department of Environmental Protection (MassDEP) (2007). 314 CMR 4.00: Massachusetts Surface Water Quality Standards.

Ohio River Valley Water Sanitation Commission (ORSANCO) (2006). Pollution Control Standards for Discharges to the Ohio River: 2006 Revision.

State Water Resources Control Board (SWRCB) (2003). Ballona Creek Recreational Use Attainability Analysis. Amendment to Water Quality Control Plan: Los Angeles Region, Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties.

United States Environmental Protection Agency (US EPA) (2008). Letter from B. Mathur to B. Pigott. June 9, 2008. (3 pp.)

US EPA (2006). Memorandum of the United States of America in Support of Joint Motion to Amend Schedule Six with Respect to the Charles River, Alewife Brook and East Boston. Civil Actions No. 85-0489-RGS and No. 83-1614-RGS. March 15, 2006.

Attachment 4

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF: WATER QUALITY STANDARDS AND EFFLUENT LIMITATIONS FOR THE CHICAGO AREA WATERWAY SYSTEM AND THE LOWER DES PLAINES RIVER: PROPOSED AMENDMENTS TO 35 Ill. Adm. Code Parts 301, 302, 303 and 304	))))))))	R08-9 (Rulemaking - Water)

ATTACHMENT 4 TO

PRE-FILED TESTIMONY OF ADRIENNE D. NEMURA

This attachment provides a description of the impact of gravity combined sewer overflows (CSOs) and other wet weather discharges on dissolved oxygen (DO) levels in the Chicago Area Waterway System (CAWS). The information presents selected results of the District's water quality model for a simulation from July 12, 2001 to November 10, 2001 for the following scenarios: (1) Existing Conditions and (2) Elimination of Gravity CSOs. The simulations show that:

- CSOs have different impacts on in-stream dissolved oxygen depending on location and the nature of the wet weather event;
- CSO impacts range from minimal duration to an impact that "could last for weeks" (Zhang et al, 2007);
- The impacts can range from less than 1 milligram per liter (mg/l) to more than 3.5 mg/l deficit in in-stream dissolved oxygen concentrations;
- Elimination of gravity CSOs may not, at varying times at different locations, result in attainment of the proposed minimum dissolved oxygen criteria; and
- "Even if all gravity CSOs were eliminated…[a] target DO value of 4 mg/l could not be satisfied 100 percent of the time at some locations in the CAWS under the

summer conditions of 2001 and 2002" (Zhang et al, 2007) because pump station discharges, sediment resuspension, stormwater, and tributary runoff will remain and impact dissolved oxygen.

Model results for these scenarios are provided for eight representative locations shown in Figure 1. These locations include three locations (Addison Street, Fullerton Avenue, and Kinzie Street) on the North Branch Chicago River (NBCR); Halsted Street on the South Branch Chicago River (SBCR); the B&O Railroad Bridge on the Chicago Sanitary Ship Canal (CSSC); Halsted Street on the Little Calumet River (LCR); and two locations (Cicero Avenue and Route 83) on the Calumet-Sag Channel (CSC). Results are presented for two CSO events shown in Table 1: July 25, 2001and August 2-3, 2001. These results are representative of the range of the 15 CSO events for the portions of 2001 and 2002 that were modeled.

Table 1. Representative CSO Events for Model Simulation Periods in 2001 and 2002

Date(s) of CSO Event	Total Gravity CSO (million gallons)	Total Pump Station Bypass (million gallons)	Total Discharge (million gallons)
July 25, 2001	585	963	1,548
August 2-3, 2001	3,136	1,118	4,254
Range for Portions of 2001 and 2002 that were Modeled	0 to 11,417	0 to 2,347	409 to 12,982

Figures 2 through 9 provide plots of the dissolved oxygen levels at the eight locations for July 24 to August 10, 2001 which includes the two CSO events in Table 1. Results are presented for existing conditions (blue line) and elimination of gravity CSOs (dashed brown line). Oxygen-demanding pollutant concentrations in these discharges vary from event to event (Zhang et al, 2007).


CHICAGO AREA WATERWAY SYSTEM
Figure 1.
Locations of Selected Modeled In-Stream Dissolved Oxygen Concentrations
Station with modeled fecal coliform data
MWRDGC water reclamation plant on CAWS
CSO pump station
Aeration station
0 1 2 3 mi
LimnoTech
Addison St.
Fullerton Ave.
Chicago
Kinzie St.
Halsted St.
Chicago River
Lake Michigan
North Shore Chan.
N. Br. Chicago R.
North Branch Canal
South Branch Chicago River
Bubbly Creek (South Fork)
North Side Water Reclamation Plant
Devon Ave. In-Stream Aeration Sta.
North Branch Pumping Station
Webster Ave. In-Stream Aeration Sta.
Stickney Water Reclamation Plant
Racine Ave Pumping Station
Chicago Sanitary and Ship Canal
B & O RR Bridge
Route 83
Calumet-Sag Channel
Cicero Ave.
Halsted St.
Little Calumet River North
Grand Calumet River
Calumet River
Lake Calumet
Calumet Water Reclamation Plant
125th St Pumping Station
Lemont Water Reclamation Plant
SEPA #1
SEPA #2
SEPA #3
SEPA #4
SEPA #5
Des Plaines R.
Salt Creek
Sag Slough
Little Calumet R. South
Thorn Cr.
DUPAGE
COOK
WILL
ILLINOIS
INDIANA

The effects of the oxygen-demanding loads from the North Branch gravity CSOs and other wet weather sources (including the North Side Pump Station and runoff and CSOs in the NBCR) on in-stream dissolved oxygen levels at Addison Road are shown in Figure 2. The gravity CSO loads affect dissolved oxygen concentrations by 0.5 to 1 mg/l for three days for the first event and 0.5 to 1.5 mg/l for eight days for the second event. Depressions after the wet weather events on July 25, 2001 and August 2-3, 2001 are still evident even with the elimination of the gravity CSOs. These wet weather impacts are more pronounced at Fullerton (Figure 3) and Kinzie Street (Figure 4).

The effect of the gravity CSOs on dissolved oxygen are also pronounced at Halsted Street on the SBCR (Figure 5). For the second event, the CSOs depress in-stream dissolved oxygen by as much as 2 mg/l. This effect is diminished at the B&O Railroad Bridge on the CSSC (Figure 6).

The effect of the gravity CSOs on in-stream dissolved oxygen is also substantial at Halsted Street on the LCR (Figure 7) for the second event, with impacts lasting for eight days and a maximum deficit of 1.5 mg/l. This effect is more pronounced at Cicero Avenue on the CSC, with a maximum deficit of 2.5 mg/l (Figure 8). The gravity CSOs impact in-stream dissolved oxygen at Route 83 on the CSC for both the first event (1 mg/l) and the second event. For the second event, the maximum dissolved oxygen deficit at this location is 3 mg/l and the CSO effects are calculated to last more than seven days.

Figure 2. Comparison of Dissolved Oxygen Levels at Addison Road, NBCR for Existing Conditions and Elimination of Gravity CSOs (2001)

Figure 3. Comparison of Dissolved Oxygen Levels at Fullerton Avenue, NBCR for Existing Conditions and Elimination of Gravity CSOs (2001)

Figure 4. Comparison of Dissolved Oxygen Levels at Kinzie Street, NBCR for Existing Conditions and Elimination of Gravity CSOs (2001)

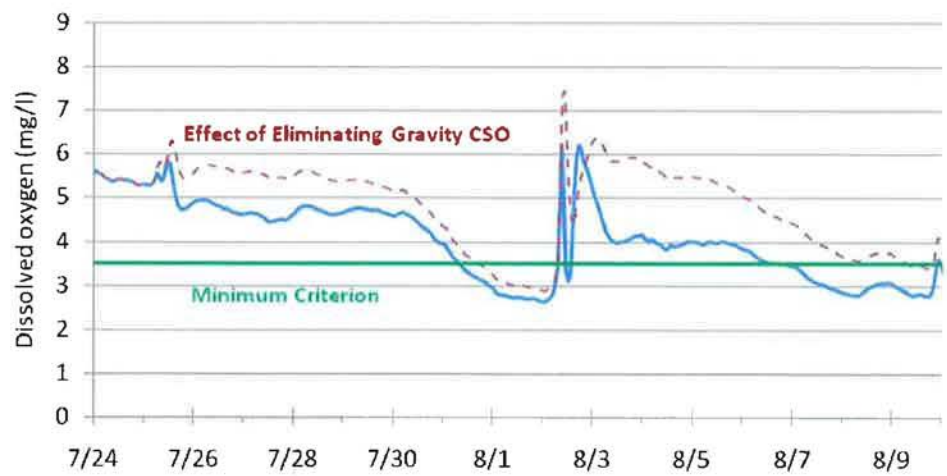


Figure 5. Comparison of Dissolved Oxygen Levels at Halsted Street, SBCR for Existing Conditions and Elimination of Gravity CSOs (2001)

Figure 6. Comparison of Dissolved Oxygen Levels at B&O Railroad Bridge, CSSC for Existing Conditions and Elimination of Gravity CSOs (2001)

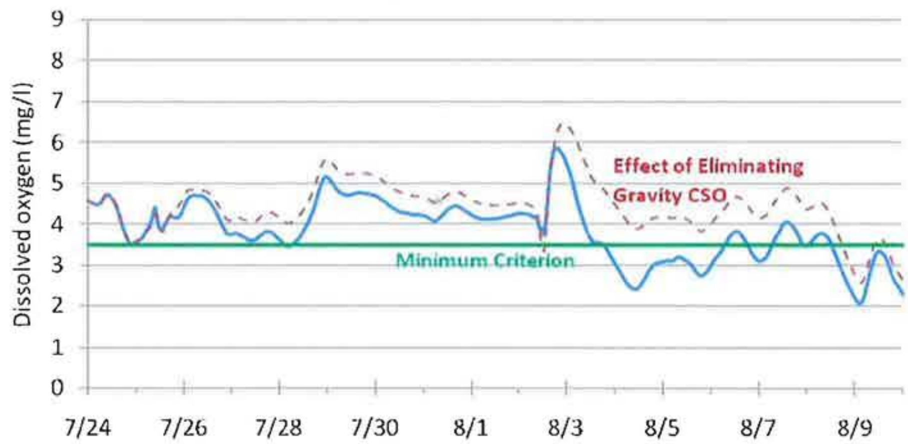


Figure 7. Comparison of Dissolved Oxygen Levels at Halsted Street, LCR for Existing Conditions and Elimination of Gravity CSOs (2001)

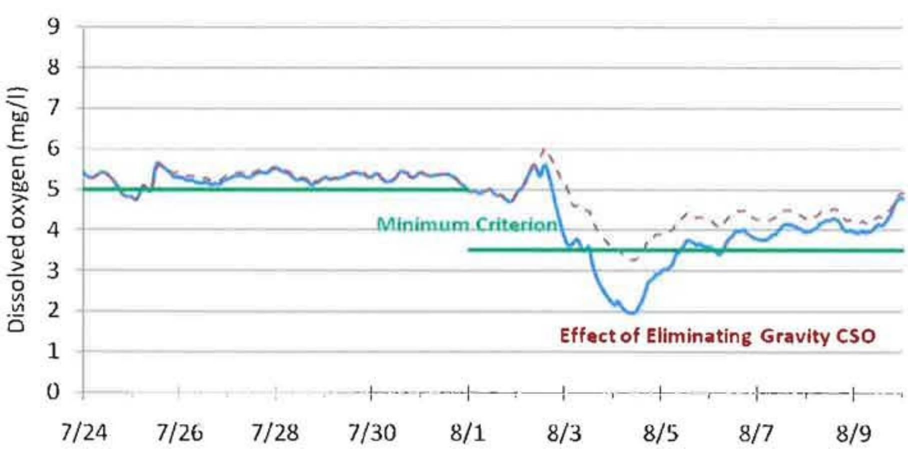


Figure 8. Comparison of Dissolved Oxygen Levels at Cicero Avenue, CSC for Existing Conditions and Elimination of Gravity CSOs (2001)

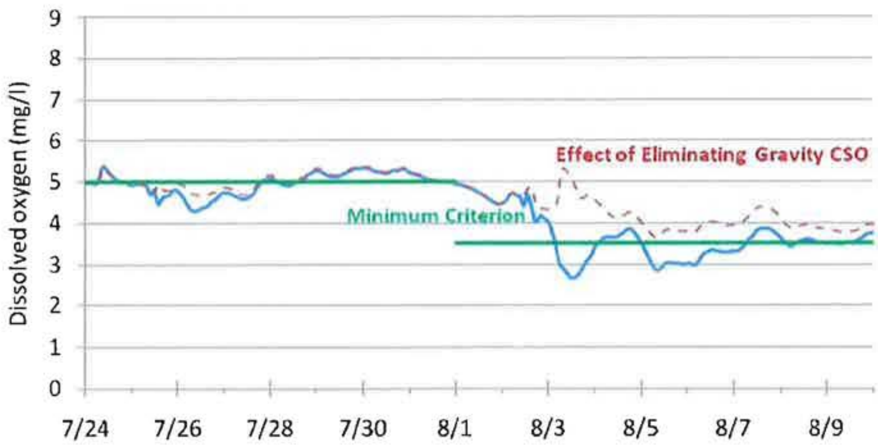


Figure 9. Comparison of Dissolved Oxygen Levels at Route 83, CSC for Existing Conditions and Elimination of Gravity CSOs (2001)

REFERENCES

Zhang, H., D. Bernstein, J. Kozak, J.S. Jain, R. Lanyon, E. Alp, and C.S. Melching. 2007. Evaluation of Eliminating Gravity CSOs on Water Quality of the Chicago Area Waterways (CAWs) Using an Unsteady Flow Water Quality Model. WEFTEC 2007. San Diego, CA. Oct. 13-17, 2007.

Attachment 5

EVALUATION OF THE DURATION OF STORM EFFECTS ON IN-STREAM WATER QUALITY

Emre Alp[1], Charles S. Melching[2]

CE DATABASE SUBJECT HEADINGS: Monte Carlo Method; Models; Watershed Management; Water Quality; Combined Sewer Overflows

---

[1] Post-Doctoral Researcher, Department of Civil and Environmental Engineering, Marquette University, P.O. Box 1881, Milwaukee, WI 53201-1881, USA. Tel: 414 2880690, Fax: 414 2887521 , e-mail: emre.alp@marquette.edu
[2] Associate Professor, Department of Civil and Environmental Engineering, Marquette University, P.O. Box 1881, Milwaukee, WI 53201-1881, USA. Tel: 414 2886080, Fax: 414 2887521 , e-mail: charles.melching@marquette.edu

Abstract

One of the primary reasons water-quality standards are not met is the effect of storm runoff and combined sewer overflows. A methodology is presented here to determine the duration of storm effects on stream water quality. The evaluation of the duration of storm effects on water quality involves two steps. First, calibration of an appropriate water quality model that is capable of simulation of unsteady-state conditions. Second, execution of the calibrated model with a number of storm loadings randomly sampled from a specific probability distribution that represents realistic ranges of pollutant concentrations. When the variations in the simulated water quality variables become negligible, it is assumed that the river system goes back to pre-storm, dry-weather conditions. To illustrate this methodology, the DUFLOW unsteady-state water quality model and Latin Hypercube Sampling are applied to evaluate the duration of storm effects on water quality in the Chicago Waterway System (CWS). The duration of the storm impacts on dissolved oxygen lasts 2 days to 2 weeks in the CWS depending on the location in the system and the magnitude of the storm. Moreover, a strong relation between the precipitation depth and the duration of the storm effects on in-stream water quality constituents was found in the CWS. Outcomes of this research suggest that the duration of the storm effect on water quality can reasonably be predicted with the help of robust unsteady-state water quality models.

Introduction

Because of storm related pollution like combined sewer overflows (CSOs), river systems may not meet the water quality standards defined by the existing uses of the river system. As the importance of the effects of CSOs on receiving water bodies is becoming more obvious, CSO regulations are becoming stricter. In 1994, The U.S Environmental Protection Agency (EPA) issued the Combined Sewer Overflow Control Policy, which contains provisions for developing appropriate, site-specific National Pollutant Discharge Elimination System requirements for all CSOs. Compliance most often takes the form of a long-term control plan, which outlines the selection and implementation of CSO control alternatives. Current EPA regulations and guidance, based on the Clean Water Act (CWA) and CSO Policy, are structured to provide States some flexibility to adapt water quality standards to reflect site-specific conditions, including those related to CSOs (Slack and Nemura, 2000). However, existing regulations provide that designated uses can only be removed if there is a reasonable basis for determining that current designated uses cannot be attained after implementing the technology based controls required by the CWA. In determining whether a use is attainable, EPA guidance requires the State to conduct and submit an Use Attainability Analysis (UAA). The methodology of the UAA is described in related manuals (USEPA, 1983a, Novotny et al., 1995)

If the problem of concern is a complicated phenomenon such that the UAA attributes the water quality standard violations to the both wet and dry weather periods, it could be necessary to determine the degree of attainment of the standards during wet and dry weather conditions to identify the problem precisely. By delineating wet and dry weather, it is possible to compare the contribution of both dry and wet weather management alternatives to the overall compliance with the water quality standards.

If continuous time series of five day carbonaceous biochemical oxygen demand ($CBOD_5$) and ammonium as nitrogen (NH_4-N) concentrations were available at short time steps, it is possible that the duration of the storm effect on these constituents could be determined from the measured $CBOD_5$ and NH_4-N concentrations. However, such a determination would require that the dry-weather conditions—temperature, flow from wastewater treatment plants and tributaries, boundary conditions, etc.—would be essentially the same as before the storm. Since such continuous data generally are not available, water-quality models must be used to estimate the duration of the storm effect. The situation for dissolved oxygen (DO) concentrations is much more complex because DO concentrations are influenced by many conditions and processes—temperature, flow dilution, treatment plant loads, $CBOD_5$, the nitrogen cycle, sediment oxygen demand (SOD), algal growth and death, etc.—each of which is subject to a different duration of storm effects. For example, DO recovery to pre-storm conditions does not indicate the end of the storm effect because the new dry weather DO concentration may have changed because of changes in temperature, SOD, treatment plant loads, etc. Again water-quality models must be used to determine the duration of the storm effect.

This paper describes a method for evaluation of the storm effects on in-stream water quality to define wet weather conditions and illustrates how different storm loadings affect the in-stream DO, $CBOD_5$, and NH_4-N concentrations in the Chicago Waterway System (CWS). A relation between precipitation and the duration of storm impacts on in-stream water quality is also examined. The relation between the precipitation and the duration of the wet weather conditions can help to estimate the duration of the wet weather conditions for future storms.

Method

Basically, an uncertainty analysis method is used together with an unsteady-state water quality model to determine the duration of wet weather conditions. This methodology starts with the assumption that the wet weather condition can be defined as the duration of storm effects on in-stream water quality. In this approach, a water quality model is successively applied with different storm loadings randomly sampled from a probability distribution representative of actual storm loads to the receiving water body using an uncertainty analysis technique. Then the variations in the water quality model output variables among the successive simulations are observed. When the variation in the model output variables approaches zero, it means the river system has returned to the pre-storm (dry weather) condition. Therefore, the duration between the start and the end of the variations in the simulated constituent concentrations can be defined as the duration of the storm effect on in-stream water quality, or the duration of the wet weather condition.

Since the purpose of this research is to separate dry weather conditions from wet weather conditions, it is necessary to work with a water quality model which is capable of simulating flows under unsteady conditions. The DUFLOW (2000) unsteady-state water-quality model developed in the Netherlands was selected for this study for the following reasons : 1) Several options are included for the simulation of water quality including a sediment flux model, 2) Compatibility with Geographical Information Systems, 3) Microsoft Windows based including a powerful graphical user interface, 4) Low license cost, 5) Low computational time, and 6) Successful application to several European rivers (e.g., Manache and Melching, 2004).

In this study, the DUFLOW water-quality simulation option that adds the DiToro and Fitzpatrick (1993) sediment flux model to the Water Quality Analysis Simulation Program (WASP4) (Ambrose et al., 1988) model of constituent interactions in the water column is applied. DUFLOW distinguishes among transported material that flows with water, bottom materials that are not transported with the water flow, and pore water in bottom materials that are not transported but that can be subject to similar water-quality interactions to those for the water column. Flow movement and constituent transport and transformation are two processes and constituent transport is defined by advection and dispersion.

The flow simulation in DUFLOW is based on the 1-D partial differential equations that describe unsteady flow in open channels (de Saint-Venant equations). These equations are the mathematical translation of the laws of conservation of mass and momentum.

The calibrated DUFLOW unsteady water quality model is successively executed with different storm loadings randomly sampled from a probability distribution to determine the duration of the storm effect on water quality. The Latin Hypercube Sampling (LHS) technique (McKay et al., 1979; McKay, 1988) is used in this study because of its good accuracy for a smaller sample size compared with Monte Carlo Simulation (MCS). For unsteady water quality models with high computational time requirements, the use of LHS has been suggested (Aalderink et al., 1996, Manache and Melching, 2004) because it provides the flexibility of MCS with less computational load. LHS has been used extensively in many studies. Vandenberghe et al. (2005) focused on diffuse nitrate pollution due to fertilizer use in the Dender River basin (Belgium) and applied LHS to analyze the uncertainty of water quality predictions caused by uncertainty in the inputs related to emissions of diffuse pollution. Sieber and Uhlenbrook (2005) used LHS to determine the most important parameters in a water quality model for the Brugga River basin and the sub-basin St. Wilhelmer Talbach (Germany). Mukhtasor et al. (2004) described an Ecological Risk Assessment procedure based on LHS. Sohrabi et al. (2003) used the ARRAMIS (Advanced Risk & Reliability Assessment Model) software package to apply the LHS scheme to analyze the uncertainty of the SWAT2000 (Soil and Water Assessment Tool) outputs concerning nutrients and sediment losses from the Warner Creek watershed, Maryland.

LHS is a type of stratified Monte Carlo sampling in which n different values are selected for each of k variables. The range of each variable is divided into n nonoverlapping intervals each having equal probability. One value from each interval is selected at random. For intervals based on equal probability, random sampling means random with respect to probability density in the interval. The n values thus obtained for X_1 are paired in a random manner with the n-values of X_2. These n pairs are combined in a random manner with the n values of X_3 to form n triplets, and so on, until n k-tuples are formed (Iman et al., 1981). This is the Latin Hypercube Sample, which is used as input for the model.

Case Study

Modeling Water Quality in the Chicago Waterway System

The Chicago Waterway System (CWS) is located in Northeastern Illinois, USA, and is composed of the Chicago Sanitary and Ship Canal (CSSC), Calumet-Sag Channel, North Shore Channel (NSC), lower portion of the North Branch Chicago River (NBCR), South Branch Chicago River (SBCR), Chicago River Main Stem, and Little Calumet River (north). The CWS, used mainly for commercial and recreational navigation and for urban drainage, is a 122.8 km branching network of navigable waterways controlled by hydraulic structures. The CWS receives pollutant loads from 3 of the largest wastewater treatment plants in the world, nearly 240 gravity CSOs, 3 CSO pumping stations, direct diversions from Lake Michigan, and eleven tributary streams or drainage areas. The water quality in the modeled portion of the CWS is also affected by the operation of four Sidestream Elevated Pool Aeration stations and two in-stream aeration stations. The Calumet and Chicago River Systems are shown in Figure 1.

The Illinois Pollution Control Board (IPCB) regulations (Title 35, Section 302.206 and Section 302.405) state that for General Use waters the DO concentration shall not be less than 6 mg/L during at least 16 hours of any 24 hour period, nor less than 5 mg/L at any time. In the CWS, only the upper NSC and the Chicago River Main Stem are considered General Use waters. The remainder of the CWS is considered Secondary Use (Indigenous Aquatic Life) waters wherein the DO concentration shall not be less than 4 mg/L at any time except that the Calumet-Sag Channel shall not be less than 3 mg/L at any time. This regulation was established in 1972 with the modification for the Calumet-Sag Channel in 1988, and since that time the Metropolitan

Water Reclamation District of Greater Chicago (MWRDGC) has made many improvements to the wastewater treatment plants (water reclamation plants), CSOs, and aeration resources of the CWS. Thus, in 2003 the Illinois Environmental Protection Agency initiated an UAA for the CWS to see if DO in the CWS could be brought closer to the General Use standard at a reasonable cost. In anticipation of this UAA and to meet other water-quality management needs the MWRDGC began an intensive sampling of hourly DO and temperature throughout the CWS in 1998, and entered into an agreement with Marquette University in 2000 to develop a water-quality model for the CWS that was suitable for simulating constituent concentrations during unsteady-flow conditions. The outcomes of this study and the DUFLOW water quality model for CWS developed by Marquette University have been supporting the CWS UAA study by identifying the causes of water quality problems and the effectiveness of management alternatives to achieve designated uses. The UAA has recommended revised uses of Modified Warm Water Aquatic Life for the NSC and the NBCR up to Fullerton Avenue and for the Calumet-Sag Channel and Little Calumet River (north), whereas the use for the rest of the system will be Limited Warm Water Aquatic Life. The exact DO targets for these uses still are under consideration by the IPCB.

The DUFLOW water-quality model was calibrated and verified for the periods of July 12-November 9, 2001, and May 1- September 23, 2002, respectively. 2001 was a relatively wet year and 2002 was a relatively dry year giving an acceptable variety of flows for the calibration and verification. Complete details of the calibration and verification are given in Alp and Melching (2006).

The comparison of measured and simulated hourly water-surface elevations at six locations throughout the CWS were used for hydraulic calibration and verification of the model. Statistical analysis for the locations used in the verification showed that the difference between the measured and simulated stages are all below 8.5 % relative to the depth of the water except for Wilmette. Wilmette is an upstream boundary location of the model located on the North Shore Channel (NSC) and observed flow was used as the upstream boundary condition. The mean and median error in water-surface elevation was 7.6 cm. Because of the generally low flows in NSC and the backwater effect from downstream portions of the CWS, it was difficult to decrease this error. This error was considered too small to significantly affect simulated water quality in the NSC, and so extraordinary means were not taken to improve this part of the hydraulic simulation. For the other locations, mean and median values of the absolute value of the difference between the measured and simulated stages are below 3.2 % relative to the depth at all locations. The simulated water-surface elevations were within 3% relative to depth for 93.7-99.9% of the measured values at all locations other than Wilmette. These high percentages of small errors and the high correlation coefficients (0.79-0.98) indicate an excellent hydraulic verification of the model.

An extensive data set including hourly in-stream DO data at 25 locations, monthly in-stream water-quality measurements at 18 locations, daily composite treatment plant effluent measurements, event mean concentrations for storm runoff from major tributaries and CSO pumping stations determined from multiple samples collected by the MWRDGC during selected events in 2001, daily solar radiation data, and detailed hydraulic data (at 15-min and 1-hour time steps) were used to calibrate and verify the water-quality model at a 1-hour output time step. All water quality variables including DO were measured by MWRDGC. The comparisons of the simulated constituent concentrations ($CBOD_5$, Nitrogen compounds, and Chlorophyll-a) with long-term mean measured concentrations, one standard deviation confidence bounds, and concentrations measured between July-November 2001 indicated reasonable simulations. There are approximately 2900 measured hourly DO data at each location within the calibration period and throughout the calibration process it was aimed to match hourly measured and simulated DO concentrations as much as possible. On the other hand, as Harremoës et al. (1996) mentioned, it is almost impossible to match all the measured hourly data if there are a large number of data to be fitted to. Hence, calibration was done manually in a way that the model can capture low DO concentrations resulting from CSOs and produce similar probability of exceedences for different DO concentrations. The focus on low concentrations was taken so that reliable management practices to mitigate the CSO effects could be determined. Comparisons of the percentage of DO concentrations less than 3, 4, 5, and 6 mg/L at different locations in the CWS for the calibration period for selected locations are listed in Table 1.

Close agreement between the calibrated and measured DO concentrations were obtained especially for the lower DO concentrations. The differences between the percentage of DO concentrations less than 3 mg/L for the calibrated and measured DO concentrations vary 0.0 to 4.5 percentage points at all 25 locations in the CWS except for the upper NSC. The differences between the percentage of DO concentrations less than 4 mg/L for the calibrated and measured DO concentrations are less than 10.6 percentage points in the CWS except for the upper NSC. Along the upper NSC it was difficult to match the measured DO concentrations because of the hydraulic conditions in the upper NSC, i.e. flow near zero except during CSO events. The differences between the percentage of DO concentrations less than 3 and 4 mg/L for the calibrated and measured DO concentrations reach up to -30.4 percentage points in the upper NSC. The overall average of the absolute differences of percentages of DO concentrations less than 3, 4, 5, and 6 mg/L for the calibrated and measured DO concentrations are 1.7, 4.4, 7.7, and 9.6 percentage points, respectively, in the CWS except for the upper NSC.

For model verification purposes, average values of constituent concentrations in CSOs taken as a mean from historic measured data were applied, whereas measured event mean concentrations were available at the CSO pumping stations for the calibration period. Verification of the CWS DUFLOW model generally shows good agreement between measured and simulated DO concentrations. For the entire CWS except the upper NSC the average error in daily DO concentration is 8.3 % and the average absolute percentage error is 26.9 % (Neugebauer and Melching, 2005). Comparison between the DUFLOW model prediction ability for the verification and calibration periods indicates that the prediction ability of the DUFLOW model is comparable for these two periods. It was concluded that, in general, the DUFLOW model represents water-quality processes in the CWS well enough for simulation of remediation strategies and to be used in the determination of the duration of the storm effects on water quality.

Duration of Effects of Combined Sewer Overflows in the Chicago Waterway System

The CWS receives a high amount of CSOs during larger storms. Hence the CWS is a good example study to determine the duration of storm effects on $CBOD_5$, NH_4-N, and DO concentrations.

Generation of the Latin Hypercube Sample

In this step, random values of the input variables are generated from their assigned distributions. Pollutant loadings from CSOs are the combination of CSO volume and pollutant concentrations. In this study, 8 constituents from each of the 3 pumping stations (Table 2) for a total of 24 variables are considered. Uncertainty in the CSO volume could affect the variability in the CSO loading. However, in order for the hydraulics of the channel to be properly simulated (i.e. to maintain the proper system-wide water balance and match the observed stage measurements) the overall CSO volume cannot vary substantially from the value used. Thus, in this study, the variation in CSO pollutant loads is considered using a fixed CSO flow and variable event mean concentrations (EMCs) of pollutants. For this reason, only CSO EMCs were used as input variables in the LHS simulations to determine the duration of the storm impact on in-stream water quality.

The flow from CSO drainage areas during storms has a substantial effect on the CWS. There are nearly 240 CSOs in the CWS drainage area. Since it is practically difficult to introduce all CSO locations in the modeling, 28 representative CSO locations were identified and flow distribution was done on the basis of drainage area for each of these locations. The volume of CSO was determined from the system wide flow balance and water level measurements at Romeoville. Successful results with hydraulic calibration and verification suggest that CSO volumes were reasonably estimated and distributed along the waterway system. Further, Novotny and Olem (1994, p. 484) state in most cases, the total load resulting from the runoff event is more important than the individual concentrations within the event due to the fact that runoff events are relatively short, the receiving water body provides some mixing, and the concentration in the receiving water body is a response to the total load rather than the concentration variability within the event. Similarly, the modeling results in this study have shown that if approximately the right amount of flow and pollutant loads are input to the CWS at approximately the right time and right location an acceptable simulation of the pollutant concentrations in the CWS has resulted. Further, the evaluation of storm durations was done at the DO monitoring locations which are sufficiently downstream from the representative CSO locations so that sufficient mixing of the water body has taken effect.

Because of the importance of the total load, the EMC has been found to be the most appropriate variable for evaluating the impact of urban runoff (U.S. EPA, 1983b). Hence, EMCs were used to characterize all storms in this study. Historic EMCs were calculated based on the measurements done by the MWRDGC for each pumping station listed in Table 2. The North Branch Pumping Station water-quality variables were used for NSC and NBCR CSOs, the Racine Avenue Pumping Station water-quality variables were used for the Chicago River Main stem and SBCR CSOs, and 125th Street Pumping Station water-quality variables were used for the Calumet-Sag Channel and Little Calumet River CSOs. The reasonableness of this approach was shown statistically in Neugebauer and Melching (2005). There are just 4 and 7 measured events for the 125th Pumping Station and the North Branch Pumping Station, respectively, for the statistical analysis. Thus, even though different probability distributions were tested, the limited number of data did not allow a robust conclusion on the appropriate probability distribution. Novotny (2004) showed that event mean concentrations in runoff follow the log-normal probability distribution. Therefore, the assumption of a log-normal probability distribution was made.

Several computer packages that include routines for MCS and LHS methods are available. In this study, the UNCSAM program developed by the Dutch Institute for Public Health and the Environment (Janssen et al., 1992) was used to generate 50 sets of random CSO pollution variables corresponding to the LHS procedure. As a general rule, as the sample size increases, the model output variability better converges to its true value. Because of the long computational time for the DUFLOW Model, selection of a reasonable sample size that can lead model output statistics to converge is an essential part of this step. In the literature different sample sizes have been suggested as varying between 4/3 to 5 times the number of the uncertain input variables (McKay, 1988; Manache, 2001). Since there are 24 input variables, fifty sets of random EMCs are enough to obtain satisfactory results.

Following the LHS method, fifty sets of the 8 input constituents were generated for each pumping station and related gravity CSOs and the DUFLOW model was run successively for each of the fifty CSO loadings. These DUFLOW model runs generated 50 sets of the concentrations of DO, $CBOD_5$, and NH_4-N in the CWS. Simulations were conducted for the DUFLOW calibration and verification periods. Calculations are based on a 15-minute computational time step and a 1 hour time step is used for the output variables to match the availability of measured DO concentrations.

Duration of the Effects of Combined Sewer Overflows on Dissolved Oxygen for 2001

To determine how long storm loadings affect the DO concentrations in the CWS for each location, the standard deviation of computed DO concentrations was plotted against time. At Romeoville the standard deviation was plotted against time together with the flow for the calibration period (Figure 2). As can be seen in Figure 2, the effects of some storms overlap and this makes it hard to distinguish the start and end time of the storm effects. Hence, some of the storms are combined and treated as a single storm.

It is a difficult question to set a rule to determine the start and the end of the storm load effect. Different approaches were tried to see if a specific rule can be applied to all constituents and locations. One of the approaches tried was to assume that there is no storm effect if the standard deviation is smaller than a certain set value. It was found that as this number gets smaller the system gets more sensitive to the selected set value. So it was difficult to select a number that works well for all storms at all locations. Another approach assumes that the standard deviations of simulated DO concentrations follow a statistical distribution (i.e. log-normal, normal) and there is no storm effect on DO after a specific probability of exceedence. For example, if the standard deviation of simulated DO concentrations compiled over all time steps follows a normal distribution with the mean and standard deviation of 0.6 and 0.2, respectively, it can be assumed that there is no storm effect after the DO standard deviation reduced to 0.27 which corresponds to a 5% probability of exceedence. This approach is problematic because every storm has different characteristics and each location responds differently to the storms making it difficult to come up with a specific execeedence probability that can be applied to all storms and locations. This makes the second approach more complicated than the first. The last approach assumes that storm effects start with the increase in the DO standard deviation and it ends when there is no significant change in the DO standard deviation (i.e. once the DO standard deviation reduces and essentially becomes a constant). Although it is hard to give a quantitative description for the rule of "no significant change in the DO concentration", since every reach in the CWS responds differently to a given storm, in general, it can be said that the DO standard deviation tends to become a constant quickly after the difference between daily average standard deviation of DO on consecutive days reduces to 15% or less. In this approach some engineering judgment is necessary to pinpoint the end of the storm event effects on DO, but this approach worked best for all storms and locations. The duration of the storm effects on DO concentrations was determined for the CWS using the last approach and the results are listed in Table 3 for the calibration period.

Substantial impact of storm loading on DO concentration in the CWS on average lasts one day to a few weeks depending on the location in the CWS (Table 3). For the combined storms (overlapping storms), the duration of wet weather effects is the result of consecutive storms hence durations of the effect of overlapping storms on in-stream water quality are longer than for other storms. Because of the hydraulic characteristics and behavior of the system, for most of the storms very similar durations are obtained at Cicero Avenue and Baltimore and Ohio Railroad, which are just upstream and downstream from Stickney Water Reclamation Plant (WRP), respectively. Effluent from the Stickney WRP dominates the hydraulics of the system. Due to small slopes and velocities (during low flow periods), the Stickney WRP discharge often flows in two directions: upstream from the plant and downstream towards Romeoville, causing in this way a "hydraulic dam" for upstream flow. In these sections water becomes practically stagnant. In such cases, the residence time of storm loads upstream from the plant are greater than downstream, and intensive self-purification processes consume DO while there is no additional source of DO other than atmospheric reaeration, which is very low.

For the larger storms (indicated by larger CSO volumes in Table 3) the system tends to respond very similarly at every location whereas for smaller storms the duration of storm impact is significantly larger at the downstream locations. For example, for the storms August 2 and 9, 2001, the duration of the storm effect lasts 15.5 and 18.2 days on the CSSC at Romeoville and on the NBCR at Fullerton Avenue, respectively, whereas for the July 25, 2001 storm, the duration of the storm effect lasts 8.6 and 5.5 days on the CSSC at Romeoville and on the NBCR at Fullerton Avenue, respectively. This is because for smaller storms a greater percentage of CSO flows occur at pumping stations, on the other hand for larger storms a greater percentage of CSO flows occur at gravity CSOs. Therefore, during larger storms the system receives a more homogenous CSO load which leads to a homogenous response time over the Chicago River System (NBCR-SBCR-CSSC). During smaller storms, the pumping stations produce relatively more CSO volume which leads to different storm impacts over the Chicago River System. The reason for this CSO flow distribution is twofold. The drainage areas for the pumping stations are 83.89, 40.97, and 15.43 km^2 for Racine Avenue, North Branch, and 125th Street, respectively. These drainage areas are far larger than those for individual gravity CSOs. Thus, because they capture runoff from larger areas the CSO pumping stations are more likely to discharge for smaller storms than are the gravity CSOs. Further, to avoid flow reversals from the CWS to Lake Michigan, the MWRDGC prefers to reserve space in the Tunnel and Reservoir Plan (TARP) tunnels for gravity CSOs at locations closer to the lake, and, thus, diverts relatively more flow during smaller storms to the CWS at the pumping stations. During larger storms all drainage areas generate runoff in excess of the interceptor capacity and the TARP tunnels fill resulting in a more even distribution of CSO flows.

Unlike the Chicago River System, the duration of storm effects for a given storm are very similar along the Calumet River System (Little Calumet River (north) – Calumet-Sag Channel). Since there is just one pumping station, 125th Street Pumping Station, and it is located close to upstream boundary (O'Brien Lock and Dam), differences in the volume of gravity and pumping station CSOs do not create a big variation in the duration of storm impacts along the river system.

Duration of the Effects of Combined Sewer Overflows on $CBOD_5$ and NH_4-N for 2001

Unlike the storm load effect on DO concentrations, it is relatively easy to pinpoint the end of the storm effect on $CBOD_5$ and NH_4-N concentrations. At Romeoville the standard deviations of simulated $CBOD_5$ and NH_4-N concentrations were plotted against time together with the flow (Figure 3). As can be seen in Figure 3, the standard deviation clearly decreases almost to zero except for overlapping storms. Hence, it is assumed that at the point where the $CBOD_5$ and NH_4-N standard deviation approaches zero the storm pollution load does not affect water quality in the system at that location anymore.

The storm effect on $CBOD_5$ and NH_4-N lasts from 2 days to 2 weeks depending on the storm and the location (Tables 4 and 5). In general, the duration of the storm effect on $CBOD_5$ and NH_4-N concentrations along the CSSC lasts 3-4 days longer than on the Calumet-Sag Channel. As expected, the duration of the storm effect on $CBOD_5$ and NH_4-N concentrations decreases towards upstream locations along CSSC and NBCR. On the other hand, in the Calumet Waterway System, the response of the river system to storm loading stays almost the same along the waterway for a given storm.

Duration of the Effects of Combined Sewer Overflows for 2002

The standard deviation of simulated DO concentrations for each location in the CWS, was plotted against time to determine how long storm loadings affect the 2002 verification period. The strategy explained in the previous section was followed to determine the duration of the storm effect on the simulated DO, $CBOD_5$, and NH_4-N concentrations. 2002 was a period of drier weather than was 2001, but the conclusions derived for 2001 are also valid for the 2002 verification period. Details of the 2002 simulations are given in Alp (2006).

Comparison of the duration of storm effects on water-quality constituents

Several statistical tests including an Analysis of Variance, Fischer's least significant difference, and the Kruskal-Wallis test were applied to compare the average of the duration of the storm impact on in-stream water quality among the studied constituents. For a given constituent, results for all storms were considered. The mean duration of the storm effects on in-stream DO, $CBOD_5$, and NH_4-N concentrations are the variables evaluated in the statistical comparison. A statistically significant difference amongst the medians was found at the 5 % significance level. Thus, from these tests it can be concluded that storm effect is longest on DO (on average 9.6 days) followed by $CBOD_5$ (7.2 days), and is shortest for NH_4-N (6.2 days). The duration of the storm effect on DO concentrations reflects a combination of different factors. Results showed that the storm effect continues on DO concentrations even though $CBOD_5$ and NH_4-N concentrations and flow go back to dry weather conditions. There are two main types of sinks of DO in the DUFLOW model, those in the water column and those from the sediments. Oxidation of $CBOD_5$, algal respiration, and nitrification are oxygen-consuming processes within the water column. The sediment sink involves diffusion of oxygen between the water body and the sediment layer and resuspension of oxygen consuming substances. Therefore, even though water column effects on DO stop, sediment effects on DO continue resulting in the almost constant DO standard deviations.

Relation between Precipitation and Duration of Storm Impact on Water Quality

It is important to understand the behavior of the CWS under storm loading conditions and to predict the duration of the storm effect on in-stream water quality constituent concentrations for future use. It was attempted to estimate the duration of the storm impact on water quality constituents by examining the precipitation data for the Chicago area.

Rainfall Data

A dense network of 25 raingages is operated by Illinois State Water Survey (ISWS) in Cook County, Ill. Since terrain effects are fairly minimal in northeastern Illinois, gridding which allows the use of simple arithmetic averaging to compute areal average precipitation depths was applied in the layout of the network (Westcott, 2003). Average precipitation for storms in 2001 and 2002 were computed using hourly precipitation data provided by the ISWS. Cook County was divided into several sub-areas to get a better understanding of rainfall distribution over the CWS drainage area. These included Cook County; the CWS drainage area (hereafter "Waterway"); the City of Chicago; the NBCR drainage area; the Chicago River main stem, SBCR, and CSSC drainage area; and the Little Calumet River and Calumet-Sag Channel drainage area.

Regression Analysis Results

Precipitation depth data were regressed against the duration of storm impact on water quality for all locations for the July 12 - November 9, 2001 and May 1 - September 23, 2002 periods. The highest correlation coefficients for DO regressions are obtained for the Chicago and Waterway sub-areas precipitation data for all locations. The overall average DO concentration correlation coefficients for the Chicago and Waterway precipitation data are very close at 0.86 and 0.87, respectively. The highest overall average $CBOD_5$ and NH_4-N concentration correlation coefficients are obtained for the Waterway precipitation data with an overall average of 0.80 for both $CBOD_5$ and NH_4-N concentrations. Results show that there is a strong relation between the total precipitation on the CWS drainage area and the duration of the storm effect on the in-stream water quality constituent concentrations. The strong relation between the precipitation depth and the duration of the wet weather effects on water quality also indicates that the hydrologic inputs to the CWS system have been reasonably estimated since precipitation is an independent variable that was not used to generate the CSO flows. The strong relations indicate it is possible to predict the duration of the storm loading effect on in-stream water quality constituent concentrations on the basis of accurate precipitation data. The regression equation plots and regression equations for a selected site are shown in Figure 4. It is possible that consideration of the duration of precipitation in the regression analysis could further improve the relations obtained, but the high coefficients of determination indicate that precipitation amount is a useful variable for a practical method to estimate the duration of storm effects for the CWS.

Figure 4 shows a clear relation between the total precipitation on the CWS drainage area and the duration of the storm effect on water-quality constituents even though a limited number of storms are used in this analysis. The correlation is the strongest for the DO concentrations and weakest for the NH_4-N concentrations. The practical side of this approach is that local authorities or decision makers can easily determine the duration of the wet weather conditions by examining precipitation data. It should be noted that these regression equations are valid for precipitation between 20.3 to 81.3 mm recorded over the CWS drainage area. For storms that result in precipitation larger than 81.3 mm, more studies are needed to extend the range of the regression estimates. The coefficient of determination, R^2, of 0.85 obtained at Romeoville for DO (Figure 4) indicates that 85% of the variance in the duration of the storm effects on DO concentrations can be explained by the magnitude of the precipitation. If the probability of occurrence of a certain magnitude of rainfall can be combined with the outcomes of the regression analyses, it may be possible to obtain generalized probabilistic conclusions about the duration of the storm impact on in-stream water quality.

Conclusions

Wet weather impacts resulting from urban catchments often create substantial problems for receiving water quality. One of the questions decision makers are always interested in is "how long does it take for a river to go back to pre-storm water quality conditions?" In other words, the question is "what is the duration of the storm effects on water quality?"

The results of this study show that application of a statistical sampling technique with an unsteady-state water quality model can result in reasonable estimates of the duration of wet weather conditions. The power of the calibrated water quality model plays an important role in the accurate determination of the duration of the wet weather period. Estimates of wet weather conditions may be as robust as the calibrated water quality model.

It was found that the duration of the wet weather period varies between 2 days to 2 weeks in the CWS. The magnitude and spatial distribution of the storm are the most important factors that affect the wet weather conditions in the receiving water body. Regression analysis showed that there is a strong relation between the precipitation measured in the CWS drainage area and the duration of the storm effects on in-stream water quality constituents. Regression equations derived from measured rainfall data and simulation results can be used to predict the duration of the storm effects on in-stream water quality for future storms so that wet weather periods can be determined from the total storm precipitation. This information can be useful for future water-quality management in the CWS. It is hoped the procedure illustrated here can be used to understand wet-weather conditions in other water bodies.

References

Aalderink, R.H., Zoeteman, A., and Jovin, R. (1996). Effect of input uncertainties upon scenario predictions for the River Vecht. *Water Science and Technology*, 33(2), 107-118.

Alp, E. (2006), "A method to evaluate duration of the storm effects on in-stream water quality." *Ph.D. Thesis*, Department of Civil and Environmental Engineering, Marquette University, Milwaukee, WI.

Alp, E. and Melching, C.S. (2006). Calibration of a model for simulation of water quality during unsteady flow in the Chicago Waterway System and application to evaluate use attainability analysis remedial actions. *Technical Report 18*, Institute of Urban Environmental Risk Management, Marquette University, Milwaukee, WI.

Ambrose, R.B., Wool, T.A., Connolly, J.P., and Schanz, R.W. (1988). WASP4, a hydrodynamic and water quality model—Model theory, User's manual, and programmer's guide. U.S. Environmental Protection Agency, *EPA/600/3-87-039*, Athens, GA.

Di Toro, D. M. and Fitzpatrick, J. (1993). *Chesapeake Bay Sediment Flux Model.* HydroQual, Inc. Mahwah, NJ. Prepared for U.S. Army Engineer Waterway Experiment Station, Vicksburg, MS. Contract Report EL-93-2.

DUFLOW (2000). *DUFLOW for Windows V3.3: DUFLOW modelling studio: User's guide, reference guide DUFLOW, and reference guide RAM*, EDS/STOWA, Utrecht, The Netherlands.

Harremoes, P., Napstjert, L., Rye, C., and Larsen, H.O. (1996). "Impact of rain runoff on oxygen in an urban river." *Water Science and Technology*, 34(12), 41-48.

Iman, R.L., Helton, J.C., and Campbell, J.E. (1981). "An approach to sensitivity analysis of computer models: Part I-Introduction, input variable selection and preliminary variable assessment." *Journal of Quality Technology*, 13(3), 174-183.

Janssen, P.H.M., Heuberger, P.S.C., and Sanders, R. (1992) *UNCSAM 1.1: a Software Package for Sensitivity and Uncertainty Analysis.* Report No. 959101004. National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands.

Manache, G. and Melching, C.S. (2004)."Sensitivity analysis of a water-quality model using Latin hypercube sampling." *Journal of Water Resources Planning and Management*, 130(3), 232-242.

Manache, G. (2001). "Sensitivity of a continuous water-quality simulation model to uncertain input parameters." *Ph.D. Thesis*, Chair of Hydrology and Hydraulics, Vrije Universiteit Brussel, Brussels, Belgium.

McKay, M.D., Beckman, R.J., and Conover W.J. (1979). "A comparison of three methods for selecting values of input variables in the analysis of output from a computer code." *Technometrics*, 21(2), 239-245.

McKay, M.D. (1988). "Sensitivity and uncertainty analysis using a statistical sample of input values." in *Uncertainty Analysis*, Y. Ronen, ed., CRC, Boca Raton, FL, p.145-186.

Mukhtasor, Husain, T., Veitch, B., and Bose, N. (2004). "An ecological risk assessment methodology for screening discharge alternatives of produced water." *Human and Ecological Risk Assessment*, 10(3), 505-524.

Neugebauer, A. and Melching, C.S. (2005). "Verification of a continuous water quality model under uncertain storm loads in the Chicago Waterway System." *Technical Report 17*, Institute of Urban Environmental Risk Management, Marquette University, Milwaukee, WI.

Novotny, V. and Olem, H. (1994). *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*, Van Nostrand Reinhold, New York.

Novotny, V., Braden, J., White, D., Capadaglio, A., Schonter, R., Larson, R., and Algozin, K. (1995). "A comprehensive UAA Technical Reference." *Proj. 91-NPS-1*, Water Environment Research Foundation, Alexandria, VA

Novotny, V. (2004). "Simplified databased total maximum daily loads, or the world is log-normal." *Journal of Environmental Engineering*, 130(6), 674-683.

Sieber, A. and Uhlenbrook, S. (2005). "Sensitivity analyses of a distributed catchment model to verify the model structure." *Journal of Hydrology*, 310(1-4), 216-235.

Slack, J. and Nemura, A. (2000). "Evolving wet weather and water quality standards issues for CSO communities." *WEFTEC 2000: Surface Water Quality and Ecology Symposium I: Wet Weather CSO Issues,* Water Environment Federation 73rd Annual Conference & Exposition on Water Quality and Wastewater Treatment, Anaheim, CA, October 14-18, 2000.

Sohrabi, T.M., Shirmohammadi, A., Chu, T.W., Montas, H., and Nejadhashemi, A.P. (2003). "Uncertainty analysis of hydrologic and water quality predictions for a small watershed using SWAT2000." *Environmental Forensics*, 4(4), 229-238.

U.S Environmental Protection Agency (USEPA). (1983a). *Water Quality Standards Handbook*, Office of Water Regulations and Standards, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). (1983b). *Results of the Nationwide Urban Runoff Program.* Vol. I. *Final Report*, *Water Planning Division*, U.S EPA, Washington, D.C.

Vandenberghe, V., van Griensven, A., Bauwens, W., and Vanrolleghem, P.A. (2005). "Propagation of uncertainty in diffuse pollution into water quality predictions: Application to the River Dender in Flanders, Belgium." *Water Science and Technology*, 51(3-4), 347-354.

Westcott, N.E. (2003). "Continued Operation of a 25-Raingage Network for Collection, Reduction, and Analysis of Precipitation Data for Lake Michigan Diversion Accounting: Water Year 2002." *Illinois State Water Survey Contract Report 2003-01*, 35 p.

List of Figures:

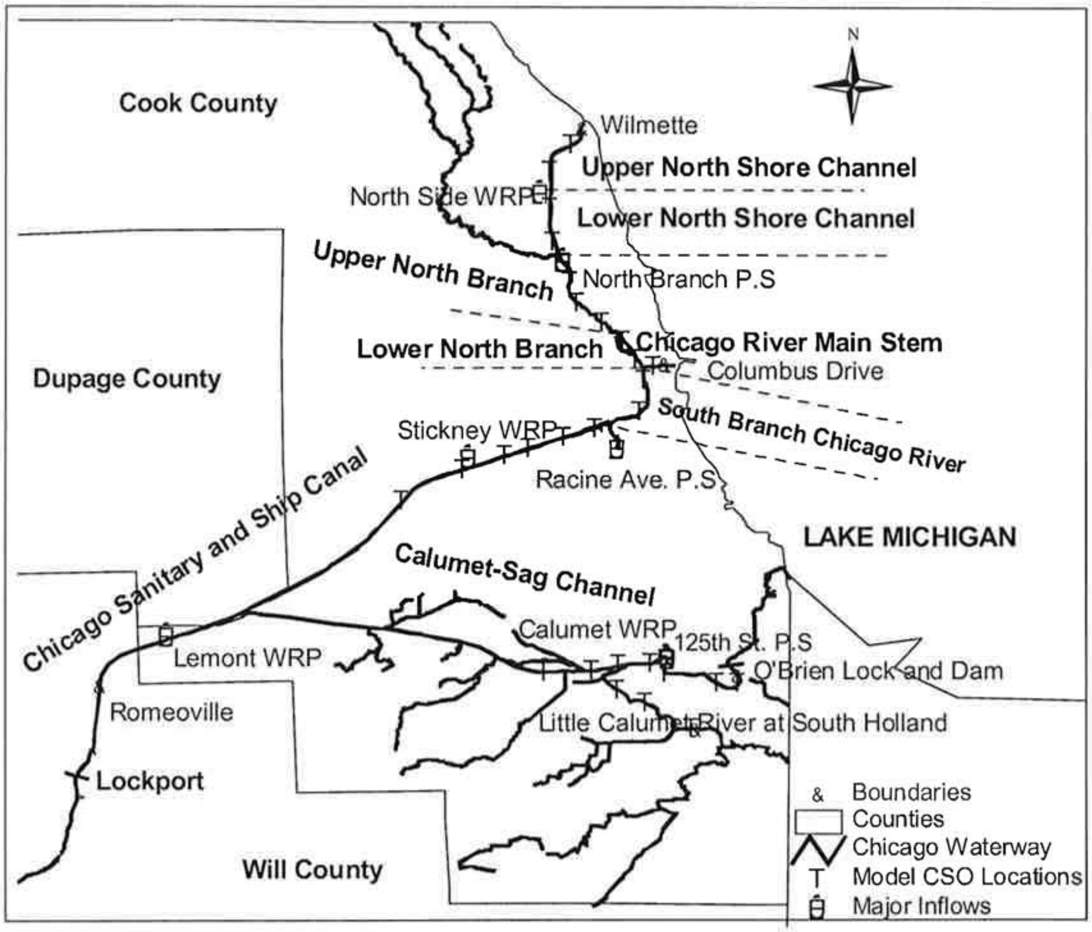


Figure 1. Schematic diagram of the Calumet and the Chicago River Systems (note: WRP means Water Reclamation Plant and P.S means Pumping Station)

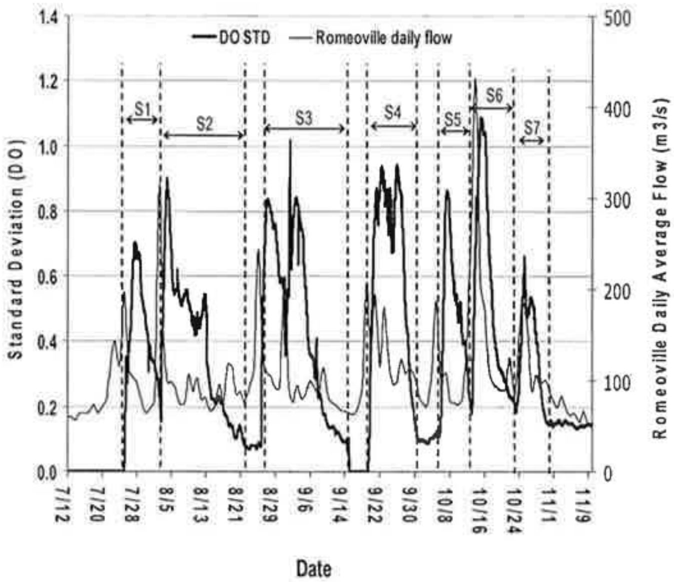


Figure 2. Flow and duration of the storm effect on the standard deviation of simulated DO concentration at Romeoville for July 12 to November 9, 2001

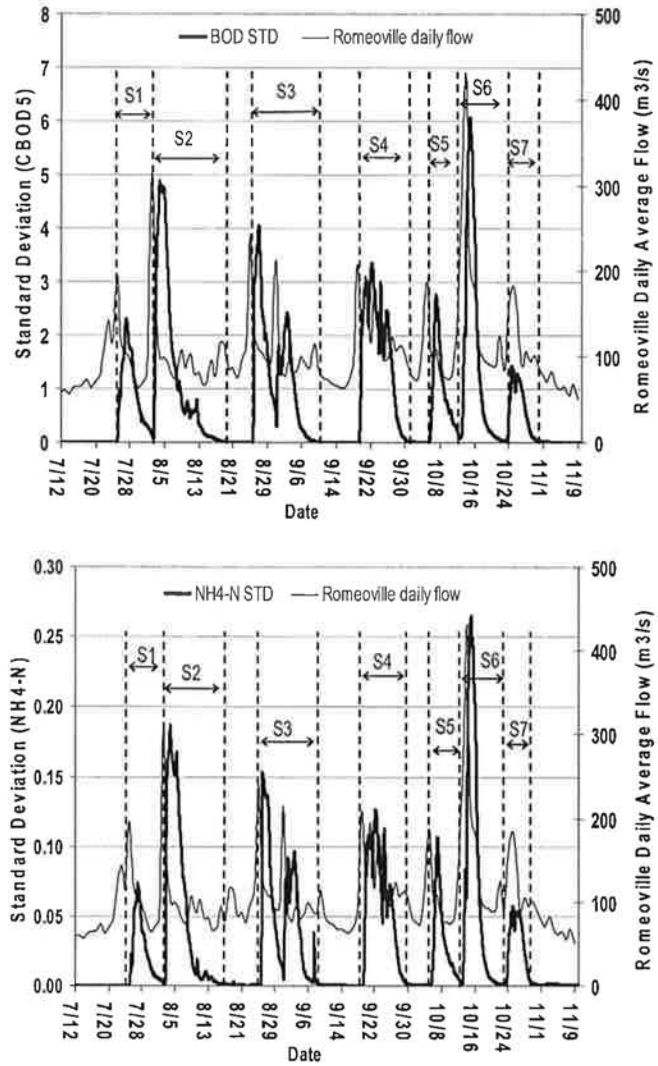


Figure 3. Flow and duration of the storm effect on the standard deviation of simulated $CBOD_5$ and NH_4-N concentrations at Romeoville for July 12 to November 9, 2001

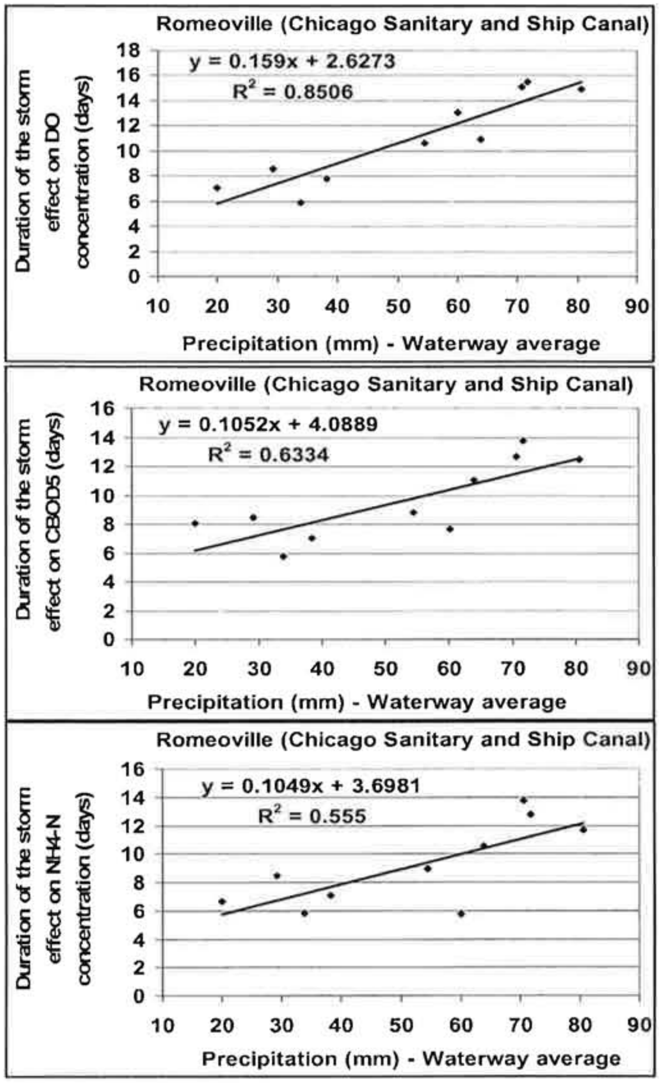


Figure 4. Relation between precipitation and the duration of the storm effects on simulated DO, $CBOD_5$, and NH_4-N concentrations at Romeoville for July 12-November 9, 2001 and May 1-September 23, 2002.

Table 1. Comparisons of the percentage DO concentrations less than 3, 4, 5, and 6 mg/L at different locations in the Chicago Waterway System for July 12-November 9, 2001

		Percent of DO (Measured and Calibrated) less than							
		< 3 mg/L		< 4mg/L		< 5 mg/L		< 6 mg/L	
Location	Waterway	Meas.*	Sim.**	Meas.	Sim.	Meas.	Sim.	Meas.	Sim.
Fullerton Avenue	NBCR	6.3	3.9	20.1	14	49.6	46.5	63.2	77
Cicero Avenue	CSSC	21.1	20.5	48.3	48.8	77	62.3	86.1	75.6
Baltimore and Ohio Railroad	CSSC	2.5	2.6	9.3	19.3	34.6	48.8	65.2	70
Romeoville	CSSC	17.2	17.9	40.8	37.3	77	61.1	87.3	74.6
Kedzie Street	Cal-Sag	1.1	0	4.7	3.9	15.6	15.1	38.9	51.1
104th Avenue	Cal-Sag	8.4	8.3	13.6	17	29.1	36.8	55.2	56.5

*Meas.: Measured; **Sim.: Simulated

Table 2. The mean values and variances used for the Latin Hypercube Sampling of the event mean concentrations in milligrams per liter for pumping stations discharging to the Chicago Waterway System

	North Branch Pumping S.		Racine Avenue Pumping S.**		125th Street Pumping S.	
Variable	Mean	Var.*	Mean	Var.	Mean	Var.
DO	4.0	3.6	6.9	8.1	4.3	0.0001
$CBOD_5$	35.4	303.2	51.2	341.8	25.7	262.0
NH_4-N	2.9	2.0	1.6	0.7	1.0	0.2
NO_3-N	0.7	0.1	0.8	0.04	1.8	0.1
N_{org}-N	6.1	11.6	4.1	0.9	3.6	1.0
P_{org}	1.0	0.5	0.2	0.003	0.4	0.049
P_{in}	0.4	0.3	0.7	0.040	1.3	3.1
SS	102	4554	825	241360	76	1634

*Var.: Variance, **S.: Station

Table 3. Magnitude of Combined Sewer Overflow (CSO) volume in m^3/s and the duration of storm effect on the simulated dissolved oxygen concentration in days at different locations in the Chicago Waterway System for July 12-November 9, 2001.

Event	1	2	3	4	5	6	7
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
Total Pump S. CSO	39.52	6.52	13.36	5.44	1.77	8.60	2.81
Total Gravity CSO	25.67	11.87	8.70	9.81	2.36	12.82	1.18
*Chicago River System**	**Duration of storm effect on dissolved oxygen concentration in days**						
Romeoville	8.6	15.5	15.1	10.9	7.8	10.6	7.0
Baltimore and Ohio Railroad	9.3	14.2	13.3	10.3	7.5	9.6	6.3
Cicero Avenue	9.2	14.7	15.8	10.2	8.0	9.5	7.7
Fullerton Avenue	5.5	18.2	12.8	9.0	5.2	5.8	3.8
*Calumet River System***	**Duration of storm effect on dissolved oxygen concentration in days**						
Route 83	7.5	10.5	15.6	11.1	6.5	9.7	2.5
Division Street	6.6	12.9	15.7	10.5	6.4	3.7	1.5
Halsted Street	8.0	13.6	15.4	10.4	7.3	11.1	1.5
Conrail Railroad	8.1	7.8	10.7	10.0	7.2	10.8	ND***

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (North)

*** ND= The duration of the storm effect on DO concentration cannot be detected since variations in simulated DO concentrations are negligible

Table 4. The duration of storm effect on the simulated $CBOD_5$ concentration in days at different locations in the Chicago Waterway System for July 12-November 9, 2001

Event	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
*Chicago River System**	**Duration of storm effect on $CBOD_5$ concentration in days**						
Romeoville	8.5	13.8	12.7	11.1	7.0	8.8	8.0
Baltimore and Ohio Railroad	9.3	13.7	12.7	10.5	7.3	7.3	7.3
Cicero Avenue	8.8	12.7	13.4	10.2	7.3	7.2	7.3
Fullerton Avenue	3.6	5.9	6.2	4.0	3.5	3.3	1.2
*Calumet River System***	**Duration of storm effect on $CBOD_5$ concentration in days**						
Route 83	7.0	9.3	11.9	10.3	5.8	10.5	4.4
Division Street	5.3	8.8	8.2	7.1	5.7	3.8	3.5
Halsted Street	1.2	1.8	2.9	4.5	0.8	1.8	0.7
Conrail Railroad	4.8	6.9	8.8	8.0	3.7	9.1	3.0

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (North)

Table 5. The duration of storm effect on the simulated NH_4-N concentration at different locations in the Chicago Waterway System for July 12-November 9, 2001

Event	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
*Chicago River System**	**Duration of storm effect on NH_4-N concentration in days**						
Romeoville	8.5	12.8	13.8	10.6	7.1	9.0	6.7
Baltimore and Ohio Railroad	6.7	7.4	10.7	9.0	6.2	6.2	5.1
Cicero Avenue	5.7	6.9	9.8	8.5	5.0	5.7	4.5
Fullerton Avenue	3.6	5.1	6.2	3.5	3.6	3.3	1.7
*Calumet River System***	**Duration of storm effect on NH_4-N concentration in days**						
Route 83	5.0	7.5	10.0	9.5	5.2	5.1	3.5
Division Street	4.9	6.2	8.4	5.8	4.0	3.7	3.7
Halsted Street	5.2	7.7	9.8	8.7	4.5	9.7	2.7
Conrail Railroad	5.0	7.4	9.6	6.3	3.8	9.8	1.9

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (North)

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
WATER QUALITY STANDARDS AND	)	
EFFLUENT LIMITATIONS FOR THE	)	R08-9
CHICAGO AREA WATERWAY SYSTEM	)	(Rulemaking - Water)
AND THE LOWER DES PLAINES RIVER:	)	
PROPOSED AMENDMENTS TO 35 Ill.	)	
Adm. Code Parts 301, 302, 303 and 304	)	

PRE-FILED TESTIMONY OF CHARLES S. MELCHING

INTRODUCTION

My name is Charles S. Melching and I am an Associate Professor of Civil and Environmental Engineering at Marquette University in Milwaukee, Wisconsin. I hold a Bachelor of Science degree from Arizona State University and Master of Science and Doctor of Philosophy degrees from the University of Illinois at Urbana-Champaign. I am also a licensed Professional Engineer in Illinois and Arizona.

I have more than 20 years of post-doctorate experience in the fields of water resources and environmental engineering research (theoretical and applied) and education. I have been awarded the 2001 Walter L. Huber Civil Engineering Research Prize from the American Society of Civil Engineers and the 2008 Outstanding Researcher Award from the College of Engineering at Marquette University. My professional experience includes 2.5 years as a Visiting Scholar at the Laboratory of Hydrology at the Vrije Universiteit Brussel in Belgium; 2.5 years as an Assistant Professor of Civil and Environmental Engineering at Rutgers University; 7.5 years as a Hydraulic Engineer/Hydrologist with the U.S. Geological Survey, Illinois District; 1 year as a Visiting Professor in the Department of Hydraulic Engineering at Tsinghua University in Beijing, China; and 9 years at Marquette University. Details of my work at these places are given in my curriculum vitae, which is Attachment 2 to this testimony.

My experience in water-quality modeling began in 1990 at Rutgers University with an uncertainty analysis of the QUAL2E model applied to the Passaic River. Other modeling experience includes developing a QUAL2E model for Salt Creek in Illinois in cooperation with the Illinois Environmental Protection Agency (IEPA); modeling of streams in Belgium; modeling the Milwaukee Outer Harbor; and advising the U.S. Geological Survey North Dakota, Kentucky, Minnesota, and Florida Districts on modeling projects. I also have a long history of working on the Chicago Area Waterway System (CAWS) beginning in 1992 when I evaluated the flow measurements at the acoustical velocity meter on the Chicago Sanitary and Ship Canal at Romeoville. I then assisted U.S. Geological Survey colleagues on the measurement program done in support of the U.S. Army Corps of Engineers Accounting of Lake Michigan Diversion. This experience with the CAWS led to my selection as the Hydrologic and Hydraulic Modeling Expert for the 5th (2003) and 6th (2008) Technical Committees for the Review of the Lake Michigan Diversion Accounting selected by the U.S. Army Corps of Engineers, Chicago District. This experience with water-quality modeling and the CAWS led to my selection by the Metropolitan Water Reclamation District of Greater Chicago (District) to develop an unsteady flow water-quality model of the CAWS (DUFLOW model) in 2000.

OVERVIEW

My opinions are set forth in greater detail in the report provided as Attachment 1 of this testimony. The purpose of my testimony is threefold. First, my testimony describes the DUFLOW model developed for the CAWS and its reliability. The model has been used to evaluate water-quality management scenarios involving (a) supplemental aeration on the North and South Branches of the Chicago River, (b) flow augmentation on the North Shore Channel, and (c) a combination of these water-quality improvement technologies for the South Fork of the South Branch (Bubbly Creek) as described in Attachments OO, PP, and QQ, respectively, of the rulemaking proposal before the Board. The model also was used to determine the ineffectiveness of pollutant removal at selected gravity combined sewer overflows (CSOs), to consider supplemental aeration in the Chicago Sanitary and Ship Canal, and to evaluate the effects of disinfection on fecal coliform concentrations in the CAWS (references are given in Attachment 1). Finally, the model is currently being refined in order to develop an integrated strategy combining flow augmentation, supplemental aeration, and perhaps other technologies to achieve the proposed water-quality standards throughout the CAWS.

Second, my testimony describes unique and complex features of the hydraulics of the CAWS determined by the modeling studies. A large amount of flow, water-surface elevation, cross-sectional geometry, aeration, and pollutant load data have been collected for the CAWS by the District, U.S. Geological Survey, and U.S. Army Corps of Engineers. The model integrates and interprets these data on the basis of hydraulic theory and well accepted pollutant transport and transformation concepts, and as such the model can facilitate understanding of the fundamental operations and flow and pollutant patterns in the CAWS. Third, implications of the unique and complex hydraulic features of the CAWS are integrated with the results of the determination of biological potential reported in the Use Attainability Analysis (Attachment B of the rulemaking proposal before the Board) to discuss reasonable aquatic life use goals for the CAWS. The second and third issues are the focus of this oral testimony.

HYDRAULICS OF THE CAWS

The following testimony will try to illustrate some key hydraulic features of the CAWS that influence the biological potential of the CAWS. IEPA indicated on pages 19-20 in its Statement of Reasons that: "Flow reversal projects, such as this one, place a premium on head differential. The entire system has minimum slope and, consequently, low velocity, stagnant flow conditions." The evaluation of flow and water-surface elevation data used to apply the

DUFLOW model and the hydraulic results of the modeling reveal just how stagnant the CAWS is and the potential limitations to the current and future biological community.

Flow reversals

It is well known that large storms can result in flow reversals from the CAWS to Lake Michigan. The flow need not result in a reversal to Lake Michigan to have a flow reversal within the CAWS. Because the water-surface slope of the CAWS is so small and the flow from the North Side, Stickney, and Calumet Water Reclamation Plants is substantially higher than the flow upstream of these Plants, flow reversals also are common during dry weather flows upstream of the Plants. Figures 4-6 in Attachment 1 show that for each of the Plants, the water-surface elevations "upstream" of the Plants frequently are lower than those "downstream" of the Plants. Thus, the outfall of each of the Plants acts as a hydraulic dam inserting treated effluent to the upstream reaches and then holding it and upstream flows back to truly stagnate in the upstream reaches. This backflow explains why the upper North Shore Channel remains ice free for many miles north of the North Side Plant. The bi-directional flow gives us some impression of the unnatural condition of the CAWS.

Slow travel times

The DUFLOW model was used to determine average travel times in the CAWS. Table 2 in Attachment 1 lists the average travel times, lengths, and average velocities for several reaches in the CAWS for the July 12 to September 15, 2001 simulation period. The hydraulic dam upstream from the Stickney Plant is obvious as it takes 2.5 days to go 8 miles from Madison Street to Cicero Avenue. The hydraulic dam upstream from the Calumet Plant also is obvious as it takes 1.5 days to go 2.3 miles from Indiana Avenue to Halsted Street.

Huge travel times and low flow velocities also are apparent upstream from the junction of the Chicago Sanitary and Ship Canal and the Calumet-Sag Channel. This is because when the

Chicago Sanitary and Ship Canal was originally constructed the Calumet-Sag Channel was not anticipated and the Chicago Sanitary and Ship Canal cross-sectional geometry is the same upstream and downstream from Sag Junction. Thus, Sag Junction acts like two lanes narrowing to one lane on the freeway with large backups and long travel times resulting. In total it takes more than 8 days for water to travel from the upstream ends of the North Shore Channel and Little Calumet River (north) to Romeoville on the Chicago Sanitary and Ship Canal. For perspective, we should remember that 5-day biochemical oxygen demand (BOD) was originally taken as the standard measurement because the test was devised in England, where the River Thames has a travel time to the ocean of less than 5 days, so there was no need to consider oxygen demand at longer times. The long travel time gives us further impression of the unnatural condition of the CAWS. This feature of the CAWS contributes to the lower dissolved oxygen that is observed in CAWS compared to general use rivers because of the reduced natural reaeration resulting from low velocity and very low slope. Further, this feature of the CAWS makes it challenging and costly to disperse dissolved oxygen that is contributed artificially from engineered aeration stations.

Wet weather effects

IEPA appears to assume that the duration of storm effects on water quality lasts only as long as the causative rainfall, or the period of elevated flow rates. However, research on the CAWS shows that the effect of storm runoff and CSOs on water quality lasts substantially longer than the hydraulic effects of the storm. That is, once a load of pollutants is introduced to the system, it takes longer for the system to dissipate the effects of these loads than it does to pass the high flows.

Merely considering the time for dissolved oxygen (DO) recovery to pre-storm levels does not indicate the end of the storm effect because the new dry weather DO concentration may have changed because of changes in temperature, sediment oxygen demand, treatment plant loads, etc. Dr. Emre Alp proposed and tested (on the CAWS) a method to determine the duration storm effects on water quality. In his approach, the DUFLOW water-quality model was successively applied with different storm 5-day carbonaceous BOD and ammonium as nitrogen loadings (i.e. Event Mean Concentrations) randomly sampled from a probability distribution representative of the Event Mean Concentration data collected by the District at the CSO pump stations using an uncertainty analysis technique. Then the variations in the DUFLOW model output parameters among the successive simulations were observed. When the variation in the model output parameters approaches zero, it means the river system has returned to the pre-storm (dry weather) condition. Therefore, the duration between the start and the end of the variations in the simulated DUFLOW model output parameters can be defined as the duration of the storm effect on in-stream water quality, or the duration of the wet-weather condition. A paper summarizing this approach was recently accepted for publication in the Journal of Water Resources Planning and Management, American Society of Civil Engineers validating the approach and the DUFLOW model of the CAWS through peer review.

Substantial impact of storm loading on DO concentration in the CAWS on average lasts one day to a few weeks depending on the location in the CAWS (see Exhibit 1, which is Table 3 in Attachment 1). The storm effect on five-day carbonaceous BOD ($CBOD_5$) and ammonium as nitrogen (NH_4-N) lasts from 2 days to 2 weeks depending on the storm and the location (see Exhibits 2 and 3, which are Tables 4 and 5 in Attachment 1). In general, the duration of the storm effect on $CBOD_5$ and NH_4-N concentrations along the Chicago River System (North Branch Chicago River-South Branch Chicago River-Chicago Sanitary and Ship Canal) lasts 3-4 days longer than on the Calumet River System (Little Calumet River (north)-Calumet-Sag Channel).

The key point to be derived from Exhibits 1-3 (i.e. Tables 3-5 in Attachment 1) is that even at upstream locations the CSO loadings can affect water quality for more than a week for some storms. This long storm effect is related to the hydraulic dams and other stagnant conditions in the CAWS. Further the long storm effects can negatively impact the aquatic community, and these long storm effects cannot be reduced until the reservoirs of the Tunnel and Reservoir Plan are fully on line. Exhibit 4 (Table 6 in Attachment 1) lists the duration of storm effects on DO, $CBOD_5$, and NH_4-N averaged over all locations in Exhibits 1-3 and compares this with the duration of elevated flows (i.e. greater than 100 m^3/s, 3,530 ft^3/s) at Romeoville for all the single storm events in simulated periods of 2001 and 2002. The comparison shows that the duration of storm effects on water quality can be up to 4 times longer than the duration of elevated flows at Romeoville. Thus, the effects of storm flows on the ability to meet water quality standards should not be considered a trivial or insignificant problem for the CAWS. The long effects of storm flows on water quality also indicate that it may be appropriate to consider wet weather standards for the CAWS.

In summary, the following hydraulic features of the CAWS distinguish it from natural systems. The normal flow in the CAWS is bidirectional in places and very slow everywhere, and as a result wet weather impacts can linger for long periods suggesting that wet weather standards may be appropriate for the CAWS. Further, the combination of low velocities and very low slope limits natural reaeration and challenges the effectiveness of supplemental aeration due to the slow distribution throughout the water body of the artificially introduced oxygen. This challenge will become greater as DO standards are raised.

RELATIONSHIPS BETWEEN HYDRAULIC AND ECOLOGICAL CONDITIONS

The CAWS effectively is a long, narrow, moderately deep impoundment not at all similar to natural streams. Even dam impoundments on formerly natural streams have variation in habitat and substrate including shelter areas for fish, whereas these features are generally absent from the CAWS.

Habitat (QHEI) and biological (IBI) scoring

Rankin (1989) examined relations between the Qualitative Habitat Evaluation Index (QHEI) and the Index of Biological Integrity (IBI) in order to develop a procedure for relating stream potential to habitat quality that would provide some insight into how habitat might affect biological expectations in a given water body. The goal of his study was to provide guidance on the specification of aquatic life uses (i.e. potential aquatic ecological community) for water bodies that were impaired by pollution impacts. To develop the relations between QHEI and its subcomponent metrics and life uses Rankin (1989) considered data from a large number and wide variety of streams in Ohio. This procedure was used by Rankin (2004) [Attachment R to the proposal before the Board] to estimate life uses of Modified Warmwater Habitat and Limited Resource Water for the reaches designated Aquatic Life Use A and B water, respectively, in the proposal before the Board.

The IEPA states that where QHEI is "higher" and IBI is "lower" this indicates that improvement in water quality is needed to achieve the ecological potential of the "higher" QHEI.[1] Rankin (1989, p. 12) noted that "using the QHEI as a site-specific predictor of IBI can vary widely depending on the predominant character of the habitat of the reach." He also presented examples that showed that a QHEI of 50 could result in a low or a very high IBI. Thus, whether the higher QHEI scores found in select portions of the CAWS are truly indicative of a higher potential ecological community for the CAWS requires further consideration.

[1] April 23, 2008 Hearing, transcript at pp. 211-216.

Effect of poor habitat on biology

One way to determine whether a higher QHEI score truly indicates higher biological potential is to consider in detail the nature of the key habitat metrics included in the QHEI. Rankin (1989, p.13) noted "Analysis of the frequency of occurrence of QHEI metric subcomponents among IBI ranges indicates that "negative" habitat characteristics generally (but not universally) contribute more to the explanation of deviations from a random distribution with IBI range than "positive" habitat characteristics." The key metric subcomponents are substrate quality, pool quality, and channel quality.

Poor habitat in the CAWS

Rankin (1989, p. 24) noted "The influence of high quality substrates is probably related to their importance in providing food organisms (macroinvertebrates) to the insectivores and benthivores that typify midwest streams." Insectivores and benthivores are different groupings of fish based on the preferred diet of the fish.

The macroinvertebrate data on the CAWS reported in CDM (2007) [Attachment B of the proposal before the Board] clearly illustrates the poor quality of the substrate present in the CAWS. For 17 of the 18 locations sampled with a petite ponar dredge the Macroinvertebrate Biotic Index (MBI) indicated very poor water-quality whereas at 16 locations where Hester Dendy samplers were used the MBI indicated that the water quality was fair or good. Hester Dendy samplers are plates placed in the water that provide an artificial substrate which can be colonized by macroinvertebrates. The grab sample reflects conditions in the sediment at a site whereas the artificial substrate shows/predicts the potential benthic community in the drift that will settle on the plate. The difference in the sampler results shows that CAWS substrate will prevent any further improvements in water quality from translating to a better macroinvertebrate community and will not likely result in improvements in aquatic life use. The fact that the

CAWS has a poor substrate is no surprise, because the system is completely human created, rather than a natural system that was allowed to geologically develop over thousands of years and, thus, develop appropriately varied substrates. Additional details on what constitutes a balanced, healthy benthic community and its preferred substrate conditions are presented in the fact witness testimony of Jennifer Wasik of the District.

With respect to pool quality, Rankin (1989, p. 24) noted sites with fast currents had higher IBI scores than expected by chance. As noted in Table 2 in Attachment 1 the average flow velocity is less than 1 ft/s and for more than 60 percent of the CAWS the average velocity is less than 0.4 ft/s. These velocities are very low compared to the reach average velocities for the 234 measurements in the U.S. Geological Survey roughness coefficient database for Illinois (http://il.water.usgs.gov/proj/nvalues/) where only one measurement was less than 0.4 ft/s and more than 87 percent of the measurements had velocities greater than or equal to 1 ft/s.

With respect to channel quality, Rankin (1989, p. 25 and 29) noted

a) streams with little or no sinuosity were associated with lower IBI scores,
b) sites with only fair to poor riffle/pool development generally have lower IBI scores and sites with excellent to good development have higher IBI scores, and
c) lower gradients are generally, but not universally, associated with lower IBI values and higher gradient scores with higher IBI values.

The CAWS falls at the lower extreme of all these factors.

Rankin (1989, p. 41) listed the key features that result in a stream to be classified as a Modified Warmwater Stream (the analogue of Warmwater Aquatic Life Use A) noting that streams with QHEI scores between 45 and 60 should have several of the primary factors to be considered a Modified Warmwater Stream. Exhibit 5 (Table 7 in Attachment 1) lists the habitat features that distinguish between Modified Warmwater Streams and Warmwater Streams (i.e. the analogue of General Use waters). Among these primary features for Modified Warmwater Streams the CAWS has recent channelization (truly permanent channelization), silt/muck substrates (in many reaches), low-no sinuosity, cover sparse to none (in many reaches), poor pool and riffle development, and lack of fast current. Thus, there can be no doubt that the potential ecological community is degraded by habitat impairment in the CAWS. Also, this analysis indicates that the Calumet-Sag Channel is more of a poor habitat (Warmwater Aquatic Life Use B) than a fair habitat (Warmwater Aquatic Life Use A). In March 10, 2008, IEPA testimony it was stated that the Calumet-Sag Channel is different from the Chicago Sanitary and Ship Canal.[2] While they are different, they are not substantially different. For example, threadbare tires are different from tires with an eighth of an inch of tread, but both are dangerous to drive on.

The ecological community in the CAWS is substantially impaired by poor habitat, as IEPA acknowledged during its testimony.[3] The U.S. Environmental Protection Agency (U.S. EPA) has established a DO criterion of 3.0 mg/L for full attainment of warmwater life uses. IEPA indicated that it does not expect Aquatic Life Use A waters to meet the Clean Water Act goals, but is here proposing that both A and B waters achieve DO levels of at least 3.5 mg/L—even higher than would be required by U.S. EPA.[4] Further, IEPA has proposed a DO standard for Aquatic Life Use A of 5.0 mg/L for March through July to support early life stages, with no evidence that the habitat and physical characteristics of the CAWS could support such a use or attain the proposed criterion. Essentially, the rulemaking proposal before the Board is requiring

[2] March 10, 2008 Hearing, transcript (morning) at pp. 31-32.
[3] January 28, 2008 Hearing, transcript at p. 220; January 29, 2008 Hearing, transcript at p. 104; March 10, 2008 Hearing, transcript (morning) at p. 33.
[4] March 10, 2008 Hearing, transcript (morning) at p. 28.

that the degraded CAWS meet in certain critical aspects the General Use standards in rule R04-25 that was recently adopted by the Board. A tabular comparison of the rulemaking proposal before the Board and the General Use standards is included in the expert testimony of Freedman.

Alternative approaches to DO criteria

In the State of Ohio the DO criteria for Modified Warmwater Streams (the equivalent of Warmwater Aquatic Life Use A) is a daily minimum of 3.0 mg/L and a daily average of 4.0 mg/L, and the minimum reduces to 2.5 mg/L in the Huron/Erie Lake Plain Ecoregion (Ohio rule 3745-1-07). Whereas for Limited Resources Waters (the equivalent of Warmwater Aquatic Life Use B) the criterion for the daily minimum is 2.0 mg/L with a daily average of 3.0 mg/L (Ohio rule 3745-1-07). Similarly, Novotny et al. (2007) [Attachment WW of the proposal before the Board] recommended a daily minimum of 3.0 mg/L and a daily mean of 4.0 mg/L for Brandon Pool, which has been designated Warmwater Aquatic Life Use B.

In the IEPA testimony on April 24, 2008, the partial justification for the selected DO criteria was the target fish species largemouth bass, smallmouth bass, and channel catfish, whose protection is sought by the target DO criteria with smallmouth bass and channel catfish as the targets for the early life stages protection.[5] Mr. Roy Smogor characterized channel catfish and smallmouth bass protection as follows: "For early life stages that are as sensitive as the early life stages of channel catfish or smallmouth bass, we need to keep the dissolved oxygen levels above a daily minimum of five in order to protect for those types of early life stages."[6]. Consideration should then be given to whether the CAWS offers suitable habitat for early life stages of these fish species.

[5] March 10, 2008 Hearing, transcript (morning) at pp. 70-71; April 24, 2008 Hearing, transcript at pp. 98-99.
[6] April 24, 2008 Hearing, transcript at p. 99.

Alternative analysis of CAWS habitat

In the early 1980s, the Fish and Wildlife Service of the U.S. Department of the Interior did detailed literature reviews seeking to identify the physical and chemical conditions of water bodies suitable for various fish species. These models are known as Habitat Suitability Indexes (HSIs), where a value of 1 indicates optimal habitat and 0 indicates unsuitable habitat. These models are not perfect predictors, and in each report for the species of interest here a statement appears indicating the species of interest may be present even if the suitability index is 0, and habitat with a high suitability index may contain few fish. The Fish and Wildlife Service recommends that the suitability indices should be compared with fish data for the water body of interest before interpreting the suitability results. HSI ratings have been developed for each of the target fish species for the CAWS.

The summary of the Habitat Suitability evaluation detailed in Attachment 1 indicates the CAWS is poor habitat for adult smallmouth bass and channel catfish, which is consistent with the low abundance of these fish in the CAWS (see fish relative abundance data in the UAA report, Attachment B to the rulemaking proposal before the Board). It is, however, near optimal habitat for adult largemouth bass, which is consistent with the high abundance of this fish in the CAWS (see fish abundance data in the UAA report, Attachment B to the rulemaking proposal before the Board). Further, the high abundance of largemouth bass implies that the current water quality of the CAWS is sufficient for a healthy largemouth bass community and higher standards are not needed. However, the CAWS is poor habitat for early life stages of all these target fish species.

The tributaries of the CAWS might have suitable habitat for early life stages of the target fish species. However, District fish sampling data from 1996, 1997, and 2001-2005 indicate that none of these species were found in the lower reaches of the North Branch Chicago River upstream from the junction with the North Shore Channel. Further, District fish sampling data from 2001-2005 indicate that none of these species were found in the Little Calumet River (south). Finally, District fish sampling data from 2001-2005 indicate largemouth and smallmouth bass are the third and fourth, respectively, most abundant species in the Calumet River upstream from O'Brien Lock and Dam. Thus, it seems these fish enter the CAWS from Lake Michigan not the CAWS tributaries. Thus, seeking to protect early life stages for these species of fish in the CAWS is inconsistent with the habitat suitability and the available fish abundance data.

CONCLUSIONS

When summarizing the relation between habitat, fish communities, and water-quality management Rankin (1989, p. 52) offered the following warning:

> It makes little sense to "protect" the biota by multimillion dollar improvements to a point source discharge while important biological uses are impaired by habitat modifications for reasons such as "flood control", construction activities, and waterway improvements.

Considering the foregoing discussion of habitat, the rulemaking proposal before the Board is contrary to the findings of the UAA contractors. For example, CDM indicated that "The data showed that the aquatic habitats were rated from very poor to fair with most reaches having habitat unable to support a diverse aquatic community."[7] CDM also stated, "Improvements to water quality through various technologies, like re-aeration may not improve the fish communities due to the lack of suitable habitat to support the fish population."[8] Further, Novotny recommended the previously described lower DO standards (relative to the proposal

[7] CDM (2007) [Attachment B to proposed rule R08-9], page 1-12.
[8] CDM (2007) [Attachment B to proposed rule R08-9] page 5-3.

before the Board) for the Warmwater Aquatic Life Use B waters in the Brandon Pool of a daily minimum of 3.0 mg/L and a daily mean of 4.0 mg/L .[9]

I hope that the Illinois Pollution Control Board will carefully consider this testimony and other supporting documents, and should not hastily approve the rulemaking proposal before the Board, when the State of Illinois and the Chicago Area have many other problems requiring public financing.

[9] Novotny et al. (2007) [Attachment WW to proposed rule R08-9].

Respectfully submitted,

Charles S. Melching

By: *Charles S. Melching*

Testimony Attachments

1. Supporting Report for the Pre-Filed Testimony of Charles S. Melching with Respect to Proposed Rule R08-9
2. Curriculum Vitae

Exhibit 1—Melching Testimony

Table 3. Magnitude of Combined Sewer Overflow (CSO) volume in m^3/s and the duration of storm effect on the simulated dissolved oxygen concentration in days in the Chicago Area Waterway System for July 12-November 9, 2001. (after Alp, 2006)

Event	1	2	3	4	5	6	7
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
Total CSO	65.19	18.39	22.06	15.25	4.13	21.43	3.99
Total Pump S. CSO	39.52	6.52	13.36	5.44	1.77	8.60	2.81
Total Gravity CSO	25.67	11.87	8.70	9.81	2.36	12.82	1.18
*Chicago River System**	**Duration of storm effect on dissolved oxygen concentration in days**						
Romeoville	8.6	15.5	15.1	10.9	7.8	10.6	7.0
River Mile 11.6	8.6	14.0	13.9	10.8	7.5	10.3	6.3
Route 83	8.8	15.3	14.9	10.8	7.7	10.3	6.9
Baltimore and Ohio Railroad	9.3	14.2	13.3	10.3	7.5	9.6	6.3
Cicero Avenue	9.2	14.7	15.8	10.2	8.0	9.5	7.7
Jackson Boulevard	9.4	16.6	15.5	9.0	6.8	10.9	4.3
Kinzie Street	8.2	17.5	13.5	8.3	6.1	7.3	4.4
Division Street	7.6	18.5	13.5	9.3	7.2	7.6	4.6
Fullerton Avenue	5.5	18.2	12.8	9.0	5.2	5.8	3.8
Addison Street	2.0	14.6	12.8	8.8	1.2	3.3	2.1
*Calumet River System***	**Duration of storm effect on dissolved oxygen concentration in days**						
Route 83	7.5	10.5	15.6	11.1	6.5	9.7	2.5
104th Street	7.9	14.0	13.3	10.9	7.2	10.8	2.3
Southwest Highway	8.1	13.4	16.9	10.6	6.2	11.2	2.0
Harlem Avenue	7.5	13.1	16.8	10.5	6.1	11.2	2.2
Cicero Avenue	7.4	14.5	16.2	10.3	7.0	11.1	2.1
Kedzie Avenue	6.9	14.3	15.9	9.9	6.4	10.9	2.0
Division Street	6.6	12.9	15.7	10.5	6.4	3.7	1.5
Halsted Street	8.0	13.6	15.4	10.4	7.3	11.1	1.5
Conrail Railroad	8.1	7.8	10.7	10.0	7.2	10.8	ND***

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (north)

*** ND= The duration of the storm effect on DO concentration cannot be detected since variations in simulated DO concentrations are negligible

Exhibit 2—Melching Testimony

Table 4. Magnitude of Combined Sewer Overflow (CSO) volume in million gallons (MG) and the duration of storm effect on the simulated five-day carbonaceous biochemical oxygen demand ($CBOD_5$) concentration in days in the Chicago Area Waterway System for July 12-November 9, 2001 (after Alp, 2006)

Event	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
Total CSO Volume	1488	4859	5828	4029	1092	5660	1054
Total P.S. CSO Volume	902	1723	3530	1437	468	2272	743
Total Gravity CSO Volume	586	3136	2298	2592	624	3388	311
Location *Chicago River System**	**Duration of storm effect on $CBOD_5$ concentration in days**						
Romeoville	8.5	13.8	12.7	11.1	7.0	8.8	8.0
River Mile 11.6	8.6	13.4	12.8	10.8	7.4	8.4	8.1
Route 83	8.8	14.5	13.0	10.8	7.3	8.2	7.8
Baltimore and Ohio Railroad	9.3	13.7	12.7	10.5	7.3	7.3	7.3
Cicero Avenue	8.8	12.7	13.4	10.2	7.3	7.2	7.3
Jackson Boulevard	6.4	12.2	11.3	8.2	5.1	4.8	5.4
Kinzie Street	5.8	8.7	8.7	8.0	6.3	4.5	4.5
Division Street	5.3	8.8	8.2	7.1	5.7	3.8	3.5
Fullerton Avenue	3.6	5.9	6.2	4.0	3.5	3.3	1.2
Addison Street	2.8	5.0	4.7	3.4	2.3	3.3	2.1
Location *Calumet River System***	**Duration of storm effect on $CBOD_5$ concentration in days**						
Route 83	7.0	9.3	11.9	10.3	5.8	10.5	4.4
104th Street	6.0	8.0	10.8	9.5	5.9	9.8	3.2
Southwest Highway	5.3	7.5	10.5	9.0	4.8	9.5	3.1
Harlem Avenue	6.1	7.5	10.1	9.0	4.8	9.5	4.8
Cicero Avenue	4.9	7.0	9.9	8.6	7.3	8.8	3.5
Kedzie Avenue	4.2	6.8	8.8	7.7	7.2	8.3	2.1
Division Street	5.3	8.8	8.2	7.1	5.7	3.8	3.5
Halsted Street	1.2	1.8	2.9	4.5	0.8	1.8	0.7
Central and Wisconsin Railroad	4.4	7.8	9.0	9.0	4.0	9.1	2.0
Conrail Railroad	4.8	6.9	8.8	8.0	3.7	9.1	3.0

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (north)

Exhibit 3—Melching Testimony

Table 5. Magnitude of Combined Sewer Overflow (CSO) volume in million gallons (MG) and the duration of storm effect on the simulated ammonium as nitrogen (NH_4-N) concentration in days in Chicago Area Waterway System for July 12-November 9, 2001 (after Alp, 2006)

Event	1	2	3	4	5	6	7
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
Total CSO Volume (MG)	1488	4859	5828	4029	1092	5660	1054
Total P.S. CSO Volume(MG)	902	1723	3530	1437	468	2272	743
Total Gravity CSO Volume (MG)	586	3136	2298	2592	624	3388	311
Location *Chicago River System**	**Duration of storm effect on NH_4-N concentration in days**						
Romeoville	8.5	12.8	13.8	10.6	7.1	9.0	6.7
River Mile 11.6	8.2	12.1	13.3	10.0	7.2	8.7	6.3
Route 83	7.4	6.9	11.7	9.5	7.0	7.0	5.6
Baltimore and Ohio Railroad	6.7	7.4	10.7	9.0	6.2	6.2	5.1
Cicero Avenue	5.7	6.9	9.8	8.5	5.0	5.7	4.5
Jackson Boulevard	4.0	6.5	10.4	8.0	5.1	4.8	3.5
Kinzie Street	4.8	6.3	9.1	6.2	4.8	4.1	2.8
Division Street	4.9	6.2	8.4	5.8	4.0	3.7	3.7
Fullerton Avenue	3.6	5.1	6.2	3.5	3.6	3.3	1.7
Addison Street	3.0	3.9	5.9	3.5	2.1	2.2	0.6
Location *Calumet River System***	**Duration of storm effect on NH_4-N concentration in days**						
Route 83	5.0	7.5	10.0	9.5	5.2	5.1	3.5
104th Street	4.8	6.9	9.5	9.0	4.7	4.3	2.5
Southwest Highway	4.9	7.0	9.5	9.0	4.8	4.3	2.5
Harlem Avenue	4.9	7.1	9.6	9.0	4.7	4.3	2.6
Cicero Avenue	5.2	7.4	9.7	9.0	4.0	4.2	2.5
Kedzie Avenue	4.8	7.0	9.3	8.5	4.0	4.0	2.0
Division Street	4.9	6.2	8.4	5.8	4.0	3.7	3.7
Halsted Street	5.2	7.7	9.8	8.7	4.5	9.7	2.7
Central and Wisconsin Railroad	4.9	7.4	9.5	8.2	3.8	9.2	1.9
Conrail Railroad	5.0	7.4	9.6	6.3	3.8	9.8	1.9

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (north)

Exhibit 4—Melching Testimony

Table 6. Duration of storm effects in days on dissolved oxygen (DO), carbonaceous biochemical oxygen demand ($CBOD_5$), and ammonium as nitrogen (NH_4-N) averaged over all locations listed in Tables 3-5 and duration of storm effects on flow for storms whose effects did not overlap onto other storm periods.

Date	DO	$CBOD_5$	NH_4-N	Flow
July 25, 2001	8.6	8.5	8.5	8.0
October 5, 2001	7.8	7.0	7.1	4.0
October 13, 2001	10.6	8.8	9.0	7.0
October 23, 2001	7.0	8.0	6.7	4.0
July 9, 2002	10.8	12.2	7.6	3.0
August 22, 2002	13.0	7.7	5.8	6.0

Exhibit 5—Melching Testimony

Table 7. Habitat Characteristics of Modified Warmwater Streams (Warmwater Aquatic Life Use A) and Warmwater Streams (General Use Waters) in Ohio. Superscripts for Modified Warmwater Streams refer to the influence of a particular characteristic in determining the use (1 = high influence, 2 = moderate influence). Characteristics apply to all ecoregions and types unless otherwise noted. [after Rankin (1989, p. 41)]

Feature Number	Modified Warmwater Streams	Warmwater Streams
1	Recent channelization[1] or recovering[2]	No channelization or recovered
2	Silt/muck substrates[1] or heavy to moderate silt covering other substrates[2]	Boulder, cobble, or gravel
3	Sand substrates[2-Boat], Hardpan origin[2]	Silt free
4	Fair-poor development[2]	Good-excellent development
5	Low-no sinuosity[2, 1-Headwater]	Moderate-high sinuosity
6	Only 1-2 cover types[2], Cover sparse to none[1]	Cover extensive to moderate
7	Intermittent or interstitial[2-with poor pools]	Fast currents, eddies
8	Lack or fast current[2]	Low-normal substrate embeddedness
9	Maximum depth < 40 cm[1-Wading, 2-Headwater]	Maximum depth > 40 cm
10	High embeddedness of substrates[2]	Low/no embeddedness

Note: Development refers to pool and riffle development

ATTACHMENT 1

SUPPORTING REPORT FOR THE

PRE-FILED TESTIMONY OF CHARLES S. MELCHING

WITH RESPECT TO PROPOSED RULE R08-9

Summary of Relevant Experience

My name is Charles S. Melching and I am an Associate Professor of Civil and Environmental Engineering at Marquette University in Milwaukee, Wisconsin. I hold a Bachelor of Science degree from Arizona State University and Master of Science and Doctor of Philosophy degrees from the University of Illinois at Urbana-Champaign. I am also a licensed Professional Engineer in Illinois and Arizona.

I have more than 20 years of post-doctorate experience in the fields of water resources and environmental engineering research (theoretical and applied) and education. I have been awarded the 2001 Walter L. Huber Civil Engineering Research Prize from the American Society of Civil Engineers "For his research on uncertainty and reliability analysis in water resources and environmental engineering, including especially uncertainty in rainfall-runoff and stream water-quality modeling." I also received the Outstanding Researcher Award from the College of Engineering at Marquette University in 2008. My professional experience includes 2.5 years as a Visiting Scholar at the Laboratory of Hydrology at the Vrije Universiteit Brussel in Belgium; 2.5 years as an Assistant Professor of Civil and Environmental Engineering at Rutgers University; 7.5 years as a Hydraulic Engineer/Hydrologist with the U.S. Geological Survey, Illinois District; 1 year as a Visiting Professor in the Department of Hydraulic Engineering at Tsinghua University in Beijing, China; and 9 years at Marquette University. Details of my work at these places are given in my curriculum vitae, which is Attachment 2 to my testimony.

My experience in water-quality modeling began in 1990 at Rutgers University with an uncertainty analysis of the QUAL2E model applied to the Passaic River sponsored by the New Jersey Water Resources Research Institute (Melching and Yoon, 1996). While with the USGS I developed a QUAL2E model for Salt Creek in Illinois (Melching and Chang, 1996) in cooperation with the Illinois Environmental Protection Agency in support of the Total Maximum Daily Load (TMDL) analysis for Salt Creek. I also headed a national project to compile and analyze all stream reaearation-rate coefficient data collected by the U.S. Geological Survey (Melching and Flores, 1999). I also became a national advisor on water-quality modeling within the U.S. Geological Survey advising on the application of QUAL2E to the Red River of the North done by the North Dakota District and to the Middle Fork and South Fork Beargrass Creek done by the Kentucky District; and of the Hydrological Simulation Program Fortran to the Minnesota River basin done by the Minnesota District and to the Reedy Creek basin done by the Florida District. I then did an uncertainty analysis for the watershed and stream water-quality models applied to the Seine River in Brussels, Belgium, sponsored by the Research in Brussels Program (Melching and Bauwens, 2000, 2001). The Seine River is similar to the Chicago Area Waterways in that it is a heavily modified urban stream fed by a network of combined sewers. I also advised on an uncertainty analysis of water-quality modeling for the Dender River in Belgium (Manache and Melching, 2004, 2007, 2008).

Because of these past experiences in water-quality modeling, I was selected by the Metropolitan Water Reclamation District of Greater Chicago (District) in 2000 to develop a water-quality model (DUFLOW model) of the Chicago Area Waterway System (CAWS). Also at Marquette University, I developed an unsteady-flow water-quality model to evaluate ammonia toxicity in the Milwaukee Outer Harbor (Melching et al., 2006) for the Milwaukee Metropolitan Sewerage District. I co-taught with Prof. Vladimir Novotny a TMDL training course for the Illinois Environmental Protection Agency in July 2002. Finally, from 2004 to 2007 I served on the "Technical Advisory Committee on Regional Water Quality Management Plan Update for the Greater Milwaukee Watersheds" and "Water Quality Modeling Subcommittee" formed by the Southeastern Wisconsin Regional Planning Commission.

I also have a long history of working on the CAWS beginning in 1992 when I evaluated the consistency of the flow measurement at the acoustical velocity meter on the Chicago Sanitary and Ship Canal at Romeoville and developed back-up equations for this meter (Melching and Oberg, 1993). I then assisted U.S. Geological Survey colleagues on the measurement program done in support of the U.S. Army Corps of Engineers Accounting of Lake Michigan Diversion. This experience with the CAWS led to my selection as the Hydrologic and Hydraulic Modeling Expert for the 5th (2003, see Espey et al. (2004)) and 6th (2008) Technical Committees for the Review of the Lake Michigan Diversion Accounting selected by the U.S. Army Corps of Engineers, Chicago District. This experience with the CAWS also contributed to my selection by the District to develop a water-quality model of the Chicago Area Waterway System.

Purpose of Testimony

The purpose of my testimony is threefold. First, my testimony will describe the DUFLOW model developed for the CAWS and its reliability. The model has been used to evaluate water-quality management scenarios involving (a) supplemental aeration on the North and South Branches of the Chicago River, (b) flow augmentation on the North Shore Channel, and (c) a combination of these water-quality improvement technologies for the South Fork of the South Branch (Bubbly Creek) as described in Attachments OO, PP, and QQ, respectively, of the rulemaking proposal before the Board. The model also was used to determine the ineffectiveness of pollutant removal at selected gravity combined sewer overflows (CSOs) (Alp and Melching, 2006; Alp et al., 2007), to consider supplemental aeration in the Chicago Sanitary and Ship Canal (Alp and Melching, 2006), and to evaluate the effects of disinfection on fecal coliform concentrations in the CAWS (Manache and Melching, 2005; Manache et al., 2007). Finally, the model is currently being refined in order to develop an integrated strategy combining flow augmentation, supplemental aeration, and perhaps other technologies to achieve the proposed water-quality standards throughout the CAWS.

Second, my testimony will describe unique and complex features of the hydraulics of the CAWS determined by the modeling studies. A large amount of flow, water-surface elevation, cross-sectional geometry, aeration, and pollutant load data have been collected for the CAWS by the District, U.S. Geological Survey, and U.S. Army Corps of Engineers. The model integrates and interprets these data on the basis of hydraulic theory and well accepted pollutant transport and transformation concepts, and as such the model can facilitate understanding of the fundamental operations and flow and pollutant patterns in the CAWS. Key findings are summarized in my testimony.

Third, implications of the unique and complex hydraulic features of the CAWS will be integrated with the results of the determination of the biological potential reported in the Use Attainability Analysis (Attachment B of the rulemaking proposal before the Board) to discuss reasonable aquatic life use goals for the CAWS.

Water Quality Model

Basic Features

Because poor water quality in the CAWS results in both dry weather and wet weather conditions, it is necessary to work with a water-quality model which is capable of simulating flows under unsteady conditions, particularly those resulting from storm runoff and CSOs. The DUFLOW (2000) unsteady-state water-quality model developed in the Netherlands by a joint effort of the Rijkswaterstaat (National Water Authority), International Institute for Hydraulic and Environmental Engineering of the Delft University of Technology, STOWA (Foundation for Applied Water Management Research), and the Agricultural University of Wageningen was selected for this study. DUFLOW was selected for the following reasons: 1) Several options are included for the simulation of water quality including a sediment flux model, 2) Compatibility with Geographical Information Systems, 3) Microsoft Windows based including a powerful graphical user interface, 4) Low license cost, 5) Low computational time, and 6) Successful application to many European rivers (see the web site http://www.mx-groep.nl/duflow/, click on the top tab "Projects", then the interior tab "Projects", and finally on the Dutch flag for a long list of applications in Dutch with some in English; if a message "Not in English is received" click of the Dutch flag again to see the list in Dutch). In particular, I had worked with DUFLOW in the modeling of the Dender River in Belgium (Manache and Melching, 2004). The uncertainty analysis involved hundreds of simulations for a one year time period with very few computational problems encountered. This indicated that the model was computationally robust, which is a very important when simulating a complex system like the CAWS. Finally, because the hydraulic and water-quality models are directly coupled, DUFLOW offered computational advantages over the versions of WASP (U.S. Environmental Protection Agency Water Quality Analysis Simulation Program) available when this project started in 2000.

In this study, the simulation of dissolved oxygen (DO) was done using the DUFLOW water-quality simulation option that adds the DiToro and Fitzpatrick (1993) sediment flux model to the WASP4 model (Ambrose et al., 1988) of constituent interactions in the water column. DUFLOW distinguishes among transported material that flows with water, bottom materials that are not transported with the water flow, and pore water in bottom materials that are not transported but that can be subject to similar water-quality interactions to those for the water column. Flow movement and constituent transport and transformation are two processes and constituent transport is defined by advection and dispersion. The following constituents, represented as both water and sediment components, are included in the DUFLOW model: algal biomass species, suspended solids concentration, total inorganic phosphorus, total organic phosphorus, total organic nitrogen as nitrogen, ammonium as nitrogen (NH_4-N), nitrate as nitrogen, DO, and carbonaceous biochemical oxygen demand (CBOD). The combination of

WASP4 and the DiToro and Fitzpatrick sediment flux model represents the state-of-the-art in stream water-quality modeling.

DUFLOW is written in an open code format that allows users to modify the existing built-in water-quality models and add new routines. This feature was utilized for the CAWS to be able to calibrate the reaeration-rate coefficient calculations and to add a simple first-order decay model to represent fecal coliform losses in the CAWS (Manache and Melching, 2005, Manache et al., 2007).

The flow simulation in DUFLOW is based on the one-dimensional (1-D) partial differential equations that describe unsteady flow in open channels (de Saint-Venant equations). These equations are the mathematical translation of the laws of conservation of mass and momentum. Solution of the de Saint-Venant equations represents the state-of-the-art in 1-D hydraulic modeling in river systems.

Model Domain, Geometry, and Inputs

Model Domain—The DUFLOW model was applied to a portion of the CAWS including the Chicago Sanitary and Ship Canal (CSSC), Calumet-Sag Channel, North Shore Channel (NSC), North Branch Chicago River (NBCR), South Branch Chicago River (SBCR), Chicago River Main Stem, Bubbly Creek, and Little Calumet River (north). The Grand Calumet River, Lake Calumet, and the Calumet River north of O'Brien Lock and Dam were not included in the DUFLOW model because of a lack of detailed hydraulic data to accurately simulate these portions of the CAWS. The simulated portion of the CAWS is a 76.3 mi branching network of navigable waterways controlled by hydraulic structures that receives flow and pollutant loads from 3 of the largest wastewater treatment plants in the world, nearly 240 gravity CSOs, 3 CSO pumping stations, direct diversions from Lake Michigan, and eleven tributary streams or drainage areas. The water quality in the modeled portion of the CAWS is also affected by the operation of four Sidestream Elevated Pool Aeration stations and two in-stream aeration stations (Devon Avenue and Webster Street). The Calumet and Chicago River Systems are shown in Figure 1.

Two hundred sixteen measured cross sections at different points along the river were used to describe the geometry of the river. Within DUFLOW cross-sections were interpolated at computational nodes spaced no more than 1,640 ft apart on the basis of the nearby measured cross sections. In DUFLOW, the hydraulic roughness is computed from Chezy's equation and Chezy's roughness coefficient was calibrated for all reaches using data from the period January 7 to February 3, 1999. The reliability of this calibration is confirmed by the successful application of the model to many other time periods and to water-surface elevation data collected at locations where data were not available during the calibration period. Discharges and pollutant loads coming from tributaries, four Water Reclamation Plants (North Side, Stickney, Calumet, and Lemont), pumping stations, and CSOs, are given at the model nodes and schematization points. There are nearly 240 gravity CSO outfalls draining to the modeled portion of the CAWS. Since it is practically difficult to include all these locations in the model, 28 representative CSO locations were identified as shown in Figure 2. A computational time step of 15 minutes was used, and hydraulic and water-quality results were output on a one hour time step.

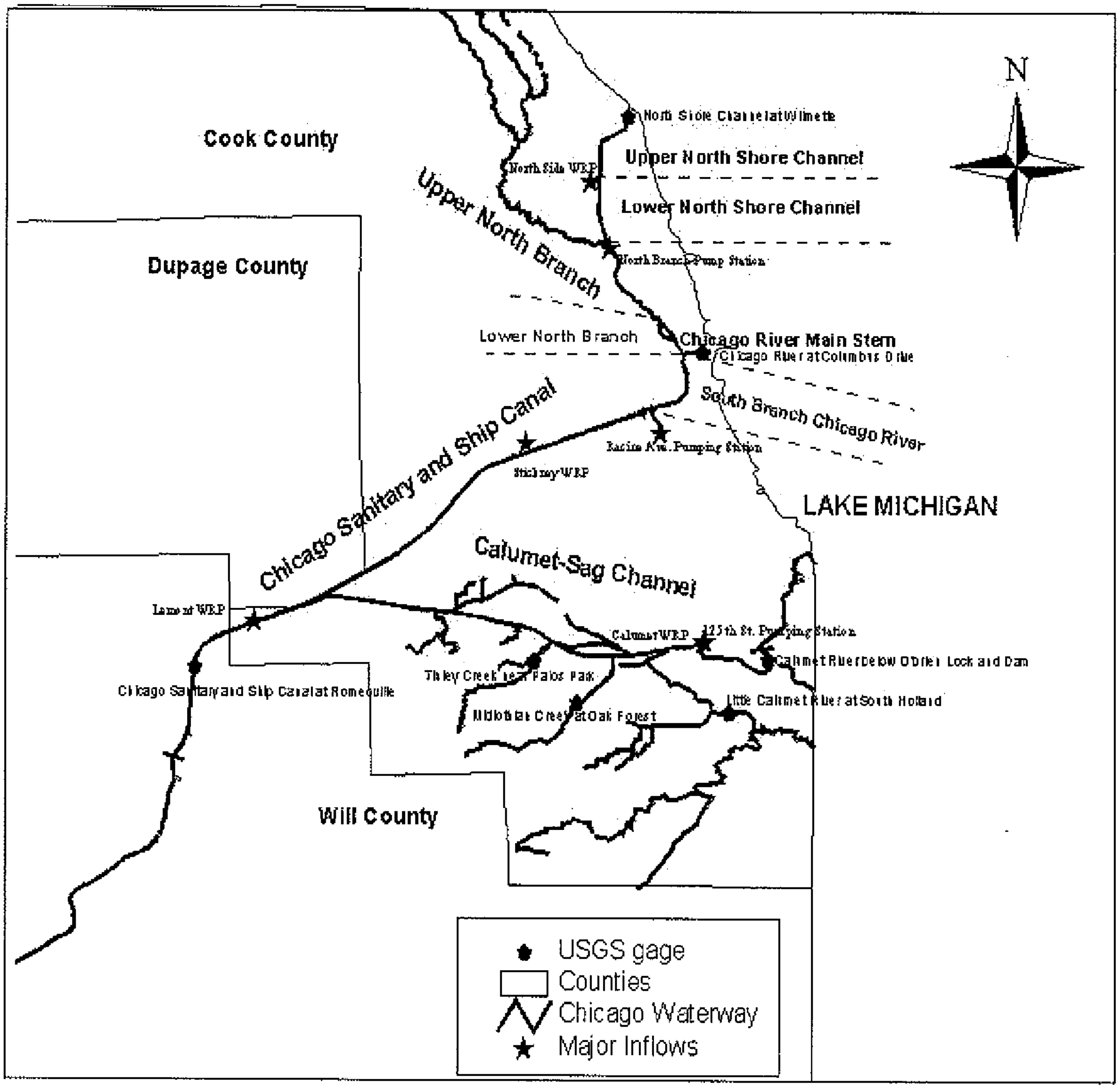


Figure 1. Schematic diagram of the Calumet and the Chicago River Systems

Inflows—The hydraulic and hydrologic data available for the CAWS have been compiled from different agencies. The U.S. Geological Survey previously had discharge and water-surface elevation gages at three primary locations where water is diverted from Lake Michigan into the CAWS. These locations are:

i) The Chicago River Main Stem at Columbus Drive (near the Chicago River Controlling Works) [still operational]
ii) The Calumet River at the O'Brien Lock and Dam
iii) The North Shore Channel at Maple Avenue (near the Wilmette Pump Station)

The data from these gages at Columbus Drive and O'Brien Lock and Dam are used as upstream water-surface elevation versus time (hourly) boundary conditions for the unsteady-flow water-quality model. At Wilmette, the original hydraulic calibration and verification used hourly water-surface elevation versus time as a boundary condition, but

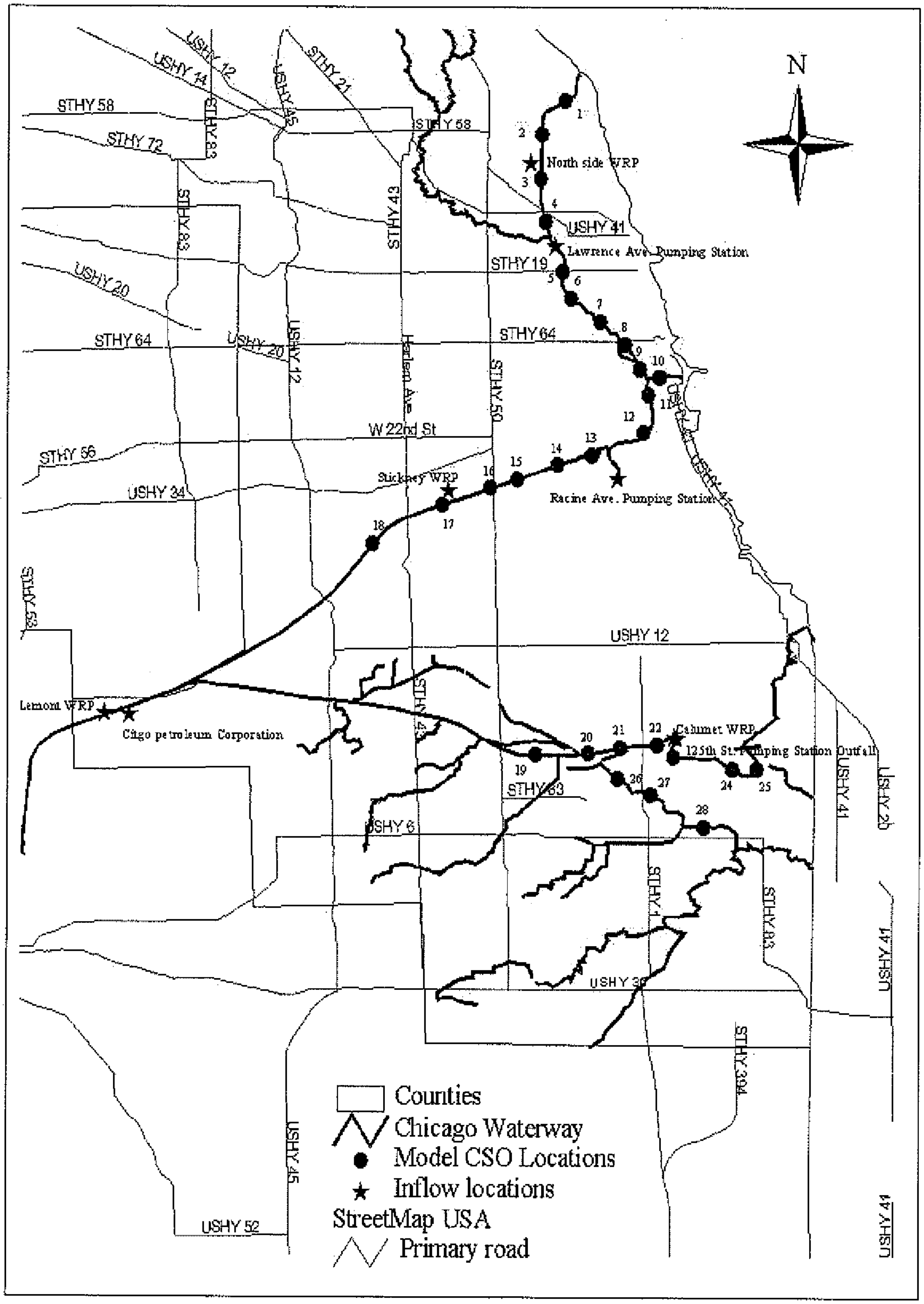


Figure 2. Locations of the 28 representative combined sewer overflows (CSOs) used in this study (note: The location of the Citgo Petroleum plant is shown above, the inflow location in the model and in reality is downstream from the Lemont WRP.)

later when water-quality improvements on the upper NSC were simulated 15-min. flow data were used as the upstream boundary condition at Wilmette. Flow versus time data (on a 15-minutes basis) from the U.S. Geological Survey gage on the Chicago Sanitary and Ship Canal at Romeoville are used as the downstream boundary condition for the model. The 15-min. data from the U.S. Geological Survey gage on the Little Calumet River (south) at South Holland provide a flow versus time upstream boundary condition for the water-quality model. Two tributaries to the Calumet-Sag Channel are gaged by the U.S. Geological Survey—Tinley Creek near Palos Park and Midlothian Creek at Oak Forest—and the 15-min. data at these sites is input to the model. The U.S. Geological Survey gage on the Grand Calumet River at Hohman Avenue at Hammond, Ind. is tributary to the Little Calumet River (north) and hourly data are input at this location. Fifteen minute flow on the North Branch Chicago River is measured just upstream of its confluence with the North Shore Channel at the U.S. Geological Survey gage at Albany Avenue and is input to the model.

There also are inflows coming from District facilities. Hourly flow data are available from the District for the treated effluent discharged to the CAWS by each of the North Side, Stickney, Calumet, and Lemont Water Reclamation Plants (daily data were used for the Lemont Plant). In addition, hourly flows discharged to the CAWS at the three CSO pump stations—North Branch, Racine Avenue, 125th Street—were estimated from operating logs of these stations.

The gravity flow CSO volume was determined from the system-wide flow balance and water level measurements at Romeoville. It was distributed in space on an area ratio basis to the 28 representative gravity CSO locations and in time on the basis of CSO pump station operation time. Successful results with hydraulic calibration and verification suggest that CSO volumes were reasonably estimated and distributed along the waterway system. The flows determined by flow balance have also been compared to CSO flows estimated by the computer models the U.S. Army Corps of Engineers uses to estimate the Lake Michigan diversion (see Espey et al. (2004) for a description of these models) for the events resulting in flow reversals to Lake Michigan in 2001 and 2002. Generally good agreement between the flow balance and U.S. Army Corps of Engineers models has been found (Alp and Melching, 2008).

Measured flows on Midlothian Creek were used to estimate flows on ungaged tributaries using drainage area ratios. In total, 15-min. flows from 107.45 mi^2 of ungaged drainage areas were estimated from Midlothian Creek flows.

Chemical Constituent Inputs—Measured daily composite constituent concentrations provided by the District were used in the model for the four Water Reclamation Plants.

For the tributary stream inflows, long-term average values were used for the dry-weather concentrations. All water-quality data used for dry-weather concentrations were collected as a part of the District's monthly waterway sampling program. Average concentrations (2001-2002) for the Little Calumet River at South Holland were calculated using data from the Little Calumet River at Wentworth Avenue (upstream of the South Holland gage) and at Ashland Avenue (downstream of the South Holland gage) and Thorn Creek at 170th Street (upstream of the South Holland gage). Concentrations measured (1990-2002) at the Grand Calumet River at Burnham Avenue were used for the concentrations at the Grand Calumet River at Hohman Avenue gage. Average concentrations (2000-2002) for the North Branch Chicago River at Albany Avenue were measured directly. Dry-weather concentrations for other tributaries are based on Little Calumet River concentrations because all of the other gaged and ungaged tributaries are on the southern portion of the Chicago metropolitan area and were assumed to be similar to the Little Calumet River drainage basin.

For wet-weather periods, event mean concentrations were calculated using water-quality data collected during storm events by the District in 2001. In most cases, the total load resulting from the runoff event is more important than the individual concentrations within the event due to the fact that runoff events are relatively short, the receiving water body provides some mixing, and the concentration in the receiving water body is a response to the total load rather than the concentration variability within the event (Novotny and Olem, 1994, p. 484). Because of the importance of the total load, the event mean concentration has been found to be the most appropriate variable for evaluating the impact of urban runoff (U.S. EPA, 1983). Hence, event mean concentrations were used to characterize all storms at tributaries and CSOs in this study. Hence, event mean concentrations were used to characterize all storms in this study. Concentrations for the Little Calumet River at South Holland were calculated using storm data on the Little Calumet River at Ashland Avenue. Event mean concentrations for the North Branch Chicago River at Albany Avenue were measured directly. Other tributaries were based on Little Calumet River event mean concentrations. For the calibration period event mean concentrations were measured for each storm, while for the verification period average event mean concentrations based on the 2001 data were used.

For the upstream boundaries in the water-quality model—near the Chicago River Controlling Works at the Chicago River at Columbus Drive, near the Wilmette Pump Station at the North Shore Channel at Maple Avenue, and O'Brien Lock and Dam—historic plots of data (1990-2002) show that there are seasonal and monthly variations at these locations and nitrogen compound concentrations for the Chicago River at Columbus Drive changed dramatically after 1997. For this reason monthly averages were determined and were used in the water-quality model.

Constituent concentrations were measured by the District at the North Branch and 125th Street Pump Stations for selected storms in 2001. When there were no measured data for a storm in 2001, the average of all event mean concentrations for storms sampled in 2001 for the given pumping station were assigned to this storm. For the simulation period in 2002, none of the pumping stations was sampled. Therefore, average values from all available historic event mean concentration data were used (2001-2002 and 1995-1999 and 2001-2002 for the North Branch and 125th Street Pumping Stations, respectively).

Since no measured data are available for the Racine Avenue Pumping Station for 2001, 5-day CBOD ($CBOD_5$) and NH_4-N concentrations were determined as a function of discharge using a regression equation based on event mean concentration data collected in 1995-1999 and 2002. DO concentrations were determined on the basis of regression relations between event mean concentration and discharge for the North Branch Pumping Station.

The North Branch Pumping Station water-quality parameters were used for North Shore Channel and North Branch Chicago River CSOs, the Racine Avenue Pumping Station water-quality parameters were used for the Chicago River Main Stem and South

Branch Chicago River CSOs, and the Calumet-Sag Channel and Little Calumet River CSO water-quality parameters were determined using concentrations measured at the 125th Street Pumping Station. The reasonableness of this approach was shown in Neugebauer and Melching (2005).

The water quality in the modeled portion of the CAWS is affected by the operation of four Sidestream Elevated Pool Aeration stations and two instream aeration stations (Devon Avenue and Webster Street). The oxygen input from the Sidestream Elevated Pool Aeration stations is computed as a rate per time on the basis of the pump operation records and the oxygen transfer efficiency determined by Butts et al. (1999, 2000). The oxygen input from the in-stream aeration stations is computed as a rate per time on the basis of blower operation records and the oxygen transfer efficiency determined by Polls et al. (1982). Details on these calculations are provided in Alp and Melching (2004) and Melching et al. (2004).

Temperature is a key variable, which affects reaction kinetics and the DO saturation concentration. Hourly measured temperature values were input at each continuous monitoring location. Therefore, temperature varies spatially and temporally in the DUFLOW model.

Fecal Coliform Inputs—The fecal coliform concentration in the Water Reclamation Plant effluents was available for a single sample on a weekly basis (i.e. about four or five measurements a month). Linear interpolation in time between these measurements was applied in the DUFLOW model to estimate coliform concentrations from the Water Reclamation Plants for each 15 min. computational time point. The 15 min. time step is necessary to simulate unsteady flow in the CAWS and is supported by 15 min. flow and/or water-surface elevation values at the boundaries and tributaries and hourly flows at the Water Reclamation Plants and CSO pumping stations.

Since no bacteriological data on discharges from CSOs were available for the study area when the model was developed, fecal coliform input concentrations to the DUFLOW model were estimated. The median value of the sampling data available for CSOs in Milwaukee for the period 2001-2004 was considered as representative of fecal coliform concentrations at the pumping stations and CSOs because both Milwaukee and Chicago have deep tunnel systems to intercept and treat the first flush of storm runoff pollutants from combined sewers. This value is about 170,000 CFU/100 ml. A similar modeling effort has been done to simulate fecal coliform concentrations in the water courses, harbor, and near shore Lake Michigan in the Milwaukee area. In this modeling effort, the geometric mean of CSO fecal coliform concentrations of 160,000 CFU/100 ml was used (Recktenwalt et al., 2004). This further supports the use of 170,000 CFU/100 ml in the simulation of the CAWS.

There were four severe rain storms in 2001 and 2002 (August 2, August 31, and October 13, 2001; and August 22, 2002) that resulted in flow reversals from the CAWS to Lake Michigan. During periods of flow reversals the District is required to intensively sample the quality of water going into the Lake. These data were used to evaluate fecal coliform concentrations in CSOs, and a value of 1,100,000 CFU/100 ml was found to give good results for 3 of the 4 events. Thus, when disinfection scenarios were evaluated runs with CSO concentrations of 170,000 CFU/100 ml and 1,100,000 were made for comparison (Manache and Melching, 2005). In 2006 the District collected fecal coliform data in CSOs and the concentrations were between 400,000 and 500,000 CFU/100 ml confirming the range in the runs reasonably bracketed actual inflow conditions from the CSOs.

Unlike other studies where relations between flow and coliform loads have been found for some rivers (e.g., Elshorbagy et al. 2005), no relations between flow and coliform concentrations were found for the tributaries to the CAWS. Thus, for the gaged tributaries–North Branch Chicago River, Little Calumet River, and Grand Calumet River–historical monthly fecal coliform concentrations were used as input with 15 min. values linearly interpolated in time between the adjacent monthly measurements. For ungaged tributaries, fecal coliform concentration data were estimated based on data analysis of Chicago area streams that are not affected by Water Reclamation Plants or CSOs. Monthly median values of fecal coliform concentration for one representative stream (Thorn Creek, which is a tributary to the Little Calumet River) were applied to each 15 min. value for all ungaged tributaries.

Model Calibration and Verification

Hydraulics—The comparison of measured and simulated hourly water-surface elevations at seven locations throughout the CAWS—North Shore Channel at Wilmette; North Branch Chicago River at Lawrence Avenue; Calumet-Sag Channel at Southwest Highway; and Chicago Sanitary and Ship Canal at Western Avenue, Willow Springs Road, Sag Junction, and Romeoville--were used for hydraulic calibration and verification of the model (details in Shrestha and Melching, 2003; Alp and Melching, 2004, 2006; and Neugebauer and Melching, 2005). Statistical analysis for the locations used in the verification showed that the difference between the measured and simulated water-surface elevations are all below 8.5 % relative to the depth of the water except for Wilmette, an upstream boundary. Mean and median values of the absolute value of the difference between the measured and simulated water-surface elevations are below 3.2 % relative to the depth at all locations. The simulated water-surface elevations were within 3% relative to depth for 93.7-99.9% of the measured values at all locations other than Wilmette. These high percentages of small errors and the high correlation coefficients (0.79-0.98) indicate an excellent hydraulic calibration and verification of the model.

Dissolved Oxygen and Related Constituents—The DUFLOW DO model was calibrated and verified for the periods of July 12-November 9, 2001, and May 1-September 23, 2002, respectively. 2001 was a relatively wet year and 2002 was a relatively dry year giving an acceptable variety of flows for the calibration and verification (i.e. Thomann (1982) recommended that the verification data set should represent a sufficiently perturbed condition to provide an adequate test for the model). Further, the period in 2001 was selected as the calibration period because during this time the District collected detailed storm loading data for the Little Calumet River and North Branch Chicago River at Albany Avenue, the two main tributaries to the CAWS, and the North Branch and 125th Street CSO pumping stations. This allowed the model to be calibrated for the case with the most detailed knowledge on the pollution loads to the CAWS. Complete details of the calibration and verification of the DO model are given in Alp and Melching (2006).

An extensive data set including hourly in-stream DO data at 26 locations and monthly in-stream water-quality measurements at 18 locations were used to calibrate and verify the water-quality model at a 1-hour output time step. All water quality parameters including DO were measured by the District. The comparisons of the simulated constituent concentrations ($CBOD_5$, Nitrogen compounds, and Chlorophyll-a) with long-term mean measured concentrations, one standard deviation confidence bounds, and concentrations measured between July-November 2001 indicated reasonable simulations. There are approximately 2,900 measured hourly DO data at each location within the calibration period and throughout the calibration process it was aimed to match hourly measured and simulated DO concentrations as much as possible [see Figures 3.16-3.33 in Alp and Melching (2006)]. On the other hand, as Harremoës et al. (1996) mentioned, it is almost impossible to fit all the measured hourly data if there are a large number of data to be matched. Hence, calibration was done manually in a way that the model can capture low DO concentrations resulting from CSOs and produce similar probabilities of exceedence for different DO concentrations. Comparisons of the percentage DO concentrations less than 3, 4, 5, and 6 mg/L at different locations in the CAWS for the calibration period for selected locations are listed in Table 1 and for I-55 on Bubbly Creek are shown in Figure 3.34 of Alp and Melching (2006).

Close agreement between the calibrated and measured DO concentrations was obtained especially for the lower DO concentrations. The differences between the percentage of DO concentrations less than 3 mg/L for the calibrated and measured DO concentrations vary 0.0 to 4.5 percentage points at all 26 locations in the CAWS except for the upper North Shore Channel and Bubbly Creek. The differences between the percentage of DO concentrations less than 4 mg/L for the calibrated and measured DO concentrations are less than 10.6 percentage points in the CAWS except for the upper North Shore Channel. In the upper North Shore Channel and Bubbly Creek it was difficult to match the measured DO concentrations because of the hydraulic conditions in these water bodies, i.e. flow near zero except during CSO events. Thus, the calibration aimed to match the low DO concentrations resulting from CSOs so that reliable management practices to mitigate the CSO effects could be determined using the DUFLOW model. The differences between the percentage of DO concentrations less than 3 and 4 mg/L for the calibrated and measured DO concentrations reach up to -30.4 percentage points in the upper North Shore Channel. The overall average of the absolute differences of percentages of DO concentrations less than 3, 4, 5, and 6 mg/L for the calibrated and measured DO concentrations are 1.7, 4.4, 7.7, and 9.6 percentage points, respectively, in the CAWS except for the upper North Shore Channel and Bubbly Creek. As described earlier, for model verification purposes, average values of constituent concentrations in CSOs taken as a mean from historic measured data were applied, whereas measured event mean concentrations were available at the CSO pumping stations for the calibration period. Verification of the DUFLOW DO model generally shows good agreement between measured and simulated DO concentrations. For the entire CAWS except the upper North Shore Channel the average error in daily DO concentration is 8.3 % and the average absolute percentage error is 26.9 % (Neugebauer and Melching, 2005). Comparison between the DUFLOW model prediction ability for the verification (May 1 to September 23, 2002) and calibration (July 12 to November 9, 2001) periods indicates that the prediction ability of the DUFLOW DO model is comparable for these two periods. It was concluded that, in general, the DUFLOW model represents water-quality processes in the CAWS well enough for simulation of water-quality management scenarios.

Table 1. Comparison of the percentages of simulated and measured hourly dissolved oxygen (DO) concentrations higher than specified targets for the Chicago Area Waterway System for July 12-November 9, 2001 (after Alp, 2006)

	Percentage of DO (Measured and Calibrated) higher than							
	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	Meas.*	Sim.**	Meas.	Sim.	Meas.	Sim.	Meas.	Sim.
Linden Street	91.4	69.5	90.0	65.5	88.4	61.0	85.3	56.8
Simpson Street	75.4	46.0	66.5	36.0	57.3	27.5	50.4	22.6
Main Street	73.7	39.4	64.9	32.6	49.9	25.3	38.3	8.1
Addison Street	99.5	100.0	98.2	98.4	89.9	82.5	52.0	33.9
Fullerton Avenue	93.7	96.1	79.9	86.0	50.4	53.5	36.8	23.0
Division Street	99.4	95.0	95.2	84.6	84.2	65.6	46.9	36.6
Kinzie Street	97.3	94.7	91.6	82.2	67.7	66.4	30.9	36.3
Chicago River Controlling Works	98.6	98.0	98.6	97.1	98.6	94.8	97.6	93.0
Clark Street	99.9	98.0	99.9	96.7	99.6	94.4	98.1	86.3
Jackson Boulevard	96.1	92.0	87.9	81.1	62.2	66.3	31.9	39.4
Cicero Avenue	78.9	79.5	51.7	51.2	23.0	37.7	13.9	24.4
Baltimore and Ohio Railroad	97.5	97.4	90.7	80.7	65.4	51.2	34.8	30.0
Route 83	82.0	86.5	66.1	60.5	30.8	37.1	18.0	22.5
Mile 11.6	87.4	89.0	74.0	71.9	47.0	46.2	25.8	28.6
Romeoville	82.8	82.1	59.2	62.7	23.0	38.9	12.7	25.4
Conrail Railroad	99.4	100	98.7	100	95.8	98.2	88.5	79.1
Central and Western Railroad	100	100	99.8	100	98.5	98.7	91.0	81.0
Halsted Street	99.9	98.8	99.2	94.1	93.9	77.8	70.3	38.9
Division Street	97.1	100	88.7	95.5	69.2	79.2	42.2	43.8
Kedzie Street	98.9	100	95.3	96.1	84.4	84.9	61.1	48.9
Cicero Avenue	98.6	99.1	94.0	93.2	81.6	74.2	58.4	43.5
Harlem Avenue	97.8	96.2	91.2	88.9	76.8	70.4	50.8	48.9
Southwest Highway	98.2	95.6	90.7	86.4	77.4	67.8	58.7	46.0
104th Avenue	91.6	91.7	86.4	83.0	70.9	63.2	44.8	43.5
Route 83	94.8	92.0	88.2	80.8	72.0	65.0	52.1	46.4

* Meas.: Measured ; ** Sim.: Calibrated

The application of the DUFLOW hydraulic and DO models to the CAWS has been subjected to extensive peer review. Each of the four modeling reports (Shrestha and Melching, 2003; Alp and Melching, 2004, 2006; Neugebauer and Melching, 2005) was reviewed by the Research and Development, Engineering, and Operations and Maintenance Departments of the District. Further, because the preliminarily calibrated DO model was used to simulate the effects of a proposed change in navigational water level policy on water quality in the CAWS, the report by Alp and Melching (2004) was also reviewed by three staff members of the U.S. Army Corps of Engineers, Chicago District. The paper on the model presented at the Watersheds 04 Conference (Melching et al., 2004) was peer reviewed before being accepted for presentation, and the paper on the effectiveness of CSO treatment (Alp et al., 2007) also was peer reviewed before publication in the journal *Water Science and Technology*. These reviews further support the reliability of the DO model for use in evaluating water-quality management scenarios in the CAWS.

Fecal Coliforms—Use of process-based, continuous simulation models is highly data intensive requiring continuous time series of flows or water-surface elevations and water-quality constituent concentrations at the boundaries and for all tributaries (streams, CSOs, etc.) and diffuse lateral loads (as described earlier). Preparation of this data including compilation, quality assurance, filling in missing record, and estimation of ungaged flows is very time consuming. Thus, it is common practice to select a reference period of a typical year, or in the case of the CAWS two representative summer periods one for a relatively wet year (2001) and the other for a relatively dry year (2002). When recreational interest in early spring (March and April) and late fall periods (October and November) were identified in the Use Attainability Analysis, periods in 1998 and 1999 were added to the representative periods simulated. For the CAWS five 2-4 month periods concentrated in the recreational season (March to early November) were considered.

During a typical year only 9 or 10 monthly fecal coliform samples may have been collected and analyzed because samples are not collected in winter months, and for the five periods a maximum of 16 monthly fecal coliform samples were available at each of 16 sampling locations in the CAWS. Thus, traditional calibration wherein the coliform decay rate, k, is adjusted for each reach to obtain a good match between the simulated and measured concentrations would haven been based on a very small set of measurements. Thus, an alternative approach for calibration, i.e. determination of k, was developed.

The new concept of calibration applied determined the fecal coliform decay rate on the basis of 14 years (1990-2003) of historical monthly fecal coliform samples rather than the limited number of monthly samples collected in the typical calibration period to which process-based, continuous simulation models are commonly applied. The application of this approach relied on careful evaluation of the historical data for representative flow and loading conditions, which were found for the CAWS (Manache et al., 2007). This approach also relies on detailed simulation of travel times in the study water courses, which was accomplished through DUFLOW's highly accurate simulation of the hydraulics of the CAWS.

A mean and median value of k was computed for every section as follows:

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

where C_t and C_0 are the fecal coliform concentrations having the same probability of exceedence (quantile) at the downstream and upstream locations (CFU/100 ml), respectively, and t is the mean travel time between upstream and downstream locations (days). This was done for many selected quantiles, and the computed mean and median k values were found. For the CAWS, similar mean decay rate values were obtained when the equation above was applied on the paired data of fecal coliform concentrations collected at two successive sampling locations on the same date.

The k values determined above were tested for the period July 12 to September 15, 2001, and values were estimated for reaches including the Water Reclamation Plants and outside the sampled reaches using data from this same period. The model was then verified for the periods September 11 to December 30, 1998; February 5 to May 24, 1999; September 2 to November 10, 2001; and May 5 to September 29, 2002. The high quality simulation results are shown in detail in Manache and Melching (2005) and Manache et al. (2007). The quality of the coliform model was confirmed through peer review by the District and the Journal of Environmental Engineering of the American Society of Civil Engineers.

HYDRAULICS OF THE CAWS

The Board characterizes its responsibility evaluating the CAWS as follows:

> In evaluating these proposed rules, the Board is required to take into account "the existing physical conditions, the character of the area involved including the character of surrounding land uses, zoning classifications, the nature of the existing air quality, or receiving body of water, as the case may be, and the technical feasibility and economic reasonableness of reducing the particular type of pollution."

IEPA Statement of Reasons p. 2. According to IEPA, some of the key hydraulic features of the CAWS that influence the biological potential of the CAWS are: "Flow reversal projects, such as this one, place a premium on head differential. The entire system has minimum slope and, consequently, low velocity, stagnant flow conditions." IEPA Statement of Reasons at pp. 19-20. The evaluation of flow and water-surface elevation data used to apply the DUFLOW model and the hydraulic results of the modeling reveal just how stagnant the CAWS is and the potential limitations to the current and future biological community.

Flow Reversals

It is well known that large storms can result in flow reversals from the CAWS to Lake Michigan. Figure 3 shows that during a large storm on August 2, 2001, the water-surface elevation at Western Avenue was higher than that at the Chicago River Controlling Works. Figure 4 shows the maximum computed water-surface elevation for the 50- and 100-year floods along the path from the Chicago River Controlling Works to Romeoville. These figures were calculated for a study of the hydraulics of the proposed new bridge over the South Branch Chicago River at Taylor Street done for the Chicago Department of Transportation using inflow calculated by the U.S. Army Corps of Engineers. These figures show that Cicero Avenue is the approximate flow divide during large storms, and water may flow from the upstream end of the Chicago Sanitary and Ship Canal toward downtown during large events.

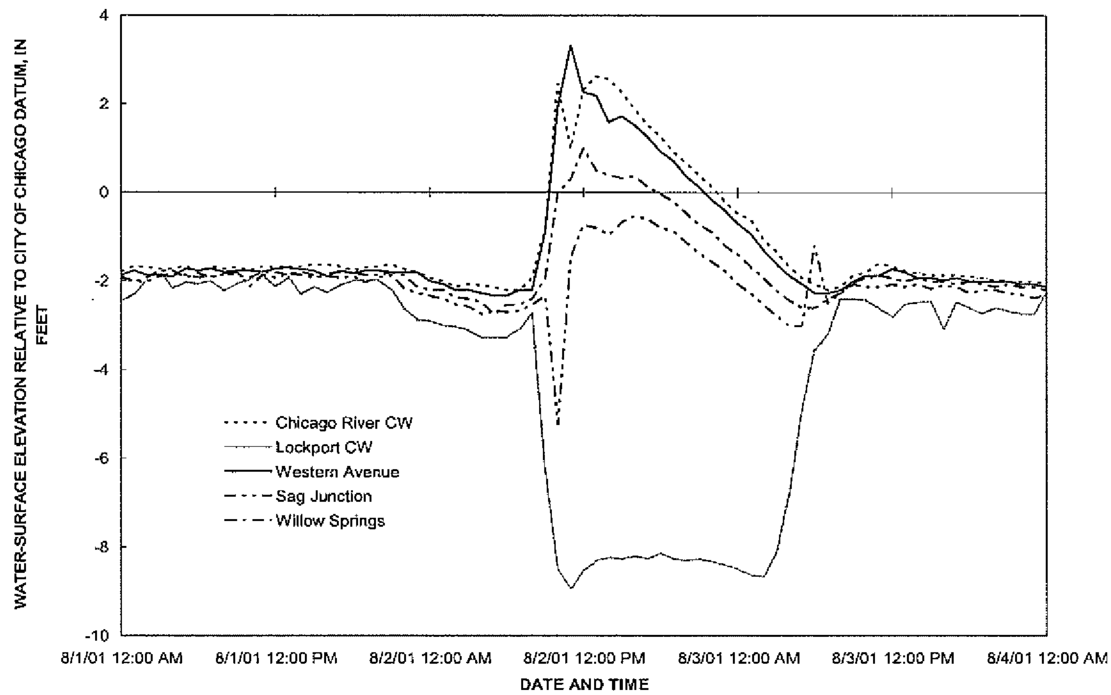
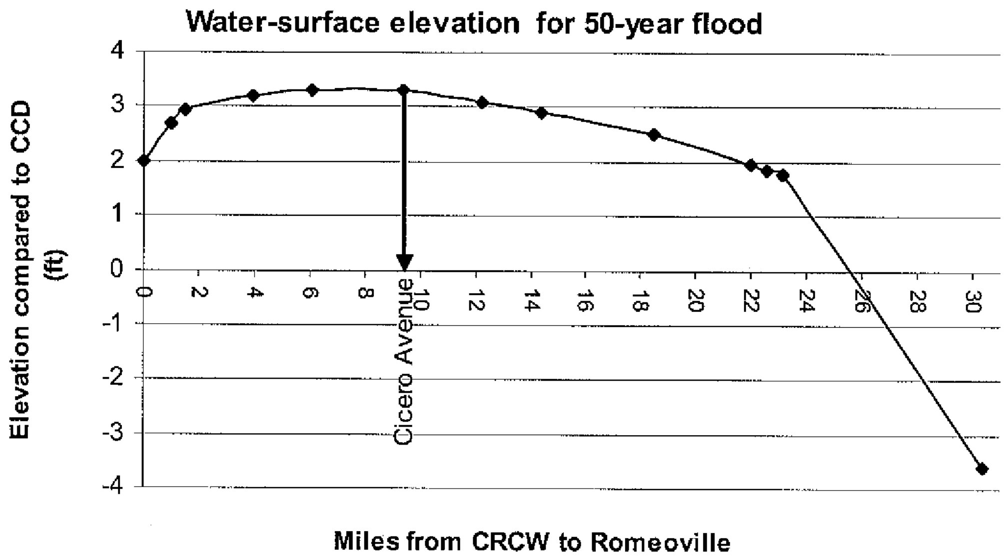


Figure 3. Measured water-surface elevations in the Chicago Area Waterway System during the flood of August 2, 2001. (note: CW means Controlling Works)

The flow need not result in a reversal to Lake Michigan to have a flow reversal within the CAWS. Figure 5 shows that the water-surface elevation on the Little Calumet River (south) at Ashland Avenue during the storm from January 22 to 27, 1999 is higher than the water-surface elevations at O'Brien Lock and Dam and Sag Junction. Thus, during storms O'Brien Lock and Dam is downstream of the Little Calumet River (south) and water backs up the Grand Calumet River until it can flow downstream toward Sag Junction when the storm flow from the Little Calumet River (south) decreases [note: it appears the water-surface elevation monitor at Ashland Avenue froze on January 27th].

Because the water-surface slope of the CAWS is so small and the flow from the North Side, Stickney, and Calumet Water Reclamation Plants is substantially higher than the flow upstream of these Plants flow reversals also are common during dry weather flows upstream of the Plants. Figures 6-8 show that for each of the Plants the water-surface elevations "upstream" of the Plants frequently are lower than those "downstream" of the Plants. Thus, the outfalls of each of the Plants act as a hydraulic dam inserting treated effluent to the upstream reaches and then holding it and upstream flows back to truly stagnate in the upstream reaches. This backflow explains why the upper North Shore Channel remains ice free for many miles north of the channel. In January 2003 when I visited the U.S. Geological Survey gage at Maple Avenue (5 miles from the North Side Plant) ice was only present upstream from the gage. The bi-directional flow gives us some impression of the unnatural condition of the CAWS.



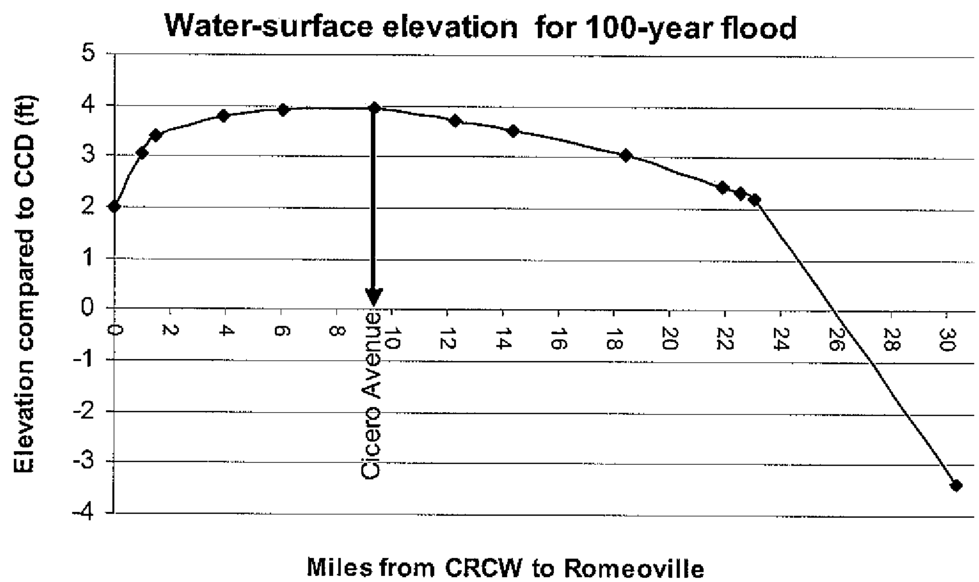


Figure 4. Computed maximum water-surface elevation from the Chicago River Controlling Works (CRCW) to Romeoville on the Chicago Sanitary and Ship Canal for the 50- and 100-year floods (inflows obtained from the U.S. Army Corps of Engineers, Chicago District)

Slow Travel Times

As mentioned earlier, the DUFLOW model was used to determine average travel times in the CAWS in the calibration of the fecal coliform model. Table 2 lists the average travel times, lengths, and average velocities for several reaches in the CAWS for the July 12 to September 15, 2001 simulation period. The hydraulic dam upstream from the Stickney Plant is obvious as it takes 2.5 days to go 8 miles from Madison Street to Cicero Avenue. The hydraulic dam upstream from the Calumet Plant also is obvious as it takes 1.5 days to go 2.3 miles from Indiana Avenue to Halsted Street.

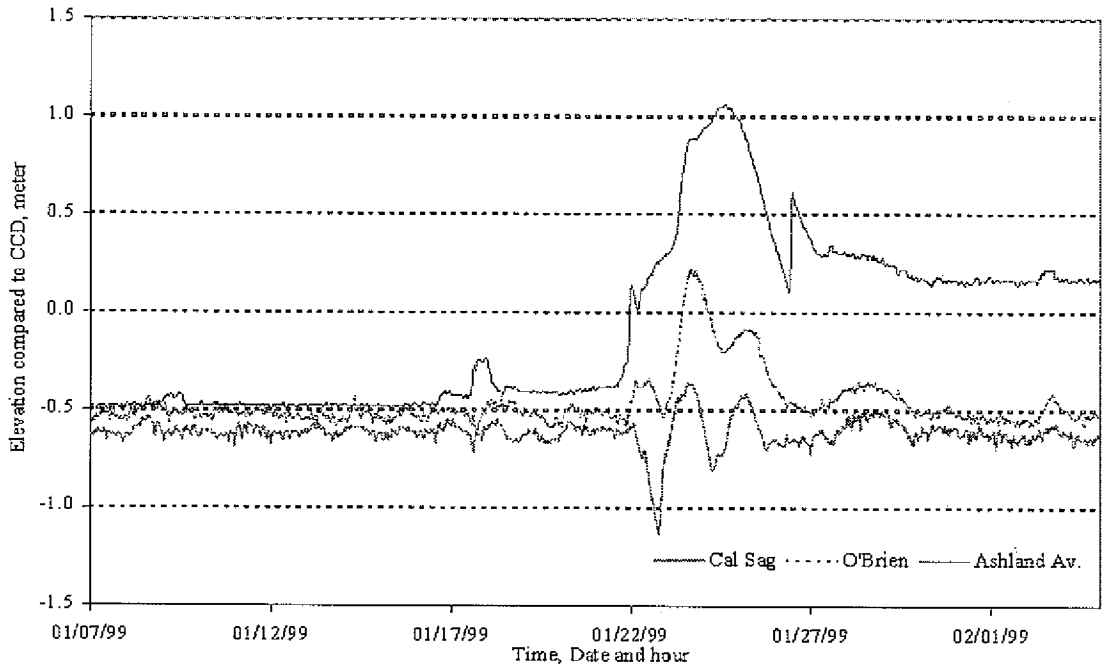


Figure 4.6. Measured stages at Cal-Sag Junction, O'Brien Lock and Dam and the Little Claumet River at Ashland Avenue for January 7 - February 3, 1999

Figure 5. Measured water-surface elevations at Calumet-Sag Junction, O'Brien Lock and Dam, and the Little Calumet River (south) at Ashland Avenue for January 7 to February 3, 1999 [after Shrestha and Melching (2003)]

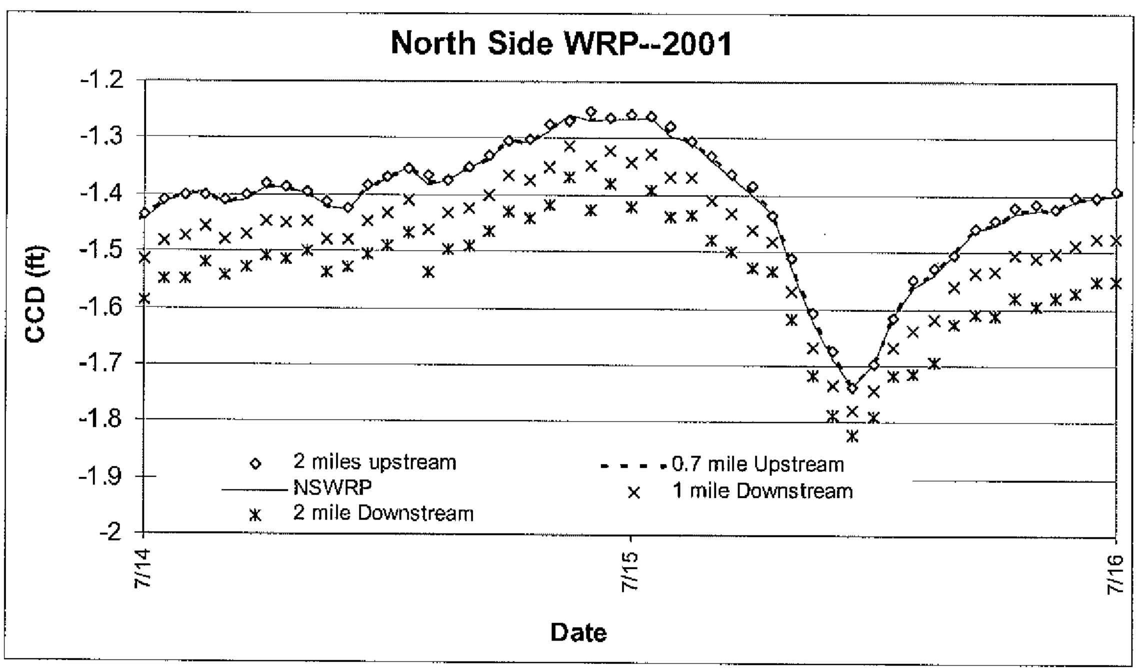


Figure 6. Simulated water-surface elevation at, upstream, and downstream of the North Side Water Reclamation Plant

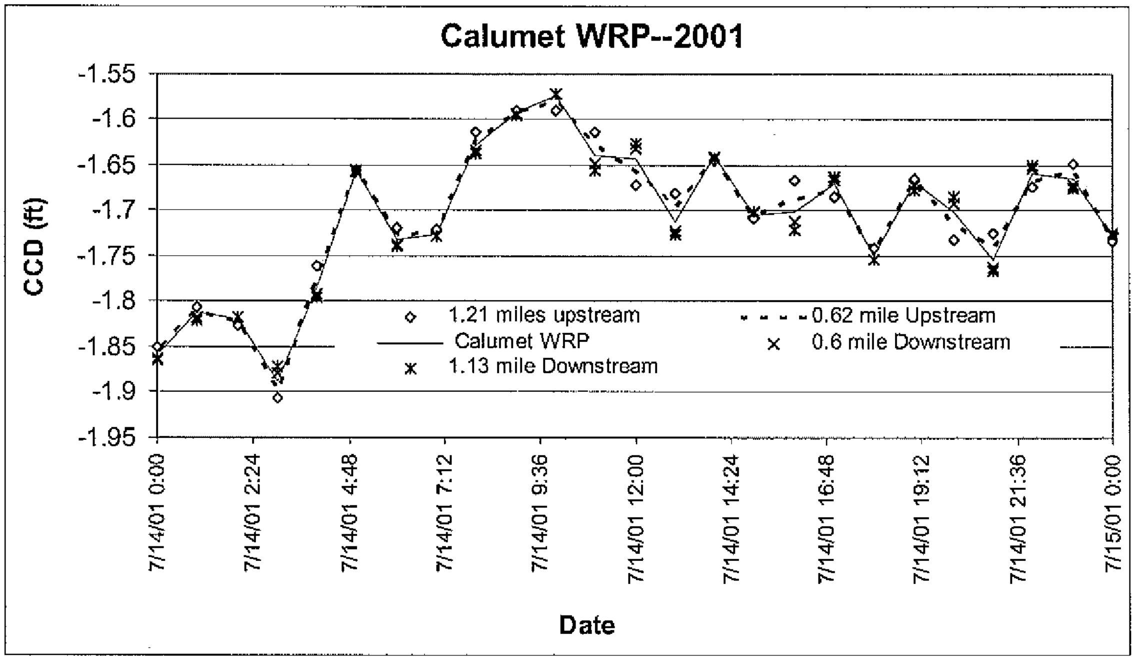


Figure 7. Simulated water-surface elevation at, upstream, and downstream of the Calumet Water Reclamation Plant

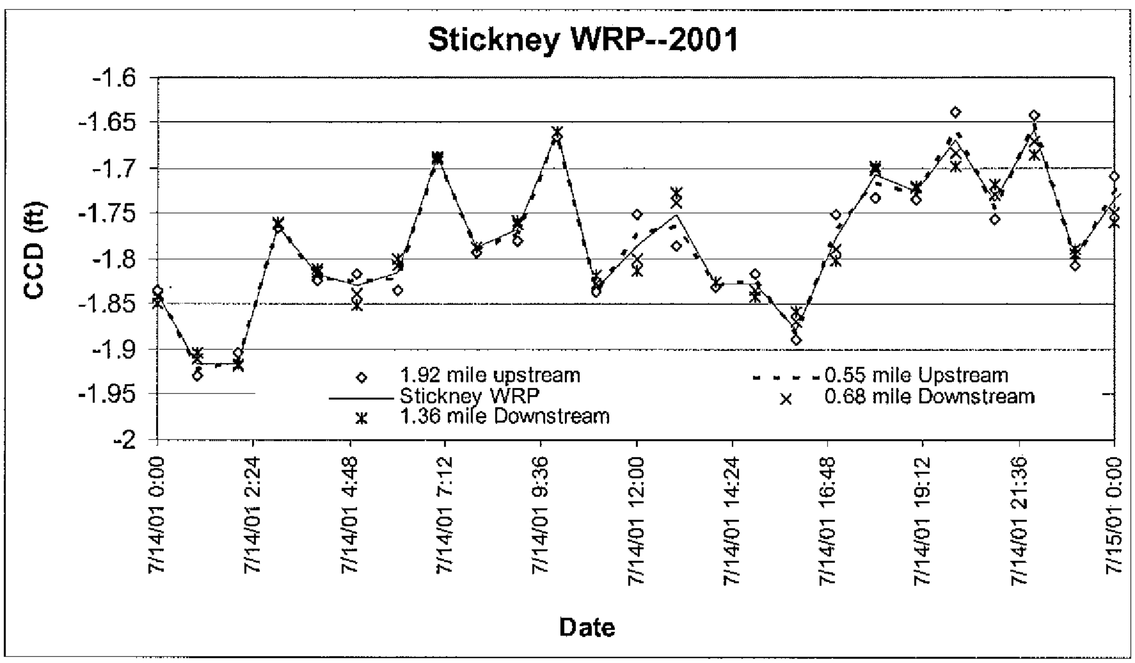


Figure 8. Simulated water-surface elevation at, upstream, and downstream of the Stickney Water Reclamation Plant

Table 2. Computed average travel time and velocity for July 12 to September 15, 2001 and distance between selected points in the Chicago Area Waterway System.

Sampling Site (Upstream)	Sampling Site (Downstream)	Waterway	Travel Time (day)	Distance (mi)	Average Velocity (ft/s)
Central Street	Oakton Street	North Shore	0.57	3.2	0.34
Oakton Street	Touhy Avenue	North Shore	0.22	1.0	0.28
Touhy Avenue	Wilson Avenue	North Branch	0.24	3.4	0.87
Wilson Avenue	Diversey Parkway	North Branch	0.25	2.5	0.61
Diversey Parkway	Madison Street	South Branch	1.12	4.8	0.26
Madison Street	Western Avenue	CSSC	1.42	4.7	0.20
Western Avenue	Cicero Avenue	CSSC	1.09	3.3	0.19
Cicero Avenue	Harlem Avenue	CSSC	0.71	3.3	0.28
Harlem Avenue	Route 83	CSSC	1.61	9.9	0.38
Route 83	Romeoville	CSSC	0.94	7.9	0.51
Indiana Avenue	Halsted Street	Little Calumet	1.46	2.3	0.10
Halsted Street	Ashland Avenue	Cal-Sag	1.72	1.0	0.04
Ashland Avenue	Cicero Avenue	Cal-Sag	1.30	4.1	0.19
Cicero Avenue	Route 83	Cal-Sag	2.97	10.7	0.22
Route 83 (Cal-Sag)	Romeoville	CSSC	0.95	8.1	0.52

Huge travel times and low flow velocities also are apparent upstream from the junction of the Chicago Sanitary and Ship Canal and the Calumet-Sag Channel. This is because when the Chicago Sanitary and Ship Canal was originally constructed the Calumet-Sag Channel was not anticipated and the Chicago Sanitary and Ship Canal cross-sectional geometry is the same upstream and downstream from Sag Junction. Thus, Sag Junction acts like two lanes narrowing to one lane on the freeway with large backups and long travel times resulting. In total then it takes more than 8 days for water to travel from the upstream ends of the North Shore Channel and Little Calumet River (north) to Romeoville on the Chicago Sanitary and Ship Canal. For perspective, we should remember that 5-day BOD was originally taken as the standard measurement because the test was devised in England, where the River Thames has a travel time to the ocean of less than 5 days, so there was no need to consider oxygen demand at longer times (Davis and Masten, 2004, p. 280). The long travel time gives us further impression of the unnatural condition of the CAWS. This feature of the CAWS contributes to the lower dissolved oxygen that is observed in CAWS compared to general use rivers because of the reduced natural reaeration resulting from low velocity and very low slope. Further, this feature of the CAWS makes it challenging and costly to disperse dissolved oxygen that is contributed artificially from engineered aeration stations.

Wet Weather Effects

IEPA appears to assume that the duration of storm effects on water quality lasts only as long as the causative rainfall, or the period of elevated flow rates. However, research on the CAWS shows that the effect of storm runoff and CSOs on water quality lasts substantially longer than the hydraulic effects of the storm. That is, once a load of pollutants is introduced to the system it takes longer for the system to dissipate the effects of these loads than it does to pass the high flows, similar to the lingering effects of a cold.

If continuous time series of $CBOD_5$ and NH_4-N concentrations were available at short time steps, it is possible that the duration of the storm effect on these constituents could be determined from the measured $CBOD_5$ and NH_4-N concentrations. However, such a determination would require that the dry-weather conditions—temperature, flow from wastewater treatment plants and tributaries, boundary conditions, etc.—would be essentially the same as before the storm. Since such continuous data generally are not available, water-quality models must be used to estimate the duration of the storm effect. The situation for DO concentrations is much more complex because DO concentrations are influenced by many conditions and processes—temperature, flow dilution, changes of treatment plant loads, $CBOD_5$, the nitrogen cycle, sediment oxygen demand, algal growth and death, etc.—each of which is subject to a different duration of storm effects. For example, DO recovery to pre-storm conditions does not indicate the end of the storm effect because the new dry weather DO concentration may have changed because of changes in temperature, sediment oxygen demand, treatment plant loads, etc. Again water-quality models must be used to determine the duration of the storm effect. Alp (2006) proposed and tested (on the CAWS) a method to determine the duration of storm effects on water quality.

In his approach, DUFLOW was successively applied with different storm CBOD and ammonium as nitrogen loadings (i.e. event mean concentrations) randomly sampled from a probability distribution representative of the event mean concentration data collected by the District at the CSO pump stations using an uncertainty analysis technique (Latin Hypercube Sampling, with a sample size of 50 simulations). Then the variations in the DUFLOW model output parameters among the successive simulations were observed. When the variation in the model output parameters approaches zero, it means the river system has returned to the pre-storm (dry weather) condition. Therefore, the duration between the start and the end of the variations in the simulated DUFLOW model output parameters can be defined as the duration of the storm effect on in-stream water quality, or the duration of the wet-weather condition. A paper summarizing this approach (Alp and Melching, in press) was recently accepted for publication in the Journal of Water Resources Planning and Management of the American Society of Civil Engineers validating the approach and DUFLOW model of the CAWS through peer review.

To determine how long storm loadings affect the DO concentrations in the CAWS for each location, the standard deviation of the computed DO concentrations was plotted against time. At Romeoville the standard deviation was plotted against time together with the flow for the calibration period in Figure 9. As can be seen in Figure 9, the effects of some storms overlap and this makes it hard to distinguish the start and end time of the storm effects. Hence, some of the storms are combined and treated as a single storm. For

DO the storm effect was assumed to end when the standard deviation in the simulated concentrations became a constant.

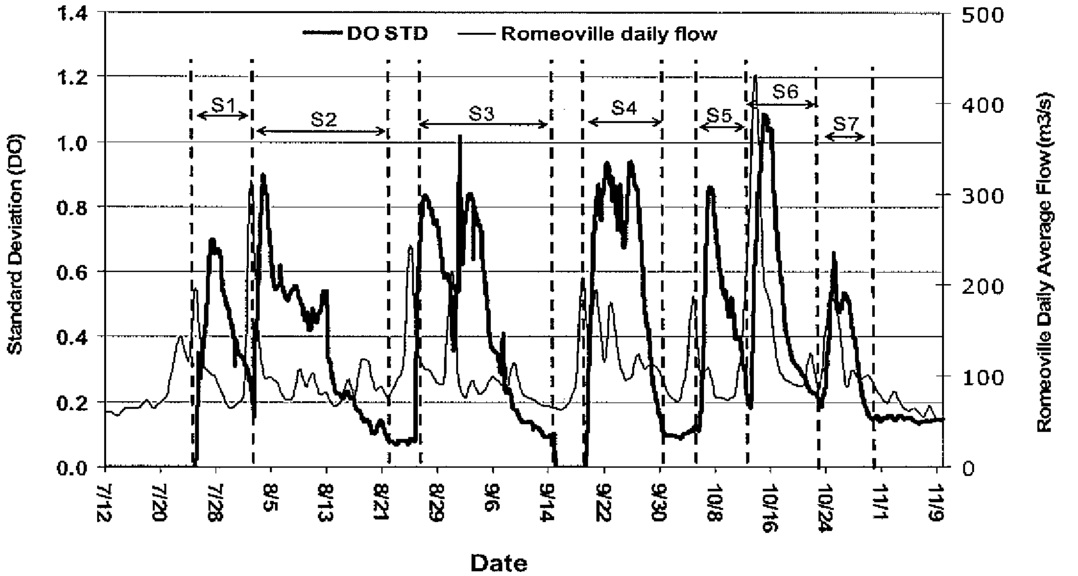


Figure 9. Flow and duration of the storm effect on the standard deviation of simulated dissolved oxygen (DO) concentration at Romeoville for July 12 to November 9, 2001 (after Alp, 2006).

Substantial impact of storm loading on DO concentration in the CAWS on average lasts one day to a few weeks depending on the location in the CAWS (Table 3). For the larger storms (indicated by larger CSO volumes in Table 3) the system tends to respond very similarly at every location whereas for smaller storms the duration of storm impact is significantly larger at the downstream locations. For example, for the storms August 2 and 9, 2001, the duration of the storm effect lasts 15.1 and 14.6 days on the Chicago Sanitary and Ship Canal at Romeoville and on the North Branch Chicago River at Addison Street, respectively, whereas for the July 25, 2001 storm, the duration of the storm effect lasts 8.6 and 2 days on the Chicago Sanitary and Ship Canal at Romeoville and on the North Branch Chicago River at Addison Street, respectively. This is because for smaller storms a greater percentage of CSO flows occur at pumping stations, on the other hand for larger storms a greater percentage of CSO flows occur at gravity CSOs. Therefore, during larger storms the system receives a more homogenous CSO load which leads to a homogenous response time over the Chicago River System (North Branch Chicago River-South Branch Chicago River-Chicago Sanitary and Ship Canal). During smaller storms, the pumping stations produce relatively more CSO volume which leads to different storm impacts over the Chicago River System.

Unlike the Chicago River System, the duration of storm effects for a given storm are very similar along the Calumet River System (Little Calumet River (north)–Calumet-Sag Channel) as shown in Table 4. Since there is just one pumping station, 125th Street Pumping Station, and it is located close to upstream boundary (O'Brien Lock and Dam), differences in the volume of gravity and pumping station CSOs do not create a big variation in the duration of storm impacts along the river system.

Table 3. Magnitude of Combined Sewer Overflow (CSO) volume in m^3/s and the duration of storm effect on the simulated dissolved oxygen concentration in days in the Chicago Area Waterway System for July 12-November 9, 2001. (after Alp, 2006)

Event	1	2	3	4	5	6	7
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
Total CSO	65.19	18.39	22.06	15.25	4.13	21.43	3.99
Total Pump S. CSO	39.52	6.52	13.36	5.44	1.77	8.60	2.81
Total Gravity CSO	25.67	11.87	8.70	9.81	2.36	12.82	1.18
*Chicago River System**	**Duration of storm effect on dissolved oxygen concentration in days**						
Romeoville	8.6	15.5	15.1	10.9	7.8	10.6	7.0
River Mile 11.6	8.6	14.0	13.9	10.8	7.5	10.3	6.3
Route 83	8.8	15.3	14.9	10.8	7.7	10.3	6.9
Baltimore and Ohio Railroad	9.3	14.2	13.3	10.3	7.5	9.6	6.3
Cicero Avenue	9.2	14.7	15.8	10.2	8.0	9.5	7.7
Jackson Boulevard	9.4	16.6	15.5	9.0	6.8	10.9	4.3
Kinzie Street	8.2	17.5	13.5	8.3	6.1	7.3	4.4
Division Street	7.6	18.5	13.5	9.3	7.2	7.6	4.6
Fullerton Avenue	5.5	18.2	12.8	9.0	5.2	5.8	3.8
Addison Street	2.0	14.6	12.8	8.8	1.2	3.3	2.1
*Calumet River System***	**Duration of storm effect on dissolved oxygen concentration in days**						
Route 83	7.5	10.5	15.6	11.1	6.5	9.7	2.5
104th Street	7.9	14.0	13.3	10.9	7.2	10.8	2.3
Southwest Highway	8.1	13.4	16.9	10.6	6.2	11.2	2.0
Harlem Avenue	7.5	13.1	16.8	10.5	6.1	11.2	2.2
Cicero Avenue	7.4	14.5	16.2	10.3	7.0	11.1	2.1
Kedzie Avenue	6.9	14.3	15.9	9.9	6.4	10.9	2.0
Division Street	6.6	12.9	15.7	10.5	6.4	3.7	1.5
Halsted Street	8.0	13.6	15.4	10.4	7.3	11.1	1.5
Conrail Railroad	8.1	7.8	10.7	10.0	7.2	10.8	ND***

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (north)

*** ND= The duration of the storm effect on DO concentration cannot be detected since variations in simulated DO concentrations are negligible

At Romeoville the standard deviations of simulated $CBOD_5$ and NH_4-N concentrations were plotted against time together with the flow (Figure 10). As can be seen in Figure 10, the standard deviation clearly decreases almost to zero except for overlapping storms. Hence, it is assumed that at the point where the $CBOD_5$ and NH_4-N standard deviation approaches zero the storm pollution load does not affect water quality in the system at that location anymore.

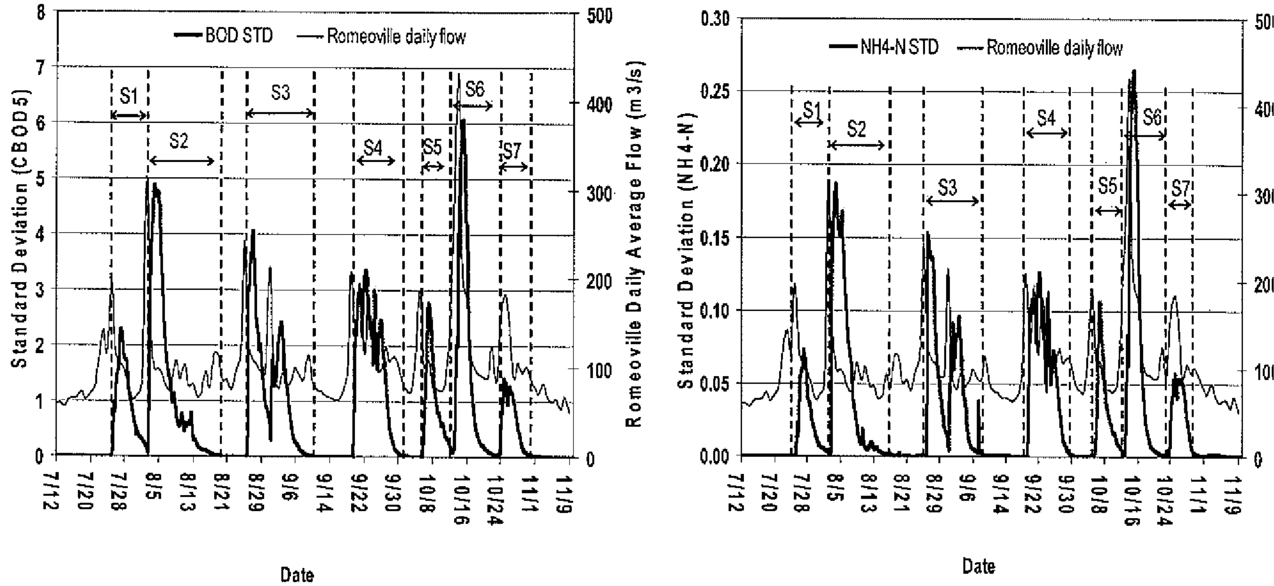


Figure 10. Flow and duration of the storm effect on the standard deviation of simulated carbonaceous biochemical oxygen demand ($CBOD_5$) and ammonium as nitrogen (NH_4-N) concentrations at Romeoville for July 12 to November 9, 2001 (after Alp, 2006).

The storm effect on $CBOD_5$ and NH_4-N lasts from 2 days to 2 weeks depending on the storm and the location (Tables 4 and 5). In general, the duration of the storm effect on $CBOD_5$ and NH_4-N concentrations along the Chicago River System lasts 3-4 days longer than on the Calumet River System. As expected, the duration of the storm effect on $CBOD_5$ and NH_4-N concentrations decreases towards upstream locations along Chicago Sanitary and Ship Canal and North Branch Chicago River. On the other hand, in the Calumet River System, the response of the system to storm loading stays almost the same along the waterway for a given storm.

The key point to be derived from Tables 3-5 is that even at upstream locations the CSO loadings can affect water quality for more than a week for some storms. This long storm effect is related to the hydraulic dams and other stagnant conditions in the CAWS. Further the long storm effects can negatively impact the aquatic community, and these long storm effects cannot be reduced until the reservoirs of the Tunnel and Reservoir Plan are fully on line. Table 6 lists the duration of storm effects on DO, $CBOD_5$, and NH_4-N averaged over all locations in Tables 3-5 and compares this with the duration of elevated flows (greater than 100 m^3/s, 3,530 ft^3/s) at Romeoville for all the single storm events in simulated periods of 2001 and 2002. The comparison shows that the duration of storm effects on water quality can be up to 4 times longer than the duration of elevated flows at Romeoville.

In summary, the effects of storm flows on the ability to meet water quality standards should not be considered a trivial or insignificant problem for the CAWS. The long effects of storm flows on water quality also indicate that it may be appropriate to consider wet weather standards for the CAWS.

Table 4. Magnitude of Combined Sewer Overflow (CSO) volume in million gallons (MG) and the duration of storm effect on the simulated five-day carbonaceous biochemical oxygen demand ($CBOD_5$) concentration in days in the Chicago Area Waterway System for July 12-November 9, 2001 (after Alp, 2006)

Event	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
Total CSO Volume	1488	4859	5828	4029	1092	5660	1054
Total P.S. CSO Volume	902	1723	3530	1437	468	2272	743
Total Gravity CSO Volume	586	3136	2298	2592	624	3388	311
Location *Chicago River System**	**Duration of storm effect on $CBOD_5$ concentration in days**						
Romeoville	8.5	13.8	12.7	11.1	7.0	8.8	8.0
River Mile 11.6	8.6	13.4	12.8	10.8	7.4	8.4	8.1
Route 83	8.8	14.5	13.0	10.8	7.3	8.2	7.8
Baltimore and Ohio Railroad	9.3	13.7	12.7	10.5	7.3	7.3	7.3
Cicero Avenue	8.8	12.7	13.4	10.2	7.3	7.2	7.3
Jackson Boulevard	6.4	12.2	11.3	8.2	5.1	4.8	5.4
Kinzie Street	5.8	8.7	8.7	8.0	6.3	4.5	4.5
Division Street	5.3	8.8	8.2	7.1	5.7	3.8	3.5
Fullerton Avenue	3.6	5.9	6.2	4.0	3.5	3.3	1.2
Addison Street	2.8	5.0	4.7	3.4	2.3	3.3	2.1
Location *Calumet River System***	**Duration of storm effect on $CBOD_5$ concentration in days**						
Route 83	7.0	9.3	11.9	10.3	5.8	10.5	4.4
104th Street	6.0	8.0	10.8	9.5	5.9	9.8	3.2
Southwest Highway	5.3	7.5	10.5	9.0	4.8	9.5	3.1
Harlem Avenue	6.1	7.5	10.1	9.0	4.8	9.5	4.8
Cicero Avenue	4.9	7.0	9.9	8.6	7.3	8.8	3.5
Kedzie Avenue	4.2	6.8	8.8	7.7	7.2	8.3	2.1
Division Street	5.3	8.8	8.2	7.1	5.7	3.8	3.5
Halsted Street	1.2	1.8	2.9	4.5	0.8	1.8	0.7
Central and Wisconsin Railroad	4.4	7.8	9.0	9.0	4.0	9.1	2.0
Conrail Railroad	4.8	6.9	8.8	8.0	3.7	9.1	3.0

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (north)

Table 5. Magnitude of Combined Sewer Overflow (CSO) volume in million gallons (MG) and the duration of storm effect on the simulated ammonium as nitrogen (NH_4-N) concentration in days in Chicago Area Waterway System for July 12-November 9, 2001 (after Alp, 2006)

Event	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Date-2001	7/25	8/2 & 8/9	8/25 & 8/31	9/19-9/23	10/5	10/13	10/23
Total CSO Volume (MG)	1488	4859	5828	4029	1092	5660	1054
Total P.S. CSO Volume(MG)	902	1723	3530	1437	468	2272	743
Total Gravity CSO Volume (MG)	586	3136	2298	2592	624	3388	311
Location *Chicago River System**	**Duration of storm effect on NH_4-N concentration in days**						
Romeoville	8.5	12.8	13.8	10.6	7.1	9.0	6.7
River Mile 11.6	8.2	12.1	13.3	10.0	7.2	8.7	6.3
Route 83	7.4	6.9	11.7	9.5	7.0	7.0	5.6
Baltimore and Ohio Railroad	6.7	7.4	10.7	9.0	6.2	6.2	5.1
Cicero Avenue	5.7	6.9	9.8	8.5	5.0	5.7	4.5
Jackson Boulevard	4.0	6.5	10.4	8.0	5.1	4.8	3.5
Kinzie Street	4.8	6.3	9.1	6.2	4.8	4.1	2.8
Division Street	4.9	6.2	8.4	5.8	4.0	3.7	3.7
Fullerton Avenue	3.6	5.1	6.2	3.5	3.6	3.3	1.7
Addison Street	3.0	3.9	5.9	3.5	2.1	2.2	0.6
Location *Calumet River System***	**Duration of storm effect on NH_4-N concentration in days**						
Route 83	5.0	7.5	10.0	9.5	5.2	5.1	3.5
104^{th} Street	4.8	6.9	9.5	9.0	4.7	4.3	2.5
Southwest Highway	4.9	7.0	9.5	9.0	4.8	4.3	2.5
Harlem Avenue	4.9	7.1	9.6	9.0	4.7	4.3	2.6
Cicero Avenue	5.2	7.4	9.7	9.0	4.0	4.2	2.5
Kedzie Avenue	4.8	7.0	9.3	8.5	4.0	4.0	2.0
Division Street	4.9	6.2	8.4	5.8	4.0	3.7	3.7
Halsted Street	5.2	7.7	9.8	8.7	4.5	9.7	2.7
Central and Wisconsin Railroad	4.9	7.4	9.5	8.2	3.8	9.2	1.9
Conrail Railroad	5.0	7.4	9.6	6.3	3.8	9.8	1.9

* *Chicago River System*: Chicago Sanitary and Ship Canal, South Branch Chicago River, and North Branch Chicago River

** *Calumet River System*: Calumet-Sag Channel and Little Calumet River (north)

Table 6. Duration of storm effects in days on dissolved oxygen (DO), carbonaceous biochemical oxygen demand ($CBOD_5$), and ammonium as nitrogen (NH_4-N) averaged over all locations listed in Tables 3-5 and duration of storm effects on flow for storms whose effects did not overlap onto other storm periods.

Date	DO	$CBOD_5$	NH_4-N	Flow
July 25, 2001	8.6	8.5	8.5	8.0
October 5, 2001	7.8	7.0	7.1	4.0
October 13, 2001	10.6	8.8	9.0	7.0
October 23, 2001	7.0	8.0	6.7	4.0
July 9, 2002	10.8	12.2	7.6	3.0
August 22, 2002	13.0	7.7	5.8	6.0

Summary

The following hydraulic features of the CAWS distinguish it from natural systems. The normal flow in the CAWS is bidirectional in places and very slow everywhere, and as a result wet weather impacts can linger for long periods suggesting that wet weather standards may be appropriate for the CAWS. Further, the combination of low velocities and very low slope limits natural reaeration and challenges the effectiveness of supplemental aeration due to the slow distribution throughout the water body of the artificially introduced oxygen. This challenge will become greater as DO standards are raised.

RELATIONS BETWEEN HYDRAULIC AND ECOLOGICAL CONDITIONS

As discussed above, the CAWS effectively is a long, narrow, moderately deep impoundment not at all similar to natural streams. Even dam impoundments on formerly natural streams have variation in habitat and substrate including shelter areas for fish, whereas these features are absent from the CAWS.

Habitat (QHEI) and Biological (IBI) Scoring

Rankin (1989) examined relations between the Qualitative Habitat Evaluation Index (QHEI) and the Index of Biological Integrity (IBI) in order to develop a procedure for relating stream potential to habitat quality that would provide some insight into how habitat might affect biological expectations in a given water body. The goal of his study was to provide guidance on the specification of aquatic life uses (i.e. potential aquatic ecological community) for water bodies that were impaired by pollution impacts. Rankin (1989, p. 2) noted that the procedure developed "needed to be useful enough to separate the relative effects of habitat versus water quality on fish community structure or at a minimum determine the baseline community that could be expected in a particular habitat." To develop the relations between QHEI and its subcomponent metrics and life uses Rankin (1989) considered data from a large number and wide variety of streams in Ohio including:

1) streams that represent sites minimally impacted by chemical water quality or habitat,

2) streams that contain areas that have relatively un-impacted water quality but have documented habitat impacts ("modified" reference sites), and
3) within stream basins where the State of Ohio had used the QHEI in some water quality management decision.

This procedure was used by Rankin (2004) [Attachment R to the rulemaking proposal before the Board] to estimate life uses of Modified Warmwater Habitat and Limited Resource Water for the reaches designated Warmwater Aquatic Life Use A and B waters, respectively, in rulemaking proposal before the Board.

The IEPA testimony in several locations/cases indicated that some judgment guided the final determination of whether a particular QHEI value resulted in a rating of Aquatic Life Use A or Aquatic Life Use B. For example, Mr. Smogor testified as follows:

> Mr. Smogor: Well, the QHEI in the Cal-Sag – let's say a QHEI score of 40 is kind of like in between the waters that – the other CAWS A waters that are scoring higher QHEI's, and most of the waters that are in the CAWS B group.
>
> * * *
>
> Mr. Smogor: It's poor based on Rankin's qualitative cut-offs that are largely in reference to attaining ability to attain or not attain clean water aquatic life goal. Now, if we say what's the ability of the CAWS A habitat to attain the goal that we've set for it, we may slide that qualitative scale from good to fair to poor a little bit downward, and that might bring a 40 up into the fair category in terms of how good is it for attaining something less than the Clean Water Act goal.

March 10, 2008 Hearing, transcript (morning) at pp. 32-33.

Essentially then the IEPA is stating that where QHEI is "higher" and IBI is "lower" this indicates that improvement in water quality is needed to achieve the ecological potential of the "higher" QHEI. Rankin (1989, p. 12) noted that "using the QHEI as a site-specific predictor of IBI can vary widely depending on the predominant character of the habitat of the reach." He also presented examples that showed that a QHEI of 50 could result in a low or a very high IBI. Thus, whether the higher QHEI scores found in select portions of the CAWS are truly indicative of a higher potential ecological community for the CAWS requires further consideration.

Effect of Poor Habitat on Biology

One way to determine whether a higher QHEI score truly indicates higher biological potential is to consider in detail the nature of the key habitat metrics included in the QHEI. A number of locations in the IEPA testimony indicate that the IEPA and Mr. Rankin (2004) [Attachment R to the rulemaking proposal before the Board] looked at the individual metrics:

> Mr. Essig: When Ed Rankin did the analysis using his habitat analysis, he's not just looking at the QHEI total score and where it sits. He's also looking at other

> types of habitat attributes that are part of the QHEI system; the individual metrics. March 10, 2008 Hearing, testimony (morning) at p. 35.
>
> * * *
>
> Mr. Smogor: To the extent we're not relying solely on the final score to make a judgment. You can look at how individual metrics score and you can tally relative numbers of what they call positive metrics versus negative metrics. April 23, 2008 Hearing, testimony at p. 199.

This idea that one can tally the number of positive versus negative metrics and give them equal weight in trying to decide the dividing line between life uses conflicts with Rankin (1989). Rankin (1989, p.13) noted "Analysis of the frequency of occurrence of QHEI metric subcomponents among IBI ranges indicates that "negative" habitat characteristics generally (but not universally) contribute more to the explanation of deviations from a random distribution with IBI range than "positive" habitat characteristics." Further, Rankin (1989) found that some metrics were more important than others. The key metric subcomponents are substrate quality, pool quality, and channel quality.

<u>Poor Habitat in the CAWS</u>

Rankin (1989, p. 24) noted "The influence of high quality substrates is probably related to their importance in providing food organisms (macroinvertebrates) to the insectivores and benthivores that typify midwest streams." Insectivores and benthivores are different groupings of fish based on the preferred diet of the fish. The macroinvertebrate data on the CAWS reported in CDM (2007) [Attachment B of the rulemaking proposal before the Board] clearly illustrates the poor quality of the substrate present in the CAWS. For 17 of the 18 locations sampled with a petite ponar dredge the Macroinvertebrate Biotic Index (MBI) indicated very poor water-quality whereas at 16 locations where Hester Dendy samplers were used the MBI indicated that the water quality was fair or good. Hester Dendy samplers are plates placed in the water that provide an artificial substrate which can be colonized by macroinvertebrates. The grab sample reflects conditions in the sediment at a site whereas the artificial substrate shows/predicts the potential benthic community in the drift that will settle on the plate. The difference in the sampler results shows that CAWS substrate will prevent any further improvements in water quality from translating to a better macroinvertebrate community and will not likely result in improvements in aquatic life use. The fact that the CAWS has a poor substrate is no surprise, because the system is completely human created, rather than a natural system that was allowed to geologically develop over thousands of years and, thus, develop appropriately varied substrates. This indicates that the macroinvertebrate "non-attainment" discussed in Mr. Essig's testimony may be more due to poor substrate than poor water quality as hypothesized by IEPA. See March 10, 2008 Hearing, testimony (morning) at pp. 12-13. Additional details on what constitutes a balanced, healthy benthic community and its preferred substrate conditions are presented in the fact witness testimony of Jennifer Wasik of the District.

With respect to pool quality, Rankin (1989, p. 24) noted sites with fast currents had higher IBI scores than expected by chance. As noted in Table 2 the average flow velocity throughout the CAWS is less than 1 ft/s and for more than 60 percent of the CAWS the average velocity is less than 0.4 ft/s. In contrast, the U.S. Geological Survey, Illinois District, has been developing a database of roughness coefficient measurements for normal ranges of main channel flows made in streams throughout the State of Illinois. The database (http://il.water.usgs.gov/proj/nvalues/) includes reach average velocities for 234 flow measurements on 38 reaches of 27 rivers and streams. Only one of the 234 measurements had a velocity less than 0.4 ft/s and more than 87 percent of the measurements had velocities greater than or equal to 1 ft/s. Thus, the flow velocities in the CAWS are substantially lower than those for normal flows in streams and rivers throughout Illinois.

With respect to channel quality, Rankin (1989, p. 25 and 29) noted

a) streams with little or no sinuosity were associated with lower IBI scores,
b) sites with only fair to poor riffle/pool development generally have lower IBI scores and sites with excellent to good development have higher IBI scores, and
c) lower gradients are generally, but not universally, associated with lower IBI values and higher gradient scores with higher IBI values.

The CAWS falls at the lower extreme of all these factors.

Rankin (1989, p. 41) listed the key features that result in a stream to be classified as a Modified Warmwater Stream (the analogue of Warmwater Aquatic Life Use A) noting that streams with QHEI scores between 45 and 60 should have several of the primary factors to be considered a Modified Warmwater Stream. Table 7 lists the habitat features that distinguish between Modified Warmwater Streams and Warmwater Streams (i.e. the analogue of General Use waters). Among these primary features for Modified Warmwater Streams the CAWS has recent channelization (truly permanent channelization), silt/muck substrates (in many reaches), low-no sinuosity, cover sparse to none (in many reaches), poor pool and riffle development, and lack of fast current. Thus, there can be no doubt that the potential ecological community is degraded by habitat impairment in the CAWS. Also, this analysis indicates that the Calumet-Sag Channel is more of a poor habitat (Warmwater Aquatic Life Use B) than a fair habitat (Warmwater Aquatic Life Use A). Mr. Sulski states that "It's (*the Calumet-Sag Channel*) different than the sanitary ship canal." March 10, 2008 Hearing, testimony (morning) at pp. 30-31. While they are different, they are not substantially different. For example, threadbare tires are different from tires with an eighth of an inch of tread, but both are dangerous to drive on.

From the foregoing discussion it is clear that the ecological community in the CAWS is substantially impaired by poor habitat. At several locations in their testimony, the IEPA concedes this fact, for example:

> Mr. Smogor: I mean, we're not saying that it can attain the Clean Water Act goal. We're saying it attains something less.

* * *

> We're already saying that CAWS A, we don't expect that it can attain that goal because it has fair and maybe even into poor category qualitatively speaking habitat.

March 10, 2008 Hearing, testimony (morning) at pp. 28, 33. The U.S. Environmental Protection Agency (U.S. EPA) has established a DO criterion of 3.0 mg/L for full attainment of warmwater life uses. IEPA indicated that it does not expect Aquatic Life Use A waters to meet the Clean Water Act goals, but is here proposing that both A and B waters achieve DO levels of at least 3.5 mg/L—even higher than would be required by U.S. EPA. March 10, 2008 Hearing, transcript (morning) at p. 28. Further, IEPA has proposed a DO standard for Aquatic Life Use A of 5.0 mg/L for March through July to support early life stages, with no evidence that the habitat and physical characteristics of the CAWS could support such a use or attain the proposed criterion. Essentially, the rulemaking proposal before the Board is requiring that the degraded CAWS meet in certain critical aspects the General Use standards in rule R04-25 that was recently adopted by the Board. A tabular comparison of the rulemaking proposal before the Board and the General Use standards is included in the expert testimony of Freedman.

Table 7. Habitat Characteristics of Modified Warmwater Streams (Warmwater Aquatic Life Use A) and Warmwater Streams (General Use Waters) in Ohio. Superscripts for Modified Warmwater Streams refer to the influence of a particular characteristic in determining the use (1 = high influence, 2 = moderate influence). Characteristics apply to all ecoregions and types unless otherwise noted. [after Rankin (1989, p. 41)]

Feature Number	Modified Warmwater Streams	Warmwater Streams
1	Recent channelization^{1} or recovering^{2}	No channelization or recovered
2	Silt/muck substrates^{1} or heavy to moderate silt covering other substrates^{2}	Boulder, cobble, or gravel
3	Sand substrates$^{2\text{-Boat}}$, Hardpan origin^{2}	Silt free
4	Fair-poor development^{2}	Good-excellent development
5	Low-no sinuosity$^{2,\ 1\text{-Headwater}}$	Moderate-high sinuosity
6	Only 1-2 cover types^{2}, Cover sparse to none^{1}	Cover extensive to moderate
7	Intermittent or interstitial$^{2\text{-with poor pools}}$	Fast currents, eddies
8	Lack or fast current^{2}	Low-normal substrate embeddedness
9	Maximum depth < 40 cm$^{1\text{-Wading},\ 2\text{-Headwater}}$	Maximum depth > 40 cm
10	High embeddedness of substrates^{2}	Low/no embeddedness

Note: Development refers to pool and riffle development

Alternative approaches to DO criteria

In the State of Ohio the DO criteria for Modified Warmwater Streams (the analogue of Warmwater Aquatic Life Use A) is a daily minimum of 3.0 mg/L and a daily average of 4.0 mg/L, and the minimum reduces to 2.5 mg/L in the Huron/Erie Lake Plain Ecoregion (Ohio rule 3745-1-07). Whereas for Limited Resources Waters (the analogue of Warmwater Aquatic Life Use B) the criterion for the daily minimum is 2.0 mg/L with a daily average of 3.0 mg/L (Ohio rule 3745-1-07). Similarly, Novotny et al. (2007) [Attachment WW of the proposal before the Board] recommended a daily minimum of 3.0 mg/L and a daily mean of 4.0 mg/L for Brandon Pool, which has been designated Warmwater Aquatic Life Use B.

In the IEPA testimony the partial justification for the selected DO standards was the target fish species as per the following statements:

> Mr. Smogor: ...the criteria that we've proposed that are consistent with Attachment X which is the National Criteria Document are set to protect for early life stages as sensitive as early life stages of channel catfish, and they're set to protect for later life stages as sensitive as later life stages of largemouth bass. March 10, 2008 Hearing, testimony (morning) at p. 71.
>
> * * *
>
> Mr. Smogor: In terms of these criteria, if you're going to protect for early life stages of fish that have early life stages that are as sensitive as channel cat and probably even small mouth bass, then you have to keep the DO above five if you're going to protect for those types of early life stages. April 24, 2008 Hearing, testimony at pp. 99.

Thus, the IEPA established largemouth bass, smallmouth bass, and channel catfish as target fish species whose protection is sought by the target DO criteria with smallmouth bass and channel catfish as the targets for the early life stages protection. March 10, 2008 Hearing, transcript (morning) at pp. 70-71; April 24, 2008 Hearing, transcript at pp. 98-99. Consideration should then be given to whether the CAWS offers suitable habitat for these fish species.

<u>Alternative Analysis of CAWS Habitat</u>

In the early 1980s, the Fish and Wildlife Service of the U.S. Department of the Interior did detailed literature reviews seeking to identify the physical and chemical conditions of water bodies suitable for various fish species. These models are known as Habitat Suitability Indexes (HSIs), where a value of 1 indicates optimal habitat and 0 indicates unsuitable habitat. These models are not perfect predictors, and in each report for the species of interest here a statement appears indicating the species of interest may be present even if the suitability index is 0, and habitat with a high suitability index may contain few fish. The Fish and Wildlife Service recommends that the suitability indices should be compared with fish data for the water body of interest before interpreting the suitability results. HSI ratings have been completed for each of the target fish species for the CAWS.

CDM (2007) [Attachment B to the rulemaking proposal before the Board] found that largemouth bass was a dominant game fish species in each reach of the CAWS. This agrees very well with the HSI information. Stuber et al. (1982) make the following statements about the optimal habitat for largemouth bass:

> "Lacustrine environments are the preferred habitat of largemouth bass. Optimal riverine habitat for largemouth bass is characterized by large slow moving rivers

or pools of streams with soft bottoms, some aquatic vegetation, and relatively clear water."

With the exception of relatively clear water this optimal riverine habitat describes the CAWS. Eleven of the twenty suitability metrics for largemouth bass in rivers listed by Stuber et al. (1982) are physical habitat measures whereas the remaining nine are water chemistry measures. These eleven suitability metrics and their ratings for the CAWS in general are listed in Table 8.

The results in Table 8 indicate that the CAWS in general is a highly suitable habitat for adult largemouth bass with 5 of the 6 adult metrics scoring 0.7 or better throughout the waterways. Thus, the high abundance of largemouth bass in the system makes complete sense. However, Table 8 also indicates that the CAWS may not be a good habitat for early life stages of largemouth bass with velocities and percent bottom cover resulting in scores near zero for much of the CAWS. The tributaries of the CAWS might have suitable habitat for early life stages of the largemouth bass. However, District fish sampling data from 1996 and 1997 (Dennison et al., 2001) and 2001-2005 (http://www.mwrd.org/RD/IEPA_Reports/Waterways/Biological%20Data/Fish%20Data%20Chicago%20Area%20Waterways%202001-2005.xls) indicate that largemouth bass were not found in the lower reaches of the North Branch Chicago River upstream from the junction with the North Shore Channel. Further, District fish sampling data from 2001-2005 indicate that largemouth bass were not found in the Little Calumet River (south). Finally, District fish sampling data from 2001-2005 indicate largemouth bass is the third most abundant species in the Calumet River at 130th Street immediately upstream from O'Brien Lock and Dam. Thus, it seems these fish enter the CAWS from Lake Michigan not the CAWS tributaries. Further, the high abundance of largemouth bass implies that the current water quality of the CAWS is sufficient for a healthy largemouth bass community and higher standards are not needed.

Table 8. Habitat suitability values for largemouth bass in the Chicago Area Waterways estimated for general conditions in the waterway system.

Symbol	Description	CAWS Condition	Suitability Value
V_1	Percent pool and backwater area during average summer flow	100%	1.0
V_3	Percent bottom cover (e.g., aquatic vegetation, logs, and debris within pools, backwaters, or littoral areas during summer (Adult, Juvenile)	<15%	0.2-0.4
V_4	Percent bottom cover (e.g., aquatic vegetation, logs, and debris within pools, backwaters, or littoral areas during summer (Fry)	<15%	0.0-0.3
V_{15}	Substrate composition within riverine pools and Backwaters	Silt and clay dominates	0.8
V_{16}	Average water level fluctuation during growing season (Adult, Juvenile)	Approx. 0 m	1.0
V_{17}	Average water level fluctuation during growing season (Embryo)	Approx. 0 m	1.0

V_{18}	Average water level fluctuation during growing season (Fry)	Approx. 0 m	1.0
V_{19}	Average current velocity at 0.6 depth during summer (Adult, Juvenile)	< 10 cm/s	0.7-1.0
V_{20}	Maximum current velocity at 0.8 depth within pools or backwaters during spawning (May-June) (Embryo)	< 10 cm/s	0.0-1.0
V_{21}	Average current velocity at 0.6 depth during summer (Fry)	< 10 cm/s	0.0*
V_{22}	Stream gradient within representative reach	< 1 m/km	1.0

*Only the reaches of the Little Calumet River (north) and the Calumet-Sag Channel between Halsted Street and Ashland Avenue are likely to have non-zero values.

CDM (2007) [Attachment B to the rulemaking proposal before the Board] found that the abundance of smallmouth bass and channel catfish in the CAWS is far less than that of largemouth bass. Is this due to poor water quality, poor habitat, or some combination of the two? Six of the thirteen suitability metrics for smallmouth bass in rivers listed by Edwards et al. (1983) are physical habitat measures whereas the remaining seven are water chemistry measures. These six suitability metrics and their ratings for the CAWS in general are listed in Table 9.

Table 9. Habitat suitability values for smallmouth bass in the Chicago Area Waterways estimated for general conditions in the waterway system.

Symbol	Description	CAWS Condition	Suitability Value
V_1	Dominant substrate type within pool or backwater area	Silt and sand and/or Rooted vegetation	0.2
V_2	Percent pools	100%	0.2
V_4	Average depth of pools during midsummer	4-8 m	0.9-1.0
V_5	Percent cover in the form of boulders, stumps, dead trees, and crevices (adults) or vegetation and rocks (fry)	< 15%	0.0-0.5
V_{14}	Water level fluctuations during spawning and for 45 days after spawning	Slow rise previous to spawning with stable levels during spawning and afterwards	1.0
V_{15}	Stream gradient within representative Reach	<0.1 m/km	≈ 0

The metrics in Table 9 indicate that the CAWS in general is a poor habitat for adult smallmouth bass, which is consistent with the limited number of smallmouth bass found in fish sampling reported in CDM (2007).

With respect to early life stages for smallmouth bass, Edwards et al. (1983) offer the following information.

- Nests are usually in water from 0.3 to 0.9 m (1 to 3 ft) deep, but may be built in water up to 7 m (23 ft) deep.

- Nests are commonly in gravel or bedrock; near boulders, logs, or other cover.
- Nests are also made over bedrock, rootlets in silt, or sand, but these substrates are less commonly used.
- Most fry remain in shallow water, although some may be found at depths of 4.6 to 6.1 m (15 to 20 ft).

This indicates that much of the CAWS is not a preferred habitat for early life stages of smallmouth bass. However, District fish sampling data from 1996 and 1997 (Dennison et al, 2001) and 2001-2005 indicate that smallmouth bass were not found in the lower reaches of the North Branch Chicago River upstream from the junction with the North Shore Channel. Further, District fish sampling data from 2001-2005 indicate that smallmouth bass were not found in the Little Calumet River (south). Finally, District fish sampling data from 2001-2005 indicate smallmouth bass are the fourth most abundant species in the Calumet River upstream from O'Brien Lock and Dam. Thus, it seems these fish enter the CAWS from Lake Michigan not the CAWS tributaries, but they find the CAWS to be poor living environment for them and their numbers are limited.

Four of the fourteen suitability metrics for channel catfish in rivers listed by McMahon and Terrell (1982) are physical habitat measures whereas the remaining ten are water chemistry measures. These four suitability metrics and their ratings for the CAWS in general are listed in Table 10.

Table 10. Habitat suitability values for smallmouth bass in the Chicago Area Waterways estimated for general conditions in the waterway system.

Symbol	Description	CAWS Condition	Suitability Value
V_1	Percent pools during average summer flow	100 %	0.5
V_2	Percent cover (logs, boulders, cavities, brush, debris, or standing timber) during summer within pools and backwater areas	<15 %	0.1-0.4
V_4	Food production potential in river by substrate type present during average summer flow	Fines or bedrock are the dominant bottom material. Little or no aquatic vegetation or rubble present.	0.2
V_{15}	Average current velocity in cover areas during average summer flow	< 15 cm/s*	1.0

*Only the North Branch Chicago River is likely to have velocities higher than this.

The results in Table 10 indicate the CAWS is a fair to poor habitat for channel catfish, which is consistent with the limited number of channel catfish found in fish sampling reported in CDM (2007).

With respect to early life stages for channel catfish, McMahon and Terrell (1982) offer the following information.

- Nests are built in cavities, burrows, under rocks, and in other protected places.
- Catfish in large rivers are likely to move into shallow, flooded areas to spawn.

- Channel catfish fry have strong shelter seeking tendencies, and cover availability will be important in determining habitat suitability.
- Fry are commonly found aggregated near cover in protected, slow-flowing areas of rocky riffles, debris-covered gravel, or sand bars in clear streams.

This indicates that much of the CAWS is not a preferred habitat for early life stages of channel catfish. The tributaries of the CAWS might have suitable habitat for early life stages of the target fish species. However, District fish sampling data from 1996 and 1997 (Dennison et al., 2001) and 2001-2005 indicate that channel catfish were not found in the lower reaches of the North Branch Chicago River upstream from the junction with the North Shore Channel. Further, District fish sampling data from 2001-2005 indicate that channel catfish were not found in the Little Calumet River (south). Finally, District fish sampling data from 2001-2005 indicate that channel catfish were not found in the Calumet River upstream from O'Brien Lock and Dam and only 10 were caught in the Des Plaines River at Material Service Road between 2001 and 2005. Thus, the origin of channel catfish in the CAWS is unclear, but those who enter find the CAWS to be poor living environment for them.

In summary, the CAWS provides poor habitat for adult smallmouth bass and channel catfish, which is consistent with the low abundance of these fish in the CAWS. It is, however, near optimal habitat for largemouth bass, which is consistent with the high abundance of this fish in the CAWS. However, the CAWS is poor habitat for early life stages of all these target fish species. The largemouth and smallmouth bass most likely spawn and spend their early life stages in Lake Michigan and then colonize the CAWS as adults. The origin of channel catfish found in the CAWS is unclear. Thus, seeking to protect early life stages for these species of fish in the CAWS is inconsistent with the habitat suitability and the available fish abundance data.

CONCLUSIONS

When summarizing the relation between habitat, fish communities, and water-quality management Rankin (1989, p. 52) offered the following warning:

> It makes little sense to "protect" the biota by multimillion dollar improvements to a point source discharge while important biological uses are impaired by habitat modifications for reasons such as "flood control", construction activities, and waterway improvements.

Considering the foregoing discussion of habitat and particularly the unsuitable habitat for the early life stages of the target fish species, the rulemaking proposal before the Board is contrary to the findings of the UAA contractors. For example, CDM (2007) [Attachment B to the rulemaking proposal before the Board] indicated on page 1-12 "The data showed that the aquatic habitats were rated from very poor to fair with most reaches having habitat unable to support a diverse aquatic community." Later on page 5-3 CDM (2007) indicated "Improvements to water quality through various technologies, like re-aeration may not improve the fish communities due to the lack of suitable habitat to support the fish population." Further, Novotny et al. (2007) (Attachment WW to the rulemaking proposal before the Board] recommended the previously described lower DO standards (relative to the proposal before the Board) for the Warmwater Aquatic Life Use B waters in the Brandon Pool of a daily minimum of 3.0 mg/L and a daily mean of 4.0 mg/L.

I hope that the Illinois Pollution Control Board will carefully consider this testimony, and should not approve the rulemaking proposal before the Board, when the State of Illinois and the Chicago Area have many other problems requiring public financing.

References

Alp, E. (2006), A method to evaluate duration of the storm effects on in-stream water quality. *Ph.D. Thesis*, Department of Civil and Environmental Engineering, Marquette University, Milwaukee, WI.

Alp, E. and Melching, C.S. (2004). Preliminary Calibration of a Model for Simulation of Water Quality During Unsteady Flow in the Chicago Waterway System and Application to Proposed Changes to the Navigation Make-Up Diversion Procedures, *Institute of Urban Environmental Risk Management Technical Report No. 15*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 04-14*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, Ill.

Alp, E. and Melching, C.S. (2006). Calibration of a Model for Simulation of Water Quality During Unsteady Flow in the Chicago Waterway System and Application to Evaluate Use Attainability Analysis Remedial Actions, *Institute for Urban Environmental Risk Management Technical Report No. 18*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 2006-84*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, Ill.

Alp, E. and Melching, C.S. (2008). "Evaluation of Procedures to Prevent Flow Reversals to Lake Michigan for the Chicago Waterway System," *Institute for Urban Environmental Risk Management Technical Report No. 19*, Marquette University, Milwaukee, WI.

Alp, E. and Melching, C.S. (in press). Evaluation of the Duration of Storm Effects on In-Stream Water Quality, *Journal of Water Resources Planning and Management*, ASCE.

Alp, E., Melching, C.S., Zhang, H., and Lanyon, R. (2007). Effectiveness of Combined Sewer Overflow Treatment for Dissolved Oxygen Improvement in the Chicago Waterways, *Water Science and Technology*, **56**(1), 215-222.

Ambrose, R.B., Wool, T.A., Connolly, J.P., and Schanz, R.W. (1988). WASP4, a hydrodynamic and water quality model—Model theory, User's manual, and programmer's guide. U.S. Environmental Protection Agency, *EPA/600/3-87-039*, Athens, GA.

Butts, T.A., Shackleford, D.B, and Bergerhouse, T.R. (1999). Evaluation of reaeration efficiencies of sidestream elevated pool aeration (SEPA) stations, *Illinois State Water Survey Contract Report 653*, Champaign, IL.

Butts, T.A., Shackleford D.B., and Bergerhouse, T.R. (2000). Sidestream elevated pool aeration (SEPA) stations: Effect on instream dissolved oxygen, *Illinois State Water Survey Contract Report 2000-02*, Champaign, IL.

Davis, M.L. and Masten, S.J. (2004). *Principles of Environmental Engineering and Science*, McGraw-Hill, New York.

Dennison, S.G., Polls, I., Sawyer, B., and Tata, P. (2001). Abundance and distribution of fish in the North Branch of the Chicago River during 1996 and 1997, *Research and Development Department Report No. 01-4*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, Ill.

Di Toro, D.M. and Fitzpatrick, J. (1993). *Chesapeake Bay Sediment Flux Model.* HydroQual, Inc. Mahwah, NJ. Prepared for U.S. Army Engineer Waterway Experiment Station, Vicksburg, MS. Contract Report EL-93-2.

DUFLOW (2000). *DUFLOW for Windows V3.3: DUFLOW modelling studio: User's guide, reference guide DUFLOW, and reference guide RAM*, EDS/STOWA, Utrecht, The Netherlands.

Edwards, E.A., Gebhart, G., Maughan, O.E. (1983). Habitat Suitability Information: Smallmouth Bass, U.S. Department of the Interior, Fish and Wildlife Service, *FWS/OBS-82/10.36*, 47 p.

Elshorbagy, A., Teegavarapu, R., and Ormsbee, L. (2005). Framework for assessment of relative pollutant loads in streams with limited data, *Water International*, **30**(4), 477-486.

Espey, W.H., Jr., Melching, C.S., and Mades, D.M. (2004). Lake Michigan Diversion—Findings of the Fifth Technical Committee for Review of Diversion Flow Measurements and Accounting Procedures, report prepared for the U.S. Army Corps of Engineers, Chicago District, Chicago, Ill.

Harremoes, P., Napstjert, L., Rye, C., and Larsen, H.O. (1996). Impact of rain runoff on oxygen in an urban river. *Water Science and Technology*, **34**(12), 41-48.

Manache, G. and Melching, C.S. (2004). Sensitivity Analysis of a Water-Quality Model Using Latin Hypercube Sampling, *Journal of Water Resources Planning and Management*, ASCE, **130**(3), 232-242.

Manache, G. and Melching, C.S. (2005). Simulation of Fecal Coliform Concentrations in the Chicago Waterway System Under Unsteady Flow Conditions, *Institute for Urban Environmental Risk Management Technical Report No. 16*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 2005-9*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, IL.

Manache, G. and Melching, C.S. (2007). Sensitivity of Latin Hypercube Sampling to Sample Size and Distributional Assumptions, *Proceedings CD-ROM*, 32nd Congress of the International Association of Hydraulic Engineering and Research, Venice, Italy, July 1-6, 2007.

Manache, G. and Melching, C.S. (2008). Identification of Reliable Regression- and Correlation-Based Sensitivity Measures for Importance Ranking of Water-Quality Model Parameters, *Environmental Modelling & Software*, **23**(5), 549-562.

Manache, G., Melching, C.S., and Lanyon, R. (2007). Calibration of a Continuous Simulation Fecal Coliform Model Based on Historical Data Analysis, *Journal of Environmental Engineering*, ASCE, **133**(7), 681-691.

McMahon, T.E. and Terrell, J.W. (1982). Habitat Suitability Index Models: Channel Catfish, U.S. Department of the Interior, Fish and Wildlife Service, *FWS/OBS-82/10.2*, 29 p.

Melching, C. S. and Bauwens, W. (2000). Comparison of Uncertainty-Analysis Methods Applied to Simulation of Urban Water Quality, in *Stochastic Hydraulics 2000*, Z.Y. Wang and S.X. Hu, eds., A.A. Balkema, Rotterdam, The Netherlands, p. 717-725.

Melching, C.S. and Bauwens, W. (2001). Uncertainty in Coupled Nonpoint Source and Stream Water-Quality Models, *Journal of Water Resources Planning and Management*, ASCE, **127**(6), 403-413.

Melching, C.S. and Chang, T.J. (1996). Simulation of Water Quality for Salt Creek in Northeastern Illinois, *U.S. Geological Survey Open-File Report 96-318*.

Melching, C.S. and Flores, H.E. (1999). Reaeration Equations Derived from USGS Data Base, *Journal of Environmental Engineering*, ASCE, **125**(5), 407-414.

Melching, C.S. and Oberg, K.A. (1993). Comparison, Analysis, and Estimation of Discharge Data from Two Acoustic Velocity Meters on the Chicago Sanitary and Ship Canal at Romeoville, Illinois, *U.S. Geological Survey Water-Resources Investigations Report 93-4098*.

Melching, C.S. and Yoon, C.G. (1996). Key Sources of Uncertainty in QUAL2E Model of Passaic River, *Journal of Water Resources Planning and Management*, ASCE, **122**(2), 105-113.

Melching, C.S., Novotny, V., and Schilling, J.B. (2006). Probabilistic Evaluation of Ammonia Toxicity in Milwaukee's Outer Harbor, *Water Science and Technology*, **53**(1), 109-116.

Melching, C.S., Alp, E., Shrestha, R.L., and Lanyon, R. (2004). Simulation of Water Quality During Unsteady Flow in the Chicago Waterway System, *Proceedings CD-ROM*, Watershed 2004, July 11-14, 2004, Dearborn, Michigan, Water Environment Federation.

Neugebauer, A. and Melching, C.S. (2005). Verification of a Continuous Water Quality Model Under Uncertain Storm Loads in the Chicago Waterway System, *Institute for Urban Environmental Risk Management Technical Report No. 17*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 2005-12*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, IL.

Novotny, V. and Olem, H. (1994). *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*, Van Nostrand Reinhold, New York.

Polls, I. Washington, B., and Lue-Hing, C. (1982). Improvements in dissolved oxygen levels by artificial in-stream aeration in Chicago Waterways, Metropolitan Sanitary District of Greater Chicago, *Department of Research and Development Report No. 82-16*, Chicago, IL.

Rankin, E.T. (1989). *The Qualitative Habitat Evaluation Index [QHEI]: Rationale, Methods, and Application*, Ecologic Assessment Section, Division of Water Quality Planning & Assessment, Ohio Environmental Protection Agency, Columbus, Ohio.

Recktenwalt, M., Nitka, J., Sear, T., and Gerold, L. (2004) Point source loading calculations for purposes of watercourse modeling, Draft Technical Memorandum, Milwaukee Metropolitan Sewerage District, Milwaukee, Wis.

Shrestha, R.L. and Melching, C.S. (2003). Hydraulic Calibration of an Unsteady Flow Model for the Chicago Waterway System, *Institute of Urban Environmental Risk Management Technical Report No. 14*, Marquette University, Milwaukee, Wis., and *Research and Development Department Report No. 03-18*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, Ill.

Stuber, R.J., Gebhart, G., and Maughan, O.E. (1982). Habitat Suitability Index Models: Largemouth Bass, U.S. Department of the Interior, Fish and Wildlife Service, *FWS/OBS-82/10.16*, 32 p.

Thomann, R.V. (1982). Verification of water quality models. Journal of the Environmental Engineering Division, ASCE, **108**(EE5), 923-940.

U.S. Environmental Protection Agency (U.S. EPA). (1983). *Results of the Nationwide Urban Runoff Program.* Vol. I. *Final Report, Water Planning Division*, U.S EPA, Washington, D.C.

ATTACHMENT 2

TO PRE-FILED TESTIMONY OF CHARLES S. MELCHING

CURRICULUM VITAE OF CHARLES S. MELCHING

CHARLES STEVEN MELCHING

EDUCATION:

Fall 1981- Summer 1987	University of Illinois, Urbana, Illinois Doctor of Philosophy, October 1987 Master of Science, Civil Engineering, January 1983
Spring 1979- Summer 1981	Arizona State University, Tempe, Arizona Graduated Summa Cum Laude, August 1981, B.S.E.
Fall 1977-Summer 1979	Mesa Community College, Mesa, Arizona

PROFESSIONAL REGISTRATION:

Professional Engineer (Civil) in Arizona since 1991, Registration No. 25326
Professional Engineer in Illinois since 1992, Registration No. 062-047430

EXPERIENCE:

August 1999-Present

Marquette University, Department of Civil and Environmental Engineering, Milwaukee, Wisconsin

Associate Professor

Teaching:

CEEN 032 Elementary Surveying
CEEN 123 Urban Hydrology and Stormwater Management
CEEN 126 Hydraulic Engineering
CEEN 249 Advanced Hydrology
CEEN 251 Water Quality Management and Modeling
CEEN 122/248 River Engineering

Research:

1. Development and Application of a Water-Quality Model for Unsteady Flow in the Chicago Waterway System
2. Evaluation of Procedures to Prevent Backflows to Lake Michigan from the Chicago Waterway System
3. Water-Quality Simulation in Support of the Development of an Integrated Strategy to Meet Dissolved Oxygen Standards for the Chicago Area Waterways
4. Des Plaines River Use Attainability Analysis *(supporting modeling and data analysis)*
5. Estimation of the Allowable Pollutant Loading Margin of Safety for the Warta River in Poland
6. Evaluation of Uncertainty in Stream Naturalization Procedures
7. Hydraulic Investigations for the Reconstructed North Halsted Street Bridge over the North Branch Canal, Division Street Bridges over the North Branch Chicago River and North Branch Canal, and the Proposed Bridge over the South Branch Chicago River at Taylor Street

Consulting:

A. U.S. Geological Survey on HSPF modeling projects in Florida, Minnesota, Massachusetts, and Wisconsin; and a unit-hydrograph project in Illinois
B. U.S. Army Corps of Engineers on the aeration design for McCook and Thornton Reservoirs of the Tunnel and Reservoir Project (TARP), and Hydrologic Modeling Expert for the 5th and 6th Technical Review Committees on Lake Michigan Diversion Accounting
C. Baird Associates on the HSPF sediment transport model of the Menomonee River
D. Aqua Nova on ammonia simulation in the Milwaukee Outer Harbor, and Taught Short Course on Introduction to TMDL Concepts and Water-Quality Modeling (with V. Novotny) to Illinois Environmental Protection Agency
E. Brown and Caldwell on project "MMSD Modeling Strategy Advisory Committee" for Milwaukee Metropolitan Sewerage District
F. JBA Consulting (United Kingdom) on "Non-invasive Flow Measurement Techniques Review" for U.K. Environment Agency.
G. Metropolitan Water Reclamation District of Greater Chicago: Flow Verification for the Flow Transfer to the Fox River Water Reclamation District South Plant

Advising:

Ph.D. Thesis of 1 student
Master's Theses of 7 students
Master's Essays of 3 students
Co-promoter of 1 Ph.D. student at the Vrije Universiteit Brussel, Belgium.

August 2005-July 2006 — Visiting Professor, Department of Hydraulic Engineering, Tsinghua University, Beijing, China

Teaching: "Probabilistic Approaches to Water Resources Engineering" and "Topics in American Water Resources Engineering," Research: proposal preparation: "A Comparative Evaluation of the Yellow River and Mississippi River Deltas"; also Visiting Scholar, International Research and Training Center on Erosion and Sedimentation, Beijing, China
Visiting Chair Professor, College of Resources, Environment & Tourism, Capital Normal University, Beijing, China

January 1992-August 1999 — U.S. Geological Survey, Water Resources Division, Illinois District, Urbana, Illinois

Hydraulic Engineer: Projects-

1. "Hydraulic Model Verification and Documentation for Unsteady Flow"--Prepare documentation for the Full EQuations (FEQ) model for one-dimensional, unsteady-flow analysis in open channels with Dr. D. Franz of Linsley, Kraeger Associates.
2. "Rainfall-Runoff Relations for Three Small Watersheds in Du Page County, Illinois" and "Rainfall-Runoff Relations in Nine Watersheds in Lake County, Illinois" - Calibrate and verify the HSPF continuous-simulation, rainfall-runoff model for use in the subject counties.
3. "Design Flood Estimation in Illinois Based on a Green and Ampt Abstraction Procedure with Physically Based Parameters."
4. "Analysis and Adjustment of Acoustical Velocity Meter measurements on the Chicago Sanitary and Ship Canal at Romeoville, Illinois for Lake Michigan Diversion Accounting."

5. "Statistical Analysis of Concurrent and Split Water-Quality Sampling Program - U.S. Geological Survey and Illinois Environmental Protection Agency."
6. "Affects of Storm Type on Precipitation Quality in Eastern Massachusetts - 1983-85"--Report Completion.
7. Flood Insurance Study for La Crosse, Wisconsin.
8. "Determination of Unit Hydrograph Parameters for Small Watersheds in Lake County, Illinois."
9. "Calibration and Verification of QUAL2E for Waste-Load Allocation on Salt Creek in Du Page and Cook Counties, Illinois"
10. "Regional Equations for Estimation of Instream Reaeration-Rate Coefficient (K_2)"--compile all instream measurements of K_2 made by the USGS using gas-tracer methods to develop the subject equations.
11. "Simulation of Runoff from the Proposed Crandon Mine (Wisconsin) Utilizing HSPF"--Assist the USEPA in the development of an HSPF model for simulation of the effects of the proposed mine.
12. "Comprehensive Assessment of Risks from Natural Disasters"--Assist World Meteorological Organization in the completion of a report summarizing economic consequences (risks) from natural disasters.
13. "Intercomparison of Principal Hydrometric Instruments--Third Phase: Evaluation of Ultrasonic Velocity Meters for Flow Measurement in Streams Canals, and Estuaries"--Joint World Meteorological Organization - U.S. Geological Survey Project
14. Advisor on hydrologic and/or water-quality modeling projects for the Minnesota River basin and the Heron Lakes basin, southwestern Minnesota (Minnesota District); Reedy Creek watershed, east-central Florida (Florida District); Middle and South Fork of the Beargrass Creek basin, Jefferson County, Kentucky (Kentucky District); and Red River of the North (North Dakota District)

Sept. 1998- February 1999 — Vrije Universiteit Brussel, Laboratory of Hydrology, Brussels, Belgium
Visiting Scholar
Project: Uncertainty Analysis for Holistic River Water-Quality Management Systems sponsored by "Research in Brussels Actions"—Apply uncertainty analysis to the suite of computer models used to simulate the pollutant loads in the combined sewers, through the proposed wastewater-treatment plant, and in the receiving stream to determine the reliability of meeting water-quality standards.
Teaching: Water-Quality Modeling
Advising: Ph.D. Thesis of one student (finished 12/01)

May 1996- June 1996 — Hong Kong University of Science and Technology, Department of Civil and Structural Engineering
Visiting Scholar

Spring 1996 and Fall 1997 — University of Illinois at Urbana-Champaign, Department of Civil Engineering, Urbana, Illinois
Visiting Lecturer - CE 356 Hydraulics of Surface Drainage, CE 255 Introduction to Hydrosystems Engineering; Adjunct Associate Professor: Spring 1998-Spring 1999
Advising: 1 M.S. Thesis and 1 M.S. Essay

July 1989- December 1991 Rutgers University, Department of Civil and Environmental Engineering Piscataway, New Jersey

Assistant Professor:

Teaching:

CE 387 Fluid Mechanics

CE 448 Elements of Hydrology

CE 563 Advanced Hydrology

CE 567 Analysis of Receiving Water Quality.

Research:

Application of reliability analysis in water resources engineering including water-quality modeling, bridge scour, groundwater-remediation design, and backwater computations.

Consulting:

Developed statistical sampling procedure for determining residential water use for New Brunswick (NJ) Water Utility

Advising:

Master's projects of 9 students and one Ph.D. student.

October 1987- July 1989 Interuniversity Post-graduate Programme in Hydrology, Vrije Universiteit Brussel, Brussels, Belgium

Visiting Lecturer:

Teaching - Full Courses: Surface Water Hydrology, Probability and Statistics, General Hydraulics, Watershed Management; Exercises: Systems Approach to Water Management Parts I and II, and Statistical Applications in Hydrology.

Advising - Master's Theses of 6 students.

Fall 1981- Summer 1987 University of Illinois at Urbana-Champaign, Department of Civil Engineering, Urbana, Illinois

Research Assistant - on projects "Application of Simulation Models to Military Training Site" and "Prioritizing Army Railroad Construction and Repair Projects";

U.S. Army Corps of Engineers Construction Engineering Research Laboratory.

Teaching Assistant - Spring 1987 taught Introduction to Hydrosystems Engineering; grader for Water Resources Design and Hydraulics of Surface Drainage.

Summer 1980 U.S. Water Conservation Laboratory, 4331 E. Broadway, Phoenix, AZ 85040.

Engineering aid -- critical-depth flume and level basin irrigation projects.

Summer 1978-Summer 1979 Engineering and Surveying of Arizona, 404 E. 1st Avenue, Mesa, AZ 85204.

Survey crew instrument man and rodman/chainman.

Summer 1977 Giffels and Webster Engineers, 2731 N. Adams, Pontiac, MI 48057.

Survey crew instrument man and rodman/chainman.

1972-1977 Charles G. Melching and Associates, Inc., 36170 Pound Road, Richmond, MI 48062

Worked and gained initial training as a rodman/chainman.

AWARDS AND HONORS

2008 Marquette University, College of Engineering, 2008 Outstanding Researcher Award

2001 Walter L. Huber Civil Engineering Research Prize, American Society of Civil Engineers—"For his research on uncertainty and reliability analysis in water resources and environmental engineering, including especially uncertainty in rainfall-runoff and stream water-quality modeling"

1997 Invited Speaker, International Symposium of Rural Environment Improvement, Korean Society of Agricultural Engineers, Kon-Kuk University, October 17, 1997

1989 Henry Rutgers Research Fellowship, Rutgers University

1988 Chester P. Seiss Civil Engineering Graduate Student Award for Outstanding Scholastic Achievement and Promise for Research, University of Illinois

1981 American Society of Civil Engineers - Arizona State University Outstanding Senior Award for 1981

1981 American Society of Civil Engineers - Pacific Southwest Conference (student) Paper Contest, 1st Place 1981 ("Portable Flow Measuring Flumes for Earthen Channels" unpublished)

1981 University of Illinois Civil Engineering Fellowship, 1981

1981 Phoenix Femineers' Scholarship, 1981

Arizona State University Certificate of Merit for Scholastic Excellence - 1979-1980 and 1980-1981

Arizona State University Dean's List, Spring 1979 through Spring 1981

SOCIETY MEMBERSHIPS:

Tau Beta Pi, Arizona Beta elected May 1980

Phi Kappa Phi, Arizona State Univ. elected May 1981

American Society of Civil Engineers:

Student Activities: Communications Vice President, 1980 (ASU); Hydrosystems Committee Chairman for Engineering Open House (Illinois) 1982.

Professional Activities: Technical Committee on Probabilistic Approaches, Water Resources Engineering Division (1991-present, Chairman, 1994-95); Task Committee on the Use of Appropriate Technology in Hydraulic Engineering, Hydraulics Division (1991); Student Chapter Faculty Advisor at Rutgers University (1991).

International Water Association

International Association for Hydraulic Research

International Association of Hydrologic Sciences

RESEARCH SPONSORS:

New Jersey Water Resources Research Institute

World Meteorological Organization

U.S. National Committee on Scientific Hydrology

Research in Brussels Action, Ministry of Economic Affairs, Brussels Capital Region, Belgium

Metropolitan Water Reclamation District of Greater Chicago

National Science Foundation

U.S. National Research Council
Illinois Environmental Protection Agency
U.S. Department of Education
Wisconsin Foundation of Independent Colleges
Chicago Department of Transportation through H.W. Lochner Consultants, Parsons
Engineering, and Earthtech

SCHOLARLY ACTIVITIES:

Book Reviewer

American Society of Civil Engineers
McGraw-Hill (review of chapter in Handbook of Water Resources)
Wylie and Sons (review of book proposals)
Kluwer Academic Publishers (review of book proposals)

Journal Referee

Associate Editor, Journal of Hydrologic Engineering, ASCE (2007-present)
Associate Editor, International Journal of Sediment Research (2002-present)
Associate Editor, Journal of Hydraulic Research (2002-2006)
Journal of Hydraulic Engineering, ASCE
Journal of Hydrologic Engineering, ASCE
Journal of Water Resources Planning and Management, ASCE
Journal of Environmental Engineering, ASCE
Journal of Irrigation and Drainage Engineering, ASCE
Water Resources Research
Water Research
Water International
Journal of Hydrology
Journal of the American Water Resources Association
IEEE Transactions on Systems, Man, and Cybernetics
Structural Safety
Hydrologic Processes
Environmental Fluid Mechanics
Environmental Modeling and Software
Water Science and Technology
Journal of Environmental Management
Stochastic Environmental Research & Risk Analysis
Journal of Hydro-environment Research
Advances in Water Resources

Invited Seminars

Technical University of Vienna (1988)
International Institute for Applied Systems Analysis (1988)
Polish Academy of Sciences (1988)
Ruhr University Bochum (1988)
Rijkswaterstaat, Utrecht, The Netherlands (1989)
University of Karlsruhe (1989)

U.S. Geological Survey, New Jersey District (1989)
University of Virginia (1990)
New Jersey Department of Environmental Protection (1990)
University of Illinois (1992, 1993, 2000, 2002)
Rutgers University (1993)
Vrije Universiteit Brussel (1993, 1994, 1998, 2001)
Hong Kong University of Science and Technology (1996, 2006)
Rural Development Corporation, South Korea (1997)
Metropolitan Water Reclamation District of Greater Chicago (2000, 2004, 2007)
Poznan University of Technology (2002)
Warsaw University of Technology (2002)
Tianjin University (2005)
Beijing University (2006)
Beijing Institute of Technology (2006, 2007)
Capitol Normal University, Beijing (2006)
China Institute of Water Resources and Hydropower Research (2006)
Northeast Agricultural University, Harbin, China (2006)
Wisconsin Department of Natural Resources (2007)
University of Wisconsin at Milwaukee (2007)
Federation of Environmental Technologists, Southeastern Wisconsin Chapter (2007, 2008)

Review of Research Proposals

Illinois Water Resources Research Center
New Jersey Sea Grant Program
Petroleum Research Fund (American Chemical Society)
Natural Environment Research Council (United Kingdom)
Fund for Scientific Research (Flanders, Belgium)
Research Grants Council (Hong Kong)
U.S. Geological Survey/National Water Resources Research Institutes
Universita degli Studi della Basilicata, Italy
Italian Ministry of Education, University and Scientific Research, Committee for Research Evaluation

Review of Project Products

Board of Experts for the Italian Ministry of Education, University and Scientific Research, Committee for Research Evaluation

Conference Organization

- Organized a Session at Hydraulic Engineering '93, ASCE National Hydraulic Engineering Conference, San Francisco, California, July 25-30, 1993.
- Local Organizing Committee, Rivertech '96: 1st International Conference on New and Emerging Concepts for Rivers, Chicago, Illinois, September 22-25, 1996, sponsored by the International Water Resources Association.
- Organized Session A.15 "Reliability-Based Design and Analysis in Water Resources" for the XXVII International Association for Hydraulic Research Congress, San Francisco, California, August 10-15, 1997.

- Organized Sessions on "Water Resources in the Geographical Region of China" for the Chinese American Water Resources Association for inclusion at the ASCE Water Resources Engineering Conference, Seattle, Washington, August 8-11, 1999.
- Chairman, Local Organizing Committee, 5th International Conference on Diffuse/Nonpoint Pollution and Watershed Management, Milwaukee, Wisconsin, June 10-15, 2001, sponsored by the International Water Association
- Invited Panelist for Session "Information Needs for Improved Watershed Decision-Making" at the Symposium on Integrated Decision-Making for Watershed Management, Chevy Chase, MD, January 7-9, Gave presentation on Hydrology Perspectives and led Hydrology Focus Group.
- Member, International Scientific Committee, and Convenor of Session of "Stochastic Hydraulics"—3rd International Conference on Environmental Hydraulics with a Special Theme in Environmental Fluid Dynamics, Tempe, Arizona, December 5-8, 2001.
- Organizer, U.S.-Chinese Joint Workshop on Sediment Transport and Environmental Studies, Milwaukee, Wisconsin, July 21-28, 2002. (sponsored by the National Science Foundation)
- Member, International Program Committee, Watermatex 2004: 6th International Symposium on Systems Analysis and Integrated Assessment in Water Management, International Water Association, Beijing, China, November 3-5, 2004.
- Member, Program and Organizing Committees for the Watermatex 2007, 7th International Symposium on Systems Analysis and Integrated Assessment, International Water Association, Washington, DC, May 7-9, 2007.
- Member, Organizing Committee, U.S.—China Water Consortium: A Wisconsin Idea Approach, Madison, Door County, and Milwaukee, Wisconsin, July 18-25, 2008.

Review Boards and Committees

- Review Team Member, Milwaukee Metropolitan Sewerage District Corridor Project, 2000-2002
- Member, Advisory Panel for Modeling of Small Watersheds, Illinois State Water Survey, 2002-2003
- Member, "Technical Advisory Committee on the Regional Water Quality Management Plan Update for the Greater Milwaukee Watersheds" and "Water Quality Modeling Subcommittee," Southeastern Wisconsin Regional Planning Commission, 2004-2007
- Member, Water Council Research/Emerging Technologies Committee, Milwaukee 7 (regional economic development agency), 2007-present

LIST OF PUBLICATIONS

Books/Reports Edited

1) Melching, C.S. and Pilon, P.J., eds., 1999. *Comprehensive Risk Assessment for Natural Hazards*, World Meteorological Organization Technical Document No. 955, 92 p.
2) Melching, C.S. and Liu, C., eds., 2003. Special Issue on Sediment Transport and Environmental Studies, *International Journal of Sediment Research*, vol. 18, no. 2 *(Proceedings, U.S.—Chinese Joint Workshop on Sediment Transport and Environmental Studies, Milwaukee, Wis., July 21-24, 2002).*
3) Tung, Y.K., Yen, B.C., and Melching, C.S., 2006. *Hydrosystems Engineering Reliability Assessment and Risk Analysis*, McGraw-Hill, New York, 495 p.

In Books

1) Yen, B.C., Cheng, S.T. and Melching, C.S, 1986. "First-Order Reliability Analysis," in *Stochastic and Risk Analysis in Hydraulic Engineering*, B. C. Yen, ed., Water Resources Publications, Littleton, CO, p. 1-34.
2) Melching, C. S., 1995. "Reliability Estimation," Chapter 3 in *Computer Models of Watershed Hydrology*, V. P. Singh, ed., Water Resources Publications, Littleton, CO, p. 69-118.
3) Melching, C. S. and Pilon, P.J., 1999. "Introduction," Chapter 1 in *Comprehensive Risk Assessment for Natural Hazards*, C. S. Melching and P. J. Pilon, eds., World Meteorological Organization, Technical Document No. 955, Geneva, Switzerland, p. 1-5.
4) Melching, C. S., 1999. "Economic Aspects of Vulnerability," Chapter 7 in *Comprehensive Risk Assessment for Natural Hazards*, C. S. Melching and P. J. Pilon, eds., World Meteorological Organization, Technical Document No. 955, Geneva, Switzerland, p. 66-76.
5) Melching, C. S., 1999. "Strategies for Risk Assessment—Case Studies," Chapter 8 in *Comprehensive Risk Assessment for Natural Hazards*, C. S. Melching and P. J. Pilon, eds., World Meteorological Organization, Technical Document No. 955, Geneva, Switzerland, 1999, pp. 77-92.
6) Manache, G., Bauwens, W., and Melching, C.S., 2003. "Reliability Analysis of a Water Quality Model Considering Uncertainty in the Model Parameters," in *Monitoring and Modeling Catchment Water Quantity and Quality, Proceedings*, 8th Conference of the European Network of Experimental and Representative Basins (ERB), Ghent, Belgium, September 27-29, 2000, N. Verhoest, J. Hudson, R. Hoeben, and F.P. De Troch, eds., International Hydrological Program, IHP-VI, Technical Documents in Hydrology No. 66, UNESCO, Paris, p. 53-60.
7) Melching, C.S., 2006, "Sewer Flow Measurement," Chapter 2.2, *Wastewater Quality Monitoring and Treatment*, P. Quevauviller, O. Thomas, and A. Van der Beken, eds., John Wiley and Sons, London.

In Journals

1) Melching, C.S. and Liebman, J.S., 1988. "Allocating Railroad Maintenance Funds by Solving Binary Knapsack Problems with Precedence Constraints," *Transportation Research*, **22B**(3), 181-194.
2) Uzarski, D.R., Melching, C.S. and Liebman, J.S., 1988. "Prioritizing U.S. Army Railroad Track Segments for Major Maintenance and Repair," *Transportation Research Record*, **1177**, 95-102.
3) Melching, C.S., Yen, B.C., and Wenzel, H.G., Jr., 1990. "A Reliability Estimation in Modeling Watershed Runoff with Uncertainties," *Water Resources Research*, **26**(10), 2275-2286.
4) Melching, C.S., Yen, B.C., and Wenzel, H.G., Jr., 1991. "Output Reliability as a Guide for Selection of Rainfall-Runoff Models," *Journal of Water Resources Planning and Management*, ASCE, **117**(3), 383-398.
5) Melching, C.S., 1992. "An Improved, First-Order Reliability Approach for Assessing Uncertainties in Hydrologic Modeling," *Journal of Hydrology*, **132**(1-4), 157-177.
6) Melching, C.S. and Anmangandla, S., 1992. "Improved First-Order Uncertainty Method for Water Quality Modeling," *Journal of Environmental Engineering*, ASCE, **118**(5), 791-805.

7) Melching, C.S. and Yoon, C.G., 1996. "Key Sources of Uncertainty in QUAL2E Model of Passaic River," *Journal of Water Resources Planning and Management*, ASCE, **122**(2), 105-113.
8) Melching, C.S. and Flores, H.E., 1999. "Reaeration Equations Derived from USGS Data Base," *Journal of Environmental Engineering*, ASCE, **125**(5), 407-414.
9) Melching, C.S. and Bauwens, W., 2001. "Uncertainty in Coupled Nonpoint Source and Stream Water-Quality Models," *Journal of Water Resources Planning and Management*, ASCE, **127**(6), 403-413.
10) Manache, G. and Melching, C.S., 2004. "Sensitivity Analysis of a Water-Quality Model Using Latin Hypercube Sampling," *Journal of Water Resources Planning and Management*, ASCE, **130**(3), 232-242.
11) Xiong, Y. and Melching, C.S., 2005. "Comparison of Kinematic-Wave and Nonlinear Reservoir Routing of Urban Watershed Runoff", *Journal of Hydrologic Engineering*, ASCE, **10**(1), 39-49.
12) Melching, C.S., Novotny, V., and Schilling, J.B., 2006. "Probabilistic Evaluation of Ammonia Toxicity in Milwaukee's Outer Harbor," *Water Science and Technology*, **53**(1), 109-116.
13) Manache, G., Melching, C.S., and Lanyon, R. 2007. "Calibration of a Continuous Simulation Fecal Coliform Model Based on Historical Data Analysis," *Journal of Environmental Engineering*, ASCE, **133**(7), 681-691.
14) Alp, E., Melching, C.S., Zhang, H., and Lanyon, R., 2007. "Effectiveness of Combined Sewer Overflow Treatment for Dissolved Oxygen Improvement in the Chicago Waterways," *Water Science and Technology*, **56**(1), 215-222.
15) Manache, G. and Melching, C.S., 2008. "Identification of Reliable Regression- and Correlation-Based Sensitivity Measures for Importance Ranking of Water-Quality Model Parameters," *Environmental Modelling & Software*, **23**(5), 549-562.
16) Booij, M.J. and Melching, C.S. 2008. "Appropriate Spatial Scales to Achieve Model Output Uncertainty Goals," in Hydrological Sciences for Managing Water Resources in the Asian Developing World, *International Association of Hydrological Sciences (IAHS) Publication No. 319.*
17) Alp, E. and Melching, C.S. in press, "Evaluation of the Duration of Storm Effects on In-Stream Water Quality, *Journal of Water Resources Planning and Management*, ASCE.
18) Wang, Z.Y. and Melching, C.S. "Ecological and Hydraulic Studies of Step-Pool Systems," *Journal of Hydraulic Engineering*, ASCE, submitted for publication.
19) Xie, X., Wang, Z.Y., and Melching, C.S. "Formation and Evolution of the Jiuduansha Shoal over the Past 50 Years," *Journal of Hydraulic Engineering*, ASCE, submitted for publication.

In Conference Proceedings

1) Melching, C.S. and Yen, B.C., 1986. "Slope Influence on Storm Sewer Risk," in *Stochastic and Risk Analysis in Hydraulic Engineering*, B.C. Yen, ed., Water Resources Publications, Littleton, CO, p. 79-89.
2) Melching, C.S., Wenzel, H.G., Jr., and Yen, B.C., 1987. "Application of System Reliability Analysis to Flood Forecasting," in *Application of Frequency and Risk in Water Resources*, V.P. Singh, ed., D. Reidel Publications, Dordrecht, The Netherlands, p. 335-350.
3) Yen, B.C. and Melching, C.S., 1991. "Reliability Analysis Methods for Sediment Problems," *Proceedings*, 5th Federal Interagency Sedimentation Conference, Vol. 2, S.-S. Fan and Y.-H. Kuo, eds., Federal Energy Regulatory Commission, Washington, DC.

4) Melching, C.S., 1991. "Reliability Assessment Method for Flood Forecasts," *Proceedings*, 1991 ASCE National Conference on Hydraulic Engineering, R.M. Shane, ed., p. 984-989.
5) Melching, C.S., 1992. "A Comparison of Methods for Estimating Variance of Water Resources Model Predictions," in *Stochastic Hydraulics '92*, Proceedings, Sixth IAHR International Symposium of Stochastic Hydraulics, Taipei, Taiwan, May 18-20, 1992, J.-T. Kuo and G.-F. Lin, eds., Department of Civil Engineering, National Taiwan University, Taipei, Taiwan, p. 663-670.
6) Singh, S. and Melching, C.S., 1993. "Importance of Hydraulic Model Uncertainty in Flood-Stage Estimation," in *Hydraulic Engineering '93*, Proceedings 1993 ASCE National Conference on Hydraulic Engineering, H.-W. Shen, S.-T. Su, and F. Wen, eds., Vol. 2, p. 1939-1944.
7) Melching, C.S., 1994. "Sensitivity of Monte Carlo Simulation to the Probability Distribution of the Input Parameters," *Proceedings*, International Symposium on Water Resources Planning in a Changing World, Karlsruhe, Germany, June 28-30, p. II.81-II.91.
8) Gonzalez, J.A., Melching, C.S., and Oberg, K.A., 1996. "Analysis of Open-Channel Velocity Measurements Collected with an Acoustic Doppler Current Profiler," *Proceedings*, Rivertech '96: 1st International Conference On New/Emerging Concepts for Rivers, W.H.C. Maxwell, H.C. Preul, and G.E. Stout, eds., Chicago, Illinois, September 22-25, 1996, p. 838-845.
9) Melching, C.S., 1997. "Effectiveness of Agricultural Best Management Practices for Control of Nutrients in Runoff," *Proceedings*, International Symposium on Rural Environment Improvement, Seoul, Korea, October 17, 1997, S.K. Kwun, C.G. Yoon, and S.J. Kim, eds. Korean Society of Agricultural Engineers, Seoul, Korea, p. 1-20. (Invited Paper).
10) Melching, C.S., 1998. "Accuracy of Tracer Measurement of Gas-Desorption Rates," in *Environmental Hydraulics*, J.H.W. Lee, A.W. Jayawardena, and Z.Y. Wang, eds., A.A. Balkema, Rotterdam, The Netherlands, p. 481-486.
11) Yen, B.C., Soong, T.W., and Melching, C.S., 1999. "Similarities of the 1998 Yangtze River Flood and 1993 Mississippi River Flood," *Proceedings*, 1999 ASCE Water Resources Engineering Conference, R. Walton, ed., 1999.
12) Melching, C. S. and Bauwens, W., 2000. "Comparison of Uncertainty-Analysis Methods Applied to Simulation of Urban Water Quality," in *Stochastic Hydraulics 2000*, Z.Y. Wang and S.X. Hu, eds., A.A. Balkema, Rotterdam, The Netherlands, p. 717-725.
13) Manache, G., Bauwens, W., and Melching, C.S., 2000. "Reliability Analysis of a Water Quality Model Considering Uncertainty in the Model Parameters," *Proceedings*, Experimental and Representative Basins (ERB) 2000—Monitoring and Modeling Catchment Water Quantity and Quality, Ghent, Belgium, September 27-29, 2000, R. Hoeben, Y. Van Herpe, and F.P. De Troch, eds., Laboratory of Hydrology and Water Management, Ghent University.
14) Lanyon, R. and Melching, C.S., 2001. "Data Collection for Development of a Water-Quality Model for Unsteady Flow in the Chicago Waterway System," *Proceedings*, ASCE Environmental and Water Resources Institute World Water & Environmental Resource Congress, May 20-24, 2001, Orlando, Florida.
15) Melching, C.S., 2001. "Sensitivity Measures for Evaluating Key Sources of Modeling Uncertainty," *Proceedings CD-ROM*, Third International Symposium on Environmental Hydraulics, Tempe, Arizona, December 5-8, 2001. Mira Digital Publishing.

16) Melching, C.S., Alp, E., Shrestha, R.L., and Lanyon, R., 2004. "Simulation of Water Quality During Unsteady Flow in the Chicago Waterway System," *Proceedings CD-ROM*, Watershed 2004, July 11-14, 2004, Dearborn, Michigan, Water Environment Federation.
17) Melching, C.S., 2004. "Water Quality Management in the Chicago Area," *Water Stories*, Proceedings of the Workshop on Occasion of the Retirement of Prof.-em. Dr. ir. Andre Van der Beken, Brussels, Belgium, September 30, 2004, *VUB-Hydrologie Special Issue*, Vrije Universiteit Brussel, p. 77-90.
18) Byrd, J.L. and Melching, C.S., 2005. "Uncertainty Evaluation in the Design of Instream Structures for Stream Restoration," *Proceedings (CD-ROM)*, XXXI Congress of the International Association for Hydraulic Engineering and Research, Seoul, Korea, September 11-16, 2005.
19) Manache, G. and Melching, C.S., 2007. "Sensitivity of Latin Hypercube Sampling to Sample Size and Distributional Assumptions," Proceedings CD-ROM, 32nd Congress of the International Association of Hydraulic Engineering and Research, Venice, Italy, July 1-6, 2007.
20) Zhang, H., Bernstein, D., Kozak, J., Jain, J.S., Lanyon, R., Alp, E., and Melching, C.S., 2007. "Evaluation of Eliminating Gravity CSOs on Water Quality of the Chicago Waterway System Using an Unsteady Flow Water Quality Model," Proceedings CD-ROM, WEFTEC 07, San Diego, CA, October 13-17, 2007, p. 5722-5735.

Technical Reports

1) Wenzel, H.G., Jr. and Melching, C.S., 1983. *Sensitivity of Sediment Yield Simulation Models to Rainfall Parameters*, Final Report, Contract No. DACA 88-83-M-0199, Department of Civil Engineering, University of Illinois, August, 1983.
2) Melching, C.S. and Wenzel, H.G., Jr., 1985. "Calibration Procedure and Improvements in MULTSED," *Hydraulic Engineering Series Report No. 38*, Department of Civil Engineering, University of Illinois at Urbana-Champaign, July, 1985.
3) Melching, C.S., 1987. A Reliability Analysis on Flood Event Forecasting with Uncertainties, Ph. D. Thesis, Department of Civil Engineering, University of Illinois at Urbana-Champaign.
4) Melching, C.S., Yen, B.C., and Wenzel, H.G., Jr., 1987 "Incorporation of Uncertainties in Real-Time Catchment Flood Forecasting," *Water Resources Center Research Report 208*, University of Illinois at Urbana-Champaign, September, 1987.
5) Wenzel, H. G., Jr. and Melching, C.S., 1987. "An Evaluation of the MULTSED Simulation Model to Predict Sediment Yield," *USA-CERL Technical Report N-87/27*, U.S. Army Construction Engineering Research Laboratory, September, 1987.
6) Uzarski, D.R., Liebman, J.S., Melching, C.S., and Plotkin, D.E., 1988. "FORSCOM Railroad Project Prioritization Program (FORPROP) for the Railer System: Development and Testing," *USA-CERL Technical Report M-88/19*, U.S. Army Construction Engineering Research Laboratory, September, 1988.
7) Melching, C.S. and Avery, C.C., 1990. "An Introduction to Watershed Management for Hydrologists," *Vrije Universiteit Brussel Hydrologie Report No. 18*.
8) Yoon, C.G. and Melching, C.S., 1992. "Sources and Reduction of Uncertainty in Stream Water Quality Modeling," Final Report to Water Resources Research Institute, Rutgers-The State University of New Jersey, New Brunswick, NJ, September, 1992.

9) Melching, C.S. and Oberg, K.A., 1993. "Comparison, Analysis, and Estimation of Discharge Data from Two Acoustic Velocity Meters on the Chicago Sanitary and Ship Canal at Romeoville, Illinois," *U.S. Geological Survey Water-Resources Investigations Report 93-4098.*
10) Melching, C.S. and Coupe, R.H., 1995. "Differences in Analytical Results for Concurrent and Split Stream-Water Samples Collected and Analyzed by the U.S. Geological Survey and Illinois Environmental Protection Agency, 1985-91," *U.S. Geological Survey Water-Resources Investigations Report 94-4141.*
11) Gay, F.B. and Melching, C.S., 1995. "Precipitation Quality Relations to Storm Types and Constituent Loads in Massachusetts, 1983-85," *U.S. Geological Survey Water-Resources Investigations Report 94-4224.*
12) Duncker, J.J., Vail, T.J., and Melching, C.S., 1995. "Regional Rainfall-Runoff Relations for Simulation of Streamflow for Watersheds in Lake County, Illinois," *U.S. Geological Survey Water-Resources Investigations Report 95-4023.*
13) Melching, C.S. and Chang, T.J., 1996. "Simulation of Water Quality for Salt Creek in Northeastern Illinois," *U.S. Geological Survey Open-File Report 96-318.*
14) Melching, C.S. and Marquardt, J.S., 1996. "Equations for Estimating Synthetic Unit-Hydrograph Parameter Values for Small Watersheds in Lake County, Illinois," *U.S. Geological Survey Open-File Report 96-474.*
15) Franz, D.D. and Melching, C.S., 1997. "Full Equations (FEQ) Model for the Solution of the Full, Dynamic Equations of Motion for One-Dimensional Unsteady Flow in Open Channels and Through Control Structures," *U.S. Geological Survey Water Resources Investigations Report 96-4240.*
16) Franz, D.D. and Melching, C.S., 1997. "Full Equations Utilities (FEQUTL) Model for the Approximation of Hydraulic Characteristics of Open Channels and Control Structures During Unsteady Flow," *U.S. Geological Survey Water-Resources Investigations Report 97-4037.*
17) Duncker, J.J. and Melching, C.S., 1998. "Regional Rainfall-Runoff Relations for Simulation of Streamflow for Watersheds in Du Page County, Illinois, *U.S. Geological Survey Open-File Report 98-4035.*
18) Melching, C.S., and Meno, M.W., 1998. "Intercomparison of Principle Hydrometric Instruments—Third Phase: Evaluation of Ultrasonic Velocity Meters for Flow Measurement in Streams, Canals, and Estuaries," World Meteorological Organization, *Technical Reports in Hydrology and Water Resources No. 69*, WMO/TD-No. 931, Geneva, Switzerland.
19) Melching, C.S., 1999. "Uncertainty Analysis for Holistic River Water-Quality Management Systems," Final Report to the Research in Brussels Action, Ministry of Economics, Brussels Capital Region, Belgium, May 1999.
20) Straub, T.D., Melching, C.S., and Kocher, K.E., 2000. "Equations for Estimating Clark Unit-Hydrograph Parameters for Small Rural Watersheds in Illinois," *U.S. Geological Survey Water-Resources Investigations Report 00-4184.*
21) Alp, E., Clark, D., Melching, C.S., and Novotny, V., 2002. "Application of Benefit Transfer with Contingent Valuation Method to the Root River Watershed," *Institute of Urban Environmental Risk Management Technical Report No. 12*, Marquette University, Milwaukee, Wis.
22) Chriscicki, J.B., Melching, C.S., Bicknell, B.R., Roy, S.D., Manoyan, S., Stewart, J.S., and Duncker, J.D., 2003. "Simulation of Streamflow, Lake, and Wetland Water-Surface Elevations in the Swamp and Pickerel Creek Watersheds in the Wolf River Watershed, Near the Proposed Crandon Mine, Wisconsin," Final Report, U.S. Environmental Protection Agency, Region 5, Chicago, Ill.

23) Todesco, D., Melching, C.S., and Novotny, V., 2003. "Analysis of a Simple Distributed Sediment and Pollutant Model Within Arcview GIS Environment," *Institute of Urban Environmental Risk Management Technical Report No. 13*, Marquette University, Milwaukee, Wis.
24) Shrestha, R.L. and Melching, C.S., 2003. "Hydraulic Calibration of an Unsteady Flow Model for the Chicago Waterway System," *Institute of Urban Environmental Risk Management Technical Report No. 14*, Marquette University, Milwaukee, Wis., and *Research and Development Department Report No. 03-18*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, Ill.
25) Espey, W.H., Jr., Melching, C.S., and Mades, D.M., 2004. "Lake Michigan Diversion—Findings of the Fifth Technical Committee for Review of Diversion Flow Measurements and Accounting Procedures," report prepared for the U.S. Army Corps of Engineers, Chicago District, Chicago, Ill.
26) Alp, E. and Melching, C.S., 2004. "Preliminary Calibration of a Model for Simulation of Water Quality During Unsteady Flow in the Chicago Waterway System and Application to Proposed Changes to the Navigation Make-Up Diversion Procedures," *Institute of Urban Environmental Risk Management Technical Report No. 15*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 04-14*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, Ill.
27) Zaidman, M.D., Lamb, R., Mawdsley, J., Lawless, M.R., Archer, D.R., and Melching, C.S., 2005. "Non Invasive Techniques for River Flow Measurement," *Science Report SC030203/SR*, Environment Agency, Bristol, U.K.
28) Manache, G. and Melching, C.S., 2005. "Simulation of Fecal Coliform Concentrations in the Chicago Waterway System Under Unsteady Flow Conditions," *Institute for Urban Environmental Risk Management Technical Report No. 16*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 2005-9*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, IL.
29) Neugebauer, A. and Melching, C.S., 2005. "Verification of a Continuous Water Quality Model Under Uncertain Storm Loads in the Chicago Waterway System," *Institute for Urban Environmental Risk Management Technical Report No. 17*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 2005-12*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, IL.
30) Alp, E. and Melching, C.S., 2006, "Calibration of a Model for Simulation of Water Quality During Unsteady Flow in the Chicago Waterway System and Application to Evaluate Use Attainability Analysis Remedial Actions," *Institute for Urban Environmental Risk Management Technical Report No. 18*, Marquette University, Milwaukee, Wis. and *Research and Development Department Report No. 2006-84*, Metropolitan Water Reclamation District of Greater Chicago, Chicago, Ill.
31) Alp, E. and Melching, C.S. (2008). "Evaluation of Procedures to Prevent Flow Reversals to Lake Michigan for the Chicago Waterway System," *Institute for Urban Environmental Risk Management Technical Report No. 19*, Marquette University, Milwaukee, WI.

PAPERS PRESENTED (not formally published)

1) Melching, C.S. and Wenzel, H.G., Jr., "Soil Erosion Model Transferability," presented at 1984 Illinois Conference on Soil Conservation and Water Quality, October 18-19, 1984, Champaign, Ill.
2) Melching, C.S., Yen, B.C., and Wenzel, H.G., Jr., "Decision Making Considering Uncertainties of Hydrologic Models," presented at the Fifth IAHR International Symposium on Stochastic Hydraulics, University of Birmingham, Birmingham, U.K., August 2-4, 1988.
3) Melching, C.S., "An Approach to Determine the Margin of Safety for Nonpoint Source Load Allocations" presented at the Midcontinent TMDL Practitioners' Workshop, U.S. Environmental Protection Agency Regions 5 and 7, Chicago, November 1, 2000.
4) Melching, C.S., "Statistical Models: Linking Nonpoint Pollution Models to Receiving Water Standards," presented at the TMDL Science Issues Conference, Water Environment Federation, March 4-7, 2001, St. Louis.
5) Aderman, P.C. and Melching, C.S., "Evaluation of the SCS/NRCS Dimensionless Unit Hydrograph for Small Watersheds in the Midwestern United States," Wisconsin Association for Floodplain, Stormwater, and Coastal Management, Wisconsin Dells, Wis., November 13-14, 2003.