BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

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

NOTICE OF FILING

To: ALL COUNSEL OF RECORD
(Service List Attached)

PLEASE TAKE NOTICE that on the 2nd day of February, 2011, I electronically filed with the Office of the Clerk of the Illinois Pollution Control Board, the **Pre-Filed Testimony of David Zenz – Cost Estimates to Meet Proposed Dissolved Oxygen Water Quality Standards for the Chicago Area Waterway System.**

Dated: February 2, 2011.

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

By: */s/ Fredric P. Andes*
One of Its Attorneys

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PROOF OF SERVICE

The undersigned attorney certifies, under penalties of perjury pursuant to 735 ILCS 5/1-109, that I caused a copy of the foregoing, **Notice of Filing** and **Pre-Filed Testimony of David Zenz – Cost Estimates to Meet Proposed Dissolved Oxygen Water Quality Standards for the Chicago Area Waterway System**, to be served via First Class Mail, postage prepaid, from One North Wacker Drive, Chicago, Illinois, on the 3rd day of February, 2011, upon the attorneys of record on the attached Service List.

/s/ David T. Ballard
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PROPOSED AMENDMENTS TO 35 Ill.	)	
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PRE-FILED TESTIMONY OF DAVID R. ZENZ

COST ESTIMATES TO MEET PROPOSED DISSOLVED OXYGEN WATER QUALITY STANDARDS FOR THE CHICAGO AREA WATERWAY SYSTEM

My name is David R. Zenz and I am presenting testimony in the matter of: "Water Quality Standards and Effluent Limitations for the Chicago Area Waterway System and Lower Des Plaines River: Proposed Amendment to 35 ILL. Adm. Code Parts 301, 302, 303 and 304 (RO8-9)." I am currently employed as a Senior Consulting Engineer by AECOM Technical Services, Inc. (AECOM), which performed the engineering studies that form the basis of my testimony. I have a Ph.D. and M.S. degrees in Environmental Engineering and a B.S. in Civil Engineering, and I am a registered Professional Engineer in the State of Illinois. Prior to joining AECOM in 1997, I was employed by the Metropolitan Water Reclamation District of Greater Chicago (District) in the Environmental Monitoring and Research Division. I worked on a variety of projects at the District and helped develop the design criteria for the existing District supplemental aeration stations on the Chicago Area Waterway System (CAWS). While at AECOM, I have worked on various municipal wastewater treatment and sludge management projects. I was the project manager for a variety of water quality studies for the District in connection with the CAWS Use Attainability Analysis (UAA). Most notably, I performed studies for the District to determine technologies and costs for supplemental aeration and flow augmentation of the CAWS and have provided previous testimony to the Illinois Pollution Control Board (IPCB) on these studies.

Background

This pre-filed testimony includes two cost estimates AECOM recently completed for the District. The District asked AECOM to perform these cost estimates in response to the Dissolved Oxygen (DO) water quality standards currently proposed for the CAWS by the Illinois Environmental Protection Agency (IEPA). These estimates include the costs required to construct and operate the aeration facilities needed to comply with the currently proposed IEPA DO standards as well as a District proposed DO standards as an alternative to the currently proposed IEPA standards. These cost estimates are based on computer simulations conducted by Marquette University using their DUFLOW water quality model (report attached). Marquette University used the model to determine the number, location, aeration capacity, and operation hours of supplemental aeration and aerated flow augmentation facilities needed to meet each set of standards 100% of the time based on waterway conditions during Water Years 2001 and 2003, which were considered by Marquette University to be representative wet and dry water years, for the following waterways:

- North Shore Channel (NSC)
- North Branch Chicago River (NBCR)
- Chicago River Main Stem (Main Stem)
- South Branch Chicago River (SBCR)
- South Fork of the SBCR (Bubbly Creek)
- Chicago Sanitary and Ship Canal (CSSC)
- Little Calumet River North (LCRN)
- Calumet-Sag Channel (Cal-Sag)

It should be noted that these DUFLOW model runs do not account for changes in CAWS DO behavior that may result from changes in Lake Michigan Diversion that may occur in the future.

The capacities and locations of facilities provided by Marquette University were used by AECOM to develop the cost estimates included in the following testimony. The cost estimates are based on the general cost estimation procedures presented in my previous testimony before the IPCB in 2008. However, the capacity and location of aeration facilities provided by Marquette University for this testimony were developed following improvements to the DUFLOW model since my previous testimony. The cost estimates provided in this testimony are based on the following assumptions:

1) The supplemental aeration technology considered was ceramic disc diffusers installed in the waterway with an on-shore blower facility.

2) The aerated flow augmentation technology considered was force-main aeration of pumped flow using a U-tube aerator and high purity oxygen.

3) The number, location, aeration capacity, and operation hours of the supplemental aeration and flow augmentation facilities were provided by Marquette University. Marquette University developed this information based on simulations using their improved DUFLOW model.

4) Unit costs from earlier studies conducted by AECOM for the District in response to the IEPA's Use Attainability Analysis (UAA) were adjusted for inflation to June 2010 dollars. The present worth costs were based on a twenty year life with a present worth factor of 19.42, 3% interest rate, and 3% inflation rate. The unit electricity cost was provided by the District at 0.0750 $/kWh.

5) It was found through inspection of aerial photographs that vacant land is available for each site and can be utilized with minimal demolition costs.

6) Any additional hours of operation of the existing Devon and Webster Avenue aeration stations or the existing Sidestream Elevated Pool Aeration (SEPA) stations

required beyond their operation during Water Years 2001 and 2003 were provided by Marquette University for use in estimating the additional cost of operating these existing stations.

7) Based upon the results provided by Marquette University, the operation of supplemental aeration stations is expected to be relatively infrequent. Achieving compliance with the standards will require a complex waterway DO monitoring network and facilities operation plan. Providing and maintaining the monitoring network and operation plan given the infrequent use of the aeration stations includes significant challenges that are currently not defined. As such, costs for a monitoring network and operational plan have not been included in this cost estimate.

As a result of these assumptions, the cost estimates presented in the following sections are roughly equivalent to a Level 5 cost estimate with an approximate accuracy range of -30% to +50% according to the cost estimate classification system recommended by the Association for the Advancement of Cost Engineering (AACE). The remainder of this pre-filed testimony contains the detailed results of each cost estimate.

Cost Estimate to Meet the Dissolved Oxygen Water Quality Standards Currently Proposed by the IEPA

As discussed, the IEPA has proposed DO water quality standards for the CAWS. **Table 1** lists the required supplemental aeration stations needed to comply with the DO water quality standards currently proposed by the IEPA, as determined by Marquette University. The DUFLOW modeling was conducted with a target of 100% compliance with the IEPA proposed DO standards. As shown, 28 supplemental aeration stations are required to meet the currently proposed IEPA standards. The hours of operation of most supplemental aeration stations are relatively low, and Marquette University indicates that in many cases Combined Sewer Overflow (CSO) events were the prime factor in determining operational hours. **Table 2** contains the required aerated flow augmentation facilities needed to comply with the DO water quality standards currently proposed by the IEPA, as determined by Marquette University. Three aerated flow augmentation facilities were found to be needed for the CAWS including one each on the NSC, Bubbly Creek, and the LCRN. For the NSC and the LCRN, flow would be diverted from the North Side and Calumet Water Reclamation Plants (WRP), respectively. For Bubbly Creek, flow would be diverted from the SBCR. Marquette University determined that additional operation of the existing Devon and Webster Avenue aeration stations was not needed to comply with the IEPA standards, however, additional operation of existing SEPA stations was required, as shown in **Table 3**. The operating hours listed in **Table 3** are the maximum additional operating hours that were shown by Marquette University to be needed during Water Years 2001 and 2003. The additional operating cost of each SEPA station was determined based on individual pump power ratings and electrical costs provided by the District, as well as the additional pump operating hours provided by Marquette University.

Table 1 – Supplementary Aeration Stations Needed to Meet the DO Water Quality Standards Currently Proposed by the IEPA

Station ID	Waterway	River Mile*	Operation Hours (2001)	Operation Hours (2003)	Max Oxygen Requirment (g/s)	Location
1	NSC	340.80	134	233	80	0.20 mile downstream of Wilmette Pump Station
2	NSC	339.66	214	0	80	0.54 mile downstream from Central Ave.
3	NSC	339.12	102	0	80	0.38 mile downstream from Simpson St.
4	NSC	338.53	113	84	80	0.97 mile downstream from Simpson St.
5	NSC	336.55	222	161	80	0.95 mile downstream from Main St.
6	NBCR	332.99	0	211	80	2.01 miles downstream from Devon Ave.
7	NBCR	331.82	102	30	80	0.78 mile downstream from Wilson Ave.
8	Main Stem	326.90	78	0	80	just upstream (east) of Lakeshore Drive
9	SBCR	325.57	376	0	80	0.03 mile downstream from NBCR Junction
10	SBCR	324.09	84	0	80	1.51 miles downstream from NBCR Junction
11	SBCR	323.52	51	168	80	2.08 miles downstream from NBCR Junction
12	SBCR	321.90	150	183	80	Throop Street
13	Bubbly Creek	N/A[1]	946	0	80	0.13 mile upstream from Bubbly Creak Junction
14	Bubbly Creek	N/A[1]	253	0	80	0.72 mi upstream from Bubbly Creek Junction
15	Bubbly Creek	N/A[1]	17	0	80	36th St.
16	CSSC	321.10	85	75	100	Damen Ave.
17	CSSC	320.60	46	0	80	Western Ave.
18	CSSC	319.82	99	0	80	0.78 mile downstream from Western Ave.
19	CSSC	318.26	100	55	90	2.34 miles downstream from Western Ave.
20	CSSC	317.21	92	0	80	0.09 mile downstream from Cicero Ave.
21	CSSC	308.60	78	31	80	3.7 miles downstream from B&O RR Bridge
22	CSSC	305.04	37	0	80	0.94 upstream from Route #83
23	CSSC	296.74	52	21	80	0.54 mile upstream from Romeoville Rd
24	LCRN	326.50	0	106	80	Grand Calumet River Junction
25	LCRN	320.50	0	165	80	0.4 mile upstream from Halsted St.
26	LCRN	320.10	129	241	100[2]	Halsted St.
27	Cal-Sag	309.40	150	289	80	Mill Creek junction
28	Cal-Sag	304.57	62	165	80	0.27 mile upstream from Route #83

Notes:

* River miles for the CAWS are often relative to the Illinois and Mississippi River confluence at Grafton, IL. For this study, river miles (RM) are based on a RM of 291 at Lockport.

1. No river mile provided.
2. 100 g/s required in 2003 and 80 g/s were required in 2001. The greater oxygen requirement was used.

Table 2 – Aerated Flow Augmentation Facilities Needed to Meet the DO Water Quality Standards Currently Proposed by the IEPA

Station ID	Waterway	Source Location	Discharge Location	Flow[1] *(mgd)*
A	NSC	North Side WRP effluent	Wilmette	40
B	Bubbly Creek	SBCR at Throop Street	Upstream end of Bubbly Creek	10
C	LCRN	Calumet WRP effluent	Confluence of LCRN and Grand-Calumet River	30

Notes:

1. Operating full-time, year-round

Table 3 – Additional Operating Hours Needed for Existing SEPA Stations to Meet the DO Water Quality Standards Currently Proposed by the IEPA

SEPA Station #	Additional Operating Hours (pump-hours/year)
2	4464
3	4263
4	5274
5	5879

AECOM estimates that the total capital cost to comply with the DO water quality standards currently proposed by the IEPA is $594,300,000, based on the cost estimating assumptions listed previously and the supplemental aeration and aerated flow augmentation facilities information provided by Marquette University. The total operation and maintenance (O&M) annual costs are estimated at $3,900,000, and the total present worth is estimated at $669,900,000. **Table 4** presents a detailed listing of the costs for each facility needed to comply with the currently proposed IEPA standards. It should again be made clear that the cost estimate presented here is roughly equivalent to a Level 5 cost estimate, and the model simulations, simplifications, assumptions, operational parameters, unit costs, etc. are all subject to change as more detailed studies and evaluations are performed.

Table 4 - Cost Estimate to Meet the DO Water Quality Standards Currently Proposed by the IEPA

Station ID	Waterway	Location or River Mile*	Aeration Capacity *(gps)*	Capital Cost†	Land Acquisition Cost†	Total Capital Cost†	Total Annual O&M Costs†	Total Present Worth O&M Cost†	Total Present Worth Cost†
A	NSC	North Side WRP	8	$27,400,000 [1]	NONE[2]	$27,400,000	$469,000	$9,100,000	$36,500,000
1	NSC	340.80	80	$17,500,000	$1,400,000	$18,900,000	$96,000	$1,900,000	$20,800,000
2	NSC	339.66	80	$17,500,000	$1,400,000	$18,900,000	$95,000	$1,800,000	$20,700,000
3	NSC	339.12	80	$17,500,000	$1,400,000	$18,900,000	$86,000	$1,700,000	$20,600,000
4	NSC	338.53	80	$17,500,000	$1,400,000	$18,900,000	$87,000	$1,700,000	$20,600,000
5	NSC	336.55	80	$17,500,000	$1,400,000	$18,900,000	$95,000	$1,800,000	$20,700,000
6	NBCR	332.99	80	$17,500,000	$1,400,000	$18,900,000	$94,000	$1,800,000	$20,700,000
7	NBCR	331.82	80	$17,500,000	$1,400,000	$18,900,000	$86,000	$1,700,000	$20,600,000
8	Main Stem	326.90	80	$17,500,000	$1,400,000	$18,900,000	$84,000	$1,600,000	$20,500,000
9	SBCR	325.57	80	$17,500,000	$1,400,000	$18,900,000	$107,000	$2,100,000	$21,000,000
10	SBCR	324.09	80	$17,500,000	$1,400,000	$18,900,000	$85,000	$1,600,000	$20,500,000
11	SBCR	323.52	80	$17,500,000	$1,400,000	$18,900,000	$91,000	$1,800,000	$20,700,000
12	SBCR	321.90	80	$17,500,000	$1,400,000	$18,900,000	$92,000	$1,800,000	$20,700,000
B	Bubbly Creek	Throop St.	2	$6,900,000 [3]	$1,400,000	$8,300,000	$117,000	$2,300,000	$10,600,000
13	Bubbly Creek	N/A[4]	80	$17,500,000	$1,400,000	$18,900,000	$150,000	$2,900,000	$21,800,000
14	Bubbly Creek	N/A[4]	80	$17,500,000	$1,400,000	$18,900,000	$97,000	$1,900,000	$20,800,000
15	Bubbly Creek	N/A[4]	80	$17,500,000	$1,400,000	$18,900,000	$80,000	$1,500,000	$20,400,000
16	CSSC	321.10	100	$21,900,000	$1,400,000	$23,300,000	$106,000	$2,100,000	$25,400,000
17	CSSC	320.60	80	$17,500,000	$1,400,000	$18,900,000	$82,000	$1,600,000	$20,500,000
18	CSSC	319.82	80	$17,500,000	$1,400,000	$18,900,000	$86,000	$1,700,000	$20,600,000
19	CSSC	318.26	80	$17,500,000	$1,400,000	$18,900,000	$86,000	$1,700,000	$20,600,000
20	CSSC	317.21	80	$17,500,000	$1,400,000	$18,900,000	$85,000	$1,700,000	$20,600,000
21	CSSC	308.60	80	$17,500,000	$1,400,000	$18,900,000	$84,000	$1,600,000	$20,500,000
22	CSSC	305.04	80	$17,500,000	$1,400,000	$18,900,000	$81,000	$1,600,000	$20,500,000
23	CSSC	296.74	80	$17,500,000	$1,400,000	$18,900,000	$82,000	$1,600,000	$20,500,000
C	LCRN	Calumet WRP	6	$20,600,000 [5]	NONE[2]	$20,600,000	$360,000	$7,000,000	$27,600,000
24	LCRN	326.50	80	$17,500,000	$1,400,000	$18,900,000	$86,000	$1,700,000	$20,600,000
25	LCRN	320.50	80	$17,500,000	$1,400,000	$18,900,000	$91,000	$1,800,000	$20,700,000
26	LCRN	320.10	100[6]	$21,900,000	$1,400,000	$23,300,000	$121,000	$2,300,000	$25,600,000
SEPA #2	LCRN	State St.	--	NONE	NONE	NONE	$34,000	$700,000	$700,000
27	Cal-Sag	309.40	80	$17,500,000	$1,400,000	$18,900,000	$100,000	$1,900,000	$20,800,000
28	Cal-Sag	304.57	80	$17,500,000	$1,400,000	$18,900,000	$91,000	$1,800,000	$20,700,000
SEPA #3	Cal-Sag	Western Ave.	--	NONE	NONE	NONE	$90,000	$1,800,000	$1,800,000
SEPA #4	Cal-Sag	Harlem Ave.	--	NONE	NONE	NONE	$111,000	$2,200,000	$2,200,000
SEPA #5	Cal-Sag	CSSC Junction	--	NONE	NONE	NONE	$90,000	$1,800,000	$1,800,000
Totals						**$594,300,000**	**$3,900,000**	**$75,600,000**	**$669,900,000**

Notes:

* River miles for the CAWS are often relative to the Illinois and Mississippi River confluence at Grafton, IL. For this study, river miles (RM) are based on a RM of 291 at Lockport.

† Costs were taken from TM-4WQ, pgs. B-9 and C-9 for flow augmentation and TM-5WQ, pgs 5-16, G-2, and G-3 for supplemental aeration. All costs were adjusted to 2010 dollar values based on Engineering News-Record (ENR) National Construction Cost Indices (CCI) of 7700 (June 2006) and 8805 (June 2010), with the exception of electricity as directed by the District.

1. Cost includes an 8 g/s U-Tube aerator, 40 mgd pump station, and a 40 mgd forcemain for flow augmentation.
2. These facilities can be accommodated at the WRP.
3. Cost includes a 2 g/s U-Tube aerator, 10 mgd pump station, and a 10 mgd forcemain for flow augmentation.
4. No river mile provided.
5. Cost includes a 6 g/s U-Tube aerator, 30 mgd pump station, and a 30 mgd forcemain for flow augmentation.
6. 100 g/s were required in 2003 and 80 g/s were required in 2001. The greater oxygen requirement was used.

Cost Estimate to Meet The District Proposed Dissolved Oxygen Water Quality Standards

At an IPCB public hearing held in March of 2009, the District indicated that it would submit to the IPCB an alternative to the DO water quality standards currently proposed by the IEPA. The District asked AECOM to prepare a cost estimate for complying with its proposed DO standards. The DO standards envisioned by the District includes the following features:

- Minimum numerical DO standards per waterway**,** which would be in keeping with current and future uses of the CAWS, historic water quality data, and the aquatic habitat present.
- A wet-weather provision, which would provide that the DO numerical standards would not apply during and shortly after wet-weather events, as the CAWS continues to receive pollution loadings from the various CSOs and urban runoff sources discharging to the waterways.
- The time period during which the wet-weather provision would apply, during and after each event, measured in hours, would depend on specific rainfall amounts. In general, the greater the rainfall, the greater the time period for which the wet-weather provision would apply.
- Numerical minimum DO standards should not be specified for Bubbly Creek, as the District considers it to be a unique, complex waterway which is stagnant during dry weather and turbulent and fast running during wet weather when CSOs occur.

The District proposed DO water quality standards include the following provisions:

- Numerical minimum DO standards of 3.5 mg/l or 4.0 mg/l, depending on the waterway, as shown in **Table 5**.

Table 5 – Numerical Minimum DO Water Quality Standards Proposed by the District

Waterway	DO Standards *(mg/l)*
North Shore Channel	4.00
Upper North Branch Chicago River to Addison Street	4.00
Lower North Branch Chicago River	3.50
Chicago River Main Stem	3.50
South Branch Chicago River	3.50
Chicago Sanitary and Ship Canal	3.50
Little Calumet River (North)	4.00
Calumet-Sag Channel	3.50

- Time periods during which the wet-weather provision would apply range from 72 to 168 hours depending on rainfall amounts for each event.

The District is proposing that a "trigger" be established to define the onset of a wet weather event during which the wet-weather provision would apply. The District is also proposing that the maximum duration (number of days following the start of an event) during which the wet-weather provision would apply would also be established. The District proposed trigger and maximum duration are shown in **Table 6**. Based upon an analysis of rainfall data from 2001-2008, there will be instances where a wet weather event will have multiple consecutive trigger days. In these instances, the maximum duration would be extended by the maximum duration following the last trigger day.

Table 6 – Wet-Weather Trigger and Maximum Duration for Potential Application of the Wet-Weather Provision

Rainfall Trigger *(inches/day)*	**Maximum Duration After "Trigger Day" to Apply Wet-Weather Provision**
0.25 - 0.49	2 days
0.50 - 1.00	4 days
> 1.00	6 days

The waterways will still have to comply with the minimum DO standards if the levels are not affected by wet weather events or the duration of wet weather impacts exceed the maximum duration specified in **Table 6**. The wet-weather provision would not be applied during a wet weather event when DO levels were greater than or equal to the minimum DO criteria. Finally, the wet-weather provision would not apply at locations for a wet weather event if the DO preceding the start of the wet weather event was less than the minimum DO criteria.

Using the improved DUFLOW model discussed previously in this testimony, Marquette University determined the number, locations, aeration capacities, and operation hours of supplemental aeration and flow augmentation facilities needed to comply with the District's proposed DO standards. **Table 7** lists the required supplemental aeration stations needed to comply with the District's proposed DO standards, as determined by Marquette University. As shown, two supplemental aeration stations are required to meet the District's proposed DO standards. **Table 8** lists the one aerated flow augmentation facility needed to comply with the District's proposed DO standards, as determined by Marquette University. The aerated flow augmentation facility would be needed for the NSC using effluent from the North Side WRP. Marquette University also determined that the existing Devon Avenue aeration station would need to be operated an additional 106 hours, while additional operation of the Webster Avenue aeration station was not needed to comply with the District's proposed DO standards. Marquette University determined that additional operation of the existing SEPA stations was not required.

Table 7 – Supplementary Aeration Stations Needed to Meet the District's Proposed DO Standards

Station ID	Waterway	Location	Maximum Operation Hours	Max Oxygen Requirement (g/s)
1	SBCR	1.5 miles downstream of Jackson Blvd.	950	80
2	SBCR	Throop St.	202	80

Table 8 – Aerated Flow Augmentation Station Needed to Meet the District's Proposed DO Standards

Waterway	Source Location	Discharge Location	Flow[1] *(mgd)*
NSC	North Side WRP effluent	Wilmette	24

Notes:

1. Operating full-time, year-round

AECOM estimates that the total capital cost to comply with the District's proposed DO standards is $54,300,000, based on the cost estimating assumptions listed previously and the supplemental aeration and aerated flow augmentation facilities information provided by Marquette University. The total annual O&M costs are estimated at $530,000 and the total present worth is estimated at $64,600,000. **Table 9** presents a detailed listing of the costs for each facility needed to comply with the District's proposed DO standards. These estimates are based on June 2010 dollar values. It should again be made clear that the cost estimate presented here is roughly equivalent to a Level 5 cost estimate, and the model simulations, simplifications, assumptions, operational parameters, unit costs, etc. are all subject to change as more detailed studies and evaluations are performed.

Table 9 – Cost Estimate to Meet the District's Proposed DO Standards

Station ID	Waterway	Location	Aeration Capacity *(gps)*	Capital Cost*	Land Acquisition Cost*	Total Capital Cost*	Total Annual O&M Costs*	Total Present Worth O&M Cost*	Total Present Worth Cost*
A	NSC	North Side WRP	5	$16,500,000 [1]	NONE [2]	$16,500,000	$281,000	$5,500,000	$22,000,000
N/A [3]	NSC	Devon Ave.	--	NONE	NONE	NONE	$5,000	$100,000	$100,000
1	SBCR	1.5 miles downstream of Jackson Blvd.	80	$17,500,000	$1,400,000	$18,900,000	$151,000	$2,900,000	$21,800,000
2	SBCR	Throop St.	80	$17,500,000	$1,400,000	$18,900,000	$94,000	$1,800,000	$20,700,000
Totals						**$54,300,000**	**$530,000**	**$10,300,000**	**$64,600,000**

Notes:

* Costs were taken from TM-4WQ, pgs. B-9 and C-9 for flow augmentation and TM-5WQ, pgs 5-16, G-2, and G-3 for supplemental aeration
All costs were adjusted to 2010 dollar values based on Engineering News-Record (ENR) National Construction Cost Indices (CCI) of 7700 (June 2006) and 8805 (June 2010), with the exception of electricity as directed by the District.

1. Cost includes a 5 g/s U-Tube aerator, 24 mgd pump station, and 24 mgd forcemain for flow augmentation.
2. These facilities can be accommodated at the WRP.
3. These stations currently exist and have not been given a Station ID.

Respectfully submitted,

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TECHNICAL REPORT # 20

DEVELOPMENT OF INTEGRATED STRATEGIES TO MEET PROPOSED DISSOLVED OXYGEN STANDARDS FOR THE CHICAGO WATERWAY SYSTEM

SUBMITTED TO
The Metropolitan Water Reclamation District of Greater Chicago

Charles S. MELCHING, Ph.D., P.E.

Emre ALP, Ph.D.

Yaping AO

Department of Civil and Environmental Engineering

Milwaukee, Wisconsin
December 2010

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Chapter 1 – INTRODUCTION

1.1 Background

The Chicago Waterway System (CWS) 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, a short portion of the Calumet River, and Little Calumet River (North). In total, the CWS is a 76.3 mile (mi) branching network of navigable waterways controlled by hydraulic structures in which the majority of flow is treated sewage effluent and there are periods of substantial combined sewer overflow. The dominant uses of the CWS are conveyance of treated municipal wastewater, commercial navigation, and flood control. The Calumet and Chicago River Systems are shown in Figure 1.1.

There have been several studies on the water quality in the CWS and the Upper Illinois River in the past. Major studies have included the study done in response to Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) by Hydrocomp, Inc. (1979a and b) for the Northeastern Illinois Planning Commission (Hey et al., 1980) and a modeling study done by Camp, Dresser & McKee (CDM, 1992) for the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). CDM (1992) used QUAL2EU to simulate dissolved oxygen (DO) on the Chicago Waterway and Upper Illinois River. This QUAL2EU model has been used by the MWRDGC throughout the 1990s for water-quality management in the CWS. Marquette University successfully applied the DUFLOW water quality model to the CWS for several purposes:

i) Alp and Melching (2004) used the DUFLOW model to investigate the possible effects of a change in navigational water level requirements and the navigation make-up diversion of water from Lake Michigan during storm events, ii) Neugebauer and Melching (2005) developed a method to verify the calibrated DUFLOW model under uncertain storm loads, iii) Manache and Melching (2005) applied the DUFLOW model to simulate fecal coliform concentrations in the CWS under unsteady flow conditions; and iv) Alp and Melching (2006) evaluated the effectiveness of flow augmentation, supplemental aeration, and combined sewer overflow (CSO) treatment acting individually to improve DO conditions in the CWS.

The hydraulic component of the DUFLOW (2000) unsteady-flow model for the CWS was calibrated and verified by Marquette University in 2003. The ability of the model to simulate unsteady flow conditions was demonstrated by comparing the simulation results to measured data for eight different periods between August 1, 1998 and July 31, 1999 (Shrestha and Melching, 2003). The DUFLOW water-quality model was calibrated and verified (Alp and Melching, 2006; Neugebauer and Melching, 2005) for the periods of July 12 to November 9, 2001 and May 1 to September 23, 2002, respectively.

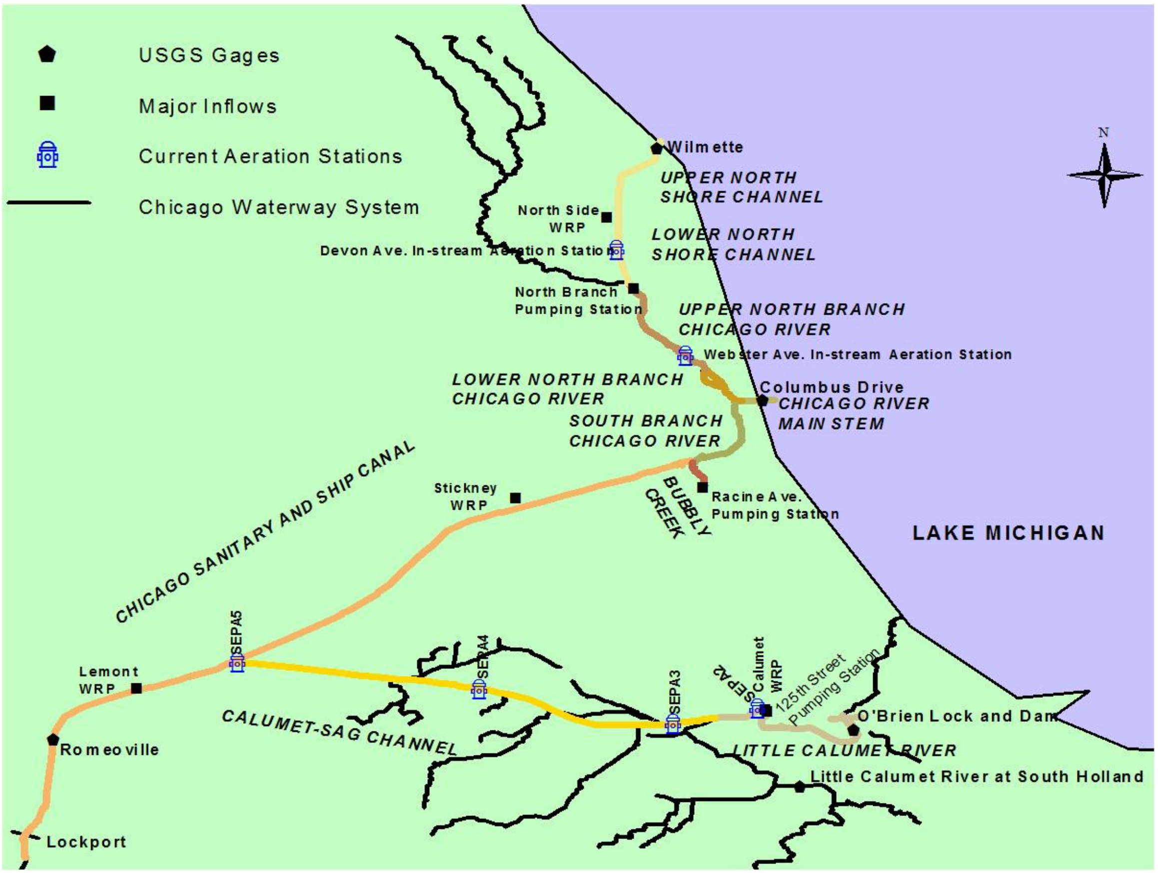


Figure 1.1 Schematic diagram of the Calumet and the Chicago River Systems (note: the upstream USGS gages compose the upstream boundaries of the simulation model)

1.2 Project Objective

The evaluation of the effectiveness of flow augmentation, supplemental aeration, and CSO treatment to improve DO conditions in the CWS was done by Alp and Melching (2006). The related cost evaluations of these techniques were done by Consoer Townsend Envirodyne (CTE, 2006, 2007a-c). These coordinated studies considered the use of technologies acting individually to meet a DO concentration target of 5 milligrams per liter (mg/L) at least 90% of the time. Further the determination of meeting the DO standard 90% of the time focused on two summer/fall periods: July 12 to November 9, 2001 and May 1 to September 23, 2002.

Given that independent applications of flow augmentation and supplemental aeration were shown to potentially be effective ways to improve DO concentrations in the CWS, this project was initiated to develop integrated strategies of combining these technologies to achieve DO standards proposed for the CWS by the Illinois Environmental Protection Agency (IEPA) to the Illinois Pollution Control Board (IPCB). As a result of an Use Attainability Analysis (UAA) of the CAWS (CDM, 2007), the IEPA proposed two aquatic life use classes for the CAWS: Chicago Area Waterway System Aquatic Life Use A waters (CAWS A) and Chicago Area Waterway System and Brandon Pool Aquatic Life Use B waters (CAWS B). For CAWS A waters the following DO concentration targets must be met or exceeded:

1) During the period of March through July, 5.0 mg/L at all times
2) During the period August through February
    A) 4.0 mg/L as a daily minimum averaged over 7 days, and
    B) 3.5 mg/L at all times

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

1) 4.0 mg/L as a daily minimum averaged over 7 days, and
2) 3.5 mg/L at all times

Figure 1.2 shows the extent of the proposed CAWS A and B waters. It should be noted that the Chicago Area Waterway System studied in the UAA and included in the IPCB rule making includes the Calumet River, Lake Calumet, and the Grand Calumet River in Illinois in addition to the CWS. Lack of hydraulic boundary data prevents these additional water bodies from being included in the DUFLOW model. Initial modeling trials found that 3.5 mg/L at all times was more restrictive than 4.0 mg/L as a daily minimum averaged over 7 days, and, thus, only the absolute minimum DO standards were used for calculating percentage compliance with the standards in this study.

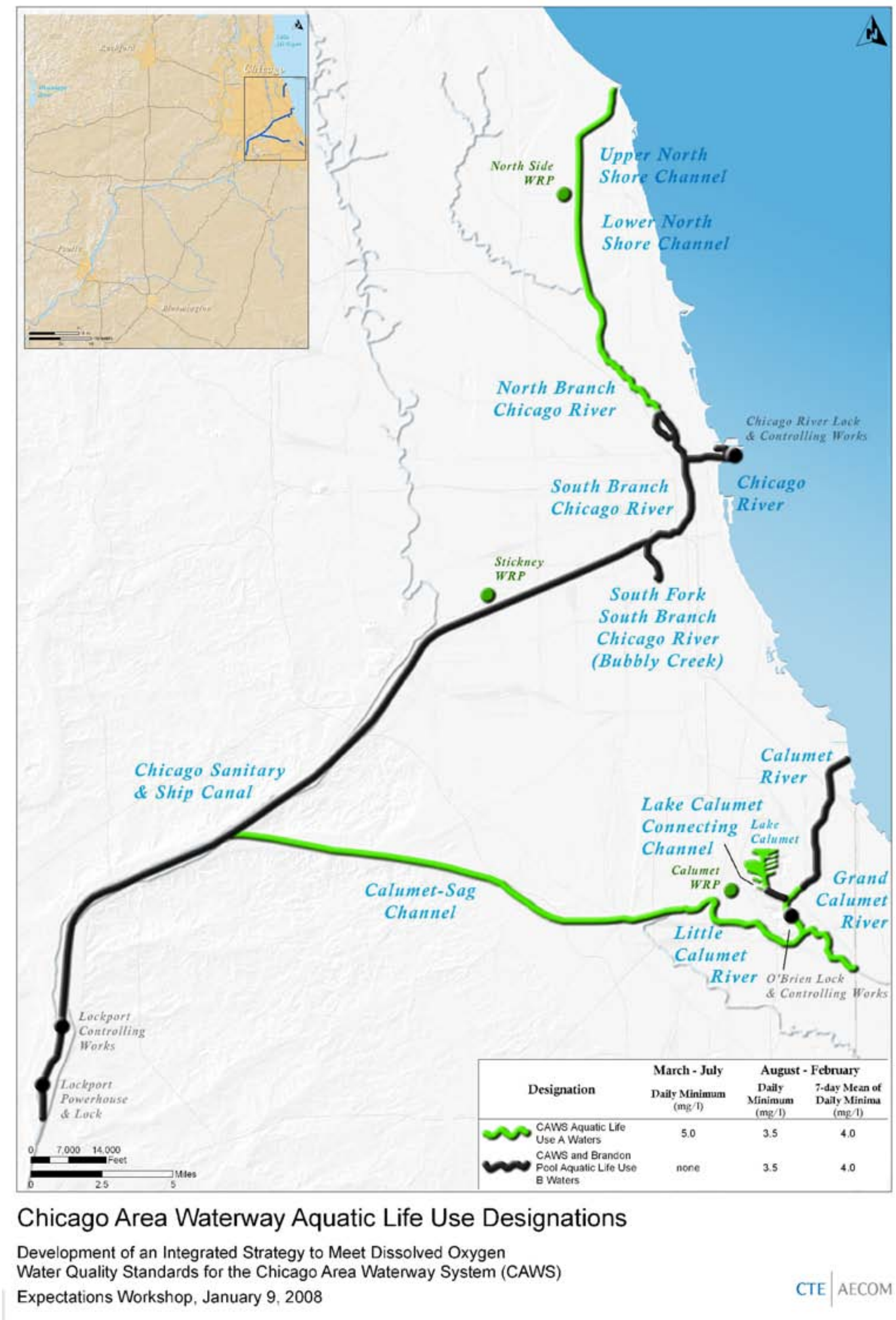


Figure 1.2 Chicago Area Waterway Proposed Aquatic Life Use Designations (IEPA, 2007)

In the course of developing integrated strategies to meet the IEPA proposed standards, the MWRDGC reviewed the historical records of hourly DO concentration measurements and was in the process of developing an alternative DO standards proposal considering the aquatic habitat in the CWS and allowing for DO criteria to not be met during wet weather periods. A scenario of an MWRDGC alternative DO standards proposal, hereinafter referred to as "Scenario A", was developed at an early stage (fall 2009) to couple the alternative DO standards for the CWS with a wet weather excursion. According to the MWRDGC's request, an integrated strategy needed to achieve Scenario "A" was determined in this study.

In Scenario "A", the total number of hours in a year of periods with DO concentrations less than the DO standard was determined on the basis of historically measured hourly DO concentrations in the various reaches. That is, the maximum allowable number of hours in the year with DO concentrations less than the standard in periods during or following rain storms with depths greater than or equal to 0.1 inches (in.) were determined for each reach. The storm-affected periods, in general, varied with the amount of rainfall from two days for storms with 0.1 to 0.49 in. of rainfall to four days for storms with 0.5 to 1.0 in. to six days for storms with more than 1 in. of rainfall. The maximum allowable hours less than the specified minimum standard specified for each reach for Scenario "A" are listed in Table 1.1.

Table 1.1 Scenario "A" of the dissolved oxygen standards proposed by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) and the maximum allowable hours less than the specified minimum standard for each reach of the Chicago Waterway System

Waterway	Minimum DO standard (mg/L)	Maximum hours less than the minimum
North Shore Channel	4.0	600
Upper North Branch Chicago River to Addison Street	4.0	88
Lower North Branch Chicago River	3.5	200
Chicago River Main Stem	3.5	88
South Branch Chicago River	3.5	88
Chicago Sanitary and Ship Canal	3.5	500
Little Calumet River (North)	4.0	320
Calumet-Sag Channel	3.5	300

*Note: Under the proposal of the Illinois Environmental Protection Agency, Bubbly Creek has a minimum DO standard of 3.5 mg/L; whereas the MWRDGC has proposed a narrative criterion for Bubbly Creek as opposed to a numeric limit.

1.3 Selection of Representative Wet and Dry Years

Representative "wet" and "dry" years were selected in order to be sure that the integrated strategy developed to improve DO concentrations in the CWS is sufficiently robust. These "wet" and "dry" years must be selected from the Water Years between 1997 and 2007 because hourly water reclamation plant (WRP) flows are no longer available prior to the 1997 Water Year. Also, the continuous temperature and DO monitors on the CWS first began collecting data in August 1998. Thus, in order to verify the model performance for the selected "wet" and "dry" years and make adjustments, if necessary, Water Years 1999 to 2007 are potential candidate years.

Normally, representative "wet" and "dry" years should be selected on the basis of flow. However, the discharge on the Chicago Sanitary and Ship Canal at Romeoville through 2005 and at Lemont between 2005 and 2007 is greatly affected by water use in the

Chicago area and seepage at the Lakefront structures separating the CWS from Lake Michigan. This discharge is, therefore, not a good measure of runoff, which composes about 25% of the flow at Romeoville/Lemont, to the CWS. The main gaged tributaries to the CWS—Little Calumet River at South Holland and North Branch Chicago River at Albany Avenue at Chicago—represent conditions to the south and north, respectively, of the CSO drainage areas tributary to the CWS. Thus, annual flows at these locations may not be representative of conditions in the main CSO areas draining to the CWS.

Given the lack of representative flow data for the CSO drainage area to the CWS, precipitation data and CSO pump station operation data were used to select the representative “wet” and “dry” years. To give a long-term perspective, precipitation data from the National Weather Service for O’Hare Airport (since Water Year 1963) and Midway Airport (since Water Year 1951) were considered (Figure 1.3). To give an area-wide perspective the average precipitation measured at the 25 precipitation gages spread over the CSO drainage area in Cook County established by the U.S. Army Corps of Engineers and operated by the Illinois State Water Survey (ISWS) for use in the Lake Michigan Diversion Accounting (since 1990) were also considered (also in Figure 1.3). Table 1.2 lists the total annual precipitation at O’Hare Airport, Midway Airport, and for the ISWS network average and the ranking from the highest of the rainfall over the period of record for each Water Year between 1997 and 2007. The long term average annual precipitation is 34.57, 35.55, and 35.94 in. at O’Hare Airport, Midway Airport, and for the 25 gage ISWS network, respectively. Five of the eleven years had above average precipitation at O’Hare Airport, three of the eleven years had above average precipitation at Midway Airport, and four of the eleven years had above average precipitation for the 25 gage ISWS network.

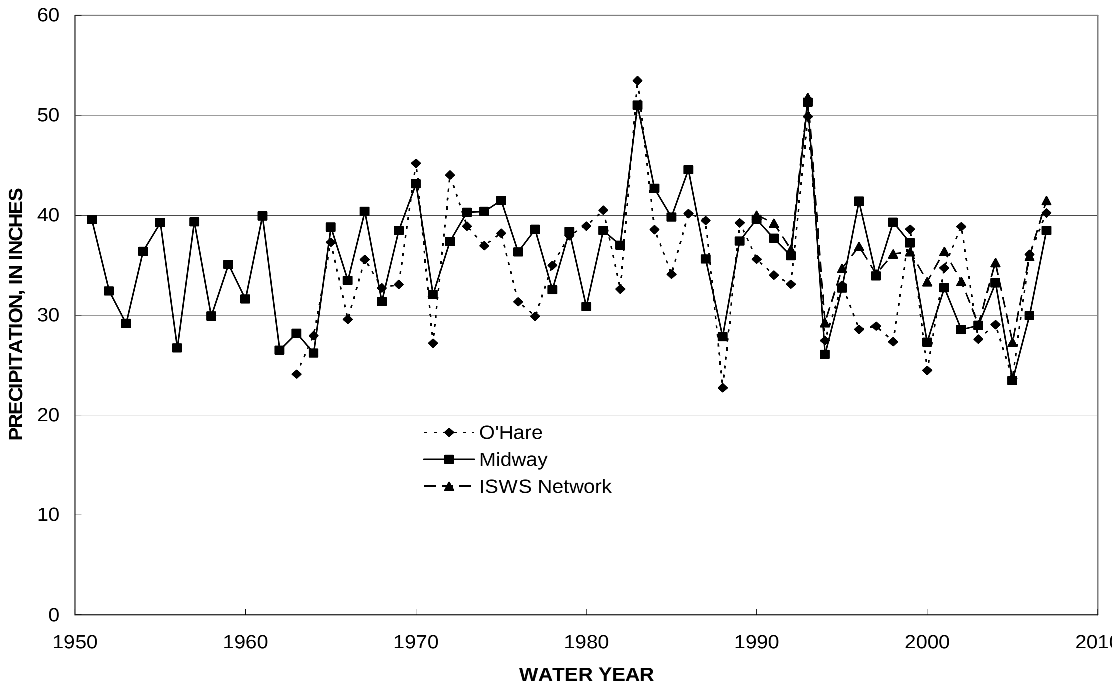


Figure 1.3 Annual Precipitation by Water Year at O’Hare Airport, Midway Airport, and for the Illinois State Water Survey (ISWS) 25 gage network in Cook County, IL.

On the basis of precipitation Water Year 2007 would appear to be an excellent representative “wet” year as it ranks in the top 15% at O’Hare Airport (over 45 years) and the second among 18 years for the ISWS Network, but only in the top 40% at Midway Airport (over 57 years). The goal of representative is to be in the top (or bottom) quartile of years, but not being the wettest or driest year. However, if the volume of CSO flow at the pumping stations is considered, Water Year 2007 ranks only 9th among the 16 years beginning in Water Year 1992 (Figure 1.4) spread over 35 pumping events (where an event is defined as a pump station operating on individual or consecutive days, if there is more than one day between pump operations a new event is recorded). Because the "wet" year should be defined on the basis of high flows having a substantial impact on the water quality in the CWS, Water Year 2007 would not be a representative "wet" year.

Table 1.2 Annual precipitation depth and rank from the highest among the recorded years for O'Hare Airport, Midway Airport, and the Illinois State Water Survey (ISWS) 25 gage network in Cook County, IL.

Water	O'Hare Airport		Midway Airport		ISWS Network	
Year	Depth	Rank among 45	Depth	Rank among 57	Depth	Rank among 18
2007	40.23	6	38.47	22	41.47	2
2001	34.71	23	32.74	37	36.39	7
1999	38.60	13	37.23	27	36.33	8
1998	27.35	40	39.30	16	36.12	9
2006	36.07	19	29.96	45	35.89	10
2004	29.05	34	33.23	36	35.24	11
1997	28.89	35	33.90	34	34.09	13
2002	38.86	12	28.53	49	33.37	14
2000	24.47	42	27.28	52	33.33	15
2003	27.58	38	28.97	48	29.03	17
2005	23.68	44	23.45	57	27.29	18

On the basis of volume of pump station CSO flow, Water Year 1999 has the largest volume, spread over 33 events, among the candidate years for this study ranking 4th among the 16 years beginning in 1992. In terms of rainfall, Water Year 1999 was 4.03, 1.68, and 0.39 in. higher than average at O'Hare Airport, Midway Airport, and for the ISWS network. In terms of percentile rankings, Water Year 1999 was in the upper 30%, 50%, and 45% at O'Hare Airport, Midway Airport, and for the ISWS network. Thus, the goal to be in the upper quartile in terms of precipitation would not be achieved if Water Year 1999 were selected. Water Year 1999 would also pose a substantial practical problem for the water-quality modeling because during that year no DO and temperature monitors were in the Little Calumet River (North) – Calumet-Sag Channel (Calumet system) reaches of the CWS. Thus, it would be difficult to have accurate temperature values for these reaches in the model.

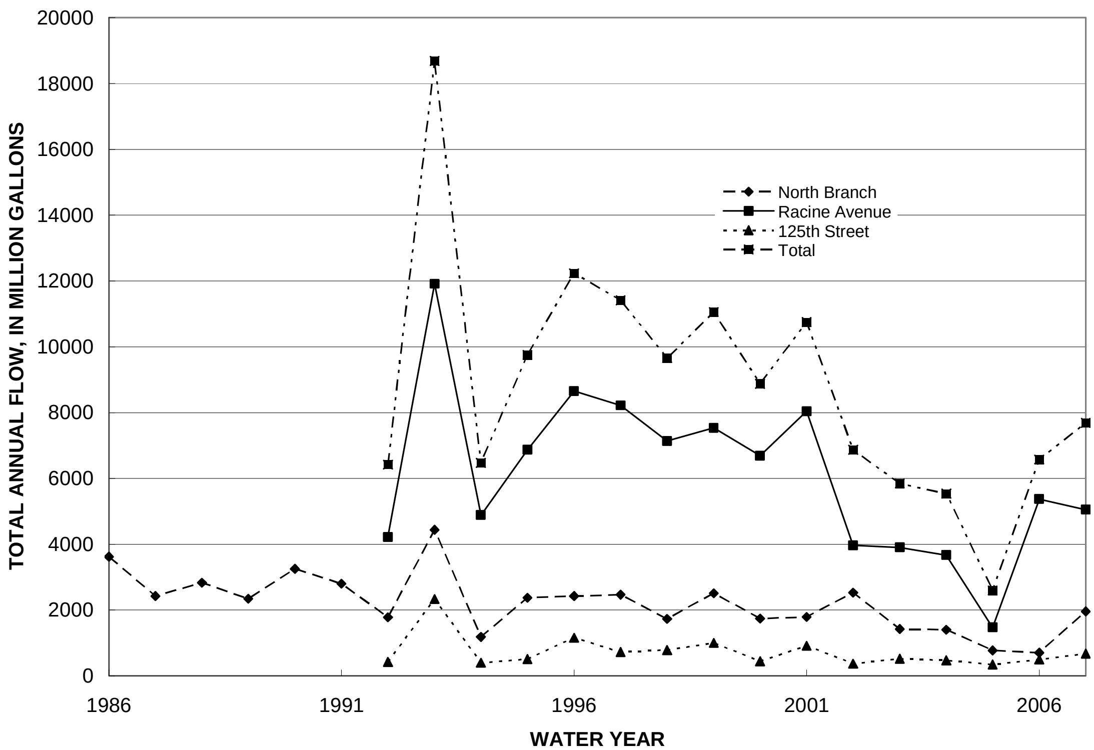


Figure 1.4 Volume of annual combined sewer overflow at the North Branch, Racine Avenue, and 125th Street Pumping Stations

On the basis of volume of pump station CSO flow, Water Year 2001 had the second largest volume (only 3% less than Water Year 1999 and 40% higher than Water Year 2007), spread over 32 events, among the candidate years for this study ranking 5th among the 16 years beginning in 1992. In terms of rainfall, Water Year 2001 was 0.14 and 0.45

in. higher than average at O'Hare Airport and for the ISWS network, but was 2.81 in. below average at Midway Airport. In terms of percentile rankings, Water Year 2001 was the median at O'Hare Airport, in the lower 35% at Midway Airport, and the upper 40% for the ISWS network. Thus, the goal to be in the upper quartile in terms of precipitation would not be achieved if Water Year 2001 were selected. However, given the higher CSO volume at the pumping stations in Water Year 2001, the lack of high precipitation in the candidate years, and the lack of temperature data for the Calumet system for Water Year 1999, Water Year 2001 was selected as the representative "wet" year for the development of an integrated strategy for DO improvement in the CWS.

The selection of the representative "dry" year was much easier. Water Year 2005 probably is the driest year in the last 50 years as it ranks last in annual rainfall at Midway (over 57 years), second to last at O'Hare Airport over 45 years, and last for the ISWS network over 18 years. Further, it yielded the smallest volume, over 16 events, of CSO flow at the pumping station among the 16 years beginning from Water Year 1992. However, the representative "dry" year should not be the driest year. Water Year 2004 has the second smallest CSO volume at the pumping stations, but its rainfall is around the 40^{th} percentile from the bottom at Midway Airport and for the ISWS network. Water Year 2003 has a 6 % larger CSO volume at the pumping stations than Water Year 2004. Water Year 2003 ranks as the third smallest CSO volume at the pumping stations among 16 years (lower 20%) and it ranks in the lower 16% of years in terms of precipitation at O'Hare Airport and Midway Airport and the lower 6% for the ISWS network (i.e. second smallest). Water Year 2003 only had 23 CSO pump station events whereas Water Year

2004 had 27 CSO pump station events. Finally, during Water Year 2004 (March 2004) data collection was discontinued by the MWRDGC at 14 DO and temperature monitoring stations. Thus, use of Water Year 2003 allows a more complete verification of the water-quality model before it is applied to evaluating the integrated strategy. Given these facts, Water Year 2003 was selected as the representative "dry" year for the development of an integrated strategy for DO improvement in the CWS.

1.4 Model Improvements and Report Organization

Prior to evaluating an integrated strategy to improve DO conditions, the MWRDGC commissioned Marquette University to update the DUFLOW model with recent information. This report describes improvements to and re-calibration of the previously calibrated DUFLOW water quality model (Alp and Melching, 2006) for the period of October 1, 2000 to September 30, 2001 (Water Year 2001) and October 1, 2002 to September 30, 2003 (Water Year 2003). There are three major improvements to the previous model. First, new CSO locations on the North Shore Channel have been added to the previous DUFLOW model. Second, sediment oxygen demand (SOD) values were adjusted based on measured SOD values from 2001. The third improvement is to use the CSO discharges simulated by the U.S. Army Corps of Engineers (Corps). Moreover, the downstream boundary was moved from Romeoville to the Lockport Controlling Works on the CSSC.

Hydraulic verification of the previously calibrated model is presented in Chapter 2. Calibration of the water quality-model is described in Chapter 3. Data used in calibration, assumptions, and calibration results are explained in this chapter. The applications of the calibrated model to determine scenarios that achieve compliance with the DO standards proposed by the IEPA 90% and 100% of the time are described in Chapter 4. The 90% compliance strategy was developed to maintain consistency with the earlier examination of flow augmentation and supplemental instream aeration done by Alp and Melching (2006). The application of the calibrated model to determine scenarios that achieve compliance with Scenario “A” of the DO standards proposed by the MWRDGC is described in Chapter 5. Finally, Chapter 6 summarizes the conclusions and recommendations of this study.

Chapter 2 - HYDRAULIC MODEL VERIFICATION

2.1 Introduction

The unsteady-flow model for the CWS was calibrated and verified by the Institute for Urban Environmental Risk Management, Marquette University in 2003. The ability of the model to simulate unsteady flow conditions was demonstrated by comparing the simulation results to measured data for eight different periods between August 1, 1998 and July 31, 1999 (Shrestha and Melching, 2003). The model was calibrated using hourly stage data at three gages operated by the MWRDGC along the CSSC and at the downstream boundary at Romeoville operated by the U.S. Geological Survey (USGS), and using daily flow data collected by the USGS near the Chicago River Controlling Works (CRCW) and O'Brien Lock and Dam upstream boundaries.

Alp and Melching (2006) used data from the period between July 12 and November 9, 2001, to verify the previously calibrated hydraulic model (Shrestha and Melching, 2003). In this study, two major hydraulic improvements were made to the previous model. First, new CSO locations on the North Shore Channel have been added to the previous DUFLOW model. The second improvement is to use the CSO discharges simulated by the Corps. Moreover, the downstream boundary was moved from Romeoville to the Lockport Controlling Works on the CSSC. In the following sections, improvements to the previous model and inputs and the results of the hydraulic verification are presented.

2.1.1 Temporal and Spatial Distribution of CSO Inputs

In the previous applications of the Marquette Model (e.g., Alp and Melching, 2006) the inflows from gravity CSOs were estimated as follows. During storm events, the measured and estimated (for ungaged tributaries) inflows were insufficient for simulated water-surface elevations at Romeoville to match the measured water-surface elevations when flow at Romeoville was the downstream boundary condition. If the simulated water-surface elevation is substantially below the observed value, the hydraulic model is artificially dewatering the CWS in order to match the observed flow at Romeoville indicating that the CWS is receiving insufficient inflow without considering the gravity CSOs. Thus, gravity CSO volume (starting with the volume imbalance between measured outflows at Romeoville and measured and estimated inflows) was added until reasonable water-surface elevations were simulated at Romeoville. This gravity CSO volume was added at the representative CSO inflow locations on a per area basis at the time of operation of the Racine Avenue Pumping Station.

The estimated gravity CSO volumes yielded excellent hydraulic results for all periods considered (Shrestha and Melching, 2003; Neugebauer and Melching, 2005; Alp and Melching, 2006). However, the percentage of impervious area varies substantially throughout the CWS watershed and the rainfall varies substantially throughout the CWS watershed and among events. Thus, the runoff and related pollutant loads must vary throughout the CWS watershed on more than a per area basis, and the time distribution of CSO flows is not uniform and may be longer or shorter than the operation hours of the Racine Avenue Pumping Station. Thus, simulations of flows, loads, and water-quality conditions could potentially be improved if the CSO discharges could be reliably modeled. Thus, CTE (2007d) suggested that "The certainty in CSO and pump station volumes could be improved through the development of a collection system model." and "Identifying locations where CSO discharges are more frequent is the first step to improve the CSO volume input in the model."

Currently the rated pump capacities and pump on-and-off times are used to develop an hourly time series of pumping station flows. The estimated accuracy of calculating pump station discharges with this methodology is 1 or 2 percent of the exact volume from on-and-off times and rated pump capacities. A collection system model is unlikely to improve the certainty of estimating actual pump station volumes because of the various rules that are used to operate each station and hydraulic losses that occur during discharge. However, a collection system model could potentially improve the spatial and temporal distribution of the estimated gravity CSOs.

For the purposes of the design of the Tunnel and Reservoir Plan (TARP) the Corps developed a series of models to simulate the surface and subsurface runoff in the TARP drainage area (which includes the CWS watershed); the flows in the major interceptors; the distribution of the flows to the WRPs or potentially to gravity CSO outfalls or TARP drop shafts; and the flows in the TARP tunnels. These models are run by the Corps for each water year in support of the Lake Michigan Diversion Accounting. The gravity CSOs simulated by these models during the months in which water from the CWS flowed to Lake Michigan at Wilmette and/or the Chicago River Controlling Works were obtained by Marquette University from the Corps for 1990 through 2002 as part of the project "Evaluation of Procedures to Prevent Flow Reversals to Lake Michigan from the Chicago Waterway System" for the MWRDGC (Alp and Melching, 2008a). Evaluations for events in 2001 and 2002 of simulated water-surface elevations in the CWS for the case of gravity CSO flows from the Corps models and pumping station flows from the operation records have yielded reasonable results throughout the CWS in comparison to the results for the original input to the Marquette Model (Alp and Melching, 2008a). Hence simulated gravity CSO flows obtained from the Corps are used in the DUFLOW simulations to identify an integrated strategy for DO improvement in the CAWS. Detailed discussion of the Corps models (a combination of the Hydrological Simulation Program-Fortran, Special Contributing Area Loading Program, and Tunnel Network Model) is given in Espey et al. (2004).

2.1.2 New Representative CSO Locations on the North Shore Channel

There are nearly 240 CSOs in the modeled portion of the CWS watershed. Since it is difficult to introduce all CSO locations in the modeling, in the previous CWS DUFLOW model, 28 representative CSO locations were identified and flow distribution was done on the basis of drainage area for each of these locations. Whereas this worked fine for the system wide simulations (Alp and Melching, 2006) and the results were used in the preliminary evaluation of potential water-quality improvement alternatives (CTE, 2006, 2007a-c), it is inadequate for a more detailed evaluation of water-quality improvement options. This is particularly true when considering conditions on the upper NSC where CSO flows dominate the stream flow and water quality conditions in the channel. For the

NSC, the original Marquette Model had four CSO inflow points that represented 24 TARP drop shaft overflow locations (there may be more than one CSO per drop shaft drainage area). With only four inflow points, the CSO flows can overpower the flows transferred as part of flow augmentation requiring higher amounts of transfer than might be needed if the flows were distributed as in reality. Thus, 19 gravity CSO locations, representing 24 TARP drop shaft overflow locations, are included as CSO inflow points to the revised DUFLOW model and the flows were redistributed to the these locations using the Corps models (Figure 2.1).

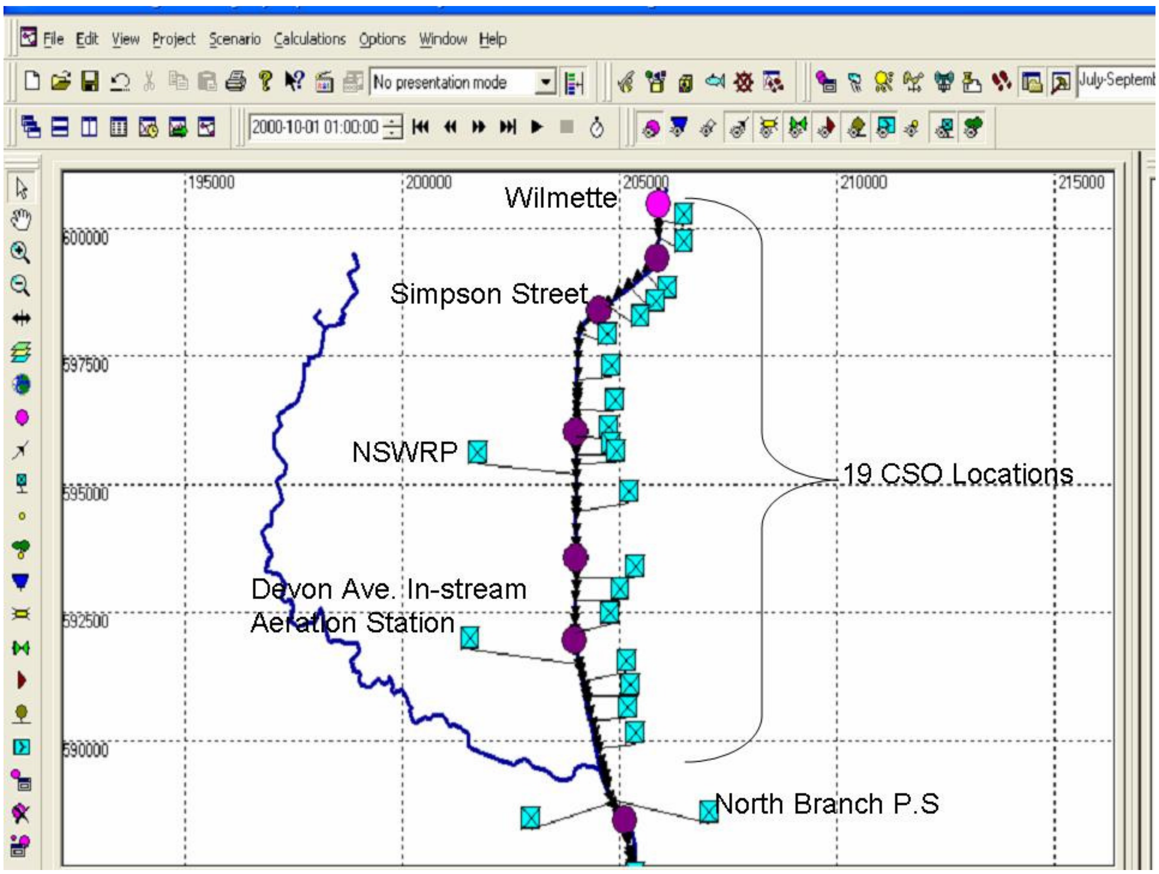


Figure 2.1 Location of the 19 representative gravity CSOs on the North Shore Channel in the improved DUFLOW model

In other areas of the CWS the CSO flows are not as dominant and the representative CSO locations were not changed outside of the NSC.

In addition to the improvements previously mentioned, the downstream boundary was moved from Romeoville to the Lockport Controlling Works on the CSSC in order to simulate the entire CSSC and increase the prediction power of the model.

2.2 Hydraulic Data used for the Model Input

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

2.2.1 Measured Inflows, Outflows, and Water-Surface Elevations

The hydraulic and hydrologic data available for the CWS have been compiled from different agencies. The USGS has established discharge and stage gages at three primary locations where water is diverted from Lake Michigan into the CWS. These locations are:

i) The Chicago River Main Stem at Columbus Drive (near CRCW)

ii) The Calumet River at the O'Brien Lock and Dam

iii) The North Shore Channel at Maple Avenue (near the Wilmette Pumping Station)

The data from the Chicago River Main Stem at Columbus Drive, the Calumet River at the O'Brien Lock and Dam, and the North Shore Channel at Maple Avenue gages are used as the primary upstream flow versus time (on a 15-minutes basis) boundary conditions for the unsteady-flow water-quality model. Elevation versus time data (on an hourly basis) from the MWRDGC gage on the CSSC at the Lockport Controlling Works (CW) are used as the downstream boundary condition for the model. The data from the USGS 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 USGS, Tinley Creek near Palos Park and Midlothian Creek at Oak Forest. The USGS gage on the Grand Calumet River at Hohman Avenue at Hammond, Ind. is used to obtain the flow from the Grand Calumet River, which is a tributary to the Little Calumet River (North). Flow on the NBCR is measured just upstream of its confluence with the NSC at the USGS gage at Albany Avenue.

During flow reversal events, the MWRDGC estimated the volume of flow reversal to Lake Michigan. Alp and Melching (2008a) compared the volume of flow reversal estimates made by the USGS and MWRDGC and found that simulations with the flow reversal volume estimated by the MWRDGC resulted in better estimates of water-surface elevations in the CWS. Since USGS flow reversal volumes were significantly lower than MWRDGC flow reversal volumes, thus, just during flow reversal events, USGS flows were multiplied by the numbers given in Table 2.1 to match the MWRDGC flow reversal volume estimates. This approach is reasonable because the USGS never made a discharge measurement during a flow reversal with which they could properly calibrate the acoustic velocity meter gages at the Lakefront structures (Jim Duncker, USGS, personal commun., 2007).

Table 2.1 Ratio of volume of flow reversal estimates (MWRDGC/USGS)

	MWRDGC/USGS Ratio		
Date	**Columbus**	**O'Brien**	**Wilmette**
8/2/2001	1.8	-	22.6
8/31/2001	-	-	-
10/13/2001	-	-	1.8

There also are inflows coming from MWRDGC facilities. Hourly flow data are available from the MWRDGC for the treated effluent discharged to the CWS by each of the four WRPs—North Side, Stickney, Calumet, and Lemont. Hourly flows were input to the model for the first three WRPs; whereas daily flows were used at Lemont. In addition, hourly flows discharged to the CWS at three CSO pumping stations—North Branch, Racine Avenue, and 125th Street—were estimated from operating logs of these stations (described in Section 2.1.1). The boundary conditions and tributary inflows for the DUFLOW model of the CWS are summarized in Section 2.2.3.

2.2.2 Estimation of flow for ungaged tributaries and combined sewer overflows

It is necessary to estimate the inflows from ungaged tributary watersheds. The same procedure was followed as applied in the original hydraulic calibration of the model (Shrestha and Melching, 2003). In the original hydraulic calibration, flows on Midlothian Creek were used to estimate flows on ungaged tributaries on an area-ratio basis. The drainage area ratios for the ungaged tributaries compared to the Midlothian Creek drainage area are listed in Table 2.2. The U.S. Army Corps of Engineers (2001) has estimated the land cover distribution in percent for the "ungaged" Calumet-Sag (including Midlothian and Tinley Creeks) and lower Des Plaines watersheds as follows.

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

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

Table 2.2 Calculation of ungaged tributaries and watersheds

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

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

Hourly flows from all 3 pumping stations were estimated from pump operation records of on and off times and the rated capacity of the various pumps and then input to the model. Daily average discharges from the 3 pumping stations are shown in Figures 2.2 and 2.3 for October 1, 2000 to September 30, 2001 and October 1, 2002 to September 30, 2003 (i.e. Water Years (WYs) 2001 and 2003).

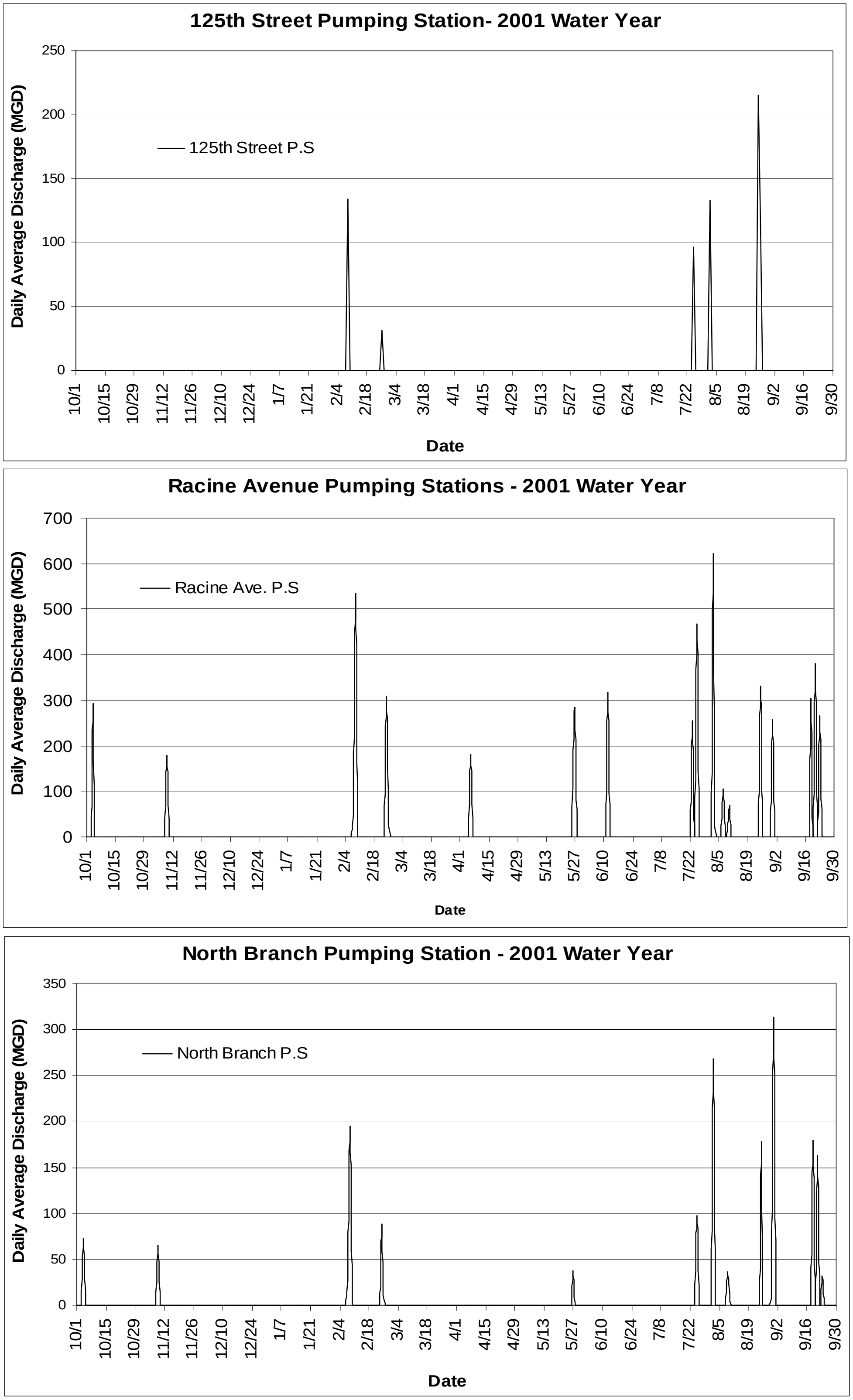


Figure 2.2 Daily average discharges from the North Branch, Racine Avenue, and 125th Street Pumping Stations for October 1, 2000 to September 30, 2001 (Water Year 2001)

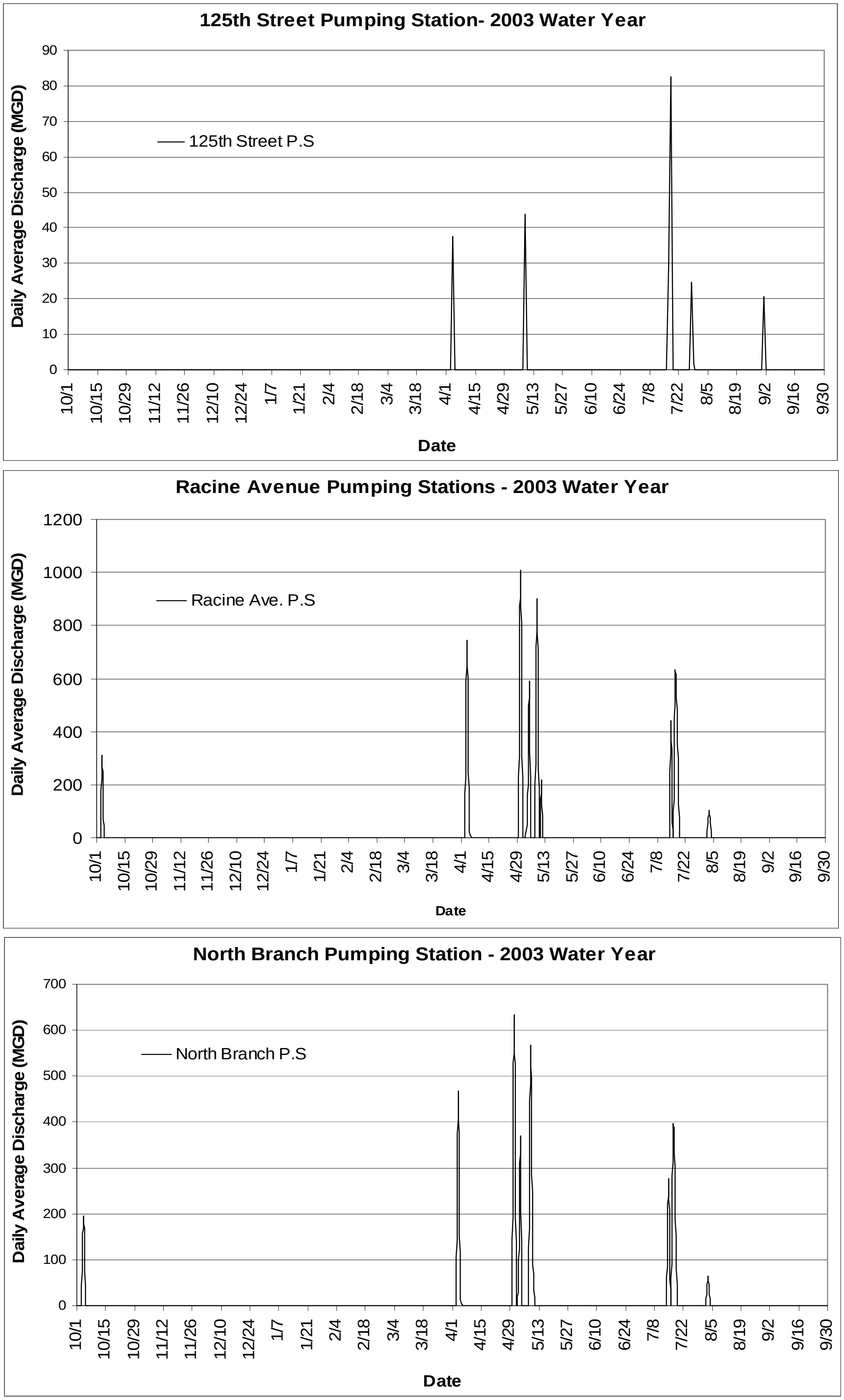


Figure 2.3 Daily average discharges from the North Branch, Racine Avenue, and 125th Street Pumping Stations for October 1, 2002 to September 30, 2003 (Water Year 2003)

2.2.3 Summary of Boundary Conditions and Tributary Inflows

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

Boundary Locations:

a. Chicago River at Columbus Drive
b. North Shore Channel at Wilmette (Maple Avenue)
c. Calumet River at O’Brien Lock and Dam
d. Little Calumet River (South) at South Holland (Cottage Grove Avenue)
e. CSSC at the Lockport Controlling Works (downstream boundary)

The major flows into CWS have been identified as follows:

a. North Side Water Reclamation Plant
b. Stickney Water Reclamation Plant
c. Calumet Water Reclamation Plant

and the minor flows into the CWS are from:

a. North Branch Chicago River at Albany Avenue
b. Racine Avenue Pumping Station
c. North Branch Pumping Station
d. 125th Street Pumping Station
e. Lemont Water Reclamation Plant

f. Tinley Creek+Navajo Creek (i.e. Navajo Creek estimated based on area ratio with Midlothian Creek and added with nearby Tinley Creek)

g. Midlothian Creek

h. Grand Calumet River

i. Mill+Stony Creek (West)*

j. Stony Creek (East)*

k. Des Plaines River Basin*

l. Calumet Union Drainage Ditch*

m. Cal-Sag Watershed West*

n. 43 representative CSO locations

* These flows were estimated based on Midlothian Creek flows

In 1995, the USGS did an evaluation of direct groundwater inflows to the CWS downstream from the USGS streamflow gages on the basis of test boring data and piezometric water levels near the waterways. The U.S. Army Corps of Engineers (1996) summarized the USGS results and determined a total groundwater inflow of 4 cubic feet per second (cfs). Therefore, the effects of direct groundwater inflow to the CWS was not directly considered in the water balance for the DUFLOW model. However, for tributary areas draining directly to the CWS, groundwater inflows are considered as part of the area ratio estimate of flows from these areas.

2.3 Channel Geometry and Roughness Coefficient

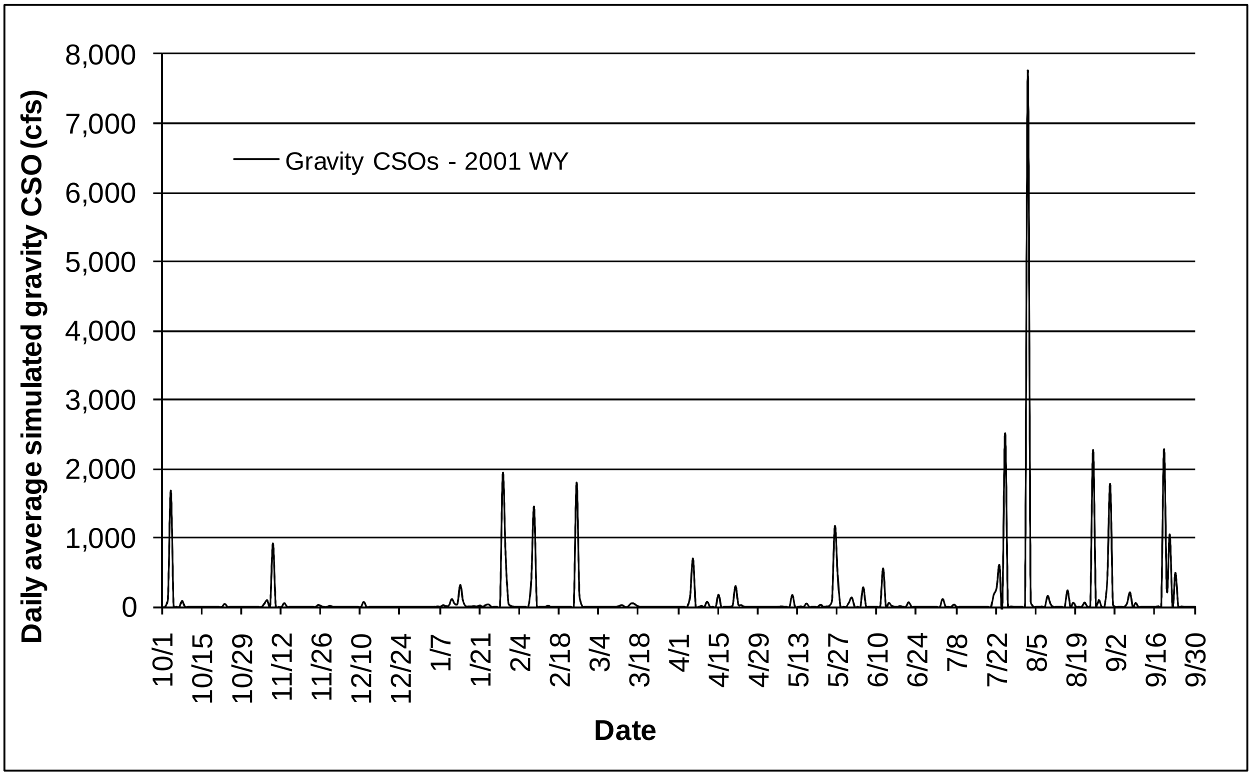
The channel geometry is represented as a series of 197 measured cross sections in the calibrated hydraulic model. The DUFLOW model uses Chezy's roughness coefficient, C, to calculate hydraulic resistance. The calibrated C values, which vary between 6 and 60 were used in this study, and the equivalent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

2.4 Model Verification Locations

Although flow in the various branches of the CWS are not measured, water-surface elevation recorded at different locations was used for calibration and verification of the model. The water-surface elevations recorded on the NSC at Wilmette; on the NBCR at Lawrence Avenue; on the CSSC at Western Avenue, Willow Springs Road, and Sag Junction by the MWRDGC and at Romeoville by the USGS; on the Calumet-Sag Channel at Southwest Highway; and on the Chicago River Main Stem at Columbus Drive by the USGS were used for model verification. Daily flows recorded or estimated by the USGS for the CSSC at Romeoville also were used for model verification.

2.5 Flow Balance

The inflow to the CWS is comprised of flows from tributaries, WRPs, pumping stations, CSOs, and from Lake Michigan at the controlling structures. All the inflows to the system are measured as flow at Romeoville. During the calculation of the flow balance, it is assumed that the difference in the water balance due to the travel time and change in storage are negligible. Daily average simulated gravity CSO flows obtained from the Corps as explained in Section 2.1.1 are shown in Figure 2.4. Comparison of the summation of all inflows to the system and outflow at Romeoville are shown in Figure 2.5. All inflows to the system and flow at Romeoville for the periods of October 1, 2000 to September 30, 2001 (WY 2001) and October 1, 2002 to September 30, 2003 (WY 2003) are listed in Tables 2.3 and 2.4. Over the full study period the inflows (except CSOs) were 3.1% and 2.8% higher than the flow at Romeoville for WYs 2001 and 2003, respectively. The flow balance indicated that inflows to the CWS are slightly overestimated.



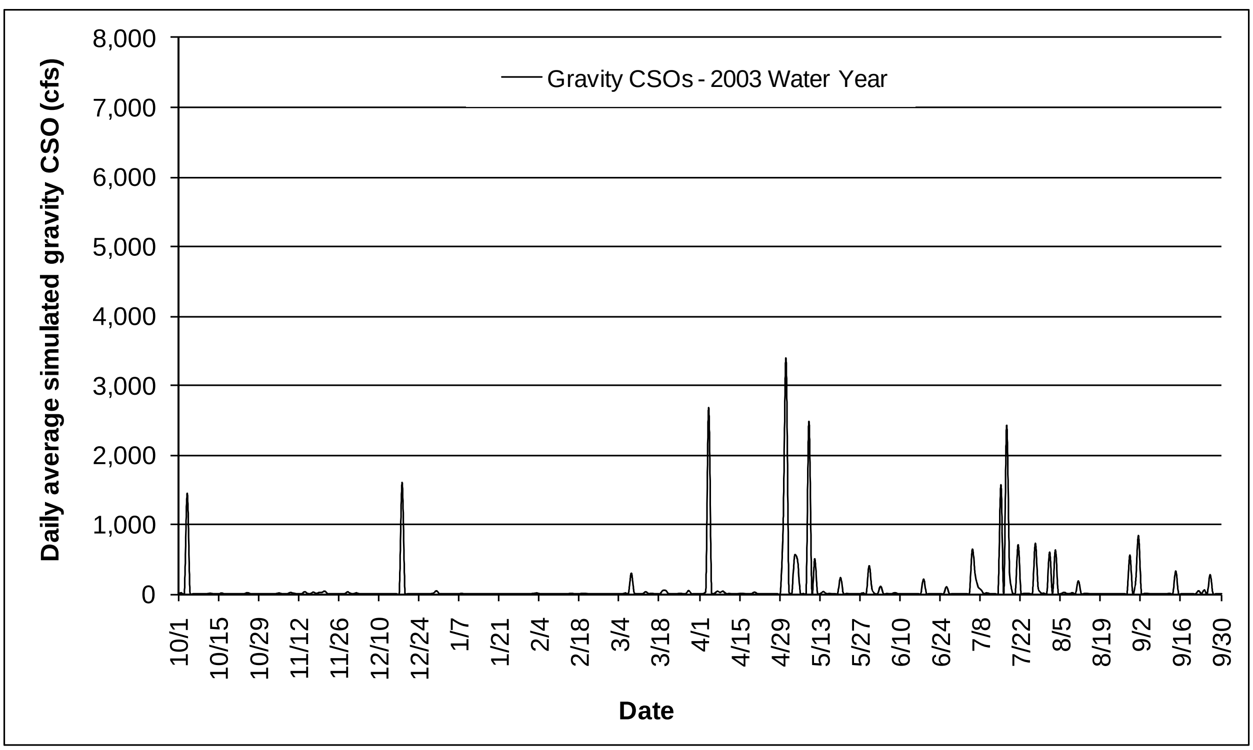


Figure 2.4 Daily average simulated gravity combined sewer overflow (CSO) flows obtained from the U.S. Army Corps of Engineers

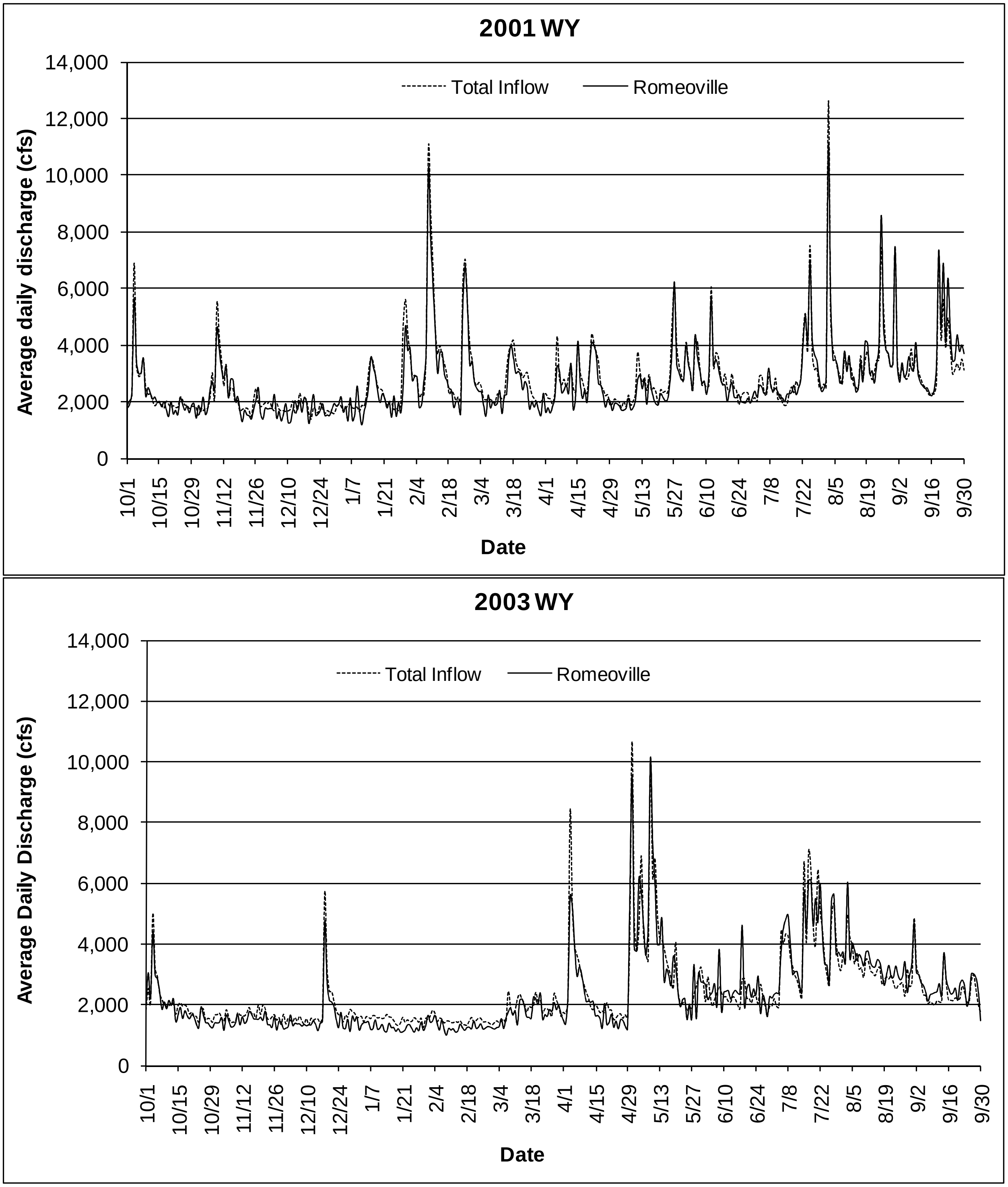


Figure 2.5 Comparison of the summation of all measured or estimated (except gravity combined sewer overflows) inflows (Total) and the measured outflow at Romeoville for October 1, 2000 to September 30, 2001 (Water Year 2001) and October 1, 2002 to September 30, 2003 (Water Year 2003)

Table 2.3 Balance of average daily flows for the Chicago Waterway System for the period of October 1, 2000 to September 30, 2001 (Water Year 2001)

Inflows (2001 WY)	Flow (cfs)
Mill Creek + Stoney Creek (W)*	19.9
Narajo Creek + Calumet-Sag basin*	4.6
Calumet Union Drainage Ditch*	14.2
Stoney Creek (E) *	5.9
Calumet-Sag End Watershed*	12.0
Lower Des Plaines basin*	8.5
Midlothian Creek	12.1
Grand Calumet River	11.8
Tinley Creek	13.3
Chicago River at Columbus Drive	119.1
O'Brien Lock and Dam	116.9
North Shore Channel at Wilmette	22.1
Little Calumet River at South Holland	160.2
North Branch Chicago River at Albany Avenue	146.4
125th Street Pump Station	3.0
North Branch Pump Station	2.2
Racine Avenue Pump Station	10.0
Lemont Water Reclamation Plant	3.2
Calumet Water Reclamation Plant	407.5
Northside Water Reclamation Plant	420.3
Stickney Water Reclamation Plant	1180.5
Total simulated gravity combined sewer overflows*	101.7
Romeoville (Outflow)	2710.5
Total Inflow	2795.6
Difference (cfs)	85.1
% Difference	3.1

*Estimated flows

Table 2.4 Balance of average daily flows for the Chicago Waterway System for the period of October 1, 2002 to September 30, 2003 (Water Year 2003)

Inflows (2003 WY)	Flow (cfs)
Mill Creek + Stoney Creek (W)	13.4
Narajo Creek + Calumet-Sag basin	3.1
Calumet Union Drainage Ditch	9.5
Stoney Creek (E)	4.0
Calumet-Sag End Watershed	8.1
Lower Des Plaines basin	5.7
Midlothian Creek	8.2
Grand Calumet River	8.5
Tinley Creek	9.1
Chicago River at Columbus Drive	138.6
O'Brien Lock and Dam	95.4
North Shore Channel at Wilmette	51.3
Little Calumet River at South Holland	144.9
North Branch Chicago River at Albany Avenue	90.0
125th Street Pump Station	1.0
North Branch Pump Station	6.1
Racine Avenue Pump Station	14.4
Lemont Water Reclamation Plant	3.1
Calumet Water Reclamation Plant	353.8
Northside Water Reclamation Plant	357.2
Stickney Water Reclamation Plant	1005.7
Total simulated gravity combined sewer overflows	75.8
Romeoville (Outflow)	2342.2
Total Inflow	2406.9
Difference (cfs)	64.7
% Difference	2.8

2.6 Results of the Hydraulic Verification

The comparison of measured and simulated water-surface elevations at various locations used in the model verification is shown in Figures 2.6 and 2.7 for WYs 2001 and 2003, respectively. Statistical analysis listed in Tables 2.5 and 2.6 shows that the difference between the measured and simulated stages are below 5% relative to the depth (where depth is measured relative to the thalweg of the channel) of the water for 100% of the simulation periods for all locations except for Wilmette, Lawrence Avenue, and Southwest Highway. The simulated water-surface elevations were within 5% of the measured values with respect to the depth at these locations 86-97% of the time except for WY 2001 and 65-93% of the time for WY 2003. As can be seen in Figure 2.7, there is a constant almost 1 ft difference between the measured and simulated water-surface elevations between October 2002 and January 2003 at Lawrence Avenue. The fact that this difference diminishes after January 2003 suggests that measured water-surface elevations at Lawrence Avenue between October 2002 and January 2003 are suspicious. Similarly, unusually high water-surface elevation values between January and March 2003 on Cal-Sag Channel at Southwest Highway are suspicious and result in a low correlation coefficient for WY 2003.

As listed in Tables 2.5 and 2.6, high percentages of small errors and the high correlation coefficients (0.64-0.94) indicate an excellent hydraulic verification of the model. Further, data were not available at Southwest Highway and Lawrence Avenue during the original hydraulic calibration. Thus, the results at Southwest Highway and Lawrence Avenue provide a more stringent verification of the model's accuracy than do the stage comparisons at locations used in the model calibration. Since the calibrated model can predict stages throughout the CWS with high accuracy, this model can be safely used for the water-quality simulation once the water-quality simulation routines are properly calibrated.

Table 2.5 Correlation coefficient and percentage of the hourly water-surface elevations for which the error in simulated versus measured water-surface elevations relative to the depth of flow (measured from the thalweg of the channel) is less than the specified percentage for October 1, 2000 to September 30, 2001 (Water Year 2001)

		Percentage		
Location	**Correlation Coefficient**	**<±2% of D**	**<±5% of D**	**<±10% of D**
Wilmette (NSC)	0.94	36	96	99
CRCW (Chicago River Main Stem)	0.87	97	100	100
O'Brien Lock and Dam (Calumet River)	0.75	97	100	100
Lawrence Avenue (NBCR)	0.74	59	86	96
Western Avenue (CSSC)	0.88	97	100	100
Willow Springs (CSSC)	0.84	97	100	100
Southwest Highway (Cal-Sag Channel)	0.67	85	97	99
Calumet-Sag Junction	0.82	97	100	100
Romeoville (CSSC)	0.92	98	100	100

Table 2.6 Correlation coefficient and percentage of the hourly water-surface elevations for which the error in simulated versus measured water-surface elevations relative to the depth of flow (measured from the thalweg of the channel) is less than the specified percentage for October 1, 2002 to September 30, 2003 (Water Year 2003)

		Percentage		
Location	**Correlation Coefficient**	**<±2% of D**	**<±5% of D**	**<±10% of D**
Wilmette (NSC)	0.82	16	78	98
CRCW (Chicago River Main Stem)	0.77	95	100	100
O'Brien Lock and Dam (Calumet River)	0.64	98	100	100
Lawrence Avenue (NBCR)	0.42	18	65	97
Western Avenue (CSSC)	0.77	97	100	100
Willow Springs (CSSC)	0.81	100	100	100
Southwest Highway (Cal-Sag Channel)	0.47	67	93	96
Calumet-Sag Junction	0.84	98	100	100
Romeoville (CSSC)	0.91	97	100	100

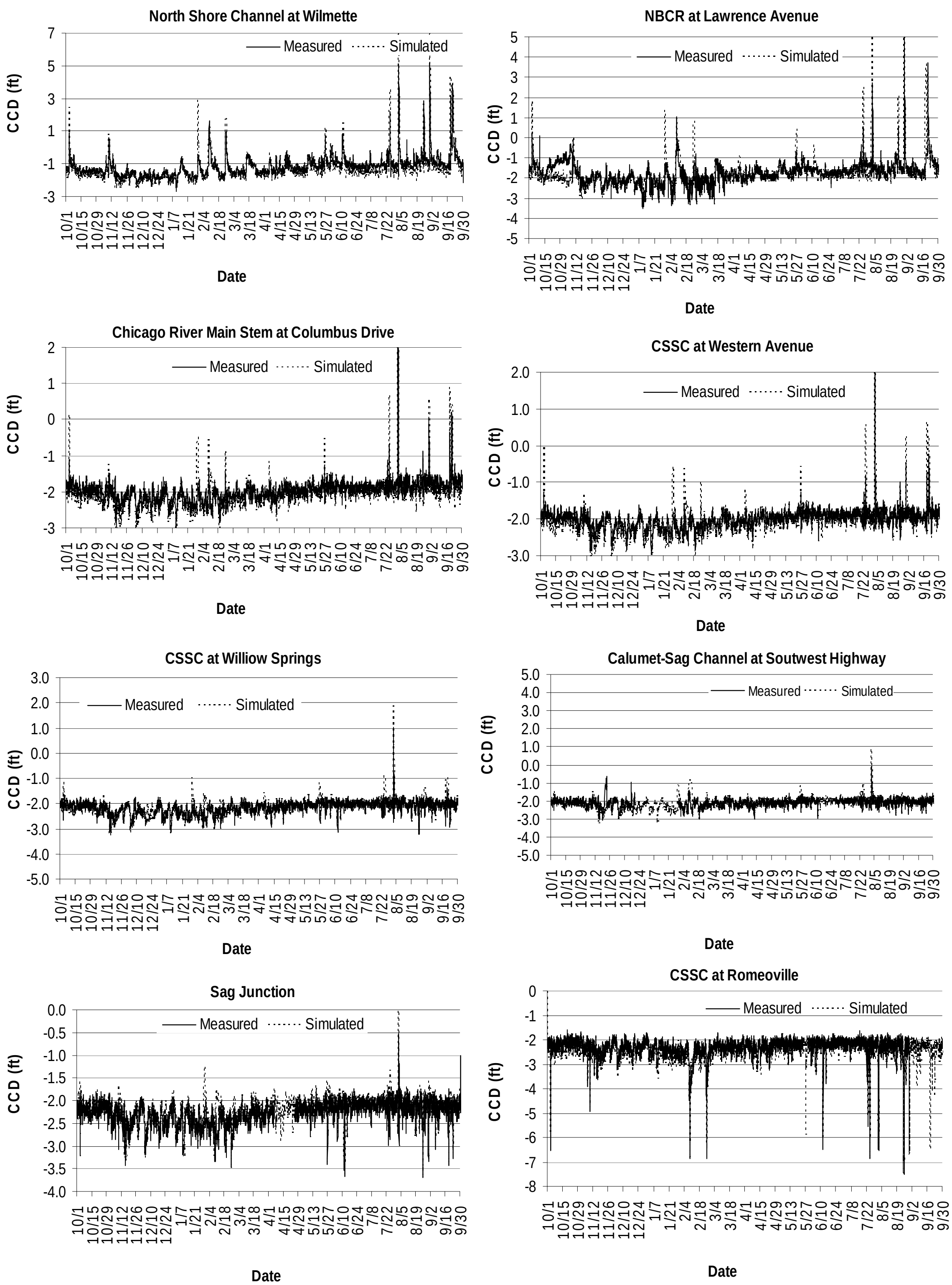


Figure 2.6 Measured and simulated water-surface elevations relative to the City of Chicago Datum (CCD) at different locations in the Chicago Waterway System for October 1, 2000 to September 30, 2001 (Water Year 2001)

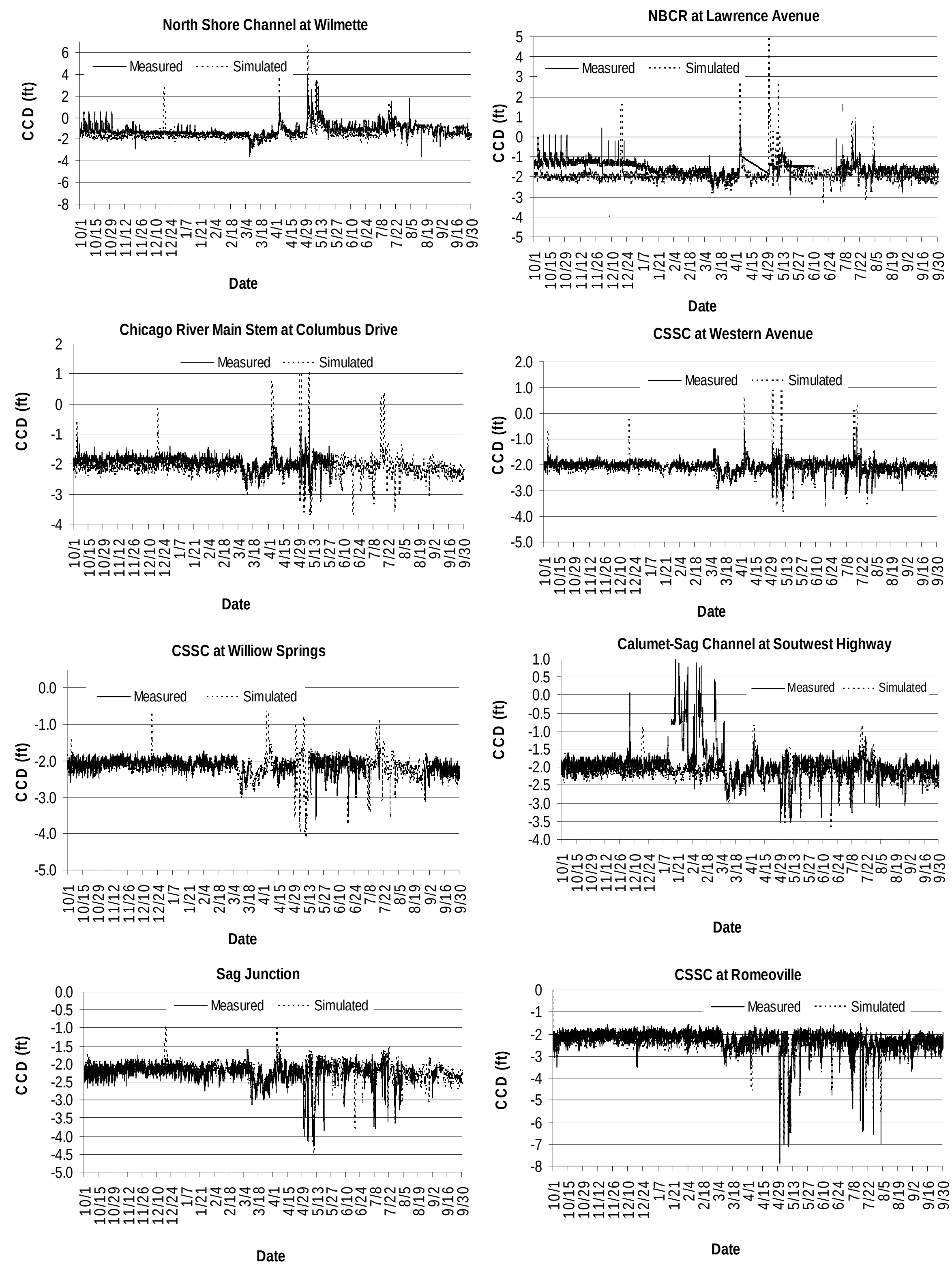


Figure 2.7 Measured and simulated water-surface elevations relative to the City of Chicago Datum (CCD) at different locations in the Chicago Waterway System for October 1, 2002 to September 30, 2003 (Water Year 2003)

The comparison of measured and simulated average daily flows on the CSSC at Romeoville is shown in Figure 2.8. The simulated average flow rates at Romeoville are 2,872.7 cfs and 2,441.5 cfs for WYs 2001 and 2003, respectively. The measured and simulated flows show very close agreement and the overall difference between the simulated and measured daily discharges at Romeoville are 6% and 4.2% for WYs 2001 and 2003, respectively.

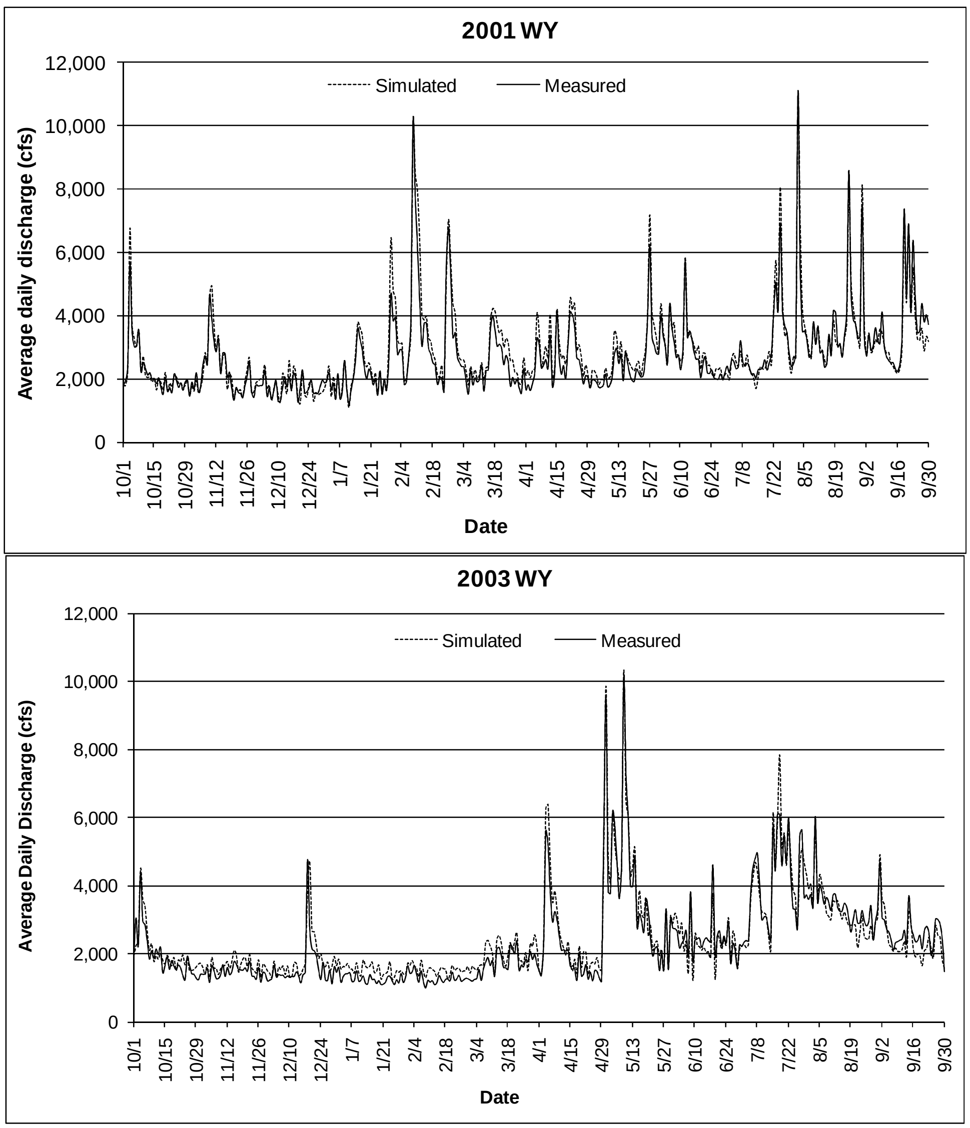


Figure 2.8 Measured and simulated average daily flows on the CSSC at Romeoville for periods of October 1, 2000 to September 30, 2001 and October 1, 2002 to September 30, 2003 (Water Years 2001 and 2003)

Chapter 3 – CALIBRATION OF THE WATER QUALITY MODEL

3.1 The DUFLOW Water-Quality Model

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

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

Neugebauer and Melching (2005). The complete EUTROF2 model is given in Appendix A.

3.2 Water-Quality Input Data

The water quality in the modeled portion of the CWS is affected by the operation of four Sidestream Elevated Pool Aeration (SEPA) stations and two in-stream aeration stations (shown in Fig. 1.1). The CWS receives pollutant loads from four WRPs, nearly 240 CSOs (condensed to 43 representative locations to facilitate the modeling), direct diversions from Lake Michigan, and eleven tributary streams or drainage areas. The effects of nonpoint source pollution are included in the CSO and tributary flow pollutant loads. Assumptions used to consider the effects of the aeration stations on water quality and to determine the various pollutant loadings are discussed in this section, as are the constituent concentrations for the various inflows to the CWS.

3.2.1 SEPA stations

Because the CWS was constructed to convey treated municipal wastewater and provide for commercial navigation and flood control, the system has low in-stream velocities. DO concentrations in the CWS, therefore, have been low compared to other rivers in Illinois. In 1984, the MWRDGC issued a feasibility report on a new concept of artificial aeration referred to as SEPA. The SEPA concept involves pumping a portion of the water from the stream into an elevated pool. Water is then aerated by flowing over a cascade or waterfall, and the aerated water is returned to the stream. There are five SEPA stations along the Calumet-Sag Channel, Little Calumet River (North), and Calumet River. Four of these SEPA stations are within the water-quality model study area. The locations of the SEPA stations are listed in Table 3.1.

Table 3.1 Locations of Sidestream Elevated Pool Aeration (SEPA) stations

SEPA STATION #	**Location**	**River Mile* from Lockport**
2	127th Street	30.3
3	Blue Island	27
4	Worth (Harlem Avenue)	20.7
5	Sag Junction	12.3

*River miles for the Chicago Waterway System often are described relative to the confluence of the Illinois River with the Mississippi River at Grafton, Ill., in this case the River Mile for Lockport is 291, and all of the values can have 291 added to them to give river mile values relative to the mouth of the Illinois River.

Two previously conducted studies (Butts et al., 1999 and 2000) were used to examine the efficiency of and calculate DO load from the SEPA stations. Summaries of these studies and the estimation of DO loads from SEPA stations are explained in detail in Alp and Melching (2004). The procedure explained in Alp and Melching (2004) was followed to estimate the DO loads from the SEPA stations for WYs 2001 and 2003.

In the water-quality modeling, the DO load from the SEPA stations was calculated using the following formula:

$$\text{OXYGEN LOAD} = Q_P \text{ x } \quad \text{x } (C_{SAT} - C_{UPSTREAM}) \text{ in g/s}$$

where:

Q_P = Flow through the SEPA station, m^3/s

= Number of Pumps Operating x Pump Capacity

C_{SAT} = Saturation concentration of DO, mg/L,

(determined from continuous in-stream temperature data)

$C_{UPSTREAM}$ = DO concentration (mg/L) upstream of SEPA station from continuous in-stream monitoring data (for calibration) or modeling results (for development of the integrated strategies)

= Fraction of saturation achieved = f(number of pumps in operation), from Butts et al. (1999)

These hourly DO loads were directly input to the CWS as a point source in the DUFLOW water-quality simulation. Average daily DO loads from SEPA stations used in the model calibration are given in Appendix B. Flow through the SEPA station was calculated using the pump operation schedule and pump capacities. The pump operation schedule was provided by the MWRDGC.

3.2.2 In-Stream Aeration Stations

Because of problems with low DO in the past, two diffused aeration stations were built. In 1979, the Devon Avenue station was completed on the NSC. A second aeration station was constructed at Webster Avenue on the NBCR and became operational in 1980. Results from a previous study (Polls et al., 1982) on the oxygen input efficiency of the Devon Avenue facility were used to determine DO loads from the in-stream aeration stations. The details of the estimation of the DO loads from in-stream aeration stations are given in Alp and Melching (2004).

Blower operation hours were provided by the MWRDGC. The following equation is used to calculate hourly DO load for input to the model:

Load = $\%DO_{increase}$ x $DO_{upstream}$ x Q/100

where:

Load = Oxygen load from the in-stream aeration station (g/s)

$\%DO_{increase}$ = Percent DO increase downstream of the aeration station

$DO_{upstream}$ = Measured DO concentration upstream of the aeration station (mg/L)

Q = Discharge at the aeration station (m^3/s)

For model calibration, the discharge and DO concentration upstream of Devon Avenue were calculated using a mass balance approach. The North Side WRP and NSC at Main Street continuous DO concentration and discharges were used to calculate DO and discharge upstream of the Devon Avenue aeration station. The Fullerton Avenue continuous DO monitoring site measurements were used to define the upstream conditions for the Webster Avenue aeration station calculations. Average daily DO load from in-stream aeration stations used for model calibration are given in Appendix B. For the evaluation of integrated strategies to meet the proposed DO standards, simulated discharge and DO concentrations upstream from the in-stream aeration stations are used.

3.2.3 Water Reclamation Plants

Four point sources potentially affect the water quality in the CWS: the North Side WRP, Stickney WRP, Calumet WRP, and Lemont WRP. Measured daily concentrations were used in the model for the four WRPs. The summation of the discharges from the North Side, Stickney, and Calumet WRPs has the greatest contribution of loads to the CWS. Daily measured concentration from these 3 WRPs are shown in Figures 3.1-3.6, respectively. In these figures and throughout the report the constituent abbreviations are as follows: DO = dissolved oxygen, CBOD5 (figures) $CBOD_5$ (text) = 5-day carbonaceous biochemical oxygen demand, TSS = total suspended solids, TKN = total Kjeldahl nitrogen as nitrogen, NH4-N (figures) NH_4-N (text) = ammonium as nitrogen, Org-N = organic nitrogen as nitrogen, NO3-N (figures) NO_3-N (text) = nitrate as nitrogen, NO2+NO3 = nitrite plus nitrate as nitrogen, P-Tot = total phosphorus, Sol-P = soluble phosphorus, Org-P = organic phosphorus, In-P = inorganic phosphorus, and Chll-a = chlorophyll a. The load from the Citgo Petroleum outfall was not considered in this study because of lack of water-quality data on this discharge and the insignificant amount of flow and pollutant load contributed by this discharger.

3.2.4 Tributaries

Long-term average values are used for the concentrations for the tributaries. All water-quality data used were collected as a part of the MWRDGC monthly waterway sampling program. A limited amount of event mean concentration data are available on the Little Calumet River (South) at Ashland Avenue (8 events) and the North Branch Chicago River at Albany Avenue (9 events) in the summer and fall 2001 (see Alp and Melching, 2006). These data were believed to be insufficient to describe storm flows for all events and all tributaries for WYs 2001 and 2003. Thus, in order to be consistent throughout the simulation periods of WYs 2001 and 2003 and use the same kinetic parameters, long-term average in-stream concentrations were used for both wet and dry periods.

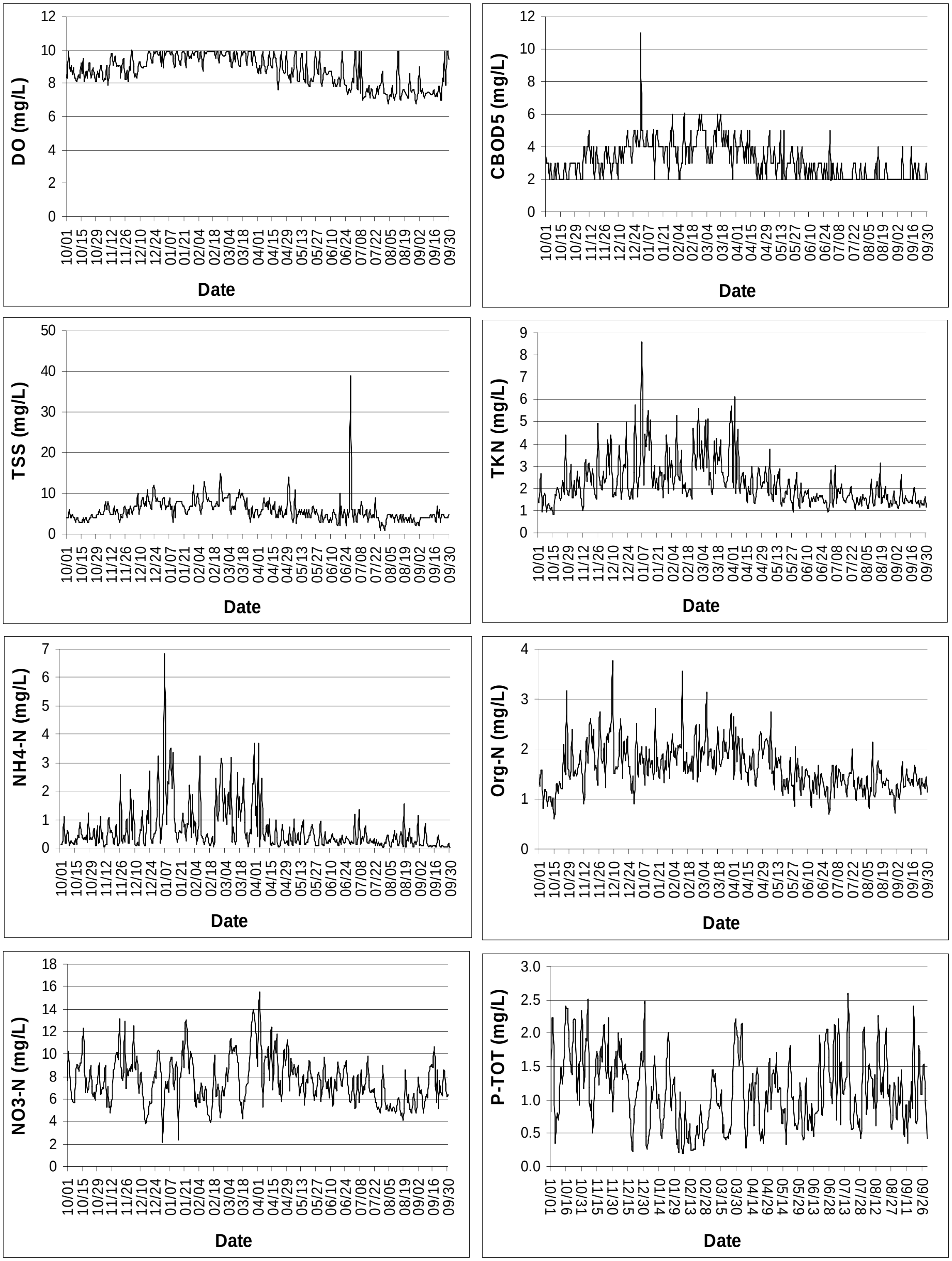


Figure 3.1 Stickney Water Reclamation Plant daily effluent concentrations for Water Year 2001

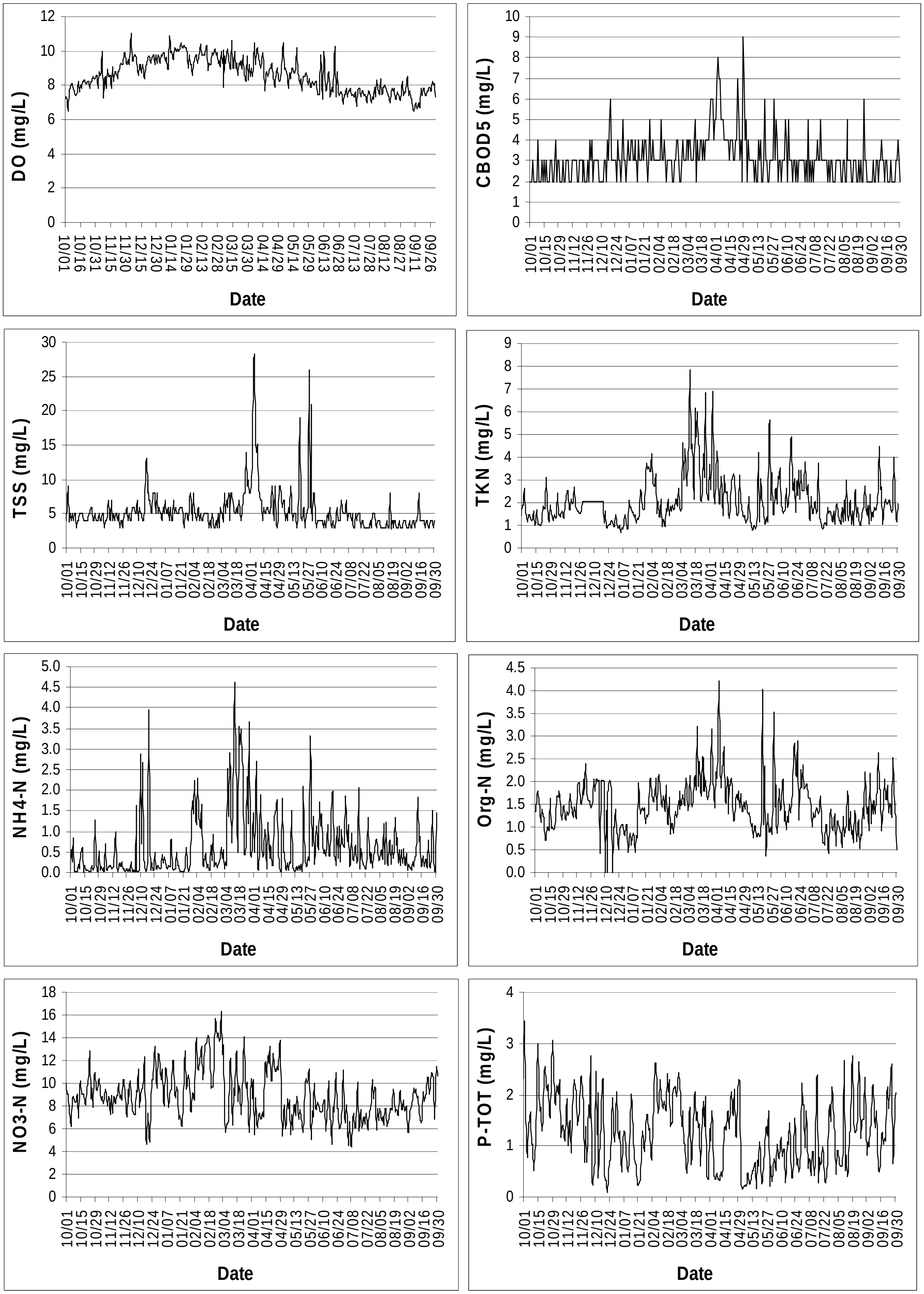


Figure 3.2 Stickney Water Reclamation Plant daily effluent concentrations for Water Year 2003

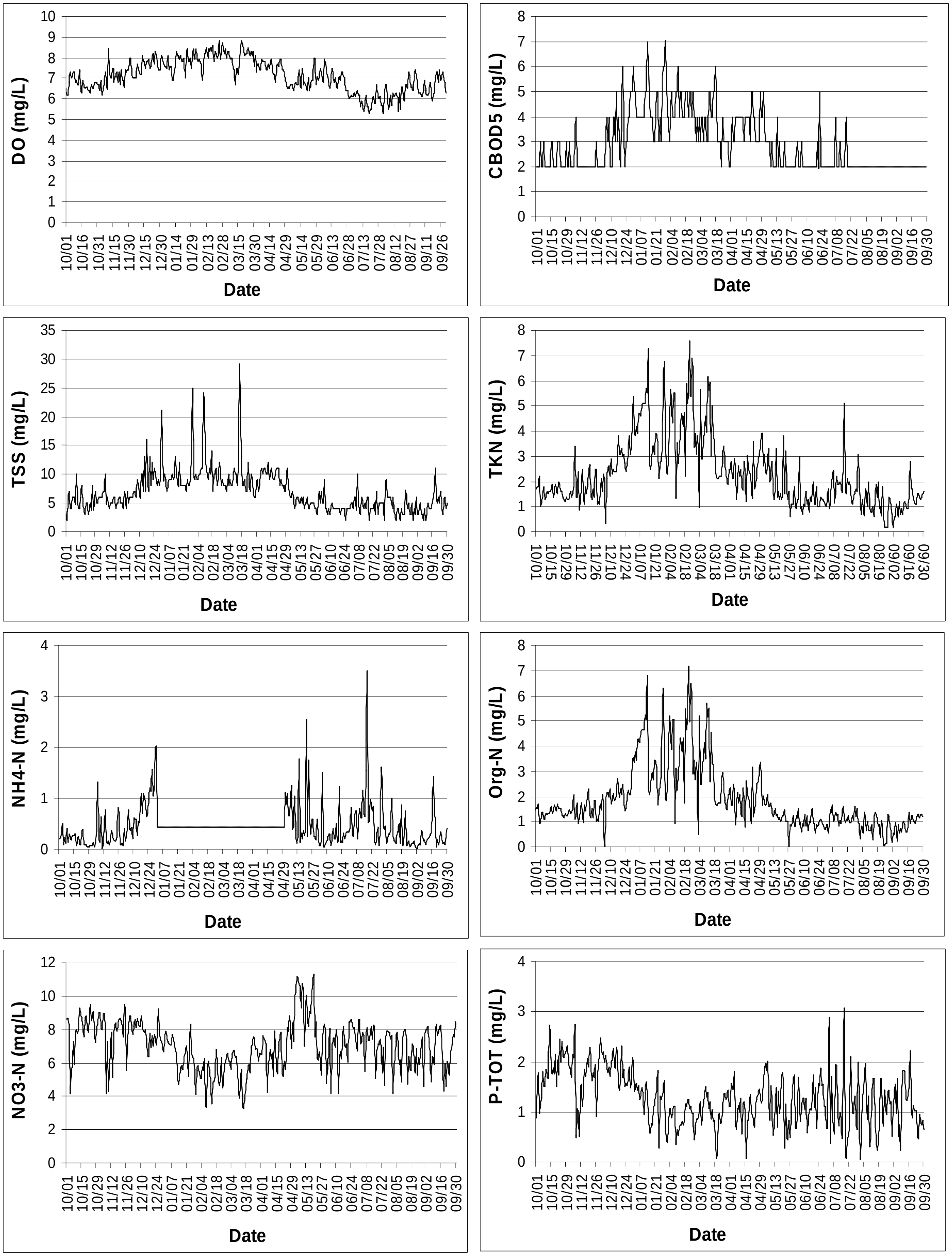


Figure 3.3 North Side Water Reclamation Plant daily effluent concentrations for Water Year 2001

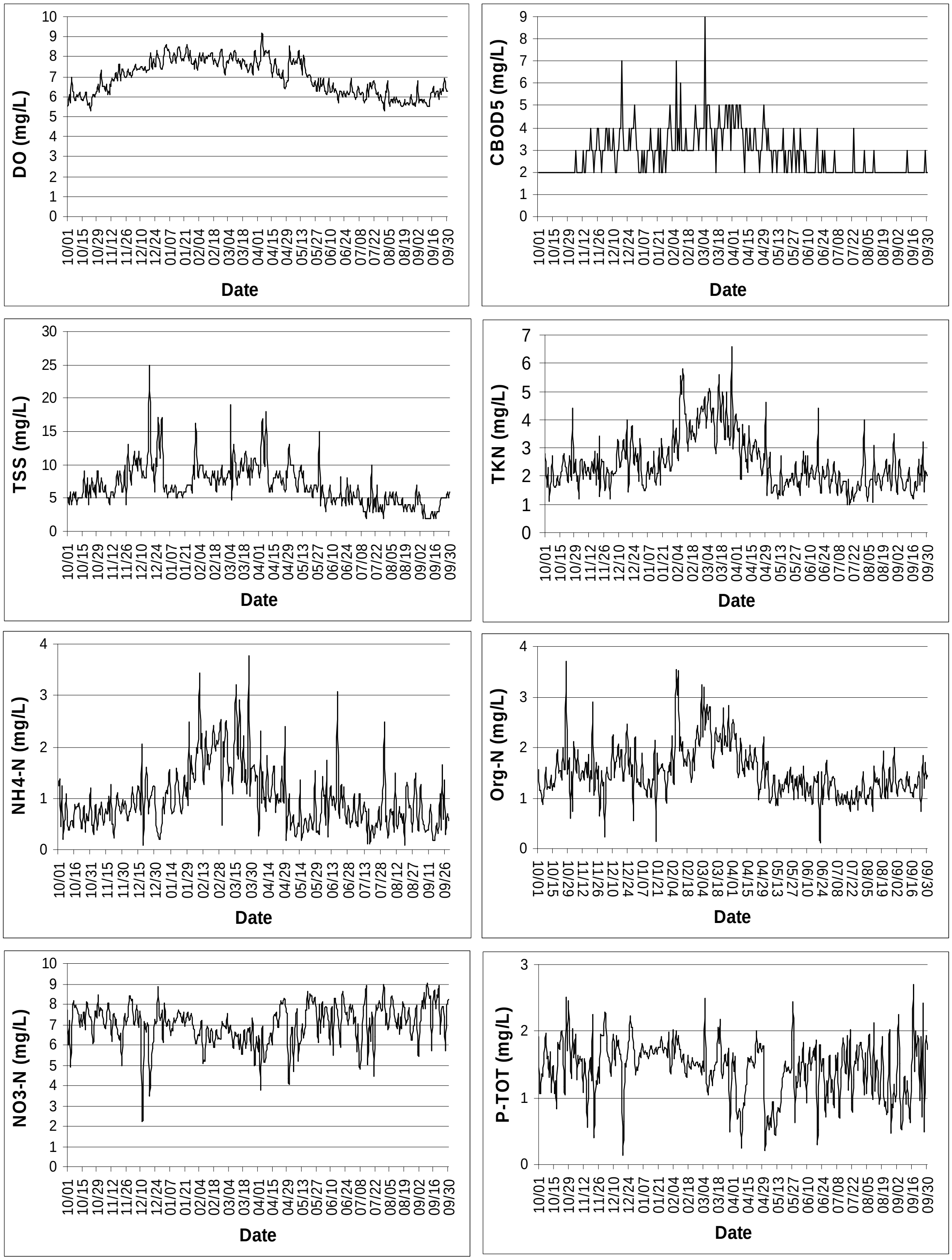


Figure 3.4 North Side Water Reclamation Plant daily effluent concentrations for Water Year 2003

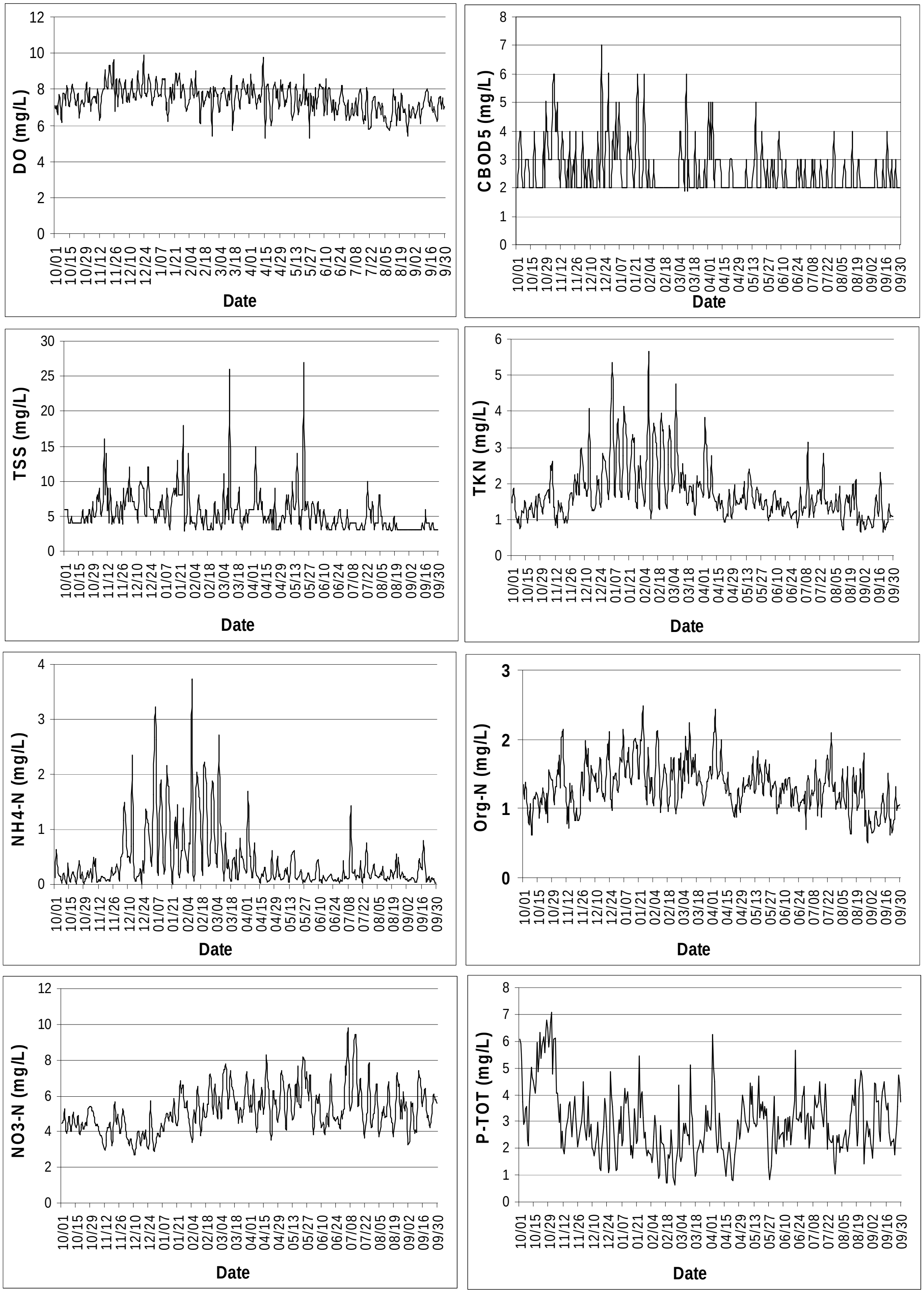


Figure 3.5 Calumet Water Reclamation Plant daily effluent concentrations for Water Year 2001

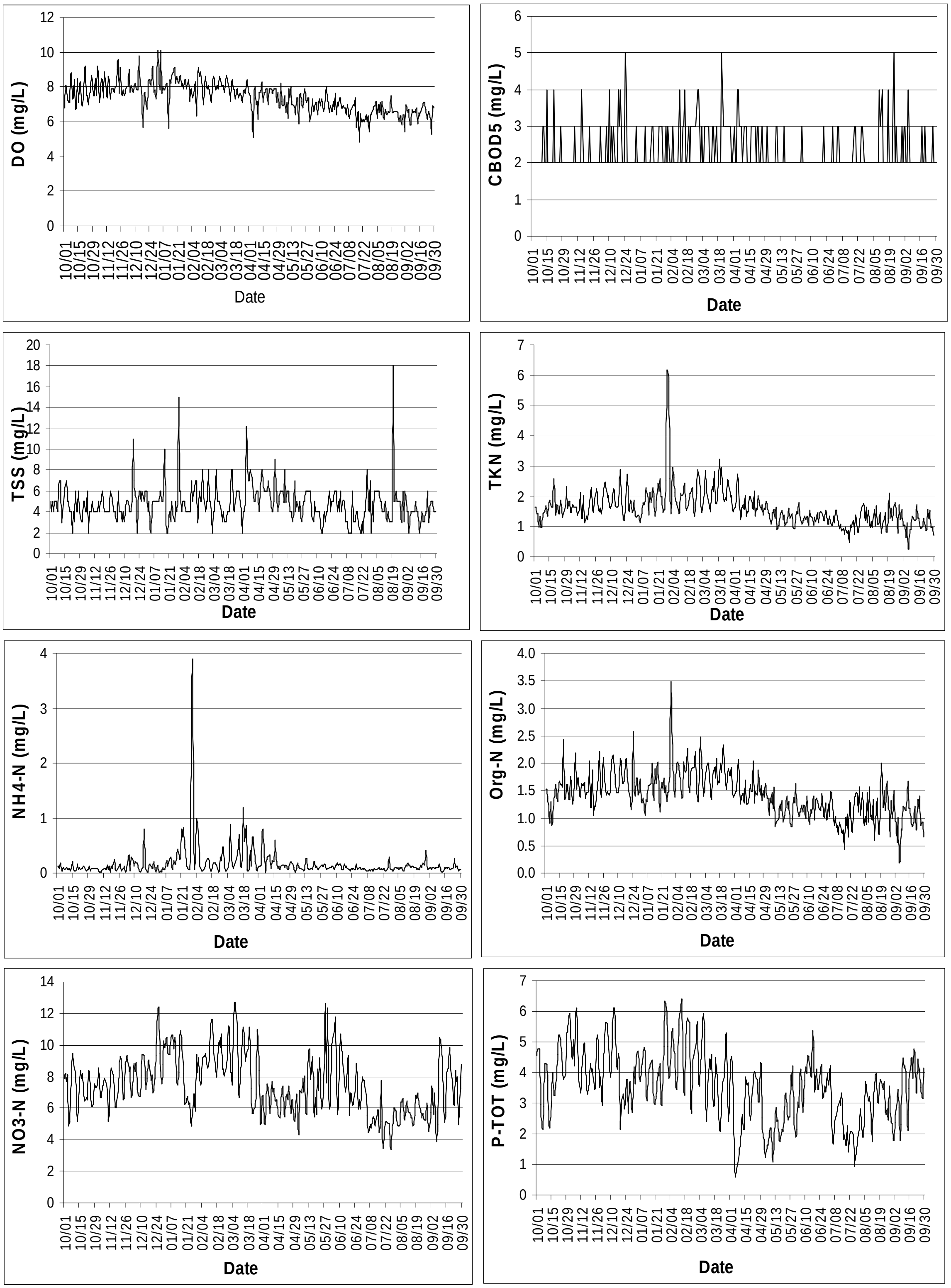


Figure 3.6 Calumet Water Reclamation Plant daily effluent concentrations for Water Year 2003

Average concentrations for Calendar Years 2000-2004 for the Little Calumet River at South Holland were calculated using a mass balance approach and data from the Little Calumet River at Wentworth Avenue (upstream from the South Holland gage) and at Ashland Avenue (downstream from the South Holland gage) and Thorn Creek at 170th Street (upstream from the South Holland gage). Results are listed in Table 3.2, where NO_2+NO_3-N represents nitrite plus nitrate as nitrogen and P-Sol represents soluble phosphorus.

Table 3.2 Little Calumet River at South Holland concentrations

$CBOD_5$ (mg/L)	**TSS (mg/L)**	**DO (mg/L)**	**TKN (mg/L)**	**NH_4-N (mg/L)**	**Org-N (mg/L)**	**P-Tot (mg/L)**	**NO_2+NO_3-N (mg/L)**	**Sol-P (mg/L)**
3.15	36.15	*	1.47	0.28	1.18	1.40	5.07	0.97

* Monthly average DO concentrations measured between 2000-2004 are used

Concentrations measured between 1990-2004 at the Grand Calumet River at Burnham Avenue were used for the concentrations at the Grand Calumet River at Hohman Avenue gage. Results are listed in Table 3.3.

Table 3.3. Grand Calumet River at Hohman Avenue concentrations

$CBOD_5$ (mg/L)	**TSS (mg/L)**	**DO (mg/L)**	**TKN (mg/L)**	**NH_4-N (mg/L)**	**Org-N (mg/L)**	**P-Tot (mg/L)**	**NO_2+NO_3-N (mg/L)**	**Sol-P (mg/L)**
6.69	34.97	***	4.33	2.01	2.32	0.74	7.73	0.22

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

Average concentrations (2000-2004) for the North Branch Chicago River at Albany Avenue are listed in Table 3.4.

Table 3.4 North Branch Chicago River at Albany Avenue concentrations

$CBOD_5$ (mg/L)	**TSS (mg/L)**	**DO (mg/L)**	**TKN (mg/L)**	**NH_4-N (mg/L)**	**Org-N (mg/L)**	**P-Tot (mg/L)**	**NO_2+NO_3-N (mg/L)**	**Sol-P (mg/L)**
4.79	21.41	*	1.38	0.28	1.10	0.93	4.20	0.81

* Monthly average DO concentrations measured between 2000-2004 are used

Since the data collected by the MWRDGC during 2001-2004 show that the chlorophyll-a concentration varies drastically from month to month, average monthly chlorophyll-a concentrations were calculated for the Little Calumet River at South Holland and measured concentrations were used at the North Branch Chicago River at Albany Avenue and Grand Calumet River at Burnham Avenue. The chlorophyll-a concentration, in micrograms per liter (µg/L), for the Little Calumet River at South Holland was computed using the same mass balance approach applied for the other constituents. The monthly chlorophyll-a concentrations used in the modeling are listed in Table 3.5.

Table 3.5 North Branch Chicago River at Albany Avenue, Little Calumet River at South Holland, and Grand Calumet River at Burnham Avenue chlorophyll-a concentrations based on data from 2001-2004

	North Branch Chicago River at Albany Avenue (µg/L)	**Little Calumet at South Holland (µg/L)**	**Grand Calumet River at Burnham Avenue (µg/L)**
October	10.8	3.5	9.4
November	7.7	10.2	21.1
December	8.0	2.1	15.0
January	7.8	12.2	9.1
February	26.6	10.6	96.3
March	19.6	18.9	132.0
April	58.8	16.1	4.5
May	22.1	6.0	17.8
June	24.5	8.9	24.6
July	13.8	9.6	24.0
August	11.1	11.3	12.6
September	9.6	4.9	50.4

Concentrations for other tributaries are based on the Little Calumet River concentrations because all of the other gaged and ungaged tributaries are on the southern portion of the

Chicago metropolitan area and were assumed to be similar to the Little Calumet River drainage basin.

3.2.5 Combined Sewer Overflows

There are nearly 240 CSO locations discharging to the modeled portion of the CWS and they are represented by 43 CSO locations in the model. In addition to CSO locations there are 3 CSO pumping stations. Table 3.6 lists the historic event mean concentrations (EMCs) calculated based on measurements done by the MWRDGC for each pumping station. Average EMCs for each pump station then were calculated using the data in Table 3.6 for the North Branch Pumping Station and 125th Street Pumping Station and are listed in Table 3.7. As explained in Alp (2006), because of lack of data, the Racine Avenue Pumping Station EMCs were determined by regression equations based on discharge and EMC. As historic data are available for $CBOD_5$, TSS, and NH_4-N at the Racine Avenue Pumping Station, these values were used in the regression analysis. For other constituents (NO_3-N, P-Tot, TKN, and DO) historic North Branch Pumping Station EMCs were used at the Racine Avenue Pumping Station. For each constituent, EMCs were regressed against the total CSO volume. After that, Racine Avenue Pumping Station CSO volume data were used to estimate EMC as listed in Table 3.7.

The EMCs for the North Branch Pumping Station in Table 3.7 were applied to all gravity CSOs discharging to the North Shore Channel and North Branch Chicago River. The EMCs for the Racine Avenue Pumping Station in Table 3.7 were applied to all gravity CSOs discharging to the Chicago River Main Stem, South Branch Chicago River, and

CSSC. Finally, the EMCs for the 125th Street Pumping Station in Table 3.7 were applied to all gravity CSOs discharging to the Little Calumet River and Calumet-Sag Channel. The reasonableness of this approach was statistically demonstrated in Neugebauer and Melching (2005).

Table 3.6 Measured event mean concentrations for combined sewer overflow pumping stations

	DO (mg/L)	$CBOD_5$* (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Org-N (mg/L)	Org-P** (mg/L)	In-P** (mg/L)	TSS (mg/L)
North Branch Pumping Station								
08/02/01	5.8	27.3	1.8	1.5	5.7	0.4	0.6	92.3
08/09/01	2.4	71.4	3.2	0.7	14.2	2.6	0.1	263.0
09/20/01	4.2	20.8	1.8	0.5	5.4	0.8	0.3	83.1
09/23/01	4.0	42.3	5.8	0.3	6.5	1.1	0.6	87.1
10/13/01	4.0	30.2	1.8	0.6	3.8	0.5	0.5	52.2
10/23/01	6.7	42.4	2.2	0.6	5.4	1.1	0.1	107.5
04/7-9/02	-	34.3	3.8	0.7	4.4	0.7	0.9	62.5
Racine Avenue Pumping Station								
07/20/95	-	76.8	3.1	-	-	-	-	-
08/15/95	-	32.4	1.8	-	-	-	-	-
11/10/95	-	8.9	0.6	-	-	-	-	-
07/17/96	-	15.8	0.4	0.8	-	-	-	113.4
07/18/97	-	54.7	-	-	-	-	-	887.5
04/22/99	-	49.1	-	-	-	-	-	232.1
06/01/99	-	120.5	-	-	-	-	-	1405.5
12/4/99	-	36.9	-	-	-	-	-	179.2
04/7-9/02	-	38.0	-	-	-	-	-	182.0
125th Street Pumping Station								
11/10/95	-	68.0	1.2	-	-	-	-	-
07/17/96	-	27.1	-	-	-	-	-	99.0
08/16/97	-	27.1	-	-	-	-	-	26.2
04/23/99	-	21.0	-	-	-	-	-	153.0
04/22/99	-	26.3	-	-	-	-	-	77.8
06/01/99	-	17.7	-	-	-	-	-	101.8
08/02/01	4.3	24.4	1.2	1.5	4.3	0.7	1.3	86.0
08/25/01	4.3	12.6	0.9	1.8	3.0	0.5	0.0	68.3
10/13/01	-	8.4	0.3	1.7	2.4	0.3	0.1	41.4
04/7-9/02	-	24.0	1.6	2.2	4.6	0.2	3.8	30.0

*$CBOD_5$ was not measured for the Racine Avenue Pumping Station. This concentration was estimated as proportional to the measured BOD_5 concentration. The ratio of BOD_5 to $CBOD_5$ for the North Branch Pumping Station ($CBOD_5 = 0.65 \cdot BOD_5$) was used to estimate $CBOD_5$ at the Racine Avenue Pumping Station.
**Organic and inorganic phosphorous concentrations were calculated based on measured total phosphorous and suspended solids concentrations from the following equations: $P_{ORGANIC} = 0.7 * 0.025 * SS$
$P_{INORGANIC} = P_{TOTAL} - P_{ORGANIC}$.

Table 3.7 The mean values of the event mean concentrations in milligrams per liter for pumping stations discharging to the Chicago Waterway System

	Constituent	Average
North Branch Pumping Station	DO	4.0
	$CBOD_5$	35.4
	NH_4-N	2.9
	NO_3-N	0.7
	Org-N	6.1
	Org-P	1.0
	In-P	0.4
	TSS	102
Racine Avenue Pumping Station	DO	6.9
	$CBOD_5$	51.2
	NH_4-N	1.6
	NO_3-N	0.8
	Org-N	4.1
	Org-P	0.2
	In-P	0.7
	TSS	825
125th Street Pumping Station	DO	4.3
	$CBOD_5$	25.7
	NH_4-N	1.0
	NO_3-N	1.8
	Org-N	3.6
	Org-P	0.4
	In-P	1.3
	TSS	76

3.2.6 Boundaries

Three of the upstream boundaries for the water-quality model are near Lake Michigan: near the CRCW at the Chicago River at Columbus Drive, near the Wilmette Pumping Station at the North Shore Channel at Maple Avenue, and near O'Brien Lock and Dam on the Calumet River. Historic plots of data (1990-2004) show seasonal variations in water quality parameters at the CRCW at the Chicago River at Columbus Drive and near the Wilmette Pumping Station at the North Shore Channel at Maple Avenue and monthly variations at O'Brien Lock and Dam (Figures 3.7-3.9). The seasonal variations are related to the use of discretionary diversion during the late spring, summer, and early fall at CRCW and the Wilmette Pumping Station. Hence, seasonal and monthly average concentrations as listed in Table 3.8 are used for WY 2001 and 2003 simulations.

Table 3.8 Mean concentrations at the water-quality model boundaries near Lake Michigan for 1990-2004 (note: all constituents are in milligrams per liter except chlorophyll-a which is in micrograms per liter)

CRCW	$CBOD_5$	Chll-a	NH_4-N	NO_3-N	In-P	Org-N	Org-P	TSS
Fall	2.67	2.7	0.14	0.89	0.05	0.39	0.07	7.79
Winter	3.62	3	0.52	2.17	0.16	0.62	0.06	11.03
Spring	3.44	6.3	0.46	2.02	0.03	0.56	0.07	9.03
Summer	1.94	1.2	0.05	0.24	0.05	0.31	0.06	9.31
Wilmette	$CBOD_5$	Chll-a	NH_4-N	NO_3-N	TIP	TON	TOP	TSS
Fall	4.11	1.8	0.16	0.35	0.05	0.46	0.08	10.63
Winter	3.83	1.5	1.02	0.62	0.29	0.86	0.09	21.16
Spring	5.25	24.9	0.33	0.49	0.07	0.82	0.08	20.03
Summer	2.27	1.5	0.1	0.21	0.04	0.39	0.04	12.54
O'Brien Lock and Dam	$CBOD_5$	Chll-a	NH_4-N	NO_3-N	TIP	TON	TOP	TSS
October	3.3	5.4	0.1	0.3	0.1	0.4	0	12.1
November	2.5	5.4	0.2	0.4	0	0.4	0.1	12.6
December	4.7	6.9	0.2	0.5	0.1	0.4	0.1	12
January	4.3	13.5	0.3	0.6	0	0.5	0	9.7
February	3.7	11.4	0.4	0.7	0	0.6	0.1	20.8
March	4.8	13.8	0.4	0.8	0.1	0.7	0	13.6
April	3.5	8.7	0.4	1	0.2	0.9	0	13.9
May	4.8	6.6	0.3	0.9	0.3	0.6	0	12.2
June	1.5	5.4	0.1	0.5	0.7	0.5	0	9.6
July	2.5	9.3	0.1	0.3	0.1	0.4	0	8.4
August	4	6	0.1	0.3	0.1	0.3	0	10.7
September	3.7	4.8	0.1	0.3	0.1	0.3	0	9.1

* Mean concentrations for nitrogen compounds were calculated for the period of 1997-2004

** Hourly measured DO concentrations were used for the boundaries. Continuous hourly DO measurements are available on the Calumet River at 130th Street, North Shore Channel at Linden Street and the Chicago River at Columbus Drive

*** For Chlorophyll a only data from 2001 and 2004 were available

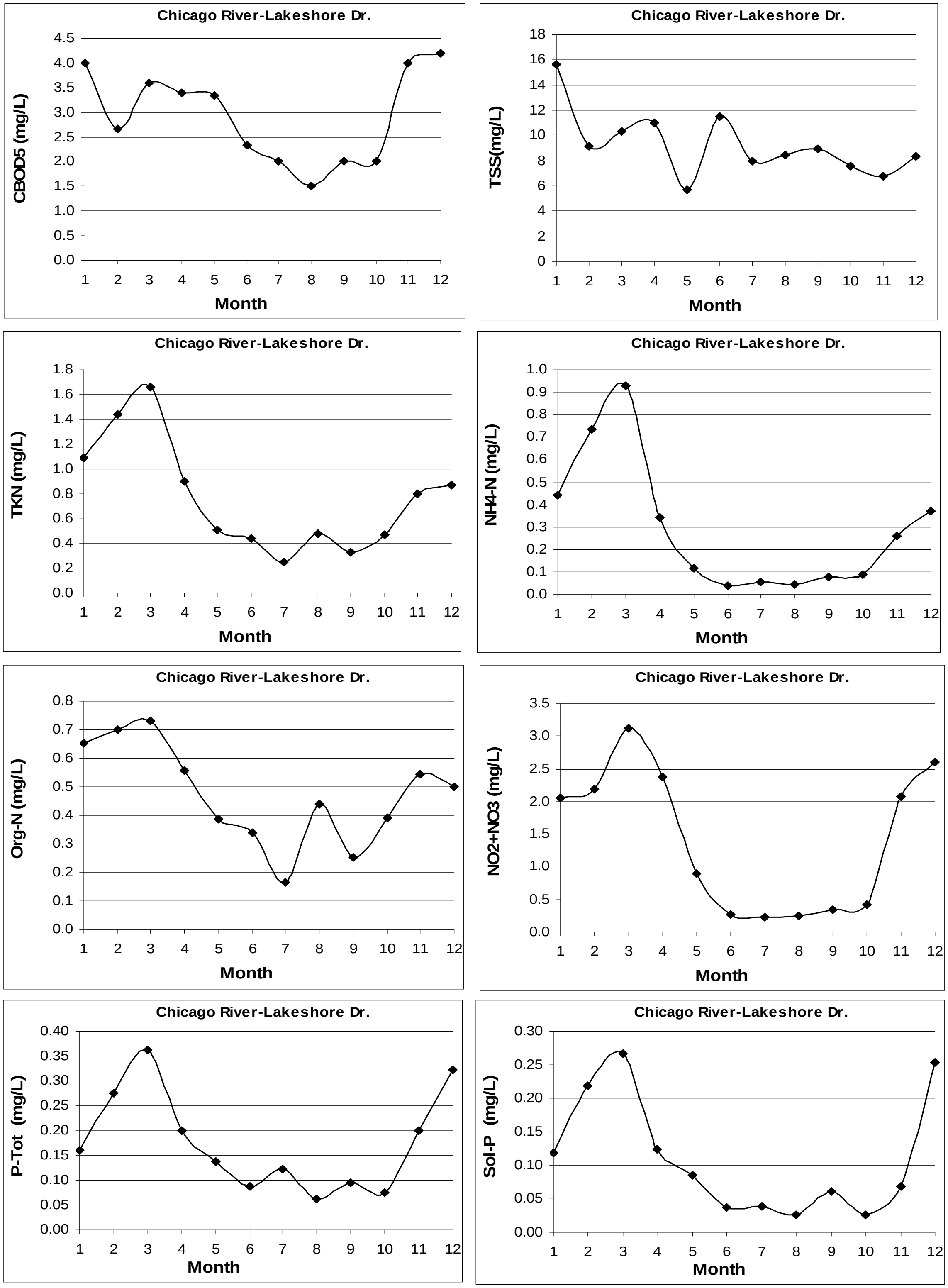


Figure 3.7 Monthly mean concentrations for the Chicago River Main Stem at Lake Shore Drive for 1997-2004 taken as representative of the boundary condition at Columbus Drive 0.3 mi downstream

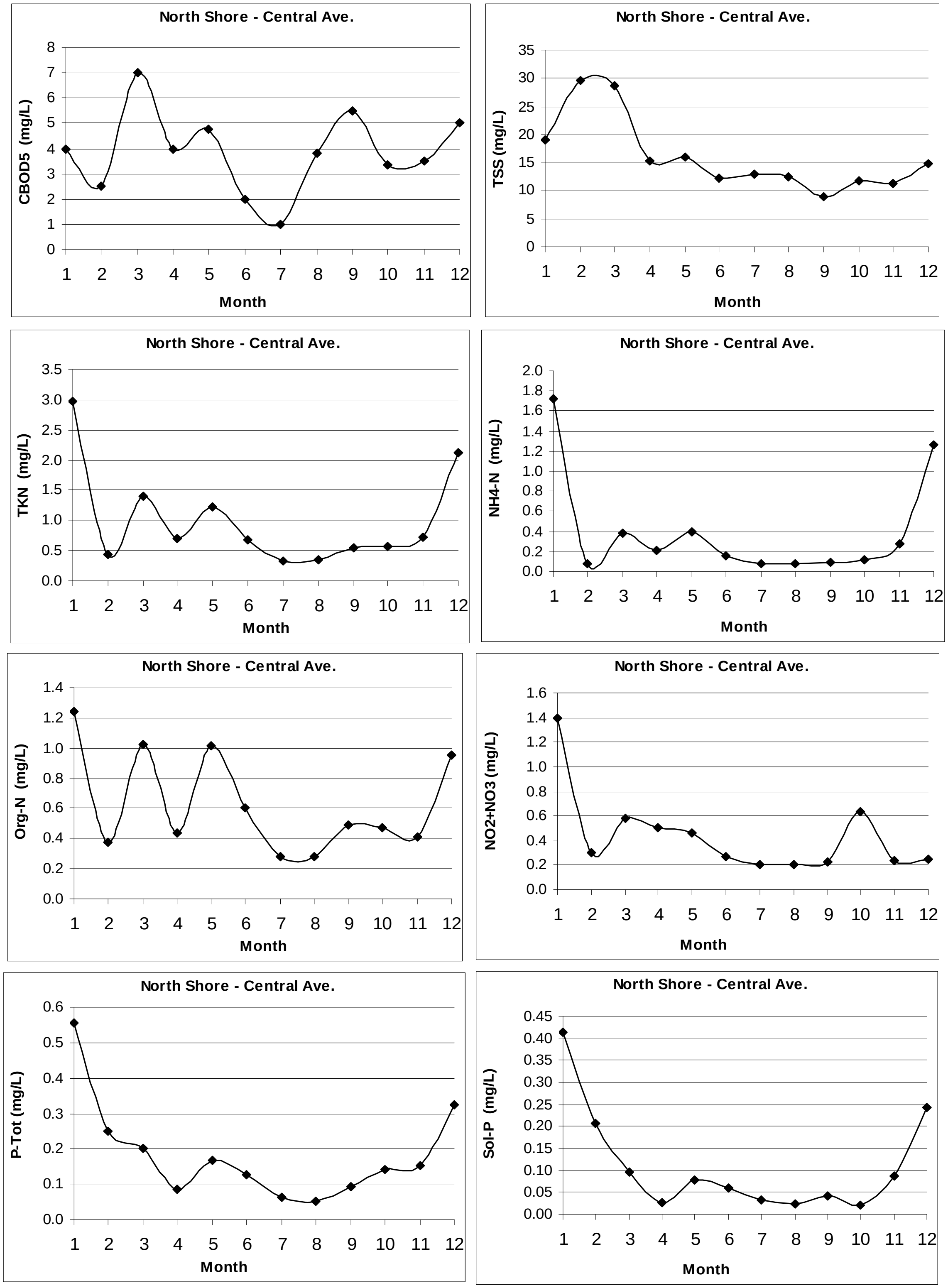


Figure 3.8 Monthly mean concentrations for the North Shore Channel at Central Avenue for 1990-2004 taken as representative of the boundary conditions at Maple Avenue 0.4 mi upstream

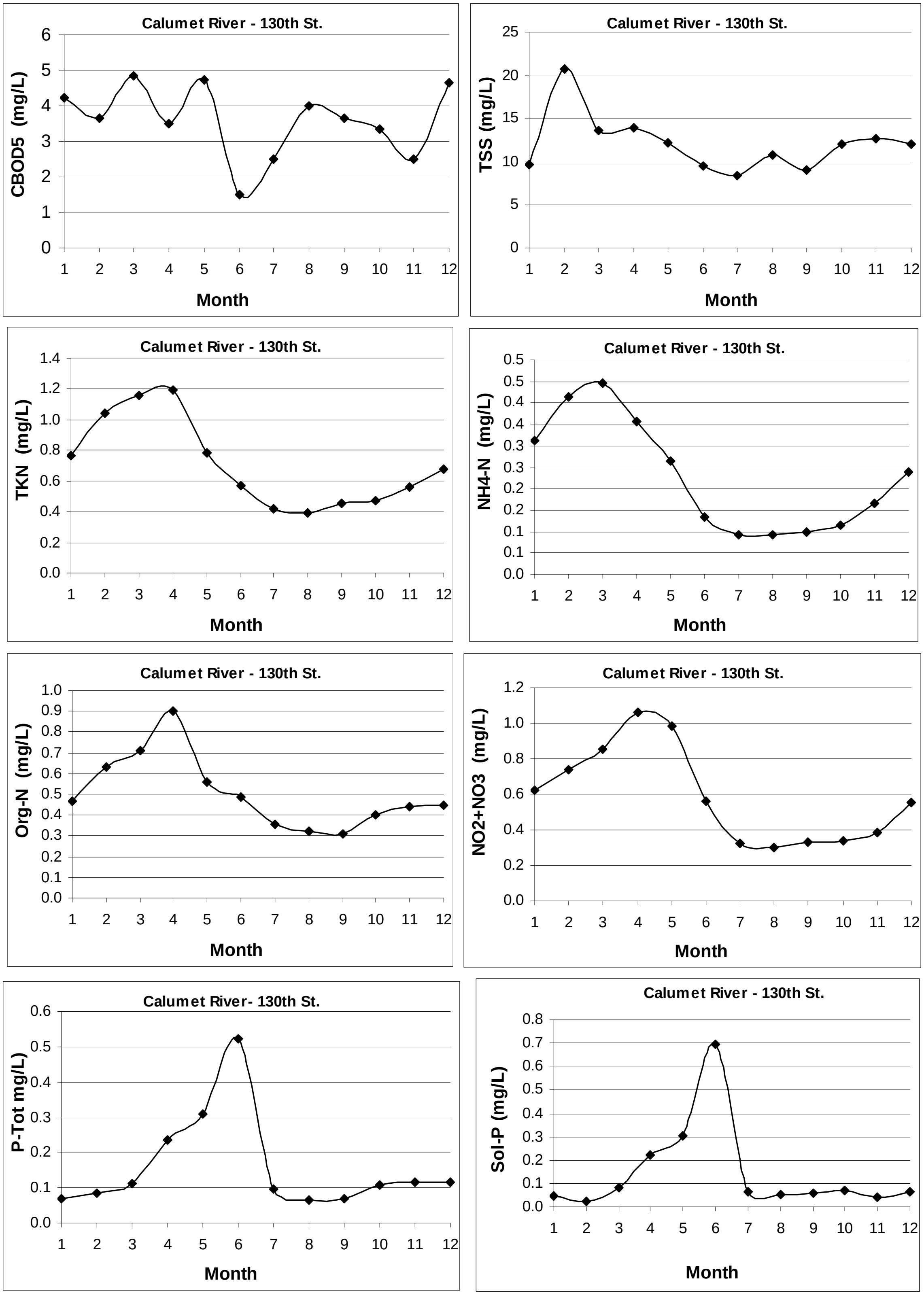


Figure 3.9 Monthly mean concentrations for the Calumet River at 130[th] Street for 1990-2004 taken as representative of the boundary condition at the O'Brien Lock and Dam 0.5 mi downstream

3.3 Initial Conditions

To start the computations, initial values for water-surface elevation and discharge, and all state variables (concentrations) are required by the DUFLOW model. Initial conditions are introduced for each DUFLOW point, i.e. each node (water quality and DO monitoring sites) or schematization points (discharge points). As stated in the DUFLOW manual (DUFLOW, 2000), the values can be based on historical measurements, obtained from former computations, or from a first reasonable guess.

Starting from upstream boundaries, initial conditions for discharge (1^{st} measurement of the simulation period) were introduced at each node by adding the cumulative flow as tributaries or treatment facilities discharge to the CWS. Water-surface elevation data provided by the MWRDGC (Southwest Highway, Western Avenue, Willow Springs Road, Sag Junction, and Lockport Controlling Works) and the USGS (Romeoville and upstream boundaries) were used to set initial conditions for water-surface elevation at each node by linear interpolation. Initial conditions for the water-quality constituents were introduced based on the water-quality measurements provided by the MWRDGC at several sampling locations. For DO concentrations the errors resulting from the assumed initial conditions are eliminated within a few hours. Default DUFLOW EUTROF2 sediment concentrations were used as initial conditions. Initial conditions, calculation nodes, and sections are provided in Appendix C.

3.4 Calibration of the Water-Quality Model

In this study, the preliminarily calibrated DUFLOW model (Alp and Melching, 2006) was adapted and improved to be used in the simulations of the Integrated Strategies to meet the proposed DO standards for the CWS. The improved DUFLOW water-quality model was first calibrated for WY 2001 and verified for WY 2003. Hydraulic improvements are explained in the previous sections. In addition to the hydraulic improvements, calibration of SOD also was improved. The EUTROF2 routines of DUFLOW include the DiToro and Fitzpatrick (1993) sediment flux model with a model of the water quality in the water column. This sediment flux model 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. In DUFLOW (2000), SOD is simulated as a diffusive exchange of oxygen between the water column and the active (top) sediment layer (which has its own CBOD, DO, nutrients, etc. in the pore water). In the previous DUFLOW model (Alp and Melching, 2006), SOD was calibrated based on a survey of sediment depth and composition conducted by the MWRDGC at 20 locations and measured DO concentrations in the CWS. In this study, SOD is recalibrated and compared with actual SOD values measured in 2001.

A total of 18 reaches are used in the current modeling study. Within these reaches computational nodes have been placed at intervals equal to or less than 1,640 ft (500 m) (Figure 3.10).

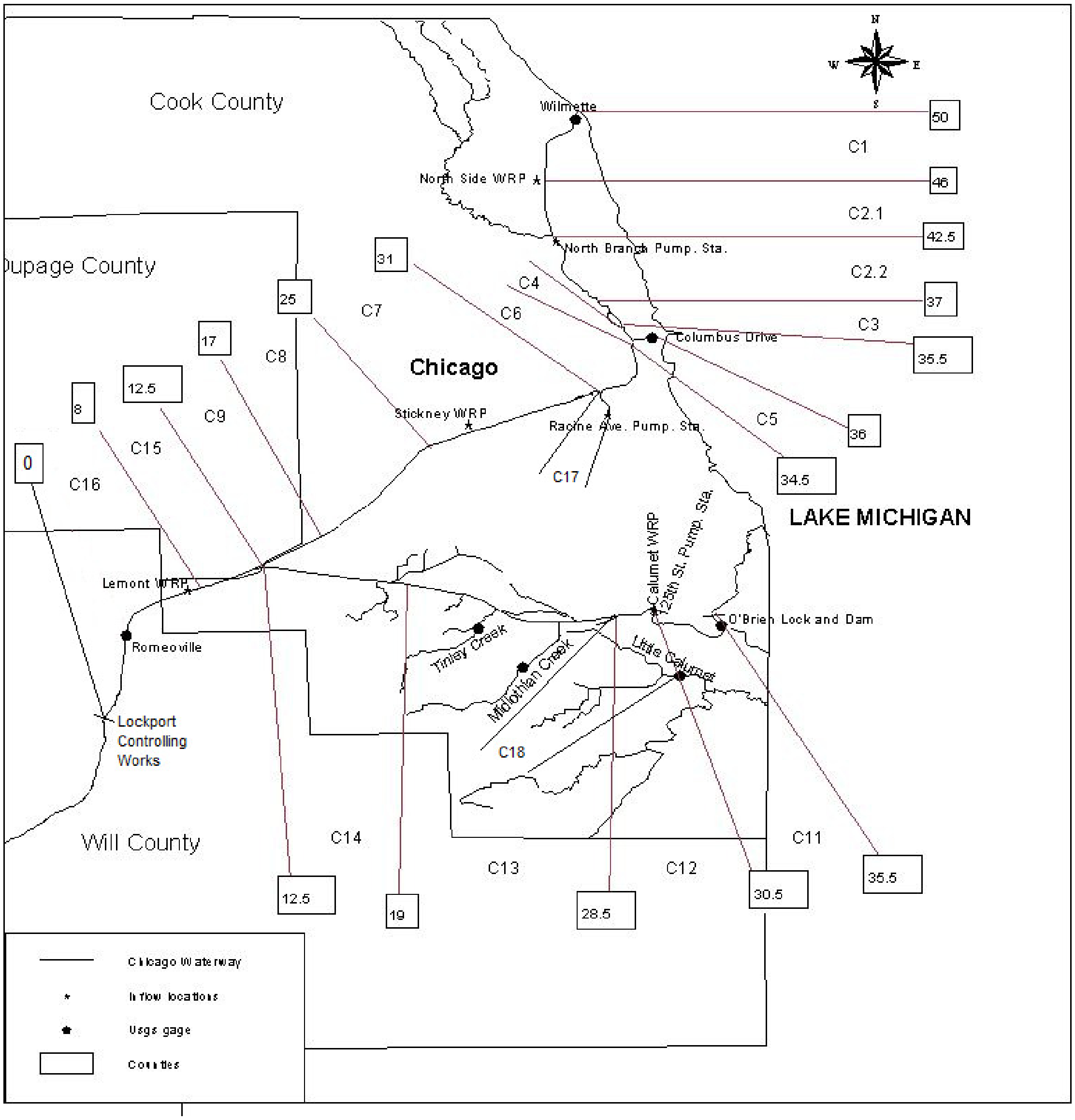


Figure 3.10 Chicago Waterway System reaches. The numbers in boxes are the river miles from the Chicago Sanitary and Ship Canal at Lockport Lock and Dam (note: the Little Calumet River (South) is the 18th reach; also the major Inflow Locations are denoted by stars and the USGS gages are denoted by pentagons)

In-Stream Water-Quality Data

The water-quality model was calibrated using monthly grab sample data at 19 locations and hourly DO concentration data at 25 locations in the CWS collected by the MWRDGC. The locations of water quality and DO sampling stations are listed in Table

3.9. The model was run with a 15-min. time step with a one-hour output time step for the period of WYs 2001 and 2003.

Temperature (^oC)

Temperature is one of the key variables because it affects reaction kinetics and the DO saturation concentration. The rate constant at a reference temperature of 20°C is multiplied by a coefficient, determining the change per °C difference from the reference temperature. In order to eliminate the bias that might result from usage of a constant temperature, hourly measured temperature values were introduced at each continuous monitoring location (node in the model). Therefore, temperature varies spatially and temporally in the water-quality model.

Model Parameters

The following parameters were set as space dependent (i.e. reach variable): Diffusive exchange rate constant for sediment (E_{dif}); nitrification rate constant (K_{nit}); $CBOD_5$ decay rate (K_{BOD}); dispersion (D); and the algal maximum growth (μ_{max}), die-off (k_{die}), and respiration rates (k_{res}). All other parameters had system wide values.

Diffusive exchange rate constant, E_{dif}, (m^2/day): Oxygen demand by benthic sediments and organisms has historically represented a large fraction of oxygen consumption in the CWS (CDM, 1992). SOD is the total result of all biological and chemical processes in sediment that utilize oxygen. The SOD in the EUTROF2 model is described by:

$SOD = E_{dif}/HB \times (O2_w - O2_B)$

where:

SOD = Sediment Oxygen Demand (g/m^2-d)

Table 3.9 Locations of the continuous monitoring and ambient water-quality sampling stations of the Metropolitan Water Reclamation District of Greater Chicago in the modeled portion of the Chicago Waterway System used for calibration

Station Location	Data Available	Waterway	River Mile*
Central Street	WQ	North Shore Channel	49.4
Simpson Street	DO	North Shore Channel	48.5
Main Street	DO	North Shore Channel	46.7
Oakton Street	WQ	North Shore Channel	46
Touhy Avenue	WQ	North Shore Channel	45.2
Foster Avenue	WQ	North Shore Channel	44
Wilson Avenue	WQ	North Branch Chicago River	41.6
Addison Street	DO	North Branch Chicago River	40.4
Diversey Parkway	WQ	North Branch Chicago River	39.2
Fullerton Avenue	DO	North Branch Chicago River	38.5
Division Street	DO	North Branch Chicago River	36.4
Grand Avenue	WQ	North Branch Chicago River	35
Kinzie Street	DO	North Branch Chicago River	34.8
Clark Street	DO	Chicago River Main Stem	34.9
Madison Street	WQ	South Branch Chicago River	34.3
Jackson Boulevard	DO	South Branch Chicago River	34
Loomis Street	WQ	South Branch Chicago River	30.8
Damen Avenue	WQ	Chicago Sanitary and Ship Canal	30
Cicero Avenue	DO, WQ	Chicago Sanitary and Ship Canal	26.2
Harlem Avenue	WQ	Chicago Sanitary and Ship Canal	22.9
Baltimore and Ohio Railroad	DO	Chicago Sanitary and Ship Canal	21.3
Route 83	DO, WQ	Chicago Sanitary and Ship Canal	13.1
Mile 11.6	DO	Chicago Sanitary and Ship Canal	11.6
Stephen Street	WQ	Chicago Sanitary and Ship Canal	9.4
Romeoville	DO	Chicago Sanitary and Ship Canal	5.1
Conrail Railroad	DO	Little Calumet River (North)	34.4
Central and Wisconsin Railroad	DO	Little Calumet River (North)	31.6
Indiana Avenue	WQ	Little Calumet River (North)	31.4
Halsted Street	DO, WQ	Little Calumet River (North)	29.1
Ashland Avenue	DO	Little Calumet River (South)	30.3
Ashland Avenue	WQ	Calumet-Sag Channel	28.1
Division Street	DO	Calumet-Sag Channel	27.6
Kedzie Avenue	DO	Calumet-Sag Channel	26.1
Cicero Avenue	DO, WQ	Calumet-Sag Channel	24
Harlem Avenue	DO	Calumet-Sag Channel	20.5
Southwest Highway	DO	Calumet-Sag Channel	19.7
104th Avenue	DO	Calumet-Sag Channel	16.3
Route 83	DO, WQ	Calumet-Sag Channel	13.3
Interstate 55 (I-55)	DO	Bubbly Creek	29.4

Notes: DO = Continuous (hourly) dissolved oxygen and temperature data;
WQ = Monthly grab sample water quality measurements

* River miles for the Chicago Waterway System often are described relative to the confluence of the Illinois River with the Mississippi River at Grafton, Ill., in this case the River Mile for Lockport is 291, and all of the values can have 291 added to them to give river mile values relative to the mouth of the Illinois River.

E_{dif} = Diffusive exchange rate constant (m^2/d)

HB = Depth of sediment top layer (m)

$O2_w$ = Water column DO concentration (mg/L)

$O2_B$ = DO concentration in the pore water in the sediment bed (mg/L)

A default initial value for $O2_B$ was used and then the value of $O2_B$ was computed over time throughout the simulation on the basis of the DO balance for the sediments, which is dominated by the E_{diff} values that have been calibrated to match, on average, the SOD values measured by the MWRDGC at 18 locations in the CWS in 2001.

$\underline{CBOD_5}$ water column oxidation rate and nitrification rate constant (day^{-1}): $CBOD_5$ decay and nitrification constants (k_{BOD} and k_{nit}) play important roles in water-quality models. Different values were determined for different reaches by calibration. Since the values of k_{BOD} and k_{nit} were determined in model calibration, it should be noted that the calibrated values have limited physical significance. That is, the rate constants were adjusted to fit measured bulk water quality data, and, thus, account for multiple processes that may affect the concentration of the individual water-quality constituents. Thus, one cannot automatically assume that a reach with a higher rate constant has more biological activity. That is, nitrification, CBOD decay, reaeration, SOD, algal activities, and hydraulic characteristics, such as diffusion, dispersion, and advection are some of the processes that have incremental effects on bulk water quality concentrations in the CWS. Since the constants that are related to these processes were not measured in the CWS, the rate constants in the DUFLOW model were adjusted to match the measured concentrations. Furthermore, there are other processes that were not considered in the calibration process and default values were assumed to represent the parameters affecting these processes. Therefore, there is a chance that effects of some processes are embedded in different parameters during the calibration process.

Dispersion, D, (m^2/s): The model requires entering a dispersion coefficient at each node. The value of the dispersion coefficient, D, either can be defined by the user or can be calculated using the properties of the flow. In this study, the dispersion coefficient has been calibrated based on the flow characteristics of a given reach in the CWS and the effects of dispersion on the DO in the CWS.

Reaeration rate coefficient, k_{aer}: In DUFLOW the reaeration rate coefficient is automatically calculated by the model using the O'Connor-Dobbins (1958) formula:

$$k=3.94*V^{0.5}/H^{1.5}$$

where k= reaeration rate coefficient, d^{-1}

V = Velocity, m/s

H = Water depth, m

In the earlier calibration of DUFLOW (Alp and Melching, 2006) it was necessary to change the multiplier from 3.94 to lower values to obtain a good match of the measured DO concentrations. However, in this study the recalibration of the SOD simulation comparing to measured SOD rates (Section 3.5.3) yielded the result that the standard O-Connor and Dobbins (1958) equation could be used throughout the CWS.

Algal Simulation Parameters: Algal maximum growth rate (μ_{max}), die-off rate (k_{die}), settling rate, and respiration rate (k_{res}) are the algal rate parameters used in the EUTROF2 routines of the DUFLOW model. Algal growth is limited by the availability of nutrients and light, and also is affected by temperature. Light intensity is related to incoming solar radiation, and, thus, hourly solar radiation data from Argonne National Laboratory was used as an input for the simulation. As previously explained temperature also varies spatially and temporally in the water-quality model. A default settling rate value was used in the calibration process.

Calibrated Model Parameters: The values of the diffusive exchange rate coefficient (E_{dif}), $CBOD_5$ water column oxidation rate (k_{bod}), nitrification rate constant (k_{nit}), dispersion coefficient (D), reaeration rate multiplier (k_{aer}), and algal parameters determined by calibration are listed in Table 3.10 for each reach. The differences in the algal growth and death rates between the Chicago River System and Calumet-Sag Waterway System reflect the elevated Chlorophyll-a concentrations measured in Calumet-Sag Waterway system. For all other model coefficients and parameters, default values given in EUTROF2 were used (see Appendix A).

Table 3.10 Reach variable calibration parameters used in the DUFLOW water-quality model for Water Years 2001 and 2003

Reach Name	Waterway	River Mile from Lockport	K_{bod} (day^{-1})	K_{nit} (day^{-1})	E_{dif} (m^2/day)	D (m^2/s)	μ_{max}	k_{die}	k_{res}
C1	North Shore Channel	50-46	0.15	1.2	0.014	25	1	0.05*	0.1*
C2.1	North Shore Channel	46-42.6	0.1	1.2	0.002	50	1	0.05*	0.1*
C2.2	North Branch	42.6-37	0.1	1.2	0.002	60	1	0.05*	0.1*
C3	North Branch	37-35.5	0.01	0.01	0.001	60	1	0.05*	0.1*
C4	North Branch	35.5-34.5	0.01	0.01	0.001	60	1	0.05*	0.1*
C5	Main Stem	34.5-36	0.01	0.01	0.0002*	10	1	0.05*	0.1*
C6	South Branch	34.5-31	0.1	1	0.005	60	1	0.05*	0.1*
C7	CSSC	31-25	0.15	1	0.004	1000	1	0.05*	0.1*
C8	CSSC	25-17	0.01	0.01	0	60	1	0.05*	0.1*
C9	CSSC	17-12.5	0.01	0.05	0	60	1	0.05*	0.1*
C15	CSSC	12.5-8	0.05	0.05	0	50	1	0.05*	0.1*
C16	CSSC	8-2.2	0.05	0.05	0	50	1	0.05*	0.1*
C11	Calumet and Little Calumet (N)	35.5-30.5	0.10	0.5	0.002**	15	1	0.2	0.1*
C12	Little Calumet (N)	30.5-28.5	0.1	0.5	0.004	15	1.5	0.2	0.1*
C13	Calumet-Sag	28.5-19	0.1	0.5	0.004	15	1.5	0.2	0.1*
C14	Calumet-Sag	19-12.5	0.1	0.5	0.004	10	1	0.2	0.1*
C17	Bubbly Creek		0.15	1.2	0.012	150	1	0.05*	0.1*
C18	Little Calumet (S)		0.035	0.3	0.002	15	1	0.05*	0.1*

* Default value (see Appendix A)
** Within Reach C11 the portion from O'Brien Lock and Dam to the junction with the Grand Calumet River has an E_{dif} value of 0.0002, which is the default value.

The typical ranges of parameter values from the water quality modeling literature for the parameters in Table 3.10 except for E_{dif} and D are listed as follows:

Parameter	Minimum	Maximum	Source
K_{bod} (day^{-1})	0.02	3.2	Brown and Barnwell (1987)
K_{nit} (day^{-1})*	0.1	1.0	Brown and Barnwell (1987)
μ_{max}	1.0	5.0	DUFLOW (2000)
k_{die}	0.0	0.3	DUFLOW (2000)
k_{res}	0.05	0.2	DUFLOW (2000)

*The ranges for QUAL2EU (Brown and Barnwell, 1987) are not strictly appropriate for DUFLOW because QUAL2EU considers the transformation of ammonia to nitrite to nitrate whereas in DUFLOW ammonia transforms directly to nitrate.

For Salt Creek in western Cook County and Eastern Du Page County, Illinois, in laboratory 20-day "bottle" measurements of CBOD indicated that K_{bod} ranged between 0.113 and 0.159 day^{-1} (Melching and Chang, 1996). Thus, the values applied in the

DUFLOW model of the CWS are generally within the ranges reported in the water-quality modeling literature.

Brown and Barnwell (1987) reported a value of D for the CSSC of 3 m^2/s and a range of D values from 4.6 to 1,480 m^2/s for rivers in the U.S. The values used in this study are higher than those found in the previous study considered in Brown and Barnwell (1987), but still within a reasonable range. The high value of 1,000 m^2/s in reach C7 reflects the intense mixing caused by discharge from the Racine Avenue Pumping Station.

Finally, no range information for E_{dif} is included in the DUFLOW (2000) user's manual, and, thus, comparisons to other studies cannot be done.

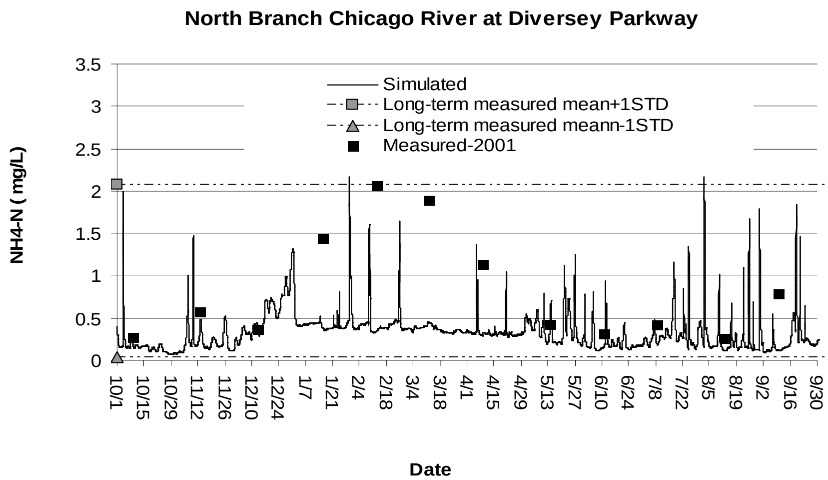
3.5 Calibration Results

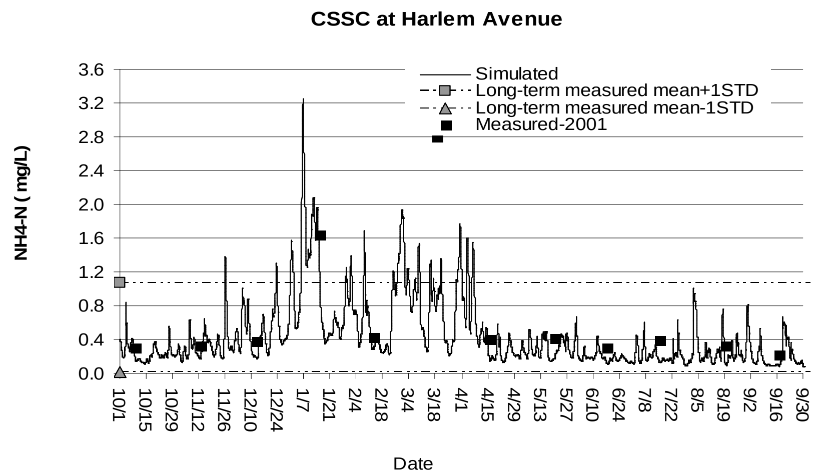
Calibration of the DUFLOW water quality model was conducted in a step-wise fashion. First, the simulated $CBOD_5$, ammonium, nitrate, and chlorophyll-a concentrations are compared with ranges of historic measurements. Then, simulated and measured hourly DO concentrations are compared at the 25 DO measurement locations. Finally simulated SOD values are compared with the SOD values measured in 2001. In the following sections calibration and verification results for WYs 2001 and 2003 are presented.

3.5.1 Biochemical Oxygen Demand, Ammonium, Nitrate, and Chlorophyll-a

When calculating the processes that affect DO in a stream system, DUFLOW also computes the concentration changes in space and time of $CBOD_5$, organic nitrogen, ammonium as nitrogen, nitrate nitrogen, total inorganic phosphorus, total organic phosphorus, suspended solids, and algal biomass species. The transformation of nitrite nitrogen to nitrate nitrogen is assumed to happen rapidly, and, thus, nitrite nitrogen is not explicitly simulated in DUFLOW. The MWRDGC collects monthly samples of $CBOD_5$ (at the request of this project), total Kjeldahl nitrogen, organic nitrogen, ammonium as nitrogen, nitrite plus nitrate nitrogen, chlorophyll-a, total phosphorus, soluble phosphorus, and total suspended solids among many other constituents (see for example, Abedin et al., 1999) at 19 locations in the simulated portion of the CWS (Table 3.9). Historical data were evaluated at each of the 19 locations to identify periods for which water-quality loading conditions at each location were similar to that of the study period. The details of the treatment of the historical data and calibration procedure are given in Alp and Melching (2004).

Adjustments were made to the $CBOD_5$ decay rate (k_{bod}) and nitrification rate (k_{nit}), such that the simulated $CBOD_5$, ammonium as nitrogen, and nitrate as nitrogen concentrations had similar spatial distributions throughout the CWS as for the long-term historic data. In this process, the simulated values of each constituent at each location were compared to the mean and one standard deviation confidence bounds determined from the measured values. The comparison was done graphically as shown, for example, in Figures 3.11-3.14 for ammonium as nitrogen and $CBOD_5$, respectively, to determine if the model was yielding unusually high or low concentrations, and if so, to determine a cause for these concentrations. It should be noted that for ammonium as nitrogen at some locations shown in Figure 3.11 the mean minus one standard deviation confidence bound results in a negative concentration. Figures 3.11-3.14 show that simulated hourly $CBOD_5$ and ammonium as nitrogen concentrations are inside the one standard deviation confidence bounds for most of the simulation period except for storm periods. During storm periods $CBOD_5$ concentrations increase and can reach values higher than the upper confidence bound. The monthly samples are predominantly composed of samples taken during low flow, and, thus, concentrations above the upper confidence bound were expected because of high pollution loads coming from CSOs during storms. In Figures 3.11 and 3.13, a limited number of ammonium as nitrogen concentration and $CBOD_5$ concentrations measured during the calibration period (WY 2001) are also shown. It can be seen that the model predicted most of the measured concentrations with reasonable accuracy for WY 2003 (Figures 3.12 and 3.14). Thus, the calibrated and verified simulation results do not yield any unusually high or low constituent concentrations. The values of k_{bod} and k_{nit} then were slightly modified in the calibration for the hourly DO concentrations.





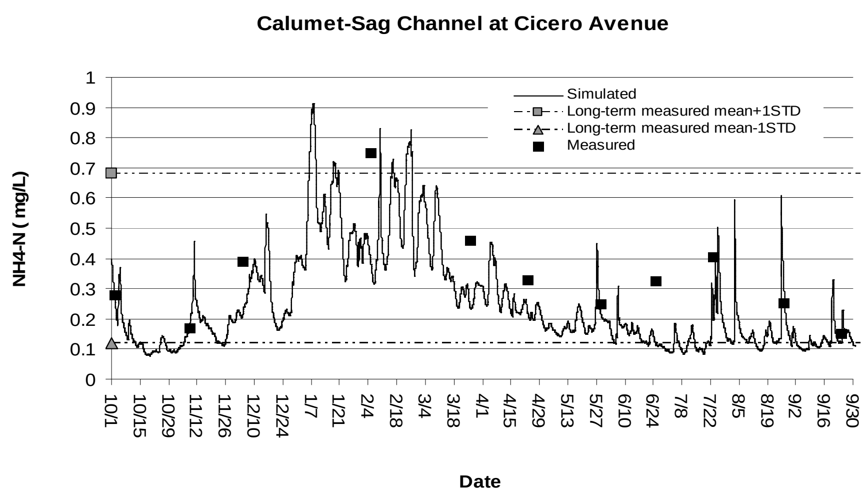


Figure 3.11 Comparison of long term (1997-2004) measured mean plus or minus one standard deviation, measured, and simulated hourly ammonium as nitrogen (NH4-N) concentrations at different locations in the Chicago Waterway System for Water Year 2001

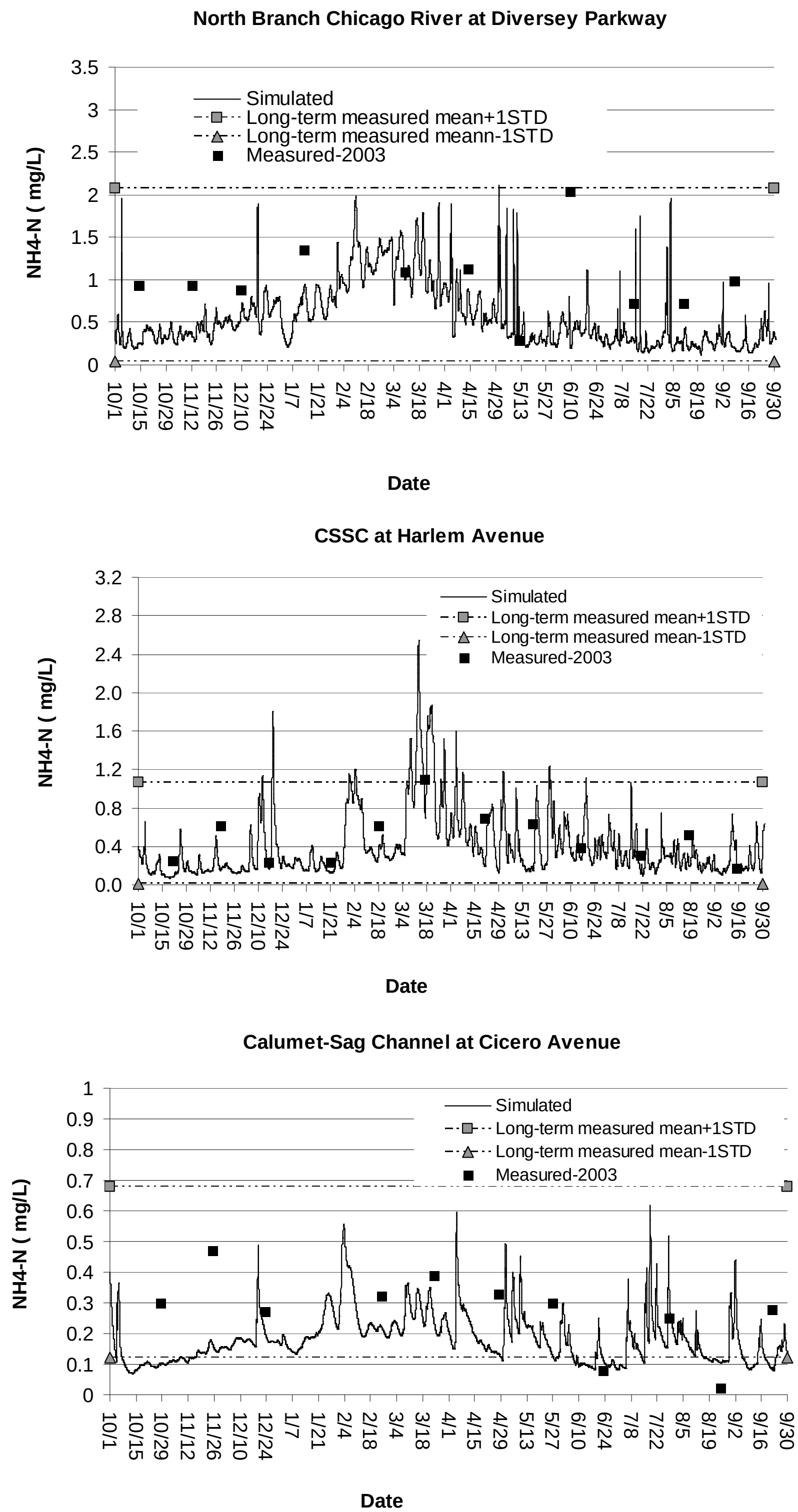


Figure 3.12 Comparison of long term (1997-2004) measured mean plus or minus one standard deviation, measured, and simulated hourly ammonium as nitrogen (NH4-N) concentrations at different locations in the Chicago Waterway System for Water Year 2003

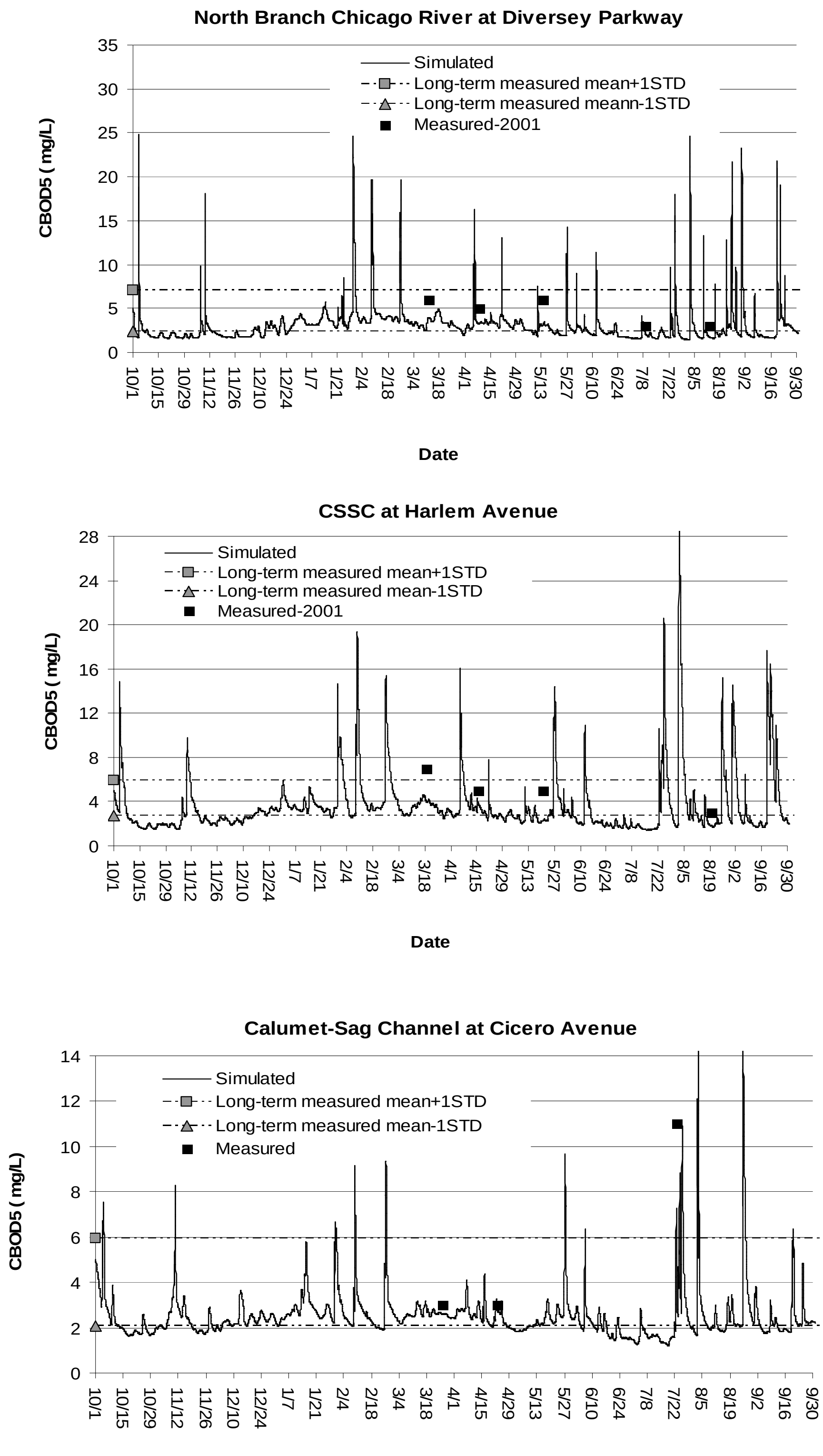


Figure 3.13 Comparison of long term (1997-2004) measured mean plus or minus one standard deviation, measured, and simulated hourly carbonaceous biochemical oxygen demand (CBOD5) concentrations at different locations in the Chicago Waterway System for Water Year 2001

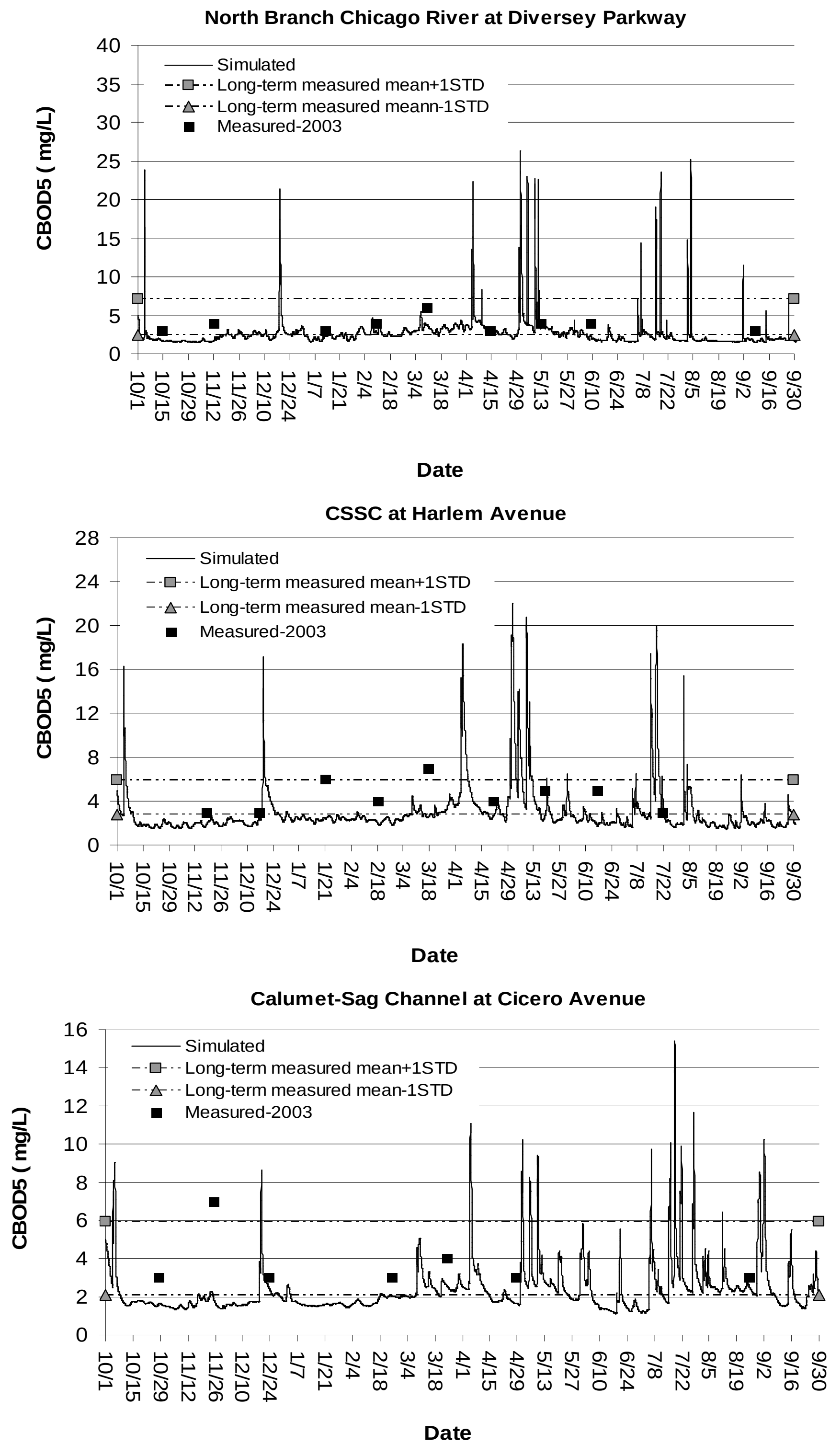


Figure 3.14 Comparison of long term (1997-2004) measured mean plus or minus one standard deviation, measured, and simulated hourly carbonaceous biochemical oxygen demand (CBOD5) concentrations at different locations in the Chicago Waterway System for Water Year 2003

Figures 3.15-3.20 compare the mean of the simulated concentrations with the mean and one standard deviation confidence bounds of the measured historic data for $CBOD_5$, ammonium as nitrogen, and nitrate as nitrogen, respectively. The comparison is shown for trajectories along the (a) NSC, NBCR, SBCR, and CSSC [the Chicago River System], and (b) the Calumet River, Little Calumet River (North), and Calumet-Sag Channel [the Calumet-Sag Waterway System].

The mean of the simulated $CBOD_5$ concentration is substantially outside the one standard deviation confidence bounds for the long-term measurements at just one location on the lower NSC for WY 2001 (Figure 3.15) and three locations on the lower NSC and upper NBCR for WY 2003 (Figure 3.16). All simulated mean $CBOD_5$ concentrations (Figures 3.15 and 3.16) are within $\pm$ 1 standard deviation of the long-term measured concentrations in the Calumet-Sag Waterway System except at Route 83. Carbonaceous BOD decay occurs very slowly in most of the CWS.

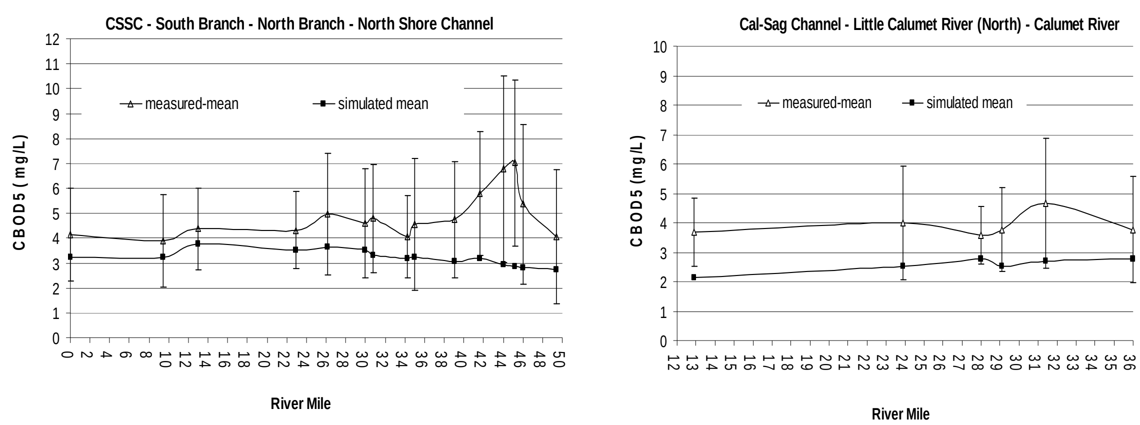


Figure 3.15 Comparison of long-term (1997-2004) measured mean (plus or minus one standard deviation) and simulated mean carbonaceous biochemical oxygen demand (CBOD5) concentrations in the Chicago Waterway System for Water Year 2001

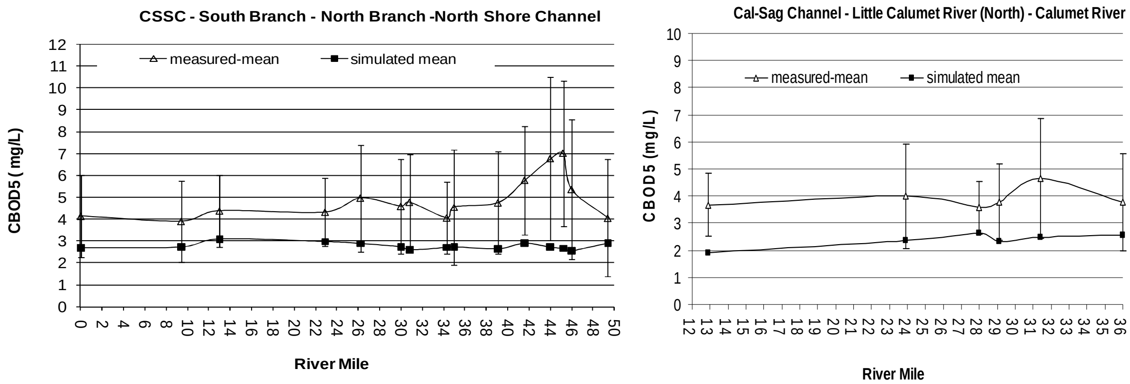


Figure 3.16 Comparison of long-term (1997-2004) measured mean (plus or minus one standard deviation) and simulated mean carbonaceous biochemical oxygen demand (CBOD5) concentrations in the Chicago Waterway System for Water Year 2003

Calibration was done for three forms of nitrogen: organic, ammonium, and nitrate all as nitrogen. Calibrated ammonium as nitrogen and nitrate as nitrogen results are shown in Figures 3.17-3.20. Although the mean of the simulated ammonium as nitrogen concentrations are lower than the mean of the measured ammonium as nitrogen concentrations, they are still within the 1 standard deviation confidence bounds at most of the locations. Nitrate nitrogen concentrations increase just after the WRPs. The monthly mean nitrate as nitrogen concentrations for the Calumet River at 130th Street for 1990-2004 taken as representative of the boundary condition at the O'Brien Lock and Dam 0.5 mi downstream as shown in Figure 3.19. Considering the large difference between the simulated and measured concentrations at O'Brien Lock and Dam, it is likely that the 130th Street data are more reflective of Lake Michigan than the Calumet River at O'Brien Lock and Dam where the nitrate as nitrogen concentrations are affected by flows from the Calumet WRP. At other locations the simulated and measured nitrate as nitrogen concentrations show similar trends in the modeled portion of the CWS.

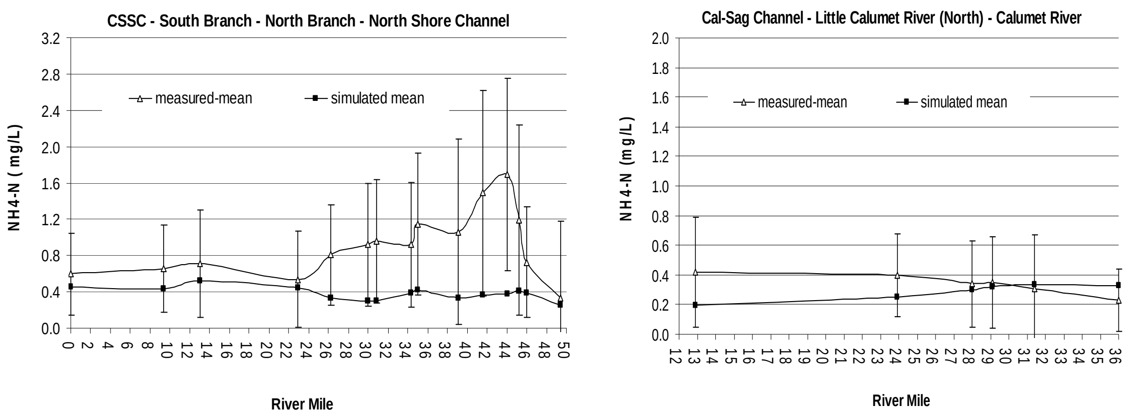


Figure 3.17 Comparison of long-term measured mean (plus or minus one standard deviation) and simulated mean ammonium as nitrogen (NH4-N) concentrations in the Chicago Waterway System for Water Year 2001

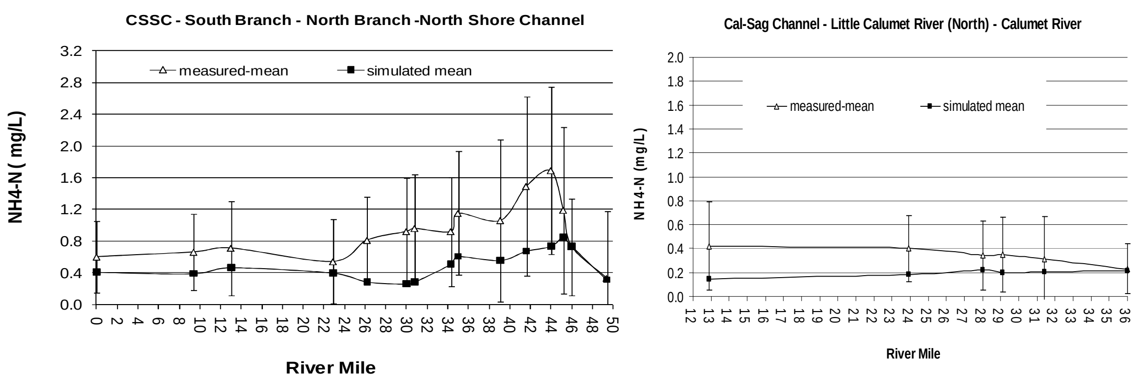


Figure 3.18 Comparison of long-term measured mean (plus or minus one standard deviation) and simulated mean ammonium as nitrogen (NH4-N) concentrations in the Chicago Waterway System for Water Year 2003

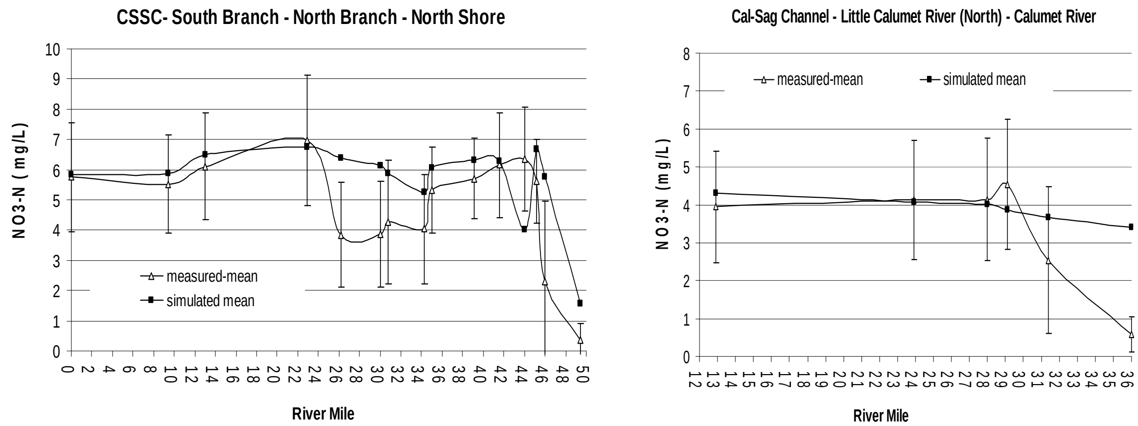


Figure 3.19 Comparison of long-term measured mean (plus or minus one standard deviation) and simulated mean nitrate as nitrogen (NO3-N) concentrations in the Chicago Waterway System for Water Year 2001

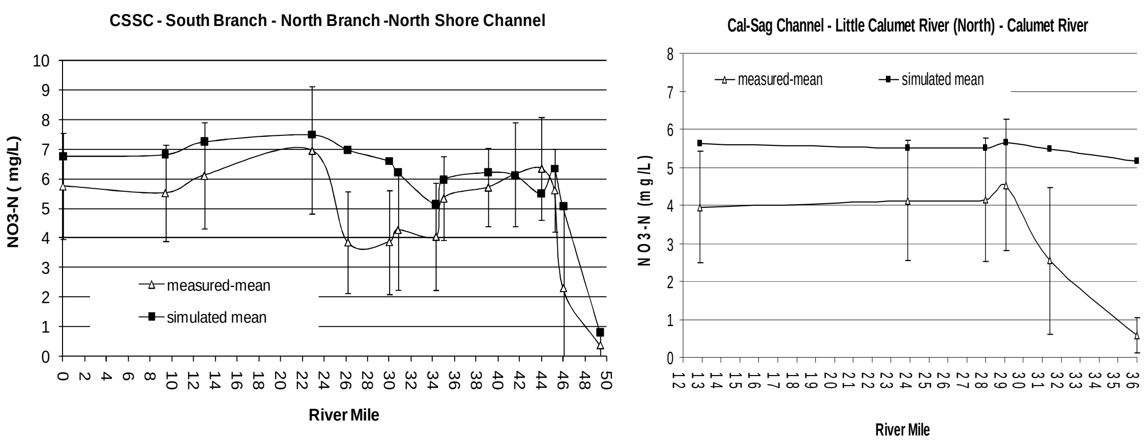


Figure 3.20 Comparison of long-term measured mean (plus or minus one standard deviation) and simulated mean nitrate as nitrogen (NO3-N) concentrations in the Chicago Waterway System for Water Year 2003

Calibrated chlorophyll-a results are shown in Figures 3.21-3.24. The limited number of data makes it difficult to calibrate and test the power of model for this constituent. But it is still possible to make some comments based on Figures 3.21 and 3.22. As can be seen from Figures 3.21 and 3.22, even though the simulated chlorophyll-a concentrations along the CSSC are lower than measured concentrations, they follow the general pattern of the measured concentrations closely. Since there is no major algae problem along the CSSC, underestimation of chlorophyll-a concentrations did not cause any problem with the DO simulation. On the other hand, high chlorophyll-a concentrations are observed along the Calumet-Sag Channel especially in the summer months of 2003. For this reason more effort was put on the calibration of chlorophyll-a concentrations along the Calumet-Sag Channel. As can be seen in Figures 3.23 and 3.24, simulated chlorophyll-a concentrations fluctuate within the 1 standard deviation confidence bounds except for Indiana Avenue (river mile 31.4) on the Little Calumet River (North). The model underestimated chlorophyll-a concentrations at this location whereas 1 of the 2 measured chlorophyll-a concentrations is also lower than the lower confidence bound and one of the measured chlorophyll-a concentrations are within the confidence bound in WY 2001 (Figure 3.23). The big difference between the measured and simulated chlorophyll-a concentrations at Indiana Avenue suggests the possibility of algal blooms at this location. Chlorophyll-a concentrations measured at all locations on Calumet River System are higher in WY 2003 than in WY 2001 and extreme fluctuations are observed at all locations in the Calumet River System in WY 2003. For example, measured chlorophyll-a concentration at Route 83 reaches from 28 μg/L in May 2003 to 92 μg/L in June 2003 (Figure 3.24). Since these high chlorophyll-a concentrations are also higher than the upper one-standard deviation confidence bound, it was difficult to match extreme chlorophyll-a fluctuations with the model.

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

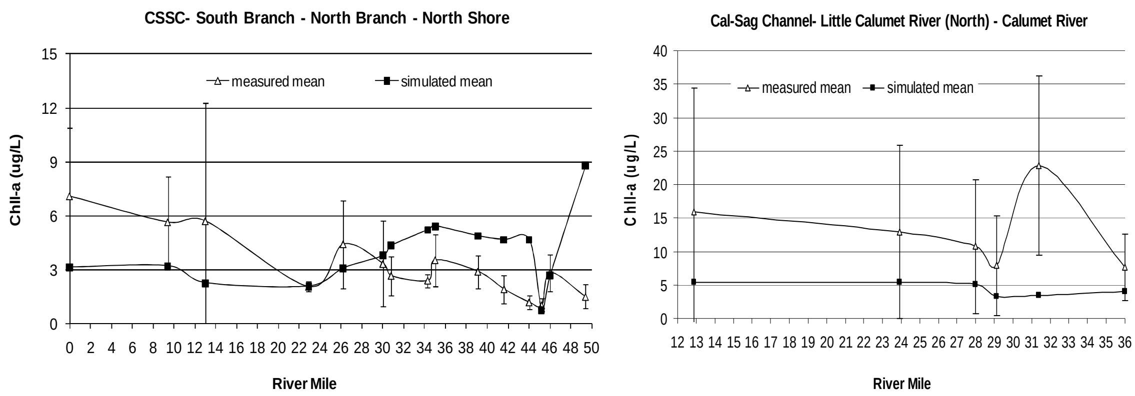


Figure 3.21 Comparison of simulated mean and measured mean (plus or minus one standard deviation) chlorophyll-a concentrations in the Chicago Waterway System for Water Year 2001

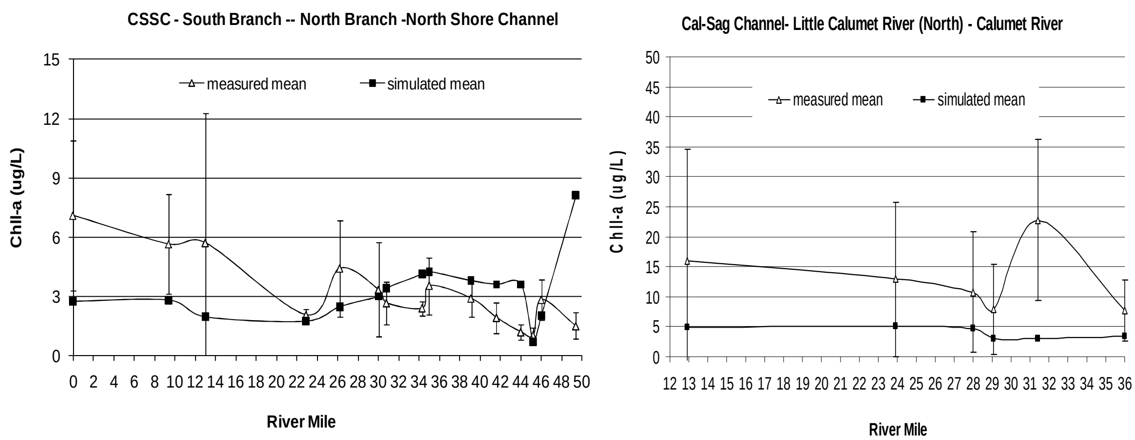


Figure 3.22 Comparison of simulated mean and measured mean (plus or minus one standard deviation) chlorophyll-a concentrations in the Chicago Waterway System for Water Year 2003

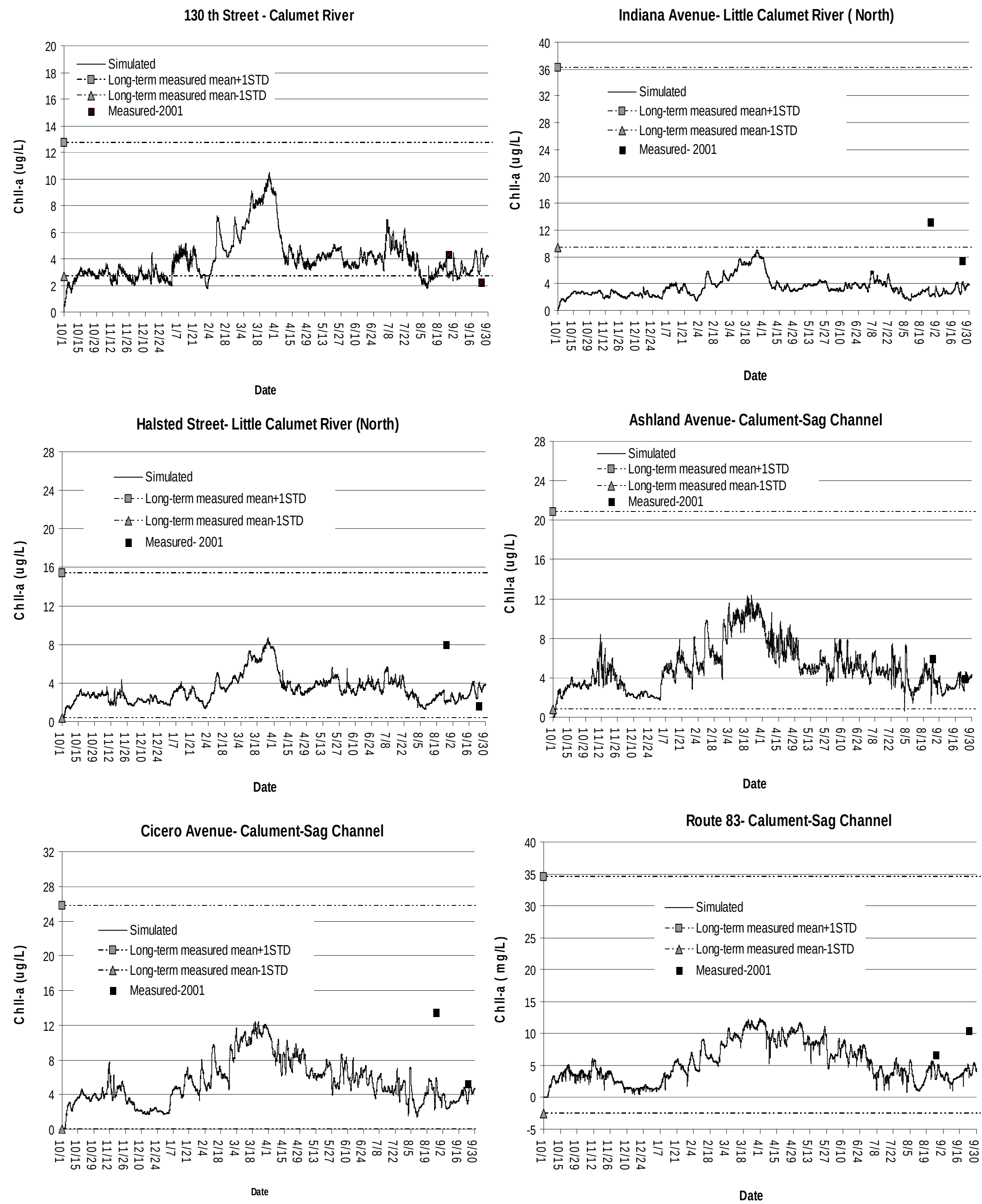


Figure 3.23 Comparison of measured mean plus or minus one standard deviation, measured, and simulated hourly chlorophyll-a concentrations in the Calumet River, Little Calumet River (North) and the Calumet Sag Channel for Water Year 2001. (note: 130th Street is upstream of O'Brien Lock and Dam and is used as a surrogate for concentrations at O'Brien Lock and Dam).

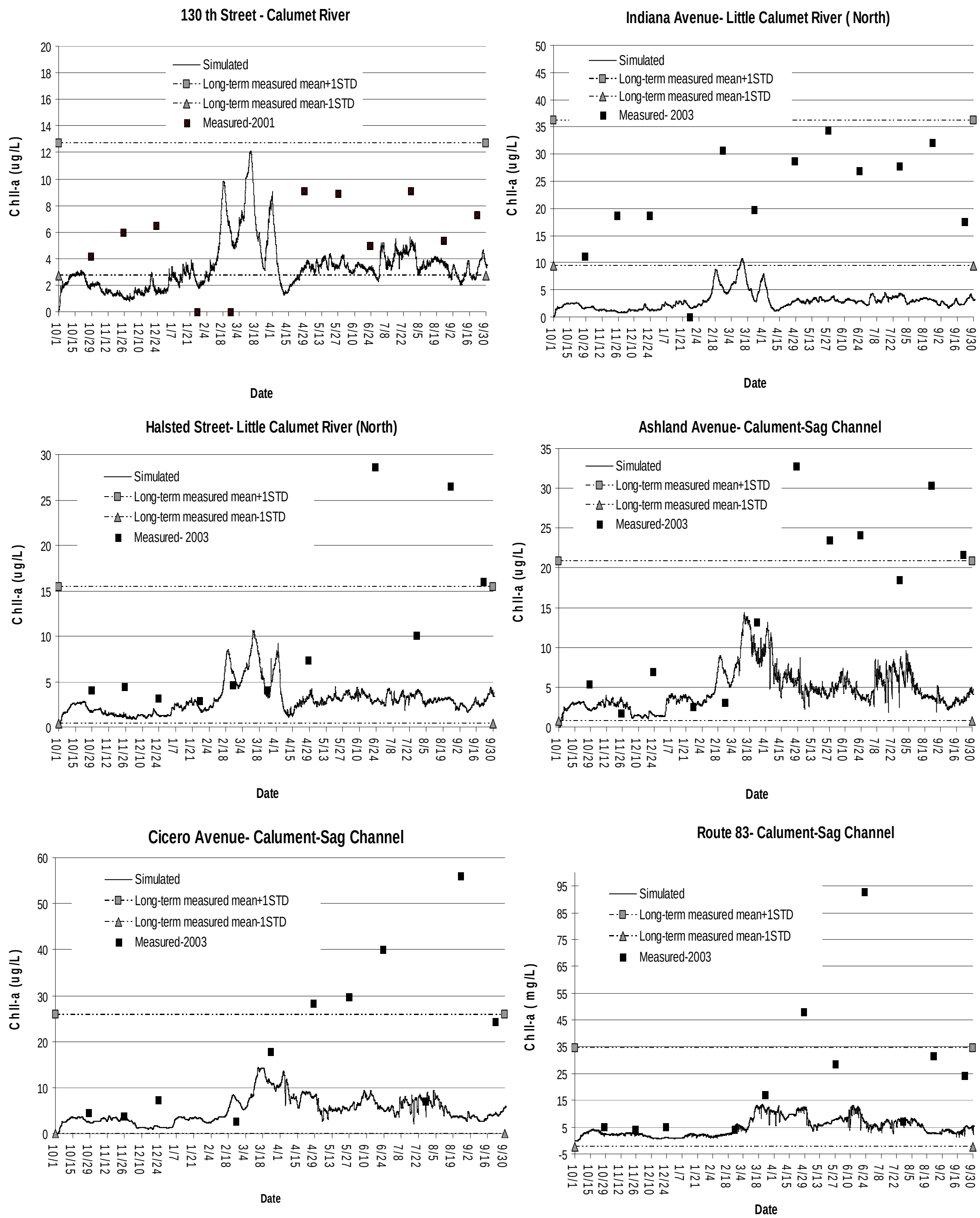


Figure 3.24 Comparison of measured mean plus or minus one standard deviation, measured, and simulated hourly chlorophyll-a concentrations in the Calumet River, Little Calumet River (North) and the Calumet Sag Channel for Water Year 2003. (note: 130th Street is upstream of O'Brien Lock and Dam and is used as a surrogate for concentrations at O'Brien Lock and Dam).

3.5.2 Dissolved Oxygen Concentration

Simulated DO concentrations were compared with hourly measured DO concentrations at 25 locations for WYs 2001 and 2003. Results are presented in 4 categories: NBCR, SBCR and CSSC, Calumet-Sag Channel, and boundaries (this includes DO monitoring sites on the NSC, Chicago River Main Stem, Bubby Creek, Little Calumet River (South) and Little Calumet River (North) upstream of the Calumet WRP).

In the following subsections, the quality of the DO simulation for WYs 2001 and 2003 are listed by season and over the entire year. For the locations in the Chicago River Main Stem (Michigan Avenue and Clark Street) and nearby locations on the NBCR (Kinzie Street) and SBCR (Jackson Boulevard) the differences in simulated and measured concentrations are particularly large for winter periods. Bi-directional/stratified flow occurs in the Chicago River Main Stem during periods without discretionary diversion (late October to early May), particularly in winter. Research suggests that this may be caused by the use of salt for road de-icing, which could lead to an increase in salinity in the NBCR (Jackson et al., 2008). Garcia et al. (2007) reported the results of monitoring for bi-directional flow resulting from density currents in and near the Chicago River Main Stem during the period from November 20, 2003 to February 1, 2004. They found that during the observation period 28 density current events occurred lasting a total of 77% of the time. Sixteen of these events were generated by underflows from the NBCR and 12 of these events were generated by overflows from the NBCR. Further, Jackson et al. (2008) noted that the underflow events were driven by differences in salinity and overflows were driven by differences in temperature. Finally, Garcia et al. (2007) noted that plunge point for the density currents can be upstream of Grand Avenue (which is upstream of Kinzie Street) and that the overflow events may propagate into the SBCR. Garcia et al. (2006) noted that the greater the density difference, the farther upstream on the NBCR the plunging point is observed.

The DUFLOW model is a one-dimensional model that assumes complete mixing over a cross section, and as such it cannot simulate the details of the stratified flow. However, the DO concentrations obtained by simulation in the winter (and also in the late fall and early spring) reflect the total pollution load in the cross section whereas the measured DO concentrations only reflect the surface layer which has higher DO concentrations because of the contact with the atmosphere. Thus, the poor agreement between the measured and simulated DO concentrations in the winter (and other times with stratified flows) in and near the Chicago River Main Stem are a result of the physics of flows in the CWS.

3.5.2.1 North Branch Chicago River

DO concentrations on the NBCR were calibrated starting from upstream to downstream locations. This section of the CWS is divided into 3 reaches and the following continuous DO stations represent each reach: i) Addison Street and Fullerton Avenue, ii) Division Street, and iii) Kinzie Street. A statistical comparison between seasonally averaged hourly simulated and measured DO concentrations is listed in Tables 3.11 and 3.12, where fall is defined as September-November, winter is defined as December-February, spring is defined as March-May, and summer is defined as June-August. In all cases, the average percent error is less than 10 % indicating unbiased estimates of DO concentrations are obtained throughout these reaches.

Table 3.11 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Branch Chicago River, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

Season	Addison Street			Fullerton Avenue			Division Street			Kinzie Street		
	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	6.4	6.5	0.1	5.7	6.4	0.7	6.2	6.7	0.5	6.0	6.6	0.6
Winter	7.9	7.3	-0.6	7.3	6.7	-0.6	7.4	6.4	-1.0	7.0	6.3	-0.7
Spring	7.0	7.2	0.2	6.1	6.7	0.6	6.2	6.8	0.6	6.2	6.6	0.4
Summer	5.9	5.6	-0.3	4.6	5.2	0.6	5.7	5.6	-0.1	5.2	5.4	0.2
Overall Average	6.8	6.6		5.9	6.3		6.4	6.4		6.1	6.2	
Error	-0.2			0.3			0.0			0.1		
% Error	-2.5			5.7			0.0			2.1		

Table 3.12 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Branch Chicago River, Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

Season	Addison Street			Fullerton Avenue			Division Street			Kinzie Street		
	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. Mg/L	Sim. mg/L	error mg/L
Fall	6.4	6.4	0.0	5.8	6.1	0.3	6.3	6.2	-0.1	5.8	6.1	0.3
Winter	7.7	6.7	-1.1	7.1	5.9	-1.2	7.4	5.6	-1.7	7.3	5.5	-1.8
Spring	7.1	6.5	-0.7	6.0	5.8	-0.1	6.4	5.8	-0.6	6.2	5.6	-0.6
Summer	6.3	5.9	-0.4	4.8	5.6	0.8	5.7	6.4	0.7	4.9	6.2	1.3
Overall Average	6.9	6.4		5.9	5.8		6.4	6.0		6.0	5.8	
Error	-0.5			-0.1			-0.4			-0.2		
% Error	-7.8			-0.9			-6.6			-3.1		

The Addison Street DO monitoring site is the first station at which the combined effects of the upper NBCR flow, North Side WRP flow, and the Devon Avenue in-stream aeration station are observed.

Figure 3.25 shows good agreement between the simulated and measured DO concentrations especially at both Addison Street and Fullerton Avenue. The average percent error in the simulated hourly average DO concentrations is -7.8 % at Addison Street in Water Year 2003. The general trend of DO concentration fluctuations throughout the simulation periods is well captured at Fullerton Avenue. The highest error between the seasonally averaged values of the simulated and the measured DO concentrations are observed for winter months. The model tends to underestimate the DO concentrations in winter months with the seasonally averaged errors of -1.1 and -1.2 mg/L for WY 2003 for Addison Street and Fullerton Avenue, respectively. The seasonally averaged error for summer in which the lowest DO concentrations are measured is less than 0.8 mg/L for both locations.

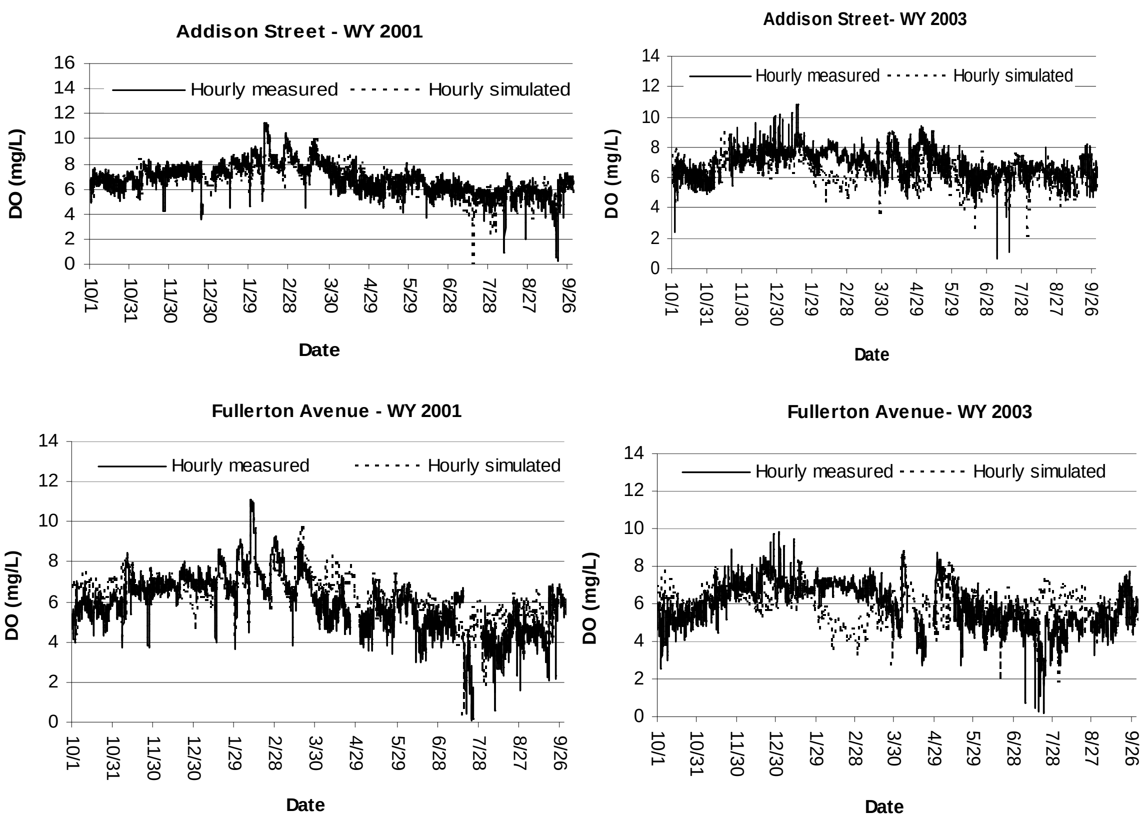


Figure 3.25 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Addison Street and Fullerton Avenue on the North Branch Chicago River for Water Years 2001 and 2003

Division Street is the first DO monitoring station downstream from the Webster Avenue in-stream aeration station. The Webster Avenue aeration facility causes a significant DO increase at downstream locations. Comparison of simulated and measured DO values at Division Street is shown in Figure 3.26.

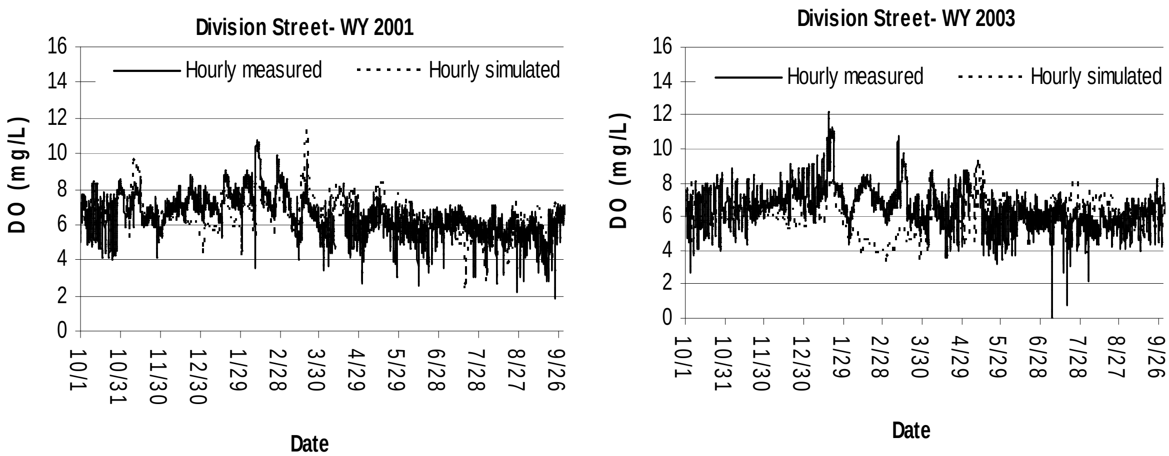


Figure 3.26 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Division Street on the North Branch Chicago River for Water Years 2001 and 2003

Measured and simulated DO concentrations at Division Street (Figure 3.26) are in close agreement for most of the simulation period except for winter months in 2003. The particularly poor results for the winter months of 2003 (at Division Street and other points downstream of the North Side WRP) are the result of calibration problems due to missing ammonium as nitrogen effluent data for January 1 to April 30, 2001 described in detail in Section 4.2. The overall average simulated and measured hourly DO concentrations are 6.4 mg/L and 6.0 mg/L, respectively, and the overall average error is less than 6.6 % for Water Year 2003.

Kinzie Street is the last DO station on the NBCR. It is located 0.2 mi upstream from NBCR junction with the Chicago River Main Stem and SBCR. Very low DO concentrations are observed especially during the storm periods in spring and summer months (Figure 3.27). The average simulated and measured DO concentrations for Summer 2001 are 5.2 mg/L and 5.4 mg/L, respectively and the error between the seasonally averaged DO concentrations for summer months is 1.3 mg/L for WY 2003 .

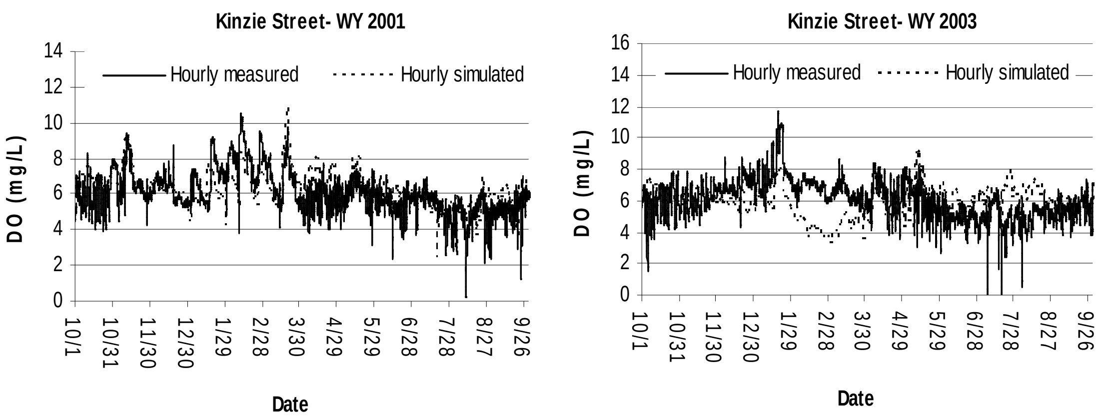


Figure 3.27 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Kinzie Street on the North Branch Chicago River for Water Years 2001 and 2003

3.5.2.2 South Branch Chicago River and Chicago Sanitary and Ship Canal (CSSC)

Since all locations are linked to each other, the approach of first calibrating upstream locations did not work in the SBCR and CSSC section of the river system. This section is divided into 6 reaches and the following DO stations represent each reach: i) Jackson Boulevard, ii) Cicero Avenue, iii) Baltimore and Ohio Railroad, iv) Route 83, v) River Mile 11.6, and vi) Romeoville. A statistical comparison between seasonally averaged simulated and measured hourly DO concentrations is listed in Tables 3.13 and 3.14. In all cases the average percent error is less than 13 % indicating unbiased estimates of DO concentrations are obtained throughout these reaches.

Table 3.13 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the South Branch Chicago River and Chicago Sanitary and Ship Canal, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Jackson Boulevard			**Cicero Avenue**			**Baltimore and Ohio RR**			**Route 83**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	6.0	6.4	0.3	4.9	5.1	0.3	6.4	6.1	-0.3	5.4	5.8	0.4
Winter	7.1	5.9	-1.2	7.2	5.6	-1.6	8.3	6.9	-1.4	7.7	6.8	-0.9
Spring	5.4	6.0	0.6	5.0	5.1	0.0	6.7	6.4	-0.3	5.5	6.3	0.8
Summer	5.3	5.7	0.3	3.8	4.2	0.5	5.1	5.4	0.3	4.1	5.2	1.0
Overall Average	6.0	6.0		5.2	5.0		6.6	6.2		5.7	6.0	
Error	0.0			-0.2			-0.4			0.4		
% Error	0.2			-4.2			-6.6			6.2		

Table 3.14 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the South Branch Chicago River and Chicago Sanitary and Ship Canal, Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Jackson Boulevard			**Cicero Avenue**			**Baltimore and Ohio RR**			**Route 83**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	6.4	5.9	-0.5	5.1	5.2	0.1	6.3	6.0	-0.3	5.5	5.9	0.4
Winter	7.1	5.1	-2.1	6.4	5.5	-0.9	8.1	6.7	-1.4	7.6	6.8	-0.8
Spring	6.2	5.0	-1.2	4.9	3.8	-1.1	6.6	5.4	-1.2	5.2	5.5	0.2
Summer	6.0	6.5	0.5	4.3	4.7	0.3	5.5	5.5	0.1	3.7	5.4	1.7
Overall Average	6.4	5.6		5.2	4.8		6.6	5.9		5.5	5.9	
Error	-0.8			-0.4			-0.7			0.4		
% Error	-12.7			-7.6			-10.7			7.3		

Jackson Boulevard is located just downstream of the junction of the NBCR, SBCR, and Chicago River Main Stem. Simulated and measured DO concentrations are shown in Figure 3.28. The simulated DO concentrations follow the general trend of the measured DO concentrations very well especially during significant storms like the August 2, 2001 storm. The lowest DO concentrations are observed in the summer months and the average errors in simulated seasonally averaged hourly DO concentrations for Summers of 2001 and 2003 are 0.3 mg/L and 0.5 mg/L, respectively. The model tends to underestimate DO concentrations during significant storm events. The target of the management alternatives to bring the water-quality conditions to desired levels requires solutions for the periods where very low DO concentrations are observed. Hence, because the model tends to underestimate low DO concentrations if the model results show that a water-quality management alternative can bring DO concentrations to a target level, actual DO concentrations would be expected to be equal to or greater than the simulated DO concentrations.

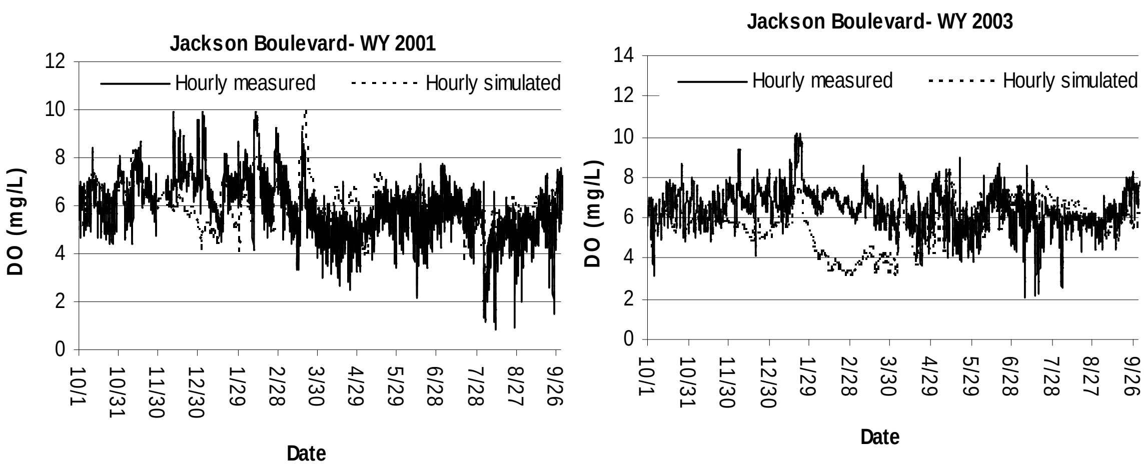


Figure 3.28 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Jackson Boulevard on the South Branch Chicago River for Water Years 2001 and 2003

Cicero Avenue is located between the Racine Avenue Pump Station and the Stickney WRP and it is possible to see the effect of both of these point sources on DO concentrations at this station (Figure 3.29). Most of the time flow from the Stickney WRP is greater than the flows from upstream of the plant. The hydraulic simulation results have found that because of the generally low flow gradient throughout the CWS, the flow leaving the Stickney WRP often flows both ways (upstream and downstream) when leaving the plant. The complexity of the hydraulic behavior of the CWS makes this station one of the most difficult locations to calibrate. The average percent error in seasonally averaged hourly DO concentrations is less than 10% for both simulation periods. Measured and simulated DO concentrations at Cicero Avenue have very close agreement for most of the periods where extremely low DO concentrations are observed, especially the July-August period and the average error in seasonally averaged hourly DO concentrations for summer months are 0.5 and 0.3 mg/L for WYs 2001 and 2003, respectively.

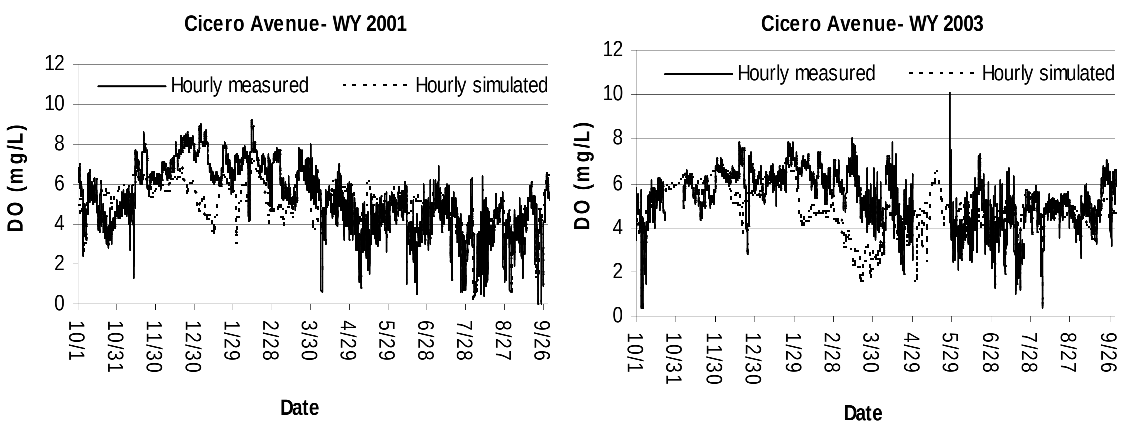


Figure 3.29 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Cicero Avenue on the Chicago Sanitary and Ship Canal for Water Years 2001 and 2003

The Baltimore and Ohio Railroad (B&O RR) is located downstream of the Stickney WRP. Therefore, the effect of the Stickney WRP is very obvious at this location. The average measured hourly DO concentration at B&O RR in summer months is 1.3 and 1.2 mg/L higher for WYs 2001 and 2003, respectively, than that at Cicero Avenue. The DO concentrations fluctuate between 4-10 mg/L and go down to 2 mg/L during significant storms (Figure 3.30). The simulated DO concentrations agree well with measured DO concentrations and the average percent error is less than 10 %. The model captured low DO concentrations during most of the storms.

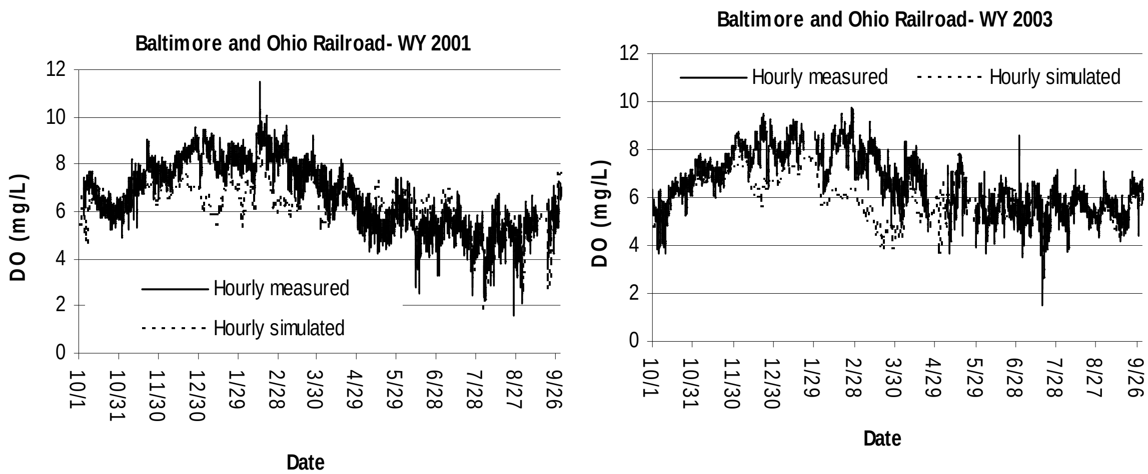


Figure 3.30 Comparison of measured and simulated dissolved oxygen (DO) concentrations at the Baltimore and Ohio Railroad on the Chicago Sanitary Ship Canal for Water Years 2001 and 2003

The last DO location on the CSSC upstream from the junction with the Calumet-Sag Channel is Route 83. The comparison of simulated and measured DO concentrations is shown in Figure 3.31. The measured DO concentrations show an unexpected trend for the period of August 8 to 16, 2001. DO concentration jumps from 0.8 mg/L to 5.6 mg/L on August 8, 2001 and suddenly drops to 4.1 mg/L from 5.5 mg/L on August 16, 2001. The average error between measured and simulated hourly DO concentrations for summer months in WYs 2001 and 2003 are 1.0 mg/L and 1.7 mg/L, respectively. The measured DO concentrations at Route 83 for the summer of WY 2003 also seem inconsistent and prone to low values. Jennifer Wasik of the MWRDGC (2010, written communication) indicated that the Route 83 location is problematic because no bridge is available to which the DO monitor may be attached, so the monitor is attached to the shore by a chain and then suspended in the water of the CSSC. The monitor sometimes is buried by sediment after storm events (such as occurred on August 2, 2001) and takes inaccurate readings. The problem is corrected by a Quality Assurance/Quality Control program that requires retrieval and replacement of a DO monitoring probe every week. Thus, model calibration should not rely on the questionable measured DO concentrations. The simulated and measured DO concentrations at this location were in general agreement, as shown in Figure 3.31, since the questionable DO concentrations represent only a very small portion of the measured data. Like the other CSSC DO monitoring locations, the model successfully matched the low DO concentrations during the major storm events in the summer.

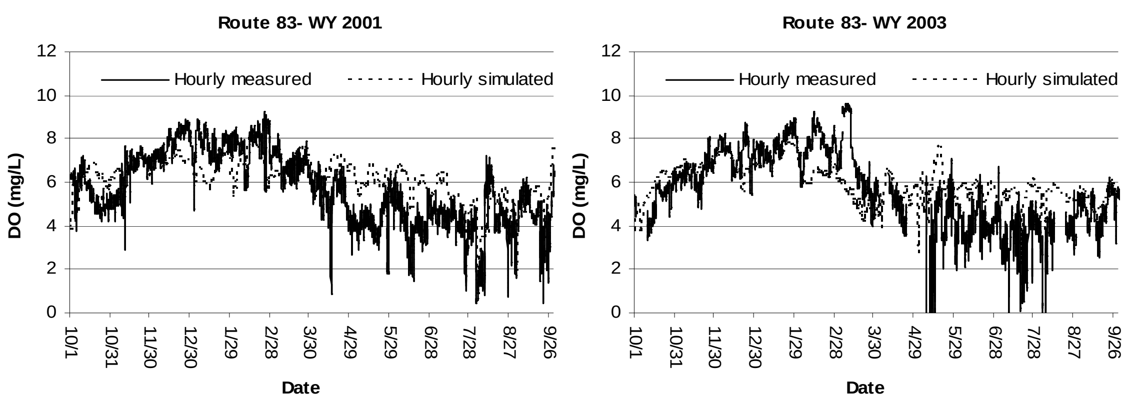


Figure 3.31 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Route 83 on the Chicago Sanitary and Ship Canal for Water Years 2001 and 2003

River Mile 11.6 is located 0.8 mi downstream from the Calumet-Sag Channel junction with the CSSC. The comparison between the measured and simulated DO concentrations shows good agreement during most of the storm events (Figure 3.32) with an overall average percent error less than 10% for the average hourly DO concentrations (Tables

3.15 and 3.16). However, the measured sudden DO concentration decrease to 0.3 mg/L on August 4, 2001 could not be duplicated by the model.

Table 3.15 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Chicago Sanitary and Ship Canal, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	River Mile 11.6			Romeoville		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	5.6	6.1	0.4	5.5	5.9	0.4
Winter	7.7	7.1	-0.7	7.9	7.0	-0.9
Spring	5.9	6.6	0.6	5.4	6.4	1.0
Summer	4.4	5.2	0.8	3.9	5.0	1.1
Overall Average	5.9	6.2		5.7	6.1	
Error	0.3			0.4		
% Error	5.1			7.2		

Table 3.16 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Chicago Sanitary and Ship Canal, Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	River Mile 11.6			Romeoville		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	5.8	6.0	0.3	5.4	5.9	0.4
Winter	8.0	7.1	-0.8	7.9	7.1	-0.8
Spring	6.0	6.0	0.0	5.6	5.8	0.2
Summer	4.6	5.5	0.8	4.1	5.3	1.2
Overall Average	6.1	6.1		5.8	6.0	
Error	0.1			0.3		
% Error	1.0			4.4		

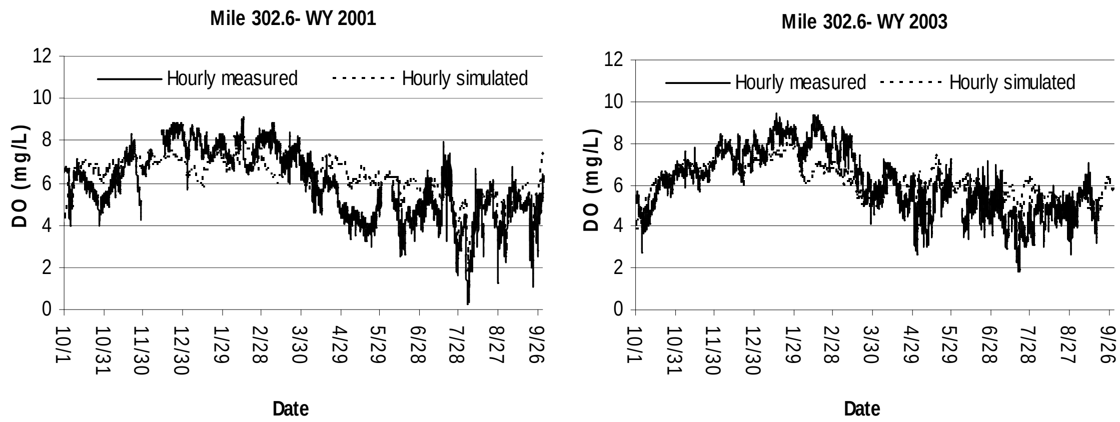


Figure 3.32 Comparison of measured and simulated dissolved oxygen (DO) concentrations at River Mile 11.6 on the Chicago Sanitary and Ship Canal for Water Years 2001 and 2003

Romeoville is the most downstream point of comparison for the water-quality model. As can be seen from Figure 3.33, the simulated and measured DO concentrations are generally in good agreement and the average percent error in the average hourly DO concentrations is less than 10%. The difference between the overall average simulated and measured hourly DO concentrations for summer months are 1.1 mg/L and 1.2 mg/L for WYs 2001 and 2003, respectively.

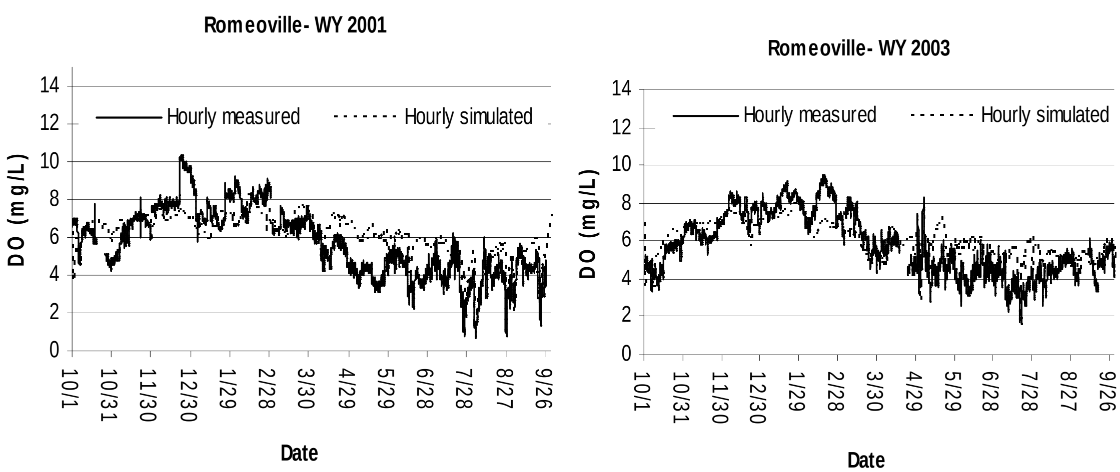


Figure 3.33 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Romeoville on the Chicago Sanitary and Ship Canal for Water Years 2001 and 2003

3.5.2.3 Calumet-Sag Channel

In this section simulation results for locations between the Calumet WRP and the Calumet-Sag Channel junction with the CSSC are presented. This section is divided into 3 reaches and the following DO stations represent each reach: i) Halsted Street, ii) Division Street, Kedzie Avenue, Cicero Avenue, Harlem Avenue, and Southwest Highway, and iii) 104th Avenue and Route 83. Similar calibrated parameter values were used throughout the Calumet-Sag Channel. A statistical comparison between seasonally averaged simulated and measured hourly DO concentrations is listed in Tables 3.17-3.20.

The comparison of simulated and measured hourly DO concentrations for WY 2001 in Tables 3.17 and 3.19 is limited to summer months for all locations except Route 83 because the DO monitors at these locations were installed in early July 2001. With the exception of 104th Avenue and Route 83, in all cases the average percent error is less than 10% for WY 2003. Further for WY 2001 the overall error in simulated average hourly DO concentrations at Route 83 is less than 1%. These results indicate that unbiased estimates of DO concentrations are obtained throughout these reaches.

Table 3.17 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Calumet-Sag Channel and Little Calumet River (North) downstream from the Calumet WRP, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100; nd = inadequate data to make comparison]

	Halsted Street			Division Street			Kedzie Avenue			Cicero Avenue		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall		7.0			6.9			7.1			6.8	
Winter		6.9			7.7			7.7			7.5	
Spring		7.1			7.2			7.1			7.0	
Summer	6.3	5.8	-0.5	4.7	5.6	0.9	5.5	5.6	0.1	5.4	5.4	0.0
Overall Average	nd	6.7		nd	6.9		nd	6.9		nd	6.7	
Error	nd			Nd			nd			nd		
% Error	nd			nd			nd			nd		

Table 3.18 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Calumet-Sag Channel and Little Calumet River (North) downstream from the Calumet WRP, Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Halsted Street			Division Street			Kedzie Avenue			Cicero Avenue		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	7.2	6.8	-0.4	6.7	6.7	0.0	7.2	6.7	-0.5	7.1	6.5	-0.6
Winter	8.2	8.4	0.2	8.8	8.5	-0.2	8.9	8.4	-0.5	8.9	8.3	-0.6
Spring	7.4	7.3	-0.1	7.2	7.3	0.2	7.6	7.6	0.0	7.6	7.4	-0.2
Summer	6.4	5.8	-0.6	5.8	5.6	-0.2	6.7	5.8	-0.8	6.2	5.6	-0.6
Overall Average	7.3	7.1		7.1	7.1		7.6	7.1		7.5	6.9	
Error	-0.2			0.0			-0.5			-0.5		
% Error	-3.3			-0.6			-6.1			-6.8		

Halsted Street is located downstream of the Calumet WRP. Diurnal fluctuations in DO concentrations are observed until the middle of September and algal activities reached a maximum in July and August (Figure 3.34). Since the DUFLOW water-quality model is not intended to simulate diurnal DO fluctuations due to algal activities, diurnal fluctuations could not be captured by the model. On the other hand, the simulated DO concentrations follow the general trend of the measured DO concentrations even in the summer. When there was less algal activity, the model predicted measured DO concentrations with high accuracy. The average percent error in the average hourly DO concentrations is less than 5%, and the difference between the overall average simulated and measured hourly DO concentrations in summer months is less than 0.6 mg/L.

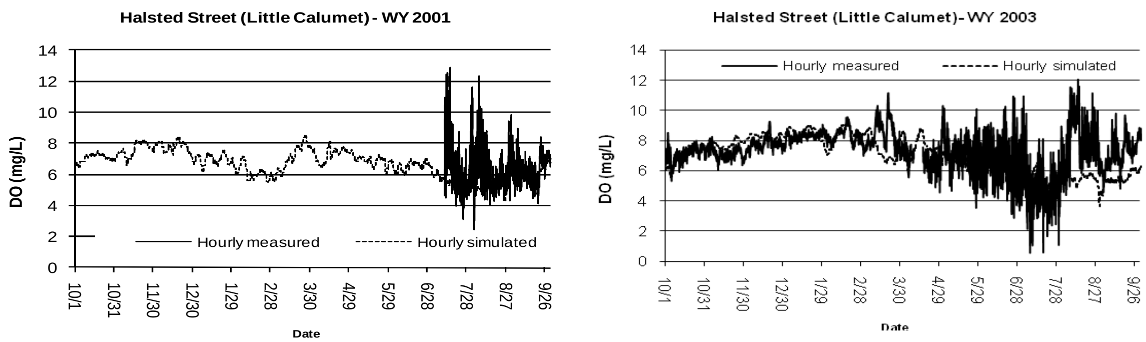


Figure 3.34 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Halsted Street on the Little Calumet River (North) for Water Years 2001 and 2003

The comparisons of simulated and measured DO concentrations have very good agreement between Division Street and Southwest Highway. The results are shown in Figures 3.35-3.36. The average and percent errors in the average hourly DO concentrations are less than or equal to 0.6 mg/L and 7.7% at all locations for WY 2003.

In general, comparison of the simulated and measured hourly DO concentrations for WY 2003 indicates strong agreement. DO concentrations get as high as 12 mg/L and as low as 2 mg/L in the summer in the Calumet-Sag Channel. In summer, algal activities dominate the fluctuations in DO. The DUFLOW model could not capture rapid DO recovery after the storm events in summer. For example, measured DO concentrations decrease to 2.5 mg/L on August 3, 2001 (because of the August 2, 2001 storm event) and increase to 10.6 mg/L (because of algal activity) on August 7, 2001 at Kedzie Avenue whereas simulated DO concentrations are around 4 mg/L for the same time period. Similar trends also are observed in WY 2003. High concentrations of chlorophyll-a measured in WY 2003 indicate algal blooms in summer months which causes diurnal fluctuations in DO concentrations.

Table 3.19 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Calumet-Sag Channel and Little Calumet River (North) downstream from the Calumet WRP, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100; nd = inadequate data to make this comparison]

	Harlem Avenue			**Southwest Highway**			**104th Avenue**			**Route 83**		
Season	Meas. mg/L	Sim. mg/L	Error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall		7.1			7.0			6.8		6.5	6.6	0.1
Winter		7.4			7.4			7.4		8.0	7.5	-0.5
Spring		7.2			7.2			7.1		6.7	6.9	0.2
Summer	4.4	5.7	1.2	4.7	5.5	0.8	5.2	5.2	0.1	4.9	5.1	0.2
Overall Average	nd	6.9		nd	6.8		nd	6.6		6.5	6.5	
Error	nd			nd			nd			0.0		
% Error	nd			nd			nd			0.3		

The last DO stations on the Calumet-Sag Channel are 104th Avenue and Route 83. Just like other Calumet-Sag Channel locations, measured values were successfully simulated with the model for periods when the algal activities were not high (Figure 3.37). The average and percent errors in the average hourly DO concentrations are less than or equal to 1.0 mg/L and 12.5%, respectively.

Table 3.20 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Calumet-Sag Channel and Little Calumet River (North) downstream from the Calumet WRP, Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Harlem Avenue			**Southwest Highway**			**104th Avenue**			**Route 83**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	7.0	6.5	-0.5	7.2	6.5	-0.7	7.1	6.3	-0.8	6.9	6.3	-0.7
Winter	9.1	8.2	-0.9	8.9	8.2	-0.7	9.7	8.2	-1.4	9.1	8.1	-1.0
Spring	7.6	7.6	0.0	7.7	7.5	-0.2	8.0	7.3	-0.7	7.5	7.1	-0.5
Summer	6.5	5.7	-0.8	6.3	5.6	-0.7	6.5	5.5	-1.1	6.8	5.4	-1.5
Overall Average	7.6	7.0		7.5	7.0		7.8	6.8		7.6	6.7	
Error	-0.5			-0.6			-1.0			-0.9		
% Error	-7.3			-7.7			-12.5			-11.9		

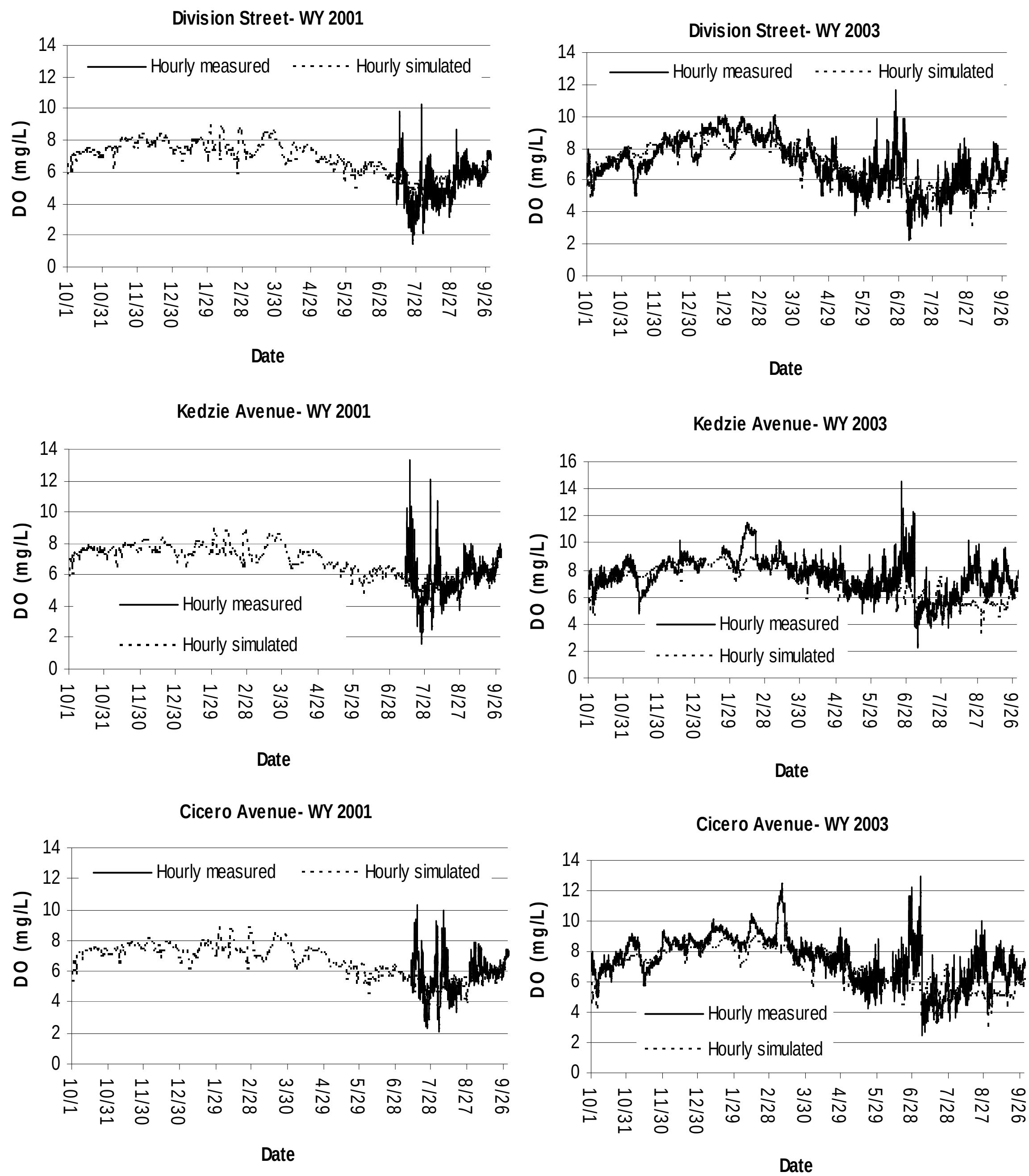


Figure 3.35 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Division Street, Kedzie Avenue, and Cicero Avenue on the Calumet-Sag Channel for Water Years 2001 and 2003

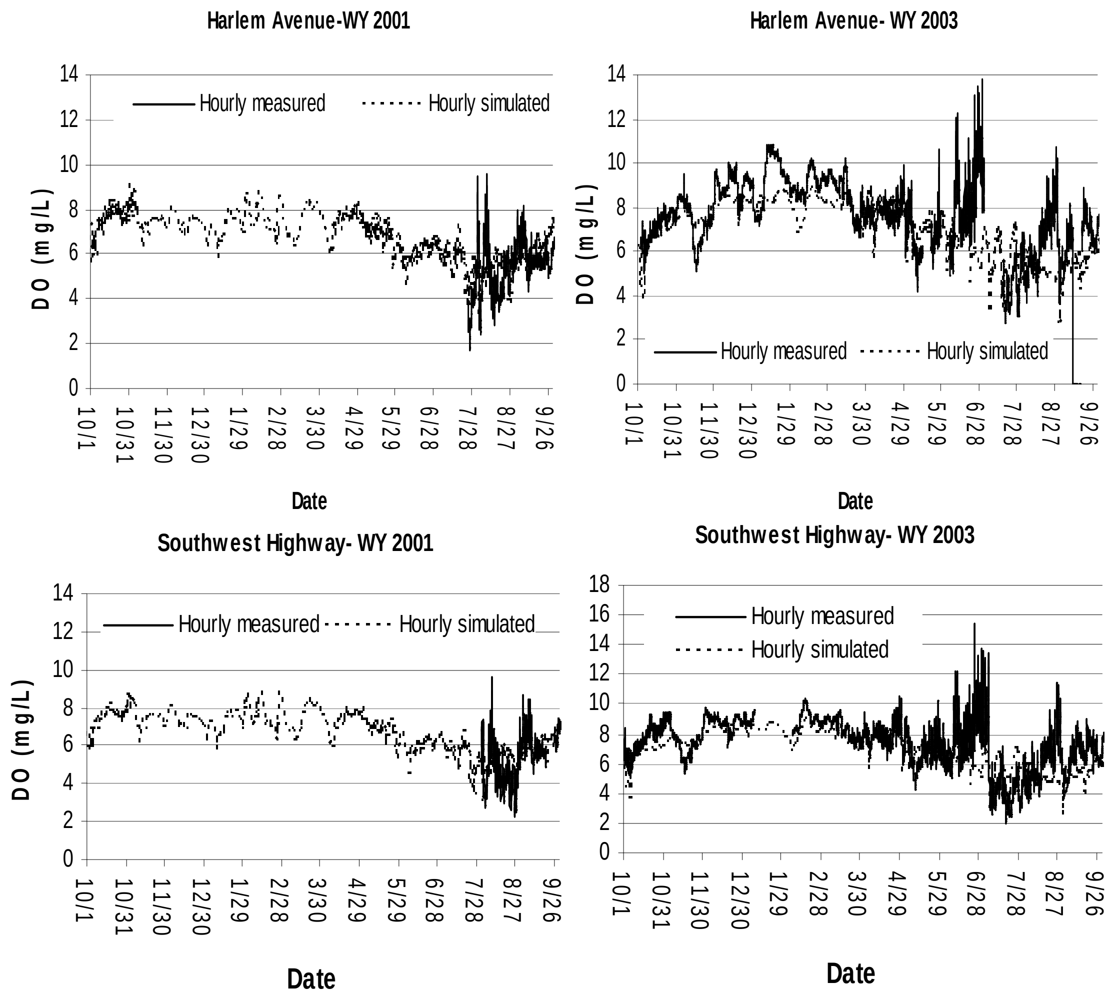


Figure 3.36 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Harlem Avenue and Southwest Highway on the Calumet-Sag Channel for Water Years 2001 and 2003

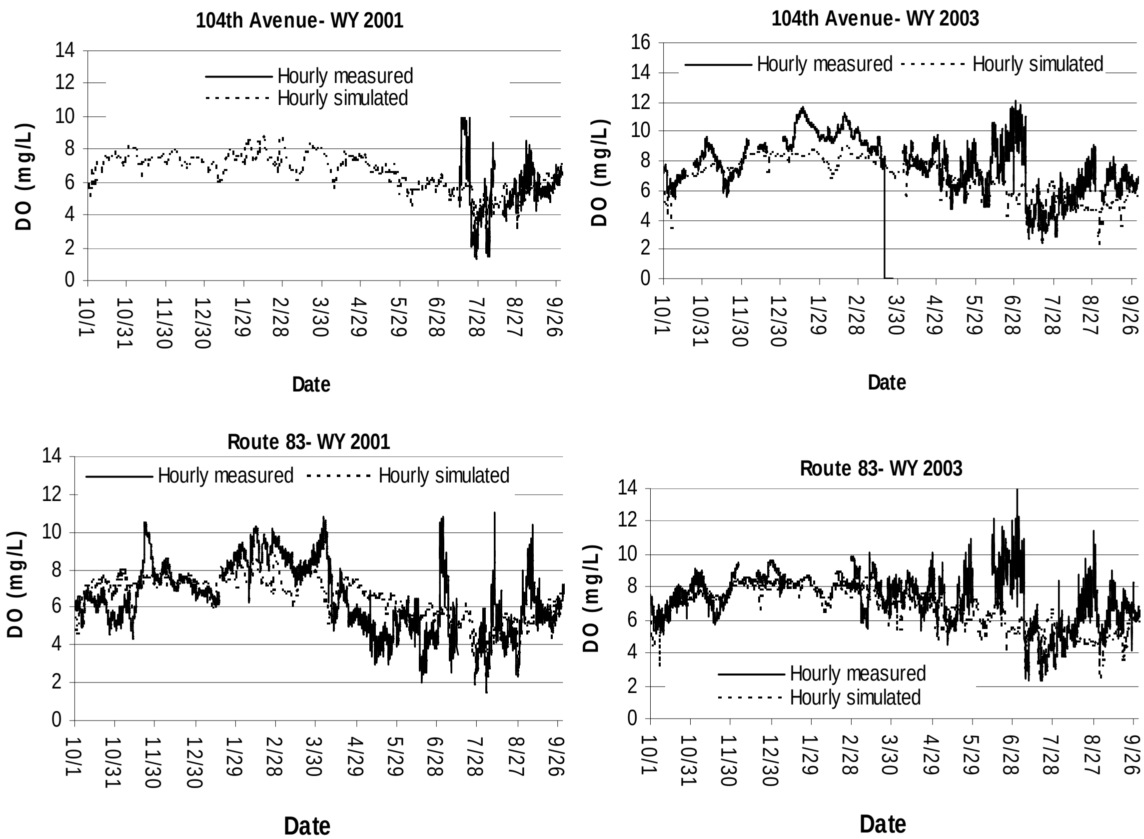


Figure 3.37 Comparison of measured and simulated dissolved oxygen (DO) concentrations at 104th Avenue and Route 83 on the Calumet-Sag Channel for Water Years 2001 and 2003

3.5.2.4 Boundaries (North Shore Channel, Chicago River Main Stem, Little Calumet River (North and South))

The comparison of simulated and measured DO concentrations on the NSC at Simpson and Main Streets is shown in Figure 3.38 and Tables 3.21 and 3.22. Even though percent errors that vary between 1.4-35.2% suggest that the model could not do a good job on the NSC, graphical comparison provides better information about the power of the model along the NSC. For WY 2001 the simulated average hourly DO concentrations were within 10% of the measured values. For WY 2003 the simulated daily average DO concentrations are substantially lower (28.6 and 35.2%) than the measured values. This large error appears to be the result of extraordinarily high measured concentrations in the winter and spring of WY 2003 on the upper NSC. The difference between simulated and measured average hourly DO concentrations in the fall and summer of WY 2003 have similar quality to locations downstream on the NBCR, SBCR, and CSSC. The fact that the flows at these sites are really low and mainly dominated by the CSOs and discretionary diversions from Lake Michigan make DO concentrations fluctuate drastically within a short period of time. Cycles of extremely low and very high concentrations are the main characteristics of the DO concentration in the NSC above the North Side WRP during the simulation period. It is hard to attribute these fluctuations to algal activities since chlorophyll-a concentrations are low during the simulation periods. It is obvious that discretionary diversion of water from Lake Michigan can bring DO concentrations almost to saturation. Whereas when there is no flow from the lake, DO concentrations can quickly go down to extremely low concentrations. The hydraulic features of the NSC and SOD play an important role in DO changes along the upper NSC. Thus, the calibration strategy along the NSC was to simulate low DO concentrations accurately and to follow the general trend of the DO concentration as much as possible. As shown in Figure 3.38, the model successfully predicted extremely low DO concentrations and follows the general DO trend along the NSC upstream from the North Side WRP.

Table 3.21 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Shore Channel, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Simpson Street			**Main Street**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	5.5	5.1	-0.4	5.1	5.2	0.1
Winter	1.2	3.5	2.3	4.6	5.3	0.8
Spring	6.6	5.6	-1.0	7.7	5.6	-2.1
Summer	4.3	5.2	0.9	2.9	4.4	1.5
Overall Average	4.4	4.8		5.1	5.1	
Error	0.4			0.1		
% Error	9.7			1.4		

Table 3.22 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the North Shore Channel, Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Simpson Street			**Main Street**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	7.4	7.1	-0.3	8.3	6.5	-1.8
Winter	13.1	6.4	-6.8	13.3	6.3	-7.0
Spring	8.0	4.0	-4.0	8.4	4.6	-3.8
Summer	5.4	6.8	1.3	6.2	6.1	-0.2
Overall Average	8.5	6.0		9.0	5.9	
Error	-2.4			-3.2		
% Error	-28.6			-35.2		

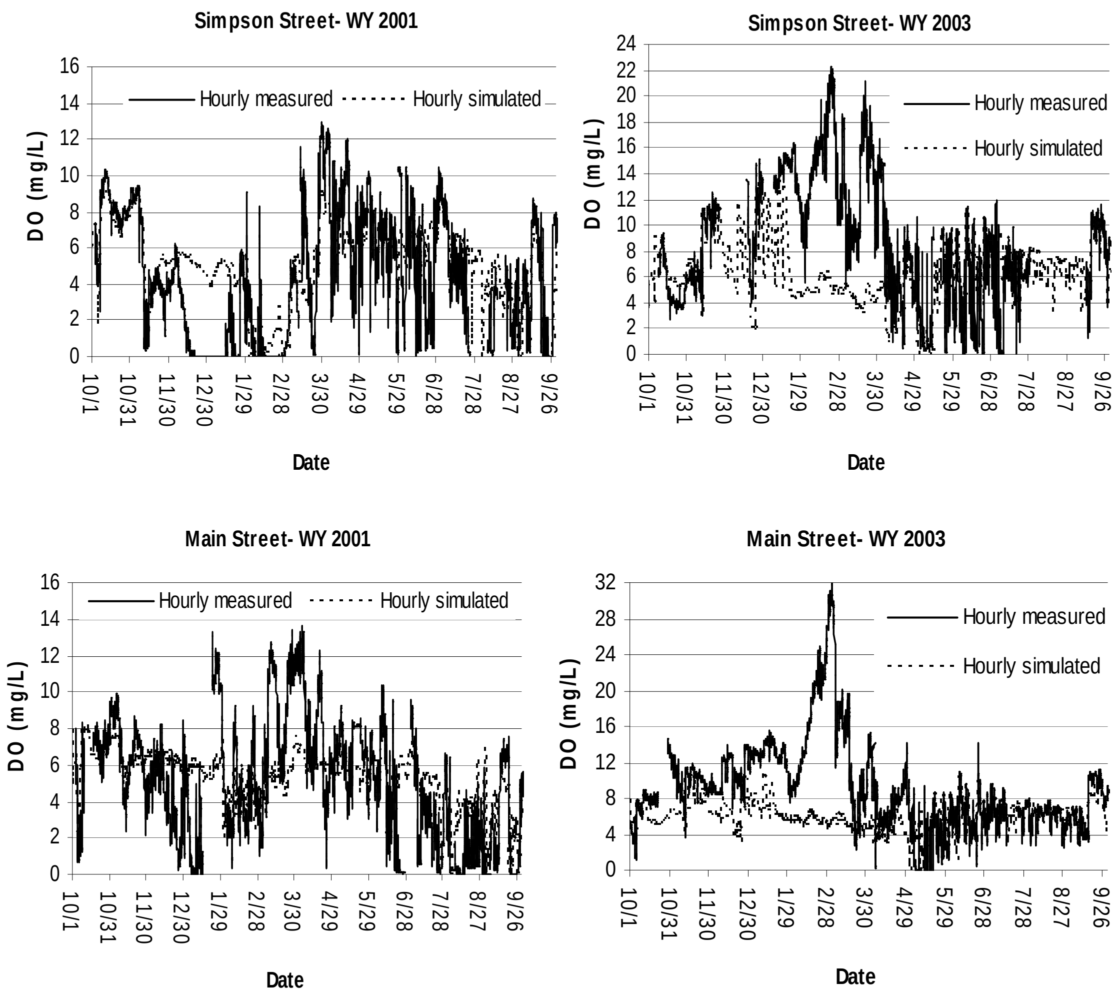


Figure 3.38 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Simpson and Main Streets on the North Shore Channel for Water Years 2001 and 2003

The Chicago River Main Stem results are shown in Figure 3.39. A statistical comparison between daily average simulated and measured DO concentrations is listed in Tables 3.23 and 3.24. Big differences between the simulated and the measured DO concentrations are obvious mainly in the winter months because of stratified flows as previously discussed. On the other hand, the model successfully simulated DO concentrations in summer months in which low DO concentrations are frequently observed. The average error in hourly DO concentrations in summer months of 2003 is just -0.3 mg/L at both Michigan Avenue and Clark Street, and -0.6 mg/L at Clark Street in the summer of 2001.

Table 3.23 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Chicago River Main Stem, Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Michigan Avenue			Clark Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	8.8	7.6	-1.2	7.9	7.1	-0.8
Winter	9.1	6.8	-2.4	8.7	6.3	-2.4
Spring	7.3	6.5	-0.7	6.7	6.3	-0.4
Summer	-	7.5	-	7.6	7.0	-0.6
Overall Average	8.4	7.1		7.7	6.7	
Error	-1.3			-1.0		
% Error	-15.4			-13.3		

Table 3.24 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Chicago River Main Stem, Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Michigan Avenue			Clark Street		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	8.6	7.4	-1.2	8.1	6.8	-1.2
Winter	8.9	6.6	-2.3	7.7	5.9	-1.8
Spring	8.8	6.4	-2.4	7.8	5.8	-1.9
Summer	8.4	8.1	-0.3	8.1	7.8	-0.3
Overall Average	8.7	7.1		7.9	6.6	
Error	-1.6			-1.3		
% Error	-18.0			-16.7		

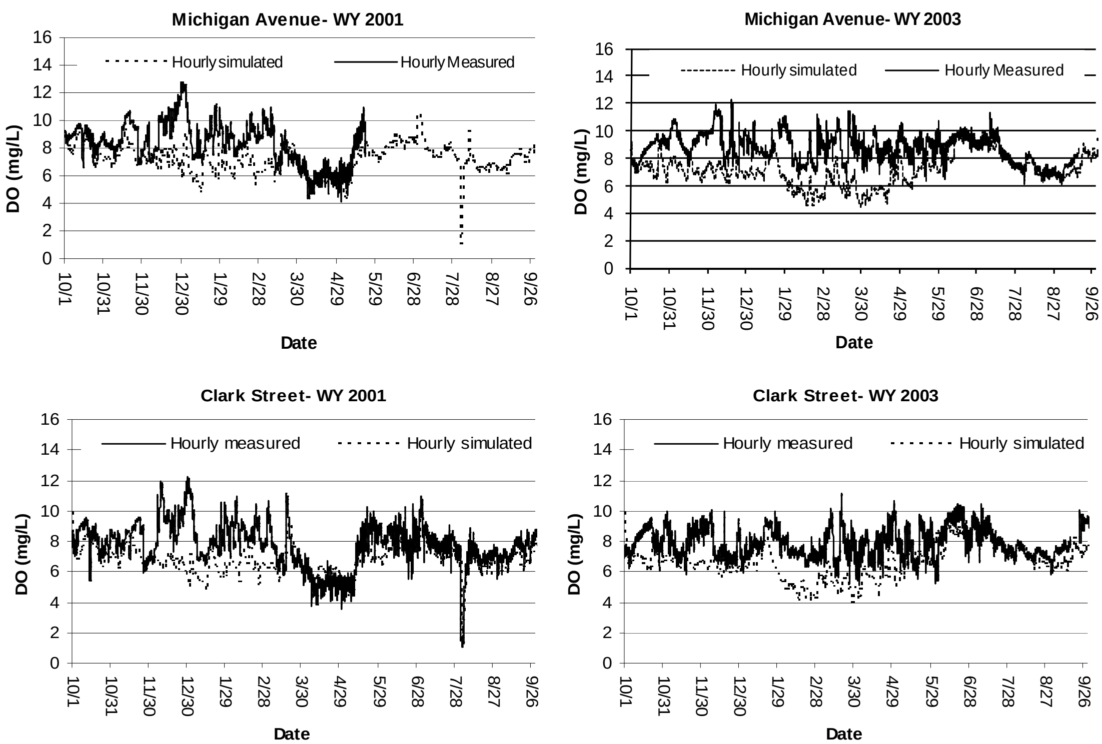


Figure 3.39 Comparison of measured and simulated dissolved oxygen (DO) concentrations on the Chicago River Main Stem at Clark Street and Michigan Avenue for Water Years 2001 and 2003

Comparison of measured and simulated DO concentrations on the Little Calumet River (South) at Ashland Avenue is shown in Figure 3.40. A major cause for the poor agreement between measured and simulated DO concentrations is the use of the long-term average DO concentration at the Little Calumet River (South) at South Holland boundary because no continuous DO data are available at this site. Calumet-Sag Channel flows are mainly dominated by Calumet WRP flows delivered by the Little Calumet River (North) and the effect of poorly estimated DO concentrations along Little Calumet River (South) on Calumet-Sag Channel and downstream from Calumet-Sag Channel and CSSC junction is not significant. Thus, not much effort was made to match measured and simulated DO concentrations at Ashland Avenue on the Little Calumet River (South).

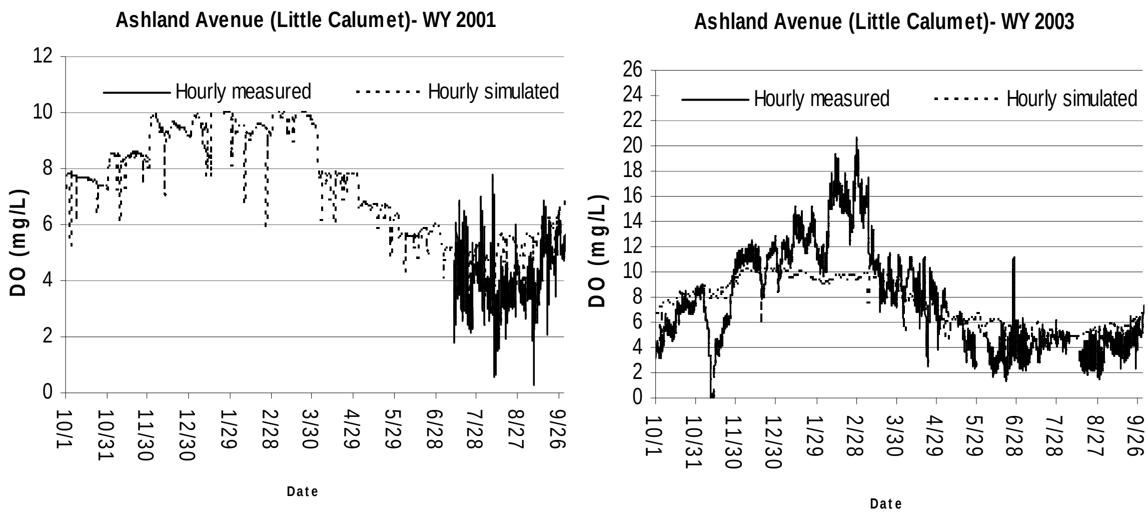


Figure 3.40 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Ashland Avenue on the Little Calumet River (South) for Water Years 2001 and 2003

The Little Calumet River (North) results are shown in Figure 3.41 and Tables 3.25 and 3.26. The average error of average hourly DO concentrations for the summers of 2001 and 2003 vary between 0 and -1.4 mg/L. However, results for fall, winter, and spring of WY 2003 are much poorer on the Little Calumet River (North). As was the case for the upper NSC, the reason for the poor results appears to be the result of extraordinarily high measured DO concentrations. Like other Calumet-Sag Channel locations, algal activities have a huge effect on DO fluctuations in summer months and the model underestimated DO concentrations especially during the periods when the algal activates reached a peak at the Central and Wisconsin Railroad as indicated by the diurnal fluctuations and supersaturated DO concentrations during the summer of 2001.

Table 3.25 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Little Calumet River (North), Water Year 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100; nd = inadequate data to make this comparison]

	Conrail Railroad			**Central and Wisconsin Railroad**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall		7.0			7.0	
Winter		7.1			7.1	
Spring		7.2			7.2	
Summer	6.8	5.8	-1.0	7.3	5.9	-1.4
Overall Average	nd	6.8		nd	6.8	
Error	nd			nd		
% Error	nd			nd		

Table 3.26 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on the Little Calumet River (North) for Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	Conrail Railroad			**Central and Wisconsin Railroad**		
Season	Meas. mg/L	Sim. mg/L	error mg/L	Meas. mg/L	Sim. mg/L	error mg/L
Fall	8.9	6.9	-2.0	9.1	6.9	-2.2
Winter	13.2	8.8	-4.4	13.2	8.7	-4.5
Spring	10.0	7.3	-2.7	10.7	7.3	-3.4
Summer	6.3	5.7	-0.6	5.8	5.7	0.0
Overall Average	9.6	7.2		9.7	7.2	
Error	-2.4			-2.5		
% Error	-25.2			-26.2		

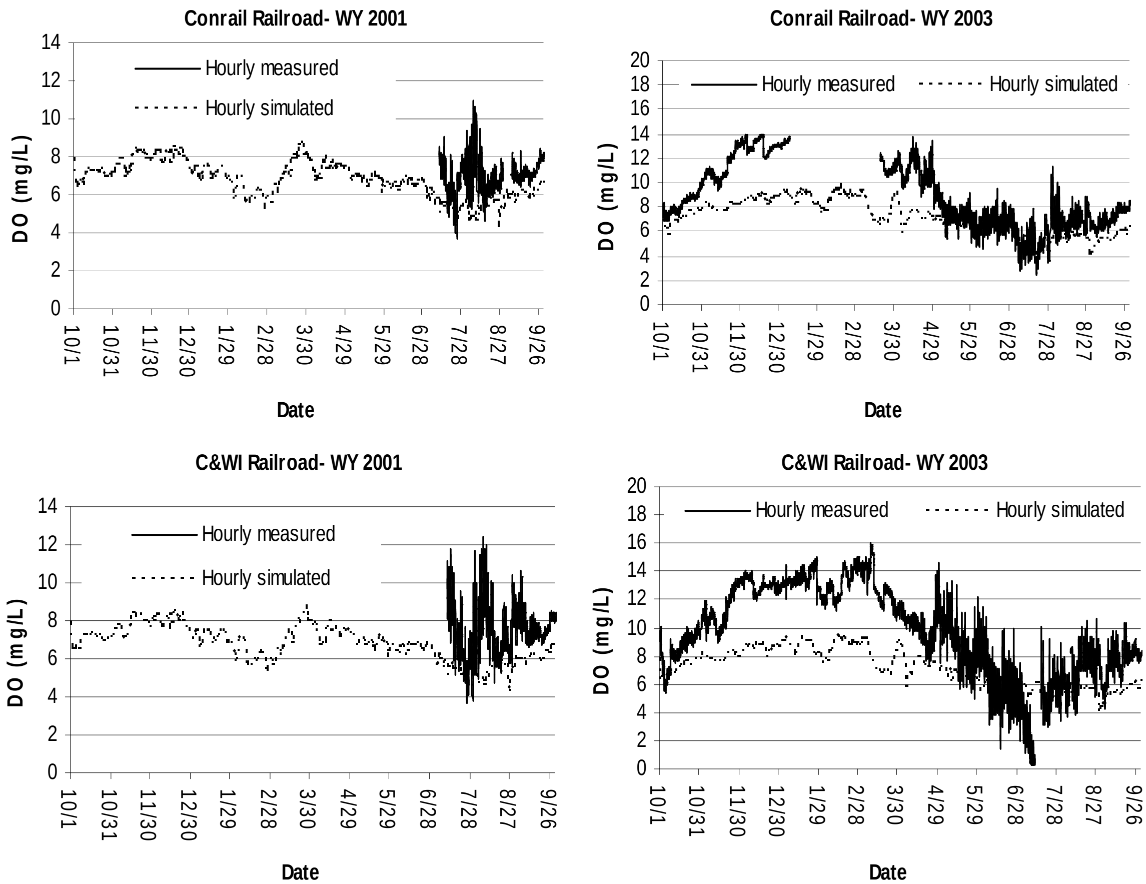


Figure 3.41 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Conrail Railroad and the Central and Wisconsin Railroad on the Little Calumet River (North) for Water Years 2001 and 2003

Bubbly Creek was not included in the preliminary calibration of DUFLOW (Alp and Melching, 2004). Since it was necessary to make some simulations regarding management alternatives for Bubbly Creek, the Bubbly Creek section was added to the model. Unfortunately, there are no data available on Bubbly Creek at I-55 from the calibration period of Water Year 2001. Hence data from Water Year 2003, were used to calibrate water quality constituents on Bubbly Creek. Comparison of the simulated and measured DO concentrations are given in Figure 3.42 and Table 3.27. The Bubbly Creek section is the most difficult part of the CWS to calibrate due to the stagnant water during non-storm periods. Further, diurnal fluctuations in DO concentrations in Bubbly Creek most likely were due to algal activity. The effects of algal activity on average daily DO concentrations could not be accounted for in the model calibration because of a lack of chlorophyll-a data. During storm periods the Bubbly Creek flows basically become the Racine Avenue Pump Station discharges. Historically water-quality conditions are extremely poor along Bubbly Creek and low DO concentrations are observed especially in spring and winter months. Since it was hard to match measured DO concentrations over the entire simulation period, the model calibration in this study was performed such that a conservative approach was taken, in which the goal was to better match the lower DO concentration. Therefore, the simulations of any management alternative that can bring DO concentrations to desired levels can also work well in the actual situation. This strategy resulted in the average error in DO concentrations of -0.8 mg/L (15.5%) at I-55 in Water Year 2003.

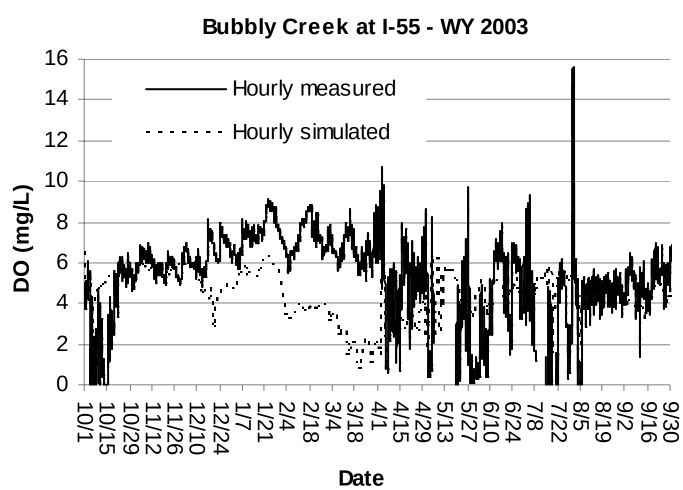


Figure 3.42 Comparison of measured and simulated dissolved oxygen (DO) concentrations at I-55 on Bubbly Creek for Water Year 2003

Table 3.27 Comparison of seasonally averaged simulated and measured hourly dissolved oxygen concentrations on Bubbly Creek at I-55, for Water Year 2003 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100]

	I-55		
Season	Meas. Mg/L	Sim. mg/L	error mg/L
Fall	4.7	4.9	0.2
Winter	7.0	4.7	-2.3
Spring	4.9	3.2	-1.7
Summer	4.0	4.6	0.6
Overall Average	5.2	4.4	
Error	-0.8		
% Error	-15.5		

3.5.3 Results of Sediment Oxygen Demand (SOD) calibrations

As previously explained, in DUFLOW (2000), SOD is simulated as a diffusive exchange of oxygen between the water column and the active (top) sediment layer (which has its own CBOD, DO, nutrients, etc. in the pore water). In the previous DUFLOW Model (e.g., Alp and Melching, 2006), SOD was calibrated based on a survey of sediment depth and composition conducted by the District at 20 locations and the measured DO concentrations in the CWS. In this study, SOD is recalibrated and compared with SOD values measured in 2001. As can be seen in Table 3.28, close agreement between the simulated and measured SOD in 2001 was obtained in the recalibrated model.

Table 3.28 Comparison of simulated and measured Sediment Oxygen Demand for Water Years 2001 and 2003

	Measured		Ave. Simulated SOD (g/sq. m/day)	
	Date	SOD @ 20°C (g/sq. m/day)	WY 2001	WY 2003
Simpson St. (NSC)	12/5/01	3.89	2.36	2.40
Main St. (NSC)	12/6/01	1.85	3.34	3.18
Belmont Ave. (NBCR)	10/24/01	3.10	5.00	4.58
Grand Ave. (NBCR)	10/23/01	1.80	2.57	2.26
LaSalle St. (Chicago River Main Stem. R)	10/22/01	0.77	0.50	0.46
Congress Pkwy. (SBCR)	10/26/01	1.93	1.69	1.49
Halsted St. (SBCR)	10/29/01	3.32	1.64	1.39
Interstate Hwy. 55 (Bubbly Cr.)	11/2/01	3.64	3.11	2.56
Cicero Ave. (CSSC)	10/31/01	1.71	1.08	0.92
Lockport Powerhouse (CSSC)	11/7/01	2.71	0.00	0.00
Conrail RR (LCR)	11/14/01	0.59	0.62	0.58
Indiana Ave. (LCR)	11/20/01	1.25	0.61	0.57
Halsted St. (LCR)	11/21/01	1.14	1.15	1.09
Division St (Cal-Sag)	11/21/01	1.07	1.21	1.15
Southwest Hwy. (Cal-Sag)	11/6/01	0.80	1.05	0.98
Route 83 (Cal-Sag)	11/5/01	0.63	0.97	0.89

3.6 Summary of Calibration

In previous sections, comparisons were shown of the simulated constituent concentrations ($CBOD_5$, Nitrogen compounds, Phosphorus compounds, and Chlorophyll-a) with long-term mean measured concentrations, one standard deviation confidence bounds, and concentrations measured in WYs 2001 and 2003. Throughout the calibration process, measured and simulated hourly DO concentrations were matched as much as possible. Since it was hard to match measured DO concentrations over the entire simulation period at certain locations, such as the NSC, SBCR, and Bubbly Creek, model calibration in this study was performed such that a conservative approach was taken, in which the goal was to better match the lower DO concentrations. Therfore, the simulations of any management alternative that can bring DO concentrations to desired levels can also work well in the actual situation. The percentage of the simulated and measured DO concentrations higher than 3, 4, 5, and 6 mg/L DO target levels in WYs in 2001 and 2003 are listed in Tables 3.29 and 3.30. The general underestimation of DO concentrations in certain regions of the CWS can be observed in Tables 3.29 and 3.30. Especially for the lower DO concentrations, the DUFLOW water-quality model predicted DO concentrations with relatively high accuracy. It can be concluded that, in general, the DUFLOW model represents water-quality processes in the CWS well enough to be a useful tool for solving water-quality planning and management problems of interest to the MWRDGC.

Table 3.29 Comparison of percentages of values greater than various target dissolved oxygen (DO) concentrations for simulated and measured hourly DO concentrations for the Chicago Waterway System for Water Year 2001

		Percentage of DO higher than							
		>3		**>4**		**>5**		**>6**	
Location	Waterway	**Meas.**	**Sim.**	**Meas.**	**Sim.**	**Meas.**	**Sim.**	**Meas.**	**Sim.**
Linden Street	NSC	85	81	80	72	78	57	75	49
Simpson Street	NSC	63	81	53	71	42	58	36	34
Main Street	NSC	70	89	61	80	52	66	42	34
Addison Street	NBCR	100	99	99	98	96	94	73	74
Fullerton Avenue	NBCR	98	99	93	98	75	89	51	63
Division Street	NBCR	100	100	98	99	91	93	63	66
Kinzie Street	NBCR	99	100	97	98	84	91	46	58
CRCW	Chicago River Main Stem	100	99	99	99	99	98	98	89
Michigan Avensue	Chicago River Main Stem	100	99	100	99	99	97	91	85
Clark Street	Chicago River Main Stem	99	99	99	99	95	97	88	80
Jackson Boulevard	SBCR	99	100	95	99	79	89	47	48
Cicero Avenue	CSSC	91	94	76	84	53	53	34	20
B and O RR	CSSC	99	99	97	96	87	91	62	62
Route 83	CSSC	95	98	85	94	61	86	45	58
Mile 11.6	CSSC	97	99	89	95	68	88	48	65
Romeoville	CSSC	95	97	81	93	57	86	46	59
Lockport	CSSC	94	97	80	92	61	84	43	57
130th Street	Calumet River	100	100	100	100	100	97	90	78
Conrail RR	LCR(N)	100	100	100	100	97	97	88	77
C and W RR	LCR(N)	100	100	100	100	98	97	87	78
Halsted Street	LCR(N)	100	100	99	100	91	98	59	78
Division Street	Cal-Sag	96	100	84	100	59	95	28	76
Kedzie Street	Cal-Sag	98	100	93	100	78	97	45	78
Cicero Avenue	Cal-Sag	98	100	91	100	74	94	40	72
Harlem Avenue	Cal-Sag	96	100	87	99	68	96	27	80
Southwest Highway	Cal-Sag	97	100	84	99	63	95	30	76
104th Avenue	Cal-Sag	90	100	84	98	67	91	33	70
Route 83	Cal-Sag	98	99	92	98	79	89	58	66

Table 3.30 Comparison of percentages of values greater than various target dissolved oxygen (DO) concentrations for simulated and measured hourly DO concentrations for the Chicago Waterway System for Water Year 2003

		Percentage of DO higher than							
		>3		**>4**		**>5**		**>6**	
Location	Waterway	**Meas.**	**Sim.**	**Meas.**	**Sim.**	**Meas.**	**Sim.**	**Meas.**	**Sim.**
Linden Street	NSC	86	87	81	82	75	72	68	60
Simpson Street	NSC	90	90	84	85	77	69	69	49
Main Street	NSC	94	96	89	90	83	76	74	45
Addison Street	NBCR	100	100	100	99	99	95	84	67
Fullerton Avenue	NBCR	99	100	95	97	77	82	48	45
Division Street	NBCR	100	100	99	96	90	84	63	54
Kinzie Street	NBCR	99	100	96	95	79	82	52	48
CRCW	Chicago River Main Stem	100	100	100	100	100	100	100	93
Michigan Avensue	Chicago River Main Stem	100	100	100	100	100	97	100	83
Clark Street	Chicago River Main Stem	100	100	100	100	100	89	99	75
I-55	Bubbly Creek	86	88	79	64	65	34	41	2
Jackson Boulevard	SBCR	100	100	99	89	94	78	69	40
Cicero Avenue	CSSC	95	92	85	80	60	43	33	15
B and O RR	CSSC	100	100	99	99	91	86	65	43
Route 83	CSSC	93	100	80	97	61	85	42	42
Mile 11.6	CSSC	99	100	93	99	73	90	51	55
Romeoville	CSSC	98	100	86	97	61	86	42	50
Lockport	CSSC	97	99	82	97	55	83	40	48
130th Street	Calumet River	100	100	100	100	99	95	94	77
Conrail RR	LCR(N)	100	100	98	99	95	95	88	76
C and W RR	LCR(N)	98	100	96	100	93	96	86	77
Halsted Street	LCR(N)	100	100	98	100	94	97	86	77
Division Street	Cal-Sag	100	100	98	100	92	96	77	73
Kedzie Street	Cal-Sag	100	100	100	100	96	97	88	77
Cicero Avenue	Cal-Sag	100	100	98	99	93	94	83	73
Harlem Avenue	Cal-Sag	100	100	98	99	94	93	86	75
Southwest Highway	Cal-Sag	99	100	96	99	90	92	82	74
104th Avenue	Cal-Sag	100	100	97	98	92	87	83	71
Route 83	Cal-Sag	99	100	96	98	91	85	78	69

Chapter 4 – INTEGRATED STRATEGIES FOR COMPLIANCE WITH THE DO STANDARDS PROPOSED BY THE IEPA

4.1 Background

In this chapter the integrated strategies needed to comply with the minimum DO standards proposed by the IEPA (described in detail in Section 1.2) are developed. Two levels of compliance were examined: full (100%) compliance and 90% compliance. The 90% compliance scenario was evaluated for consistency with the earlier planning evaluations of 90% compliance with a 5 mg/L DO standard at all times throughout the year done in support of the UAA process by Alp and Melching (2006) and CTE (2006, 2007a-c).

4.2 Missing Ammonium as Nitrogen Data Problem

With respect to the 100% compliance scenario and the MWRDGC DO standards evaluated in Chapter 5, the evaluation for WY 2003 required careful consideration. When initially evaluating the compliance of simulated DO concentrations with the DO standards proposed by the MWRDGC some unexpected results were encountered in the South Branch Chicago River and the CSSC upstream from the Stickney WRP. For a simulation including a continuous transfer of 24 MGD of aerated effluent from the NSWRP to Wilmette, it was found that the DO concentrations in the South Branch Chicago River and upper CSSC frequently did not meet the proposed 3.5 mg/L standard during dry weather flow from February 4 to April 20, 2003. Noncompliance with the proposed DO standard was not found during the same period in WY 2001. Thus, an analysis was done to determine the nature of the low DO in February to April 2003, and what to do about it in formulating water-quality management scenarios.

Comparing the calibration results for the South Branch Chicago River and CSSC in Tables 3.13 and 3.14 for WYs 2001 and 2003, respectively, one can see that for the Fall (September-November), Winter (December-February), and Summer (June-August) the model performance (as compared to the measured data) is similar for both water years. However, for Spring (March-May) the simulated DO concentrations substantially underestimate the measured concentrations by at least 1.1 mg/L (on average) in the region of interest during WY 2003 whereas in WY 2001 the simulated DO concentrations are essentially equal to or overestimate (on average) the measured concentrations.

The low simulated DO concentrations in the winter of both years are attributed to density currents resulting from the use of road salt in the winter (see Section 3.5.2). However, the cause of the low simulated DO concentrations in the spring of WY 2003 at first was unclear (i.e. it is unlikely road salt was needed until the end of April in 2003). Figure 3.28 shows that at Jackson Boulevard in WY 2001 the period of underestimation lasts from late November to early February (i.e. the winter period), whereas for WY 2003 the period of underestimation lasts from late November to early May. Moving upstream to Division Street, Figure 3.26 shows similar periods of underestimation in WYs 2001 and 2003, in particular, underestimated DO concentrations result from late November until mid-April of WY 2003. Therefore, the cause of the low simulated DO concentrations in WY 2003 must come from upstream on the North Branch Chicago River or the North Shore Channel.

Figure 4.1 shows the effluent ammonium as nitrogen concentrations from the North Side WRP for WYs 2001 and 2003. The measured effluent ammonium as nitrogen concentration for January 1 to April 30, 2001 was not included in the MWRDGC's on-line database of daily WRP effluent quality, and a long term average ammonium as nitrogen concentration of 0.4 mg/L was used in the DUFLOW model for this period. However, as shown for WY 2003 in Figure 4.1, ammonium as nitrogen concentrations that were discharged in the North Side WRP effluent during the winter were greater than the long-term average. Thus, had the true ammonium as nitrogen concentrations been available for WY 2001, the simulated DO concentrations in WY 2001 would have been lower and similar to those in WY 2003. Because the model was calibrated to 2001 conditions (using the erroneous North Side WRP ammonium as nitrogen effluent data), this adversely affects interpretation of simulation results for January to April 2003.

Solution

In the long term, the nitrification rate should be recalibrated for the North Shore Channel and upper North Branch Chicago River (reaches 1-2.2) where the current value of 1.2 is beyond the normal maximum of 1.0 (according to Brown and Barnwell, 1987). This recalibration would involve applying the actual daily effluent ammonium as nitrogen values for January-April 2001 for the North Side WRP effluent that were found by the Monitoring and Research Division of the MWRDGC in October 2009, after the calibration and verification in Chapter 3 were completed. The recalibration of the nitrification rate considering both WYs 2001 and 2003, also may require adjustments to some of the other model parameters on a reach-wise basis.

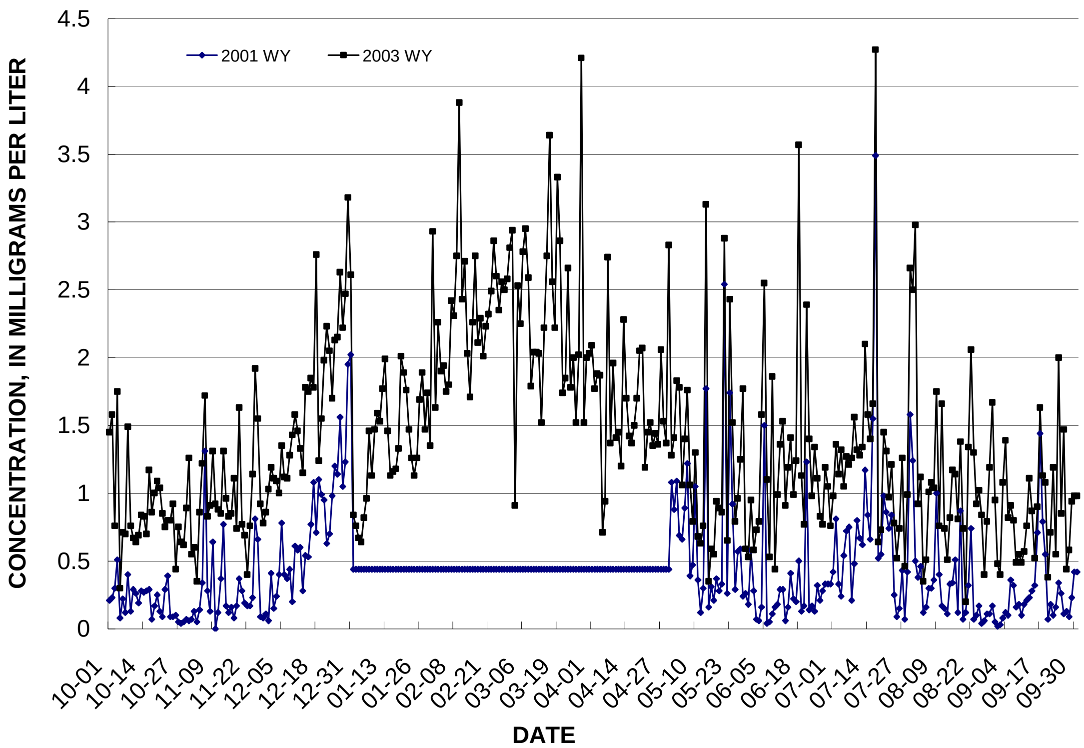


Figure 4.1 Ammonium as nitrogen concentration in the North Side Water Reclamation Plant effluent for water years 2001 and 2003.

The end result of the recalibration of the nitrification rate on simulated DO concentrations would be a reduction of the DO consumption due to nitrification in the winter and spring of WY 2003 relative to the current simulations, such that the simulation results for these periods are similar to the current results for WY 2001. That is, in the current simulations for WY 2001, the DO consumption due to nitrification in spring is low because of the artificially low effluent ammonium as nitrogen concentrations. Given that the current performance in spring 2001 is good, the recalibrated model should aim for similar performance in both WYs. The DO consumption due to nitrification in the winter of WY 2003 also would decrease relative to the current simulations. However, the density current related problem will prevent close agreement between the simulated and observed DO concentrations in the winter.

Recalibration of the model could take up to 2 months. Thus, because the correct data were found relatively late in the project, the evaluation of scenarios for compliance with the various proposed DO standards were evaluated as follows in this project. The low simulated DO concentrations from January to April 2003 do not represent true DO conditions during this period, and the recalibrated model probably would show a closer match to the measured DO concentrations. Thus, the evaluation was done excluding the hourly simulated DO concentrations from January to April 2003 (effectively assuming full compliance during this period), and the proposed remedial measures on the North Shore Channel, North Branch Chicago River, Chicago River Main Stem, South Branch Chicago River and CSSC is focused on compliance in October through December 2002 and May through September 2003. Further, the measured hourly DO concentrations shown in Figures 3.25-3.28 indicate that DO concentrations below the proposed DO standards did not occur often in the period of January through April in either 2001 or 2003 and a review of measured DO concentrations in the same period on other years indicated that this is a general case. Thus, the assumption of full compliance without additional aeration in January through April 2003 is supported by the measured DO concentrations. The Little Calumet River (North) and Calumet-Sag Channel are not affected by this problem and the full WY 2003 is considered for these waterways. If the model is to be used in the future to further refine the proposed remediation plan/scenario, the nitrification rate (and other affected parameters) will be recalibrated to yield better simulated results in the spring of both WYs while maintaining good simulation quality in fall and summer.

4.3 90% Compliance Scenario

4.3.1 Locations needing remedial measures

The first step in developing the 90% compliance scenario is to determine the locations in the CWS that currently do not meet the IEPA proposed DO standards 90% of the time. For the measured DO concentrations the percentage compliance was computed as the number of DO concentrations divided by the total number of measured DO concentrations. Thus, if the DO concentrations during the periods of missing data more frequently met the DO standard than DO concentrations during the periods with measured concentrations the percentage compliance for the measured DO concentrations would underestimate the true percentage compliance.

On the Chicago River Main Stem both the simulated and measured DO concentrations indicated 100% compliance for WY 2003 and between 98.3 and 100% compliance for WY 2001 with the IEPA proposed DO standards at the Chicago River Controlling Works, Clark Street, and Michigan Avenue. Figures 4.2 and 4.3 show the percentage compliance with the IEPA proposed DO standards achieved by the measured and simulated DO concentrations for WYs 2001 and 2003, respectively, along the North Shore Channel, North Branch Chicago River, South Branch Chicago River, and CSSC. Figures 4.4 and 4.5 show the percentage compliance with the proposed DO standards achieved by the measured and simulated DO concentrations for WYs 2001 and 2003, respectively, along the Little Calumet River (North) and Calumet-Sag Channel. Figure 4.6 shows the percentage compliance with the proposed DO standards achieved by the simulated DO concentrations for WYs 2001 and 2003 and the measured DO concentrations for WY 2003 at I-55 on Bubbly Creek (note: no measured DO concentrations were available for WY 2001). These figures show that the upper North Shore Channel (Linden Street, Simpson Street, and Main Street), Bubbly Creek (for WY 2001 only), and Cicero Avenue on the CSSC (for WY 2001 only) do not meet the proposed DO standards 90% of the time on the basis of simulated and/or measured DO concentrations. Thus, remedial measures need to be developed for these locations.

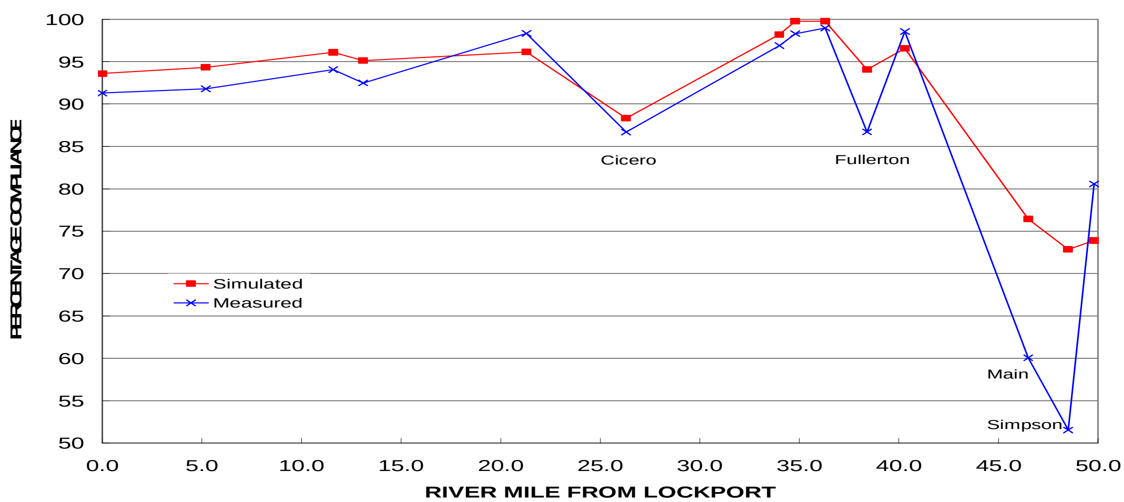


Figure 4.2 Simulated and measured compliance with the IEPA proposed dissolved oxygen standards for Water Year 2001 along the North Shore Channel, North Branch, South Branch, and Chicago Sanitary and Ship Canal.

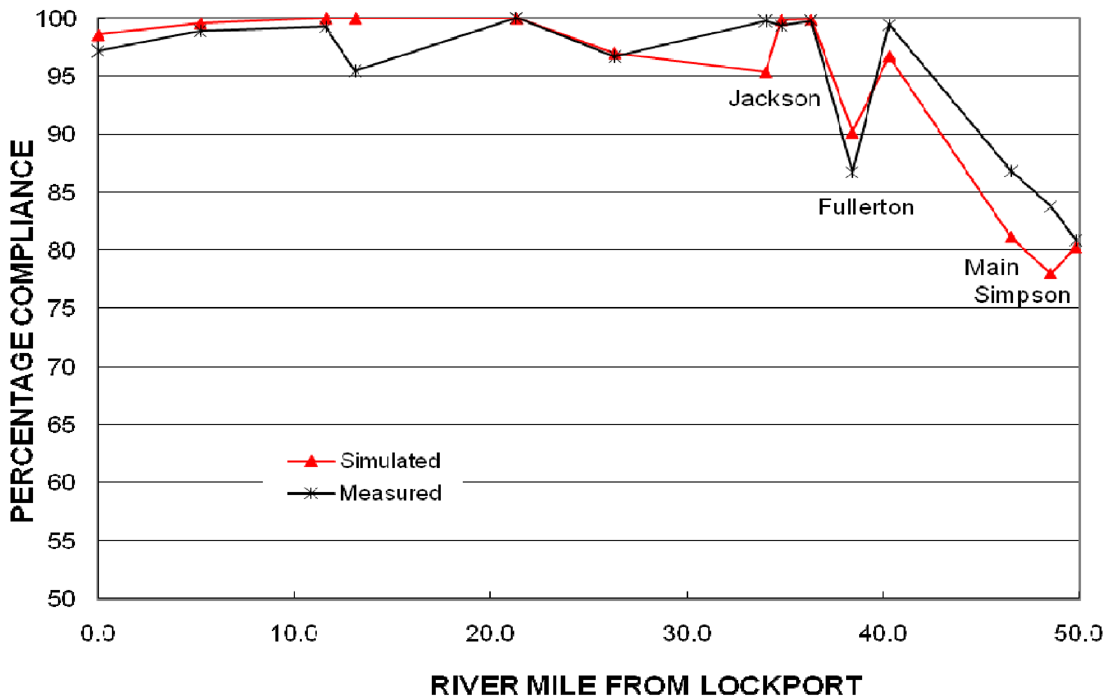


Figure 4.3 Simulated and measured compliance with the IEPA proposed dissolved oxygen standards for Water Year 2003 along the North Shore Channel, North Branch, South Branch, and Chicago Sanitary and Ship Canal.

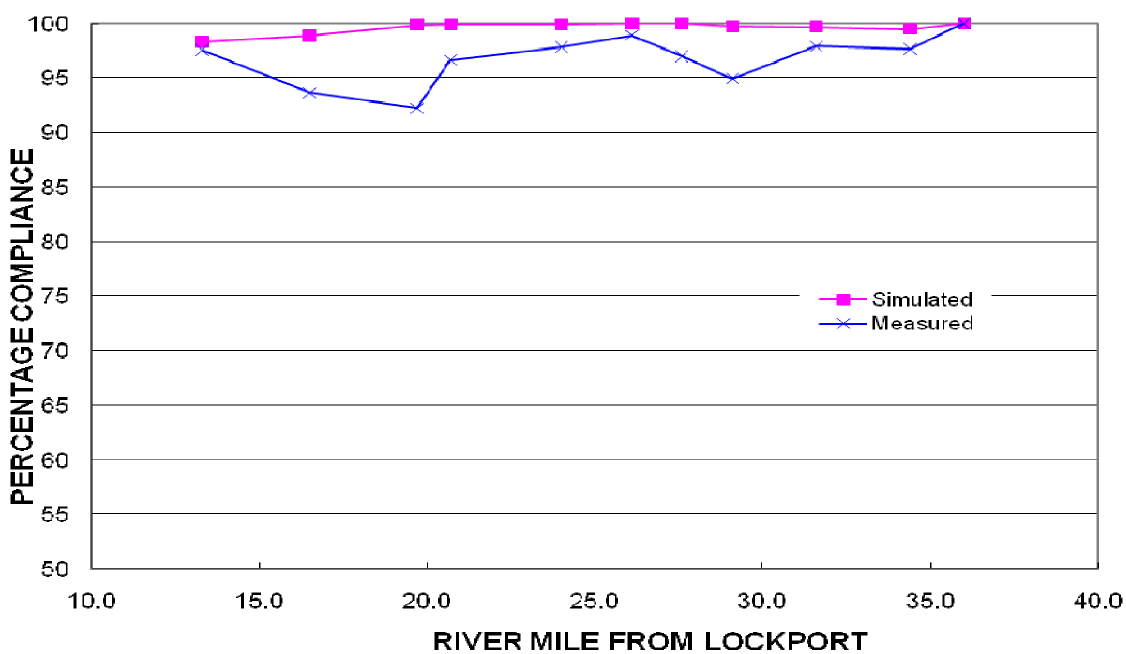


Figure 4.4 Simulated and measured compliance with the IEPA proposed dissolved oxygen standards for Water Year 2001 along the Little Calumet River (North) and Calumet-Sag Channel.

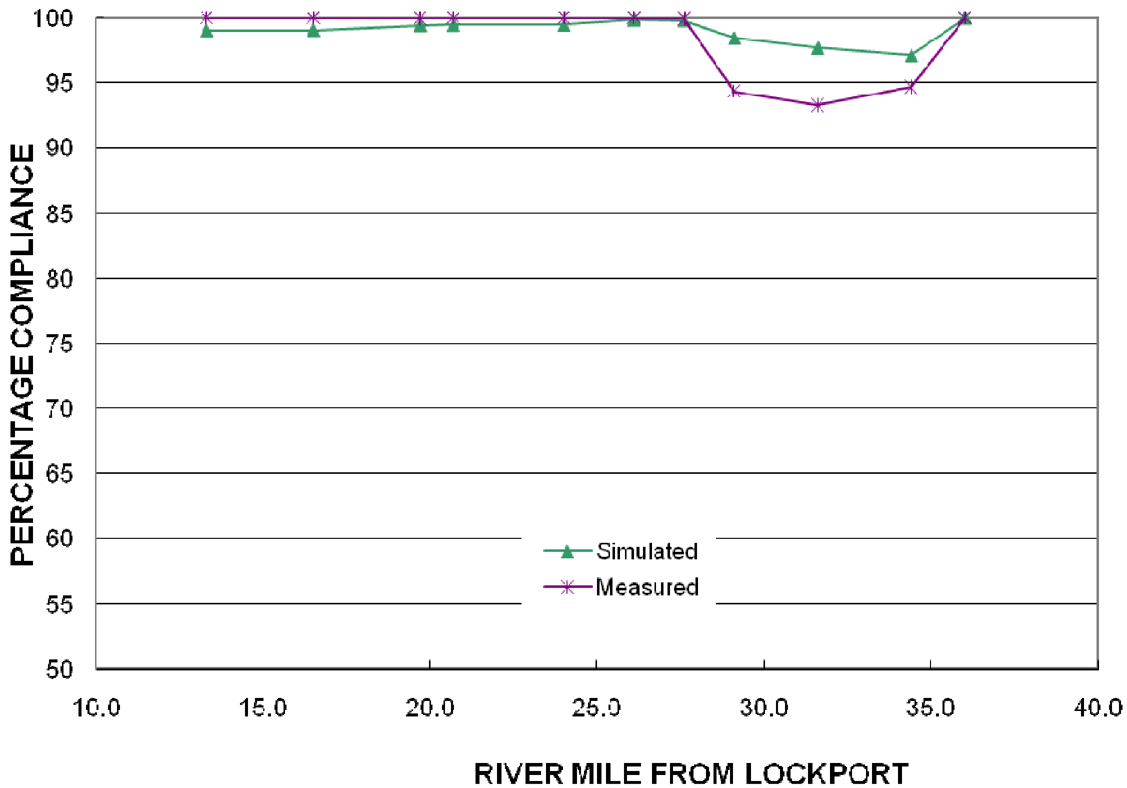


Figure 4.5 Simulated and measured compliance with the IEPA proposed dissolved oxygen standards for Water Year 2003 along the Little Calumet River (North) and Calumet-Sag Channel.

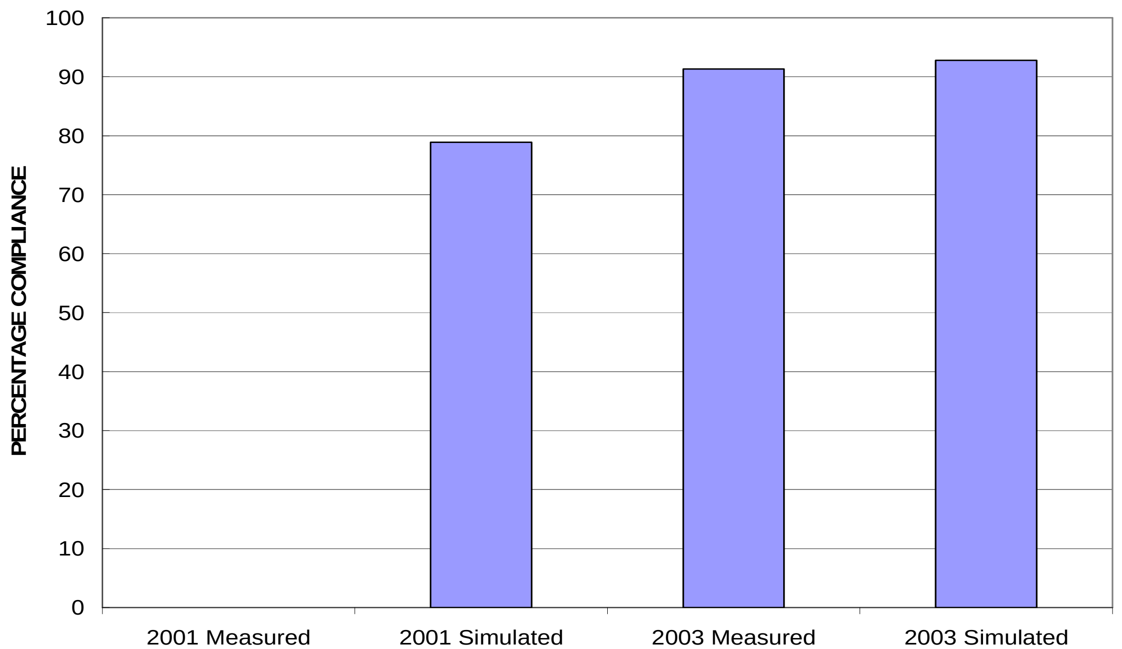


Figure 4.6 Measured and simulated compliance with the IEPA proposed dissolved oxygen (DO) standards on Bubbly Creek at Interstate 55. (note: no measured DO data were available for WY 2001 at this location)

Figures 4.2 and 4.3 show that the measured DO concentrations at Fullerton Avenue on the North Branch Chicago River also do not meet the proposed DO standards 90% of the time (each year achieves 86.7% compliance), whereas the simulated DO concentrations do meet the proposed DO standards 90% of the time. Thus, further analysis is needed to determine whether there is a compliance problem at Fullerton Avenue, and, if so, what to do about it. Similarly, the measured percentage compliance is far smaller than the simulated percentage compliance for Main Street and Simpson Street on the upper North Shore Channel for WY 2001 while the simulated percentage compliance is lower than the measured percentage compliance for WY 2003. Thus, there is uncertainty regarding whether achieving 90% compliance in the simulations will result in 90% compliance in actual operation.

Three factors can affect the differences in the percentage compliance for the simulated and measured DO concentrations. These factors are:

1) Missing measured data—The simulations yield DO concentrations for every hour in the WY under consideration, whereas at each measurement location some data are missing throughout the year. If data were missing during a period of compliance, the percentage compliance computed for the year would be lower than the actual compliance. Table 4.1 lists the percentage of missing data for each DO monitoring location in the CAWS. The large percentages of missing data in WY 2001 in the Little Calumet River (North) and Calumet-Sag Channel is because these monitors were installed in July 2001.

2) Model error relative to the measured DO concentrations.
3) Error in the measured DO concentrations relative to the true cross sectional average DO concentration.

These issues are discussed in detail for each key location in the following subsections.

4.3.1.1 Fullerton Avenue

Table 4.1 indicates that 3.92 and 7.60% of the possible DO measurements are missing for WYs 2001 and 2003, respectively. In each Water Year, the simulated DO concentrations in the periods of missing data were less than the proposed DO standards for 95 hours or 1.1 percent of the entire year. Thus, if the true DO concentrations were similar to the simulated concentrations, DO concentrations at Fullerton Avenue would meet the proposed DO standards more than 90% of the time (86.7 + (7.6-1.1) = 93.2) for WY 2003. Whereas the DO concentrations for WY 2001 would meet the proposed DO standards slightly less than 90% of the time (86.7 + (3.9-1.1) = 89.5).

Figure 4.7 shows the measured percentage compliance with the proposed DO standards for calendar years 2005-2007 along the North Shore Channel, North Branch Chicago River, South Branch Chicago River, and CSSC. For 2006 and 2007, measured DO concentrations met the proposed DO standards more than 90% of the time at Fullerton Avenue and also for each of these years the amount of missing data was less than for other years with no data missing in 2007 and 3.86% of the data missing for 2006. For 2005, the percentage compliance with the proposed DO standards was 85.3%, but also

10.16% of the possible data values were missing. Thus, the low percentage compliance with the proposed DO standards at Fullerton Avenue for measured DO in WYs 2001 and 2003 appears to be the result of missing data. The conclusion that 90% compliance with the proposed DO standards is achieved at Fullerton Avenue determined on the basis of the simulated DO concentrations, thus, is accepted as reasonable, and no remedial measures will be applied to the North Branch Chicago River to meet 90% compliance at Fullerton Avenue.

Table 4.1 Percentage of missing data for Water Years 2001 and 2003 for the dissolved oxygen monitoring locations in the Chicago Waterway System

Location	Waterway	2001	2003
Linden Street	North Shore Channel	34.84	2.02
Simpson Street	North Shore Channel	7.00	24.13
Main Street	North Shore Channel	6.43	4.89
Addison Street	North Branch Chicago River	2.01	5.24
Fullerton Avenue	North Branch Chicago River	3.92	7.60
Division Street	North Branch Chicago River	2.00	1.99
Kinzie Street	North Branch Chicago River	0.07	0.02
Chicago River Controlling Works	Chicago River	4.02	2.28
Michigan Avenue	Chicago River	36.05	4.57
Clark Street	Chicago River	0.09	1.96
Jackson Boulevard	South Branch Chicago River	2.18	0.01
Interstate 55	Bubbly Creek	100.0	5.78
Cicero Avenue	Chicago Sanitary and Ship Canal	0.35	11.65
Baltimore and Ohio Railroad	Chicago Sanitary and Ship Canal	3.21	8.34
River Mile 11.6	Chicago Sanitary and Ship Canal	4.83	5.65
Romeoville	Chicago Sanitary and Ship Canal	3.32	3.90
130th Street	Calumet River	78.93	14.89
Conrail Railroad	Little Calumet River (north)	79.54	19.19
Central and Wisconsin Railroad	Little Calumet River (north)	77.66	1.63
Halsted Avenue	Little Calumet River (north)	77.68	1.96
Division Street	Calumet-Sag Channel	77.66	1.93
Kedzie Street	Calumet-Sag Channel	77.67	3.87
Cicero Avenue	Calumet-Sag Channel	79.59	1.94
River Mile 20.7	Calumet-Sag Channel	81.50	10.32
Southwest Highway	Calumet-Sag Channel	85.33	8.00
104th Avenue	Calumet-Sag Channel	80.23	12.05
Route 83	Calumet-Sag Channel	4.04	21.12

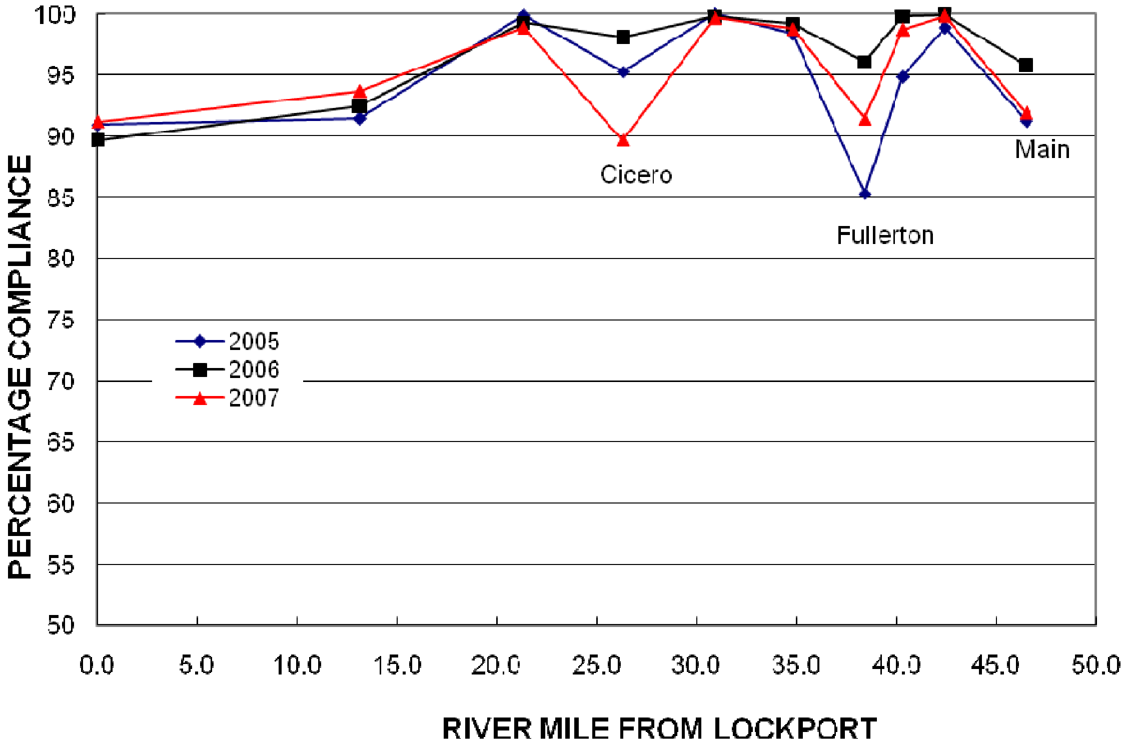


Figure 4.7 Measured percentage compliance with the IEPA proposed dissolved oxygen standards for calendar years 2005-2007 along the North Shore Channel, North Branch, South Branch, and Chicago Sanitary and Ship Canal.

4.3.1.2 Upper North Shore Channel

The following table lists the percentage compliance with the proposed DO standards for the measured and simulated DO concentrations and the percentage of missing data for WYs 2001 and 2003 for the DO monitoring locations on the upper North Shore Channel. The compliance percentages for the measured data were computed from calendar year data provided by the District where percentage compliance equals the number of hours meeting the standard divided by the number of hours with measured DO concentrations at that location.

Location	2001			2003		
	Measured	Simulated	Missing	Measured	Simulated	Missing
Linden Street	80.57	73.89	34.84	80.90	80.27	2.02
Simpson Street	51.53	72.85	7.00	83.76	78.00	24.13
Main Street	60.06	76.44	6.43	86.81	81.15	4.89

The primary concern here is that the simulated results indicate much higher compliance with the proposed DO standards at Simpson Street and Main Street for WY 2001 than do the measured DO concentrations. This comparison implies that a remediation scenario that achieves 90 or 100% compliance in the simulations might not achieve 90 or 100% compliance in the actual case. Thus, the difference in compliance for the measured and simulated DO concentrations requires further analysis.

Unlike Fullerton Avenue, the difference here cannot be completely attributed to missing data because the amount of missing data is substantially smaller than the difference in compliance and at these locations it is not reasonable to assume that the vast majority of the missing data would be for periods of compliance. The MWRDGC does quality assurance (QA) measurements at each DO monitoring location three times per year—roughly April or May, August, and October or November. In these QA measurements DO concentrations are measured at multiple points (typically at 3 depths at 3 positions laterally) in the cross section. The average of these point measurements is taken as the cross-sectional mean and is compared to the concentration measured at the continuous monitor. For Main Street, 25 QA measurements are available (1999-2008) and they indicate that on average the continuous monitor value is 0.56 mg/L lower than the cross-sectional mean DO concentration. For Simpson Street, 10 QA measurements are available (1998-2003) and they indicate that on average the continuous monitor value is

1.47 mg/L lower than the cross-sectional mean DO concentration. Thus, the primary reason for the difference in compliance between simulated and measured DO concentrations appears to be that the DO monitors at Simpson Street and Main Street are prone to low DO values relative to the cross-sectional mean concentration. Therefore, it is concluded that scenarios that achieve 90% or 100% compliance with the proposed DO standards on the upper North Shore Channel in the simulations also will achieve 90% or 100% compliance in reality.

4.3.1.3 Lower Calumet-Sag Channel

Since data from calendar years 2005-2007 were used to verify that DO concentrations at Fullerton Avenue meet the proposed DO standards 90% of the time, it was thought that data from these years also should be used to check the percentage compliance along the Little Calumet River (North) and Calumet-Sag Channel. Figure 4.8 shows the percentage compliance with the proposed DO standards for the measured data along the Little Calumet River (North) and Calumet-Sag Channel for calendar years 2005-2007. At Route 83, the measured data did not achieve 90% compliance in any of the years. The percentage compliance and percentage of missing data for these years are as follows:

Year	Compliance	Missing
2005	85.28	4.14
2006	89.22	0.05
2007	87.38	3.88

Thus, because of missing data it is likely that 90% compliance was achieved in calendar year 2007, but just missed (about 89% compliance) in calendar years 2005 and 2006. At 104th Avenue, the measured data did not achieve 90% compliance in either 2006 or 2007, but each of these years had large percentages of missing data—17.98 and 41.32%, respectively—thus, it is likely that 90% compliance truly was achieved at 104th Avenue for all three years. Finally, at Cicero Avenue, the measured data did not achieve 90% compliance in 2007, but again a large percentage (13.42%) of the data were missing in this year, and it is likely that 90% compliance truly was achieved at Cicero Avenue in 2007. In summary, it is reasonable to assume that the Little Calumet River (North) and Calumet-Sag Channel already meet the proposed DO standards 90% of the time, and no remedial measures will be evaluated for these waterways for the 90% compliance scenario.

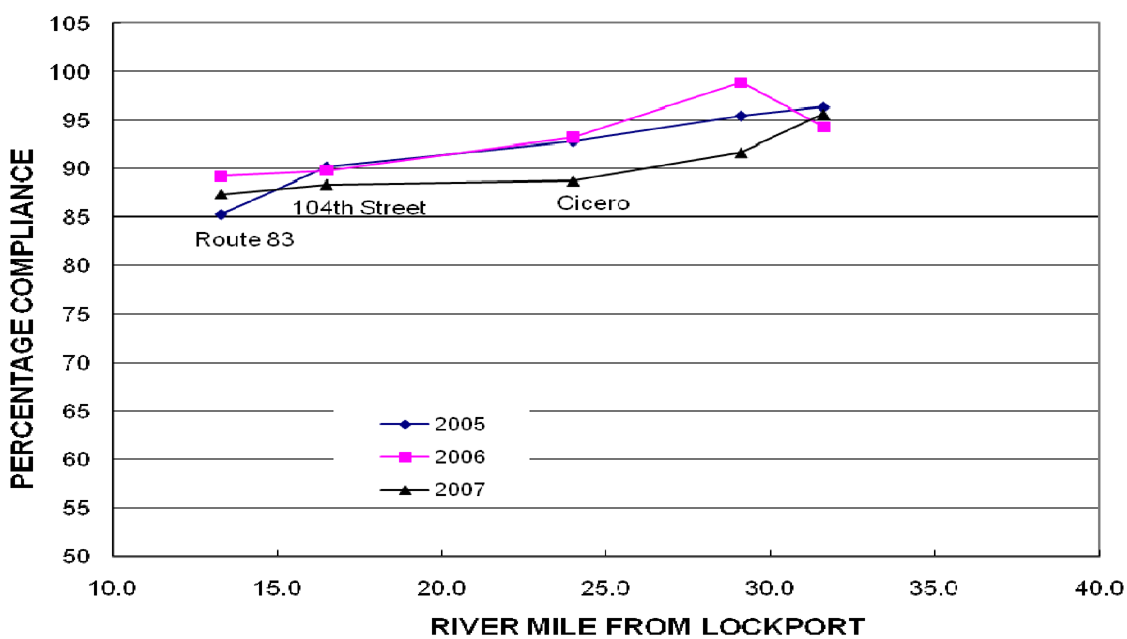


Figure 4.8 Measured percentage compliance with the IEPA proposed dissolved oxygen standards for calendar years 2005-2007 along the Little Calumet River (North) and Calumet-Sag Channel.

4.3.2 Components of the Integrated Strategy for 90% Compliance

4.3.2.1 Flow Transfer for the Upper North Shore Channel

Figure 4.9 shows the percentage compliance with the proposed DO standards on the Upper North Shore Channel (UNSC) at Main Street as a function of the transferred amount of aerated effluent from the North Side WRP to the upstream end of the UNSC at Wilmette. From Figure 4.9, it can be seen that transfer of 29 MGD is needed to achieve at least 90% compliance at Main Street for both WYs 2001 and 2003. Further, a transfer of 30 MGD is needed to achieve at least 90% compliance throughout the entire UNSC. This transfer of 30 MGD is far smaller than the 90 MGD needed to achieve 90% compliance with a DO standard of 5 mg/L at Main Street reported in Alp and Melching (2006) or 100 MGD needed to achieve 90% compliance with a DO standard of 5 mg/L throughout the UNSC (CTE, 2007b). This large difference results from the fact that in the proposed DO standards 5 mg/L does not need to be met in August, September, and October as compared to the case evaluated by Alp and Melching (2006) and CTE (2007b). Figure 4.10 shows the improvement in DO concentrations resulting from the 30 MGD transfer of aerated effluent for WY 2001.

Figure 4.9 also indicates that the proposed DO standard can be met at Main Street at least 94.5% of the time for both WYs 2001 and 2003 with a transfer of 40 MGD of aerated effluent. This means that the proposed DO standards would not be met for a period of approximately 20 days. One hundred percent compliance can probably be more efficiently achieved by adding aeration stations that would only operate as needed on these 20 days rather than by a continuously operating flow transfer. Therefore, the 100% compliance scenario will be developed combining an aerated flow transfer of 40 MGD with the placement and operation of instream aeration stations along the UNSC.

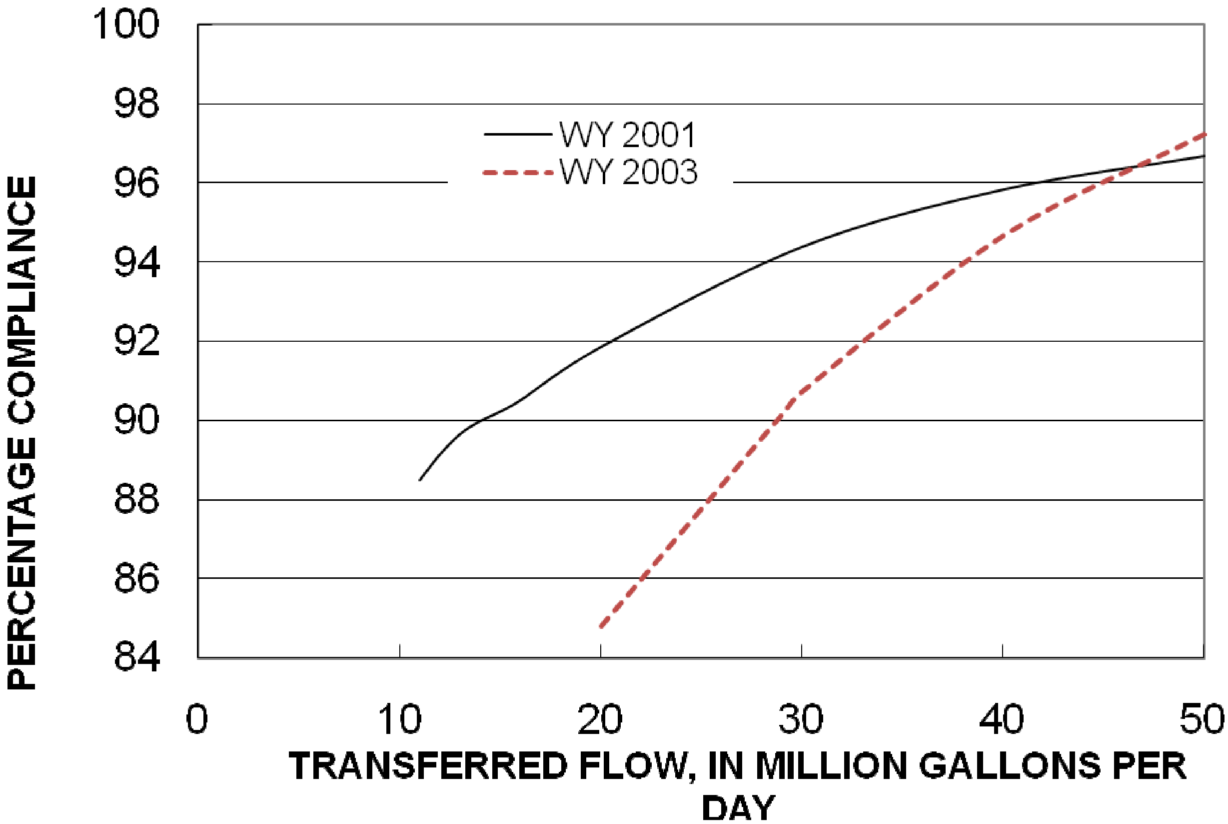
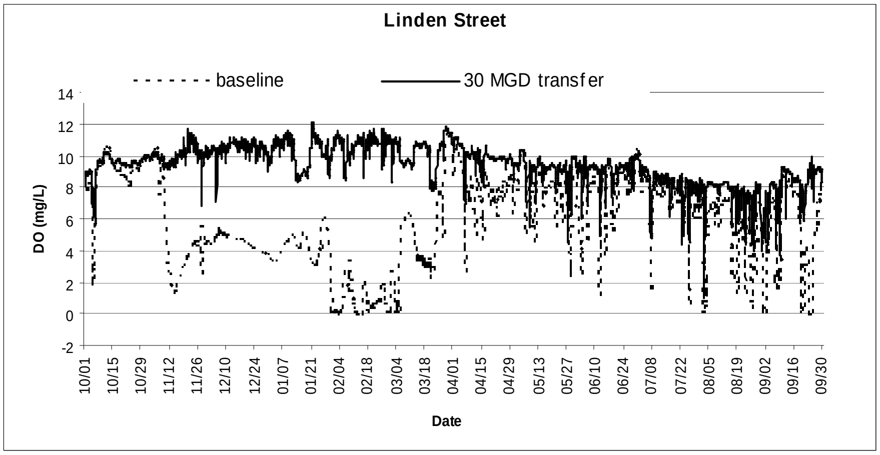
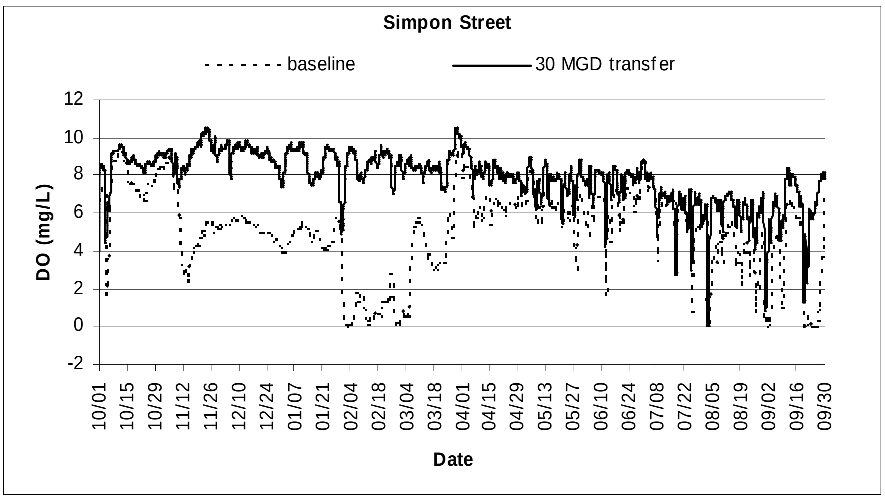


Figure 4.9 Percentage compliance with the IEPA proposed dissolved oxygen standards at Main Street on the Upper North Shore Channel (UNSC) as a function of the transfer of aerated effluent from the North Side Water Reclamation Plant to the upstream end of the UNSC.





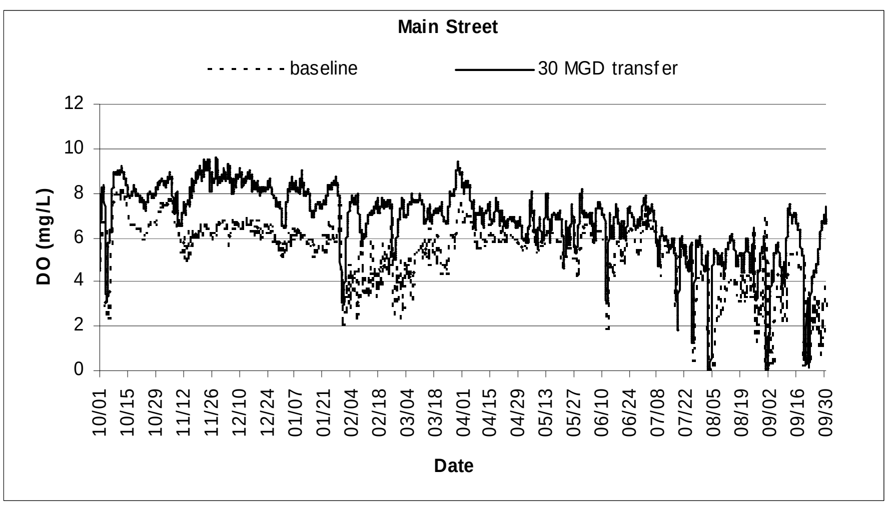


Figure 4.10 Simulated hourly DO concentrations at Linden Street, Simpson Street, and Main Street on the NSC for a 30 MGD transfer of aerated effluent from the NSWRP to the upstream end of the NSC compared with baseline simulated concentrations for WY 2001

4.3.2.2 Flow Transfer for Bubbly Creek

When considering flow transfers from the South Branch of the Chicago River (SBCR) to the upstream end of Bubbly Creek the maximum amount of the transfer is limited to a flow that will not scour the bottom sediments in Bubbly Creek. The sediment quality in Bubbly Creek is considered to be very poor and resuspension of these sediments would substantially degrade water quality in Bubbly Creek and the CSSC. The two-dimensional (2-D) and three-dimensional (3-D) modeling of water quality in Bubbly Creek being done by the University of Illinois at Urbana-Champaign (UIUC) and related measurements of sediment mobility may eventually define a best estimate of the true upper bound on flow transfer for Bubbly Creek. However, in this study the best available information was used to set the maximum flow transfer. On the basis of preliminary runs of the 2-D model, Motta et al. (2009) suggested that for a recirculation discharge of 50 MGD sediment resuspension from the bed is avoided. In 2003, the MWRDGC conducted a series of field tests of creating flow in Bubbly Creek by drawing water from the creek into the Racine Avenue Pumping Station and sending it to the Stickney WRP for treatment. In these experiments, Bubbly Creek flow was maintained at 38 MGD for six days or 75 MGD for five days during each demonstration event (Sopcek, 2004). Since sediment resuspension was not reported as a product of these demonstration events, 75 MGD has been set as the maximum flow transfer in the simulations evaluated here.

Aerated Flow Transfer

As was done in Alp and Melching (2006), flow was withdrawn from the SBCR at Throop Street, aerated to saturation, and inserted at the upstream end of Bubbly Creek. In order to compute the saturated DO concentration, the water temperature at Throop Street was determined by linear interpolation from the hourly temperature data at Jackson Boulevard and Cicero Avenue (the nearest upstream and downstream, respectively, monitoring stations for the time periods under consideration). The concentrations of all other constituents in the transferred flow were the computed values for Throop Street assuming an aerated flow transfer of 30 MGD on the upper NSC and the actual operations of the Devon Avenue and Webster Avenue in-stream aeration stations.

Figures 4.11 and 4.12 show the percentage compliance along Bubbly Creek for different amounts of aerated flow transfer for WYs 2001 and 2003, respectively. As can be seen from the figures, an aerated flow transfer of 10 MGD achieves at least 90% compliance along all of Bubbly Creek for both WYs 2001 and 2003. Further this transfer raises the compliance at Cicero Avenue to 91.6% for WY 2001.

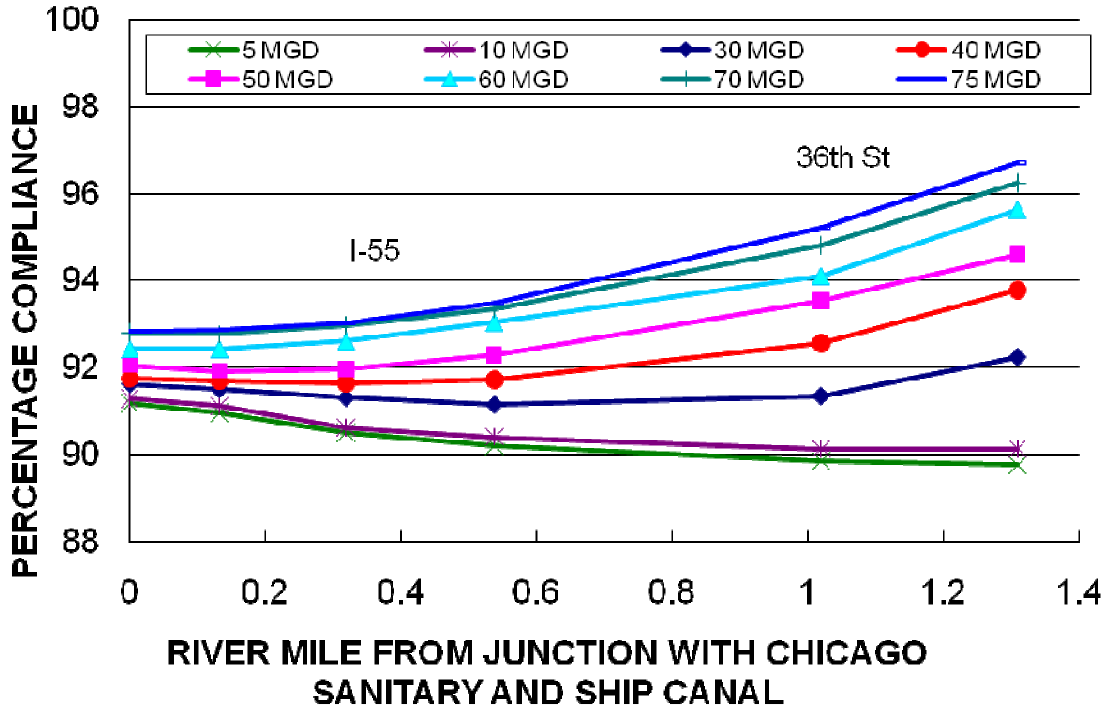


Figure 4.11 Simulated compliance with the IEPA proposed dissolved oxygen standards for Water Year 2001 along Bubbly Creek for different amounts (in million gallons per day, MGD) of aerated flow transfer.

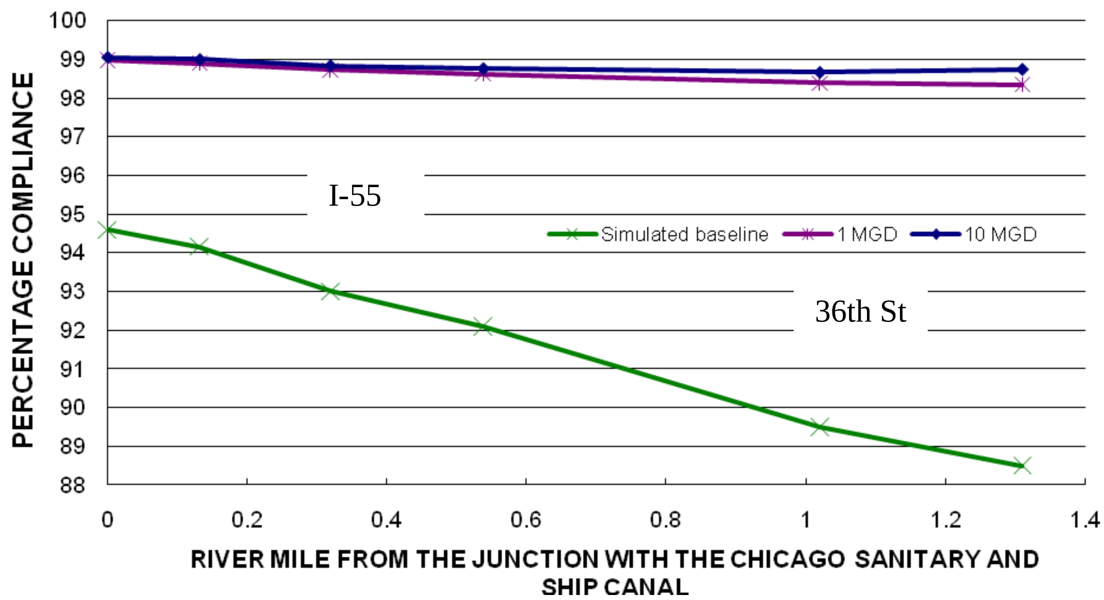


Figure 4.12 Simulated compliance with the IEPA proposed dissolved oxygen standards for Water Year 2003 along Bubbly Creek for different amounts (in million gallons per day, MGD) of aerated flow transfer.

Finally, for WY 2001 a transfer of 10 MGD of aerated flow to the upstream end of Bubbly Creek yields a minimum percentage compliance of 90.13% (at 36th Street) whereas a transfer of 75 MGD of aerated flow yields a minimum compliance of 92.83% (at the junction with the CSSC). For 90.13% compliance supplemental aeration would be required for about 36 days, whereas for 92.83% compliance supplemental aeration would be needed for about 26 days. Thus, a transfer of 7.5 times more flow would only reduce the time that supplemental aeration is needed by 10 days. It seems that these 10 days can more effectively be raised to full compliance via supplemental aeration. Thus, for the 100% compliance scenario a transfer of 10 MGD of aerated flow will be applied.

Unaerated Flow Transfer

For the evaluation of unaerated flow transfer, the simulated concentrations of all water-quality constituents, including DO, at Throop Street were used for the transferred flows. The concentrations of all constituents were computed assuming an aerated flow transfer of 30 MGD on the upper NSC and the actual operations of the Devon Avenue and Webster Avenue in-stream aeration stations. Figures 4.13 and 4.14 show the percentage compliance along Bubbly Creek for different amounts of unaerated flow transfer for WYs 2001 and 2003, respectively. For WY 2003, the transfer of 30 MGD of aerated flow on the upper NSC results in greater than 90% compliance with the proposed DO standard throughout Bubbly Creek. Whereas, for WY 2001, a transfer of 70 MGD of unaerated flow from Throop Street to the upstream end of Bubbly Creek results in 90% compliance with the proposed DO standard throughout Bubbly Creek (Figure 4.13). Further the transfer of 70 MGD raises the compliance at Cicero Avenue to 92.5% for WY 2001.

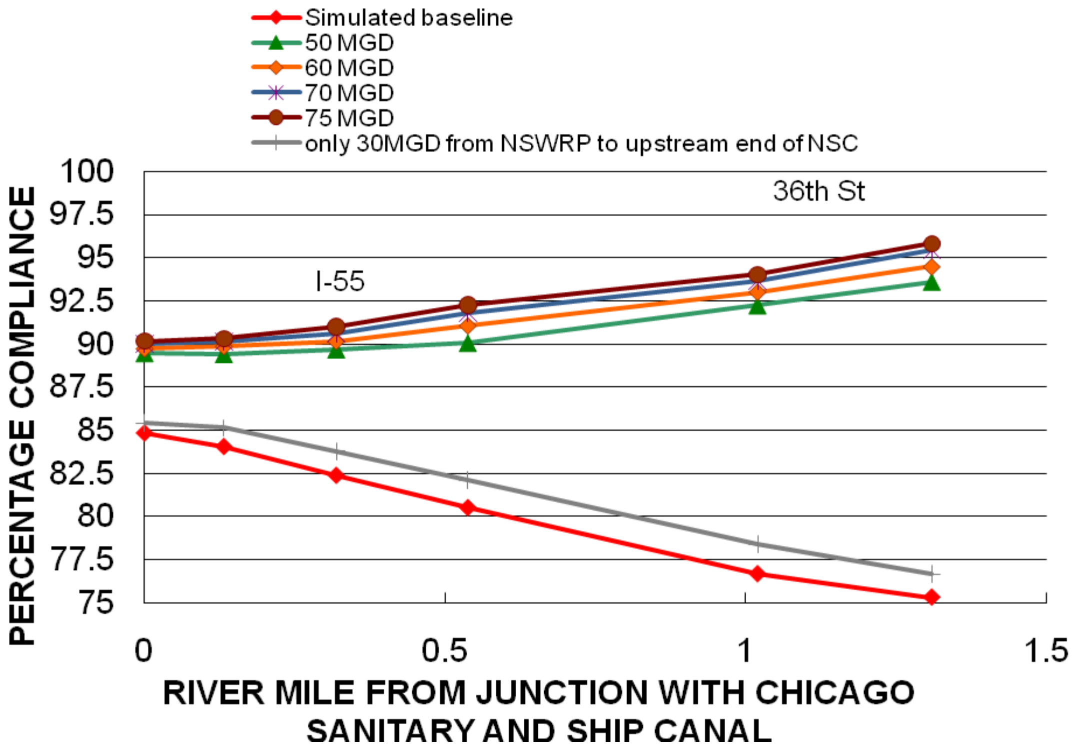


Figure 4.13 Simulated compliance with the IEPA proposed dissolved oxygen standards for Water Year 2001 along Bubbly Creek for different amounts (in million gallons per day, MGD) of unaerated flow transfer.

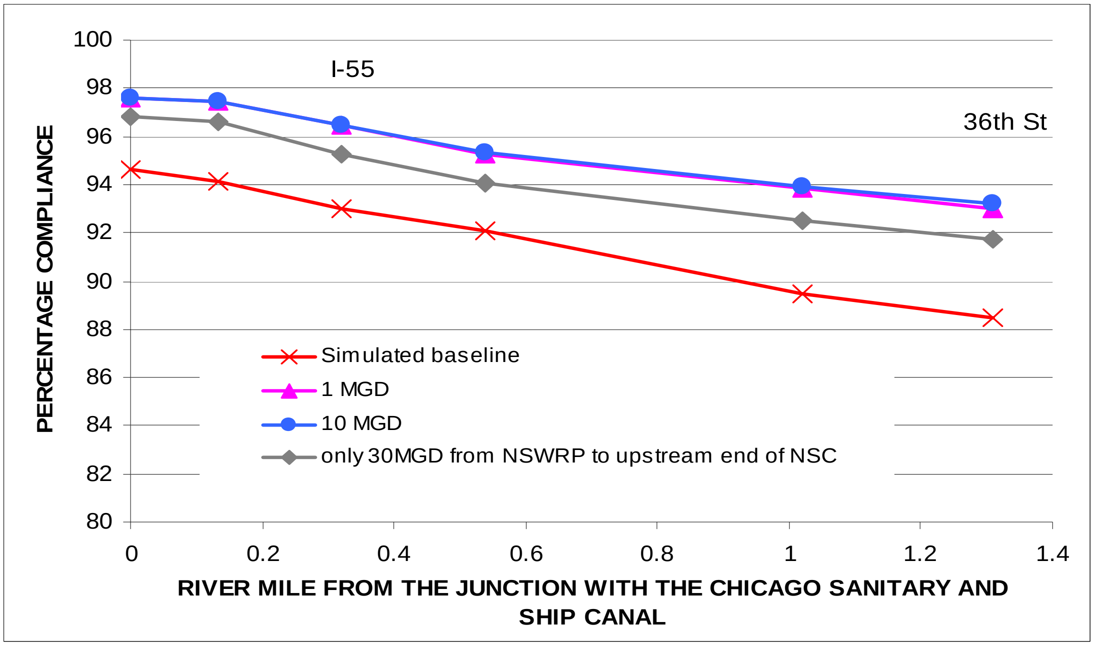


Figure 4.14 Simulated compliance with the IEPA proposed dissolved oxygen standards for Water Year 2003 along Bubbly Creek for different amounts (in million gallons per day, MGD) of unaerated flow transfer.

Figure 4.15 compares the relative effectiveness of 10 MGD of aerated flow and 70 MGD of unaerated flow in increasing DO concentrations at I-55 Bridge on Bubbly Creek. It is clear that the aerated flow transfer is much more effective in improving DO and, thus, only aerated flow transfer is considered in developing the integrated strategy for 100% compliance.

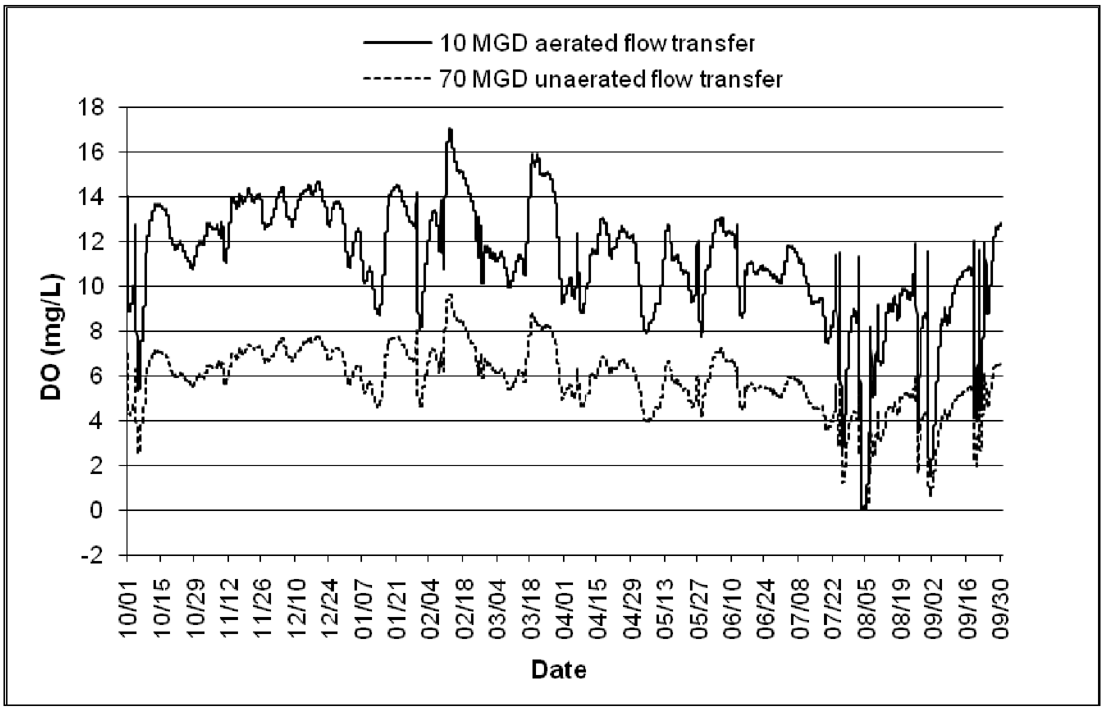


Figure 4.15 Comparison of flow augmentation effectiveness with and without aeration along Bubbly Creek for WY 2001 at I-55

4.4 100% Compliance Scenario

4.4.1 Flow Transfer Components

The 100% Compliance Scenario will involve aerated flow transfers from the North Side WRP to the upstream end of the North Shore Channel, the South Branch of the Chicago River to the upstream end of Bubbly Creek, and from the Calumet WRP to the O'Brien Lock and Dam on the Calumet River. The transfers from the North Side WRP and from the South Branch of the Chicago River have already been discussed in Sections 4.3.2.1 and 4.3.2.2. The results have shown that a transfer of 40 MGD of aerated effluent from the North Side WRP to the upstream end of the North Shore Channel and of 10 MGD of aerated flow from the South Branch of the Chicago River to the upstream end of Bubbly Creek seem to maximize the relative improvement in the percentage compliance that can be achieved by flow transfer, and the remaining periods that do not achieve compliance will be best remediated by the addition of aeration stations.

For the actual conditions of WYs 2001 and 2003, the proposed DO standards were met more than 90% of the time between the O'Brien Lock and Dam and the Calumet WRP. Thus, there was no need for additional aeration resources for the 90% compliance scenario. However, achievement of 100% compliance in this reach will require additional aeration resources. In the rough-cut evaluation (Alp and Melching, 2008b) 100% compliance was evaluated assuming aerated flow transfer only. The proposed DO standards could be met in WY 2001 with a constant transfer of 182.6 MGD (or the actual total flow from the plant, whichever is smaller [about 15% of flows are smaller than this value]) of aerated effluent. This flow value is more than half of the rated capacity of the plant and is greater than the typical minimum flow of about 130 MGD from the plant. Thus, it is clear that a combination of aerated flow transfer and new aeration stations is the best means to achieve 100% compliance in the reach between the O'Brien Lock and Dam and the Calumet WRP.

For WY 2001 a high percentage compliance with the proposed DO standards is achieved for every level of aerated flow transfer from the Calumet WRP to the O'Brien Lock and Dam (Fig. 4.16). Thus, WY 2003 is the critical year to determine the flow that maximizes the effectiveness of the flow transfer. The simulated percentage compliance for a variety of flow transfer values for WY 2003 is shown in Fig. 4.17. An aerated flow transfer of 30 MGD yields a minimum percentage compliance of 95.18% with the IEPA proposed DO standards at the O'Brien Lock and Dam. This means that the proposed DO standards would not be met for a period of approximately 18 days. One hundred percent compliance can probably be more efficiently achieved by adding aeration stations that would only operate as needed during these 18 days rather than by a continuously operating flow transfer. Therefore, the 100% compliance scenario was developed combining an aerated flow transfer of 30 MGD with the placement and operation of supplemental aeration stations along the Calumet River and Little Calumet River (North).

In addition to the transfer of 30 MGD of aerated effluent from the Calumet WRP to O'Brien Lock and Dam, the locations of new supplemental aeration stations on the Little Calumet River (North) and Calumet-Sag Channel were determined assuming that the SEPA stations were operating at their practical maximum flow rates of two pumps on for SEPA 2 and three pumps on for SEPAs 3, 4, and 5. Table 4.2 lists the increase in pump operation hours relative to the actual operating hours in WYs 2001 and 2003. The simulation results indicated that additional supplemental aeration would be needed to meet the IEPA proposed DO standards on the Little Calumet River (North) and Calumet-Sag Channel. These findings agree with a field study done by the MWRDGC on July 10-

31, 2008, which found that even with 3 pumps on at SEPA stations 3 and 4, the measured DO concentrations downstream from these stations were below the IEPA proposed DO standards (Moran et al., 2009).

Table 4.2 Additional pump operation hours assumed for Sidestream Elevated Pool Aeration (SEPA) Stations 2, 3, 4, and 5 in the determination of an Integrated Strategy to meet the IEPA proposed dissolved oxygen standards for water years (WYs) 2001 and 2003

	WY 2001				WY 2003			
Increase in number of pumps operating	SEPA 2	SEPA 3	SEPA 4	SEPA 5	SEPA 2	SEPA 3	SEPA 4	SEPA 5
0 to 3	4296*	5890	3882	4067	4368*	4497	4518	4436
1 to 3	4464*	2788	4876	4597	4392*	4065	3844	2237
2 to 3	0	80	2	96	0	198	398	1282

* For SEPA 2 there are only 2 pumps, thus, these numbers represent the number of hours changing from 0 to 2 and 1 to 2 pumps on, respectively.

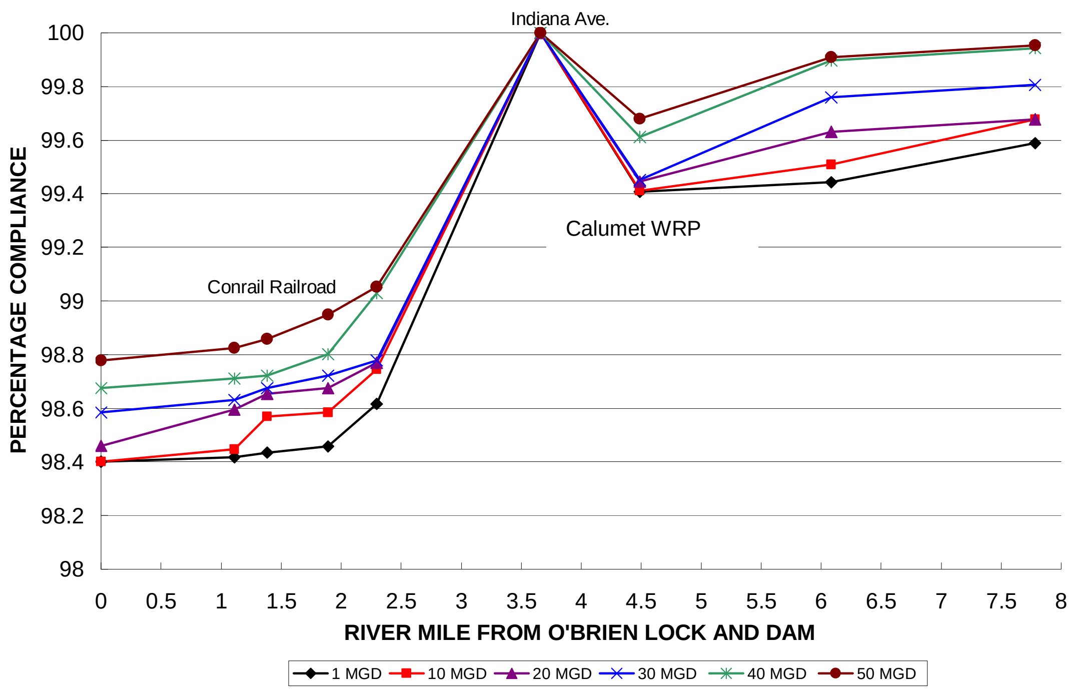


Figure 4.16 Simulated compliance with the IEPA proposed dissolved oxygen standards for Water Year 2001 upstream from O'Brien Lock and Dam to Division Street on the Calumet-Sag Channel (0.6 mi upstream from SEPA station 3) for different amounts (in million gallons per day, MGD) of aerated flow transfer.

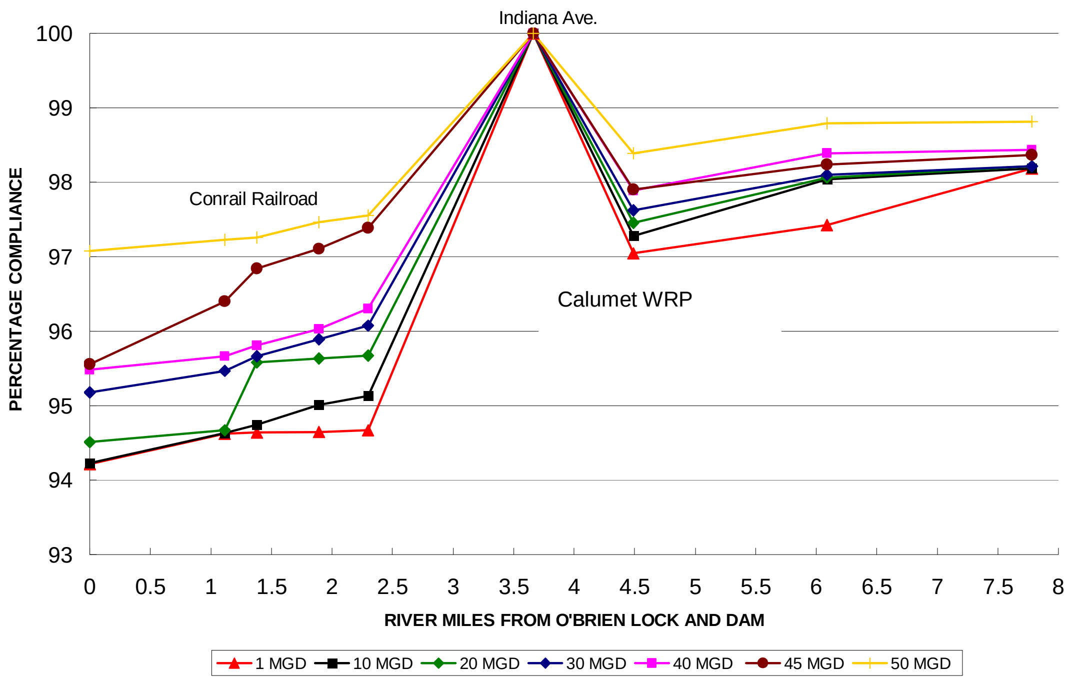


Figure 4.17 Simulated compliance with the IEPA proposed dissolved oxygen standards for Water Year 2003 upstream from O'Brien Lock and Dam to Division Street on the Calumet-Sag Channel (0.6 mi upstream from SEPA station 3) for different amounts (in million gallons per day, MGD) of aerated flow transfer.

4.4.2 Supplemental Aeration Stations

Supplemental aeration stations then were added to the various waterways sequentially beginning at the upstream boundaries and progressing downstream until the IEPA proposed DO standards were met 100% of the time. For the path from the North Shore Channel through the North Branch Chicago River, Chicago River Main Stem, South Branch Chicago River, and the CSSC up to Sag Junction WY 2001 was a more critical period and was used to determine an initial layout of the new supplemental aeration stations. For the path from the Calumet River, Little Calumet River (North), and Calumet-Sag Channel WY 2003 was a more critical period and was used to determine an initial layout of the new supplemental aeration stations. The layout of the new supplemental aeration stations was then determined for the other year using the locations selected in the critical period (critical year) as much as possible. Finally locations of new supplemental aeration stations were determined for the CSSC downstream from Sag Junction for WY 2001 and these locations were then confirmed for WY 2003. In the course of adding these aeration stations the actual operation hours of the Devon Avenue and Webster Avenue in-stream aeration were used in the simulations.

DO loads of 80 grams per second (g/s) were used to try to maintain DO concentrations above 5 mg/L or 3.5 mg/L as appropriate, but in some cases, loads of 100 g/s were needed. As a new aeration station was added, the effect of the new aeration station was observed and another aeration station was added at the location where the DO concentration dropped below the proposed standards. This exercise was a trial and error practice and space available for construction of an aeration station was not considered during the initial selection of aeration station locations. Three of the selected aeration station locations were later modified to consider available space for construction in consultation with AECOM.

Figure 4.18 illustrates the iterative addition of supplemental aeration stations using the upper North Shore Channel as an example. It was decided to place an aeration station at River Mile (RM) 340.8 with a goal to achieve full compliance up to Simpson Street. The operation hours of the aeration station were set as the hours of non-complying DO concentrations at Simpson Street (i.e. 134 hr). This achieved full compliance through

RM 340.2, and, thus, a second aeration station was placed at RM 339.66 with the goal to achieve full compliance up to RM 337.24. The operation hours of the aeration station were set as the hours of non-complying DO concentrations at RM 337.24 (i.e. 214 hr). This achieved 100% compliance through RM 339.5, and, thus, a third aeration station was placed at RM 339.12 with the goal to achieve full compliance up to RM 337.24. The operation hours of the aeration station were initially set as the hours of non-complying DO concentrations at RM 337.24 (i.e. 97 hr), but were increased to 102 hr to account for the flow travel time for some of the non-complying periods. This achieved 100% compliance through RM 339.12, and, thus, a fourth aeration station was placed at RM 338.53 with the goal to achieve full compliance up to the North Side WRP. The operation hours of the aeration station were initially set as the hours of non-complying DO concentrations at RM 337.12 (i.e. 43 hr), but were increased to 222 hr to account for the flow travel time from the aeration station to downstream locations.

In general, the operation hours for the supplemental aeration stations were initially set to the hours of non-complying DO concentrations downstream. If this did not achieve full compliance in the desired reach, the operation hours were increased to start when CSO flows started. If this did not achieve full compliance in the desired reach, the operation hours were increased to start the aeration station 4, 8, or 12 hours before the CSO flows started.

Location	River mile	hours (based on 40MGD NSWRP-Wilmette)	hours (based on 1st AS @SCH000 034)	hours (based on 2nd AS @SCH000 063)	hours (based on 3rd AS @SCH000 065)	hours (based on 4th AS @SCH000 066 (3))
Wilmette	341	5	0	0	0	0
SEC00000:SCH00034 (MDS115-116)	340.8	10	0	0	0	0
SEC00000:SCH00035(MDS114)	340.61	14	0	0	0	0
Central Ave.	340.2	25	0	0	0	0
SEC00001:SCH00037(MDS 112)	339.97	55	2	0	0	0
SEC00001:SCH00063 (MDS 111)	339.66	78	17	0	0	0
SEC00001:SCH00064(MDS-110)	339.61	122	35	0	0	0
Simpson St.	339.5	134	43	0	0	0
SEC00002:SCH00065(MDS108-109)	339.12	166	62	3	0	0
SEC00002:SCH00066(MDS106-107)	338.53	251	116	27	6	0
SEC00002:SCH00067 (MDS105)	338.16	330	181	55	19	0
Main St.	337.5	374	212	75	31	0
SEC00003:SCH00068 (MDS104)	337.45	372	215	84	38	0
SEC00003:SCH00069(MDS103)	337.24	349	214	97	40	0
SEC00003:SCH00077(MDS102)	337.12	293	179	78	43	0
North Side Water Reclamation Plant	336.9	52	16	3	1	0

Figure 4.18 The addition of supplemental aeration stations on the upper North Shore Channel to achieve 100% compliance with the IEPA proposed dissolved oxygen standards for Water Year 2001. The locations marked in yellow are the selected locations for the supplemental aeration stations.

Table 4.3 lists the locations, operation hours, and DO loads of the supplementary aeration stations need to achieve full (100%) compliance with the IEPA proposed DO standards for WYs 2001 and 2003. Simulation results showed 25 new supplementary aeration stations with varying operation hours were needed to achieve the IEPA proposed DO standards for WY 2001. DO profiles along the waterway segments with the 25 new supplementary aeration stations operating are shown in Figures 4.19-4.22. The various periods were selected as examples for the various waterways showing compliance in the March-July period requiring DO concentrations equal to or greater than 5 mg/L and the August-February period requiring DO concentrations equal to or greater than 3.5 mg/L. The August 2-4 period also represents a period with substantial CSO flows in response to a large storm. Thus, this period represents a time when the large number of aeration stations was truly needed to achieve 100% compliance with the IEPA proposed DO standards.

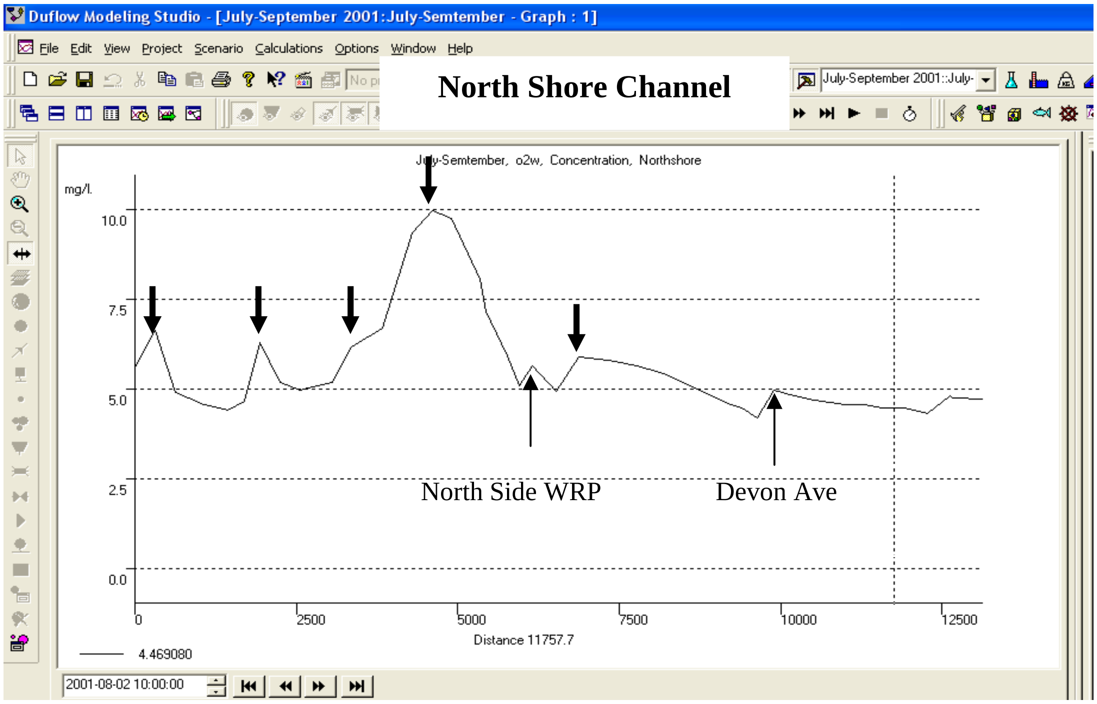
Simulation results showed 16 new supplementary aeration stations with operation hours different from those for WY 2001 were needed to achieve 100% compliance with the IEPA proposed DO standards for WY 2003. The locations, DO loads, and operation hours of the proposed aeration stations are listed in Table 4.3. As shown in the Table 4.3, two new aeration stations would be needed on the upper NSC (the same locations as the first and fourth aeration stations in WY 2001), whereas one aeration station would be needed for the lower NSC. For WY 2003, only one new aeration station on the NBCR (as was needed for WY 2001) was not enough to meet the proposed DO standards. Thus, another new aeration station was added on the NBCR. The DO concentrations in the Chicago River Main Stem already met the proposed DO standards so no new aeration station was needed in WY 2003. Two new aeration stations were needed at the downstream end of the SBCR in WY 2003 corresponding to the final two locations on the SBCR needed for WY 2001. For Bubbly Creek, no new aeration stations would be needed for WY 2003, because flow transfer on the upper NSC, two in-stream aeration stations at Devon Avenue and Webster Avenue, and the seven new aeration stations upstream were sufficient to meet 3.5 mg/L in the creek. Compared to WY 2001, the number of new aeration stations was halved on the CSSC, but the DO concentrations were still above 3.5 mg/L at all locations. However, a transfer of 30 MGD of aerated flow from the Calumet WRP to O’Brien Lock and Dam cannot provide enough DO to meet the proposed DO standards along the Little Calumet River (North), therefore, two new aeration stations were added to the one new aeration station needed for WY 2001 (for a total of three new stations). Similarly, because the four SEPA stations are assumed to operate at full capacity, only two new aeration stations would be needed along the Cal-Sag Channel. Fourteen of the new aeration stations operated with a maximum DO load of 80 g/s, while 2 aeration stations need to operate with a 100 g/s maximum DO load, one on the CSSC and the other on the Little Calumet River (North). Like the simulations for WY 2001, most of the new aeration stations need to turn on 12-hours before the periods of low DO concentrations due to the travel time of flow, whereas the two aeration stations on the NSC needed to operate 24-hours in advance. The locations of the 3 new aeration stations (relative to WY 2001) are shown in Figure 4.23.

Table 4.3 Locations, operation hours and oxygen loads of the supplementary aeration stations in the Chicago Waterway System for 100% compliance with the IEPA proposed dissolved oxygen standards

No.	Waterways	River Mile*	Operation Hours-2001	Operation Hours-2003	Max Loads (g/s)	Locations
1	NSC	340.8	134	233	80	0.20 mi downstream from Wilmette Pumping Station
2	NSC	339.66	214	0	80	0.54 mi downstream from Central Ave.
3	NSC	339.12	102	0	80	0.38 mi downstream from Simpson St.
4	NSC	338.53	113	84	80	0.97 mi downstream from Simpson St.
5	NSC	336.55	222	161	80	0.95 mi downstream from Main St.
6	NBCR	332.99	0	211	80	2.01 mi downstream from Devon Ave.
7	NBCR	331.82	102	30	80	0.78 mi downstream from Wilson Ave.
8	Main Stem	326.9	78	0	80	just upstream of Lake Shore Drive
9	SBCR	325.57	376	0	80	0.03 mi downstream from NBCR Junction
10	SBCR	324.09	84	0	80	1.51 mi downstream from NBCR Junction
11	SBCR	323.52	51	168	80	2.08 mi downstream from NBCR Junction
12	SBCR	321.9	150	183	80	Throop St.
13	Bubbly Creek (BC)	-	946	0	80	0.13 mi upstream from Bubbly Creak Junction
14	BC	-	253	0	80	0.72 mi upstream from Bubbly Creak Junction
15	BC	-	17	0	80	36th St.
16	CSSC	321.1	85	75	100	Damen Ave.
17	CSSC	320.6	46	0	80	Western Ave.
18	CSSC	319.82	99	0	80	0.78 mi downstream from Western Ave.
19	CSSC	318.26	100	55	90	2.34 mi downstream from Western Ave.
20	CSSC	317.21	92	0	80	0.09 mi downstream from Cicero Ave.
21	CSSC	308.6	78	31	80	3.7 mi downstream from the Baltimore and Ohio Railroad (B&O RR) Bridge
22	CSSC	305.04	37	0	80	0.94 mi upstream from Route #83
23	CSSC	296.74	52	21	80	0.54 mi upstream from Romeoville
24	LCRN	326.5	0	106	80	Grand Calumet River Junction
25	LCRN	320.5	0	165	80	0.4 mi upstream from Halsted St.
26	LCRN	320.1	129	241	80 (2001) 100 (2003)	Halsted St.
27	Cal-Sag	309.4	150	289	80	Mill Creek Junction
28	Cal-Sag	304.57	62	165	80	0.27 mi upstream from Route #83

* : River miles for the CWS often are described relative to the confluence of the Illinois River with the Mississippi River at Grafton, IL., in this case the River Mile for Lockport is 291, and all of the values are based on the Lockport River Mile

- : no available river mile values



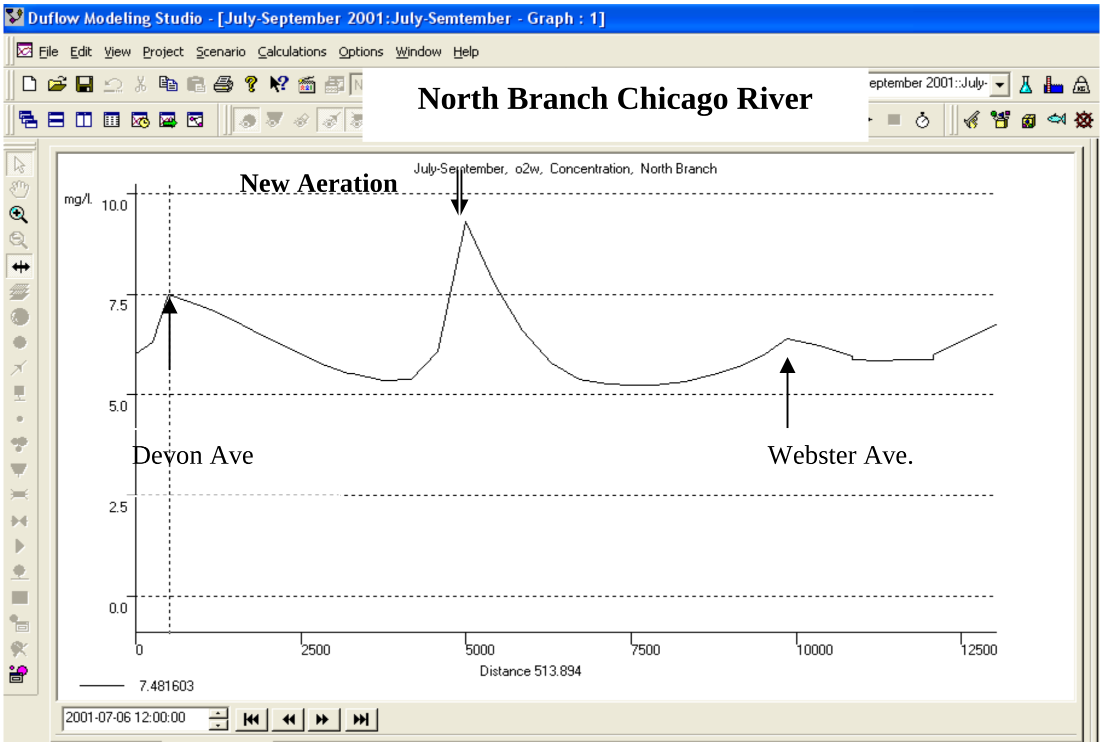


Figure 4.19 Dissolved oxygen concentration profiles in the Chicago Waterway System for selected critical periods of August 2, 2001 (North Shore Channel) and July 6, 2001(North Branch Chicago River) where the downward arrows indicate locations of new aeration stations

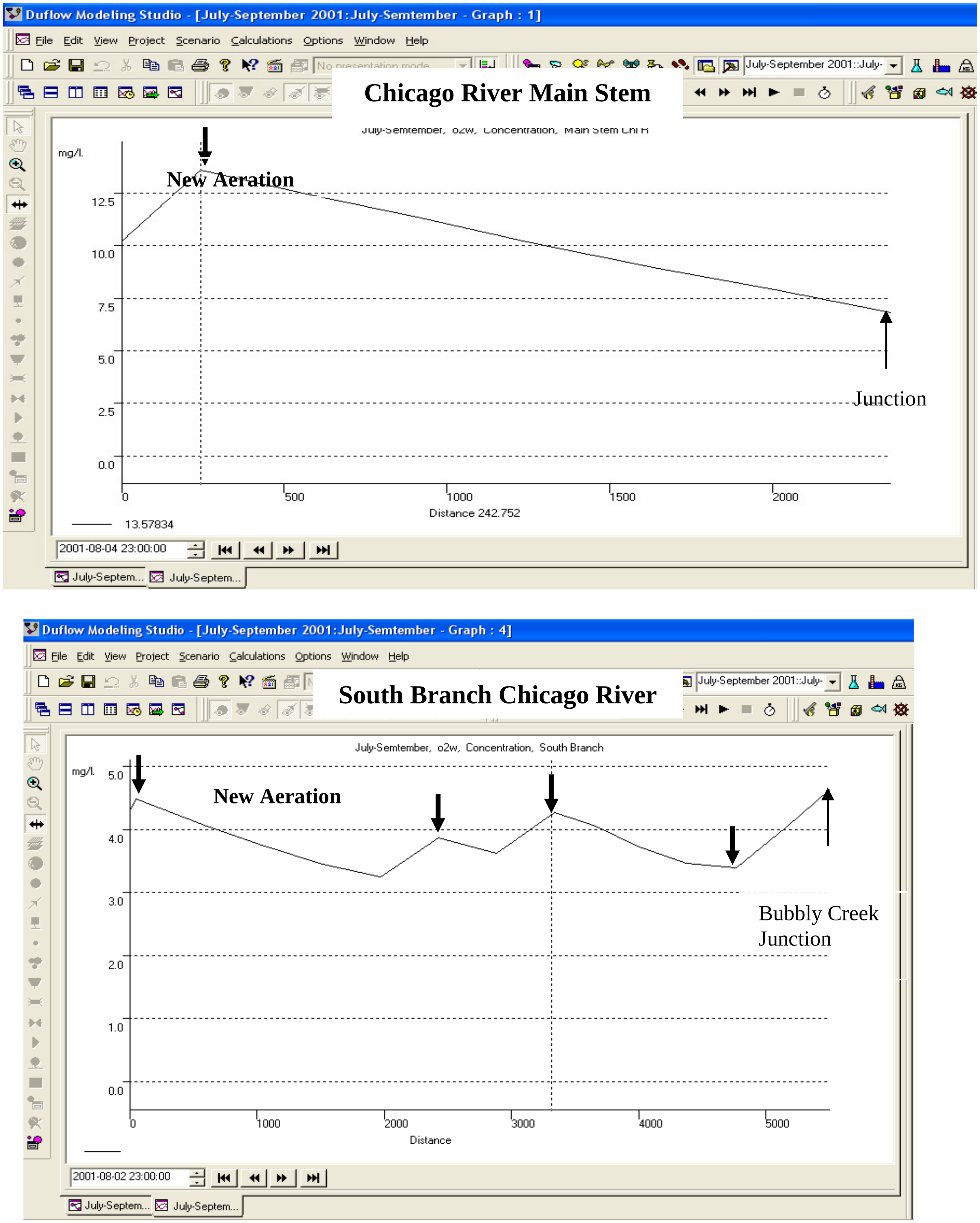
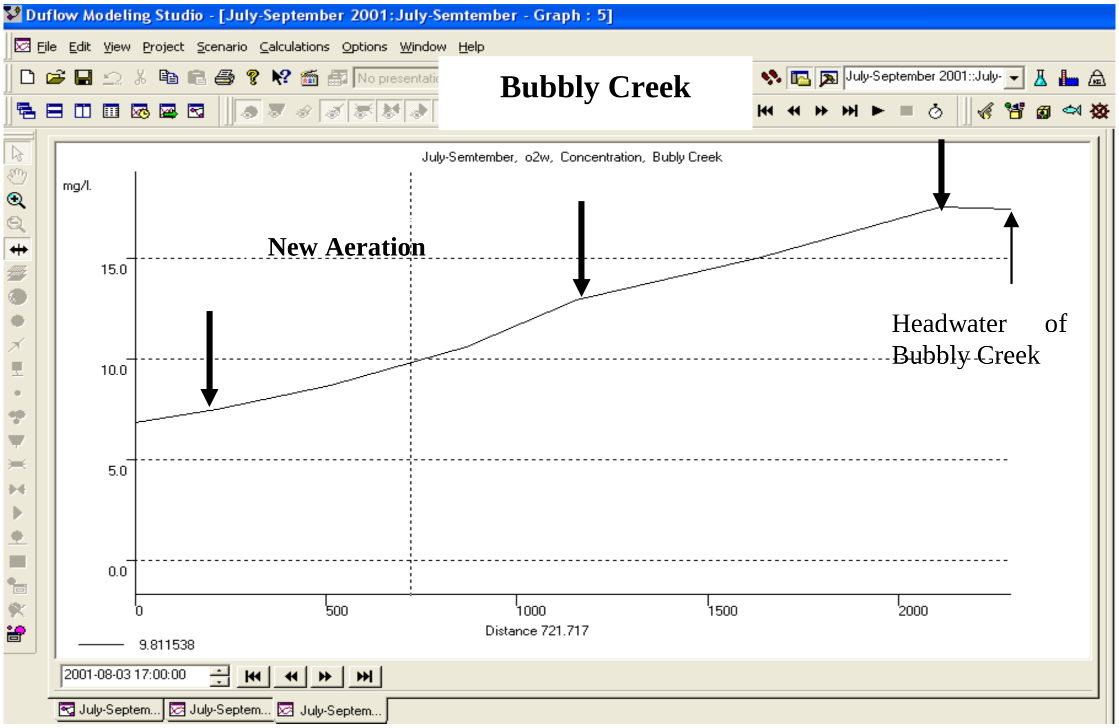


Figure 4.20 Dissolved oxygen concentration profiles in the Chicago Waterway System for selected critical periods of August 4, 2001 (Chicago River Main Stem) and August 2, 2001 (South Branch Chicago River) where the downward arrows indicate locations of new aeration stations



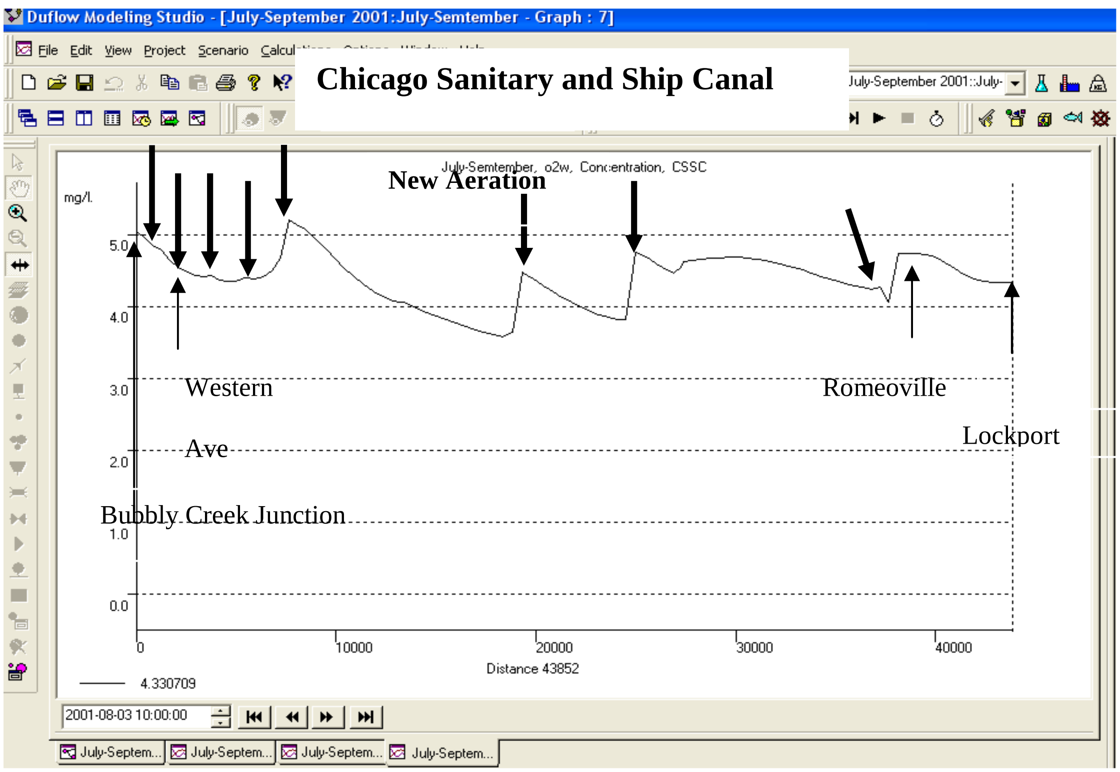
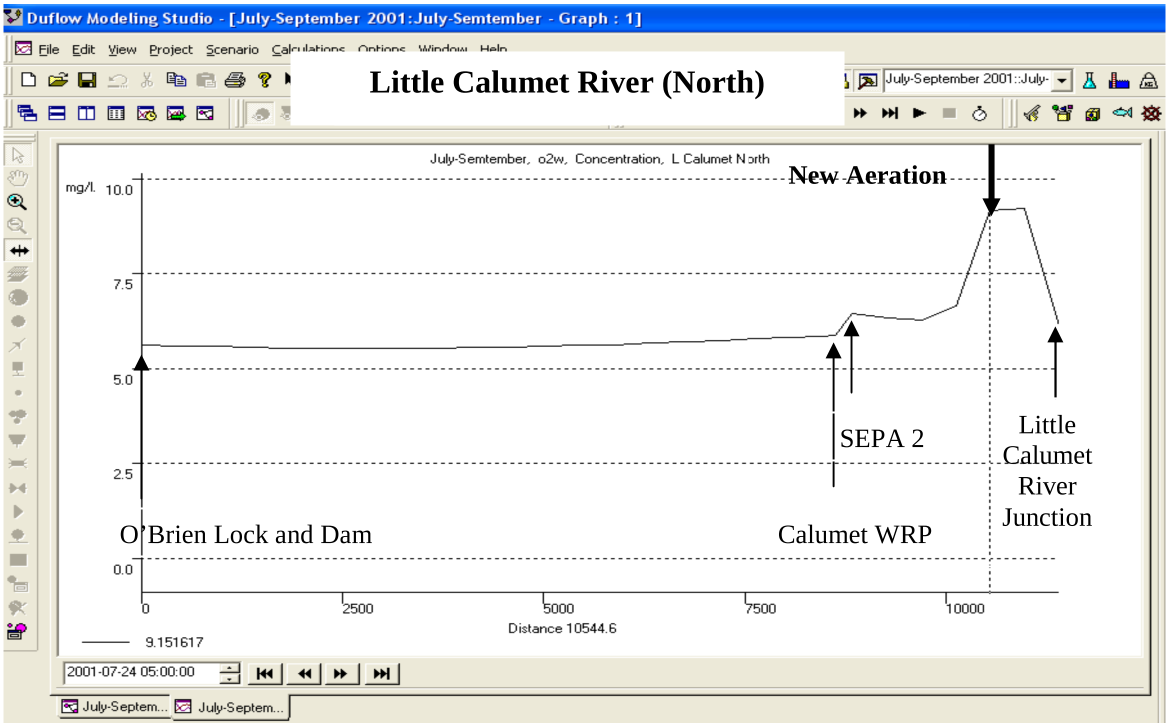


Figure 4.21 Dissolved oxygen concentration profiles in the Chicago Waterway System for a selected critical period of August 3, 2001 (Bubbly Creek and Chicago Sanitary and Ship Canal) where the downward arrows indicate locations of new aeration stations



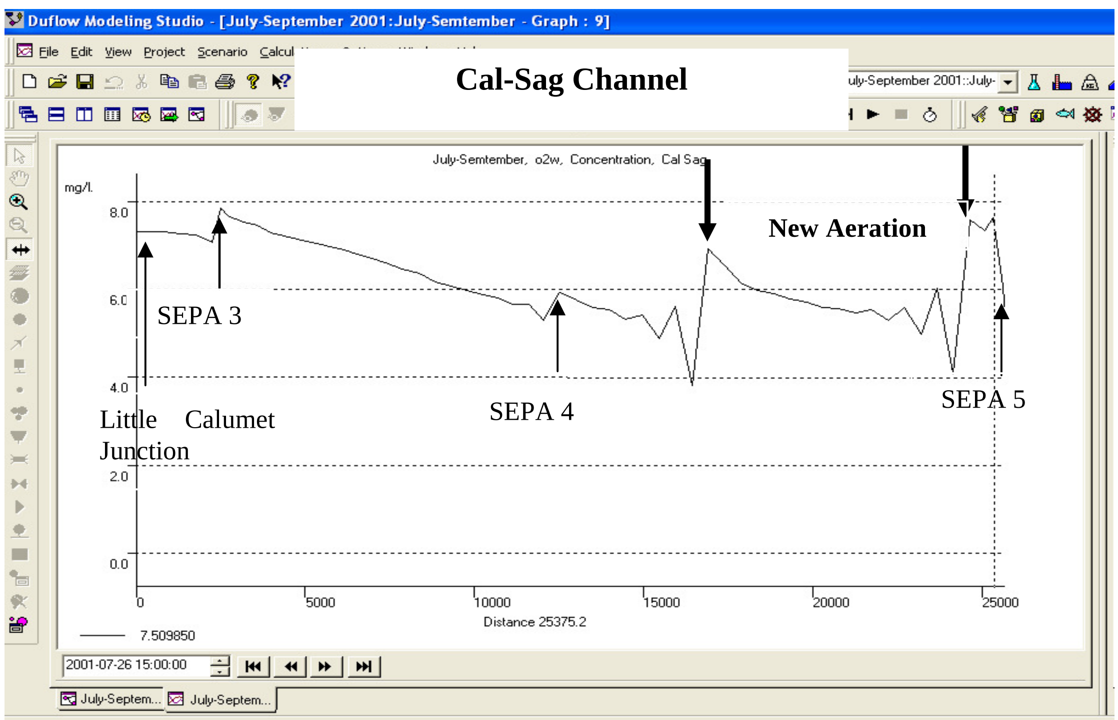
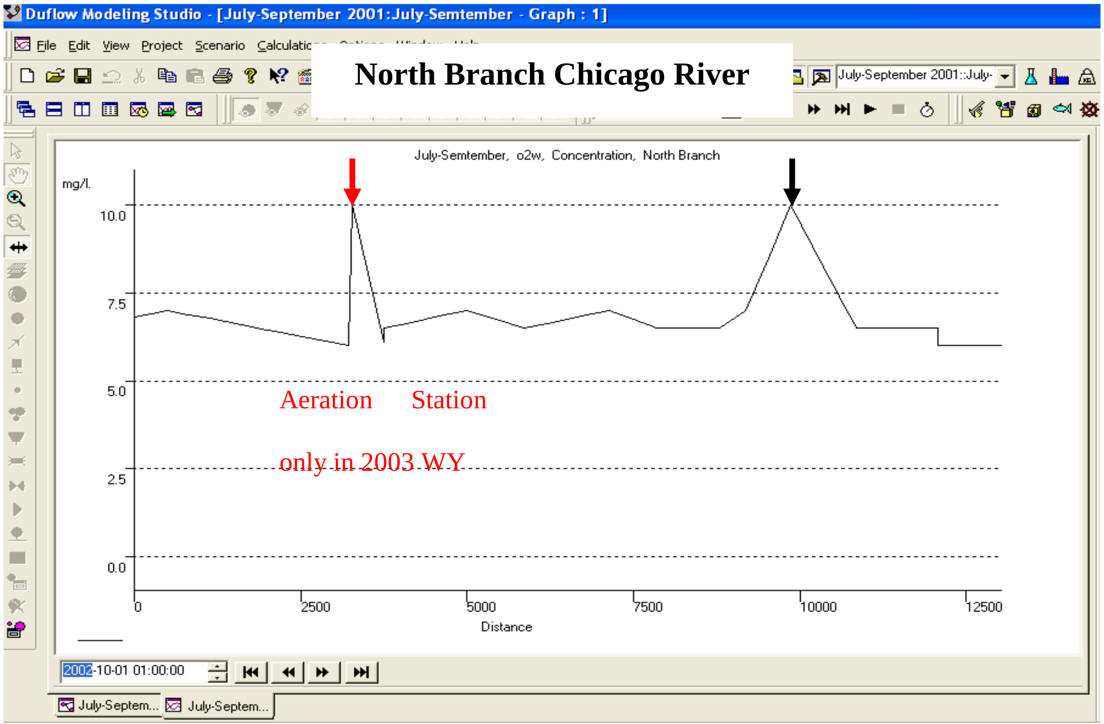


Figure 4.22 Dissolved oxygen concentration profiles in the Chicago Waterway System for selected critical periods of July 24, 2001 (Little Calumet River north) and July 26, 2001 (Cal-Sag Channel) where the downward arrows indicate locations of new aeration stations



[Little Calumet River (North)]

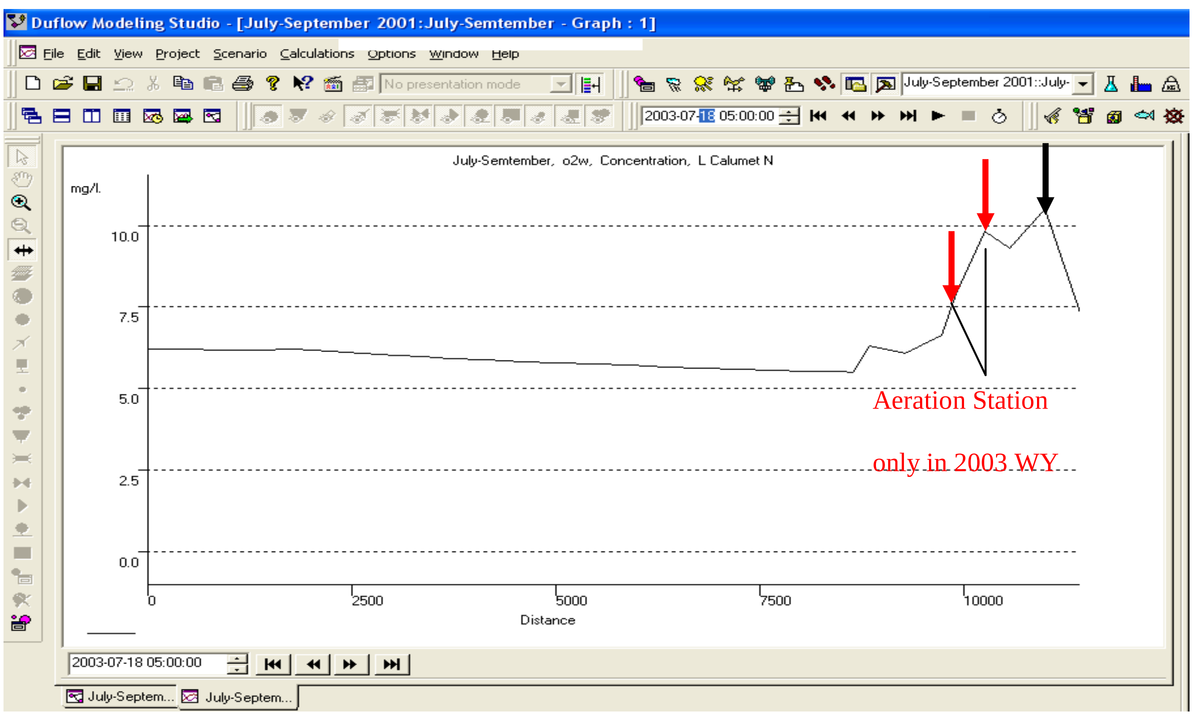


Figure 4.23 Dissolved oxygen concentration profiles in the Chicago Waterway System for selected critical periods of October 1, 2003 (North Branch Chicago River) and July 18, 2003 (Little Calumet River North) where the downward arrows indicate locations of new aeration stations

4.4.3 100% Compliance Summary

On the basis of the analysis of the DUFLOW model for WYs 2001 and 2003, a total of 28 new supplementary aeration stations with a maximum DO load of 80 or 100 g/s and aerated flow transfers on the North Shore Channel, Bubbly Creek, and the Calumet River would be needed to achieve the IEPA proposed DO standards 100% of the time for both the representative wet and dry years. **In theory, the combinations of flow augmentation and new supplemental aeration stations can achieve 100% compliance with the IEPA proposed DO standards, however, this will be hard to achieve IN PRACTICE because of two issues found in developing the foregoing integrated strategy.**

The first problem is how to establish an operation procedure for turning on the aeration stations. For some new aeration stations the operation hours were the same as hours of non-complying DO concentrations downstream. For other new aeration stations, operation hours begin with start of CSOs and end with end of non-complying DO concentrations downstream. Finally, for still other new aeration stations, operation hours begin as much as 12 or even 24 hours before CSOs begin. Such operations are easy to identify after the fact as was done in this study, but establishing operation rules that achieve 100% compliance without many hours of unnecessary station operations will be difficult.

The second problem is illustrated by the need for a new aeration station on the North Branch Chicago River for WY 2003 on top of those needed for WY 2001. That is, the five new upstream aeration stations (identified for WY 2001) and revised operations at the Devon Avenue in-stream aeration station could not bring the area near River Mile 332.99 into compliance with the IEPA proposed DO standards and a new aeration station was needed for this location in WY 2003. Thus, it is likely that for another year a localized high load during a storm could result in violation of the DO standard even with the aerated flow transfers, 28 additional aeration stations, and the 6 existing aeration stations (in the modeled portion of the CAWS) in operation.

Tables 4.4 and 4.5 list the number of operation hours of the new supplemental aeration stations related to large storms, defined as storms when at least one of the three CSO pumping stations were in operation, for WYs 2001 and 2003, respectively. The storm-related aeration station operation hours are summarized as occurring before, during, and up to 6 days after CSO pumping station operation. In total, 11 of the 25 new supplemental aeration stations needed for WY 2001 are only needed to counteract the effects of these larger storms, and more than 50% of the operations of 11 other new supplemental aeration stations are used to counteract the effects of these larger storms. Only 3 of the 25 stations primarily operate in non-storm periods (i.e. less than 50% of operations in storm periods in Table 4.4). Similarly, 5 of the 16 new supplemental aeration stations needed for WY 2003 are only needed to counteract the effects of these larger storms, and more than 50% of the operations of 6 other new supplemental aeration stations are used to counteract the effects of these larger storms. Only 5 of these stations primarily operate in non-storm periods (i.e. less than 50% of operations in storm periods in Table 4.5). Using aeration stations to counteract storm loads is not an efficient way to improve water quality. These results indicate that if an allowance for low DO concentrations during storm periods was made as in Scenario "A" (see Chapter 5), a much simpler system of aeration stations could yield 99% or better compliance with the IEPA proposed DO standards.

Table 4.4 Operation hours of the new supplementary aeration stations before, during, and up to 6 days after the operations of the combined sewer overflow pumping stations and the percentage of the total operation hours in water year 2001 that correspond to these storm period operations.

Station	Waterway	Before CSO	During CSO	Up to 6 days after CSO	Total storm	Total annual hours	Percentage of annual hours
1	NSC	0	39	71	110	134	82.1
2	NSC	0	51	83	134	214	62.6
3	NSC	0	49	17	66	102	64.7
4	NSC	21	45	3	69	113	61.1
5	NSC	14	6	21	41	222	18.5
7	NBCR	3	13	0	16	102	15.7
8	NBCR	0	17	61	78	78	100.
9	Main Stem	7	57	147	211	376	56.1
10	SBCR	4	25	55	84	84	100.
11	SBCR	4	17	30	51	51	100.
12	SBCR	2	43	105	150	150	100.
13	Bubbly Creek (BC)	6	94	521	621	946	65.6
14	BC	0	56	197	253	253	100.
15	BC	0	1	16	17	17	100.
16	CSSC	1	27	57	85	85	100.
17	CSSC	0	17	29	46	46	100.
18	CSSC	0	9	55	64	99	64.6
19	CSSC	0	15	52	67	100	67.
20	CSSC	0	13	48	61	92	66.3
21	CSSC	0	5	44	49	78	62.8
22	CSSC	0	2	35	37	37	100.
23	CSSC	0	0	0	0	52	0.0
26	LCRN	7	32	54	93	129	72.1
27	Cal-Sag	19	24	107	150	150	100.
28	Cal-Sag	12	5	45	62	62	100.

Table 4.5 Operation hours of the new supplementary aeration stations before, during, and up to 6 days after the operations of the combined sewer overflow pumping stations and the percentage of the total operation hours in water year 2003 that correspond to these storm period operations.

Station	Waterway	Before CSO	During CSO	Up to 6 days after CSO	Total storm	Total annual hours	Percentage of annual hours
1	NSC	63	46	45	154	233	66.1
4	NSC	0	0	0	0	84	0.0
5	NSC	23	2	136	161	161	100.
6	NBCR	56	34	4	94	211	44.5
7	NBCR	16	14	0	30	30	100.
11	SBCR	0	4	35	39	168	23.2
12	SBCR	0	38	88	126	183	68.9
16	CSSC	0	30	30	60	75	80.0
19	CSSC	0	19	36	55	55	100.
21	CSSC	0	5	26	31	31	100.
23	CSSC	0	0	0	0	21	0.0
24	LCRN	30	36	40	106	106	100.
25	LCRN	31	33	11	75	165	45.5
26	LCRN	85	41	24	150	241	62.2
27	Cal-Sag	27	42	169	238	289	82.4
28	Cal-Sag	0	19	92	111	165	67.3

Chapter 5 – INTEGRATED STRATEGY FOR COMPLIANCE WITH SCENARIO "A" OF THE DO STANDARDS PROPOSED BY THE MWRDGC

As discussed in Section 1.2, the MWRDGC developed a scenario that includes allowing DO concentrations to decrease below the MWRDGC proposed DO standard during periods of wet weather, known as Scenario "A" in this report. The total number of hours in a year of periods with DO concentrations less than the proposed DO standard was determined on the basis of historically measured DO concentrations in the various reaches and the potential application of water quality improvement alternatives. Detailed allowable maximum hours less than the DO standards are listed in Table 1.1. The first step in developing the compliance scenario is to determine the locations and hours in the CWS that currently do not meet Scenario "A" based on the baseline simulations for both WYs 2001 and 2003. The development of an integrated strategy to meet Scenario "A" of the proposed DO standards is presented in this chapter.

5.1 Supplementary Aeration Stations

The DUFLOW model for WY 2001 was used to evaluate scenarios for achieving DO concentrations that meet Scenario "A" at all locations in the CWS. The purpose of the new aeration stations is to maintain the total number of hours in the periods with DO concentrations less than the allowable DO standards to values less than the maximum number of hours specified in Table 1.1 for each waterway. In this case, new aeration stations were added to the river network wherever needed starting upstream and moving downstream in the same iterative fashion used to achieve 100% compliance with the

IEPA proposed DO standards. This means, when the total number of non-compliance hours of simulated DO concentrations are above the allowable non-compliance hours at a location, a new aeration station was added at that location. The maximum DO load of all new aeration stations was chosen as 80 g/s and operation hours were based on the number of hours which exceeded maximum allowable non-compliance hours. Simulation results for WYs 2001 and 2003 are provided in the following sections.

5.1.1 Water Year 2001

From the WY 2001 baseline simulation only the North Shore Channel, North Branch Chicago River, South Branch Chicago River, and CSSC needed improvements in DO concentrations. In order to achieve compliance, the following approaches were applied in the model:

1) Flow augmentation of 24 MGD of aerated flow from the North Side WRP to the Wilmette Pumping Station on the North Shore Channel.
2) The Devon Avenue in-stream aeration station was to be operated for additional 106 hours at the maximum capacity (3 blowers on; 64 hours changed from 0 to 3 blowers on, 30 hours changed from 1 to 3 blowers on, and 12 hours changed from 2 to 3 blowers on) instead of actual blower operations in the baseline simulation.
3) The Webster Avenue in-stream aeration station was operated as per its actual number of working blowers and operation hours.
4) The first new supplemental aeration station was added between Canal Street and 18th Street on the SBCR (1.5 miles downstream from Jackson Boulevard) with 950

operation hours (operation hours were defined as the sum of the hours exceeding the allowable hours of non-compliance with the aeration station starting 6-hours earlier than the occurrence of each DO concentration problem to account for the flow travel time from the aeration station to the points of non-complying DO concentrations).

5) The second new aeration station was added at Throop Street on the SBCR with 202 operation hours (the same method as for the first new aeration station was used to determine the operation hours).

The improvements in compliance with Scenario “A” on the South Branch Chicago River and CSSC resulting from the step-wise development of the integrated strategy are listed in Table 5.1. It can be seen that the integrated strategy results in a drastic increase in DO concentrations for WY 2001. For example, at Throop Street the DO concentration is less than 3.5 mg/L for only 65 hours (0.74% of the entire year) with the integrated strategy in operation. Plots of DO concentrations for the baseline and the integrated strategy simulations are shown in Figures 5.1 and 5.2, and the locations of the new added aeration stations in the model are shown in Figure 5.3. Comparing the two simulations—baseline and integrated strategy—the approach of integrating flow augmentation on the North Shore Channel, adjusted operating hours at Devon Avenue, and new supplemental aeration stations on the South Branch Chicago River is an effective method to improve DO concentrations in order to achieve compliance with Scenario “A”.

Table 5.1 Number of hours that dissolved oxygen concentrations are less than Scenario "A" dissolved oxygen standards at different locations for WY 2001 with the step-wise development of the integrated strategy (i.e. the fourth column shows the results of adding the first aeration station to the components listed in the third column, and the fifth column shows the results of adding the second aeration station to the components listed in the third and fourth columns)

Location	Allowable hours of less than the DO standard	Hours less than the DO standard with 24 MGD transfer from NSWRP to Wilmette and Devon Avenue operations adjustment	Hours less than the DO standard with the 1st new aeration station on the SBCR	Hours less than the DO standard with the 2nd new aeration station on the SBCR
Halsted Street	88	477	68	62
Throop Street	88	866	202	65
Bubbly Creek Junction	500	1062	418	306
Cicero Avenue	500	676	418	353

Note: the 1st aeration station is located at 1.5 miles downstream from Jackson Boulevard and the 2nd aeration station is located at Throop Street both on the SBCR.

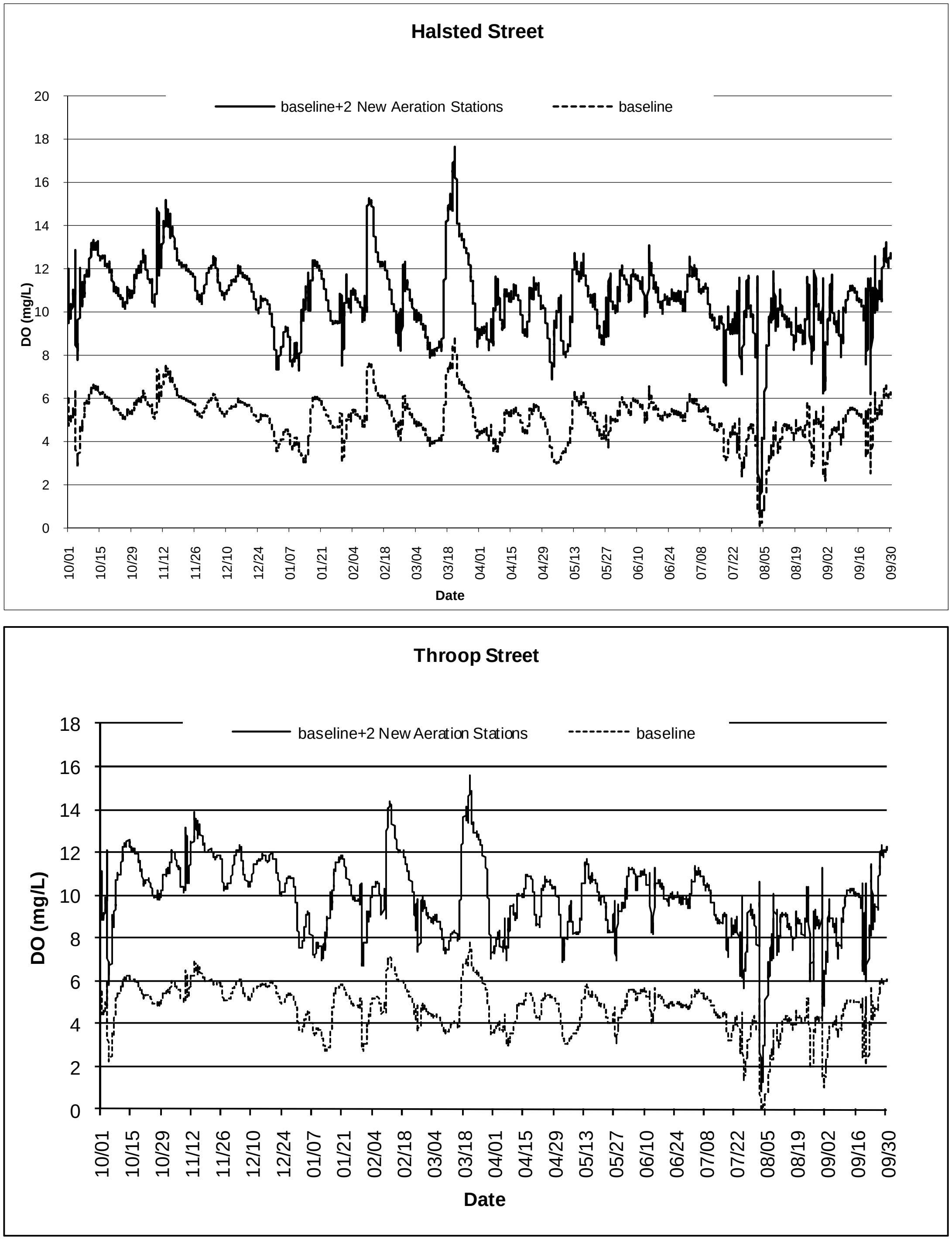
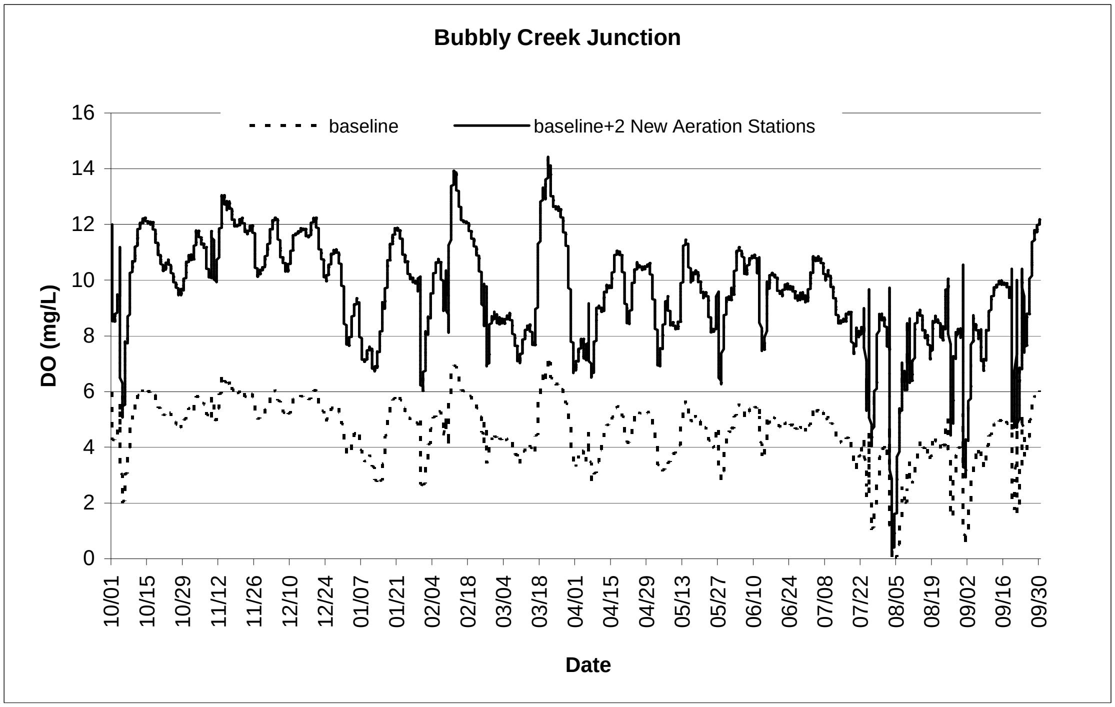


Figure 5.1 Dissolved Oxygen (DO) concentrations for the baseline and the integrated strategy simulations on the South Branch Chicago River for Water Year 2001



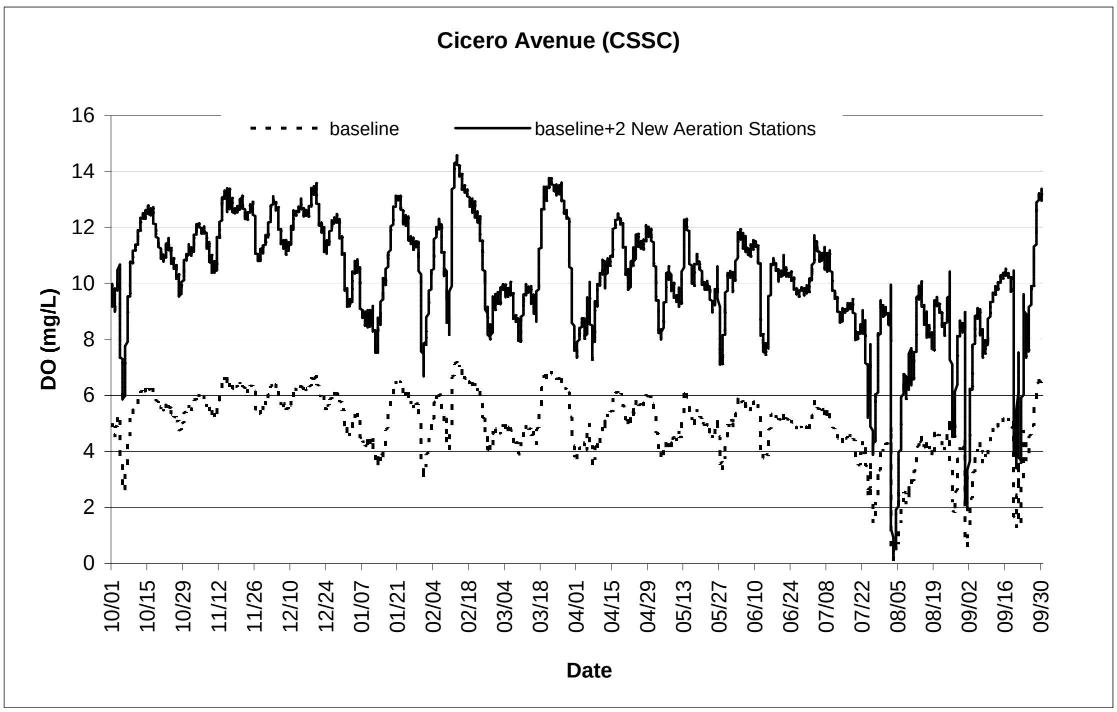
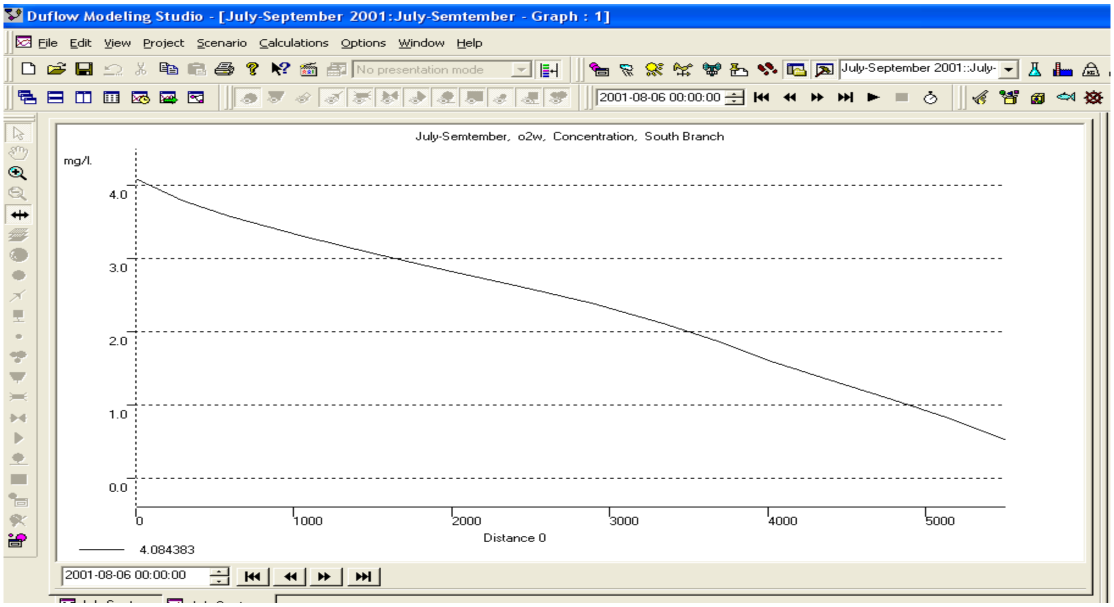


Figure 5.2 Dissolved Oxygen (DO) concentrations for the baseline and integrated strategy simulations on the South Branch Chicago River and Chicago Sanitary and Ship Canal for Water Year 2001



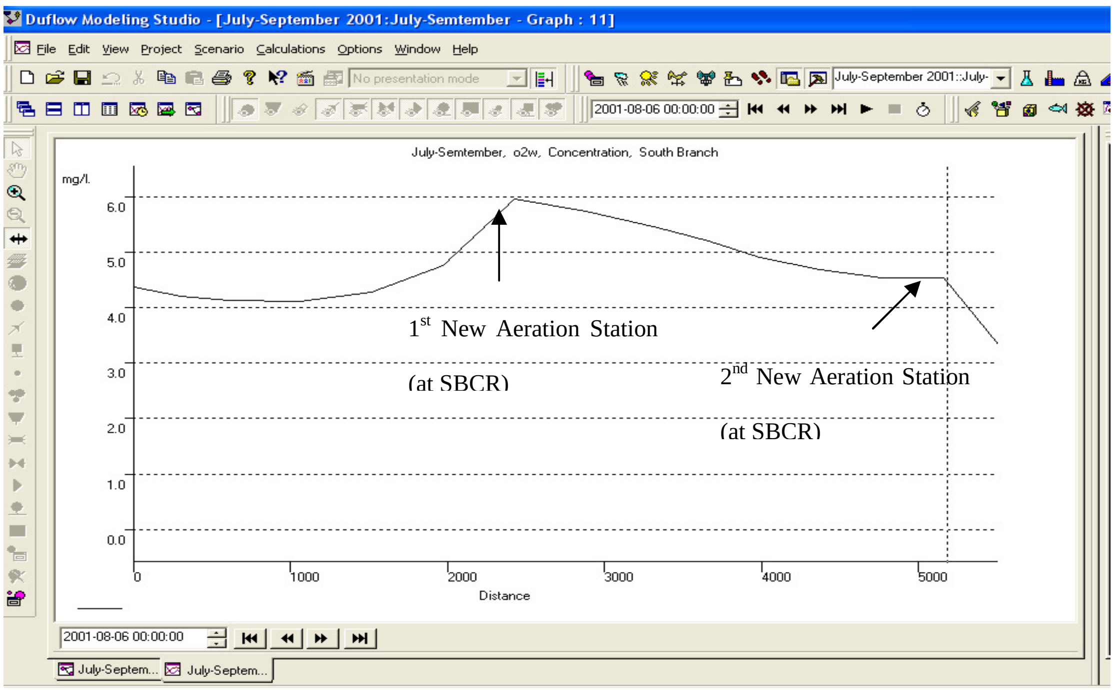


Figure 5.3 Identification of new aeration station locations on the South Branch Chicago River (SBCR) for WY 2001, where the upper and lower figures show the dissolved oxygen concentration along the SBCR without and with supplemental aeration, respectively, for midnight on August 6, 2001

5.1.2 Water Year 2003

Similarly, from the WY 2003 baseline simulation, the North Shore Channel, South Branch Chicago River, and CSSC needed additional supplemental aeration. Only one new aeration station was needed to achieve compliance with Scenario "A" for WY 2003, where a maximum number of hours could be less than the DO standard. The approach described below is slightly different from that needed for WY 2001 as follows.

1) Flow augmentation of 24 MGD of aerated flow from the North Side WRP to the Wilmette Pumping Station on the North Shore Channel.
2) No changes from the actual operations of both the Devon Avenue and Webster Avenue in-stream aeration stations were required.
3) An aeration station was added at Throop Street on the South Branch Chicago River with 186 operation hours (the same location as the second new aeration station for WY 2001).

It is important to remember that because of the missing effluent ammonium as nitrogen data for the North Side WRP (described in Section 4.2), only October through December 2002 and May through September 2003 were evaluated along the North Shore Channel, North Branch Chicago River, South Branch Chicago River, and CSSC for WY 2003.

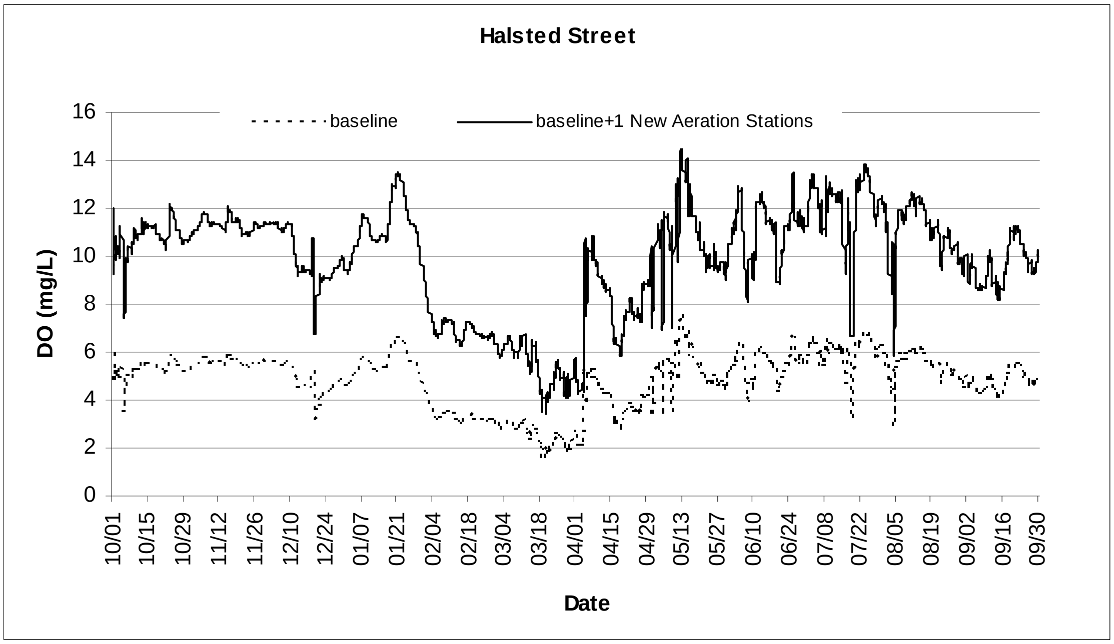
The improvements in compliance with Scenario "A" on the South Branch Chicago River and CSSC resulting from the step-wise development of the integrated strategy are listed in Table 5.2. It can be seen that only one new aeration station is needed on the SBCR to achieve compliance with Scenario "A" for WY 2003. On the South Branch Chicago River, only Throop Street (186 hours) cannot meet the required maximum hours (88 hours) of DO concentrations less than 3.5 mg/L after flow augmentation on the North Shore Channel. However, when a new aeration station is added at Throop Street, required compliance can be achieved at this location. Plots of DO concentrations for the baseline and the new aeration station simulations are shown in Figures 5.4 and 5.5.

Table 5.2 Number of hours that dissolved oxygen concentrations are less than Scenario "A" dissolved oxygen standards at different locations for WY 2003 with the step-wise development of the integrated strategy (i.e. the fourth column shows the results of adding the aeration station to the components listed in the third column)

Location	Allowable hours less than the DO standard	Hours less than the DO standard 24 MGD transfer from NSWRP to Wilmette and Devon Avenue operations adjustment	Hours less than the DO standard with new aeration station on the SBCR
Halsted Street	88	48	24
Throop Street	88	186	0
Bubbly Creek Junction	500	329	159
Cicero Avenue	500	317	240

Note: this new aeration station is located at Throop Street on the SBCR.

The location of the new added aeration station is shown in Figure 5.6. Like the simulations for WY 2001, after adding the aeration station and North Shore Channel flow augmentation the DO concentrations on the South Branch Chicago River and the CSSC are substantially better than the DO concentrations for baseline simulation. The approach of integrating aerated flow augmentation on the North Shore Channel and new supplemental aeration stations is an effective strategy to improve DO concentrations for both the representative wet and dry years (WYs 2001 and 2003, respectively).



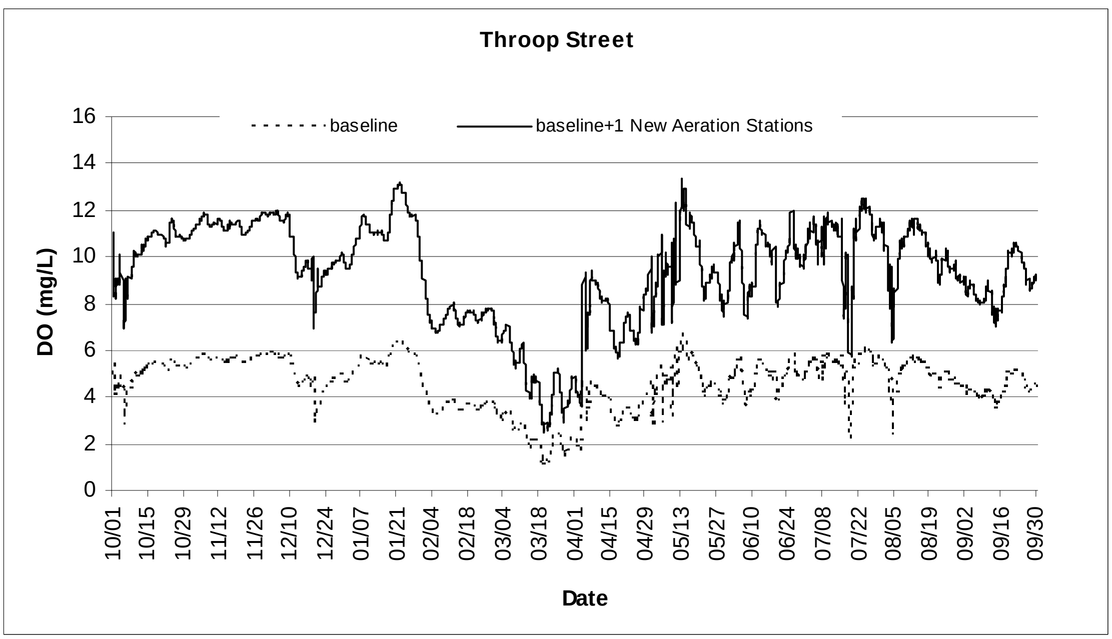
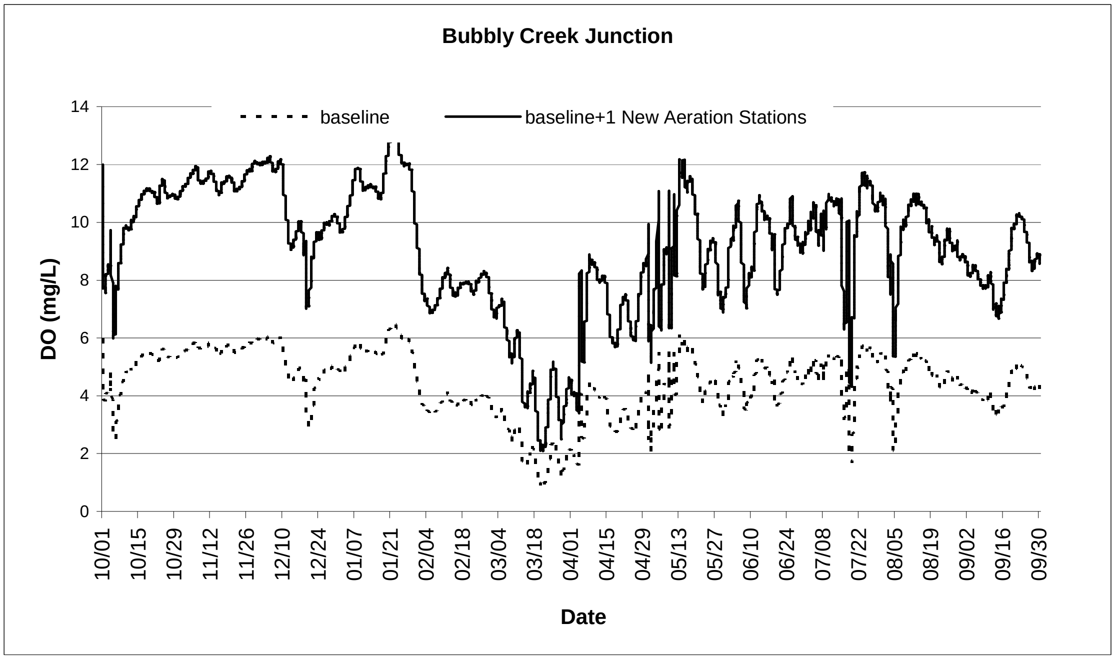


Figure 5.4 Dissolved Oxygen (DO) concentrations for the baseline and the integrated strategy simulations on the South Branch Chicago River for Water Year 2003



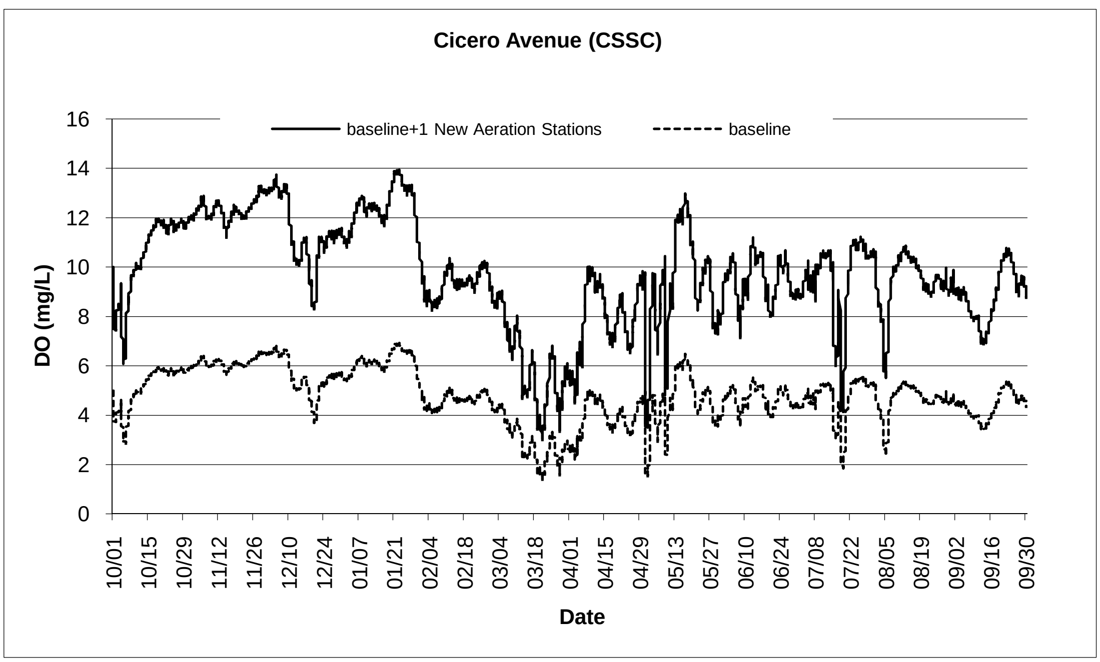


Figure 5.5 Dissolved Oxygen (DO) concentrations for the baseline and the integrated strategy simulations on the South Branch Chicago River and Chicago Sanitary and Ship Canal for Water Year 2003

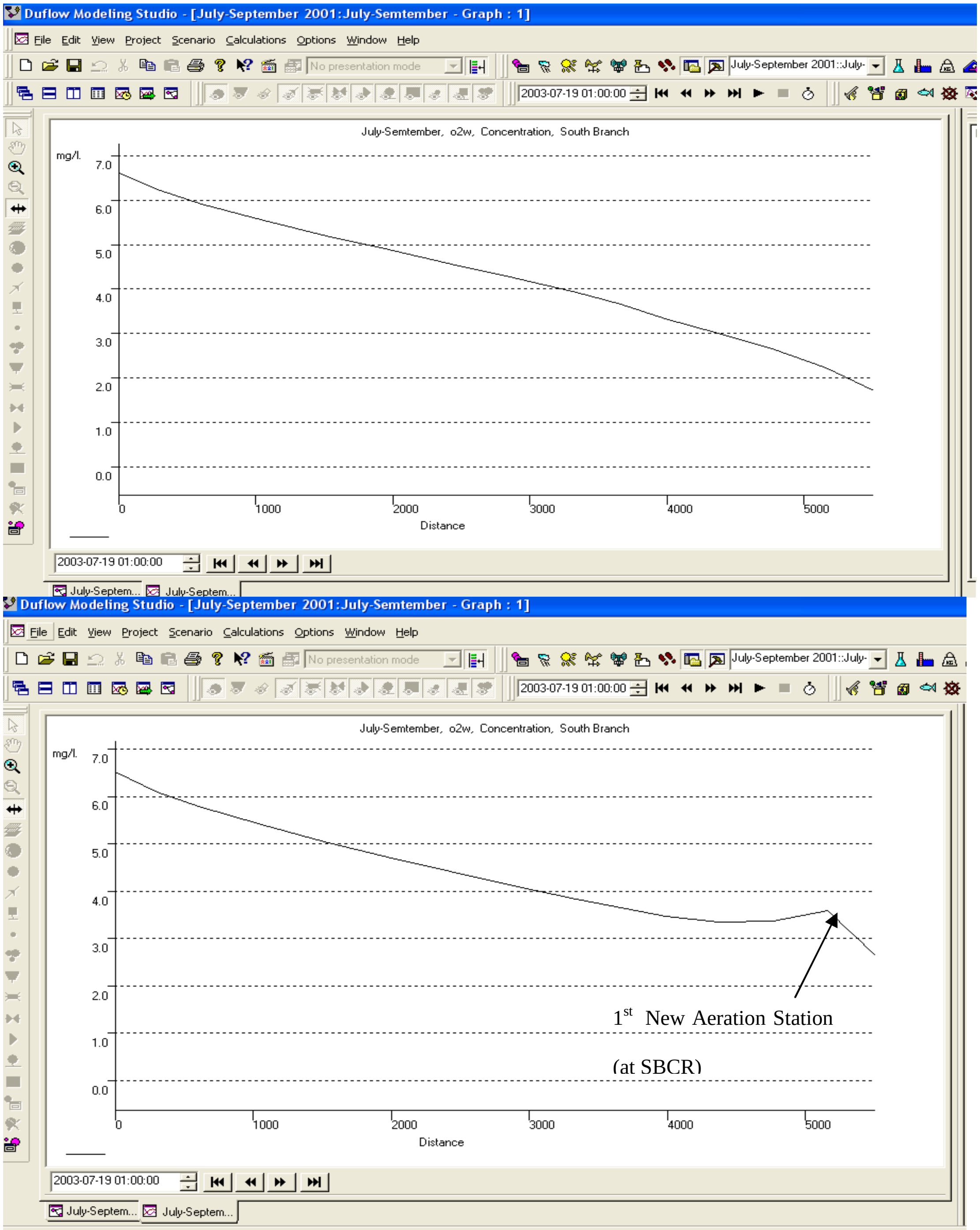


Figure 5.6 Identification of the new aeration station new aeration station locations on the South Branch Chicago River (SBCR) for WY 2003, where the upper and lower figures show the DO concentration along the SBCR without and with supplemental aeration, respectively, for 1 a.m. on July 19, 2003

Chapter 6 – Conclusions

The DUFLOW model used in previous studies (e.g., Alp and Melching, 2006) was modified to consider the details of the gravity CSO discharges to the North Shore Channel and the downstream boundary was extended to the Lockport Controlling Works. For the former modification, 4 representative CSO locations were expanded to 19 representative CSO locations on the North Shore Channel. For the latter modification, hourly stage at the Lockport Controlling Works replaced 15 min. flows at Romeoville Road (3 miles upstream) as the downstream boundary condition. Also the gravity CSO inflows were determined on the basis of the U.S. Army Corps of Engineers models of surface and subsurface runoff, the combined sewer collector system, and the deep tunnel system (described in detail in Espey et al., 2004). Furthermore, the modeling periods were expanded from July through November of 2001 and May through September of 2002 to the entire 2001 and 2003 Water Years, which represent typical wet and dry years, respectively, for the period 1997 through 2007. Considering these modifications to the model and changes in the input compared to Alp and Melching (2006), the DUFLOW model of the CWS was recalibrated. SOD data collected in 2001 was used to further strengthen physical basis of the calibration compared to the earlier calibration of DUFLOW for the CWS (Alp and Melching, 2006).

Despite the improvements described above the calibration of the DUFLOW model of the CWS could be further improved because it was recalibrated using long-term average effluent ammonium as nitrogen concentrations for the North Side WRP for January through April 2001 because the daily values were not available on the MWRDGC web site when the recalibration was done. Later when it was discovered that this resulted in inconsistencies in the DO concentrations simulated for the North Branch Chicago River and points downstream for January through April 2003 (for which daily data were available), the MWRDGC provided the correct daily values, but time was not available to recalibrate the model again. Thus, the modeling period of January through April of 2003 for the reaches within the Chicago River System was excluded in the scenario evaluation during the application of the model for developing integrated strategies. However, the measured hourly DO concentrations shown in Figures 3.25-3.28 indicate that DO concentrations below the proposed DO standards did not occur often in the period of January through April in either 2001 or 2003 and a review of measured DO concentrations in the same period on other years indicated that this is a general case. Thus, the assumption of full compliance without additional aeration in January through April 2003 is supported by the measured DO concentrations.

The modified, recalibrated model then was used to develop integrated strategies that would yield DO concentrations throughout the CWS that meet the IEPA proposed DO standards (described in Section 1.2) 90% and 100% of the time. Initial modeling trials found that 3.5 mg/L at all times was more restrictive than 4.0 mg/L as a daily minimum averaged over 7 days, and, thus, only the absolute minimum DO standards were considered in this study, i.e. it was assumed that the minimum DO criteria controlled. The 90% compliance scenario was done for consistency with earlier planning studies done in response to the Use Attainability Analysis for the CWS (Alp and Melching, 2006; CTE, 2006, 207a-c). Whereas, the 100% compliance scenario is aimed to comply with the IEPA proposed DO standards. In the course of this project, the MWRDGC developed a scenario of an MWRDGC alternative DO standards proposal, referred to as Scenario "A" in this report (presented in Section 1.2), on the basis of a habitat study by LimnoTech (2009a, b) and the MWRDGC's evaluation of the historical hourly DO data throughout the CWS. Scenario "A" was later refined to include a Wet Weather Limited Used (WWLU) designation based on rainfall amount triggering CSO events and a maximum duration that the WWLU could be applied. An integrated strategy to meet Scenario "A" also was developed using the modified, recalibrated DUFLOW model. Since it was hard to match measured DO concentrations over the entire simulation period at certain locations, such as the NSC, SBCR, and Bubbly Creek, the model calibration in this study was performed such that a conservative approach was taken, in which the goal was to better match the lower DO concentrations. Therefore, the simulations of any integrated strategy that can bring DO concentrations to desired levels can also work well in the actual situation.

Table 6.1 summarizes the components of the various integrated strategies to meet the IEPA proposed and Scenario "A" of the MWRDGC proposed DO standards. It is clear from Table 6.1 that getting the last 10% of compliance with the IEPA proposed DO standards requires a massive increase in the water-quality improvement facilities relative to what is required to achieve 90% compliance. This is because a large number of supplemental aeration stations are needed to counteract the localized effects of CSO discharges on DO concentrations.

As can be seen from this study, supplemental aeration stations are not an efficient way to combat storm loadings. **Further, while IN THEORY, the combinations of flow augmentation and new supplemental aeration stations listed in Table 6.1 can achieve 100% compliance with the IEPA proposed DO standards, this will be hard to achieve IN PRACTICE because of two issues found in developing the integrated strategy.**

Table 6.1 Components of the integrated strategies needed to achieve various levels of compliance with the IEPA proposed and Scenario "A" of the MWRDCG proposed dissolved oxygen standards for the Chicago Waterway System

Water quality improvement method	**IEPA standard**			**MWRDGC Scenario A**
	90% comp	90% comp	100% comp	
Aerated flow transfer from the North Side Water Reclamation Plant to Wilmette	30 MGD	30 MGD	40 MGD	24 MGD
Flow transfer from SBCR at Throop Street to upstream end of Bubbly Creek	10 MGD (aerated)	70 MGD (unaerated)	10 MGD (aerated)	0
Aerated flow transfer from the Calumet Water Reclamation Plant to O'Brien Lock and Dam	0	0	30 MGD	0
Hours of increase to 3 blowers on at Devon Avenue in-stream aeration station	0	0	0	106
Number of new 80 g/s aeration stations	0	0	26	2
Number of new 100 g/s aeration stations	0	0	2	0

notes: The operation hours for the new aeration stations of 100% compliance vary from as few as 17 to as many as 946 as detailed in Table 4.3. Also, the 100% compliance scenario assumed 2 pumps in operation for SEPA 2 and 3 pumps in operation for SEPAs 3-5 throughout the entire year. See Table 4.2 for the respective changes in operation for these stations.

The first problem is how to establish an operation procedure for turning on the aeration stations. For some new aeration stations the operation hours were the same as hours of non-complying DO concentrations downstream. For other new aeration stations, operation hours begin with start of CSOs and end with end of non-complying DO concentrations downstream. Furthermore, for still other new aeration stations, operation hours begin as much as 12 or even 24 hours before CSOs begin. Such operations are easy to identify after the fact as was done in this study, but establishing operation rules that achieve 100% compliance without many hours of unnecessary station operations will be difficult.

The second problem is illustrated by the need for a new aeration station on the North Branch Chicago River for WY 2003 on top of those needed for WY 2001. That is, the five new upstream aeration stations (identified for WY 2001) and revised operations at the Devon Avenue in-stream aeration station could not bring the area near River Mile 332.99 into compliance with the IEPA proposed DO standards 100% of the time and a new aeration station was needed for this location in WY 2003. Thus, it is likely that for another year a localized high load during a storm could result in violation of the DO standard even with the aerated flow transfers, 28 additional aeration stations, and the 6 existing aeration stations (in the modeled portion of the CAWS) in operation. WY 2001 and WY 2003 were selected to provide a conservative assessment of the technologies needed to achieve compliance with the IEPA proposed and Scenario “A” of the MWRDGC proposed DO standards. It should be noted, however, that design and implementation of a strategy to ensure 100% compliance with any DO standard may be difficult because of localized effects and variations in storms that were not reflected in the model simulations.

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APPENDIX-A Eutrophication Model EUTROF2

```
/* Eutrophication model EUTROF2          DUFLOW v2.0              */
/* Hans Aalderink                                                 */
/*                Wagingen Agricultural University                */
/*                Department of Nature Conservation               */
/*                Water Quality Managment Section                 */
/*                P.O. BOX 8080                                   */
/*                6700 DD Wageningen                              */
/*                The Netherlands                                 */
/* November 1992                                                  */
/* EUTROF2L.MOD: linear equations for the estimation of the       */
/* secchi depth and the extinction coefficient                    */
/* G. Blom en J. Icke, July 1997                                  */

water      SSW      [  8.00]    g/m3     ;Suspended solids concentration water column
water      TIPW     [  0.70]    g-P/m3   ;Inorganic P water column
water      TOPW     [  0.20]    g-P/m3   ;Organic P water column
water      TONW     [ 1.200]    g-N/m3   ;Organic N water column
water      NH4W     [ 1.000]    g-N/m3   ;Ammonia N water column
water      O2W      [  7.00]    g-O2/m3  ;Oxygen water column
water      BODW     [  5.00]    g-O2/m3  ;BOD water column
water      A1       [ 0.070]    g-C/m3   ;Algal biomass species 1
water      A2       [ 0.000]    g-C/m3   ;Algal biomass species 2
water      A3       [ 0.000]    g-C/m3   ;Algal biomass species 3
water      NO3W     [  3.00]    g-N/m3   ;Nitrate N watet column
water      DET      [  1.00]    g/m3     ;Detritus concentration
water      FC       [10000.0]   count/ml ;Fecal Coliform concentration

bottom     TIPB     [  0.10]    g-P/m3   ;Inorganic P sediment
bottom     TOPB     [  0.10]    g-P/m3   ;Organic P sediment
bottom     TONB     [  1.00]    g-N/m3   ;Organic N sediment
bottom     NH4B     [  1.00]    g-N/m3   ;Ammonia N sediment
bottom     O2B      [  0.00]    g-O2/m3  ;Oxygen sediment
bottom     BODB     [ 20.00]    g-O2/m3  ;BOD sediment
bottom     AB       [ 0.000]    g-C/m3   ;Total algal biomass sediment
bottom     NO3B     [ 3.000]    g-N/m3   ;Nitrate N sediment

parm       Is1      [40.000]    W/m2     ;Optimal light intensity species 1
parm       Is2      [40.000]    W/m2     ;Optimal light intensity species 2
parm       Is3      [40.000]    W/m2     ;Optimal light intensity species 3
parm       achlc1   [30.000] ug Chl/mg C ;Chlorophyll to Carbon ratio species 1
parm       achlc2   [30.000] ug Chl/mg C ;Chlorophyll to Carbon ratio species 2
parm       achlc3   [30.000] ug Chl/mg C ;Chlorophyll to Carbon ratio species 3
parm       tra1     [ 1.040]    -        ;Temperature coefficient die-off species 1
parm       tra2     [ 1.040]    -        ;Temperature coefficient die-off species 2
parm       tra3     [ 1.040]    -        ;Temperature coefficient die-off species 3
parm       Tcs1     [25.000]    oC       ;Critical temperature species 1
parm       Tcs2     [25.000]    oC       ;Critical temperature species 2
parm       Tcs3     [25.000]    oC       ;Critical temperature species 3
parm       Tos1     [20.000]    oC       ;Optimal temperature species 1
parm       Tos2     [20.000]    oC       ;Optimal temperature species 2
parm       Tos3     [20.000]    oC       ;Optimal temperature species 3
parm       kn1      [ 0.010]    g-N/m3   ;Nitrogen monod constant species 1
parm       kn2      [ 0.010]    g-N/m3   ;Nitrogen monod constant species 2
parm       kn3      [ 0.010]    g-N/m3   ;Nitrogen monod constant species 3
parm       kp1      [ 0.005]    g-P/m3   ;Phosphorus monod constant species 1
parm       kp2      [ 0.005]    g-P/m3   ;Phosphorus monod constant species 2
parm       kp3      [ 0.005]    g-P/m3   ;Phosphorus monod constant species 3
parm       Vsa1     [ 0.001]    m/day    ;Settling velocity species 1
parm       Vsa2     [ 0.001]    m/day    ;Settling velocity species 2
parm       Vsa3     [ 0.001]    m/day    ;Settling velocity species 3

parm       Vss      [  1.00]    m/day    ;Fall velocity suspended solids
parm       POR      [  0.90]    -        ;Sediment porosity
parm       RHO      [1200.0]    kg/m3    ;Density suspended solids
parm       HB       [  0.02]    m        ;Depth of sediment top layer


parm       KpipW    [  0.01]    m3/g SS  ;Partition constant P water column
parm       KpipB    [0.0001]    m3/g SS  ;Partition constant P sediment
parm       fdpoW    [  0.00]    -        ;Fraction DOP water coloumn
parm       fdpoB    [  0.00]    -        ;Fraction DOP sediment
parm       TIPLB    [  0.05]    g/m3     ;Inorganic P lower sediment layer
parm       TOPLB    [  0.01]    g/m3     ;Organic P lower sediment layer
parm       fporg    [  0.80]    -        ;Fraction organic P released by respiration
```

```
parm       apc       [ 0.025]    mgP/mgC  ;Phosphorus to Carbon ratio

parm       fdnoW     [  0.00]    -        ;Fraction dissolved organic N water column
parm       fdnoB     [  0.00]    -        ;Fraction dissolved organic N sediment
parm       TONLB     [  1.00]    g-N/m3   ;Organic N lower sediment layer
parm       fnorg     [  0.80]    -        ;Fraction organic N released by respiration
parm       anc       [  0.25]    mgN/mgC  ;Nitrogen to Carbon ratio

parm       NH4LB     [  1.00]    g-N/m3   ;Ammonia N lower sediment layer
parm       Kmn       [ 0.025]    g-N/m3   ;Ammonia preference constant
parm       tnit      [ 1.080]    -        ;Temperature coefficient nitrification
parm       Kno       [ 0.100]    mg-O2/m3 ;Oxygen half sat. constant nitr.

parm       NO3LB     [ 3.000]    g-N/m3   ;Nitrate lower sediment layer
parm       Kden      [ 0.100]    1/day    ;Denitrification rate constant water column
parm       tden      [ 1.040]    -        ;Temperature coefficient denetrification water column
parm       Kdno      [ 0.500]    g-N/m3   ;Oxygen half sat. constant denitrification
parm       KdenB     [ 0.050]    1/day    ;Denitrification rate constant sediment
parm       tdenB     [ 1.040]    -        ;Temperature ceoefficient denitrification sediment

parm       O2LB      [   0.0]    g/m3     ;Oxygen lower sediment layer
parm       Krmin     [  0.01]    m/day    ;Minimum oxygen mass transfer coefficient
parm       trea      [ 1.024]    -        ;Temperature coefficient reaeration
parm       aoc       [  2.67]    g-O2/g-C ;Oxygen to Carbon ratio

parm       BODLB     [ 20.00]    g/m3     ;BOD lower sediment layer
parm       tbod      [  1.04]    -        ;Temperature coefficient oxidation water column
parm       fdbodW    [  1.00]    -        ;Fraction dissolved BOD water column
parm       fdbodB    [  0.00]    -        ;Fraction dissolved BOD sediment
parm       Kbodo     [  2.00]    g/m3     ;Oxygen half sat constant oxidation
parm       KbodB     [  0.05]    1/day    ;Anaerobic decomposition rate BOD sediment
parm       tbodB     [  1.04]    -        ;Temperature coefficient anaerobic BOD decomposition

parm       KdaB      [  0.01]    1/day    ;Anaerobic decay algae sediment
parm       tdaB      [ 1.040]    -        ;Temperature coefficient algal decay sediment


parm       KminB     [0.0004]    1/day    ;Anearobic decomposition rate
parm       tminB     [1.080 ]    -        ;Temperature coefficient anaerobic decomposition
parm       Kmin      [0.1000]    1/day    ;Decomposition rate organic matter water column
parm       tmin      [1.0400]    -        ;Temperature coefficient decomposition

parm       ma        [ 1.884]   g alg/g C ;Biomass to Carbon ratio algae
parm       E0        [0.627]    m-1       ;Background extinction
parm       Eads      [0.0498]   -         ;Contribution of yellow substance to extinction
parm       Ealg      [0.0209]   m-1mg-1m3 ;Contribution of algae to extinction
parm       Edet      [0.0490]   m-1g-1m3  ;Contribution of detritus to extinction
parm       Ess       [0.0253]   m-1g-1m3  ;Contribution of suspended solids to extinction
parm       Sd0       [3.31]     m         ;Background secchi depth
parm       Sdads     [0.0107]   -         ;Contribution of gelbstoff to inverse secchi depth
parm       Sdalg     [0.0111]   m-1mg-1m3 ;Contriution of algae to inverse secchi depth
parm       Sddet     [0.0636]   m-1g-1m3  ;Contribution of detritus to inverse secchi depth
parm        Sdss       [0.0606]   m-1g-1m3  ;Contribution of suspended solids to inverse secchi
depth


xt         Fres      [  5.00]    g/m2,day ;Resuspension flux
xt         T         [ 15    ]    oC       ;Temperature
xt         Ia        [      25]   W/m2     ;Average light intensity
xt         L         [ 13.94]     hour     ;Day length
xt         Ads       [  8.5]     m-1      ;Adsorption at 380 nm
xt         Edif      [0.0002]    m2/day   ;Diffusive exchange
xt         Kbod      [  0.15]    1/day    ;Oxidation rate constant BOD water column
xt         Knit      [0.1000]    1/day    ;Nitrification rate constant
xt         Kfec      [0.800]    1/day     ;Decay rate for Fecal Coliform
xt         umax1     [ 2.000]    1/day    ;Maximum growth rate species 1
xt         umax2     [ 2.000]    1/day    ;Maximum growth rate species 2
xt         umax3     [ 2.000]    1/day    ;Maximum growth rate species 3
xt         kres1     [   0.1]    1/day    ;Respitation rate species 1
xt         kres2     [   0.1]    1/day    ;Respitation rate species 2
xt         kres3     [   0.1]    1/day    ;Respitation rate species 3
xt         kdie1     [ 0.05]    1/day    ;Die-off rate species 1
xt         kdie2     [ 0.05]    1/day    ;Die-off rate species 2
xt         kdie3     [ 0.05]    1/day    ;Die-off rate species 3
xt         k         [ 3.94]    1/day    ;Coefficient of O'Connor Dobbins equation
```

```
flow      Z        [  8.00]    m        ;Depth
flow      As       [375.00]    m2       ;Flow area
flow      Q        [ 75.00]    m3/s     ;Flow
flow      dx       [ 500.00]   m        ;Flow

{
Atot=A1+A2+A3;

Kdif=Edif/HB;

mino=Kmin*tmin^(T-20);
minoB=KminB*tminB^(T-20);
minaB=KdaB*tdaB^(T-20);

k1(SSW)=-Vss/Z;
k0(SSW)=Fres/Z;
SSB=RHO*1000*(1-POR);
Fsed=Vss*SSW;
Vs=Fsed/(RHO*(1-POR)*1000);
Vr=Fres/(RHO*(1-POR)*1000);
Vsd=Vs-Vr;
Vsnet=(Fsed-Fres)/SSW;

Chla=achlc1*A1+achlc2*A2+achlc3*A3;

Etot= E0 + Ealg*Chla + Eads*Ads + Ess*SSW + Edet*DET;
Secchi=1/((1/Sd0) + Sdalg*Chla + Sdads*Ads + Sdss*SSW + Sddet*DET);

alfa01=Ia/Is1;
alfa11=alfa01*exp(-1*etot*z);
alfa02=Ia/Is2;
alfa12=alfa02*exp(-1*etot*z);
alfa03=Ia/Is3;
alfa13=alfa03*exp(-1*etot*z);
f=L/24;
fl1=2.718*f*(exp(-1*alfa11)-exp(-1*alfa01))/(etot*z);
fl2=2.718*f*(exp(-1*alfa12)-exp(-1*alfa02))/(etot*z);
fl3=2.718*f*(exp(-1*alfa13)-exp(-1*alfa03))/(etot*z);
if (T>Tcs1)
    {
    ft1=0.;
    }
else
    {
    beta1=(Tcs1-T)/(Tcs1-Tos1);
    ft1=beta1*exp(1-beta1);
    }
if (T>Tcs2)
    {
    ft2=0.;
    }
else
    {
    beta2=(Tcs2-T)/(Tcs2-Tos2);
    ft2=beta2*exp(1-beta2);
    }
if (T>Tcs3)
    {
    ft3=0.;
    }
else
    {
    beta3=(Tcs3-T)/(Tcs3-Tos3);
    ft3=beta3*exp(1-beta3);
    }
DINW=NO3W+NH4W;
fdpW=1/(1+KpipW*SSW);
DIPW=fdpW*TIPW;
fn1=min(DIPW/(DIPW+kp1),DINW/(DINW+kn1));
fn2=min(DIPW/(DIPW+kp2),DINW/(DINW+kn2));
fn3=min(DIPW/(DIPW+kp3),DINW/(DINW+kn3));
Gr1=umax1*fl1*ft1*fn1;
Gr2=umax2*fl2*ft2*fn2;
Gr3=umax3*fl3*ft3*fn3;
GrT=Gr1*A1+Gr2*A2+Gr3*A3;
Resp1=kdie1+kres1*tra1^(T-20);
```

```
Resp2=kdie2+kres2*tra2^(T-20);
Resp3=kdie3+kres3*tra3^(T-20);
RespT=Resp1*A1+Resp2*A2+Resp3*A3;
k1(A1)=Gr1-Resp1-Vsa1/Z;
k1(A2)=Gr2-Resp2-Vsa2/Z;
k1(A3)=Gr3-Resp3-Vsa3/Z;

k0(DET)=RespT*ma;
k1(DET)=-1*mino-Vsnet;

k1(AB)=-minaB;
k0(AB)=(Vsa1*A1+Vsa2*A2+Vsa3*A3)/HB;

fdpB=1/(1+KpipB*SSB);
DIPB=fdpB*TIPB/POR;
PIPW=(1-fdpW)*TIPW/SSW;
PIPB=(1-fdpB)*TIPB/SSB;
FipD=Kdif*(DIPB-DIPW);
FipS=Fsed*PIPW+Vs*POR*DIPW;
FipR=Fres*PIPB+Vr*POR*DIPB;
FipB=-Vsd*TIPB;
If (Vsd<0.0)
        {
        FipB=+Vsd*TIPLB;
        }
k0(TIPW)=mino*TOPW-GrT*apc+RespT*apc*(1-fporg)+(FipD-FipS+FipR)/Z;
k0(TIPB)=minoB*TOPB+(-FipD+FipS-FipR+FipB)/HB;

NH4I=NH4B/POR;
Fnh4D=Kdif*(NH4I-NH4W);
Fnh4S=Vs*POR*NH4W;
Fnh4R=Vr*POR*NH4I;
Fnh4B=-Vsd*NH4B;
If (Vsd<0.0)
        {
        Fnh4B=+Vsd*NH4LB;
        }
if (NO3W==0.0 && NH4W==0.0)
        {
        pnh4=0.;
        }
else
        {
        pnh4=NH4W*NO3W/((kmn+NH4W)*(kmn+NO3W))+NH4W*kmn/((NH4W+NO3W)*(kmn+NO3W));
        }
Nitr=Knit*tnit^(T-20)*O2W/(O2W+Kno);
k1(NH4W)=-Nitr;
k0(NH4W)=mino*TONW-anc*Pnh4*GrT+(1-fnorg)*anc*RespT+(Fnh4D-Fnh4S+Fnh4R)/Z;
k1(NH4B)=0;
k0(NH4B)=minoB*TONB+(-Fnh4D+Fnh4S-Fnh4R+Fnh4B)/HB;

NO3I=NO3B/POR;
Fno3D=Kdif*(NO3I-NO3W);
Fno3S=Vs*POR*NO3W;
Fno3R=Vr*POR*NO3I;
Fno3B=-Vsd*NO3B;
If (Vsd<0.0)
        {
        Fno3B=+Vsd*NO3LB;
        }
denitW=Kden*tden^(T-20)*Kdno/(Kdno+O2W);
denitB=KdenB*tdenB^(T-20);
k1(NO3W)=-denitW;
k0(NO3W)=nitr*NH4W-anc*(1-pnh4)*GrT+(Fno3D-Fno3S+Fno3R)/Z;
k1(NO3B)=-denitB;
k0(NO3B)=(-Fno3D+Fno3S-Fno3R+Fno3B)/HB;


DOPW=fdpoW*TOPW;
DOPB=fdPoB*TOPB/POR;
POPW=(1-fdpoW)*TOPW/SSW;
POPB=(1-fdpoB)*TOPB/SSB;
FopD=Kdif*(DOPB-DOPW);
FopS=Fsed*POPW+Vs*POR*DOPW;
FopR=Fres*POPB+Vr*POR*DOPB;
FopB=-Vsd*TOPB;
```

```
If (Vsd<0.0)
        {
        FopB=+Vsd*TOPLB;
        }
k1(TOPW)=-mino;
k0(TOPW)=fporg*RespT*apc+(FopD-FopS+FopR)/Z;
k1(TOPB)=-minoB;
k0(TOPB)=apc*minaB*AB+(-FopD+FopS-FopR+FopB)/HB;

DONW=fdnoW*TONW;
DONB=fdnoB*TONB/POR;
PONW=(1-fdnoW)*TONW/SSW;
PONB=(1-fdnoB)*TONB/SSB;
FonD=Kdif*(DONB-DONW);
FonS=Fsed*PONW+Vs*POR*DONW;
FonR=Fres*PONB+Vs*POR*DONB;
FonB=-Vsd*TONB;
If (Vsd<0.0)
        {
        FonB=+Vsd*TONLB;
        }
k1(TONW)=-mino;
k0(TONW)=fnorg*RespT*anc+(FonD-FonS+FonR)/Z;
k1(TONB)=-minoB;
k0(TONB)=anc*minaB*AB+(-FonD+FonS-FonR+FonB)/HB;

DBODW=fdbodW*BODW;
DBODB=fdbodB*BODB/POR;
PBODW=(1-fdbodW)*BODW/SSW;
PBODB=(1-fdbodB)*BODB/SSB;
FbodD=Kdif*(DBODB-DBODW);
FbodS=Fsed*PBODW+Vs*POR*DBODW;
FbodR=Fres*PBODB+Vr*POR*DBODB;
FbodB=-Vsd*BODB;
If (Vsd<0.0)
        {
        FbodB=vsd*BODLB;
        }
oxidW=Kbod*tbod^(T-20)*O2W/(O2W+Kbodo);
oxidB=KbodB*tbodB^(T-20);
kdieT=Kdie1*A1+Kdie2*A2+kdie3*A3;
XCONV=1-exp(-5*kbod);
k1(BODW)=-oxidW;
k0(BODW)=(kdieT*aoc-5/4*32/14*denitW*NO3W)*XCONV+(FbodD-FbodS+FbodR)/Z;
k1(BODB)=-oxidB;
k0(BODB)=+(aoc*minaB*AB-5/4*32/14*denitB*NO3B)*XCONV+(-FbodD+FbodS-FbodR+FbodB)/HB;

k1(FC)=-Kfec;
k0(FC)=0;

O2I=O2B/POR;
Fo2D=Kdif*(O2I-O2W);
Fo2S=Vs*POR*O2W;
Fo2R=Vr*POR*O2I;
Fo2B=-Vsd*O2b;
If (Vsd<0.0)
        {
        Fo2B=+Vsd*O2LB;
        }
u=ABS(Q/As);
tv=(2.0*dx)/u;
tvmin=tv/60;
tvhr=tvmin/60;
tvd=tvhr/24;
kmas=(k*u^0.5*z^(-0.5))*trea^(t-20);
if (kmas<krmin)
       {
       kmas=krmin;
       }
kre=kmas/z;
cs=14.5519-0.373484*t+0.00501607*t*t;
k1(O2W)=-kre;
k0(O2W)=kre*cs-oxidW*BODW/XCONV-64/14*nitr*NH4W-32/12*RespT+GrT*(32/12+48/14*anc*(1-pnh4)*NO3W)+(Fo2D-
Fo2S+Fo2R)/Z;
k0(O2B)=(-oxidB*BODB)/XCONV+(-Fo2D+Fo2S-Fo2R+Fo2B)/HB;
};
```

APPENDIX-B Average Daily Dissolved Oxygen (DO) loads from SEPA and Aeration Stations

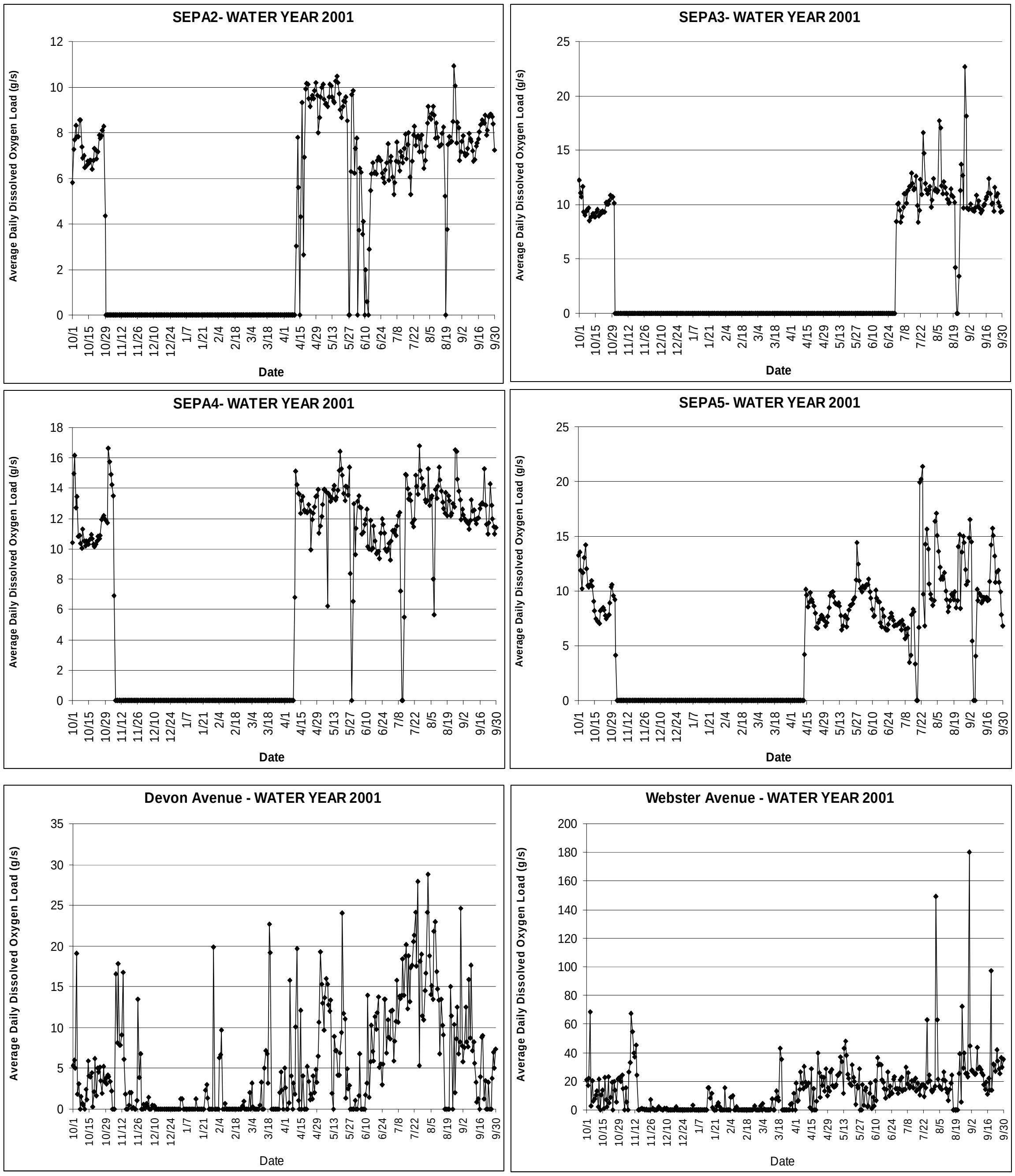

Figure B.1 Average Daily DO loads (g/s) from SEPA and Aeration Stations for Water Year 2001

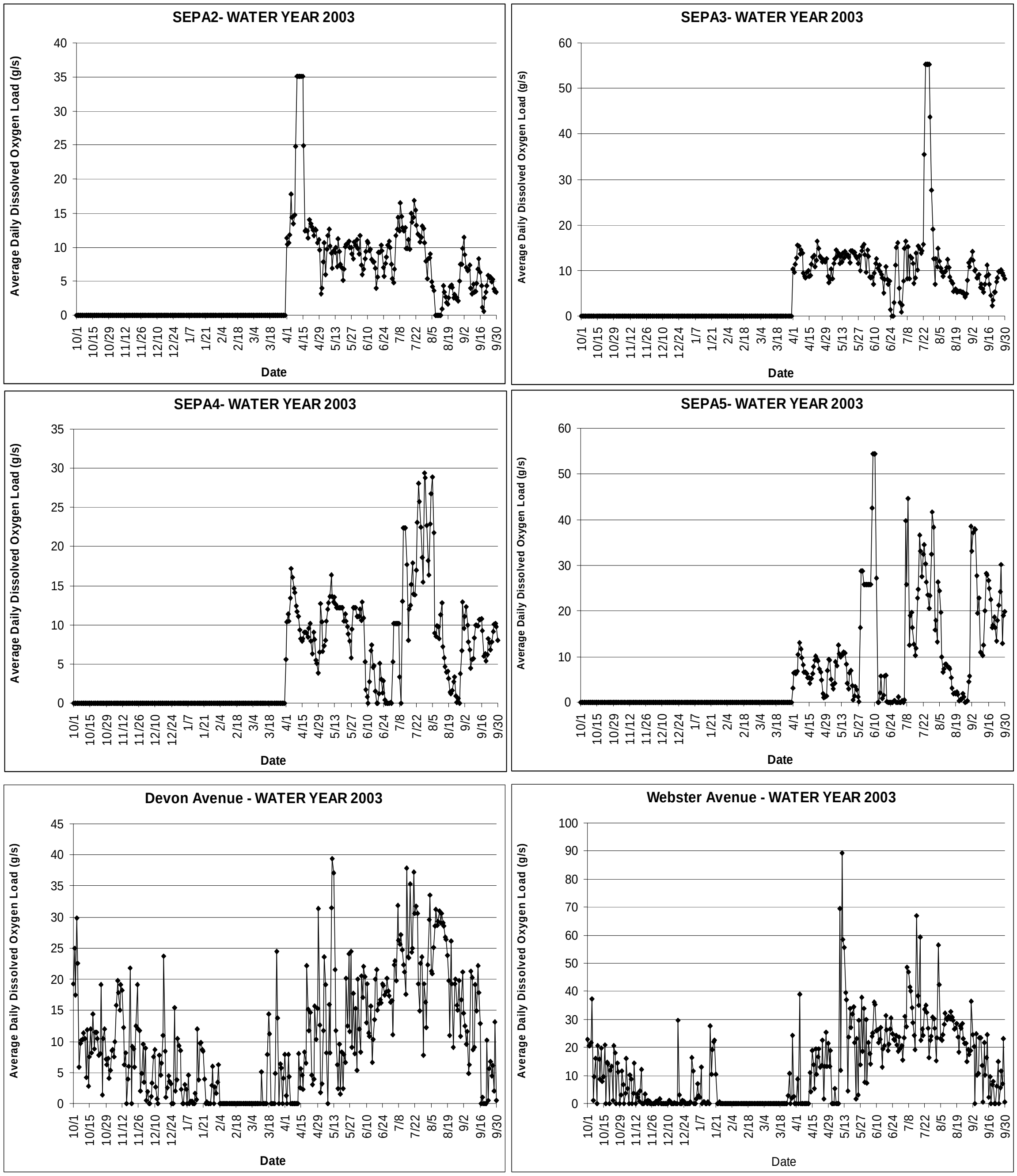

Figure B.2 Average Daily DO loads (g/s) from SEPA and Aeration Stations for Water Year 2003

APPENDIX-C Initial Conditions

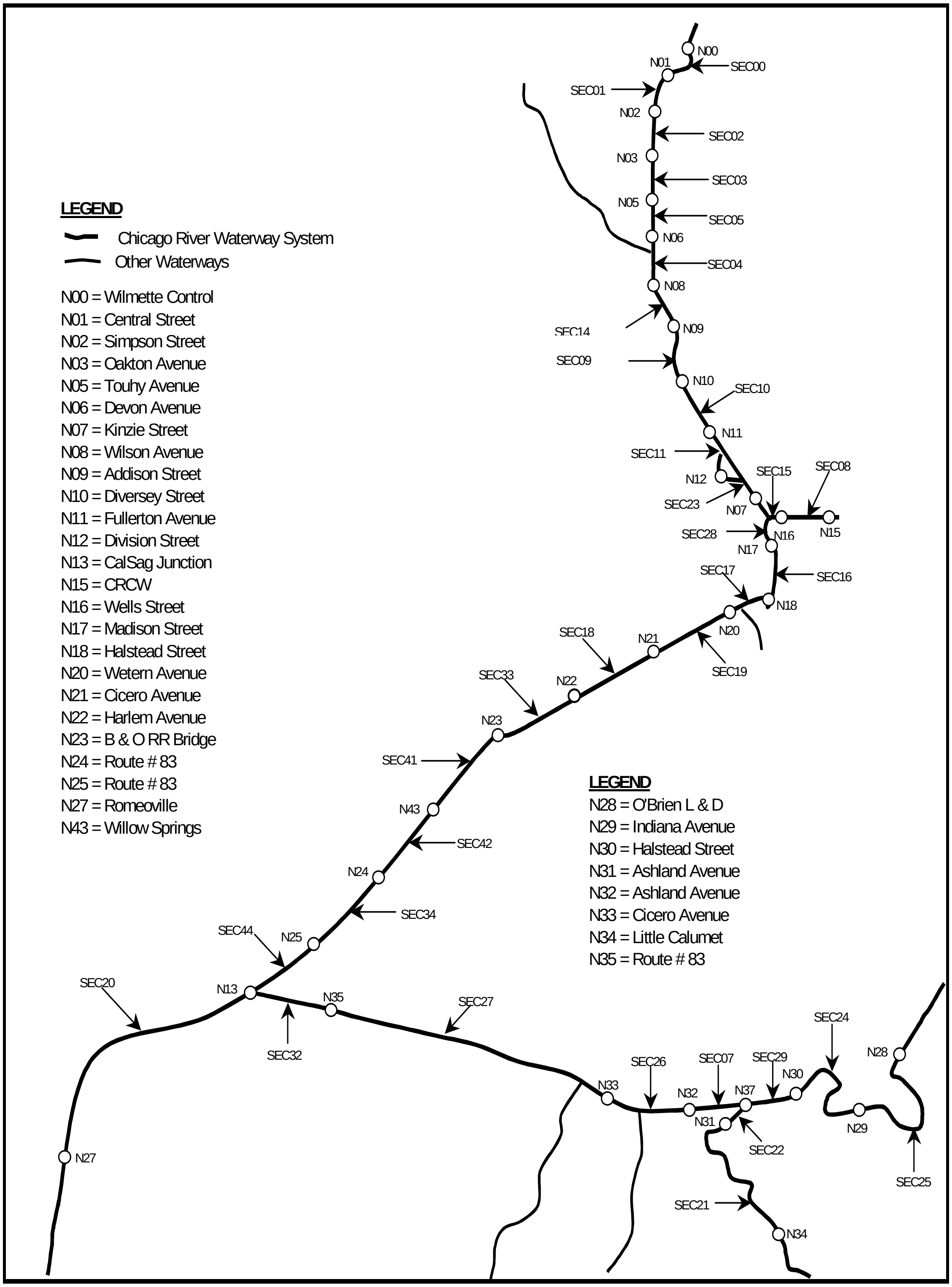

Figure C.1 Calculation nodes sections for the Chicago Waterway System

Table C.1 Initial conditions used in DUFLOW model

	Flow	Level	a1	ab	bodb	bodw	nh4b	nh4w	no3b	no3w	o2b	o2w	ssw	tipb	tipw	tonb	tonw	topb	topw
SEC00000 - begin	1.3	-0.3719	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00000 - end	1.3	-0.3792	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00001 - begin	1.3	-0.3792	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00001 - end	1.3	-0.3909	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00002 - begin	1.3	-0.3909	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00002 - end	1.3	-0.4077	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00005 - begin	12.08	-0.4246	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00005 - end	12.08	-0.4357	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00014 - begin	13.3	-0.4615	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00014 - end	13.3	-0.4758	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00009 - begin	13.3	-0.4758	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00009 - end	13.3	-0.4896	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00010 - begin	13.3	-0.4896	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00010 - end	13.3	-0.4962	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00011 - begin	13.3	-0.4962	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00011 - end	13.3	-0.51029	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00016 - begin	21.4	-0.5384	0	0	20	5	1	0.4	3	3	1	5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00016 - end	21.4	-0.5659	0	0	20	5	1	0.4	3	3	1	5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00019 - begin	21.4	-0.5898	0	0	20	5	1	0.4	3	3	1	5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00019 - end	21.4	-0.6058	0	0	20	5	1	0.4	3	3	1	5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00033 - begin	51.19	-0.6198	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00033 - end	51.19	-0.6302	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00034 - begin	51.19	-0.6565	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00034 - end	51.19	-0.6576	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00008 - begin	8.1	-0.5854	0	0	20	5	1	0.4	3	3	1	11.9	10	0.1	0.05	1	0.3	0.1	0.025
SEC00008 - end	8.1	-0.5527	0	0	20	5	1	0.4	3	3	1	10	10	0.1	0.05	1	0.3	0.1	0.025
SEC00021 - begin	1.1	0.1402	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00021 - end	1.14	-0.5162	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00022 - begin	1.14	-0.5162	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00022 - end	22.75	-0.587	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025

SEC00029 - begin	21.61	-0.5846	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00029 - end	22.75	-0.587	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00007 - begin	22.75	-0.587	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00007 - end	22.75	-0.5893	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00032 - begin	22.88	-0.6571	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00032 - end	74.12	-0.6588	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00025 - begin	9.32	-0.5579	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00025 - end	9.77	-0.574	0	0	20	5	1	0.4	3	3	1	8	15	0.1	0.05	1	0.3	0.1	0.025
SEC00041 - begin	51.19	-0.6302	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00041 - end	51.19	-0.65	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00042 - begin	51.19	-0.65	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00042 - end	51.19	-0.6565	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00044 - begin	51.19	-0.6576	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00044 - end	51.21	-0.6586	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00003 - begin	1.3	-0.4077	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00003 - end	12.08	-0.4246	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00004 - begin	12.08	-0.4357	0	0	20	5	1	0.4	3	3	1	6.8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00004 - end	13.3	-0.4615	0	0	20	5	1	0.4	3	3	1	6.1	10	0.1	0.05	1	0.3	0.1	0.025
SEC00015 - begin	8.1	-0.5527	0	0	20	1	1	0.4	3	3	1	10	1	0.1	0.05	1	0.3	0.1	0.025
SEC00015 - end	21.4	-0.5385	0	0	20	1	1	0.4	3	3	1	10	1	0.1	0.05	1	0.3	0.1	0.025
SEC00017 - begin	21.4	-0.5659	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00017 - end	21.4	-0.57644	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00018 - begin	21.4	-0.6058	0	0	20	5	1	0.4	3	3	1	5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00018 - end	51.19	-0.6198	0	0	20	5	1	0.4	3	3	1	5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00020 - begin	74.12	-0.6588	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00020 - end	74.19	-0.672	0	0	20	5	1	0.4	3	3	1	4	10	0.1	0.05	1	0.3	0.1	0.025
SEC00024 - begin	9.77	-0.574	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00024 - end	21.61	-0.5846	0	0	20	5	1	0.4	3	3	1	8	10	0.1	0.05	1	0.3	0.1	0.025
SEC00026 - begin	22.75	-0.5893	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00026 - end	22.79	-0.6076	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00027 - begin	22.79	-0.6076	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00027 - end	22.88	-0.6571	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00023 - begin	13.3	-0.517	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025

SEC00023 - end	13.3	-0.52542	0	0	20	5	1	0.4	3	3	1	6.5	10	0.1	0.05	1	0.3	0.1	0.025
SEC00028 - begin	13.3	-0.5317	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00028 - end	21.4	-0.5384	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00006 - begin	13.3	-0.51029	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00006 - end	13.3	-0.517	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00012 - begin	13.3	-0.52542	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00012 - end	13.3	-0.5317	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00013 - begin	13.3	-0.52	0	0	20	5	1	0.4	3	3	1	6	8	0.1	0.05	1	1	0.1	0.025
SEC00013 - end	13.3	-0.52	0	0	20	5	1	0.4	3	3	1	6	8	0.1	0.05	1	1	0.1	0.025
SEC00043 - begin	0	0	0.07	0	20	5	1	1	3	3	0	7	8	0.1	0.7	1	1.2	0.1	0.2
SEC00043 - end	0	0	0.07	0	20	5	1	1	3	3	0	7	8	0.1	0.7	1	1.2	0.1	0.2
SEC00045 - begin	21.4	-0.57644	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025
SEC00045 - end	21.4	-0.5898	0	0	20	5	1	0.4	3	3	1	6	10	0.1	0.05	1	0.3	0.1	0.025

* W = WATER; S = SEDIMENT