Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

RESEARCH AND DEVELOPMENT DEPARTMENT

REPORT NO. 06-84

TECHNICAL REPORT # 18

CALIBRATION OF A MODEL FOR SIMULATION OF WATER QUALITY DURING UNSTEADY FLOW IN THE CHICAGO WATERWAY SYSTEM AND APPLICATION TO EVALUATE USE ATTAINABILITY ANALYSIS REMEDIAL ACTIONS

Prepared by

Institute for Urban Environmental Risk Management
Marquette University, Milwaukee WI 53201-1881

February 2006

Metropolitan Water Reclamation District of Greater Chicago

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SUBMITTED TO

The Metropolitan Water Reclamation District of Greater Chicago

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Chapter 1 – INTRODUCTION

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, and Little Calumet River (North). In total, the CWS is a 76.3 mi branching network of navigable waterways controlled by hydraulic structures in which the majority of flow is treated sewage effluent. The dominant uses of the CWS are for commercial and recreational navigation and for urban drainage, i.e. draining combined sewer overflows (CSOs), stormwater runoff, and treated wastewater from the Chicago area away from Lake Michigan. 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, and iii) Manache and Melching (2005) applied the DUFLOW model to simulate fecal coliform concentrations in the CWS under unsteady flow conditions.

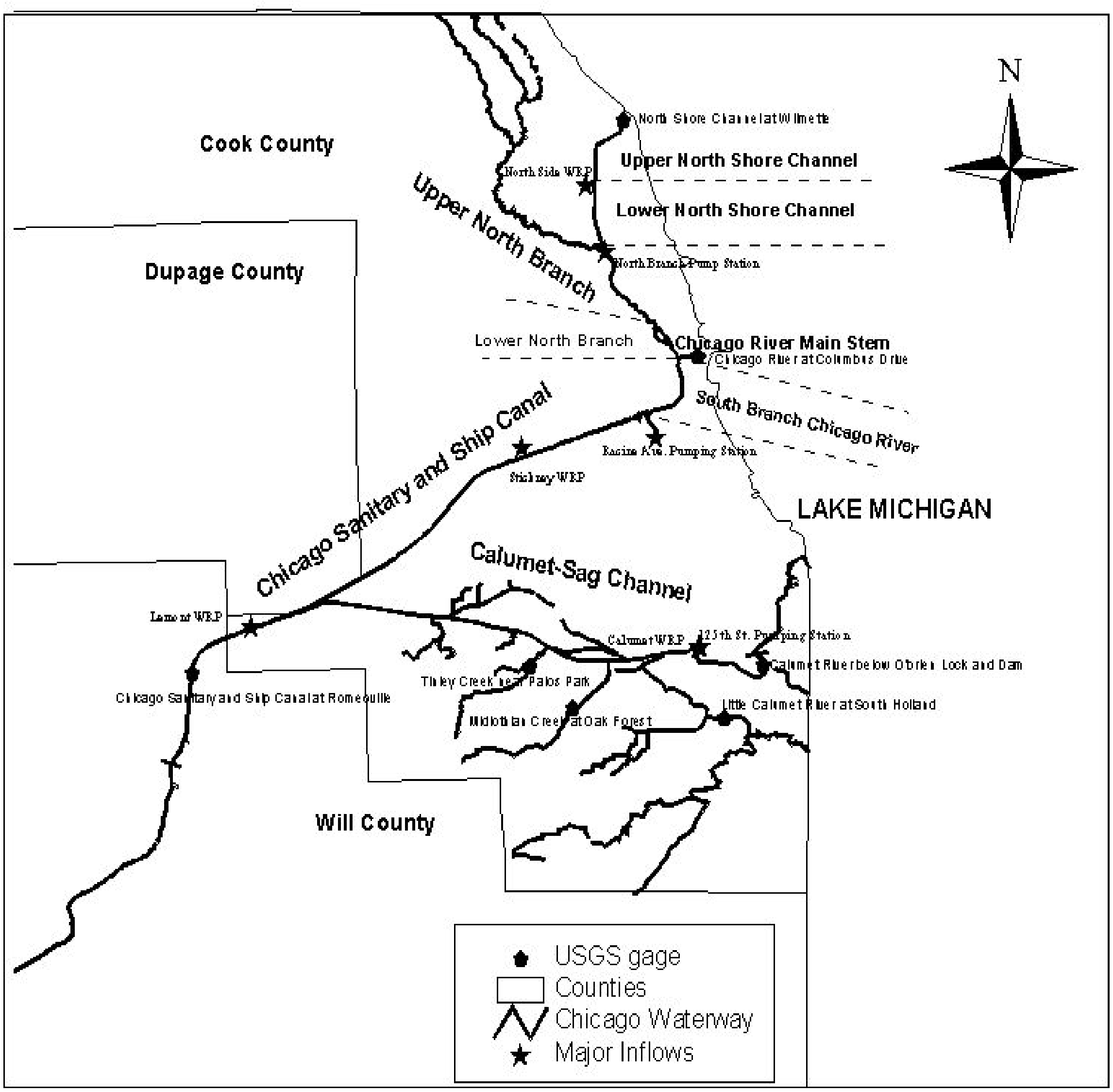


Figure 1.1. Schematic diagram of the Calumet and the Chicago River Systems

The MWRDGC currently is or will soon be faced with a number of difficult management issues including the impact of reduced discretionary diversions from Lake Michigan for water-quality improvement in the summer, the outcome of a use attainability analysis (UAA) for the CWS, and development total maximum daily load allocations. Because of the dynamic nature of the CWS the available QUAL2EU model was considered inadequate to evaluate these management issues and their impact on water quality in the CWS. A model capable of simulating hydraulics and water-quality processes under unsteady-flow conditions is needed to assist the MWRDGC in water-quality management and planning decision making processes. Therefore, the MWRDGC entered into an agreement with Marquette University to adapt the DUFLOW model developed in The Netherlands (DUFLOW, 2000) for simulation of the hydraulics and water-quality processes of the CWS. This report describes the development, calibration, and application to evaluate DO improvement scenarios defined by the UAA of the DUFLOW water-quality model for the period of July 12 to November 9, 2001, and also its application to the period May 1-September 23, 2002.

Before the water-quality model was calibrated, the previously calibrated hydraulic model (Shrestha and Melching, 2003) was tested for the water-quality calibration study period. 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.

Although data from the MWRDGC treatment facilities show that treatment plant effluent concentrations meet the applicable standards and most reaches of the CWS meet General Use water quality standards, there are periods when DO standards are not being met in the waterways, especially during and after wet-weather CSO periods. DO deficiencies also exist in waterway reaches subject to periods of limited or no flow, such as the Upper NSC. During CSO events and in flow challenged reaches, selected management strategies will be required to ensure that standards are met and designated uses are protected.

Where it was identified that current conditions fall short of potential standards, the UAA team identified several DO improvement alternatives and it was concluded that the following specific alternatives deserve further detailed evaluation with respect to DO to meet three different potential DO criterion levels: 4, 5, and 6 mg/L:

1. Diverting a portion of the MWRDGC North Side Water Reclamation Plant (NSWRP) effluent to a point near Sheridan Road to improve channel flow and DO conditions in the Upper NSC
2. Installing supplement aeration stations
3. Performing end-of-pipe treatment of CSOs

In Chapter 4, results of the simulations for flow augmentation on the NSC are presented. Evaluation of the installation of supplementary new aeration stations is explained in Chapter 5. Removal of carbonaceous biochemical oxygen demand ($CBOD_5$) and ammonia at all gravity flow (non-pump) CSOs is evaluated in Chapter 6. The MWRDGC also asked Marquette to evaluate the effects of diverting some portion of the flows in the SBCR to Bubbly Creek to improve poor water-quality conditions in Bubbly Creek. Results of this scenario are given in Chapter 7.

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 DUFLOW model developed in The Netherlands was selected for the calibration and simulations. 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.

In this study, data from the period between July 12 and November 9, 2001, were used to verify the previously calibrated hydraulic model (Shrestha and Melching, 2003). The model was run at a 15-min. time step and measured and simulated stage values were compared for a 60-min. time interval. Assumptions, data used, and results are presented in the following sections.

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 and the Calumet River at the O'Brien Lock and Dam gages are used as the primary upstream elevation versus time (hourly) boundary conditions for the unsteady-flow water-quality model. Flow versus time data on the North Shore Channel at Maple Avenue is also used as an upstream boundary condition. Since acoustic velocity meter (AVM) was not working properly after the middle of September 2001, two different downstream boundary conditions (flow and water elevation) were used at Romeoville for the DUFLOW simulations for different time periods. Flow versus time data (on a 15-minutes basis) from the USGS gage on the CSSC at Romeoville are used for the period between July 12 to September 14, 2001 and elevation versus time data from the USGS gage on the CSSC at Romeoville are used for the period between September 1 to November 9, 2001 as the downstream boundary condition for the model. Even though September 1, 2001 is the start date for the stage downstream boundary condition period, simulation output beginning on September 15, 2001 were used for the evaluation of the both water quality and hydraulic simulations to eliminate initial condition effects and provide a smooth transition between the simulations for the two different downstream boundary conditions. Benefits of this approach are obvious and can be seen in the following sections. 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 considered as tributary flow 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.

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 Water Reclamation Plants (WRPs)—North Side, Stickney, Calumet, and Lemont (although daily flows were used at Lemont). In addition, 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. 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 2.1. 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 2.1. 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 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 given in Figure 2.1 for July 12-November 9, 2001.

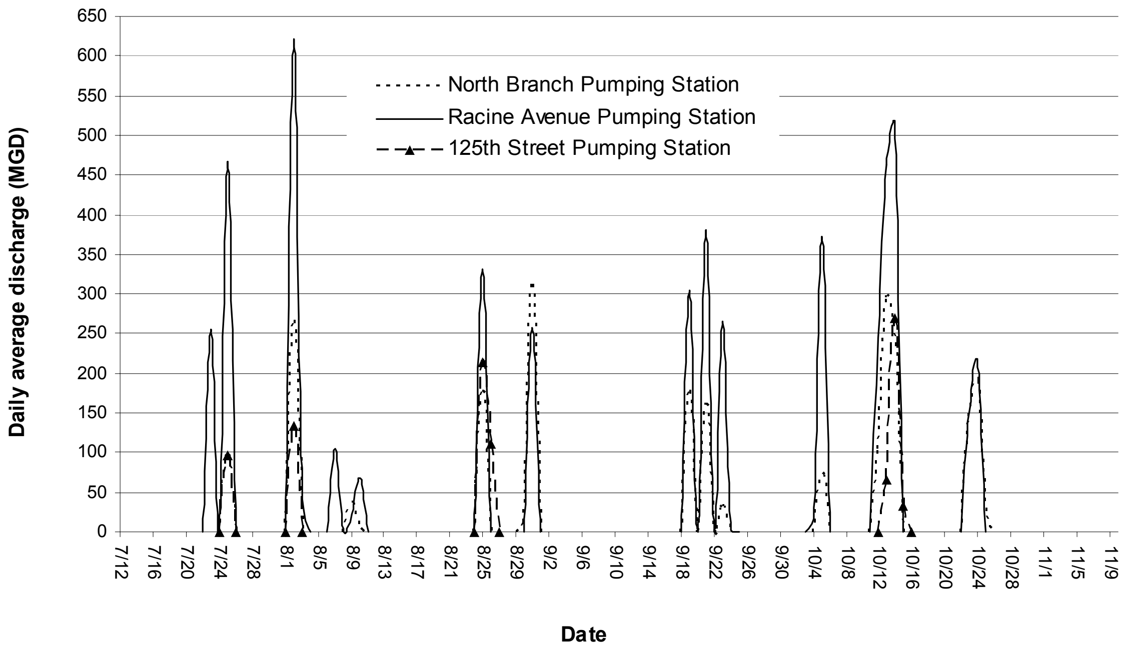


Figure 2.1 Daily average discharges from the North Branch, Racine Avenue, and 125th Street Pumping Stations for July 12-November 9, 2001

There are nearly 200 CSOs in the modeled portion of the CWS drainage area. Since it is practically difficult to introduce all CSO locations in the modeling, 28 representative CSO locations were identified and flow distribution was done on the basis of drainage area for each of these locations. Figure 2.2 and Table 2.2 give the locations and drainage areas of the 28 representative CSO locations. The volume of CSO was determined from the system wide flow balance and water level measurements at Romeoville. The flow balance calculation is explained in Section 2.5.

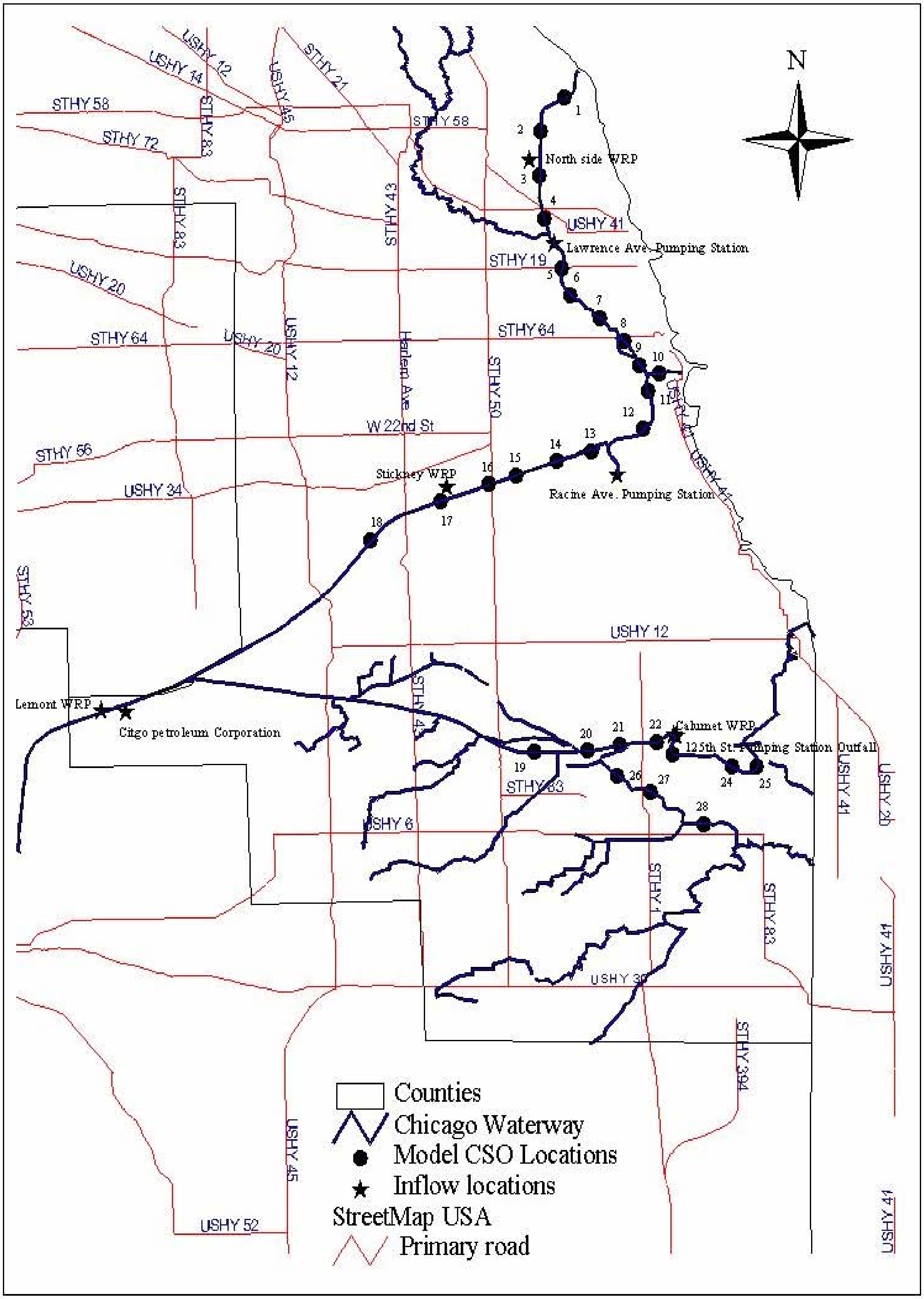


Figure 2.2 Locations of the 28 representative combined sewer overflows (CSOs) used in this study (note: The location of the Citgo Petroleum plant is shown above, the inflow location in the model and in reality is downstream from the Lemont WRP.)

Table 2.2 Drainage areas of each of the 28 representative combined sewer overflow (CSO) locations

CSO Number	River Mile relative to Lockport*	Drainage Area (mi^2)	Waterway
1	49	8.91	North Shore Channel
2	47	8.48	North Shore Channel
3	45	8.65	North Shore Channel
4	43	2.71	North Shore Channel
5	40	4.84	North Branch Chicago River
6	39	11.57	North Branch Chicago River
7	38	7.16	North Branch Chicago River
8	36	4.83	North Branch Chicago River
9	35	3.52	North Branch Chicago River
10	35	1.63	Chicago River Main Stem
11	34	2.45	South Branch Chicago River
12	32	9.55	South Branch Chicago River
13	30	3.90	Chicago Sanitary and Ship Canal
14	29	12.44	Chicago Sanitary and Ship Canal
15	27	10.75	Chicago Sanitary and Ship Canal
16	26	20.56	Chicago Sanitary and Ship Canal
17	25	20.57	Chicago Sanitary and Ship Canal
18	21	4.78	Chicago Sanitary and Ship Canal
19	25	8.45	Calumet-Sag Channel
20	27	4.02	Calumet-Sag Channel
21	28	10.70	Little Calumet River (North)
22	30	4.10	Little Calumet River (North)
23	31	3.58	Little Calumet River (North)
24	34	5.12	Little Calumet River (North)
25	35	5.64	Little Calumet River (North)
26	31	1.40	Little Calumet River (South)
27	32	6.17	Little Calumet River (South)
28	35	0.62	Little Calumet River (South)

*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.

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 and USGS data at Romeoville and 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 Romeoville (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 Ditch*

m. Cal-Sag Watershed West*

n. 28 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 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 193 measured cross sections in the calibrated hydraulic model. The same channel geometry values were used for the verification simulations. The DUFLOW model uses Chezy's roughness coefficient, C, to calculate hydraulic resistance. For verification purposes, 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 at Wilmette, Western Avenue, Willow Springs Road, Southwest Highway and Cal-Sag Junction by the MWRDGC and at Romeoville by the USGS (when discharge was the downstream boundary condition) were used for model verification. Daily flows recorded on the Chicago River at Columbus Drive and the Calumet River at O'Brien Lock and Dam and estimated by the USGS for the CSSC at Romeoville (when elevation was the downstream boundary condition) 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 outflow at Romeoville. Missing data from gaged sites, ungaged tributaries, and CSO flows have been estimated by various mathematical and statistical methods described in detail in Shrestha and Melching (2003). 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. Comparison of the summation of all inflows (except CSOs) to the system and outflow at Romeoville is shown in Figure 2.3. All inflows to the system and flow at Romeoville for the July 12-November 9, 2001 period are listed in Table 2.4. Over the full study period the inflows (except CSOs) were 8.1 % lower than the outflow at Romeoville. Since there are no measured discharge data available at Romeoville after September 19, 2001, discharges estimated by the USGS were used in the flow balance from September 19 to November 9, 2001.

During the storm events, the measured and estimated inflows were insufficient to maintain simulated water-surface elevations at Romeoville near the measured water-surface elevations. 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. Thus, CSO volume was added until reasonable water-surface elevations were simulated at Romeoville. This CSO volume is proportioned on the basis of CSO drainage areas listed in Table 2.2 divided by the total CSO drainage area (i.e. volume CSO 1 = [Area CSO 1/Total CSO area] x Total CSO volume) and applied uniformly in time over the period of operation of Racine Avenue Pumping Station. Estimated daily average flows from CSOs during major storms are listed in Table 2.3.

Table 2.3 Daily average discharges (mgd) from 28 Combined Sewer Overflows (CSOs), during major storms in 2001.

Date	7-25	8-2	8-25	8-31	9-19
Total gravity flow CSO (mgd)	586.6	3136.1	1625.1	673.3	1004.3
Date	9-21	9-23	10-5	10-14	10-23
Total gracity flow CSO (mgd)	817.1	773.7	623.1	3387.2	310.4

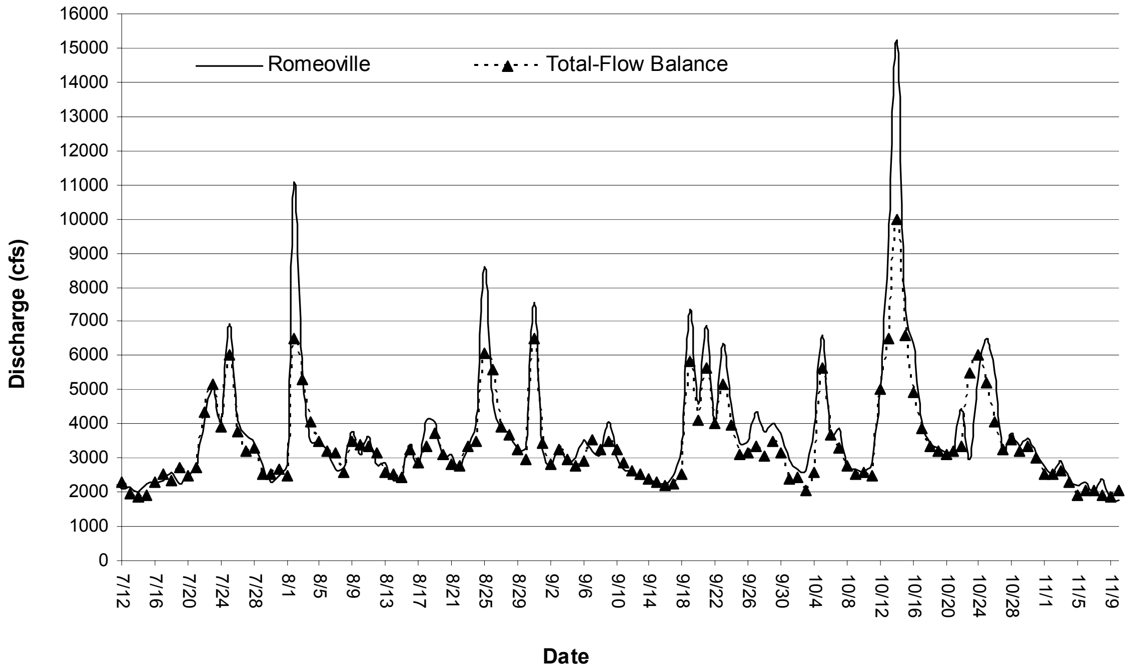


Figure 2.3. Comparison of the summation of all measured or estimated (except combined sewer overflows) inflows (Total) and the measured outflow at Romeoville for July 12 - November 9, 2001

Table 2.4. Balance of average daily flows for the Chicago Waterway System for the period of July12 to November 9, 2001

Inflows	Flow (cfs)
Mill Creek + Stoney Creek (W)*	30.7
Narajo Creek + Calumet-Sag basin*	7.2
Calumet Union Ditch*	21.9
Stoney Creek (E)*	9.1
Calumet-Sag End Watershed*	18.6
Lower Des Plaines basin*	13.2
Midlothian Creek	18.7
Grand Calumet River	14.0
Tinley Creek	17.8
Chicago River at Columbus Drive	264.5
O'Brien Lock and Dam	183.0
North Shore Channel at Wilmette	30.7
Little Calumet River at South Holland	180.9
North Branch Chicago River at Albany Avenue	246.3
125th Street Pump Station	10.9
North Branch Pump Station	27.7
Racine Avenue Pump Station	59.7
Lemont Water Reclamation Plant	3.3
Calumet Water Reclamation Plant	428
Northside Water Reclamation Plant	450.3
Stickney Water Reclamation Plant	1311
Romeoville (Outflow)	3644.4
Total Inflow	3347.5
Difference (cfs)	-296.9
% Difference	-8.1

*Estimated flows

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 Figure 2.4. Statistical analysis listed in Table 2.5 and Table 2.6 (note: the difference in the number of data in the table for the various locations results because of different amounts of missing or erroneous data at these locations) showed that difference between the measured and simulated stages are all below 8.5 % relative to the depth (where depth is measured relative to the thalweg of the channel) of the water except for Willmette. Mean and median values of the absolute value of the difference between the measured and simulated stages are below 3.2 % relative to the depth of the water at all locations. The simulated water-surface elevations were within 2 % of the measured values with respect to the depth for 72.6-99.2% of the values and within 3% for 93.7-99.9% of the values in all locations other than Wilmette. These high percentages of small errors and the high correlation coefficients (0.79-0.98) indicate an excellent hydraulic verification of the model. Further, data were not available at Southwest Highway during the original hydraulic calibration. Thus, the results at Southwest Highway are a more stringent verification of the model's accuracy. Since the calibrated model can predict stages throughout the CWS with high accuracy, this model can be safely used for the water-quality calibration.

Table 2.5. Correlation coefficient and percentage of the hourly water-surface elevations for which the error in simulated versus measured elevations relative to the depth of flow (measured from the thalweg of the channel) is less than the specified percentage

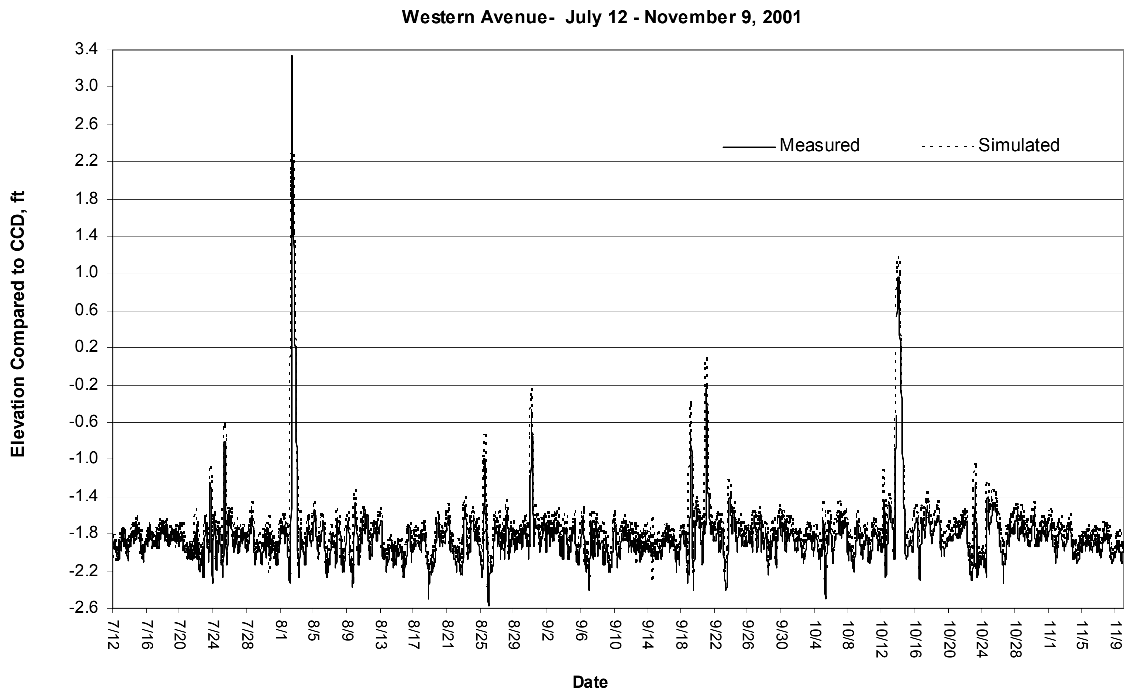
		Percentage		
Location	**Correlation Coefficient**	**<±1% of D**	**<±2% of D**	**<±3% of D**
Southwest Highway (Cal-Sag Channel)	0.89	26.7	72.6	93.7
Western Avenue (CSSC)	0.95	90.7	99.2	99.6
Willow Springs (CSSC)	0.90	82.7	99.1	99.9
Sag Junction	0.79	64.9	97.3	99.2
Romeoville (CSSC) July 12-September 14, 2001	0.98	92.4	97.9	99.0
Wilmette (North Shore Channel)	0.88	5.04	25.03	66.6

Table 2.6. Comparison of simulated and measured water-surface elevations relative to CCD, July 12-November 9, 2001 [note: Elevation Error =simulated–measured; Abs Error =absolute value of simulated–measured; Percent Error =(simulated–measured)/measured x 100; Abs Percent Error =absolute value of (simulated–measured)/measured x 100; Percent Error wrt Depth = (simulated elevation–measured elevation)/measured depth x 100; Abs Percent Error wrt Depth=absolute value of (simulated elevation–measured elevation)/measured depth x100; R = Correlation coefficient]

		Measured Elevation (ft)	Simulated Elevation (ft)	Measured Water Depth (ft)	Elevation Error (ft)	Abs Error	Percent Error	Abs Percent Error	Percent Error wrt Depth	Abs Percent Error wrt Depth
	Min.	-2.57	-2.38	22.00	-1.50	0.00	-228.9	0.01	-5.42	0.00
	Max.	3.33	2.28	26.66	1.98	1.98	90.24	228.99	8.44	8.44
Western	**Mean**	-1.85	-1.74	22.63	0.10	0.12	-5.56	6.61	0.46	0.52
Avenue	**Med.**	-1.87	-1.78	22.60	0.10	0.10	-5.25	5.54	0.44	0.46
	STD	0.35	0.35	0.35	0.11	0.10	9.14	8.41	0.48	0.42
# of Data =		2902		**R =**	0.95					
	Min.	-3.20	-3.23	23.25	-1.16	0.00	-300.4	0.00	-4.22	0.00
	Max.	1.00	0.62	27.10	0.73	1.16	86.3	300.42	3.05	4.22
Willow	**Mean**	-2.02	-1.87	24.60	0.15	0.16	-7.40	8.21	0.61	0.66
Spring	**Med.**	-2.00	-1.86	24.62	0.15	0.15	-7.52	7.63	0.62	0.63
	STD	0.26	0.25	0.25	0.12		8.92	8.19	0.48	0.41
# of Data =		2898		**R =**	0.90					
	Min.	-3.70	-3.71	24.38	-1.81	0.00	-37.56	0.02	-6.73	0.00
	Max.	-0.46	-0.42	27.66	0.80	1.81	311.9	311.95	3.24	6.73
Cal Sag.	**Mean**	-2.16	-1.96	26.13	0.20	0.23	-8.48	11.08	0.77	0.88
Junction	**Med.**	-2.13	-1.91	26.18	0.21	0.22	-9.90	10.08	0.82	0.83
	Min.	0.29	0.27	0.27	0.18	0.15	15.24	13.47	0.70	0.56
# of Data =		2897		**R =**	0.79					

Table 2.6 (cont.). Comparison of simulated and measured water-surface elevations relative to CCD, July 12-November 9, 2001 [note: Elevation Error =simulated–measured; Abs Error =absolute value of simulated–measured; Percent Error =(simulated–measured)/measured x 100; Abs Percent Error =absolute value of (simulated–measured)/measured x 100; Percent Error wrt Depth = (simulated elevation–measured elevation)/measured depth x 100; Abs Percent Error wrt Depth=absolute value of (simulated elevation–measured elevation)/measured depth x100; R = Correlation coefficient]

		Measured Elevation (ft)	Simulated Elevation (ft)	Measured Water Depth (ft)	Elevation Error (ft)	Abs Error	Percent Error	Abs Percent Error	Percent Error wrt Depth	Abs Percent Error wrt Depth
	Min.	-7.51	-8.15	21.35	-1.68	0.00	-55.36	0.01	-7.05	0.00
	Max.	-1.63	-1.20	28.29	1.55	1.68	52.97	55.36	5.81	7.05
Romeoville	**Mean**	-2.35	-2.32	27.17	0.03	0.12	-1.87	5.07	0.11	0.45
	Med.	-2.13	-2.09	27.40	0.05	0.09	-2.19	3.82	0.18	0.32
	STD	0.80	0.88	0.88	0.18	0.14	7.01	5.19	0.70	0.55
# of Data =		1559		**R =**	0.98					
	Min.	-2.80	-2.77	10.23	-0.30	0.00	-160.71	0.02	-2.71	0.00
	Max.	-0.07	0.04	13.03	0.72	0.72	46.82	160.71	6.52	6.52
Southwest	**Mean**	-2.01	-1.85	11.14	0.17	0.17	-8.13	8.57	1.51	1.57
Cal-Sag	**Med.**	-2.00	-1.84	11.15	0.16	0.16	-8.16	8.20	1.48	1.49
	STD	0.23	0.22	0.22	0.11	0.10	6.17	5.54	0.98	0.89
# of Data =		2902		**R =**	0.89					
	Min.	-2.74	-1.96	8.94	-2.40	0.00	-25419	0.00	-16.40	0.00
Wilmette	**Max.**	7.18	5.89	16.78	5.51	5.51	3929	25419	54.97	54.97
NSC.	**Mean**	-0.63	-0.88	10.01	-0.25	0.33	-0.43	93.74	-2.38	3.15
	Med.	-0.93	-1.17	9.72	-0.25	0.26	23.29	27.38	-2.55	2.61
	STD	0.96	0.91	0.91	0.40	0.33	686.88	680.45	3.71	3.08
# of Data =		2894		**R =**	0.88					



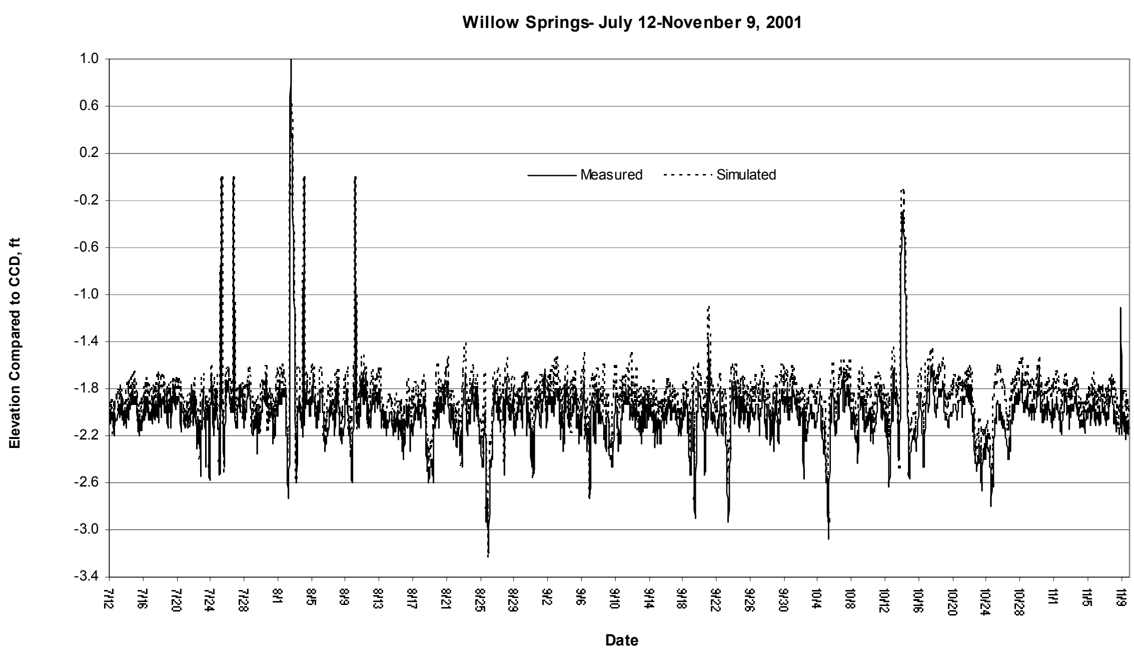
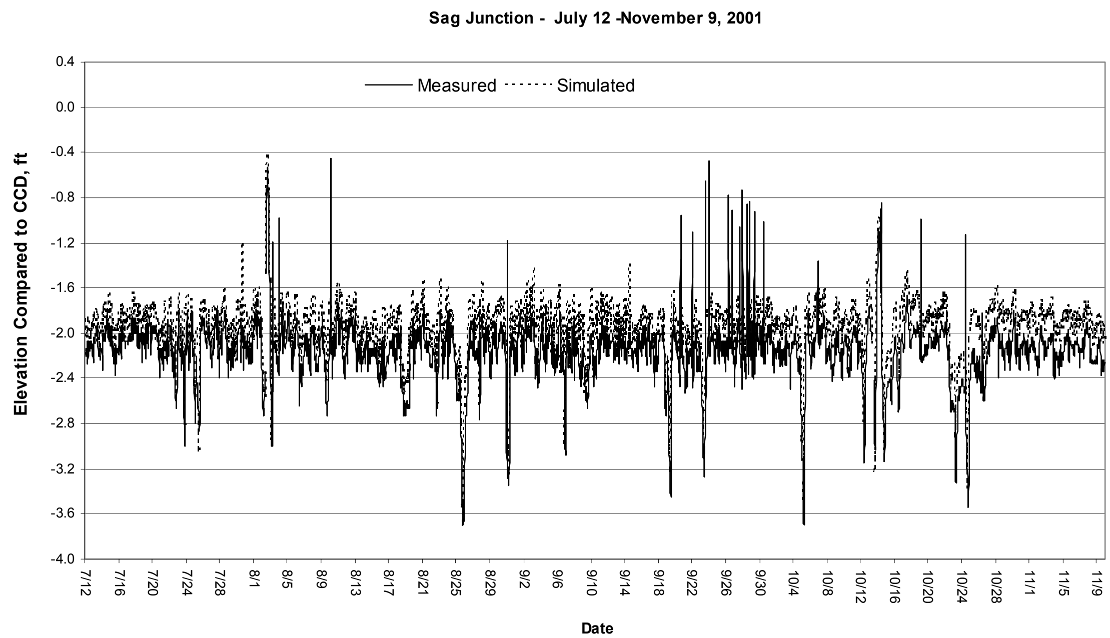


Figure 2.4. Comparison of measured and simulated water-surface elevations relative to the City of Chicago Datum (CCD) at different locations in the Chicago Waterway System for July 12-November 9, 2001



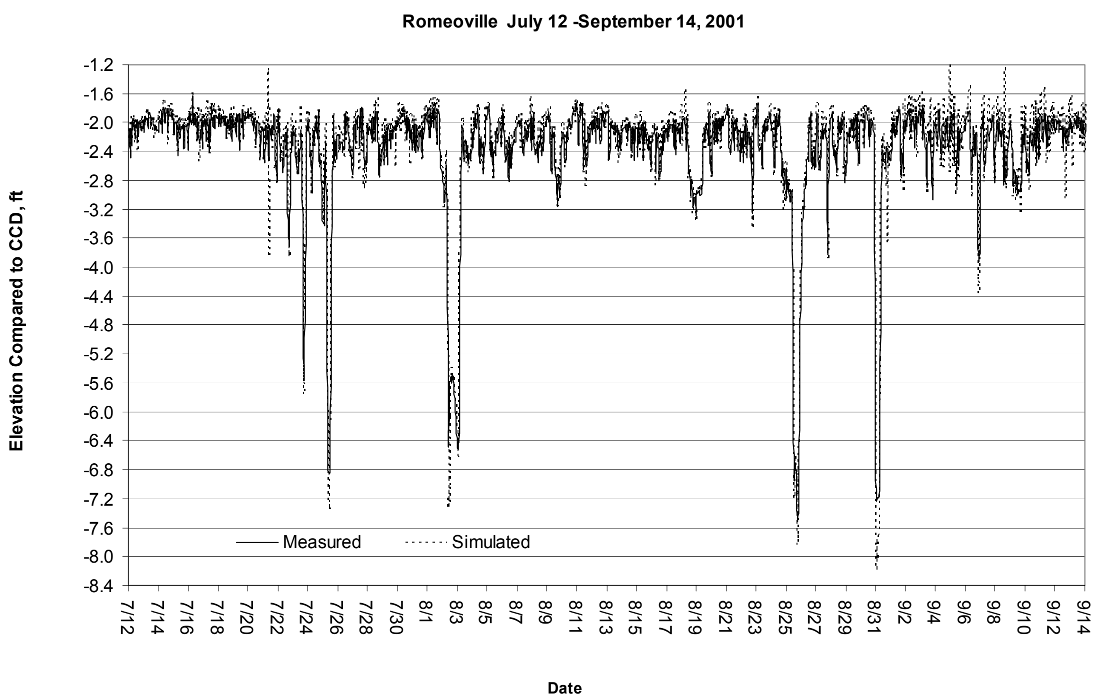
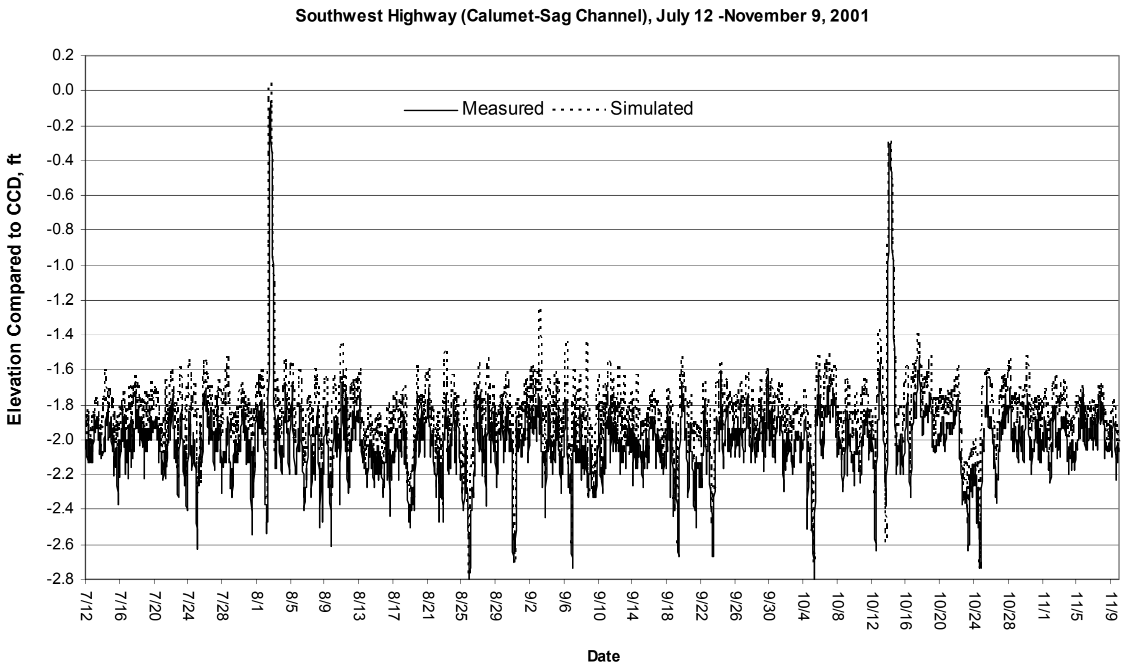


Figure 2.4. (cont.) Comparison of measured and simulated water-surface elevations relative to the City of Chicago Datum (CCD) at different locations in the Chicago Waterway System for July 12-November 9, 2001



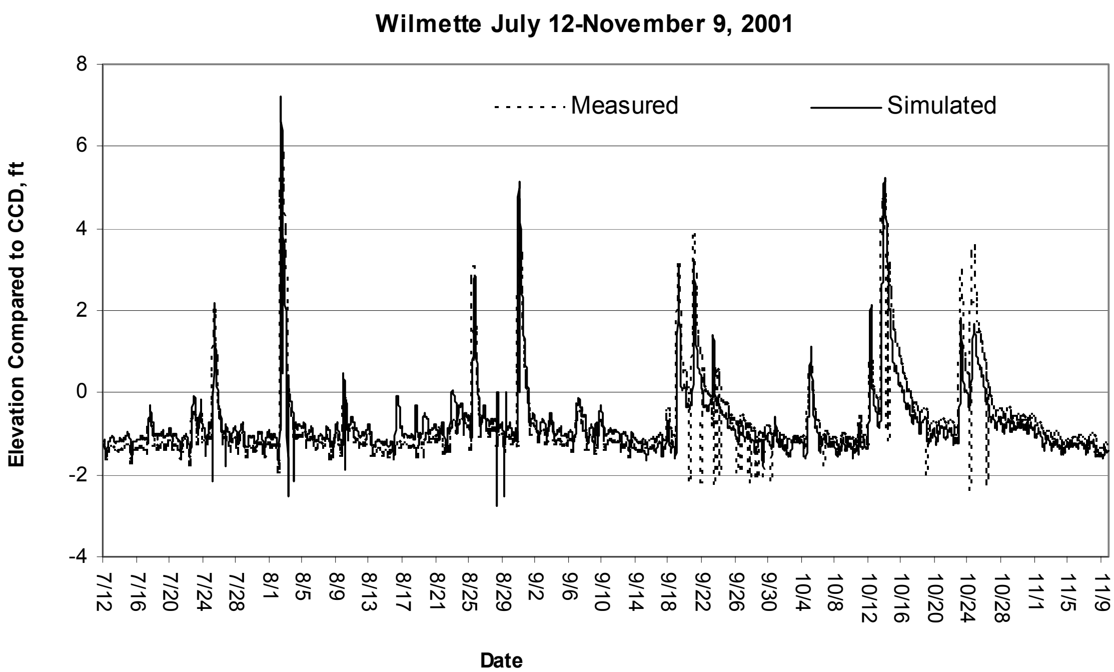


Figure 2.4 (cont.). Comparison of measured and simulated water-surface elevations relative to the City of Chicago Datum (CCD) at different locations in the Chicago Waterway System for July 12-November 9, 2001

The comparison of measured and simulated average daily flows at the boundaries is shown in Figure 2.5. Both the measured and simulated flows at these locations are very small compared to the total flow at Romeoville. Especially during storm periods large deviations from the measured values are observed. Similar deviations were found in the original hydraulic calibration (Shrestha and Melching, 2003), and readers should review Shrestha and Melching (2003) to understand the causes of these deviations. Comparison of measured and simulated average discharges at the boundaries is listed in Table 2.7. For both the Columbus Drive and O'Brien Lock and Dam boundaries, simulated flow is higher than measured flow. The simulated inflows at these locations is 147.8 cfs greater than the measured inflows. The difference between simulated and measured average flow for the period of September 15-November 9, 2001 at Romeoville is just -9.3 cfs.

Table 2.7 Comparison of average simulated and measured flow at the boundaries

	Measured (cfs)	**Simulated (cfs)**
Columbus	260.9	321.0
O'Brien	179.3	267.0
Romeoville*	4067.8	4058.5

*Values are based on simulated and USGS estimated daily flows from September 15-November 9, 2001

Since the system is dominated mainly by treatment plant and tributary flows, the effects of the overestimate of inflows at Columbus Drive and O'Brien Lock and Dam on water-quality simulation accuracy decrease as the water gets farther from these boundaries. Detailed discussion of water-quality simulations at the boundaries is given in Section 3.5.2.4.

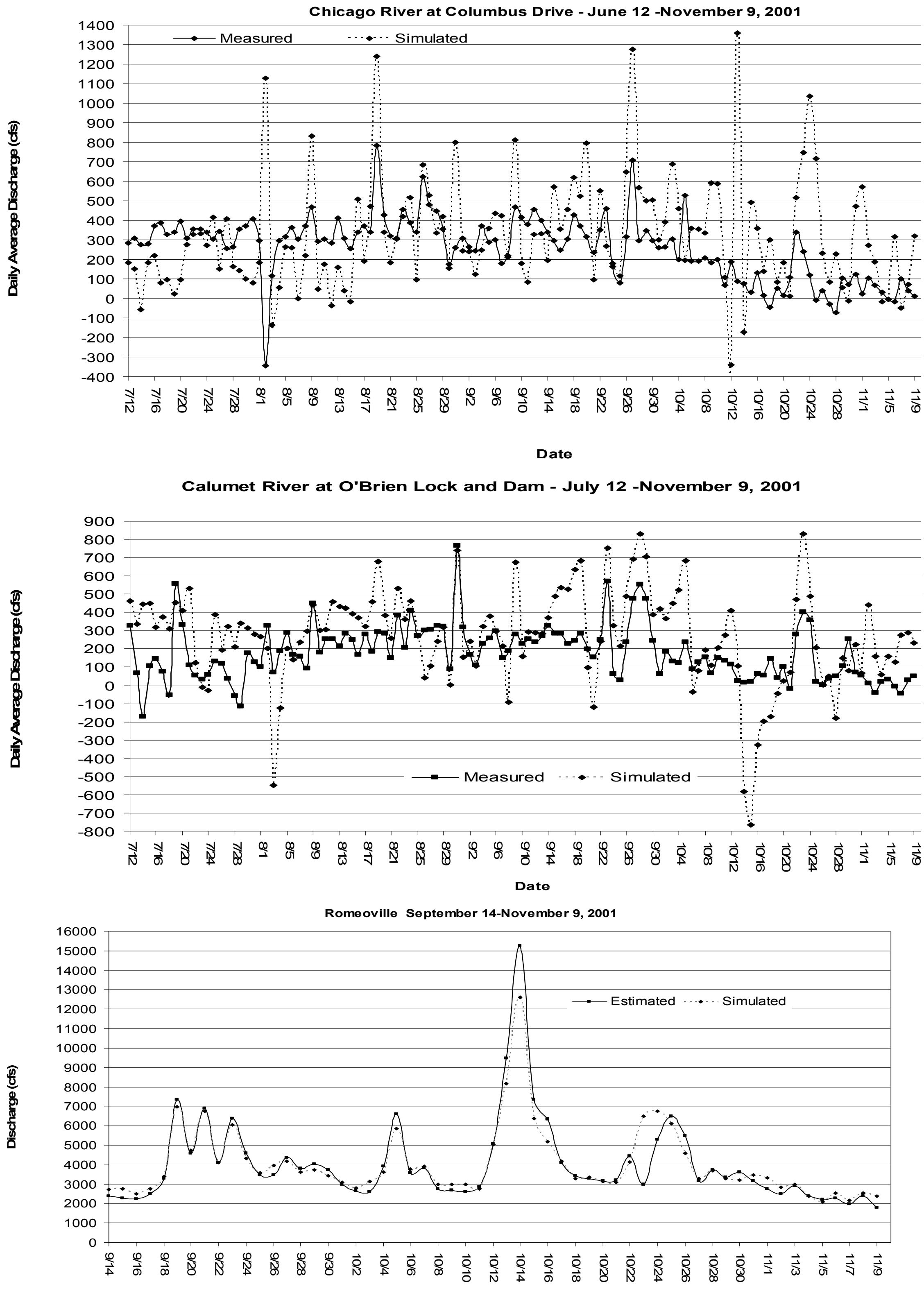


Figure 2.5 The comparison of measured (or estimated) and simulated average daily flows at the boundaries

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 is designed for various categories of users. The model can be used by water authorities, designers, and educational institutions. DUFLOW runs on a personal computer with a graphical user interface. It can, therefore, be operated in most scientific or engineering environments.

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 oxygen 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. The CWS also receives pollutant loads from four WRPs, nearly 200 CSOs (condensed to 28 representative locations to facilitate the modeling), direct diversions from Lake Michigan, and eleven tributary streams or drainage areas. 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

As a result of substantial pollutant loading and low in-stream velocities, DO concentrations in the CWS historically have been low. 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	Cal-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 oxygen load from the SEPA stations. The summaries of these studies and the estimation of DO loads from SEPA stations are explained in detail in Alp and Melching (2004). The same procedure explained in Alp and Melching (2004) was followed to estimate the oxygen loads from the SEPA stations for July 12-November 9, 2001.

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

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

where:

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

These hourly oxygen loads were directly input to the CWS as a point source in the DUFLOW water-quality simulation. Average daily DO loads from SEPA stations 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. During the study period (July 12-November 9, 2001), most of the time SEPA stations were in use and just one pump was operating.

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 Street 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 oxygen loads from the in-stream aeration stations. The details of the estimation of the oxygen loads from in-stream aeration stations are given in Alp and Melching (2004)

Blower operation hours were provided by the MWRDGC. Unfortunately only the total number of operating hours per day was provided. Since blower start and stop times are unknown, blower operation hours were carefully determined using time intervals where increases and decreases in DO concentrations were observed downstream of the aeration stations. The Addison and Division Street continuous DO station observations were used for downstream of the Devon Avenue and Webster Street aeration stations, respectively. The following equation is used to calculate hourly DO load for input to the model:

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

where:

Load = Oxygen load from 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)

Discharge and DO concentration upstream of Devon Avenue were calculated using a mass balance approach. The NSWRP 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 Street aeration station calculations. Average daily oxygen load from in-stream aeration stations are given in Appendix B.

3.2.3 Water Reclamation Plants

Four point sources of flow potentially affect the water quality in the CWS: the NSWRP, 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 given in Figures 3.1-3.3, respectively. In these figures and throughout the report the constituent abbreviations are as follows: DO = dissolved oxygen, CBOD5 (figures) $CBOD_5$ (text) = 5-day carbonaceous biochemical oxygen demand, TSS = total suspended solids, TKN = total Kjeldahl nitrogen as nitrogen, NH4-N (figures) NH_4-N (text) = ammonia as nitrogen, Org-N = organic nitrogen as nitrogen, NO3-N (figures) NO_3-N (text) = nitrate as nitrogen, and P-Tot = total phosphorus. 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 contributed by this discharger.

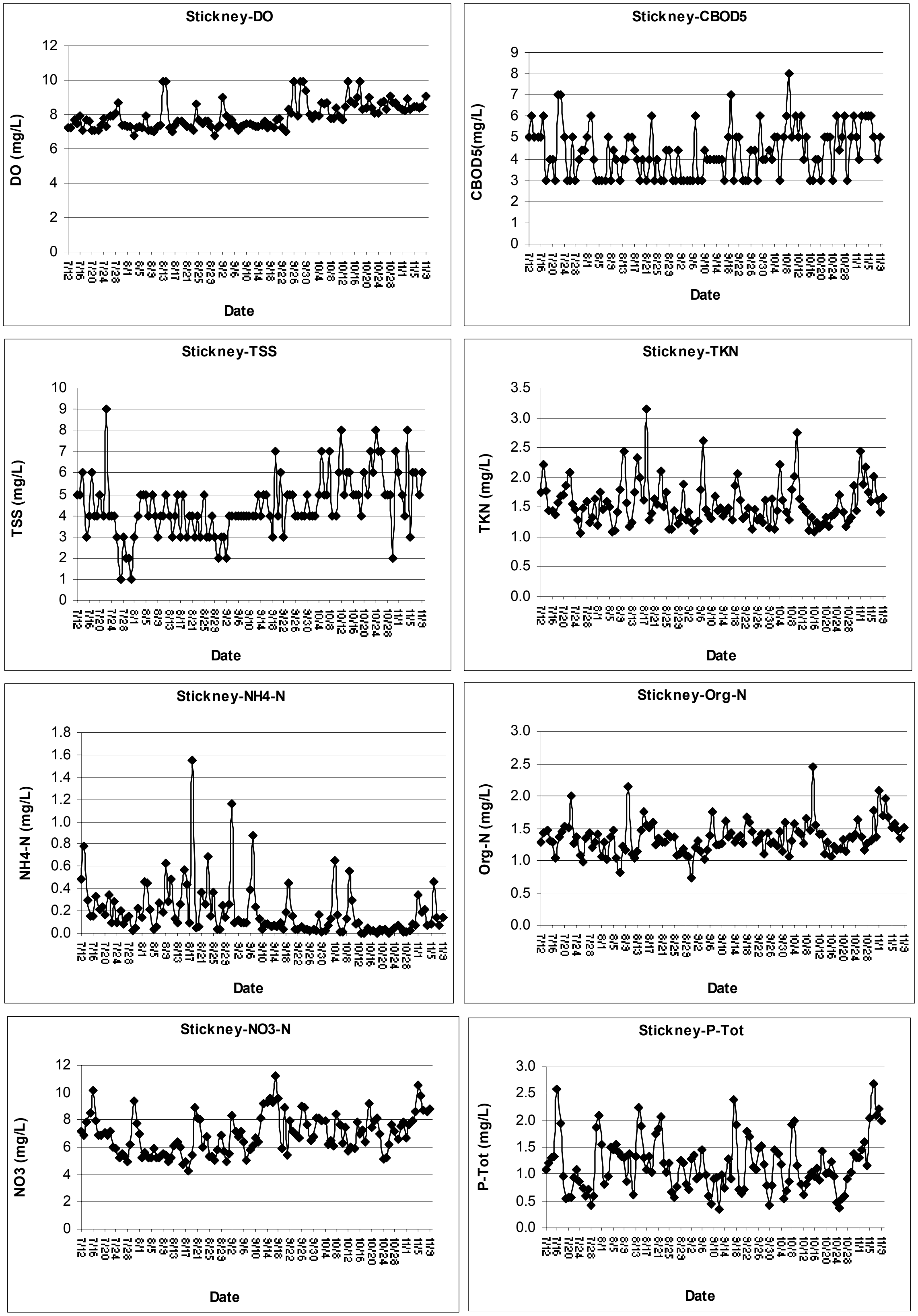


Figure 3.1 Stickney Water Reclamation Plant daily effluent concentrations for July 12-November 9, 2001

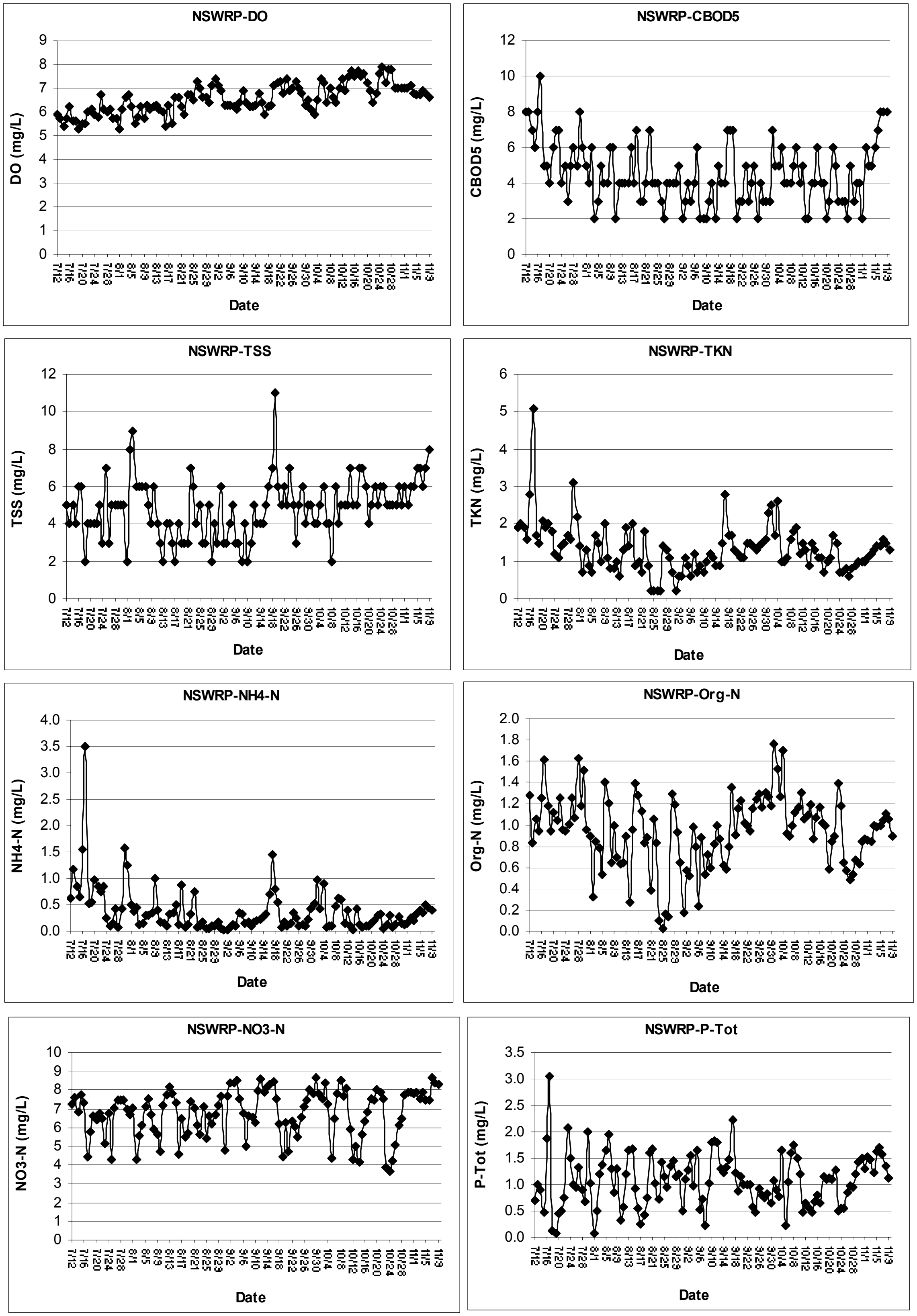


Figure 3.2. North Side Water Reclamation Plant daily effluent concentrations for July 12-November 9, 2001

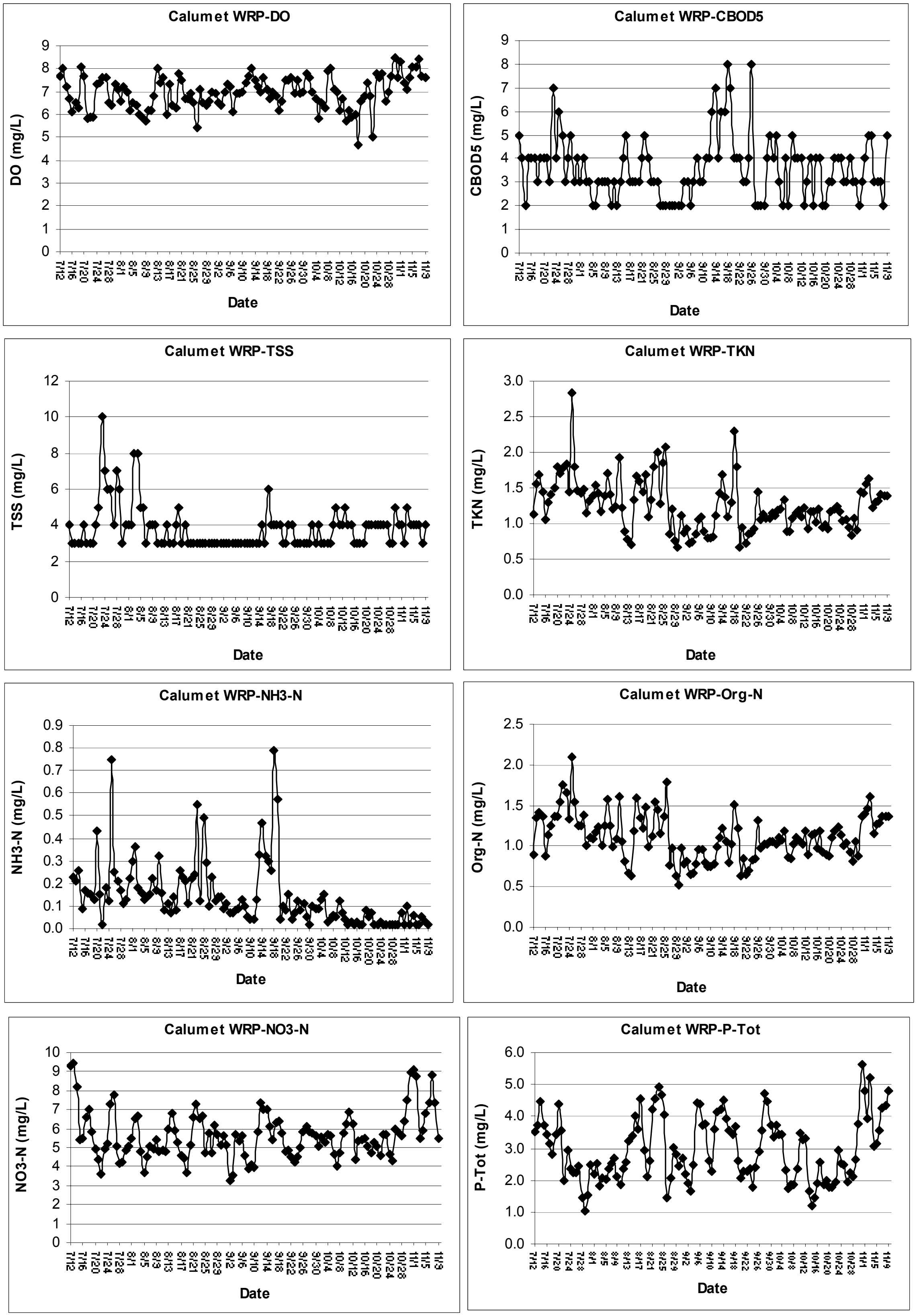


Figure 3.3. Calumet Water Reclamation Plant daily effluent concentrations for July 12-November 9, 2001

3.2.4 Tributaries

There are two data categories related to the tributaries:

i) Dry weather long-term average concentrations

ii) Wet weather event mean concentrations

Values for each of these categories are discussed in the following subsections.

3.2.4.1 Dry Weather Concentrations

Long-term average values are used for the dry-weather concentrations. All water-quality data used for dry-weather concentrations were collected as a part of the MWRDGC monthly waterway sampling program.

Average concentrations for 2001-2002 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 dry-weather 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)	P-Sol (mg/L)
3.15	53.05	5.61	1.71	0.30	1.42	1.19	3.39	0.97

Concentrations measured between 1990-2002 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 dry-weather 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)	P-Sol (mg/L)
6.69	37.63	***	4.48	2.09	2.41	0.76	8.04	0.22

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

Average concentrations (2000-2002) 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 dry-weather 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)	P-Sol (mg/L)
4.0	23.12	5.3*	1.71	0.37	1.34	0.85	3.41	0.81

*Average of data from July-November (2000-2002)

Since the data collected by the MWRDGC during 2001-2004 show that the chlorophyll-a concentration varies drastically from month to month, average July-November chlorophyll-a concentrations were calculated for the Little Calumet River at South Holland and North Branch Chicago River at Albany Avenue. The chlorophyll-a concentration for the Little Calument River at South Holland was computed using the same mass balance approach applied for the other constituents. Results are listed in Table 3.5.

Table 3.5 North Branch Chicago River at Albany Avenue and Little Calumet at South Holland chlorophyll-a concentrations

	Chlorophyll-a (µg/L)				
Location	**July**	**August**	**September**	**October**	**November**
Albany Avenue	13.8	11.1	9.6	10.8	7.7
South Holland	9.6	9.4	5.2	3.1	13.4

Dry-weather concentrations for other tributaries are based on Little Calumet River concentrations because all of the other gaged and ungaged tributaries are on the southern portion of the Chicago metropolitan area and were assumed to be similar to the Little Calumet drainage basin.

3.2.4.2 Wet Weather Concentrations

Event mean concentrations were calculated using water-quality data collected during storm events by the MWRDGC. In most cases, the total load resulting from the runoff event is more important than the individual concentrations within the event due to the fact that runoff events are relatively short, the receiving water body provides some mixing, and the concentration in the receiving water body is a response to the total load rather than the concentration variability within the event (Novotny and Olem, 1994, p. 484). Hence, event mean concentrations were used to characterize all storms in this study. Concentrations for the Little Calumet River at South Holland were calculated using storm data on the Little Calumet River at Ashland Avenue. Results are listed in Table 3.6.

Table 3.6. Event mean concentrations measured at the Little Calumet River at Ashland Avenue in 2001

Date	$CBOD_5$ (mg/L)	DO (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	P-Tot (mg/L)	TKN (mg/L)	SS (mg/L)
07/22 - 07/26	1.28	3.99	0.11	1.72	0.30	1.07	1.64	78.28
08/02 - 08/07	2.03	4.37	0.10	0.97	0.30	1.26	2.38	141.67
08/25 - 08/29	2.33	4.82	0.08	1.48	0.24	1.07	1.90	105.72
09/19 - 09/21	3.27	5.17	0.09	2.85	0.16	1.95	1.77	107.24
09/23 - 09/28	3.00	5.60	0.08	3.40	0.20	1.30	1.96	52.00
10/04 - 10/11	1.78	6.28	0.06	1.82	0.16	1.30	1.86	94.58
10/11 - 10/21	3.72	6.60	0.05	1.40	0.08	0.73	1.38	80.00
10/23 - 10/31	3.38	6.18	0.06	1.50	0.10	1.01	1.62	69.43

Event mean concentrations for the North Branch Chicago River at Albany Avenue are listed in Table 3.7.

Table 3.7. Event mean concentrations measured at the North Branch Chicago River at Albany Avenue in 2001

Date	$CBOD_5$ (mg/L)	DO (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	P-Tot (mg/L)	TKN (mg/L)	SS (mg/L)
07/22 - 07/26	4.18	4.42	0.08	1.91	0.29	0.69	2.02	96.19
08/02 - 08/06	3.48	4.83	0.08	1.55	0.31	0.66	2.23	151.51
8/13	0.00	4.90	0.03	1.29	0.06	0.64	1.31	23.00
08/23 - 08/28	1.40	5.41	0.05	1.23	0.17	0.46	1.61	81.11
08/31 - 09/02	3.46	5.99	0.06	1.37	0.22	0.29	1.59	77.42
9/10	0.00	5.30	0.06	2.38	0.11	0.50	1.25	34.00
09/19 - 10/01	1.72	6.59	0.07	1.25	0.19	0.37	1.54	64.61
10/12 - 10/22	1.75	6.85	0.03	0.86	0.05	0.32	0.91	49.06
10/22 - 11/05	2.42	7.10	0.03	0.79	0.05	0.28	1.10	34.29

Other tributaries are based on Little Calumet River event mean concentrations.

3.2.5 Combined Sewer Overflows

There are nearly 200 CSO locations discharging to the modeled portion of the CWS and they are represented by 28 CSO locations in the model (Figure 2.2 and Table 2.2). In addition to CSO locations there are 3 CSO pumping stations. Water-quality parameters were measured by the MWRDGC at the North Branch and 125th Street Pump Stations for selected storms in 2001. Event mean concentrations of the measured parameters for the pumping stations listed in Tables 3.8-3.10 were used in the model. When there were no measured data for a storm, the average of all 2001 event mean concentrations for the given pumping station were assigned to this storm. Since there are no measured data for the Racine Avenue Pumping Station for 2001, concentrations were determined by regression equations based on discharge and event mean concentration. As historic data are available for $CBOD_5$, TSS, and NH_4-N at the Racine Avenue Pumping Station (listed in Neugebauer and Melching (2005)), these values were used in the regression analysis.

For other constituents (NO_2-N, NO_3-N, P-Tot, TKN, and DO) historic North Branch Pumping Station values were used. The correlation coefficient of the estimation equations varyies between 0.5 and 0.99. Since a limited number of data are available, low or high correlation coefficients do not necessarily mean that there is a strong or weak relation between the even mean concentrations and the pumpage. On the other hand, regression figures (Figure 3.4) show an obvious relation between the discharge and event mean concentrations. In order to evaluate the effects of this approach (regression based event mean concentration estimation), a detailed uncertainty analysis is necessary.

The North Branch Pumping Station water-quality parameters were used for NSC and NBCR CSOs, the Racine Avenue Pumping Station water-quality parameters were used for the Chicago River Main Stem and SBCR CSOs, and the Calumet-Sag Channel and Little Calumet River CSO water-quality parameters were determined using concentrations measured at the 125th Street Pumping Station. The reasonableness of this approach was discussed in detail in Neugebauer and Melching (2005).

Table 3.8. Event mean concentrations at the North Branch Pumping Station measured in 2001

	DO (mg/L)	**$CBOD_5$ (mg/L)**	**NH_4-N (mg/L)**	**NO_3-N (mg/L)**	**Org-N (mg/L)**	**P-Tot (mg/L)**	**TSS (mg/L)**
08/02/01	5.8	27.269	1.812	1.516	5.678	1.023	92.332
08/09/01	2.4	71.415	3.228	0.656	14.155	2.696	262.973
09/19/01	4.2	14.851	2.384	0.565	3.441	0.777	67.006
09/20/01	2.6	20.828	1.765	0.510	5.407	1.167	83.100
09/23/01	4.0	42.281	5.813	0.265	6.479	1.735	87.087
10/13/01	4.0	30.221	1.831	0.581	3.816	1.012	52.226
10/23/01	6.7	42.396	2.201	0.613	5.406	1.290	107.540

Table 3.9. Event mean concentrations at the 125th Street Pumping Station measured in 2001

	DO (mg/L)	$CBOD_5$ (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Org - N(mg/L)	P-Tot (mg/L)	TSS (mg/L)
08/02/01	4.3	24.441	1.239	1.542	4.318	2.020	85.959
08/25/01	4.3	12.577	0.876	1.825	3.037	0.483	68.304
10/13/01	4.3	8.402	0.315	1.733	2.446	0.457	41.435

Table 3.10. Estimated event mean concentrations at the Racine Avenue Pumping Station for 2001

	DO (mg/L)	$CBOD_5$ (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	P-Tot (mg/L)	TKN (mg/L)	TSS (mg/L)
7/23	5.3	59.5	1.9	0.70	1.0	6.6	990.4
7/25	6.8	45.8	1.3	0.82	0.8	5.2	640.6
8/2	7.8	39.3	1.1	0.90	0.7	4.6	497.7
8/7	3.6	87.5	3.4	0.56	1.4	9.2	1883.9
8/8	3.4	92.6	3.7	0.54	1.5	9.6	2068.5
8/25	5.9	53.1	1.6	0.75	0.9	6.0	820.6
8/31	5.3	59.4	1.9	0.70	1.0	6.6	989.6
9/19	5.6	55.2	1.7	0.74	1.0	6.2	875.2
9/21	6.2	50.1	1.5	0.78	0.9	5.7	744.0
9/23	5.4	58.3	1.9	0.71	1.0	6.5	959.1
10/4	6.3	49.6	1.5	0.78	0.9	5.6	731.9
10/12	5.2	60.6	2.0	0.70	1.0	6.7	1022.7
10/13	9	33.2	0.8	0.99	0.7	4.0	376.3
10/23-24	6.1	50.9	1.5	0.77	0.9	5.7	763.6

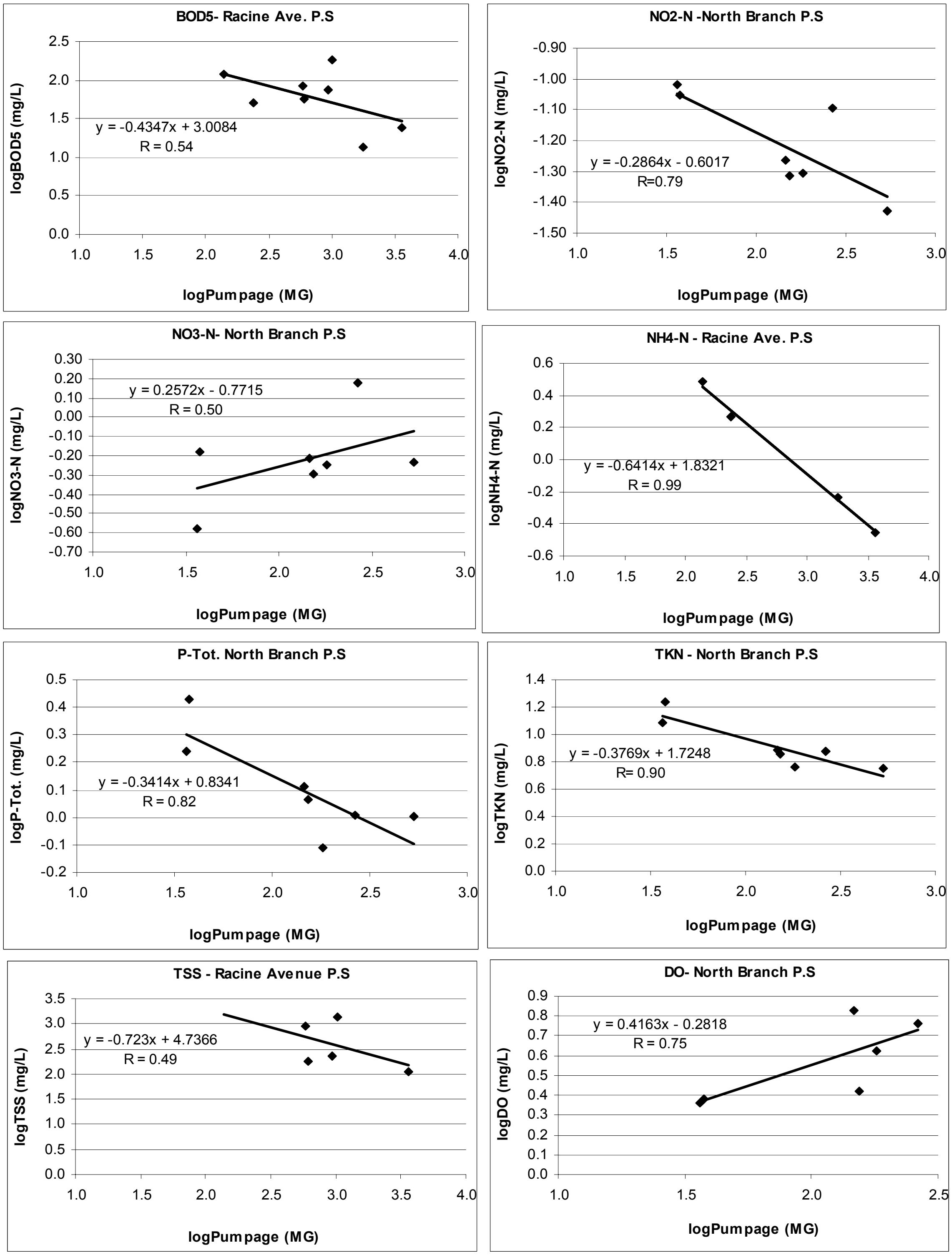


Figure 3.4 Relations between the event mean concentrations and pumpage for the Racine Avenue Pumping Station and the North Branch Pumping Station

3.2.6 Boundaries

Three of the 3 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 O'Brien Lock and Dam. Historic plots of data (1990-2002) show that there are seasonal and monthly variations at these locations and nitrogen compound concentrations for the Chicago River at Columbus Drive changed after 1997. Chlorophyll-a concentration also shows monthly variations according to the measurements done between 2001 and 2004.

In the summer, the water quality parameters measured near the lake front are very close to the Lake Michigan water quality values since the flow near the lake front primarily is Lake Michigan water because of the discretionary diversion from the lake. The inflow at the lake front boundaries should reflect the quality of Lake Michigan water rather than the mixed flows measured in the calibration period. Thus, except for DO, the concentrations of $CBOD_5$, ammonia, nitrate, etc. at Wilmette and Columbus Drive were set equal to the mean measured concentration during periods with discretionary diversion. Daily water temperature data near the lake shore was obtained from the Chicago Department of Water Management. These data were used to compute the saturation concentration of DO for Lake Michigan water for the July 12 to November 9, 2001 period at the CRCW. Comparison of DO saturation concentrations for summer months with daily average monitoring data near the lake front during discretionary flow periods indicate that the Lake Michigan water is a little less than saturated. Nevertheless saturation was assumed for convenience. Measured DO concentrations at Linden Street DO monitoring station were assigned to the Wilmette upstream boundary condition.

July-November average concentrations were used in the water-quality model for the Calumet River at O'Brien Lock and Dam since the concentrations at this location were based on measurements at 130th Street upstream from the dam. Results are given in Figures 3.5-3.7 and Table 3.11.

Table 3.11. Mean concentrations at the water-quality model boundaries near Lake Michigan for 1990-2002

Location	Date	$CBOD_5$ (mg/L)	TSS (mg/L)	DO (mg/L)	TKN* (mg/L)	NH_4-N* (mg/L)	Org N* (mg/L)	P-Tot (mg/L)	NO_2+ NO_3 (mg/L)	Sol. P (mg/L)	Chl-a (µg/L) ****
Columbus Drive	*Summer*	1.63	9.80	**	0.42	0.04	0.38	0.09	0.26	0.04	1.4
Wilmette	*Summer*	2.96	11.33	***	0.49	0.09	0.41	0.09	0.22	0.04	1.5
O'Brien	*July*	2.5	8.3	***	0.43	0.08	0.38	0.10	0.32	0.07	9.4
	August	4.0	11.2	***	0.40	0.09	0.34	0.07	0.30	0.05	6.0
	September	3.7	9.5	***	0.46	0.09	0.32	0.07	0.34	0.06	4.8
	October	3.3	12.1	***	0.49	0.10	0.44	0.13	0.35	0.07	5.5
	November	2.0	13.2	***	0.57	0.15	0.47	0.12	0.37	0.04	5.5

* Mean concentrations for nitrogen compounds were calculated for the period of 1997-2002
** Saturation DO concentrations calculated using daily water temperature data near the lake shore
*** Continuous hourly DO measurements on the Calumet River at 130th Street
**** For Chlorophyll a only data from 2001 and 2002 were available

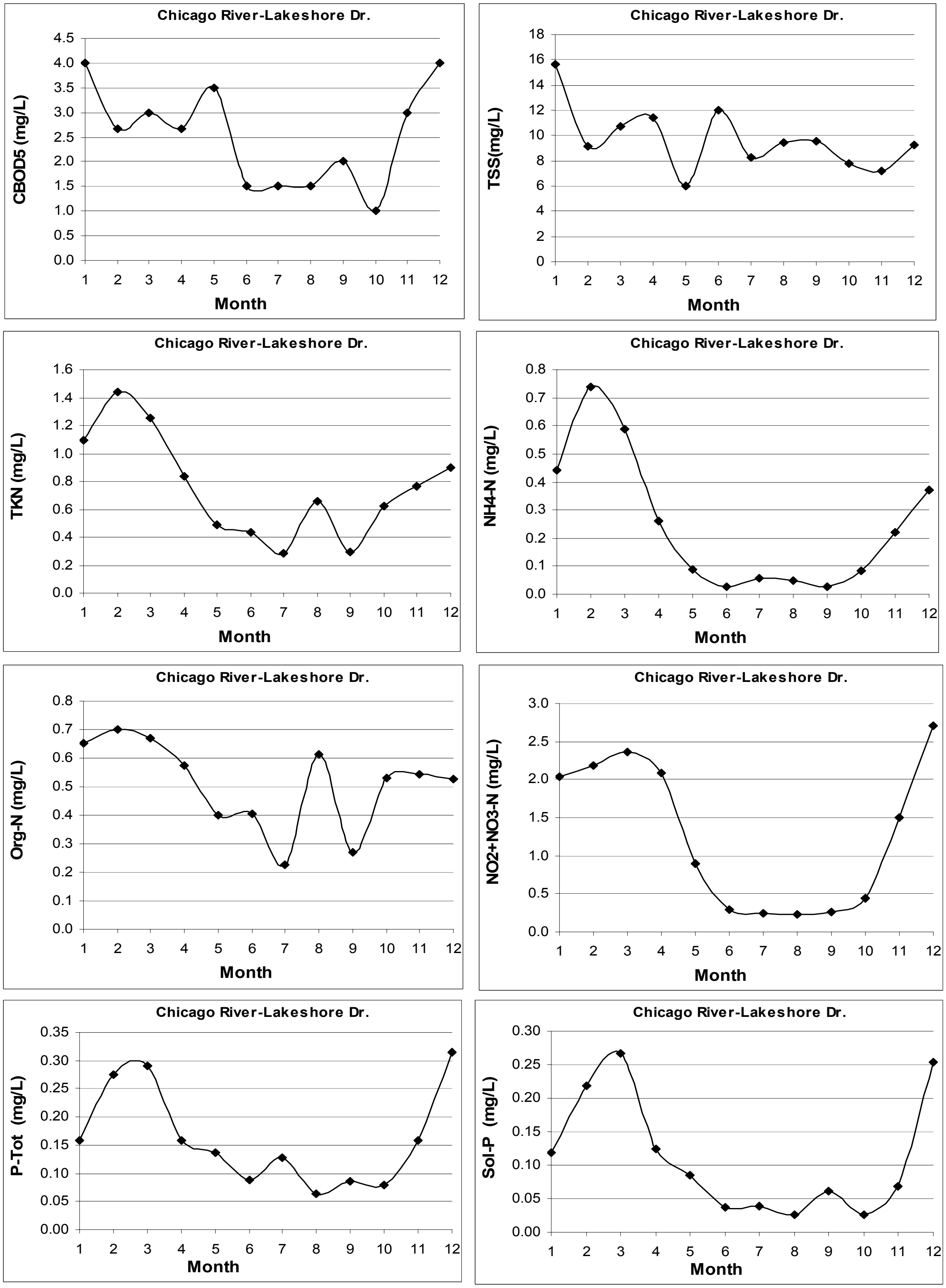


Figure 3.5. Monthly mean concentrations for the Chicago River Main Stem at Lake Shore Drive for 1997-2002 taken as representative of the boundary condition at Columbus Drive 0.3 mi downstream

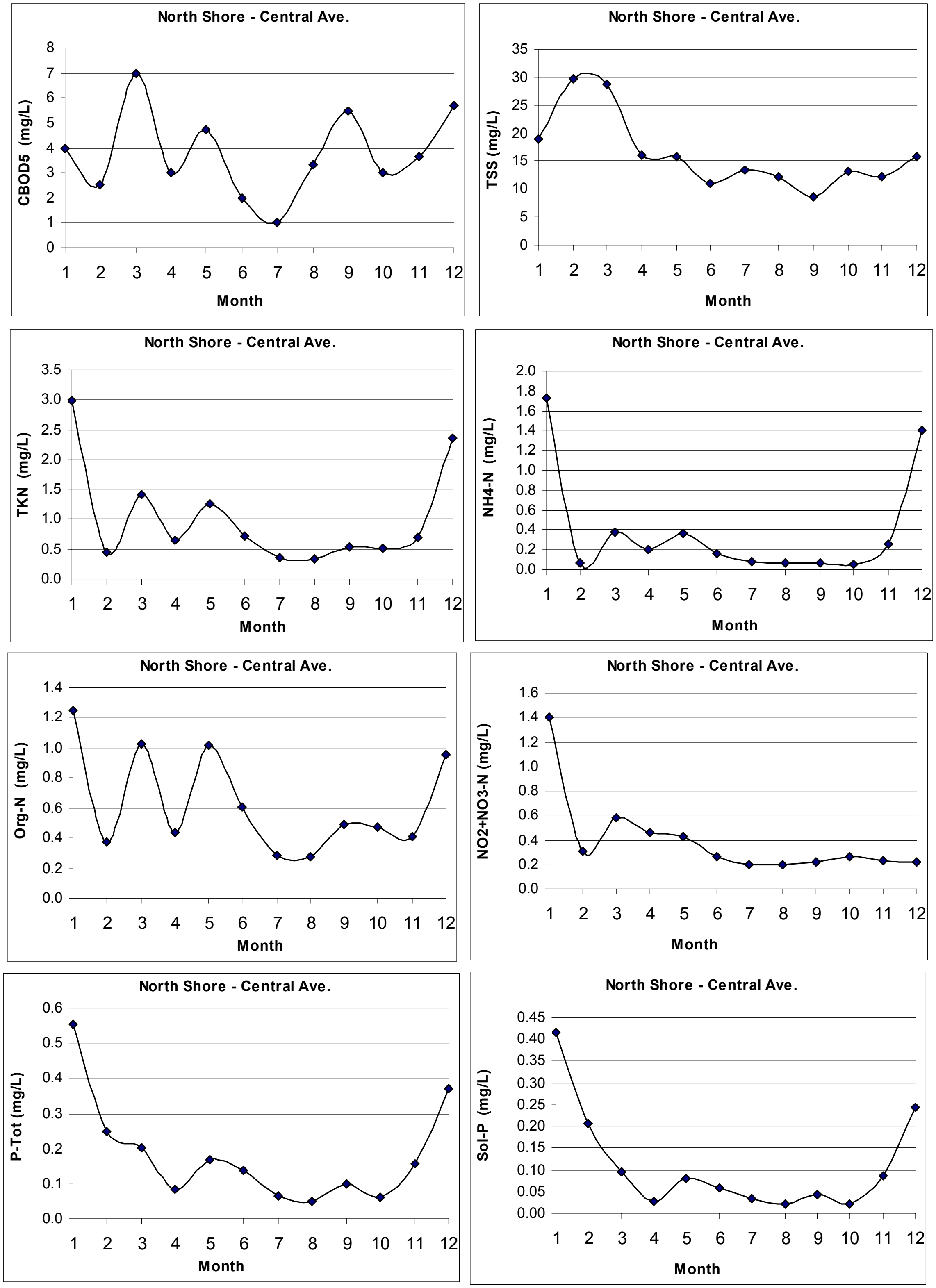


Figure 3.6. Monthly mean concentrations for the North Shore Channel at Central Avenue for 1990-2002

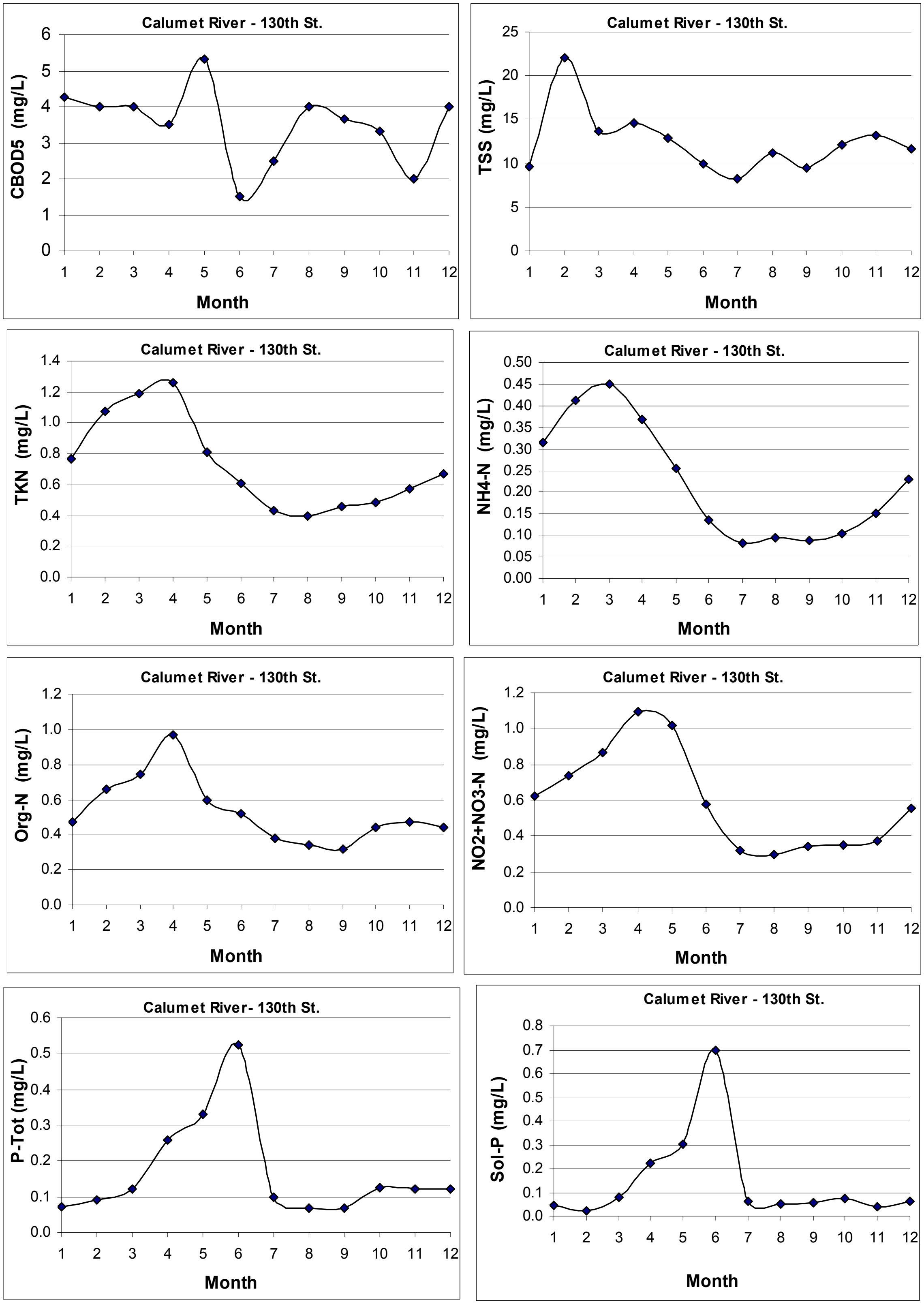


Figure 3.7. Monthly mean concentrations for the Calumet River at 130th Street for 1990-2002

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, and Sag Junction) and the USGS (boundary conditions) 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 (Figures 3.16-3.32) it also can be seen that the errors resulting from the assumed initial conditions are eliminated with a few hours on July 12, 2001. Default DUFLOW EUTROF2 sediment concentrations were used as initial conditions. Initial conditions, calculation nodes, and sections are given in Appendix C.

3.4 Calibration of the Water-Quality Model

Alp and Melching (2004) used the QUAL2EU model developed by the Camp Dresser & McKee (CDM, 1992) as a starting point for preliminary calibration of the CWS. In this study, the preliminarily calibrated DUFLOW model (Alp and Melching, 2004) was adapted and improved to be used in the simulations of the Use Attainability Analysis (UAA) remedial actions. The study area was divided into 17 reaches for water-quality simulation by Camp Dresser & McKee (CDM, 1992). These 17 reaches are shown in Figure 3.8. Fifteen of the reaches used in the current study are identical to those used by CDM. CDM Reach C10 is outside the boundaries of the current study, and only about half of reach C16 is included in the current study from river mile 8 to river mile 5.1 (the USGS Romeoville gage) where the river miles are from Lockport. Reach C17 (not marked in Figure 3.8) is the reach on the Little Calumet River (South) from the USGS South Holland gage to the confluence with the Calumet-Sag Channel. The Bubbly Creek section, which was not considered in the preliminary model calibration (Alp and Melching, 2004), was also added to the DUFLOW model for this study. Thus, a total of 18 reaches are used in the current modeling study. Within these reaches computational nodes have been placed at approximately 1,640 ft (500 m) intervals.

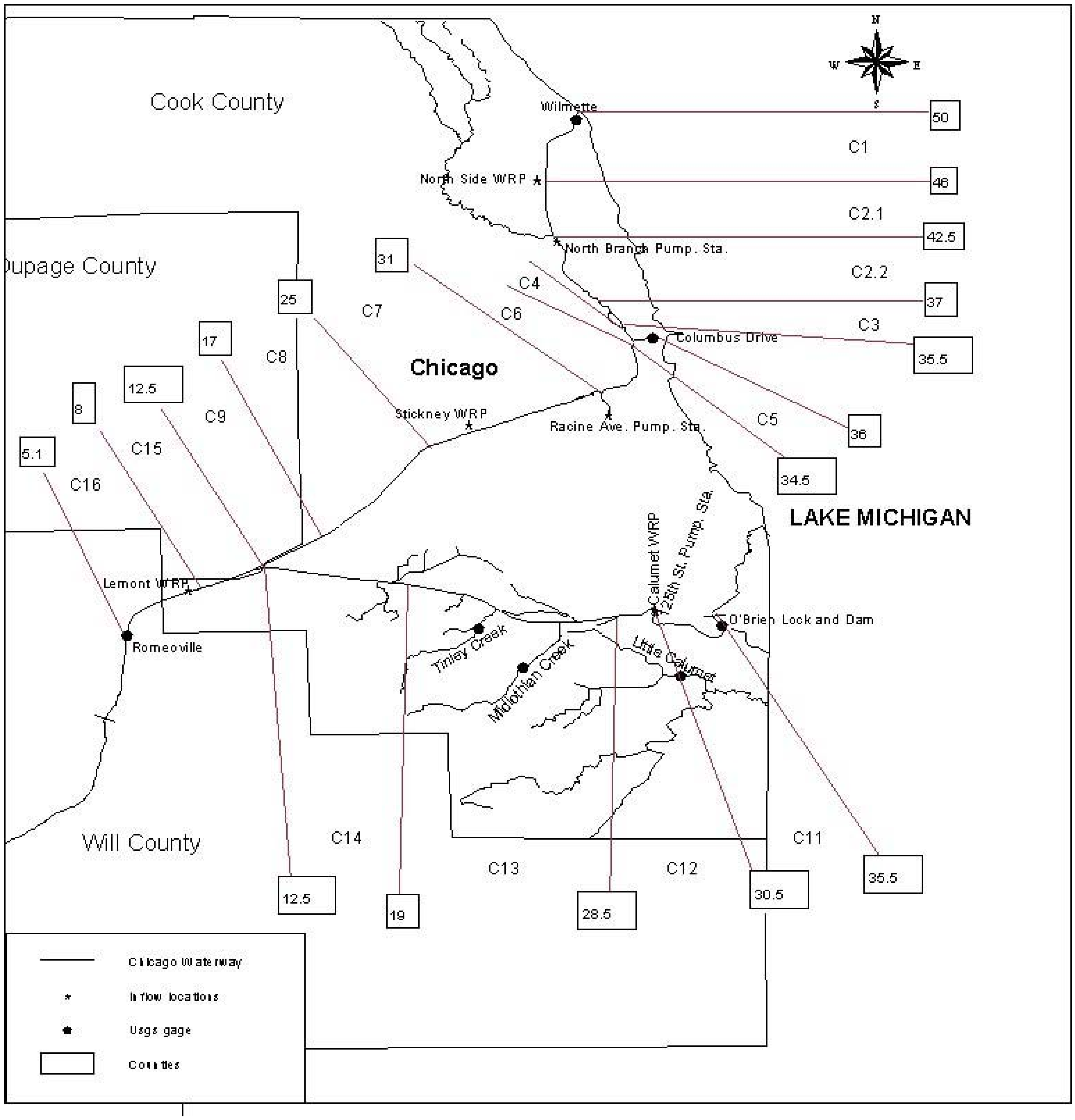


Figure 3.8. Chicago Waterway System reaches. The numbers in boxes are the river miles from the Chicago Sanitary and Ship Canal at Lockport Lock and Dam, Ill.

The following parameters were set as space dependent: Diffusive exchange rate constant for sediment; nitrification rate constant; $CBOD_5$ decay rate; dispersion; reaeration-rate coefficient; and the algal maximum growth, die-off, and respiration rates. Temperature was set as a time and spatially varying parameter.

In-Stream Water-Quality Data

The water-quality model was calibrated using monthly grab sample data at 18 locations and hourly DO concentration data at 25 locations all collected by the MWRDGC. The locations of water quality and DO sampling stations are listed in Table 3.12. The model was run with a 15-min. time step for the period of July 12 to November 9, 2001. Like for the hydraulic simulations the flow downstream boundary condition was used for July 12-September 14, 2001 and stage downstream boundary condition was used for September 15-November 9, 2001.

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.

Table 3.12. 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
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 Street	DO	Calumet-Sag Channel	16.3
Route 83	DO, WQ	Calumet-Sag Channel	13.3
Interstate 55 (I-55)	DO	Bubbly Creek	29.4

*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.

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). Sediment Oxygen Demand (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:

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

where:

SOD = Sediment Oxygen Demand (g/(day*m^2)

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

HB = Depth of sediment top layer (m)

$O2_w$ = Water column dissolved oxygen concentration (mg/L)

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

In November 2001, the MWRDGC did a survey of sediment depth and composition at 20 locations in the CWS. The sediment survey results were used during the calibration processes to set E_{dif} values to nearly zero or zero where little bed sediment was found, essentially, setting SOD to zero at these locations. Values of E_{dif} for other reaches were determined by calibration. The sediment survey indicated ranges of sediment depth, such as “sediment approximately one to two feet thick was collected near the southeast bank of the channel, 250 feet upstream from Simpson Street”, however, in the modeling the default value of 2 cm was used for the depth of the top (active) sediment layer.

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.

Dispersion, D, (m^2/s)

The model requires entering dispersion coefficients 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.

Reaeration rate coefficient multiplier, k_{aer}

In DUFLOW the reaeration rate coefficient is automatically calculated by the model using the O'Connor-Dobbins (1958) formula:

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

where;

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

V = Velocity, m/s

H = Water depth, m

k_{aer} = Reaeration rate multiplier

In the O'Connor-Dobbins formula, k_{aer} is given as 3.94. During the calibration process it was found that 3.94 resulted in high reaeration rates causing inflated DO concentrations at some locations. Hence, a spatially varying reaeration rate coefficient multiplier was introduced to the model as a calibration parameter.

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 EUTROF2 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 diffuse 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 3.13 for each reach. For all other model coefficients and parameters, default values given in EUTROF2 were used (see Appendix A).

Table 3.13 Reach calibration parameters used in the DUFLOW water-quality model for July 12 to November 9, 2001

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}	k_{aer}
C1	North Shore Channel	50-46	0.15	1.2	0.02	25	2*	0.05*	0.1*	1.5
C2.1	North Shore Channel	46-42.6	0.1	0.2	0.002	15	2*	0.05*	0.1*	1.5
C2.2	North Branch	42.6-37	0.1	1.2	0.03	100	2*	0.05*	0.1*	3.94*; 0.1[1]
C3	North Branch	37-35.5	0.01	0.01	0.001	100	2*	0.05*	0.1*	3.94*
C4	North Branch	35.5-34.5	0.01	0.01	0.001	100	2*	0.05*	0.1*	0.1
C5	Main Stem	34.5-36	0.10	0.01	0.02	100	2*	0.05*	0.1*	3.94*
C6	South Branch	34.5-31	0.15	1	0	100	2*	0.05*	0.1*	0.1
C7	CSSC	31-25	0.15	1	0.002	1000	2*	0.05*	0.1*	0.1
C8	CSSC	25-17	0.01	0.01	0	60	2*	0.05*	0.1*	0.1
C9	CSSC	17-12.5	0.01	0.05	0	60	2*	0.05*	0.1*	0.1
C15	CSSC	12.5-8	0.05	0.05	0	50	2*	0.05*	0.1*	0.1
C16	CSSC	8-5.1	0.05	0.05	0	50	2*	0.05*	0.1*	0.1
C11	Little Calumet (N)	35.5-30.5	0.05	0.01	0.0002*	1000	6	0.05*	0.1*	3.94*
C12	Little Calumet (N)	30.5-28.5	0.1	0.5	0.02	15	6	0.05*	0.1*	3.94*
C13	Calumet-Sag	28.5-19	0.1	0.5	0	15	6	0.05*	0.1*	0.1
C14	Calumet-Sag	19-12.5	0.1	0.5	0	10	6	0.05*	0.1*	0.1
C17	Little Calumet (S)		0.035	0.3	0.002	15	6	0.05*	0.1*	3.94*
Bubbly Creek	Bubbly Creek		0.15	1.2	0.001	150	2*	0.05*	0.1*	0.1

1 k = 3.94 between river miles 41.6 and 39.2; k = 0.1 between river miles 39.2 and 37.0
* Default value (see Appendix A)

The typical ranges of parameter values from the water quality modeling literature for the parameters in Table 3.13 except E_{dif}, D, and k_{aer} 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 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 Kbod 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 a previous study, but still within a reasonable range. The high value of 1,000 m^2/s in reaches C7 and C11 reflects the intense mixing caused by the Racine Avenue and 125th Street Pumping Stations.

The approach to reaeration taken in this study has not been done previously and the results reported here cannot be compared to previous studies. Finally, no range information for E_{dif} is included in the DUFLOW user's manual, and, thus, comparisons to other studies cannot be done.

3.5 Calibration Results

In the following subsections calibration results are presented. First, the simulated $CBOD_5$, ammonia, nitrate, and chlorophyll-a concentrations are compared with historic measurements. Then, simulated and measured hourly DO concentrations are compared at the 25 DO measurement locations.

3.5.1 Biochemical Oxygen Demand, Ammonia, 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, ammonia 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, ammonia 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 18 locations in the simulated portion of the CWS (Table 3.12). This means that at most only five measured values of the other constituents simulated with DUFLOW were available for the study period, which is insufficient to evaluate the simulation accuracy of the model. Thus, historical data were evaluated at each of the 18 locations to try 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 $CBOD_5$, ammonia nitrogen, and nitrate 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 3.9 and 3.10 for ammonia nitrogen and $CBOD_5$, respectively, to try 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 ammonia at some locations shown in Figure 3.9 the mean minus one standard deviation confidence bound results in a negative concentration. Figures 3.9 and 3.10 show that simulated hourly $CBOD_5$ and ammonia 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 the same figures, a limited number of $CBOD_5$ and ammonia concentration values measured during the simulation period are also shown. It can be seen that model predicted most of the measured concentrations with reasonable accuracy. Thus, the calibrated 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.

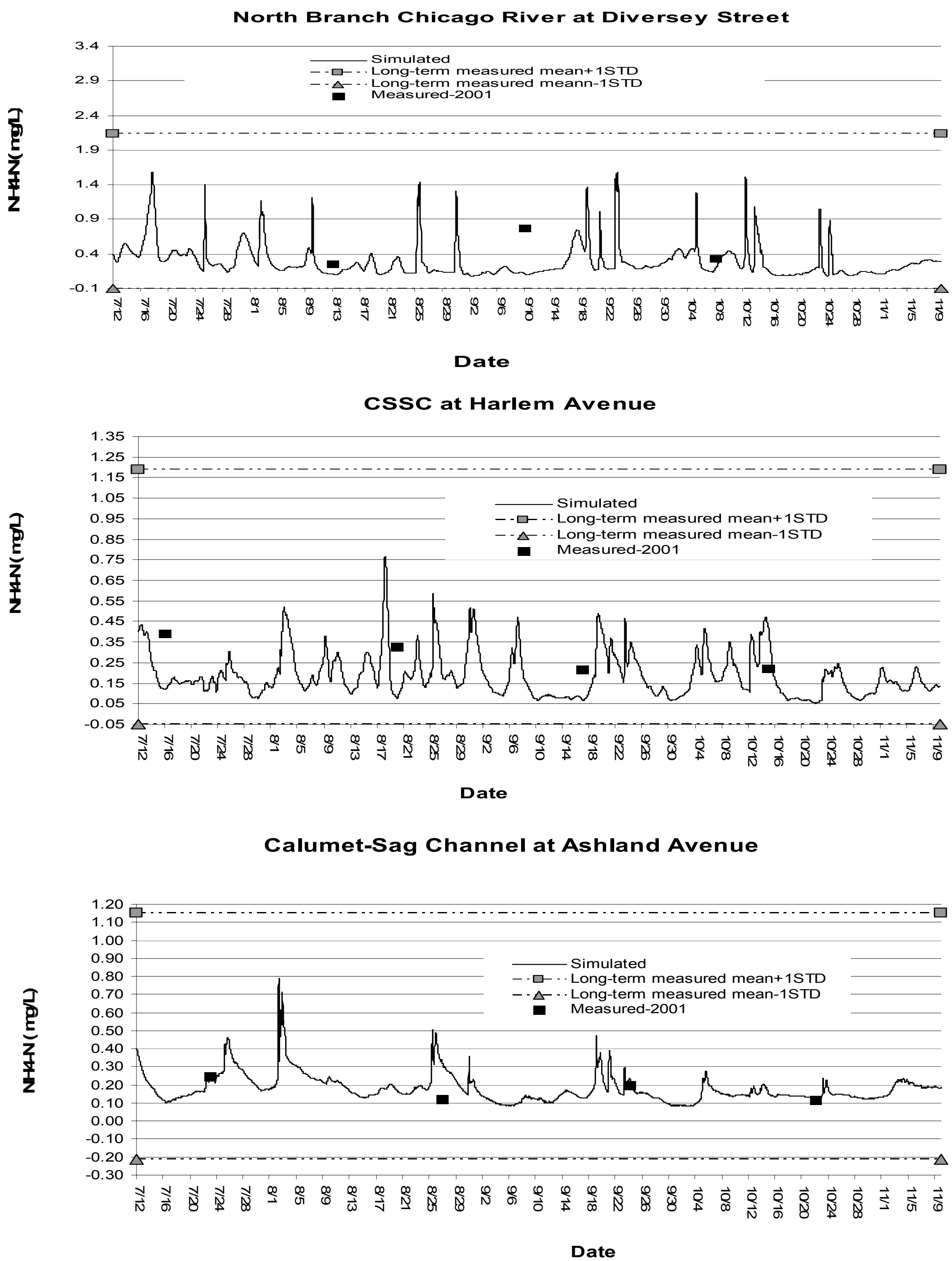


Figure 3.9. Comparison of long term measured mean plus or minus one standard deviation, measured, and simulated hourly ammonia nitrogen (NH4-N) concentrations at different locations in the Chicago Waterway System for July 12-November 9, 2001

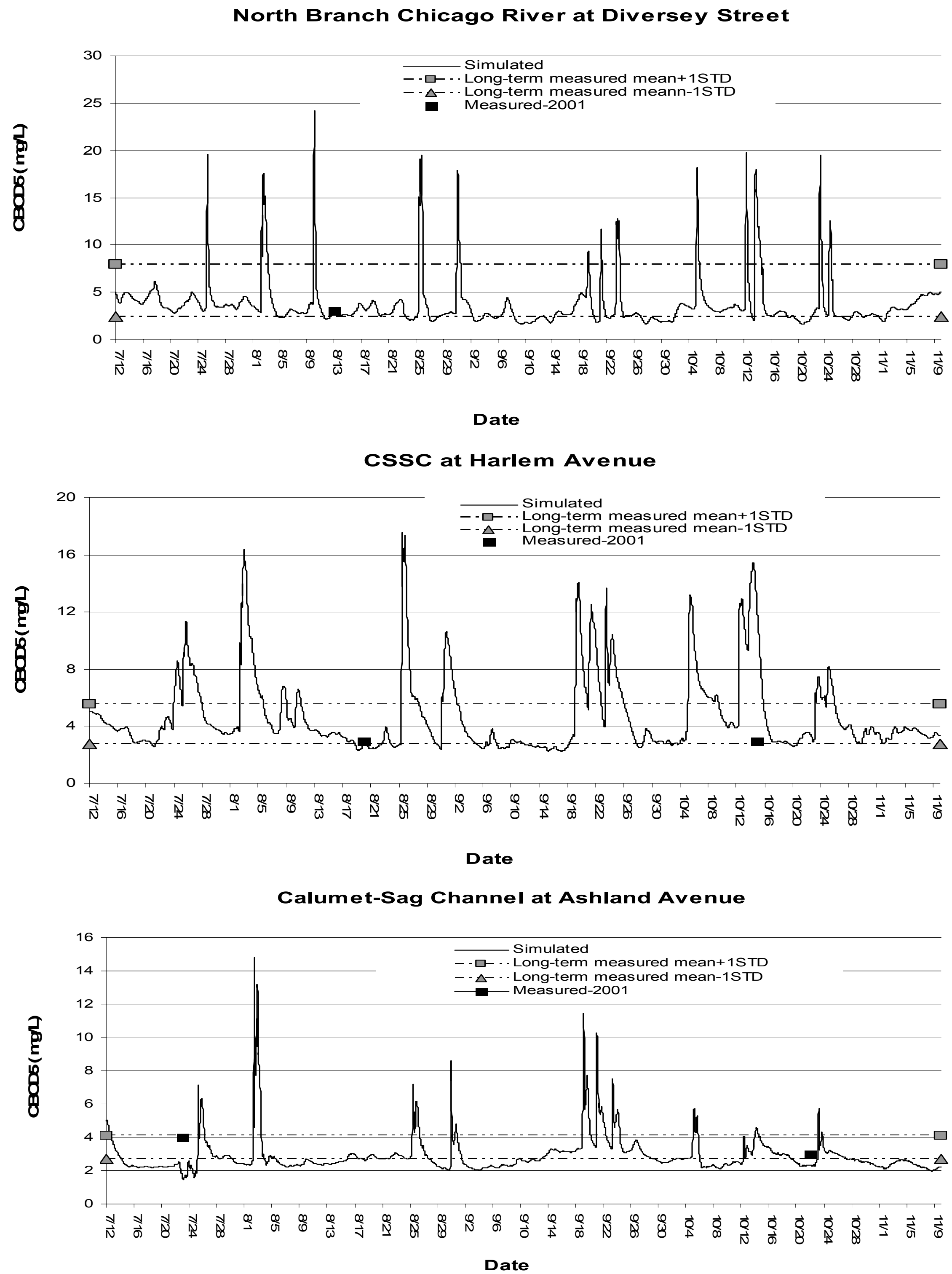
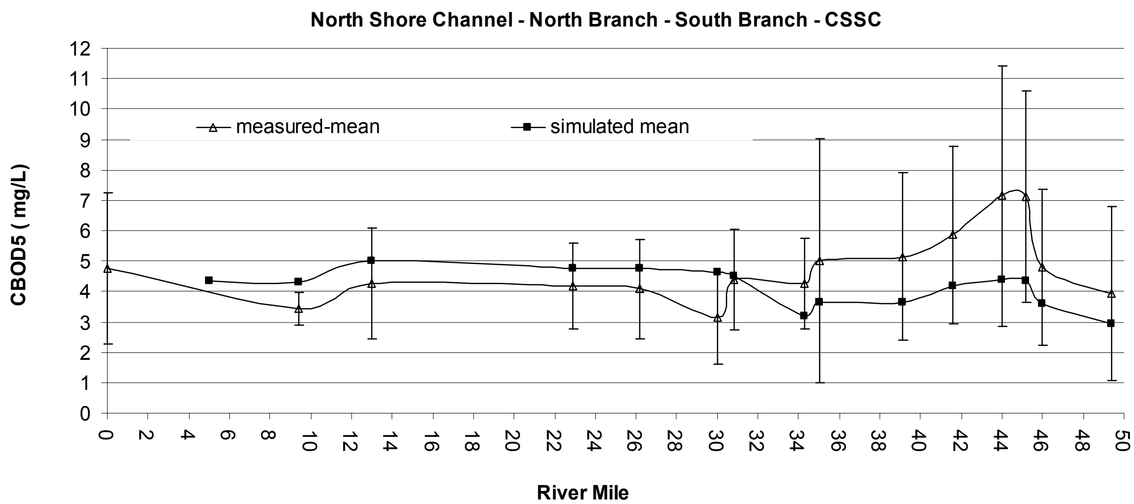


Figure 3.10. Comparison of long term measured mean plus or minus one standard deviation, measured, and simulated hourly carbonaceous biochemical oxygen demand (CBOD5) concentrations at different locations in the Chicago Waterway System for July 12-November 9, 2001

Figures 3.11-3.13 compare the mean of the simulated concentrations with the mean and one standard deviation confidence bounds of the measured historic data for $CBOD_5$, ammonia nitrogen, and nitrate nitrogen, respectively. The comparison is done as 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].

At just one location on the CSSC the mean of the simulated $CBOD_5$ concentration is slightly outside the one standard deviation confidence bounds (Figure 3.11). All simulated mean $CBOD_5$ concentrations (Figure 3.11) are within ± 1 standard deviation of the measured concentrations in the Calumet-Sag Waterway System. Carbonaceous BOD decay occurs very slowly in most of the CWS.



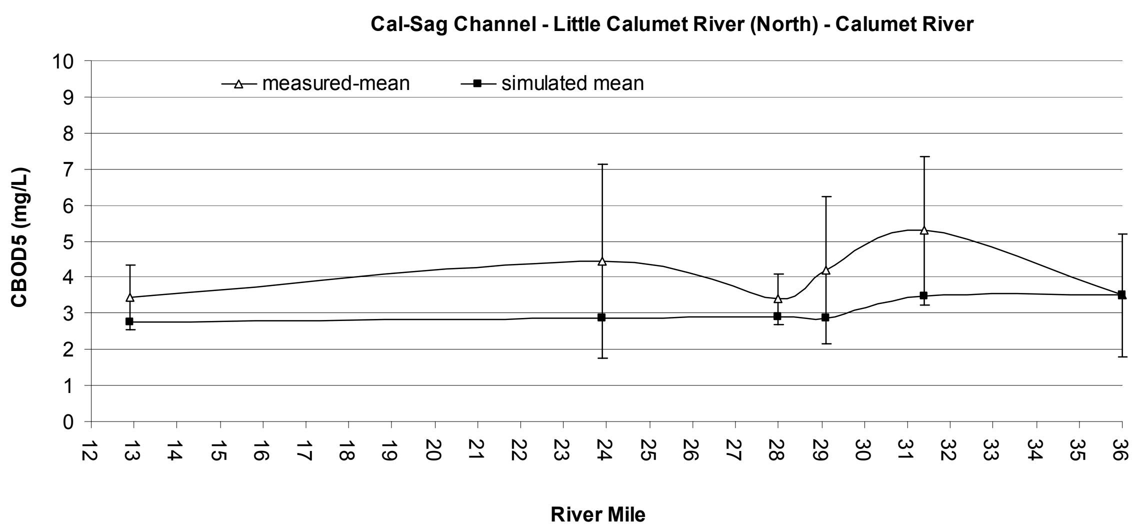
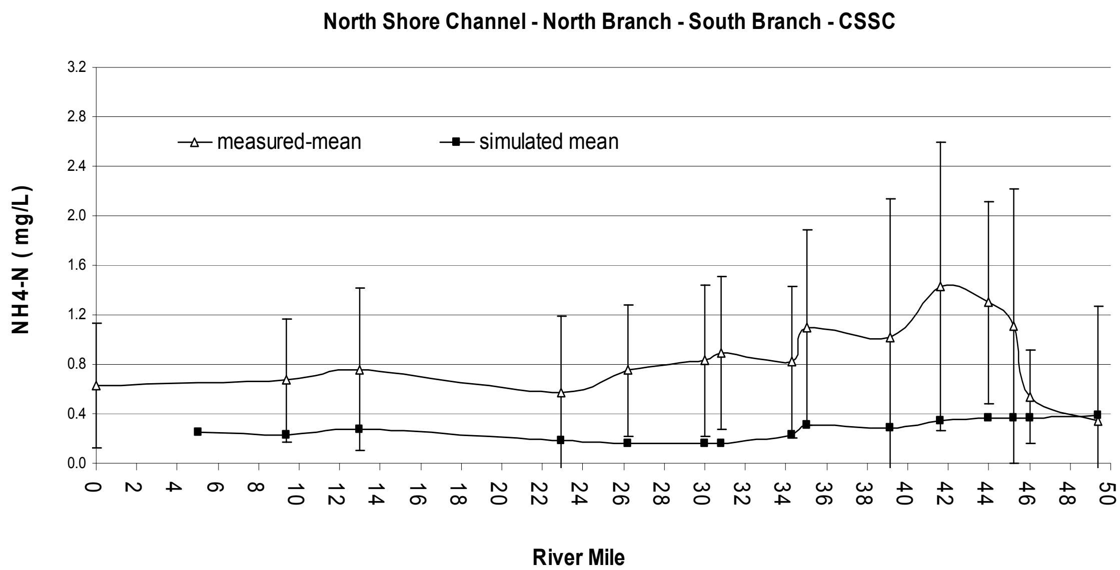


Figure 3.11. Comparison of long-term measured mean (plus or minus one standard deviation) and simulated mean carbonaceous biochemical oxygen demand (CBOD5) concentrations in the Chicago Waterway System for July 12-November 9, 2001

Calibration was done for three forms of nitrogen: organic, ammonia, and nitrate all as nitrogen. Calibrated ammonia nitrogen and nitrate nitrogen results are shown in Figures 3.12 and 3.13, respectively. Although the mean of the simulated ammonia nitrogen concentrations are lower than the mean of the measured ammonia nitrogen concentrations, they are still within the 1 standard deviation confidence bounds at the most of the locations. Nitrate nitrogen concentrations increase just after the WRPs. The simulated and measured nitrate nitrogen concentrations have very good agreement in the modeled portion of the CWS.



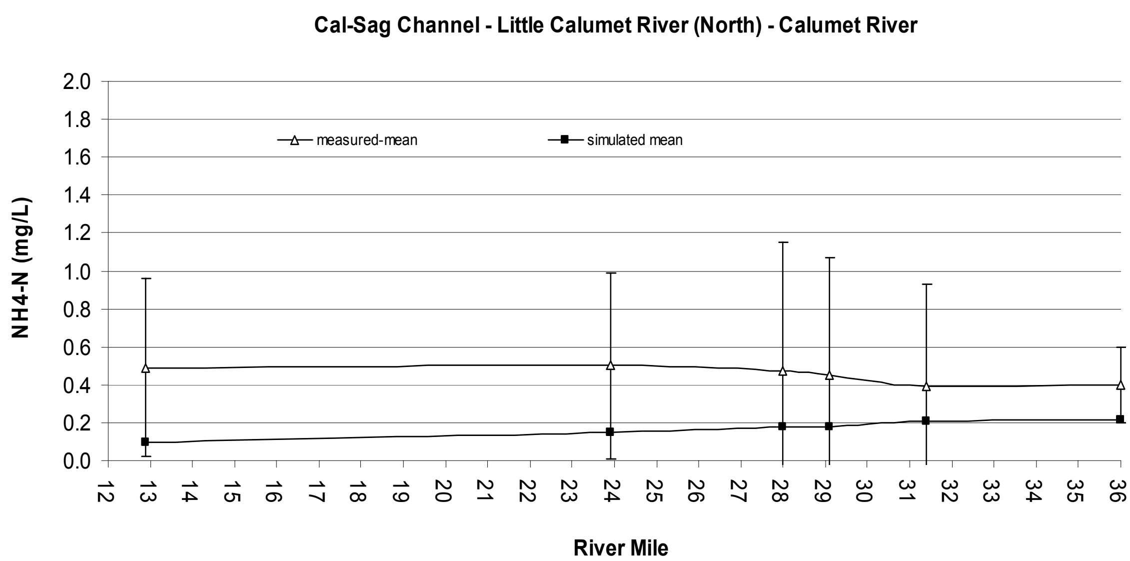
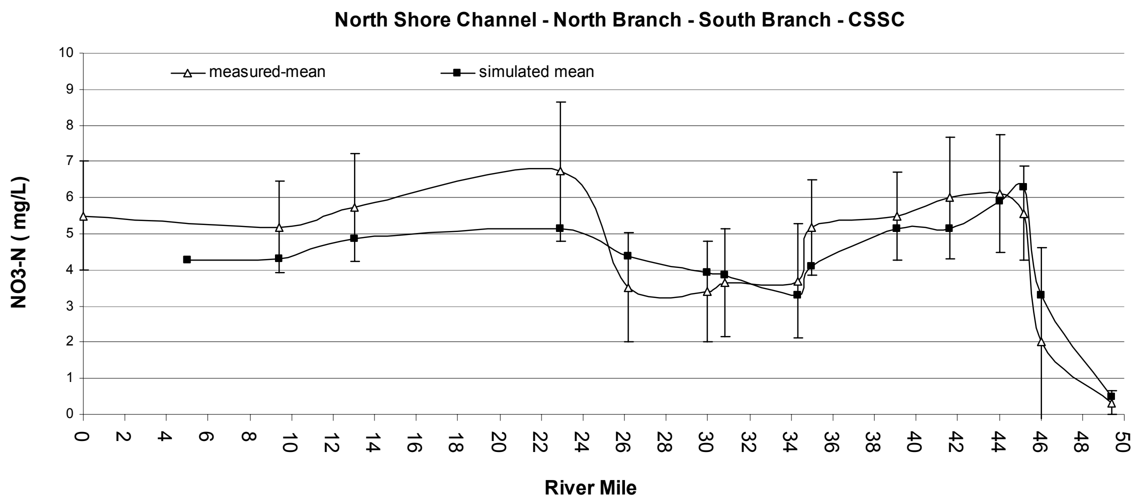


Figure 3.12 Comparison of long-term measured mean (plus or minus one standard deviation) and simulated mean ammonia nitrogen (NH4-N) concentrations in the Chicago Waterway System for July 12-November 9, 2001



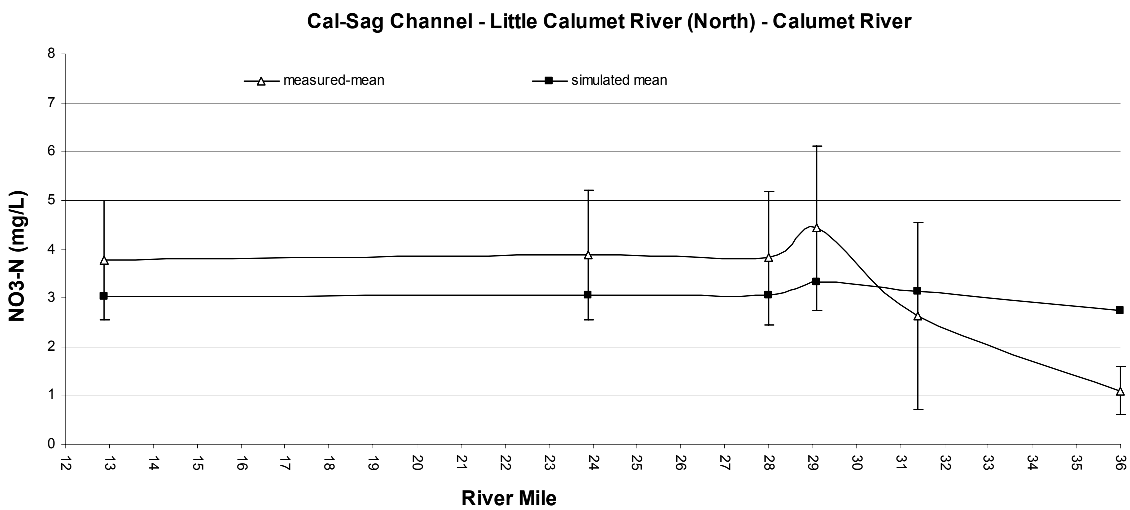
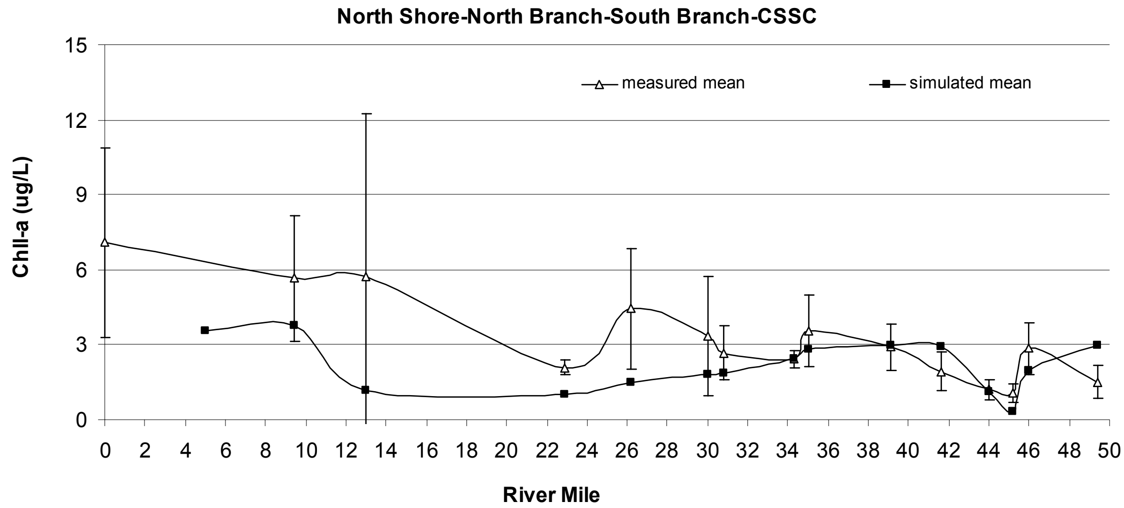


Figure 3.13. Comparison of long-term measured mean (plus or minus one standard deviation) and simulated mean nitrate nitrogen (NO3-N) concentrations in the Chicago Waterway System for July 12-November 9, 2001

Calibrated chlorophyll-a results are shown in Figures 3.14 and 3.15. 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 3.14 and 3.15. The simulated and measured chlorophyll-a concentrations have good agreement in the Chicago River System except for the CSSC. As can be seen from Figure 3.14, even though the simulated chlorophyll-a concentrations along the CSSC are always 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 Calumet-Sag Channel especially in summer months. For this reason more effort was put on the calibration of chlorophyll-a concentrations along the Calumet-Sag Channel. As can be seen in Figure 3.15, simulated chlorophyll-a concentrations fluctuate within 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 2 of the 3 measured chlorophyll-a concentrations are also lower than the lower confidence bound and one of the measured chlorophyll-a concentrations (31.5 μg/L measured on 10/22/2001) is higher than upper confidence bound. The big difference between the measured chlorophyll-a concentrations at Indiana Avenue suggest the possibility of algal blooms at this location.

In summary, the comparisons of the simulated constituent concentrations with long-term mean measured concentrations, one standard deviation confidence bounds, and concentrations measured between July-November 2001 did not indicate anything unusual. Thus, the DUFLOW simulation of these constituents was considered acceptable.



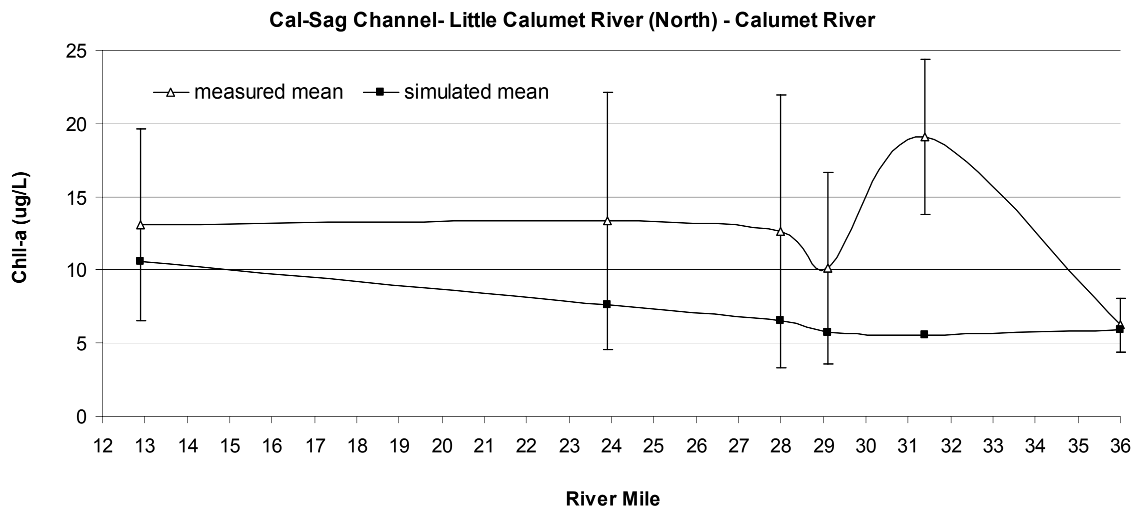


Figure 3.14 Comparison of simulated mean and measured mean (plus or minus one standard deviation) chlorophyll-a concentrations in the Chicago Waterway System for July 12-November 9, 2001

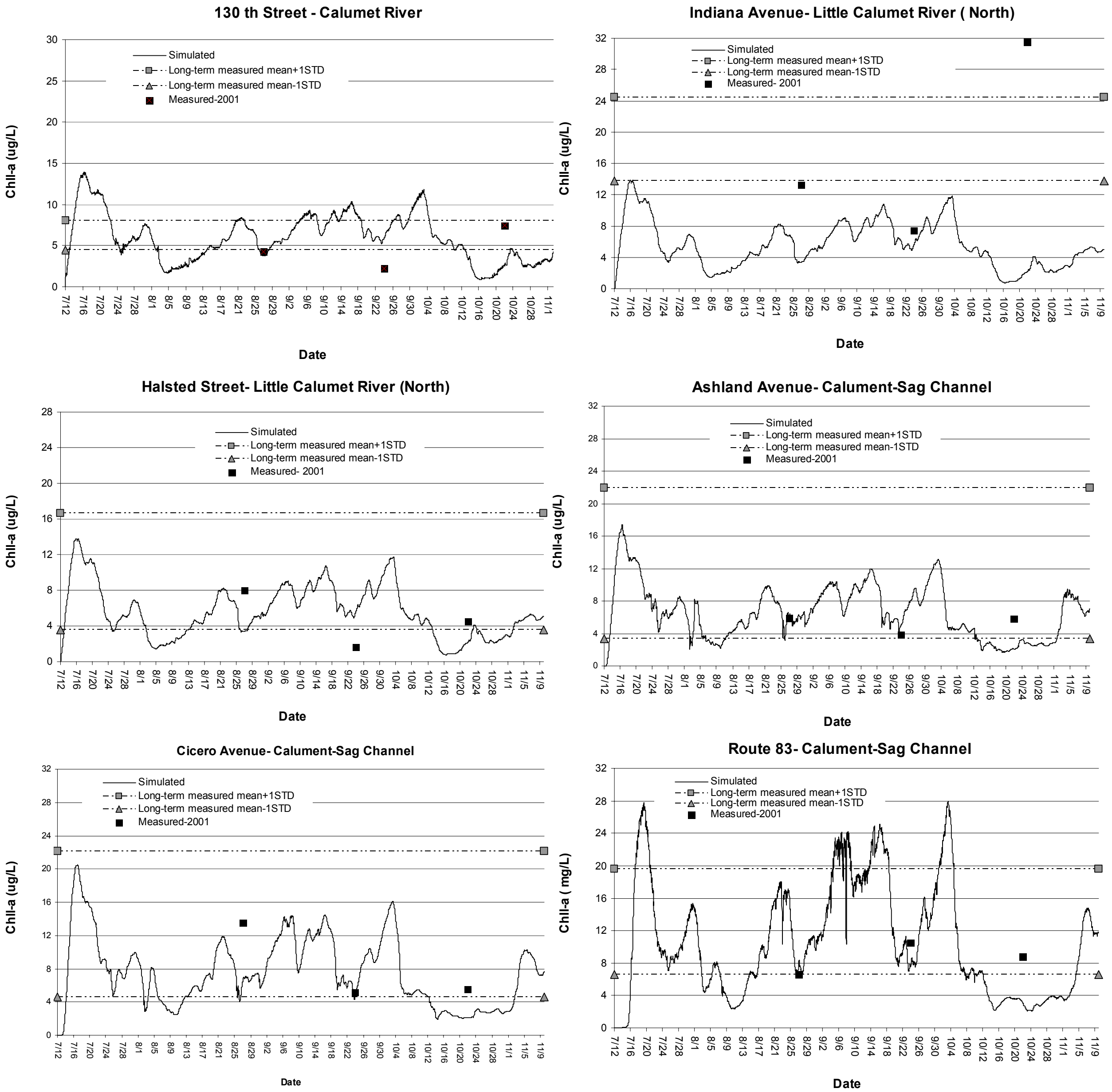


Figure 3.15 Comparison of measured mean plus or minus one standard deviation, measured, and simulated hourly chlorophyll-a concentrations in the Little Calumet River (North) and the Calumet Sag Channel for July 12-November 9, 2001. (note: 130th Street is upstream of O'Brien Lock and Dam and is used as a surrogate for concentrations at O'Brien Lock and Dam.)

3.5.2 Dissolved Oxygen Concentration

Simulated DO concentrations were compared with hourly measured DO concentrations at 25 locations for the period of July 12 to November 9, 2001. Results are presented in 4 categories: NBCR, SBCR and CSSC, Calumet-Sag Channel, and boundary conditions (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.

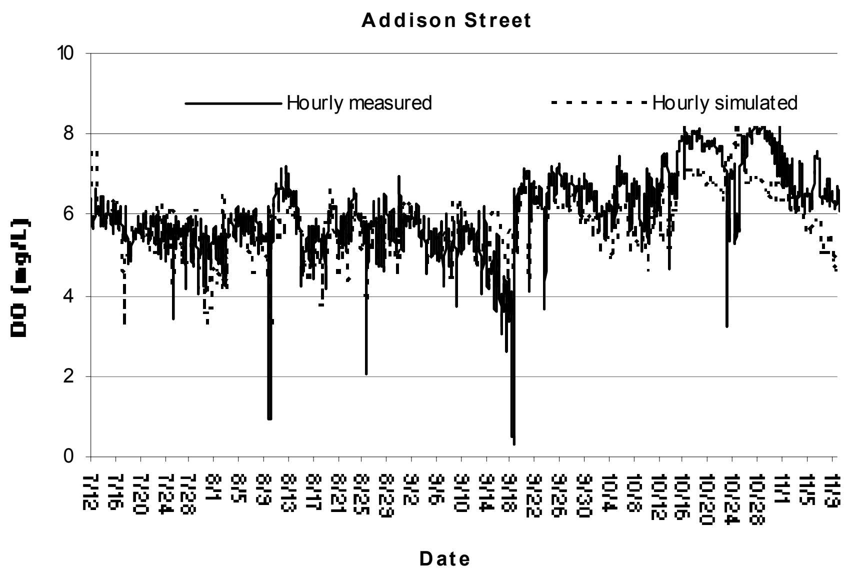
3.5.2.1 North Branch Chicago River

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 daily average simulated and measured DO concentrations is listed in Table 3.14. In all cases, the average percent error is less than 10 % indicating unbiased estimates of DO concentrations are obtained throughout these reaches.

Table 3.14 Comparison of daily average simulated and measured dissolved oxygen concentrations on North Branch Chicago River, July 12-November 9, 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100, Abs. Error = Average absolute value of simulated–measured; Abs. % Error = Average absolute value of (simulated–measured)/average measured x 100]

Location	AverageMeasured in mg/L	Average Simulated in mg/L	Error	% Error	Abs. Error	Abs. % Error
Addison Street	6.12	5.71	-0.40	-5.89	0.58	9.37
Fullerton Avenue	5.17	5.08	-0.09	-0.27	0.61	13.21
Division Street	5.82	5.58	-0.24	-3.61	1.02	18.13
Kinzie Street	5.32	5.52	0.20	4.15	0.92	17.97

The Addison Street DO monitoring site is the first station at which the combined effects of the upper NBCR flow, NSWRP flow, and Devon Avenue aeration station are observed. Figure 3.16 shows good agreement between the simulated and measured DO concentrations especially at both Addison Street and Fullerton Avenue. The average absolute percent error in the simulated daily average DO concentrations is 9.37 % at Addison Street. Although the average absolute percent error in the simulated daily average DO concentrations is 13.21% at Fullerton Avenue, the general trend of DO concentration fluctuations throughout the simulation period is well captured. While a similar DO trend is observed at Fullerton Avenue and there are just 1.9 miles between Addison Street and Fullerton Avenue, the average measured DO concentration at Fullerton Avenue is 0.95 mg/L lower than that of Addison Street (Table 3.14). In the calibration process, since it is difficult to obtain 0.95 mg/L DO difference by manipulating $CBOD_5$ and ammonia kinetic rates in such a short distance, SOD was increased within this section of the model to capture the drastic DO decrease between Addison Street and Fullerton Avenue. In the calibrated model, an average DO difference between Addision Street and Fullerton Avenue of 0.63 mg/L is obtained. Existence of a wide area on the NBCR at Diversey Parkway that has shallow water and deep sediments off to the side of the river channel makes the assumption of using high SOD values in this area reasonable.



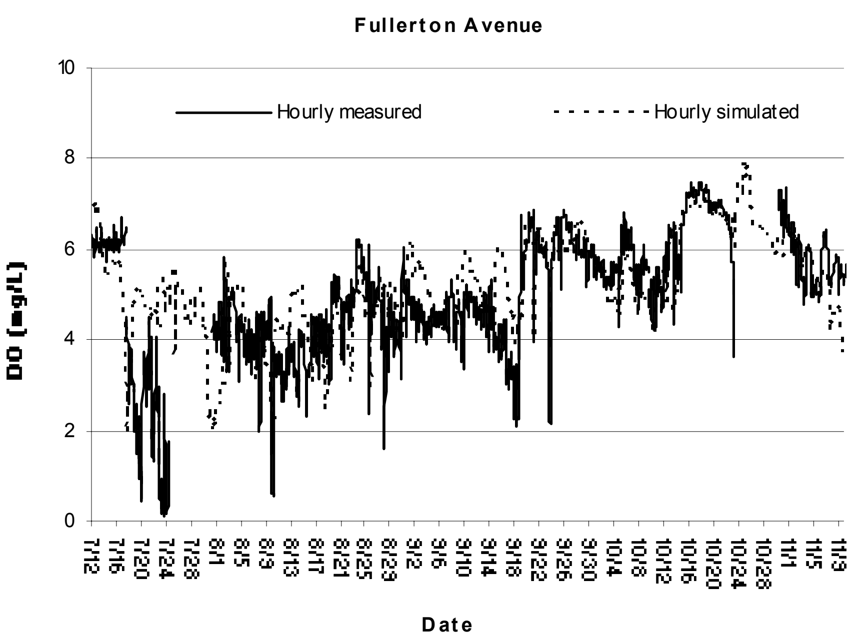


Figure 3.16. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Addison Street and Fullerton Avenue on the North Branch Chicago River for July 12 - November 9, 2001

Division Street is the first DO monitoring station downstream from the Webster Street aeration station. The Webster Street aeration facility causes a significant DO increase at the downstream locations. Comparison of simulated and measured DO values at Division Street is given in Figure 3.17.

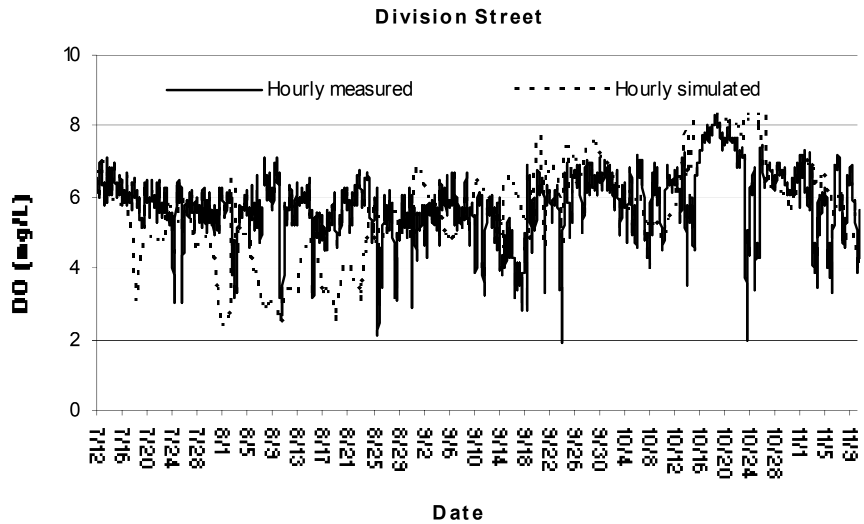


Figure 3.17. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Division Street on the North Branch Chicago River for July 12-November 9, 2001

Measured and simulated DO concentrations at Division Street (Figure 3.17) are in very close agreement for most of the simulation period particularly after August 25th. The model tends to be lower than the measured DO concentrations especially during the storm events. The average simulated and measured DO concentrations are 5.58 mg/L and 5.82 mg/L, respectively, an overall average error less than 4 %. The average absolute error in the average daily DO concentrations is 18.1 %.

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 (Figure 3.18). The average simulated and measured DO concentrations are 5.52 mg/L and 5.32 mg/L, respectively. Both measured and simulated DO concentrations show that DO concentrations decrease between Division Street and Kinzie Street. Sediments and slack-water in the North Branch Canal (eastside of Goose Island between Chicago and North Avenues) could be the reason for the DO drop between these two locations. Although SOD was introduced on the both side of Goose Island between Chicago Avenue and North Avenue, it was difficult to make adjustment between the east and west side of Goose island since there is no DO monitoring station on the east side of Goose Island.

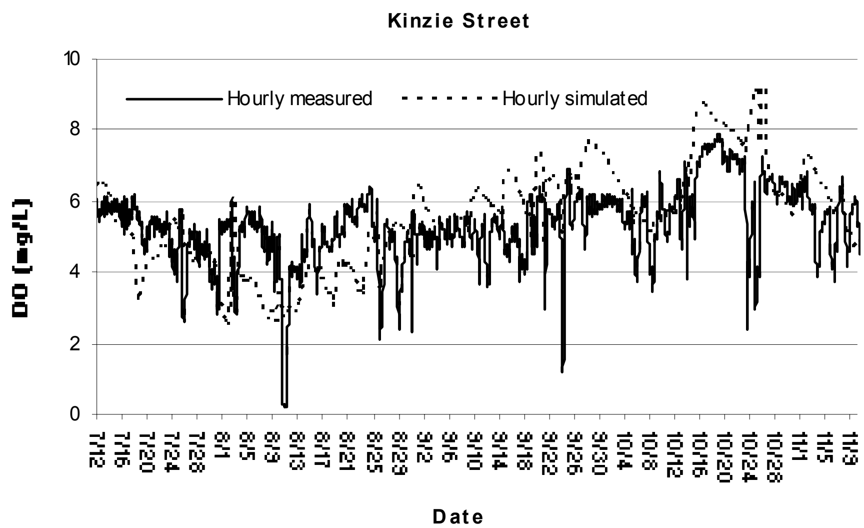


Figure 3.18. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Kinzie Street on the North Branch Chicago River for July 12-November 9, 2001

3.5.2.2 South Branch Chicago River and Chicago Sanitary and Ship Channel (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 5 reaches and the following DO stations represent each reach: i) Jackson Boulevard, ii) Cicero Avenue, iii) Baltimore and Ohio Railroad, iv) Route 83, and v) River Mile 11.6 and Romeoville. A statistical comparison between daily average simulated and measured DO concentrations is listed in Table 3.15. With the exception of Cicero Avenue, in all cases the average percent error is less than 10 % indicating unbiased estimates of DO concentrations are obtained throughout these reaches.

Table 3.15 Comparison of daily average simulated and measured dissolved oxygen concentrations on South Branch Chicago River and Chicago Sanitary and Ship Channel, July 12-November 9, 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100, Abs. Error = Average absolute value of simulated–measured; Abs. % Error = Average absolute value of (simulated–measured)/average measured x 100]

Location	Waterway	Average Measured in mg/L	Average Simulated in mg/L	Error	% Error	Abs. Error	Abs. % Error
Jackson Boulevard	South Branch	5.21	5.58	0.38	8.06	1.20	23.84
Cicero Avenue	CSSC	3.89	4.41	0.52	15.83	1.06	29.65
Baltimore and Ohio Railroad	CSSC	5.34	5.20	-0.13	-2.59	0.81	15.53
Route 83	CSSC	4.37	4.50	0.13	8.79	1.02	26.92
River Mile 11.6	CSSC	4.77	4.87	0.10	5.63	0.89	20.91
Romeoville	CSSC	4.17	4.42	0.25	8.65	0.93	24.94

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 3.19. 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. Average monthly DO concentrations for the period of July 12- November 9 2001 are 5.8, 4.4, 5.4, 5.6, 4.5 mg/L, respectively, for measured data, and 4.4, 3.9, 6.3, 7.1, and 6.4 mg/L, respectively, for the calibrated model at Jackson Boulevard. The model mostly overestimated DO concentrations for the October-November period in which measured DO concentrations are already high and underestimated DO concentrations for the periods where low DO concentrations are frequently observed. One of the targets of the management alternatives to bring the water-quality condition to desired levels is to solve the water-quality problems within the periods where very low DO concentrations are often 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 or higher than the simulated DO concentrations.

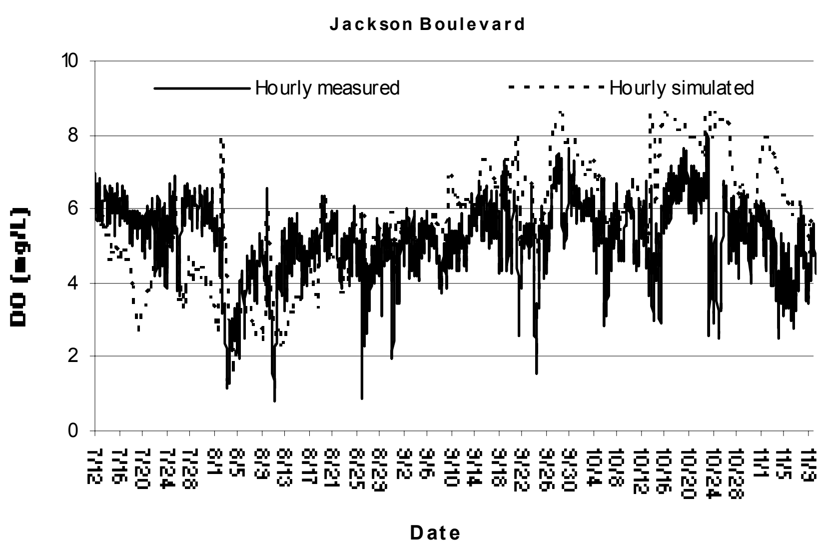


Figure 3.19. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Jackson Boulevard on the South Branch Chicago River for July 12-November 9, 2001

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 3.20). 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 absolute error in daily average DO concentrations is 29.7 %. Like Jackson Boulevard, the model over estimated DO concentrations for the October-November 2001 period. On the other hand, measured and simulated DO concentrations at Cicero Avenue are in very close agreement for most of the periods where extremely low DO concentrations are observed, especially the July-August 2001 period.

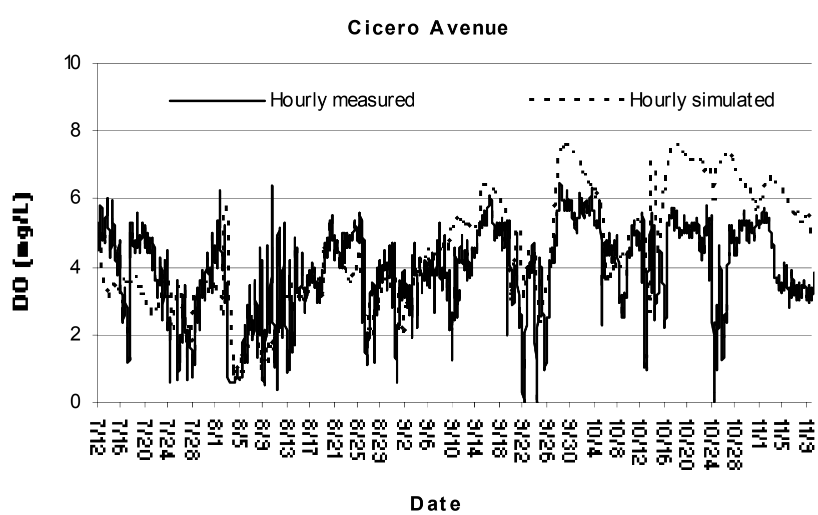


Figure 3.20. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Cicero Avenue on the Chicago Sanitary and Ship Canal for July 12-November 9, 2001

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 DO concentration is 1.76 mg/L higher than that at Cicero Avenue. The DO concentrations fluctuate between 4-6 mg/L and go down until 2 mg/L during the significant storms (Figure 3.21). The simulated DO concentrations agree well with measured DO concentrations and the average absolute percent error is 15.5 %. The model captured low DO concentrations during most of the storms.

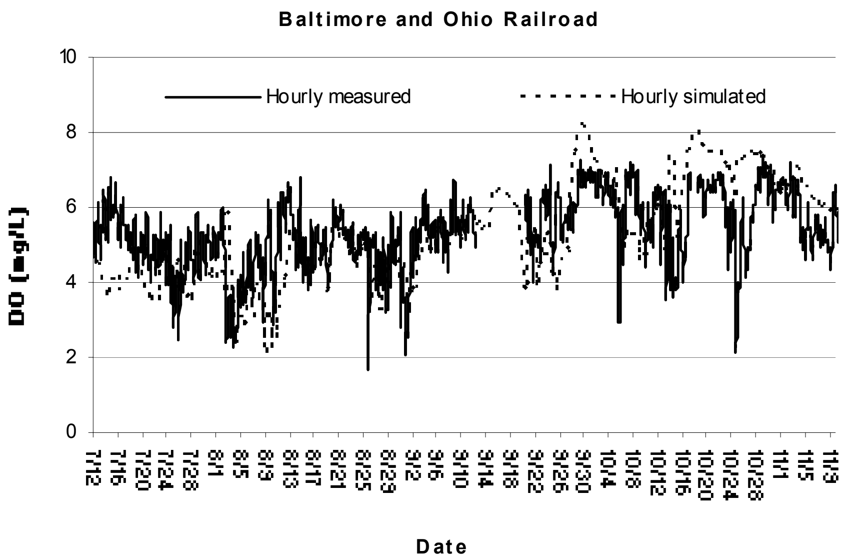


Figure 3.21. Comparison of measured and simulated dissolved oxygen (DO) concentrations at the Baltimore and Ohio Railroad on the Chicago Sanitary Ship Canal for July 12-November 9, 2001

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 3.22. The measured DO concentrations show unexpected trend for the periods 8/9-8/16, 2001 and 10/23-11/1, 2001. DO concentration jumps from 0.8 mg/L to

5.6 mg/L on August 8 and suddenly drops to 4.1 mg/L from 5.5. mg/L on August 16 and shows irregular pattern between October 23 and November 1. The average measured and simulated DO concentrations are 4.37 mg/L and 4.50 mg/L, respectively. Like other CSSC DO monitoring locations, the model overestimated DO concentrations for October and November, whereas it successfully matched the low DO concentrations during the major storm events in the summer. If the previously mentioned periods of uncertain data are deleted from the comparison, the average error, average percent error, average absolute error, and average absolute percent error are 0.3 mg/L, 11.5 %, 0.9 mg/L, and 24.8 %, respectively.

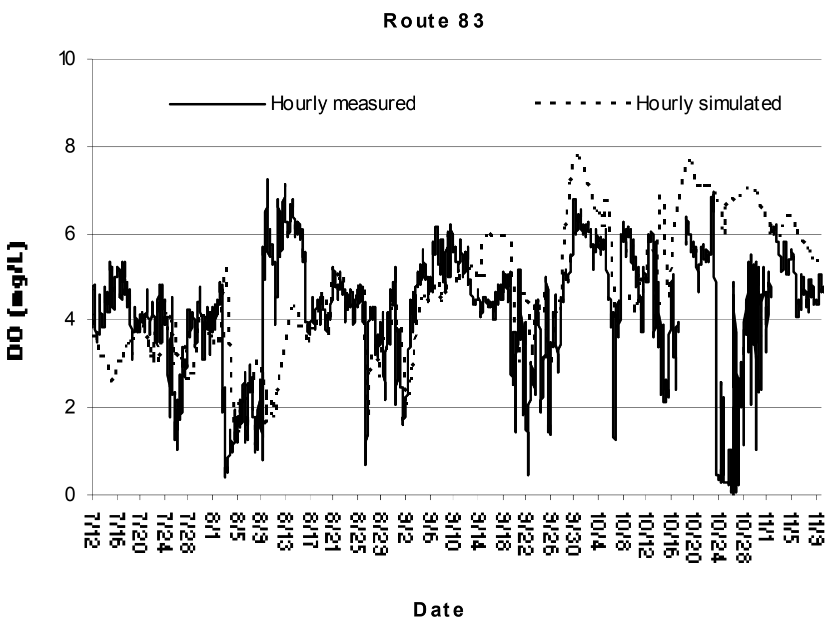


Figure 3.22. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Route 83 on the Chicago Sanitary and Ship Canal for July 12-November 9, 2001

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 the storm events (Figure 3.23) with a overall

20.9 % average absolute error in the daily average DO concentrations. However, the measured sudden DO concentration decreases to 0.3 mg/L on August 4 and 0.0 mg/L on October 5 could not be duplicated by the model. The causes of these sudden drops in the measured DO concentrations are unknown. Measured high concentrations observed in July are due to the contribution of Calumet-Sag Channel flows. As can be seen in the next section, diurnal DO fluctuations especially in summer months are a common characteristic of the Calumet-Sag Channel because algal activities play an important role in the Calumet-Sag Channel.

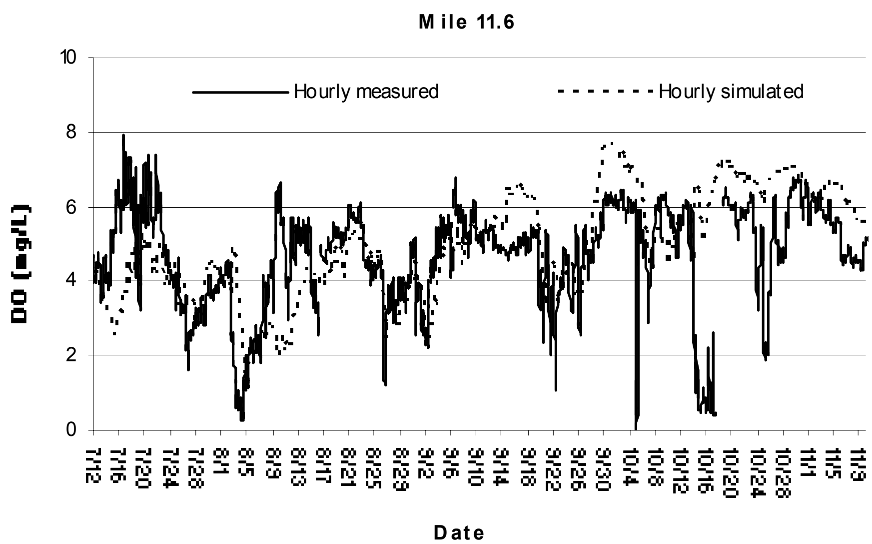


Figure 3.23. Comparison of measured and simulated dissolved oxygen (DO) concentrations at River Mile 11.6 on the Chicago Sanitary and Ship Canal for July 12-November 9, 2001

Romeoville is the downstream boundary condition for the water-quality model. As can be seen from Figure 3.24, the simulated and measured DO concentrations are generally in good agreement. Even though the average absolute error in the daily average DO concentrations is 24.9 %, the difference between the overall average simulated and measured DO concentrations is just 0.25 mg/L.

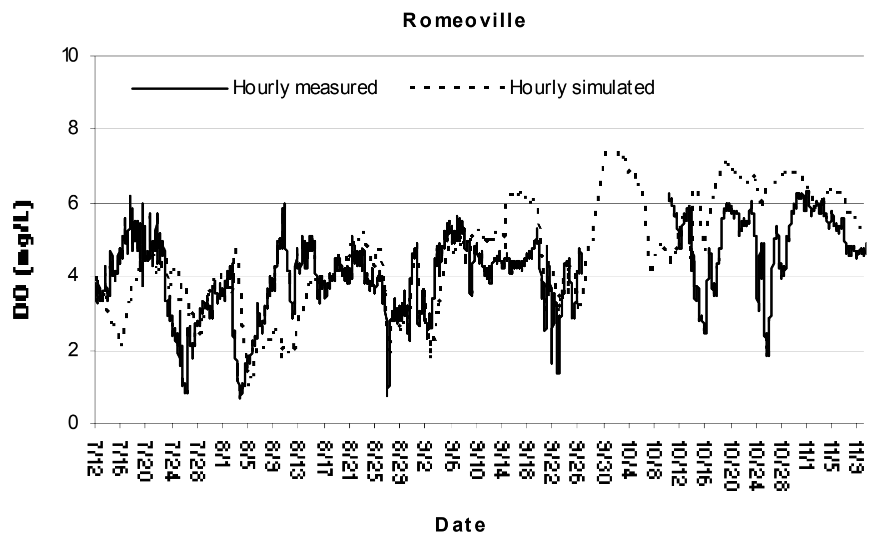


Figure 3.24. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Romeoville on the Chicago Sanitary and Ship Canal for July 12-November 9, 2001

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. Very similar calibrated parameter values were used throughout the Calumet-Sag Channel. A statistical comparison between daily average simulated and measured DO concentrations are listed in Table 3.16. With the exception of Halsted Street, in all cases the average percent error is less than 10%

indicating that unbiased estimates of DO concentrations are obtained throughout these reaches.

Table 3.16 Comparison of daily average simulated and measured dissolved oxygen concentrations on Calumet-Sag Channel and Little Calumet River (North, downstream from Calumet WRP) for July 12-November 9, 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100, Abs. Error = Average absolute value of simulated–measured; Abs. % Error = Average absolute value of (simulated–measured)/average measured x 100]

Location	Waterway	Average Measured in mg/L	Average Simulated in mg/L	Error	% Error	Abs. Error	Abs. % Error
Halsted Street	Little Calumet (N)	6.42	5.66	-0.76	-11.22	0.86	12.86
Division Street	Calumet-Sag	5.47	5.67	0.20	6.22	0.65	13.93
Kedzie Avenue	Calumet-Sag	6.12	5.94	-0.17	-1.19	0.62	10.98
Cicero Avenue	Calumet-Sag	5.98	5.73	-0.25	-2.52	0.70	12.31
Harlem Avenue	Calumet-Sag	5.65	5.65	0.00	1.95	0.96	17.68
Southwest Highway	Calumet-Sag	5.89	5.66	-0.23	-2.85	0.80	14.47
104^{th} Avenue	Calumet-Sag	5.64	5.19	-0.45	-4.23	1.14	21.25
Route 83	Calumet-Sag	5.65	5.50	-0.15	-1.10	0.95	17.83

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 to maximum in July and August (Figure 3.25). 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 summer. When there was less algal activity, the model predicted measured DO concentrations with a high accuracy. The average absolute error in the daily average DO concentrations is 12.9 %, and the difference between the overall average simulated and measured DO concentrations is -0.76 mg/L.

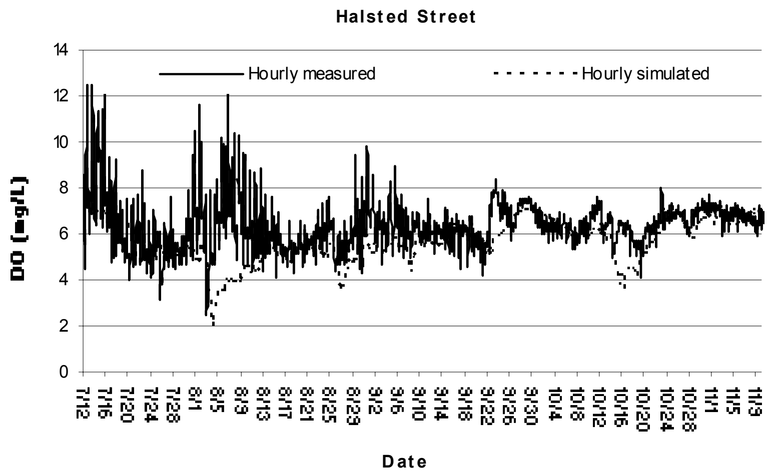


Figure 3.25. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Halsted Street on the Little Calumet River (North) for July 12-November 9, 2001

The comparisons of simulated and measured DO concentrations have very good agreement between Division Street and Southwest Highway. The results are shown in Figures 3.26 and 3.27. The average absolute errors in the daily average DO concentrations vary between 11 and 17.7 %. DO concentrations get as high as 12 mg/L and as low as 2 mg/L in the summer. 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 go down to 2.5 mg/L on August 3, and raise upto 10.6 mg/L until August 7 at Kedzie Avenue whereas simulated DO concentrations are just around 4 mg/L for the same time period. Even though the comparisons of the simulated chlorophyll-a concentrations with long-term mean measured concentrations, one standard deviation confidence bounds, and concentrations measured between July 12 and November 9, 2001 did not indicate anything unusual, it is obvious that algal activities have a very important role in Calumet-

Sag Channel which is beyond the abilities of the DUFLOW model without having more extensive chlorophyll a data with which to further adjust the model.

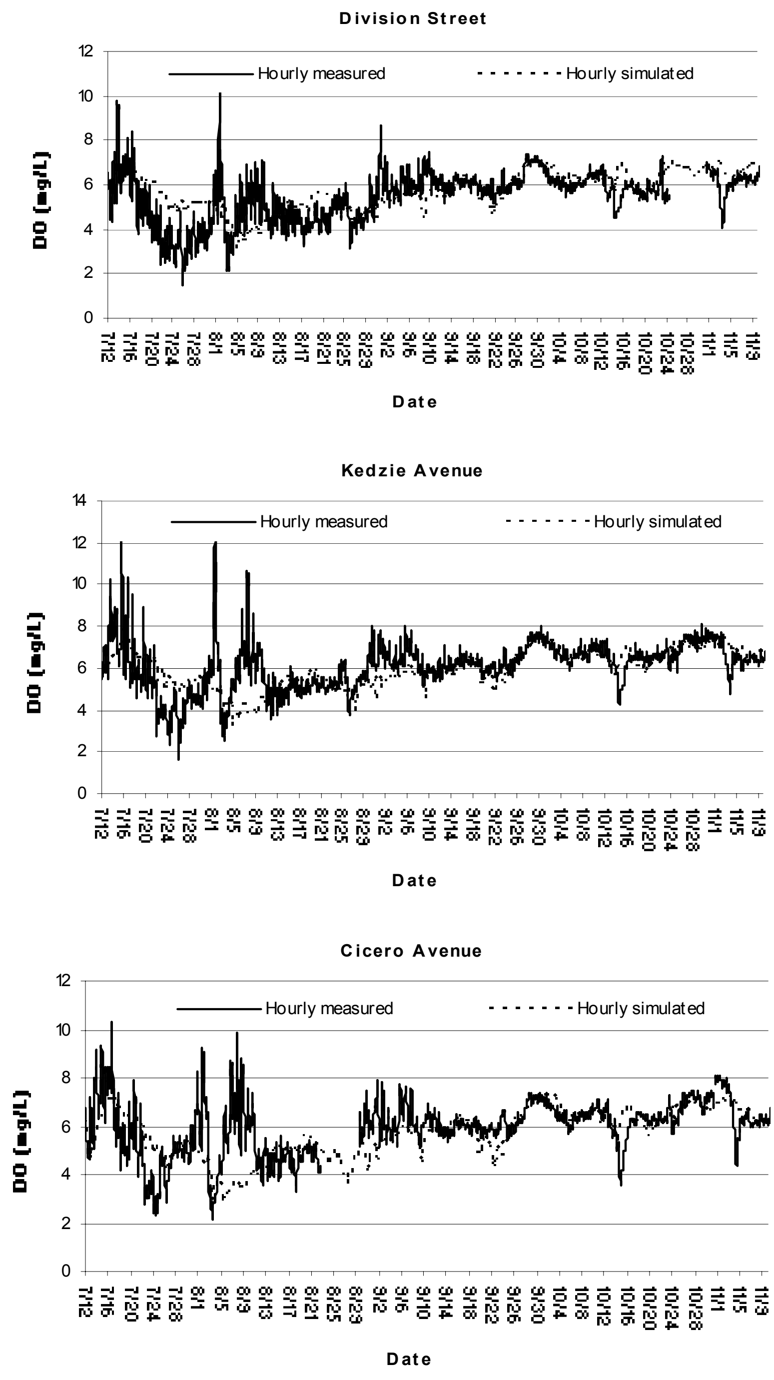


Figure 3.26. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Division Street, Kedzie Avenue, and Cicero Avenue on the Calumet-Sag Channel for July 12-November 9, 2001

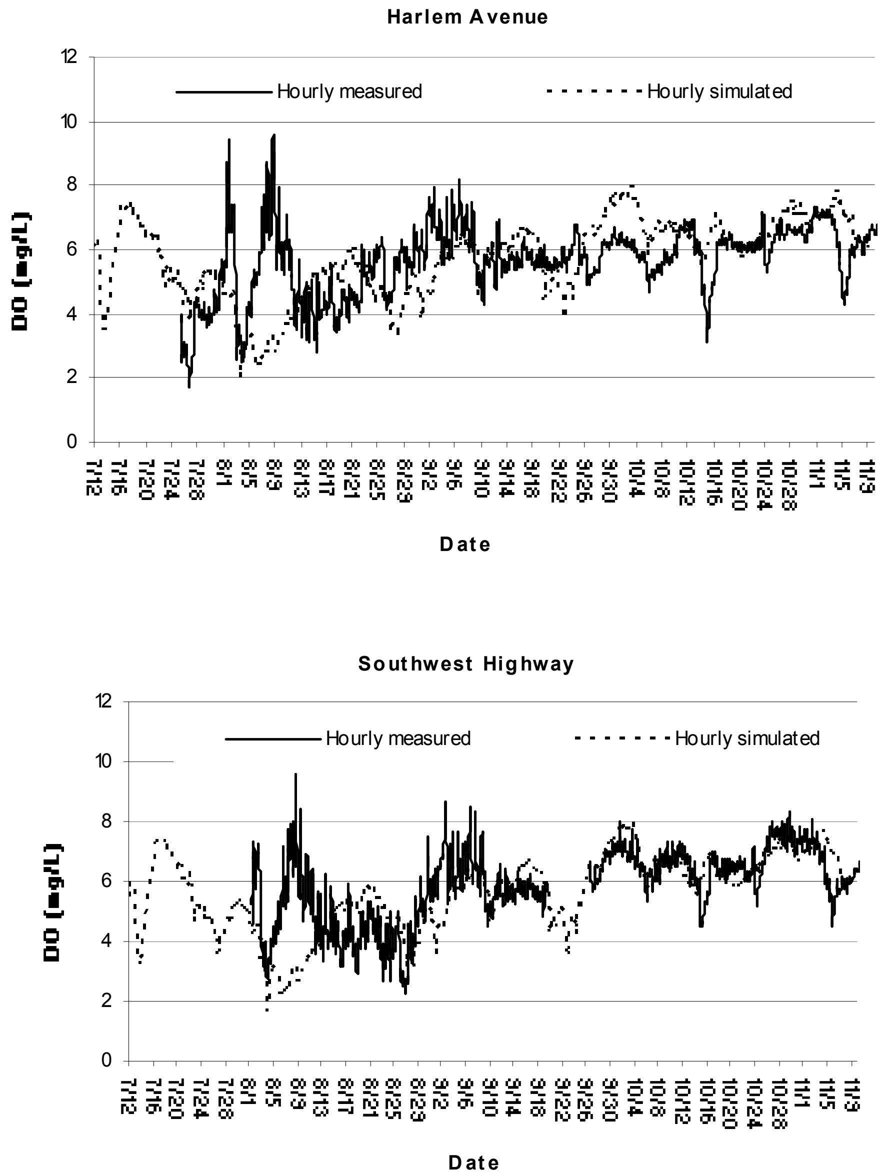
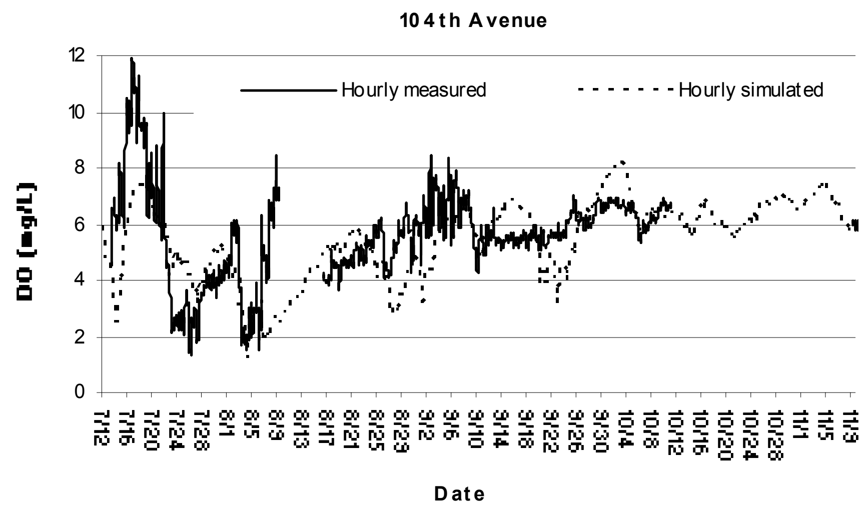


Figure 3.27. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Harlem Avenue and Southwest Highway on the Calumet-Sag Channel for July 12-November 9, 2001

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 when the algal activities were not high (Figure 3.28). The average absolute errors in the daily average DO concentrations are 21.3 and 17.9 % at 104th Avenue and Route 83, respectively.



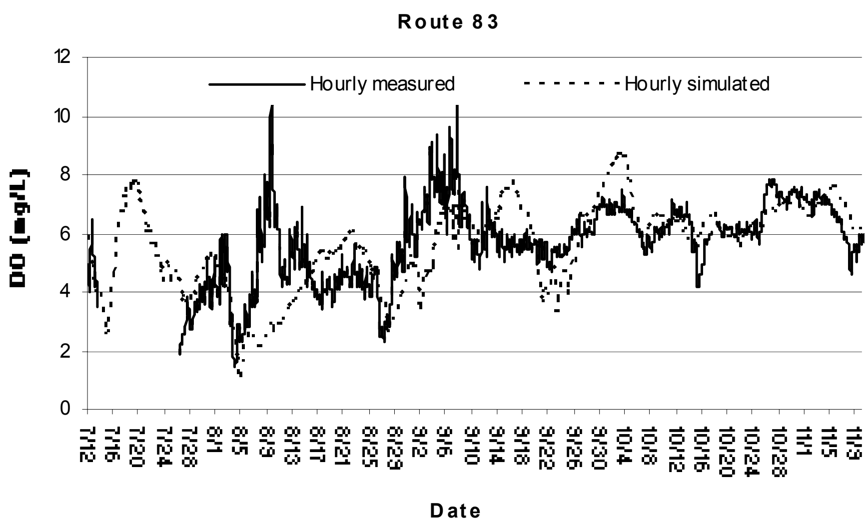


Figure 3.28. Comparison of measured and simulated dissolved oxygen (DO) concentrations at 104th Avenue and Route 83 on the Calumet-Sag Channel for July 12-November 9, 2001

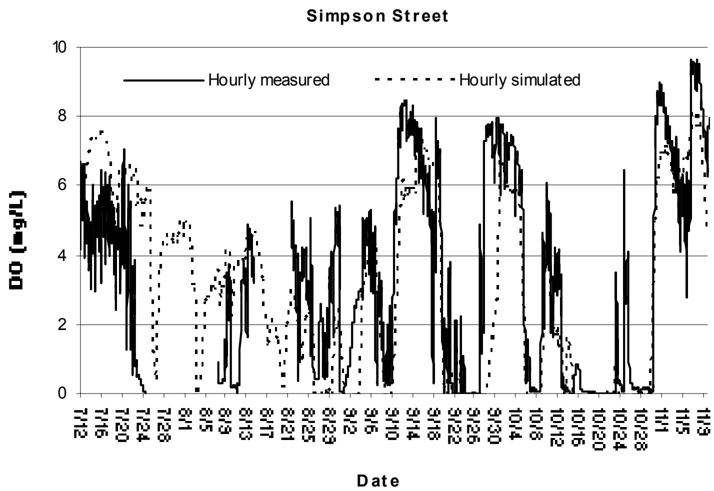
3.5.2.4 Boundaries (North Shore Channel, Chicago River Main Stem, Little Calumet River (North and South))

The comparison of simulated and measured DO concentrations on the NSC at Simpson and Main Streets is shown in Figure 3.29 and Table 3.17. Even though absolute percent errors that vary between 57.2-68.7% suggest that the model could not do a good job on the NSC, graphical comparison will give a better judgment about the power of the model along the NSC. For example, if the measured DO concentration is 0.1 mg/L and the simulated DO concentration is 0.25 mg/L at a particular time, the percent absolute error would be 250 % even though the error is just 0.15 mg/L. 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 trend in the NSC above the NSWRP during the simulation period. It is hard to attribute this trend to algal activities since chlorophyll-a concentrations are low during the July 12-November 9, 2001 period. It is obvious that lake discretionary flow can bring DO concentrations to almost saturation. Whereas when there is no flow from the lake, DO concentrations 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. As the calibration strategy along the NSC, it was aim to simulate low DO concentrations accurately and to follow the general trend of the DO concentration as much as possible. As shown in Figure 3.29, the model successfully predicted extremely low DO concentrations and follows the general DO trend along the NSC upstream from the NSWRP.

Table 3.17 Comparison of daily average simulated and measured dissolved oxygen concentrations on the North Shore Channel, July 12-November 9, 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100, Abs. Error = Average absolute value of simulated–measured; Abs. % Error = Average absolute value of (simulated–measured)/average measured x 100]

Location	Waterway	Average Measured in mg/L	Average Simulated in mg/L	Error	% Error	Abs. Error	Abs. % Error
Simpson	North Shore Channel	4.40	3.81	-0.59	1.44	1.63	68.71
Main	North Shore Channel	3.27	3.37	0.11	28.11	1.16	57.18

The Chicago River main stem results are shown in Figure 3.30. A statistical comparison between daily average simulated and measured DO concentrations is listed in Table 3.18. Big differences between the simulated and the measured DO concentrations are obvious mainly in the summer months. The model could not estimate the sharp DO drops especially during big storms. In order to simulate the DO concentrations in the Chicago River main stem the hydraulics of the main stem must be very accurately simulated. Because a water-surface elevation boundary condition is applied at Columbus Drive, flow is calculated by the model at Columbus Drive. Without a substantial improvement in the flow balance for the CWS, DO concentrations will be poorly simulated on the Chicago River main stem. Alp and Melching (2004) provide additional discussion of this problem.



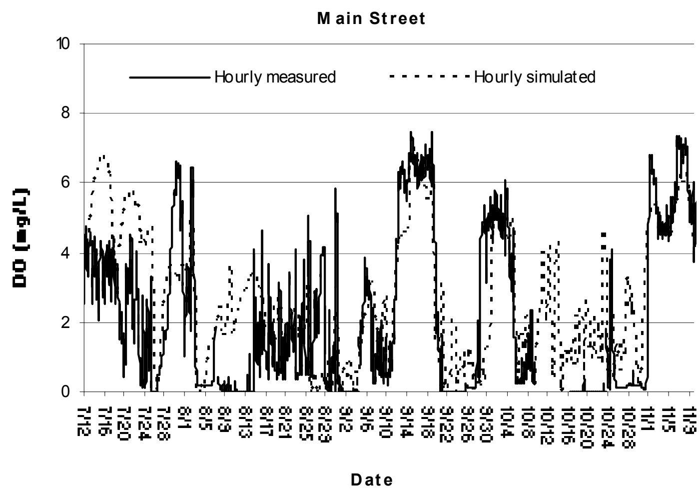


Figure 3.29. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Simpson and Main Streets on the North Shore Channel for July 12-November 9, 2001

Table 3.18 Comparison of daily average simulated and measured dissolved oxygen concentrations on the Chicago River main stem, July 12-November 9, 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100, Abs. Error = Average absolute value of simulated–measured; Abs. % Error = Average absolute value of (simulated–measured)/average measured x 100]

Location	Waterway	Average Measured in mg/L	Average Simulated in mg/L	Error	% Error	Abs. Error	Abs. % Error
Clark Street	Chicago River main stem	7.15	6.12	-1.02	-10.85	1.70	25.67

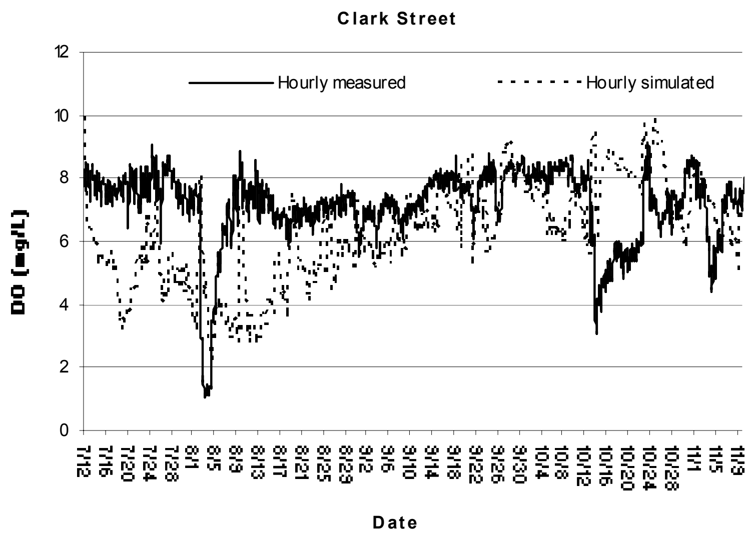


Figure 3.30. Comparison of measured and simulated dissolved oxygen (DO) concentrations on the Chicago River at Clark Street for July 12-November 9, 2001

Comparison of measured and simulated DO concentrations on the Little Calumet River (South) at Ashland Avenue is given in Figure 3.31. 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 Little Calumet River (North) flows and the effect of overestimated 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).

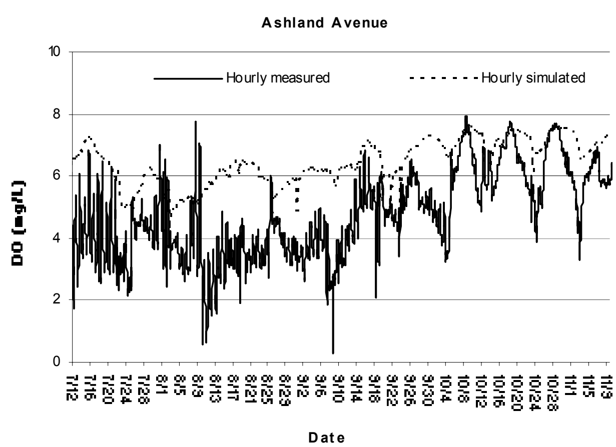
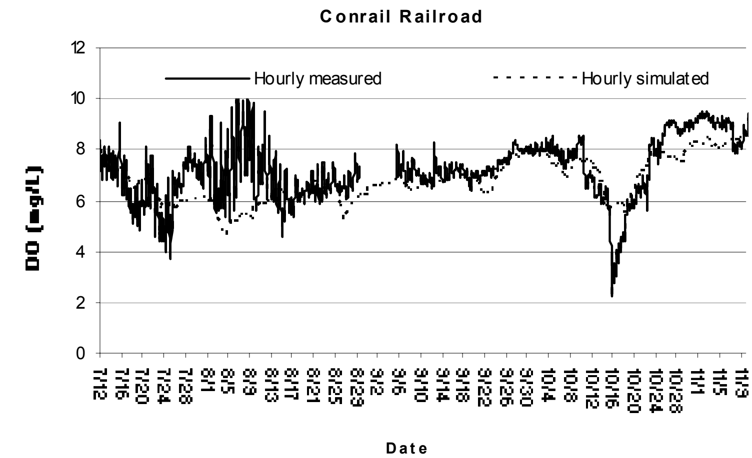


Figure 3.31 Comparison of measured and simulated dissolved oxygen (DO) concentrations at Ashland Avenue on the Little Calumet River (South) for July 12-November 9, 2001

The Little Calumet River (North) results are shown in Figure 3.32 and Table 3.19. The average absolute error of average daily DO concentrations are varying between 10.6% and 15%. 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 in the first two weeks of August 2001 when the algal activates reached a peak at the Central and Wisconsin Railroad as indicated by the diurnal fluctuations and supersaturated DO concentrations during this period.

Table 3.19 Comparison of daily average simulated and measured dissolved oxygen concentrations on the Little Calumet River (North)for July 12-November 9, 2001 [note: Error = average of simulated–measured in mg/L; % Error = Average of (simulated-measured)/average measured x 100, Abs. Error = Average absolute value of simulated–measured; Abs. % Error = Average absolute value of (simulated–measured)/average measured x 100]

Location	Waterway	Average Measured in mg/L	Average Simulated in mg/L	Error	% Error	Abs. Error	Abs. % Error
Conrail Railroad	Little Calumet River (North)	7.20	6.78	-0.42	-4.26	0.72	10.55
Central and Wisconsin Railroad	Little Calumet River (North)	7.96	6.77	-1.19	-13.76	1.26	15.00



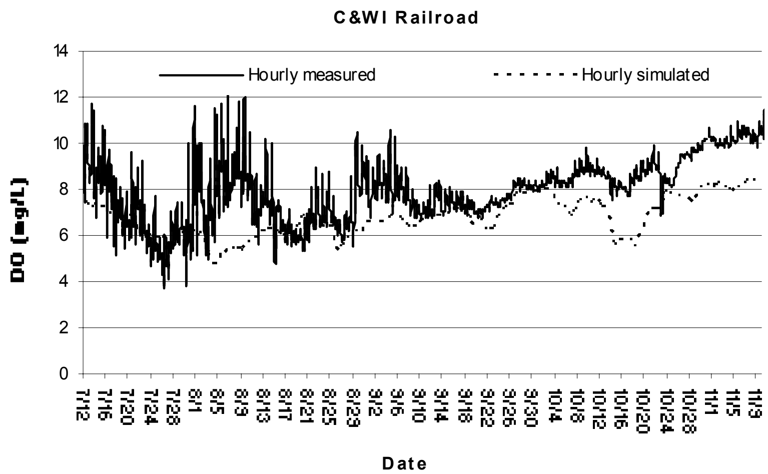


Figure 3.32. Comparison of measured and simulated dissolved oxygen (DO) concentrations at Conrail Railroad and the Central and Wisconsin Railroad on the Little Calumet River (North) for July 12-November 9, 2001

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 July 12-November 9, 2001. Hence data from the verification period, May 1-September 23, 2002, were used to calibrate water quality constituents on Bubbly Creek. Comparison of the simulated and measured DO concentrations are given in

Figures 3.33 and 3.34. 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 become basically the Racine Avenue Pump Station discharges. Since it was hard to match measured DO concentrations the goal became to underestimate DO concentration so that the simulations of any management alternative that can bring DO concentrations to desired levels can also work well in the actual situation. This safely factor should be well understood during the evaluation of the scenarios presented in Chapter 7. Historically water-quality conditions are extremely poor along Bubbly Creek and measured DO concentrations are lower than 4 mg/L for 70 % of the verification period of May 1-September 23, 2002 (Figure 3.34). In Figure 3.34 it can be seen that 80 % of the simulated DO concentrations are lower than 4 mg/L, which brings a 10 % safety factor.

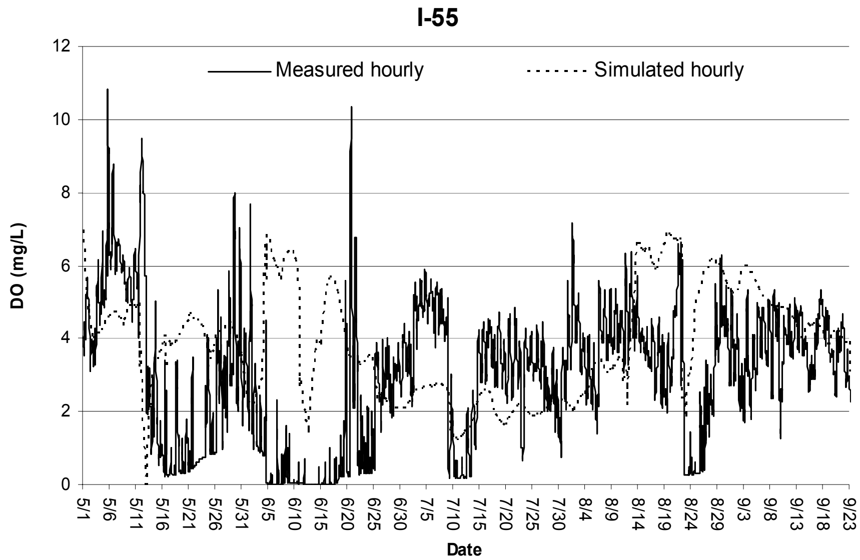


Figure 3.33 Comparison of measured and simulated dissolved oxygen (DO) concentrations at I-55 on Bubbly Creek for May 1-September 23, 2002

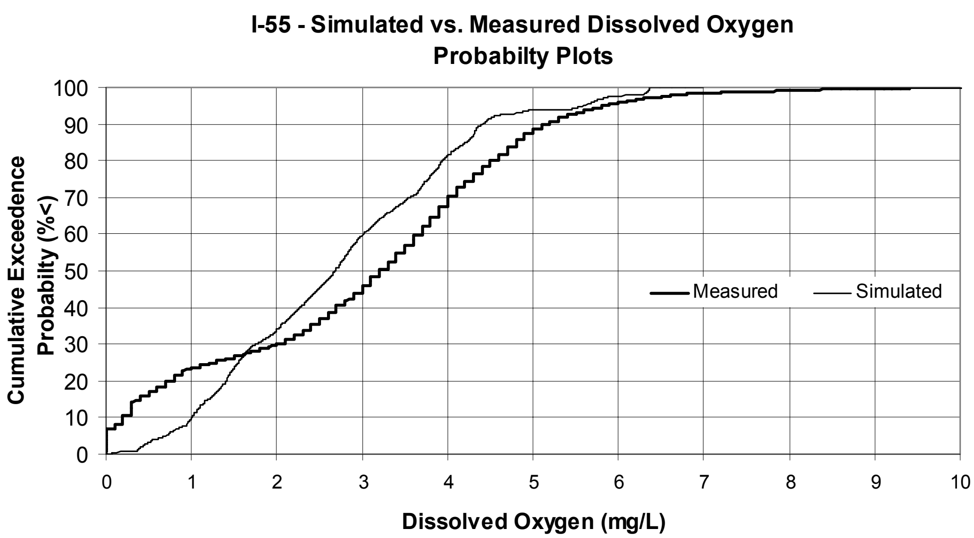


Figure 3.34 Comparison of measured and simulated dissolved oxygen (DO) probability plots for Bubbly Creek at I-55 for May 1-September 23, 2002

3.6 Summary of Calibration and Verification

In previous sections it was shown that the comparisons 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 between July-November 2001 did not indicate anything unusual. Throughout the calibration process, it was aimed to match hourly measured and simulated DO concentrations as much as possible. Overall (all locations for July 12-November 9, 2001), the average error, average percent error and average absolute percent error are -0.18 mg/L, -1.06 %, and 21.69 %, respectively. The calibrated model was verified and results are reported by Neugebauer and Melching (2005). For the verification period no detailed storm loading data were available for the pumping stations, CSO discharges, and tributaries. For model verification purposes, average values derived as a mean from historic measured data were applied. Verification of the CWS DUFLOW model generally shows good agreement between measured and simulated DO concentrations. In most of the locations, the average absolute percentage error does not exceed 40% (Neugebauer and Melching, 2005). Comparison between the DUFLOW model prediction ability for the verification (May 1 to September 24, 2002) and calibration (July 12 to November 9, 2001) periods indicates that the prediction ability of the DUFLOW model is comparable for these two different periods. 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.

The simulations of water quality during unsteady flow in the CWS for the UAA remedial actions are given in the next chapters. Comparison of the different management alternatives are based on wet and dry period evaluations. Comparison of hourly simulated and measured DO concentrations for dry weather and wet weather periods for the Chicago Waterway System for July 12-November 9, 2001 is listed in Table 3.20. Dry-weather periods were distinguished from wet-weather periods based on discharges at Romeoville. Flows greater than 100 m^3/s (3,530 cfs) which were not short-term flow fluctuations, were considered wet-weather periods (Appendix D). As shown in Figure 3.35 high flow periods at Romeoville correspond to high flow periods for the major tributaries (Little Calumet River and North Branch Chicago River at Albany Avenue) to the CWS and at internal points (North Branch Chicago River at Grand Avenue) in the CWS. Thus, using high flows at Romeoville to define wet weather periods appears to be reasonable.

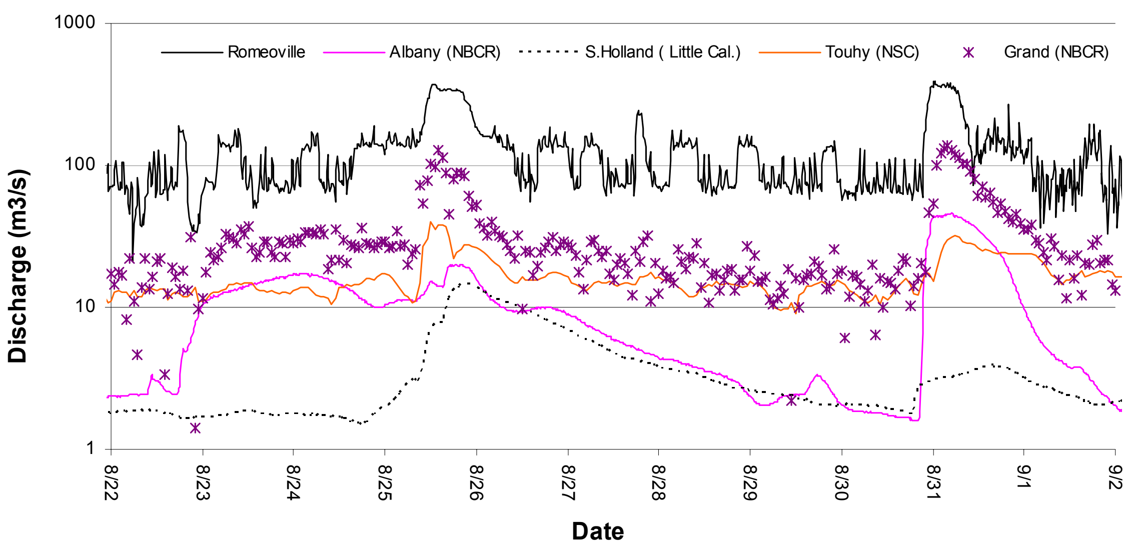


Figure 3.35 Measured flows on the North Branch Chicago River (NBCR) at Touhy Avenue and Albany Avenue, the Little Calumet River at South Holland, the Chicago Sanitary and Ship Canal at Romeoville and simulated flows on the North Branch Chicago River at Grand Avenue for August 22 to September 2, 2001.

In the following chapters, comparisons of simulations for the management alternatives for the dry and wet weather periods are evaluated in detail.

Table 3.20 Comparison of percentages of values less than various target dissolved oxygen (DO) concentrations for hourly simulated and measured DO concentrations for dry weather and wet weather periods for the Chicago Waterway System for July 12-November 9, 2001

	Percent of DO (Measured) during dry and wet weather periods higher than								Percent of DO (Calibrated) during dry and wet weather periods higher than							
	3 mg/L		4 mg/L		5 mg/L		6 mg/L		3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
Linden Street	91	63	89	56	88	50	86	42	81	42	77	32	72	24	62	17
Simpson Street	69	30	60	17	47	9	41	5	62	19	50	17	37	12	26	6
Main Street	53	21	42	12	29	7	26	4	47	22	36	15	20	6	9	0
Addison Street	100	99	98	98	86	95	51	53	100	100	98	100	79	87	28	42
Fullerton Avenue	95	92	77	84	47	56	43	27	95	97	82	92	48	61	19	29
Division Street	100	99	96	94	85	83	52	40	94	97	79	93	58	77	34	41
Kinzie Street	98	96	93	90	66	70	35	24	93	97	79	87	63	71	36	37
CRCW	100	96	100	94	100	89	100	87	100	99	95	97	84	92	70	77
Clark Street	100	96	100	93	99	89	98	81	98	97	85	93	74	82	55	54
Jackson Boulevard	98	93	91	82	68	54	42	17	91	94	78	86	63	71	42	36
Cicero Avenue	84	72	55	47	28	16	23	0	86	70	59	40	44	29	28	19
B and O RR	100	94	97	81	77	49	46	18	97	97	84	76	58	41	34	24
Route 83	93	64	81	43	44	11	28	2	85	88	63	57	42	30	24	20
Mile 11.6	94	77	86	56	61	26	38	6	88	90	75	67	52	37	32	24
Romeoville	93	68	74	38	31	12	22	0	80	86	64	61	42	33	29	21
130th Street	100	100	100	100	100	100	89	89	100	100	100	100	100	95	86	68
Conrail RR	100	99	100	97	100	90	93	81	100	100	100	100	100	95	87	67
C and W RR	100	100	100	100	99	98	92	90	100	100	100	100	100	97	89	68
Halsted Street	100	100	100	98	96	91	76	61	100	97	97	90	85	67	48	26
Division Street	100	93	92	83	72	65	55	22	100	100	96	95	86	69	50	35
Kedzie Street	100	97	99	89	87	80	66	54	100	100	96	96	88	80	54	41
Cicero Avenue	100	96	98	86	84	77	64	49	100	98	94	93	83	61	49	35
Harlem Avenue	99	96	91	91	74	80	61	36	96	97	90	87	80	55	56	38
Southwest Highway	100	95	95	84	83	69	66	47	96	96	87	85	78	52	53	35
104th Avenue	97	84	91	81	74	67	61	23	91	92	85	80	73	49	52	31
Route 83	98	90	90	86	75	67	65	32	92	93	82	79	73	52	55	33

Chapter 4 – FLOW AUGMENTATION FOR THE NORTH SHORE CHANNEL

In this chapter, different forms of flow augmentation practices on the NSC will be evaluated. First, results of moving a portion of the NSWRP effluent to the upstream end of the NSC is presented. Second, the flow is transferred to and divided between two discharge points: one at the upstream end of the NSC and the other at 1.74 miles upstream from the NSWRP. Last, a case of flow augmentation wherein oxygen would be added to the NSWRP effluent in the force main is considered.

4.1 Single Point Flow Augmentation without Aeration

In this section, evaluations of a set of simulations considering moving a portion of the NSWRP effluent to the upstream end of the NSC are given. Two types of flow transfer have been considered: the transfer of (1) a fixed amount (50 or 100 mgd) and (2) a percentage (10, 50, 75, or 100%) of the NSWRP effluent have been evaluated for the periods July 12 – September 14, 2001 and September 15 – November 9, 2001. The minimum one hour flow from the NSWRP during these periods was 110 mgd. Thus, it was necessary to consider a percentage flow transfer rather than a fixed amount transfer to evaluate higher transfer levels. The percentage of hours that target DO concentrations of 3, 4, 5, and 6 mg/L are equaled or exceeded for the total period of July 12 – November 9, 2001 are listed in Tables 4.1-4.3 for Simpson Street, Main Street, and Addison Street, respectively.

Table 4.1 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Simpson Street on the North Shore Channel for July 12 – November 9, 2001 for different transfers of the North Side Water Reclamation Plant effluent

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Measured	69.0	29.9	60.2	17.0	47.0	9.3	41.5	4.7
Calibrated	62.4	19.1	49.9	17.3	36.8	12.3	26.0	6.1
50 mgd	92.0	79.7	74.2	41.5	46.6	13.0	23.4	0.0
100 mgd	98.5	98.9	92.2	92.8	67.4	60.2	27.9	5.5
10 %	77.5	58.4	64.4	27.8	41.8	6.7	19.6	0.0
50 %	99.3	**100.0**	95.2	99.6	78.1	84.7	33.6	44.5
75 %	99.5	**100.0**	97.9	99.9	85.2	93.9	40.5	56.7
100 %	**100.0**	**100.0**	99.1	**100.0**	88.9	96.8	44.8	65.9

Table 4.2 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Main Street on the North Shore Channel for July 12 – November 9, 2001 for different transfers of the North Side Water Reclamation Plant effluent

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Measured	53.1	20.6	41.7	11.5	28.8	6.6	25.5	4.4
Calibrated	46.7	22.1	35.7	15.5	19.6	6.3	9.2	0.0
50 mgd	72.0	35.2	48.3	9.6	27.0	3.8	6.1	0.0
100 mgd	90.6	88.9	74.6	73.3	35.0	8.9	13.4	0.0
10 %	61.7	28.3	41.6	7.8	24.2	0.0	5.8	0.0
50 %	94.8	99.7	86.0	89.1	47.3	62.9	17.9	19.0
75 %	98.0	**100.0**	90.6	97.7	64.8	79.7	26.6	42.0
100 %	98.7	**100.0**	94.5	99.8	74.1	87.0	31.3	49.3

Table 4.3 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Addison Street on the North Branch Chicago River for July 12 – November 9, 2001 for different transfers of the North Side Water Reclamation Plant effluent

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Measured	99.7	99.1	98.1	98.3	86.4	95.1	51.0	53.5
Calibrated	**100.0**	**100.0**	97.5	99.7	79.4	87.3	28.2	42.4
50 mgd	**100.0**	**100.0**	97.0	98.6	78.0	81.1	27.2	35.2
100 mgd	99.6	**100.0**	94.8	97.0	77.3	79.9	25.3	35.4
10 %	**100.0**	**100.0**	97.4	99.2	79.8	83.5	29.1	36.0
50 %	99.4	**100.0**	94.9	96.9	76.4	80.7	25.3	38.3
75 %	98.7	**100.0**	94.1	96.8	74.6	79.1	24.8	39.1
100 %	97.9	**100.0**	93.3	96.1	74.1	78.2	24.8	39.6

The simulation results for Simpson Street and Main Street show the improvement of DO concentrations in the upper NSC resulting from the flow transfer whereas the simulation results at Addison Street show the change in DO concentrations downstream from the NSWRP resulting from the transfer. It can be seen that even transferring the complete NSWRP flow does not result in attainment of DO concentrations in excess of 4 mg/L at Simpson Street and 3 mg/L at Main Street during dry weather 100 percent of the time. Whereas these target DO concentrations are achieved 100 percent of the time during wet weather. Surprisingly, for nearly all target DO concentrations and all transfer scenarios higher percentages of compliance are achieved for wet weather than for dry weather. Thus, extra flow for dilution of CSOs is effective in improving DO concentrations in the upper NSC during storms.

The surprising result that transferring even the entire flow from the NSWRP to the upstream end of the NSC does not result in DO concentrations greater than 4 mg/L at all times during dry weather flow is because of two causes. The first is that for most days in

July and August 2001 the DO concentration in the NSWRP effluent is 6 mg/L or less (Figure 4.1). Thus, there is a small margin between the effluent DO concentration and the 4 mg/L target, and the $CBOD_5$ and ammonia loads and sediment oxygen demand are sufficient to reduce DO concentrations below the 4 and 3 mg/L targets. The second is that occasionally higher concentrations of $CBOD_5$ and ammonia are present in the NSWRP effluent. Figure 4.2 shows the simulated hourly and daily mean DO concentrations at Simpson Street and Main Street on the upper NSC resulting from a 100 percent transfer of the NSWRP effluent to the upstream end of the NSC. The occasional instances of low DO concentrations are the result of periods with relatively higher $CBOD_5$ and ammonia concentrations in the NSWRP effluent. For example, on July 17, 2001, the daily mean $CBOD_5$ and ammonia concentrations in the NSWRP effluent were 10.0 and 3.49 mg/L, respectively (and the daily mean DO concentration was 5.4 mg/L). Although these concentrations are not high relative to the NSWRP permit limits and general performance of wastewater treatment plants nationwide, they are more than double and triple, respectively, compared to the $CBOD_5$ and ammonia concentrations in the NSWRP effluent on most days. Thus, occasional higher concentrations in the effluent and the small difference between the effluent DO concentration and DO concentration targets means that 100 percent compliance with targets will be difficult to achieve.

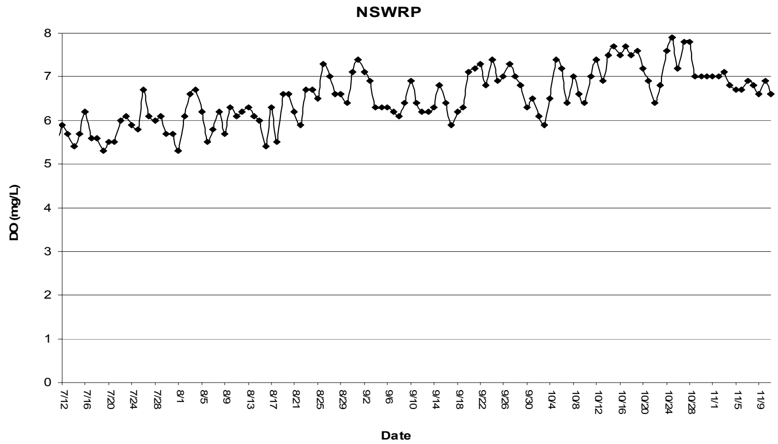


Figure 4.1 Daily mean dissolved oxygen concentration in the North Side Water Reclamation Plant Effluent for July 12 – November 9, 2001.

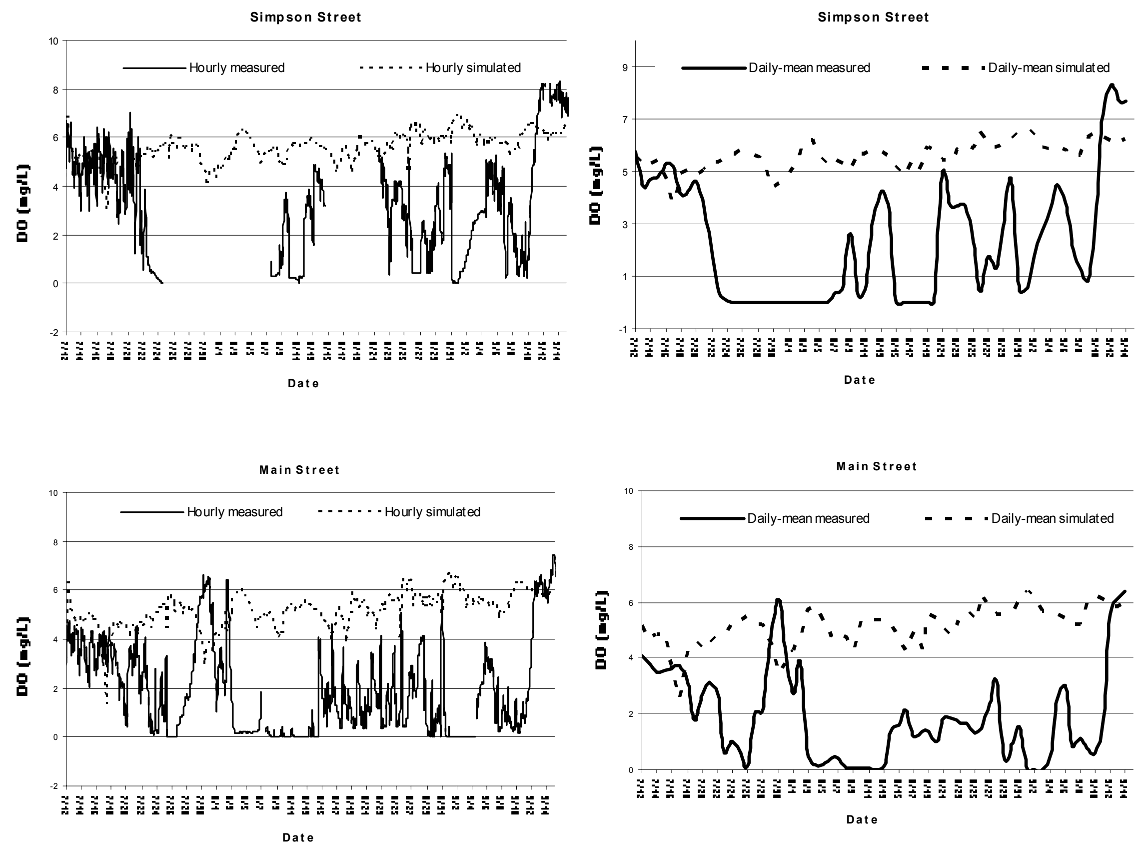


Figure 4.2 Simulated hourly and daily mean dissolved oxygen concentrations at Simpson Street and Main Street on the North Shore Channel for a 100 percent transfer of the effluent of the North Side Water Reclamation Plant to the upstream end of the North Shore channel compared with measured concentrations for July 12 to September 14, 2001.

Other Noteworthy Simulation Results

Two aspects of the simulation results require discussion. The first is that the transfer of NSWRP effluent to the upstream end of the NSC results in a decrease in the percentage of time that DO concentrations comply with the various DO concentration targets at Addison Street. Because of the longer traveltime for the transferred flow to reach Addison Street biological processes act to reduce DO concentrations at Addison Street. This is somewhat offset by the increased oxygen load produced by the Devon Avenue in-stream aeration station. That is, keeping the operating hours for the station the same, the lower the percentage of DO saturation coming into the station the higher the increase in DO load from the station.

The in-stream aeration station at Devon Avenue is turned on when DO concentrations at the North Branch Pumping Station fall below the following targets: 1 blower - < 5.5 mg/L, 2 blowers - < 5 mg/L, and 3 blowers - < 4.5 mg/L (targets raised if 3 blowers are on at Webster Street). The in-stream aeration station at Webster Street is turned on when the DO concentrations at Ohio Street go below the following targets: 1 blower - < 5.5 mg/L, 2 blowers - < 5 mg/L, and 3 blowers - < 4.5 mg/L. Because the reference locations are downstream of the in-stream aeration stations, adjusting the operating hours of the in-stream aeration stations in response to changed DO concentrations resulting when NSWRP effluent is transferred to points along the upper NSC would involve complicated iterations. That is, changing the operating hours of the in-stream aeration stations change the downstream DO concentrations which in turn change the operating hours of the in-stream aeration stations. Thus, it is impractical for the purpose of this study to evaluate possible changes in the operation hours of the in-stream aeration stations and all simulations are done assuming the operation hours of the in-stream aeration stations remain the same as the actual operation hours for the days considered.

The second aspect of the results that requires discussion is the reduction in the percentage of the time in compliance with various target DO concentrations when small amounts of effluent (50 mgd or 10 percent) are transferred to the upstream end of the NSC relative to the no transfer (calibrated model) case. For the no transfer case compliance with the various target DO concentrations is achieved at certain times. For some of these times the addition of a $CBOD_5$ and ammonia load in the transferred effluent may result in a decrease in DO concentrations below the targets. For small flow transfers the number of hours with reduced DO may be greater than the number of hours improved by the effluent transfer. At higher levels of flow transfer, the number of hours improved is substantially more than those that are adversely affected.

4.2 Flow Augmentation with Two Discharge Points

The results reported in the previous section are for the case of NSWRP effluent transferred to a single discharge point at the upstream end of the NSC. In this case, the flow is transferred to and divided between two discharge points: one at the upstream end of the NSC and the other at 1.74 miles upstream from the NSWRP. Again results were obtained for the period of July 12 to November 9, 2001, and the results for Simpson, Main, and Addison Streets are listed in Tables 4.4-4.6, respectively.

Table 4.4 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Simpson Street on the North Shore Channel for July 12 – November 9, 2001 for different transfers of the North Side Water Reclamation Plant effluent with two outlet points

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Measured	69.0	29.9	60.2	17.0	47.0	9.3	41.5	4.7
Calibrated	62.4	19.1	49.9	17.3	36.8	12.3	26.0	6.1
100 mgd	98.3	98.4	90.1	90.0	63.7	62.8	26.2	5.9
50 %	99.1	**100.0**	93.2	99.3	72.0	80.8	31.1	39.5
75 %	99.4	**100.0**	97.1	99.7	82.9	91.8	38.7	53.4
100 %	**100.0**	**100.0**	99.1	**100.0**	89.0	96.8	45.0	66.0

Table 4.5 The percentage of time that dissolved oxygen concentrations are higher than the target concentrations at Main Street on the North Shore Channel for July 12 – November 10, 2001 for different transfers of the North Side Water Reclamation Plant effluent with two outlet points

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	Dry	wet
Measured	53.1	20.6	41.7	11.5	28.8	6.6	25.5	4.4
Calibrated	46.7	22.1	35.7	15.5	19.6	6.3	9.2	0.0
100 mgd	99.3	**100.0**	95.9	**100.0**	75.9	87.8	31.7	48.2
50 %	99.2	**100.0**	95.5	**100.0**	76.0	87.6	31.4	49.3
75 %	99.1	**100.0**	94.9	99.9	74.9	87.6	31.3	49.5
100 %	98.7	**100.0**	94.5	99.8	74.2	87.2	31.3	49.5

Table 4.6 The percentage of time that dissolved oxygen concentrations are higher than the target concentrations at Addison Street on the North Branch Chicago River for July 12 – November 9, 2001 for different transfers of the North Side Water Reclamation Plant effluent with two outlet points

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	Wet	dry	wet
Measured	99.7	99.1	98.1	98.3	86.4	95.1	51.0	53.5
Calibrated	**100.0**	**100.0**	97.5	99.7	79.4	87.3	28.2	42.4
100 mgd	98.9	**100.0**	94.0	96.7	74.4	79.2	24.1	37.4
50 %	98.6	**100.0**	94.0	96.7	74.2	78.6	24.2	38.6
75 %	98.3	**100.0**	93.8	96.4	74.2	78.5	24.1	39.4
100 %	97.9	**100.0**	93.3	96.2	73.8	78.1	24.3	39.7

For flow transfers less than 100 percent, splitting the flow results in slightly worse (a few percent less) percentages of compliance with the various target DO concentrations at

Simpson Street, but substantially improved percentages of compliance at Main Street. For complete (100 %) flow transfers the results with one or two outlets are nearly identical in terms of percentage of compliance. These results indicate that if a transfer of NSWRP effluent is utilized a final design with multiple outlets would be most efficient as it would yield nearly identical (or even improved) DO concentrations at a smaller construction and operation costs (note: a cost estimate was not done, but it stands to reason that pumping less flow to the upstream end of the NSC will reduce the operation cost and using a smaller pipe upstream from the mid-point would reduce the construction cost).

4.3 North Shore Channel Flow Augmentation with Aeration

It was previously found that even shifting the entire NSWRP effluent discharge to the upstream end of the NSC could not achieve 100 percent compliance with a 4 mg/L DO criterion at Main Street during the period July 12 to November 9, 2001. It was speculated that this resulted because DO concentrations in the NSWRP effluent often were relatively low (between 5 and 6 mg/L) in July and August 2001. CTE's review of aeration technologies as part of the UAA alternatives review found that it would be relatively easy to bring the flow to saturation in the force main used to transfer flow from the NSWRP to the upstream end of the NSC. Thus, it was decided to consider a case of flow augmentation wherein oxygen would be added to the NSWRP effluent in the force main.

Daily mean temperature data for the NSWRP effluent for the periods July 12 to November 9, 2001 and May 1 to September 23, 2002 were used to determine the saturation DO concentration in the force main. Some of this DO would be consumed during travel from the NSWRP to the upstream end of the NSC, but this would be matched by a decrease in the $CBOD_5$. Thus, for simplicity the quality of the transferred flow was taken as that of the NSWRP effluent with the DO concentration raised to saturation. The transfer amount was taken as the lesser of the selected transfer value or the actual effluent flow for a particular hour. Table 4.7 lists the percentage of time compliance is achieved with DO criteria of 4, 5, and 6 mg/L for dry weather and wet weather periods at Main Street.

Table 4.7 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Main Street on the North Shore Channel for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration.

Scenario*	4 mg/L		5 mg/L		6 mg/L	
	Dry	Wet	Dry	Wet	Dry	Wet
50 mgd	94.7	68.5	81.4	49.6	56.9	29.7
80 mgd	98.1	89.2	94.8	79.0	78.2	56.0
90 mgd	98.5	90.9	96.0	84.4	83.2	64.9
100 mgd	98.8	92.5	96.6	88.0	86.8	72.1
120 mgd	99.1	94.6	98.0	90.5	92.6	81.6
130 mgd	99.2	95.7	98.5	91.6	93.9	85.7
140 mgd	99.4	96.3	98.7	92.2	94.6	88.2
150 mgd	99.6	96.7	98.9	93.2	95.4	89.3
170 mgd	99.8	97.6	99.1	94.4	97.3	90.4
180 mgd	99.9	98.0	99.2	95.1	97.7	91.1
190 mgd	100.0	98.2	99.4	95.3	98.0	91.4
200 mgd	100.0	98.9	99.6	95.7	98.3	91.8
220 mgd	100.0	99.5	99.7	96.4	98.6	92.8
230 mgd	100.0	99.6	99.8	96.7	98.7	93.3
240 mgd	100.0	99.6	99.8	97.0	98.8	93.7

*The flows listed are the nominal flows, the actual flow is the lesser of the selected transfer value and the actual effluent flow.

The results in Table 4.7 indicate that a transfer of 190 million gallons per day (mgd) is necessary to achieve DO concentrations in excess of 4 mg/L at Main Street 100 percent of the time during dry weather periods. The DO criterion of 5 mg/L could only be met 99.8 percent of the time at Main Street. The problem date is July 17, 2001, on which the effluent $CBOD_5$ and ammonia concentrations were 10.0 mg/L and 3.49 mg/L, respectively. This relatively higher load (yet still within the NSWRP permit limits) results in DO concentrations less than 5 mg/L at Main Street. The NSWRP effluent flows on July 17, 2001, ranged between 200 and 240 mgd. Thus, diversions greater than 240 mgd had no effect on the simulated DO concentrations as shown in Figure 4.3.

In the charge to CTE for the NSWRP Facility Plan a target of 90 percent compliance with DO criteria of 4, 5, and 6 mg/L during all periods (wet and dry) was set for developing cost estimates. Thus, in this report the aerated transfer amount necessary to meet 90 percent compliance with the DO criteria during the simulated periods is evaluated. The simulated periods are dominated by summer (July-September) conditions during which temperature stresses on DO concentrations are greatest. Thus, 90 percent compliance in the summer implies much higher compliance over an entire year, and the transfer amounts determined are conservative relative to 90 percent compliance over the entire 2 year period.

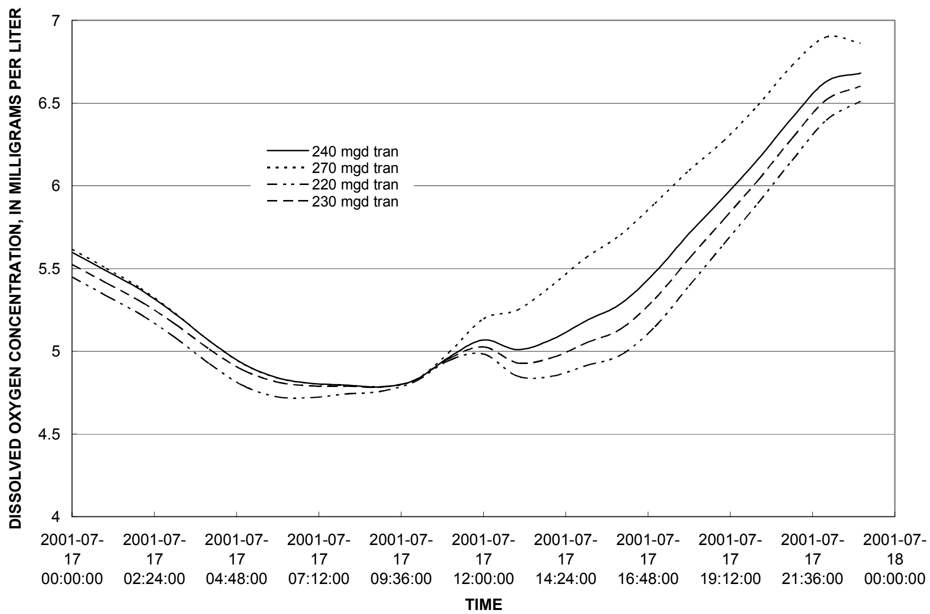


Figure 4.3 Simulated dissolved oxygen concentrations at Main Street on the North Shore Channel for July 17, 2001, for different flow augmentation with aeration scenarios.

Table 4.8 and Figure 4.4 list and show, respectively, the overall percentage compliance with the 4, 5, and 6 mg/L DO criteria resulting from different amounts of flow transfer from the NSWRP to the upstream end of the NSC. Ninety percent compliance with the 4, 5, and 6 mg/L criteria is achieved with a transfer of approximately 65, 90, and 130 mgd, respectively, of aerated effluent.

Table 4.8 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Main Street on the North Shore Channel for all periods during July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration

Scenario	> 4 mg/L	> 5 mg/L	> 6 mg/L
50 mgd	85.7	70.5	47.6
80 mgd	95.1	89.4	70.6
90 mgd	95.9	92.1	76.9
100 mgd	96.7	93.7	81.7
120 mgd	97.6	95.5	88.8
130 mgd	98.0	96.1	91.1
140 mgd	98.3	96.5	92.4
150 mgd	98.6	96.9	93.3
170 mgd	99.1	97.5	94.9
180 mgd	99.3	97.8	95.5
190 mgd	99.4	98.0	95.8
200 mgd	99.6	98.3	96.1
220 mgd	99.8	98.6	96.6
230 mgd	99.9	98.7	96.9
240 mgd	99.9	98.9	97.1

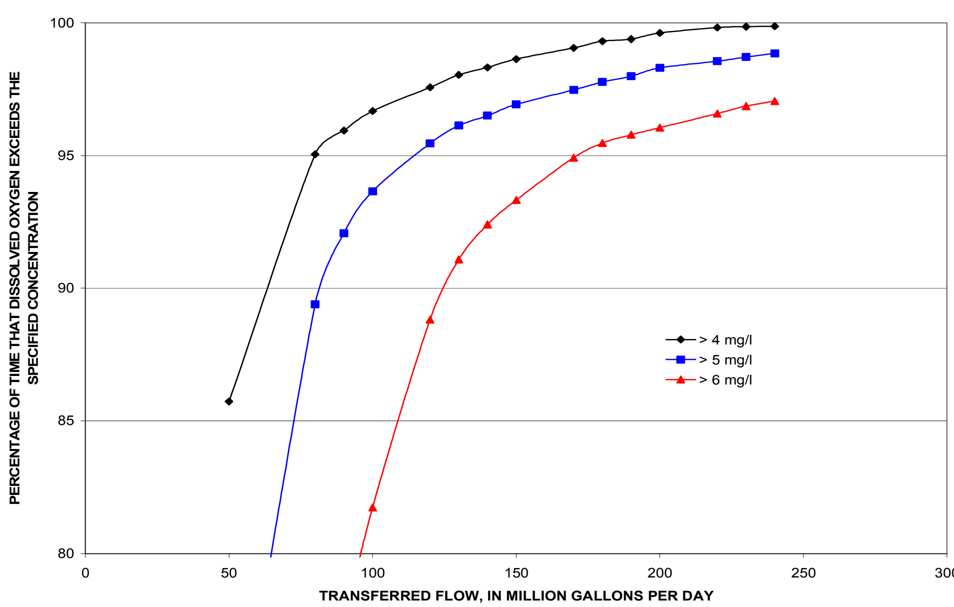


Figure 4.4 Relation between aerated North Side Water Reclamation Plant effluent and percentage compliance at Main Street with dissolved oxygen concentration criteria of 4, 5, and 6 mg/L.

The overall percentage compliance with the 4, 5, and 6 mg/L DO criteria resulting from transfer of 80, 120, 170, and 190 mgd NSWRP flow to the upstream end of the NSC at the locations downstream from NSWRP are shown in Tables 4.8-Table 4.14. Even though the increase in DO is not as drastic as that observed along the NSC, at least 10% improvement is achieved by transferring 190 mgd compared to 80 mgd at Addison Street for 6 mg/L target level (Table 4.9). The DO criterion of 5 mg/L could be met 95 and 94.1 percent of the time for wet and dry weather periods, respectively at Addison Street by a transfer of 80 mgd. Even a transfer of 190 mgd aerated NSWRP flow could not result in 95 % compliance with a 5 mg/L criterion at Fullerton Avenue, Division Street, and Kinzie Street (Tables 4.9-4.11).

Table 4.9 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Addison Street on the North Branch Chicago River for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration.

	>4 mg/L		>5 mg/L		>6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	99.0	99.8	89.9	91.3	55.4	62.2
80 mgd	99.6	99.8	95.0	94.1	68.8	67.2
120 mgd	99.6	99.7	96.6	94.9	74.2	71.0
170 mgd	99.7	99.7	97.7	96.4	81.5	75.6
190 mgd	99.8	99.7	98.1	96.8	83.9	78.3

Table 4.10 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Fullerton Avenue on the North Branch Chicago River for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration.

	>4 mg/L		>5 mg/L		>6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	89.5	95.5	54.1	72.3	18.6	38.6
80 mgd	93.8	95.8	70.2	80.3	28.6	46.7
120 mgd	96.2	96.0	75.5	84.1	32.3	49.5
170 mgd	97.5	96.8	79.6	86.7	41.5	54.3
190 mgd	97.9	97.2	81.2	87.5	44.7	56.9

Table 4.11 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Division Street on the North Branch Chicago River for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration.

	>4 mg/L		>5 mg/L		>6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	91.1	95.5	54.9	79.4	26.8	51.5
80 mgd	93.1	95.7	71.6	88.3	33.9	57.6
120 mgd	94.1	97.1	75.4	90.1	37.2	60.4
170 mgd	96.3	97.6	79.3	91.6	42.8	67.4
190 mgd	97.1	98.9	80.7	92.0	44.7	70.7

Table 4.12 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Kinzie Street on the North Branch Chicago River for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration

	>4 mg/L		>5 mg/L		>6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	78.0	88.8	50.5	74.4	25.5	45.5
80 mgd	92.5	93.8	57.9	79.7	29.4	46.5
120 mgd	93.8	95.3	61.0	80.4	33.4	50.8
170 mgd	95.9	96.4	65.4	81.5	36.5	54.9
190 mgd	96.5	96.8	67.2	82.2	37.5	56.2

Results show that the effect of flow augmentation with aeration decreases considerably at locations downstream from the junction of the NBCR and SBCR (Tables 4.12-4.14). The effect of this aerated transfer is almost zero at Romeoville (Table 4.15).

Table 4.13 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Jackson Boulevard on the South Branch Chicago River for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration

	>4 mg/L		>5 mg/L		>6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	65.7	83.3	51.5	69.6	28.5	40.6
80 mgd	70.3	84.8	56.0	72.1	31.4	42.3
120 mgd	72.2	85.8	57.0	72.5	33.5	43.6
170 mgd	75.1	86.7	58.0	74.1	35.6	44.8
190 mgd	76.6	87.2	58.7	74.5	36.5	45.4

Table 4.14 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Cicero Avenue on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration.

	>4 mg/L		>5 mg/L		>6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	55.0	48.5	32.1	34.2	14.8	14.8
80 mgd	56.3	50.1	32.6	34.2	15.3	15.6
120 mgd	57.1	51.7	33.3	34.9	15.6	16.3
170 mgd	58.2	54.1	34.6	35.9	16.1	17.0
190 mgd	58.6	54.9	35.0	36.0	16.2	17.2

Table 4.15 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at Romeoville on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 and May 1 – September 23, 2002 for different transfers of North Side Water Reclamation Plant effluent brought to saturation DO concentration

	>4 mg/L		>5 mg/L		>6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	63.6	66.6	38.9	43.4	19.9	23.7
80 mgd	65.1	66.5	39.4	44.6	20.4	24.4
120 mgd	65.7	66.9	39.8	44.9	20.7	24.8
170 mgd	66.2	67.6	40.4	45.5	21.2	25.2
190 mgd	66.5	67.9	40.4	45.7	21.3	25.4

Chapter 5 – SUPPLEMENTARY AERATION STATIONS

The simulations regarding the existing in-stream aeration stations and proposed new aeration stations are presented in this chapter. First, evaluation of additional aeration stations on the NBCR and the SBCR is given in Section 5.1. In Section 5.2, additional aeration stations on the CSSC are examined. The results of the simulation regarding raising the Stickney WRP effluent DO to saturation are also given in the later section.

5.1 Supplementary Aeration Stations on the North Branch Chicago River and the South Branch Chicago River

The first set of simulations (D3W3) consider the existing Devon Avenue and Webster Street in-stream aeration stations operating at full capacity (3 blowers each). These scenarios are considered as the hypothetical baseline for comparison of the different scenarios with new aeration stations. The second set of simulations includes 4 new aeration stations and the current in-stream aeration stations operating at full capacity.

In general, the 2002 study period is dryer than 2001 study period. The sub-period of July 10 to August 10, 2002 was selected as the baseline to determine the size and the locations of the new aeration stations. During this period the CSO pumping stations were inactive except for the operation of the North Branch Pump Station for 4 hours between July 13 and July 14, 2002. Therefore, it was assumed that this period represents dry weather periods well. The purpose of the new aeration stations is to keep DO concentrations above 5 mg/L for 90 % of the time during dry weather periods along the NBCR and the

SBCR. In this exercise new aeration stations were added to the river network wherever needed. This means that when the simulated DO concentration drop below 5 mg/L at a location a new aeration station was introduced upstream from that location. Once the size and the locations of the new aeration stations are determined, efficiencies of the new aeration stations were tested for the other periods (July 12-November 9, 2001 and May 1-September 23, 2002). Results of the simulations for the full 2001 and 2002 periods are given in the following sections.

5.1.1 Determination of the Size and the Location of the New Aeration Stations on the Basis of Simulations for July 10-August 10, 2002

In this exercise, the aim was to achieve 5 mg/L 100% of the time as much as possible between July 10 and August 10, 2002. Different DO loads were tried at the new aeration stations to keep DO concentration above 5 mg/L along the NBCR and the SBCR. The system was examined starting from the junction of the NBCR and the NSC to downstream locations. 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 DO dropped under 5 mg/L. This exercise was a trial and error practice and availability of space was not taken into account during the simulations.

For the baseline (D3W3) the overall percentage compliance with target DO concentrations of 3, 4, 5, and 6 mg/L for different locations for July 10 to August 10, 2002 are listed in Table 5.1.

Table 5.1 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline simulation (D3W3) for July 10-August 10, 2002

	3.0 mg/L	4.0 mg/L	5.0 mg/L	6.0 mg/L
Addison Street	100	100.0	99.3	85.5
Fullerton Avenue	100	97.9	63.0	4.8
Division Street	100	100	49.1	5.9
Kinzie Street	100	95.6	18.4	0.0
Jackson Boulevard	87.2	32.4	16.7	0.0
SBCR and Bubbly Creek Junction	18.6	0.0	0.0	0.0

Even though 99.3 % of the time the DO is greater than 5 mg/L at Addison Street, for the rest of the stations, 5 mg/L is achieved between 63 and 0 % of the time when both Devon Avenue and Webster Street stations work at full capacity between July 10 and August 10, 2002 (Table 5.1). The 4 mg/L target level is attained 95 % of the time or more along NBCR for the baseline simulation. As can be seen in Table 5.1, DO concentrations are far below the goal at the locations on the SBCR.

Even though results are presented at certain locations in this section, the NBCR and the SBCR were examined throughout their length to determine the locations and size of the new aeration stations. It was determined that 4 new aeration stations would be sufficient to keep DO concentrations above 5 mg/L at most of the locations in the study area between July 10 and August 10, 2002. The locations and DO loads of the new stations are listed below:

1* Slightly upstream from Diversey Avenue (30 g/s)

2* Slightly downstream from Chicago Avenue (30 g/s)

3* Slightly downstream from Madison Avenue (30 g/s)

4* Slightly upstream from Halsted Street (80 g/s)

For the new aeration station simulations the overall percentage compliance for 3, 4, 5, and 6 mg/L for different locations for July 10 to August 10, 2002 are listed in Table 5.2. Plots of DO concentrations for the baseline and the new aeration stations simulations are given in Figure 5.1.

Table 5.2 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the '4 New Aeration Stations' simulation for July 10-August 10, 2002

	3.0 mg/L	4.0 mg/L	5.0 mg/L	6.0 mg/L
Addison Street	100	100	100	91.7
Fullerton Avenue	100	100	100	97.9
Division Street	100	100	100	100
Kinzie Street	100	100	100	100
Jackson Boulevard	100	100	100	100
SBCR and Bubbly Creek Junction	100	100	97.8	88.3

Table 5.2 shows that the addition of the 4 new aeration stations results in drastic increase in DO for July 10-August 10, 2002. The 5 mg/L DO target is achieved 97.8 % of the time at the junction of Bubbly Creek and the SBCR. For the other locations DO concentrations are equal or greater than 5 mg/L 100% of the time. It was observed that the new aeration station at Diversey Avenue renders the Webster Street Aeration Station ineffective when DO concentrations reach saturation concentrations upstream from the Webster Street Aeration Station for some periods. In reality, aerations stations can be turned on and off depending on measured DO concentrations. But in these simulations all new aeration stations are assumed to produce a constant DO load all the time, hence, very high DO concentrations are sometimes observed in these simulations even though they might not occur in the actual operation of such stations. Results of the new aeration stations simulations for July 12-November 9, 2001 and May 1-September 23, 2002 are given in the following sections.

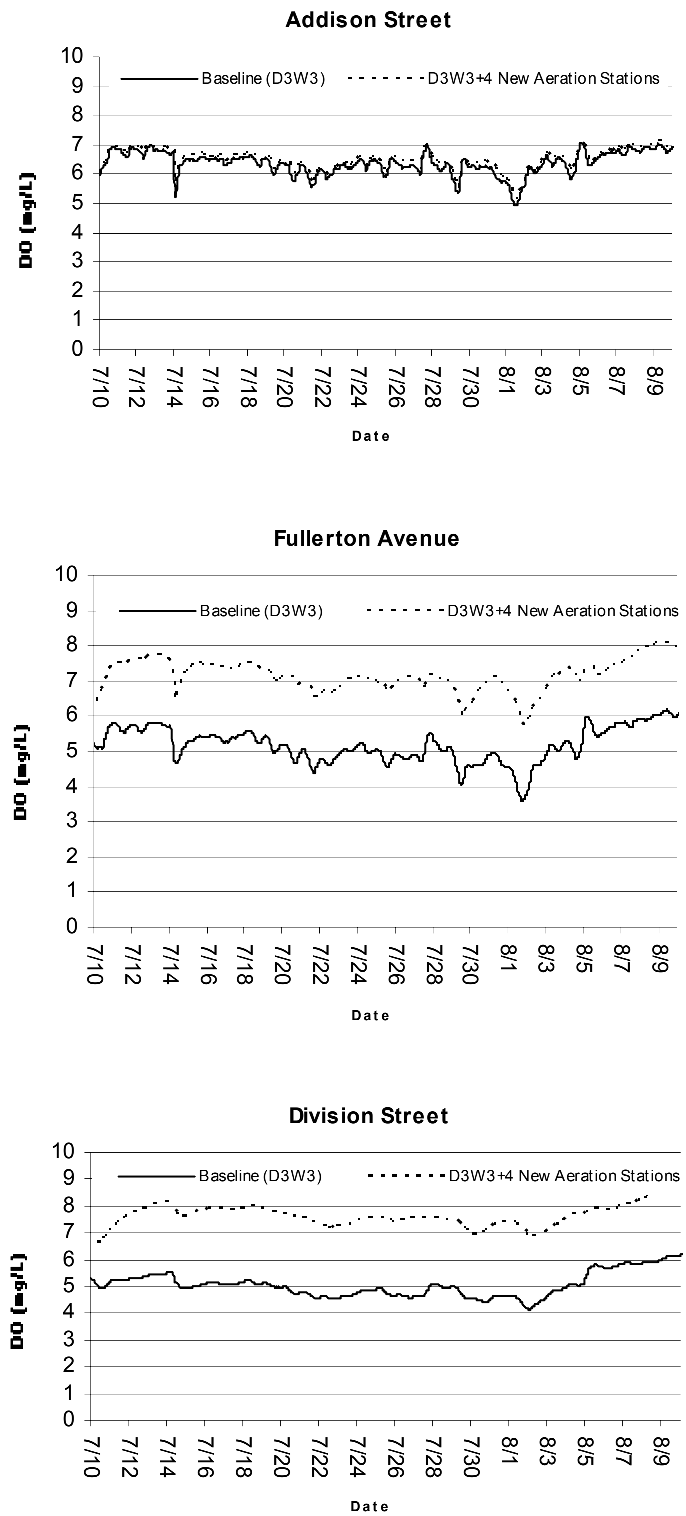
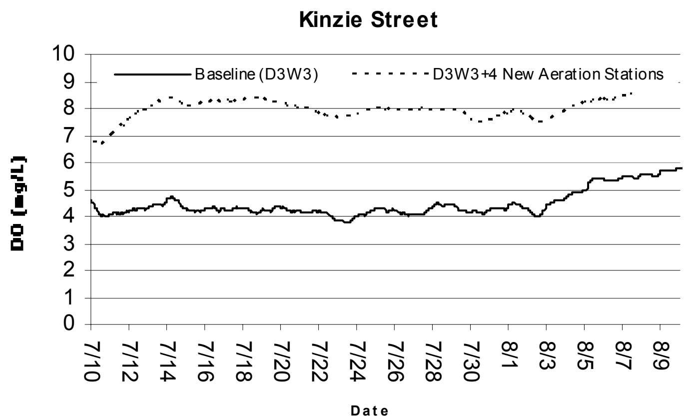
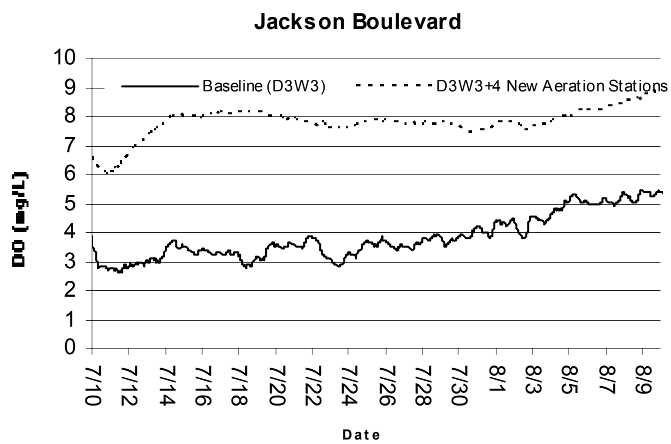


Figure 5.1 Dissolved Oxygen (DO) concentrations for the baseline (D3W3) and the new aeration stations simulations for July 10-August 10, 2002





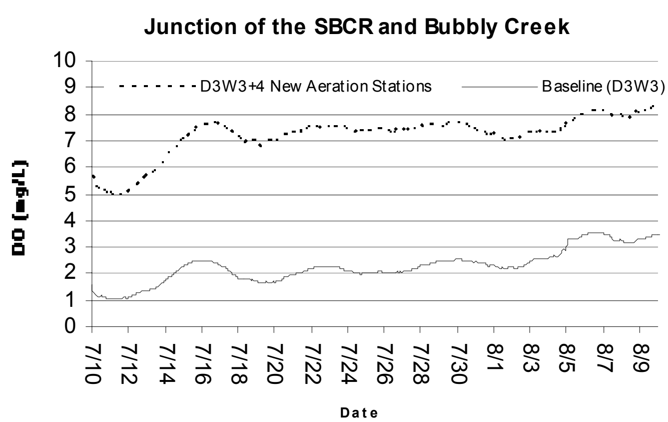


Figure 5.1 (continued) Dissolved Oxygen (DO) concentrations for the baseline (D3W3) and the new aeration stations simulations for July 10-August 10, 2002

5.1.2 July 12- November 9, 2001

For the Baseline (D3W3) and the New Aeration Stations (D3W3+NAS) simulations, the overall percentage compliance for 3, 4, 5, and 6 mg/L for different locations for July 12 - November 9, 2001 are listed in Tables 5.3-5.6.

Table 5.3 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline simulation for July 12-November 9, 2001

	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	Dry	wet	dry	wet
Addison Street	100	100	98.3	100	92.4	95.0	62.6	70.1
Fullerton Avenue	97.3	97.9	94.5	95.7	81.7	84.5	49.1	49.4
Division Street	100	97.4	96.7	97.0	83.6	93.1	62.5	71.0
Kinzie Street	100	99.6	96.7	97.0	75.5	85.0	60.9	67.0
Jackson Boulevard	99.5	96.2	85.9	89.3	69.5	81.9	57.6	57.3
SBCR and Bubbly Creek Junction	80.7	74.2	61.3	55.7	50.7	39.7	34.5	26.6

Table 5.4 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline simulation for July 12-November 9, 2001

	3 mg/L	4 mg/L	5 mg/L	6 mg/L
Addison Street	100	99.0	93.4	65.6
Fullerton Avenue	97.5	95.0	82.8	49.2
Division Street	99.0	96.8	87.4	65.9
Kinzie Street	99.8	96.8	79.3	63.3
Jackson Boulevard	98.2	87.2	74.4	57.5
SBCR and Bubbly Creek Junction	78.1	59.1	46.3	31.4

Table 5.5 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the '4 New Aeration Stations' simulations for July 12-November 9, 2001

	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	Wet	dry	wet
Addison Street	100	100	99.3	100	94.3	95.8	71.8	72.3
Fullerton Avenue	100	100	99.9	99.8	98.9	97.0	95.2	87.1
Division Street	100	100	100	100	100	100	100	97.0
Kinzie Street	100	100	100	100	100	100	100	96.6
Jackson Boulevard	100	100	100	100	100	96.9	100	94.8
SBCR and Bubbly Creek Junction	100	95.7	99.6	93.8	94.8	87.2	86.1	77.2

Table 5.6 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the '4 New Aeration Stations' simulations for July 12-November 9, 2001

	3 mg/L	4 mg/L	5 mg/L	6 mg/L
Addison Street	100	99.6	94.9	72.0
Fullerton Avenue	100	99.9	98.1	91.9
Division Street	100	100	100	98.8
Kinzie Street	100	100	100	98.7
Jackson Boulevard	100	100	98.8	97.9
SBCR and Bubbly Creek Junction	98.3	97.3	91.8	82.5

Tables 5.3 and 5.4 show that the best DO conditions for the baseline simulation occur at Addison Street and compliance with DO concentration targets gradually decrease at the downstream locations. The lowest compliance with DO concentration targets is observed at the Junction of Bubbly Creek and the SBCR for the period for July 12-November 9, 2001. The 5 mg/L target concentration is achieved 92.4 % and 95 % of the dry and wet weather periods, respectively, for the period of July 12-November 9, 2001 at Addison Street (Table 5.3). Even though 5 mg/L is attained 93.4 % of the time (dry + wet) at Addison Street, 5 mg/L is achieved just 46.3 % of the time (dry + wet) at the junction of the SBCR and Bubbly Creek.

Tables 5.5 and 5.6 show that the new aerations stations result in dramatic improvement in DO conditions as compared to the baseline simulation in Tables 5.3 and 5.4. DO concentrations are greater than 5 mg/L for 94.8 % of the dry periods for July 12-November 9, 2001 at the junction of the SBCR and Bubbly Creek (Table 5.5). At the junction of Bubbly Creek and the SBCR the percentage compliance with the 5 mg/L DO target concentration increased from 46.3 % for the baseline to 91.8 % for the new aeration stations simulations for July 12- November 9, 2001 (dry + wet) (Tables 5.4-5.6).

Since DO conditions get drastically better at the junction of the SBCR and Bubbly Creek, it is likely that DO would increase at locations downstream of the SBCR and Bubbly Creek with the addition of the new aeration stations.

5.1.3 May 1- September 23, 2002

For the Baseline (D3W3) and the New Aeration Stations (D3W3+NAS) simulations, the overall percentage compliance with 3, 4, 5, and 6 mg/L DO target concentrations for different locations for May 1- September 23, 2002 are listed in Tables 5.7-5.10.

Table 5.7 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline simulation for May 1-September 23, 2002

	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Addison Street	100	100	100	100	99.7	97.0	89.8	93.8
Fullerton Avenue	100	100	99	99.2	81.1	90.5	36.2	69.2
Division Street	100	100	100	99.3	78.6	94.4	35.7	75.4
Kinzie Street	100	98.4	97.0	96.2	53.5	82.2	29.6	69.2
Jackson Boulevard	97.5	88.8	61.3	80.8	49.1	76.7	30.2	63.3
SBCR and Bubbly Creek Junction	62.7	73.5	49.6	57.8	25.8	40.6	6.7	16.0

Table 5.8 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline simulation for May 1-September 23, 2002

	3 mg/L	4 mg/L	5 mg/L	6 mg/L
Addison Street	100	100	98.9	89.7
Fullerton Avenue	100	99.1	83.8	46.0
Division Street	100	99.8	83.3	47.5
Kinzie Street	99.5	96.7	61.9	41.3
Jackson Boulevard	94.9	67.1	57.2	40.0
SBCR and Bubbly Creek Junction	65.9	52.0	30.2	9.5

Table 5.9 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the '4 New Aeration Stations' simulations for May 1-September 23, 2002

	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Addison Street	100	100	100	100	100	97.2	95.2	94.6
Fullerton Avenue	100	100	100	99.8	100	96.2	98.5	91.2
Division Street	100	100	100	100	100	99.5	100	94.5
Kinzie Street	100	100	100	100	100	99.5	100	93.3
Jackson Boulevard	100	97.7	100	94.4	99.7	92.8	98.9	90.8
SBCR and Bubbly Creek Junction	100	94.2	100	88.8	99.2	83.2	96.4	75.9

Table 5.10 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the '4 New Aeration Stations' simulations for May 1-September 23, 2002

	3 mg/L	4 mg/L	5 mg/L	6 mg/L
Addison Street	100	100	99.2	93.8
Fullerton Avenue	100	99.9	98.9	96.4
Division Street	100	100	99.9	98.4
Kinzie Street	100	100	99.9	98.0
Jackson Boulevard	99.3	98.3	97.7	96.5
SBCR and Bubbly Creek Junction	98.3	96.7	94.5	90.3

Like the simulations for 2001, water quality conditions on the NBCR are better than water quality conditions on the SBCR for the baseline simulation (Tables 5.7 and 5.8). DO concentrations are greater than 5 mg/L 100 % of the time for the dry periods on the NBCR and 99 % of the time for the dry periods on the SBCR for the new aeration stations simulations (Table 5.9). At least 94% of the time (wet+dry) DO concentrations are greater than 5 mg/L at the all locations listed in Table 5.10.

5.2 Supplementary Aeration Stations Downstream from the Junction of Bubbly Creek and the South Branch Chicago River

In this section, an extension of the new aeration stations (NAS) given in Section 5.1 for the NSC, NBCR, and SBCR to the entire waterway system is evaluated. Throughout the text some abbreviations explained below will be used to explain the simulations.

NAS : New Aeration Stations

4NAS : 4 aerations stations located on the NBCR (2) and the SBCR (2)

6NAS : 6 aeration stations located on the NBCR (2), the SBCR (2), and the CSSC (2)

D3W3 : Devon Avenue and Webster Street in-stream aeration stations operating at full capacity (3 blowers each)

maxSEPA : The SEPA stations operating at maximum capacity

maxAeration : D3W3+maxSEPA, but no new aeration stations

Stickney=satDO : Stickney WRP effluent DO concentrations raised to saturation

The first simulation ("4NAS+maxAeration") considers the existing in-stream aeration stations and SEPA stations operating at full capacity (D3W3+maxSEPA), and the 4 proposed (in Section 5.1) new aeration stations (4NAS) located upstream from the junction of Bubbly Creek and the SBCR. This scenario was used as a reference ("4NAS+maxAeration") to locate and size the new aeration stations along the CSSC. The same procedure explained in the previous section that was applied to add new aeration stations on the SBCR and the NBCR was followed to locate and the size the proposed aeration stations along the CSSC. Alternatively, an additional simulation considering raising the DO concentration in the Stickney WRP effluent to saturation with the 4 proposed new aeration stations located on the SBCR and the NBCR, and the existing in-stream aeration and the SEPA stations operating at full capacity has been completed.

5.2.1 Determination of the Size and the Location of New Aeration Stations along The Chicago Sanitary and Ship Canal on the Basis of Simulations for July 10-August 10, 2002

In this exercise, the aim was to achieve 5 mg/L 100% of the time as much as possible between July 10 and August 10, 2002. Different DO loads were tried at the new aeration stations to keep the DO concentration above 5 mg/L along the CSSC. The system was examined starting from the junction of the SBCR and Bubbly Creek to downstream locations. 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 5 mg/L. This exercise was a trial and error practice and availability of space for construction of an aeration station was not taken into account during the simulations. For the reference (4NAS+maxAeration) simulation, the overall percentage compliance with the 4, 5, and 6 mg/L target DO concentrations for different locations for July 10 to August 10, 2002 are listed in Table 5.11.

Table 5.11 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations on the CSSC for the reference simulation ("4NAS+maxAeration") for July 10-August 10, 2002

Location	>4 mg/L	>5 mg/L	>6 mg/L
Cicero Avenue	100.0	91.1	84.8
Baltimore and Ohio Railroad	100.0	100.0	75.4
Route 83	100.0	81.8	9.8
River Mile 11.6	100.0	99.9	67.2
Romeoville	100.0	91.8	28.3

Even though the DO concentration is greater than 5 mg/L at Baltimore and Ohio Railroad 100% of the time, for the rest of the stations, 5 mg/L is not achieved 100% of the time between July 10 and August 10, 2002 (Table 5.11). The 4 mg/L target concentration is exceeded 100 % of the time along the CSSC. The simulation results also show that when the SEPA stations operate at the maximum capacity, the 5 mg/L target DO concentration is exceeded along the Calumet-Sag Channel and the Little Calumet River (North) (Figure 5.2).

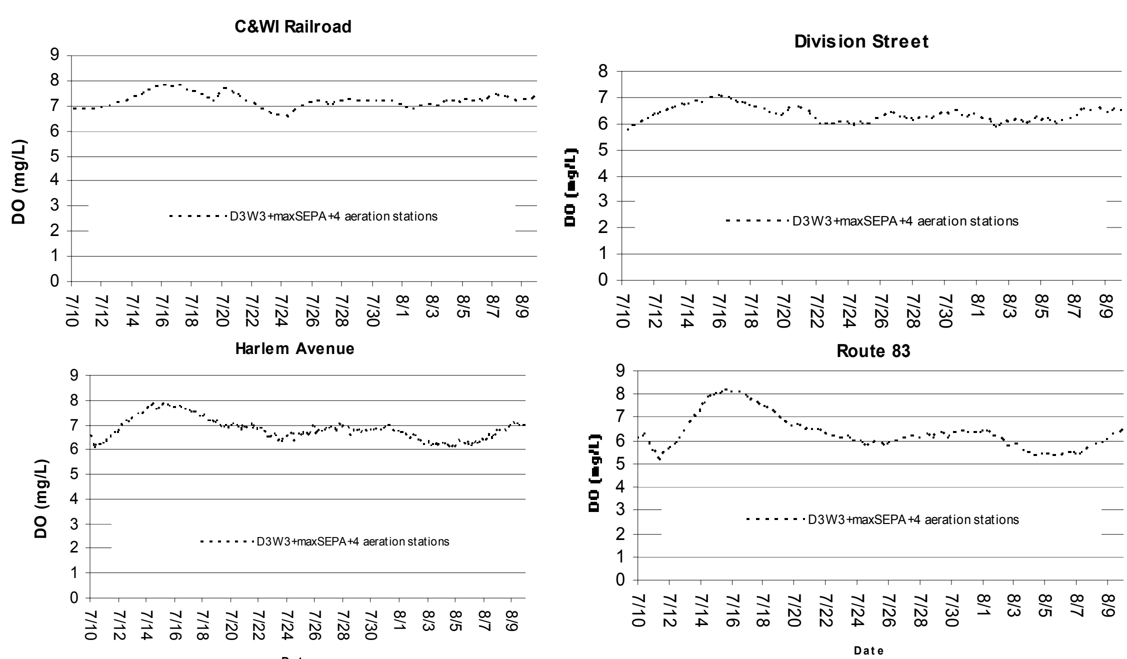


Figure 5.2 Dissolved oxygen (DO) concentrations along Little Calumet River (North) and Calumet-Sag Channel for the reference simulation ("4NAS+maxAeration") for July 10-August 10, 2002

The trial-error simulations indicated that 2 more new aeration stations located on the CSSC would be sufficient to keep DO concentrations above 5 mg/L at most of the locations in the study area between July 10 and August 10, 2002. Hence, a total of 6 new aeration stations distributed as 2 on the NBCR, 2 on the SBCR, and 2 on the CSSC and the in-stream aeration and the SEPA stations working at their maximum capacity could bring DO to 5 mg/L almost 100% of the time between July 10 to August 10, 2002. The locations and the DO loads of the 2 new stations on the CSSC are:

1* 0.75 miles upstream from Western Avenue (30 g/s)

2* Slightly upstream from Willow Springs Road (30 g/s)

The overall percentage compliance with the 4, 5, and 6 mg/L target DO concentrations for different locations for July 10 to August 9, 2002 are listed in Table 5.12. With the addition of the 2 new aeration stations, there are a total of 6 proposed new aeration stations on the CWS. From this point of the report, simulations with the 6 aeration stations will be referred to "6NAS+maxAeration". Plots of DO concentrations comparing the reference and the new aeration stations simulations are shown in Figure 5.3.

Table 5.12 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "6NAS+maxAeration" simulations for July 10-August 10, 2002

Location	>4.0 mg/L	>5.0 mg/L	>6.0 mg/L
Cicero Avenue	100.0	100.0	89.6
Baltimore and Ohio Railroad	100.0	100.0	88.5
Route 83	100.0	100.0	85.9
River Mile 11.6	100.0	100.0	94.7
Romeoville	100.0	98.7	81.5

Table 5.12 indicates that the addition of the 2 new aeration stations results in achieving 5 mg/L 100% of the time along the CSSC. The only exception is that 5 mg/L DO is exceeded 98.7% of the time at Romeoville, which is the downstream boundary of the modeled portion of the CWS.

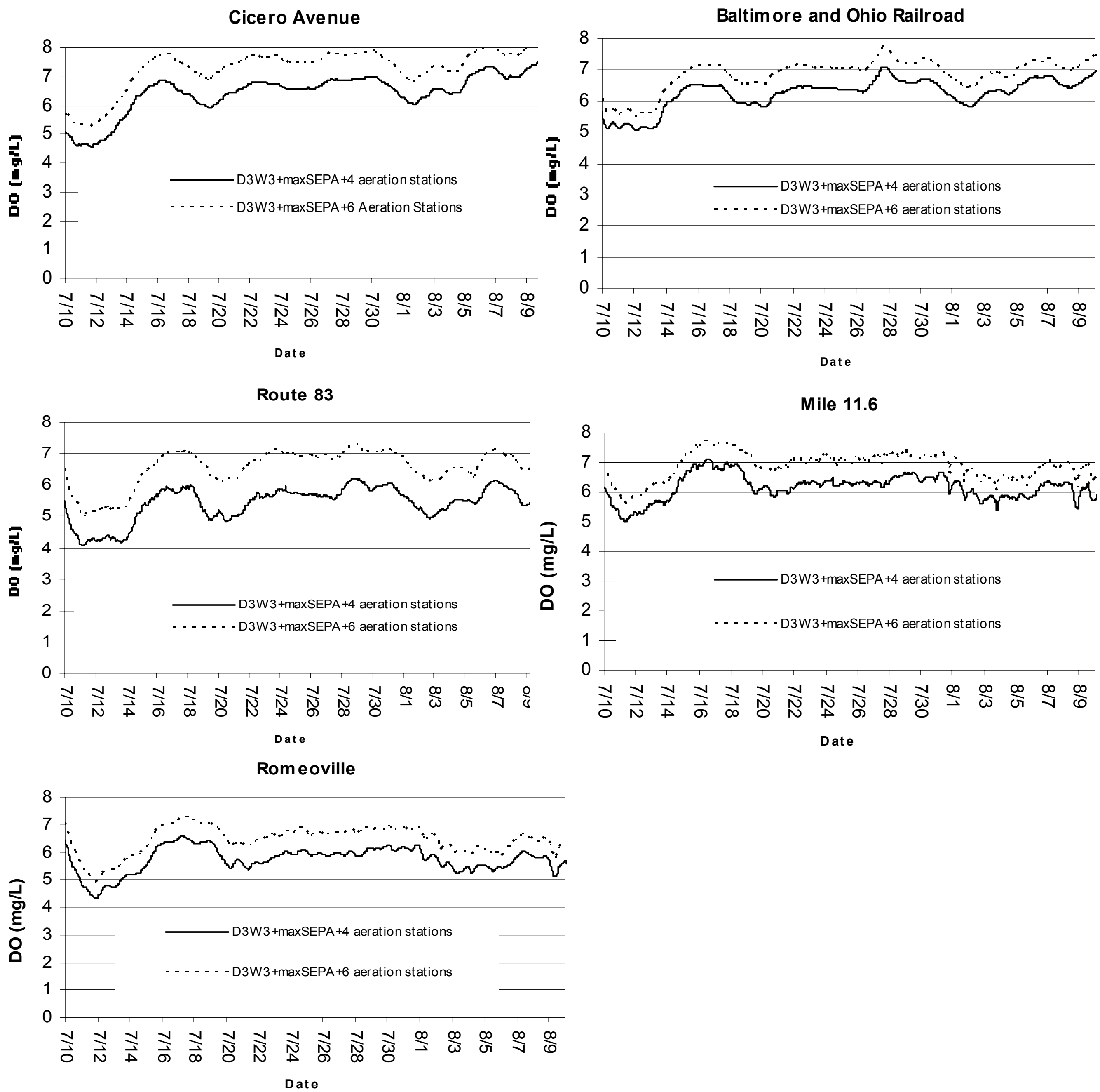


Figure 5.3 Dissolved oxygen (DO) concentrations for the “4NAS+maxAeration” and “6NAS+maxAeration” scenarios for July 10-August 10, 2002

5.2.2 July 12- November 9, 2001

For the Baseline ("maxAeration") and the New Aeration Stations ("6NAS+maxAeration") simulations, the overall percentage compliance with the 3, 4, 5, and 6 mg/L target DO concentrations for different locations for July 12 -November 9, 2001 are listed in Tables 5.13-5.16.

Table 5.13 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline ("maxAeration") simulation for July 12-November 9, 2001

Location	>3 mg/L		>4 mg/L		>5 mg/L		>6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Cicero Avenue	87.6	77.5	62.1	55.9	49.7	34.8	36.1	22.8
Baltimore and Ohio Railroad	97.9	97.7	86.1	82.6	63.0	52.3	38.1	28.0
Route 83	89.1	89.6	69.0	62.9	46.8	40.4	35.1	24.6
River Mile 11.6	99.8	97.2	91.9	88.9	74.7	58.1	49.5	33.4
Romeoville	97.0	93.9	79.1	82.0	60.2	50.5	36.1	29.6

Table 5.14 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline ("maxAeration") simulation for July 12-November 9, 2001

Location	>3 mg/L	>4 mg/L	>5 mg/L	>6 mg/L
Cicero Avenue	83.6	59.6	43.7	30.8
Baltimore and Ohio Railroad	97.8	84.7	58.7	34.1
Route 83	89.3	66.6	44.3	30.9
River Mile 11.6	98.8	90.7	68.1	43.1
Romeoville	95.8	80.3	56.4	33.5

Table 5.15 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "6NAS+maxAeration" simulation for July 12-November 9, 2001

	>3 mg/L		>4 mg/L		>5 mg/L		>6 mg/L	
Location	dry	wet	dry	wet	dry	wet	dry	wet
Cicero Avenue	100.0	95.9	99.8	94.4	94.1	85.2	87.2	73.8
Baltimore and Ohio Railroad	100.0	100.0	100.0	95.7	95.3	91.4	85.4	76.6
Route 83	100.0	97.6	97.2	93.4	86.4	85.2	77.5	70.8
River Mile 11.6	100.0	100.0	100.0	95.8	93.7	89.8	81.3	75.8
Romeoville	99.7	96.5	97.2	93.5	83.6	85.7	72.8	70.4

Table 5.16 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "6NAS+maxAeration" simulation for July 12-November 9, 2001

Location	>3 mg/L	>4 mg/L	>5 mg/L	>6 mg/L
Cicero Avenue	98.4	97.7	90.5	81.8
Baltimore and Ohio Railroad	100.0	98.3	93.8	81.9
Route 83	99.0	95.7	85.9	74.8
River Mile 11.6	100.0	98.3	92.2	79.1
Romeoville	98.4	95.7	84.4	71.9

Tables 5.13 and 5.14 indicate that the best DO conditions for the baseline simulation occur at River Mile 11.6. Since water quality conditions are better along the Calumet-Sag Channel, DO concentrations downstream from the CSSC and Calumet-Sag Channel junction are improved. The lowest percentage compliance with DO concentration targets is observed at Cicero Avenue for the period for July 12-November 9, 2001. The 5 mg/L target concentration is achieved only 43.7 to 68.1% of the time along the CSSC.

The results of the "6NAS+maxAeration" simulation are listed in Tables 5.15 and 5.16 for July 12-November 9, 2001. Tables 5.15 and 5.16 show that the new aeration stations result in a substantial improvement in DO conditions as compared to the baseline simulation ("maxAeration") listed in Tables 5.13 and 5.14. DO concentrations are greater than 5 mg/L for 94.1% of the dry periods for July 12-November 9, 2001 at Cicero Avenue (Table 5.15). At Romeoville the percentage compliance with the 5 mg/L target DO concentration increased from 56.4% for the baseline ("maxAertion") to 84.4% for the new aeration stations ("6NAS+maxAeration") simulation for July 12-November 9, 2001 (dry + wet) (Tables 5.14 and 5.16).

Simulation results considering raising the Stickney WRP effluent DO concentration to saturation are listed in Tables 5.17 and 5.18. Daily average temperature values were used to calculate saturation DO concentrations for the Stickney WRP effluent (Figure 5.4).

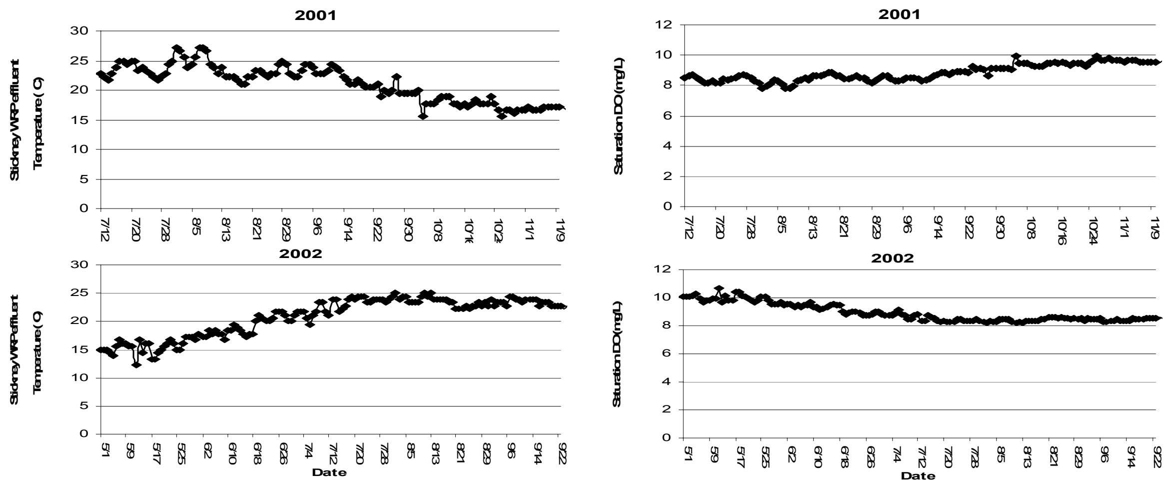


Figure 5.4 Stickney Water Reclamation Plant (WRP) effluent daily temperature and corresponding saturation dissolved oxygen (DO) concentration for July 12 to November 9, 2001 and May 1 to September 23, 2002

Table 5.17 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "Stickney=satDO+4NAS+maxAeration" simulation for July 12-November 9, 2001

	>3 mg/L		>4 mg/L		>5 mg/L		>6 mg/L	
Location	dry	wet	dry	wet	dry	wet	dry	wet
Cicero Avenue	100	95.7	99.5	94.1	92.5	83.9	84.9	69.9
Baltimore and Ohio Railroad	100	100	100	98.8	96.2	93.6	86.4	81.0
Route 83	100	97.3	93.9	91.5	81.4	84.6	68.5	68.8
River Mile 11.6	100	99.4	100.0	95.7	90.4	88.3	78.3	73.7
Romeoville	99.7	96.4	94.0	92.4	80.3	85.1	67.1	67.4

Table 5.18 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "Stickney=satDO+4NAS+maxAeration" simulation for July 12-November 9, 2001

Location	>3 mg/L	>4 mg/L	>5 mg/L	>6 mg/L
Cicero Avenue	98.3	97.3	89.1	78.9
Baltimore and Ohio Railroad	100.0	99.5	95.2	84.2
Route 83	98.9	92.9	82.7	68.6
River Mile 11.6	99.8	98.3	89.6	76.5
Romeoville	98.4	93.4	82.2	67.2

Even though improvement in DO is slightly lover than that obtained with the addition of 2 new aeration stations on the CSSC, the results are still impressive since the percentage compliances are very close to the values from the “6NAS+maxAeration” simulation. The 5 mg/L target DO concentration is exceeded 89.6% of the time for the “Stickney=satDO+4NAS+maxAeration” simulation for the period of July 12-November 9, 2001 at River Mile 11.6 (Table 5.18). For the same period and simulation, the 5 mg/L target concentration is exceeded 80.3% and 85.1% of the time during dry and wet weather periods, respectively, at Romeoville.

5.2.3 May 1- September 23, 2002

For the Baseline (“maxAeration”) and the new aeration stations (“6NAS+maxAeration”) simulations, the overall percentage compliance with the 3, 4, 5, and 6 mg/L target DO concentrations for different locations for May 1-September 23, 2002 are listed in Tables 5.19 and 5.20.

Table 5.19 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline (“maxAeration”) simulation for May 1-September 23, 2002

	>3 mg/L		>4 mg/L		>5 mg/L		>6 mg/L	
Location	dry	wet	Dry	wet	dry	wet	dry	wet
Cicero Avenue	70.7	79.7	55.7	61.2	31.7	45.6	7.5	10.7
Baltimore and Ohio Railroad	98.9	93.5	66.3	71.8	41.3	54.9	12.1	33.1
Route 83	85.6	83.3	57.7	64.6	36.6	51.6	8.0	21.2
River Mile 11.6	100.0	97.7	99.5	86.2	66.3	71.7	35.2	51.1
Romeoville	100.0	93.8	92.5	80.4	54.6	64.4	25.2	39.7

Table 5.20 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the baseline ("maxAeration") simulation for May 1-September 23, 2002

Location	>3 mg/L	>4 mg/L	>5 mg/L	>6 mg/L
Cicero Avenue	73.3	57.3	35.8	8.4
Baltimore and Ohio Railroad	97.3	67.9	45.3	18.3
Route 83	84.9	59.8	41.0	11.9
River Mile 11.6	99.3	95.6	67.9	39.9
Romeoville	98.2	88.9	57.5	29.5

Table 5.21 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "6NAS+D3W3+maxSEPA" simulation for May 1-September 23, 2002

Location	>3 mg/L		>4 mg/L		>5 mg/L		>6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Cicero Avenue	100.0	93.5	100.0	90.3	100.0	84.1	97.6	73.7
Baltimore and Ohio Railroad	100.0	97.3	100.0	92.9	98.3	85.9	95.2	75.8
Route 83	100.0	92.4	100.0	88.7	100.0	83.8	96.5	75.3
River Mile 11.6	100.0	100.0	100.0	94.0	100.0	87.3	99.4	80.1
Romeoville	100.0	97.5	100.0	91.3	99.8	82.4	95.6	75.2

Table 5.22 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "6NAS+maxAeration" simulation for May 1-September 23, 2002

6NAS+maxAeration	>3 mg/L	>4 mg/L	>5 mg/L	>6 mg/L
Cicero Avenue	98.1	97.1	95.3	90.5
Baltimore and Ohio Railroad	99.2	97.9	94.6	89.5
Route 83	97.8	96.6	95.2	90.2
River Mile 11.6	100.0	98.2	96.2	93.7
Romeoville	99.3	97.4	94.7	89.5

Like the simulations for 2001, water quality conditions were improved drastically by the addition of the new aeration stations (Tables 5.19-5.22). DO concentrations are greater than 5 mg/L 100 % of the time during dry weather flow at 3 locations on the CSSC. The results of simulations considering raising DO concentration of the Stickney WRP effluent to saturation are listed in Tables 5.23 and 5.24. One of the outcomes of the simulations is that raising the Stickney WRP effluent DO concentration to saturation is as effective as adding 2 new aeration stations on the CSSC. It is obvious that an economic analysis would be a necessary tool to compare these two different management alternatives.

Table 5.23 The percentage of time (dry vs. wet weather periods) that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "Stickney=satDO+4NAS+maxAeration" simulation for May 1-September 23, 2002

	>3 mg/L		>4 mg/L		>5 mg/L		>6 mg/L	
Location	dry	wet	dry	wet	dry	wet	dry	wet
Cicero Avenue	100.0	93.1	100.0	90.8	100.0	85.1	98.1	72.9
Baltimore and Ohio Railroad	100.0	97.8	100.0	93.7	98.3	87.1	95.5	74.9
Route 83	100.0	92.3	100.0	88.1	96.6	79.5	78.7	73.4
River Mile 11.6	100.0	100.0	100.0	94.0	100.0	86.6	98.3	78.2
Romeoville	100.0	97.0	100.0	89.1	99.7	81.2	84.9	72.9

Table 5.24 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at different locations for the "Stickney=satDO+4NAS+maxAeration" simulation for May 1-September 23, 2002

Location	>3 mg/L	>4 mg/L	>5 mg/L	>6 mg/L
Cicero Avenue	98.0	97.3	95.6	90.6
Baltimore and Ohio Railroad	99.3	98.1	95.0	89.4
Route 83	97.7	96.5	91.6	77.1
River Mile 11.6	100.0	98.2	96.0	92.3
Romeoville	99.1	96.8	94.2	81.4

Chapter 6 - POLLUTANT REMOVAL AT COMBINED SEWER OVERFLOWS

There are nearly 200 CSOs in the modeled portion of the CWS drainage area and in the DUFLOW water-quality model, 28 CSO locations were used to represent the whole system of CSOs. In addition to gravity flow CSO locations, there are 3 CSO pumping stations. Four different $CBOD_5$ and ammonia treatment removal levels (30%, 60%, 90%, and 100%) were applied to all 28 gravity flow (i.e. nonpump) CSO sites. In addition to these simulations, a simulation with increased DO concentration in conjunction with 100% $CBOD_5$ and ammonia removal at gravity flow CSOs has also been completed. Throughout the text this last simulation is referred to 100% treatment with raised DO. The MWRDGC measured DO concentrations as well as temperature values for certain storms at the North Branch and 125th Street Pumping Stations in 2001. According to measured data, temperatures at the pumping stations varied from 20 to 25°C, and the average temperature was around 23°C. Hence, the saturation DO concentration of 8.5 mg/L at 23° C was used for the 100% treatment with raised DO simulation.

Water-quality parameters were measured by the MWRDGC at the North Branch and 125th Street Pump Stations for selected storms in 2001. Event mean concentrations of $CBOD_5$, ammonia, and DO for the pumping stations listed in Tables 6.1-6.3 were used in the model. When there were no measured data for a storm in 2001, the average of all 2001 event mean concentrations for the given pumping station were assigned to this storm. Since there are no measured data for the Racine Avenue Pumping Station for 2001, concentrations that were determined by regression based on discharge and event mean concentration at the North Branch Pumping Station and Racine Avenue Pumping Station were used in the model. Estimation of Racine Avenue Pumping Station event mean concentrations is discussed in detailed in Section 3.2.5. The North Branch Pumping Station water-quality parameters were used for NSC and NBCR CSOs, the Racine Avenue Pumping Station water-quality parameters were used for the Chicago River Main Stem and SBCR CSOs, and the Calumet-Sag Channel and Little Calumet River CSO water-quality parameters were determined using concentrations measured at the 125th Street Pumping Station. The reasonableness of this approach was discussed in detail in Neugebauer and Melching (2005). For the simulation period in 2002, none of the pumping stations was sampled. Therefore, average values from all available historic event mean concentration data were used.

Table 6.1 Event Mean Concentrations of Carbonaceous Biochemical Oxygen Demand ($CBOD_5$), Ammonia (NH_4-N), and Dissolved Oxygen (DO) at the North Branch Pumping Station used in the simulations

Date	$CBOD_5$ (mg/L)	NH_4-N (mg/L)	DO (mg/L)
2001-07-25	35.6	2.7	4.0
2001-08-02	27.3	1.8	5.8
2001-08-09	71.4	3.2	2.4
2001-08-25	35.6	2.7	4.0
2001-08-30	35.6	2.7	4.0
2001-09-19	14.9	2.4	4.2
2001-09-20	20.8	1.8	2.6
2001-09-23	42.3	5.8	4.0
2001-10-04	35.6	2.7	4.0
2001-10-12	35.6	2.7	4.0
2001-10-13	30.2	1.8	4.0
2001-10-23	42.4	2.2	6.7
2001-10-24	35.6	2.7	6.7
2002	35.4	2.9	3.5

Table 6.2 Event Mean Concentrations of Carbonaceous Biochemical Oxygen Demand ($CBOD_5$), Ammonia (NH_4-N), and Dissolved Oxygen (DO) at the Racine Avenue Pumping Station used in the simulations

Date	$CBOD_5$ (mg/L)	NH_4-N (mg/L)	DO (mg/L)
2001-07-23	59.5	1.9	5.3
2001-07-25	45.8	1.3	6.8
2001-08-02	39.3	1.1	7.8
2001-08-07	87.5	3.4	3.6
2001-08-09	92.6	3.7	3.4
2001-08-25	53.0	1.6	5.9
2001-08-31	59.4	1.9	5.3
2001-09-19	55.2	1.7	5.6
2001-09-20	50.1	1.5	6.2
2001-09-23	58.3	1.9	5.4
2001-10-04	49.6	1.5	6.3
2001-10-12	60.6	2.0	5.2
2001-10-13	33.2	0.8	9.0
2001-10-23	50.9	1.5	6.1
2001-10-24	50.9	1.5	6.1
2002	52.1	2.9	2.6

Table 6.3 Event Mean Concentrations of Carbonaceous Biochemical Oxygen Demand ($CBOD_5$), Ammonia (NH_4-N), and Dissolved Oxygen (DO) at the 125th Street Pumping Station used in the simulations

Date	$CBOD_5$ (mg/L)	NH_4-N (mg/L)	DO (mg/L)
2001-07-25	25.9	0.9	4.3
2001-08-02	24.4	1.2	4.3
2001-08-25	12.6	0.9	4.3
2001-08-30	25.9	0.9	4.3
2001-09-19	25.9	0.9	4.3
2001-09-20	25.9	0.9	4.3
2001-09-23	25.9	0.9	4.3
2001-10-04	25.9	0.9	4.3
2001-10-13	8.4	0.3	4.3
2001-10-23	25.9	0.9	4.3
2001-10-24	25.9	0.9	4.3
2002	25.7	1.0	4.8

6.1 Results of Simulations for the Pollutant Removal at Combined Sewer Overflows - July 12 – November 9, 2001

The percentage of time that target DO concentrations of 4, 5, and 6 mg/L are equaled or exceeded for the period of July 12 – November 9, 2001 are listed in Tables 6.4-6.6 for the NSC DO monitoring station locations: Linden Street, Simpson Street and Main Street, respectively. Since upper NSC flows upstream from NSWRP are mainly dominated by CSO flows, the effect of CSO treatment is obvious at the upper NSC locations. Even though pollutant removal at CSOs improves the water quality conditions, DO concentrations do not get higher than 5 mg/L even 60 % of the time during wet weather periods along the upper NSC. The DO criterion of 5 mg/L could be met 57.1 and 39.7 % of the time for wet and dry weather periods, respectively, at Main Street after 100 % removal of $CBOD_5$ and ammonia with the DO concentration raised to 8.5 mg/L. This indicates that the poor quality of the stagnant water in the upper NSC prior to a storm and high sediment oxygen demand in the upper NSC cannot be easily counteracted.

Table 6.4 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Linden Street on the North Shore Channel for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

–	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	76.7	32.3	71.9	24.4	61.7	17.4
30%	78.0	35.3	73.1	25.9	63.9	19.4
60%	79.4	39.5	74.5	28.6	65.7	20.7
90%	80.3	48.7	76.3	32.4	68.4	23.9
100%	80.6	51.4	76.6	35.0	69.5	25.2
100%+DO=8.5 mg/L	80.8	62.3	76.8	49.4	70.1	31.3

Table 6.5 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Simpson Street on the North Shore Channel for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	49.9	17.3	36.8	12.3	26.0	6.1
30%	57.0	17.7	38.6	14.0	34.0	7.1
60%	66.7	21.4	44.8	15.3	35.2	7.6
90%	70.7	30.4	60.8	20.6	37.5	8.3
100%	72.1	39.2	64.0	23.0	39.0	8.4
100%+DO=8.5 mg/L	73.6	64.8	64.9	52.9	39.3	26.6

Table 6.6 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Main Street on the North Shore Channel for July 12 – November 9, 2001 for different pollutant removal levels for the combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	Wet
Baseline	35.7	15.5	19.6	6.3	9.2	0.0
30%	36.5	16.6	30.1	8.4	12.2	0.0
60%	47.1	22.7	32.2	9.2	21.4	0.0
90%	68.9	43.5	34.5	11.7	26.8	2.1
100%	77.1	59.0	38.0	16.2	28.0	2.2
100%+DO=8.5 mg/L	80.6	78.2	39.7	57.1	28.2	27.4

The overall percentage compliance with the target 4, 5, and 6 mg/L DO concentrations resulting from different pollutant removal levels are listed in Tables 6.7 and 6.8 for the period of July 12 – November 9, 2001 for Addison Street and Kinzie Street on the NBCR. The Addison Street DO monitoring station is the first location downstream from the junction of the NBCR and the NSC. The flow at Addison Street is dominated by the NSWRP, North Branch Pumping Station, and the upper NBCR. Hence, the effect of pollutant removal at CSOs is not as significant as was observed along the upper NSC. It can be seen that the 100% treatment with raised DO results in attainment of DO concentrations in excess of 5 mg/L at Addison Street during dry and wet weather 88.7

and 94.4 % of the time, respectively, which are less than 10 percentage point improvements over the baseline conditions. At Kinzie Street the percentage compliance with the 5 mg/L DO target concentration increased from 63.1 % and 71.4 % for dry and wet periods, respectively, during calibration (baseline) to 71.1% and 87.2% for dry and wet periods, respectively, for 100 % treatment with raised DO. Even 100 % treatment with raised DO does not result in DO concentrations greater than 4 mg/L at all times during dry and wet weather flows at Kinzie Street.

Table 6.7 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Addison Street on the North Branch Chicago River for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	Wet
Baseline	97.5	99.7	79.4	87.3	28.2	42.4
30%	98.0	100.0	83.1	90.0	32.5	47.3
60%	98.3	100.0	86.3	92.7	36.6	53.1
90%	98.7	100.0	87.8	93.5	39.1	56.4
100%	98.8	100.0	88.6	93.7	40.0	57.6
100%+DO=8.5 mg/L	98.8	100.0	88.7	94.4	40.2	65.0

Table 6.8 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Kinzie Street on the North Branch Chicago River for July 12 – November 9, 2001 for different pollutant removal levels for the combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	Dry	wet
Baseline	78.8	87.2	63.1	71.4	35.7	37.2
30%	82.0	93.4	65.8	77.3	37.1	42.8
60%	83.9	93.5	69.3	83.4	40.3	50.6
90%	85.4	93.6	71.0	86.2	46.1	61.0
100%	86.2	93.8	71.3	86.6	48.2	63.3
100%+DO=8.5 mg/L	84.9	93.8	71.1	87.2	47.5	67.4

The percentage of hours that target DO concentrations of 4, 5, and 6 mg/L are equaled or exceeded for the period of July 12 – November 9, 2001 are listed in Tables 6.9-6.11 for Jackson Boulevard (SBCR) and Cicero Avenue and Route 83 on the CSSC. The 4 mg/L target concentration is attained 92.6 % of the time during wet weather periods at Jackson Boulevard for 60% treatment. Even though 100% treatment with raised DO significantly improves DO concentrations along the CSSC, the 5 mg/L target concentration is still not achieved more than 53% of the time at Route 83.

Table 6.9 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Jackson Boulevard on the South Branch Chicago River for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	Dry	wet
Baseline	78.1	85.6	63.3	70.7	41.8	35.8
30%	80.3	88.5	64.3	74.6	44.0	40.1
60%	83.1	92.6	65.5	77.3	46.7	50.3
90%	85.7	95.7	67.2	80.7	50.1	58.5
100%	86.6	95.8	68.6	82.2	50.9	61.7
100%+DO=8.5 mg/L	85.9	95.4	68.7	83.3	49.3	66.7

Table 6.10 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Cicero Avenue on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	Dry	wet
Baseline	58.7	40.0	43.6	28.9	27.7	19.4
30%	60.9	46.6	45.1	30.7	28.7	20.5
60%	62.0	54.0	45.6	33.1	29.5	21.5
90%	65.3	67.0	49.6	36.0	30.1	23.2
100%	66.1	69.4	50.9	37.3	30.4	24.3
100%+DO=8.5 mg/L	66.4	70.9	50.4	43.5	30.5	26.0

Table 6.11 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Route 83 on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	Wet
Baseline	63.0	56.7	42.1	29.7	24.0	20.4
30%	64.6	62.5	44.1	35.2	25.4	21.3
60%	66.7	70.7	47.9	40.8	25.7	22.3
90%	69.7	77.2	51.4	45.8	26.0	26.3
100%	71.3	79.0	52.5	48.8	26.1	27.3
100%+DO=8.5 mg/L	72.0	80.7	52.8	52.1	26.2	32.2

Romeoville is the downstream boundary of the modeled part of the Chicago Waterway System. Hence, it is possible to observe the effect of pollutant removal at all 28 CSOs at this location. Percentage compliances with target DO concentrations at Romeoville for July 12 – November 9, 2001 for different pollutant removal levels are listed in Table 6.12. The percentage compliance with the 5 mg/L DO target concentration increased from 42.5 and 33.4 % for dry and wet periods, respectively, during calibration (baseline) to 54.8 and 55.3% for dry and wet periods, respectively, for 100 % treatment with raised DO (Table 6.12).

Table 6.12 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Romeoville on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	63.9	60.9	42.5	33.4	28.5	20.8
30%	66.0	67.0	47.5	35.5	29.5	20.7
60%	68.6	72.5	50.9	41.7	29.5	22.8
90%	70.0	82.4	53.5	49.4	29.9	24.8
100%	70.6	85.8	54.5	51.1	30.1	26.1
100%+DO=8.5 mg/L	70.8	88.0	54.8	55.3	30.3	29.1

In general water quality conditions along Little Calumet River (North) and Calumet-Sag Channel are better than those for the NBCR, SBCR, and CSSC. Hence, the effect of CSO treatment is not large especially along Little Calumet River (North) (Tables 6.13-6.14). The other reason why CSO treatment did not result in significant DO improvement is that there are just 4 CSOs in the DUFLOW model on Little Calumet River (North). The 5 mg/L DO target concentration is met or exceeded 80.7% of the time during wet weather periods at Halsted Street for 100% treatment with raised DO.

Table 6.13 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at the Central and Wisconsin Railroad on the Little Calumet River (North) for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	Dry	wet	dry	wet	Dry	wet
Baseline	100.0	100.0	100.0	96.6	89.4	68.4
30%	100.0	100.0	100.0	100.0	91.1	72.3
60%	100.0	100.0	100.0	100.0	91.7	74.3
90%	100.0	100.0	100.0	100.0	92.0	75.2
100%	100.0	100.0	100.0	100.0	92.1	75.4
100%+DO=8.5 mg/L	100.0	100.0	100.0	100.0	92.1	84.1

Table 6.14 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Halsted Street on the Little Calumet River (North) for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	96.8	90.0	84.7	67.4	47.7	25.6
30%	99.7	93.5	87.2	72.7	51.4	33.9
60%	100.0	95.3	88.5	74.8	52.0	36.5
90%	100.0	96.4	89.0	77.4	52.9	37.8
100%	100.0	96.8	89.5	78.1	53.0	37.8
100%+DO=8.5 mg/L	100.0	97.9	89.5	80.7	53.0	40.6

As expected, the effect of CSO treatment becomes more noticeable closer to the Calumet-Sag Channel and CSSC junction (Tables 6.15-6.17). Even though an improvement of 21.7 percentage points for 5 mg/L target concentration can be achieved by 100% CSO treatment with raised DO for wet weather periods at Route 83 on Calumet-Sag Channel, the 5 mg/L target concentration is attained just 74.1% of the time during wet weather periods.

Table 6.15 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Division Street on the Calumet-Sag Channel for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	95.5	95.4	85.8	69.3	49.7	34.8
30%	99.7	97.2	87.2	74.4	52.5	37.8
60%	100.0	98.4	87.8	76.6	52.9	40.9
90%	100.0	99.2	88.2	79.3	53.2	44.4
100%	100.0	99.5	88.4	80.2	53.3	45.2
100%+DO=8.5 mg/L	100.0	100.0	88.4	83.2	53.3	51.6

Table 6.16 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Cicero Avenue on the Calumet-Sag Channel for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	93.6	92.5	82.8	61.1	49.1	35.1
30%	97.8	93.4	81.9	65.5	53.2	37.0
60%	98.4	95.1	82.8	68.7	54.7	37.8
90%	99.3	97.6	83.6	69.8	55.4	39.7
100%	99.6	97.9	84.0	70.1	55.7	39.9
100%+DO=8.5 mg/L	99.7	98.8	84.0	74.9	55.7	52.3

Table 6.17 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Route 83 on the Calumet-Sag Channel for July 12 – November 9, 2001 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	82.1	78.8	73.4	52.4	55.3	33.1
30%	82.8	87.3	73.9	56.4	59.7	31.6
60%	83.2	89.2	74.3	61.7	61.3	34.7
90%	85.5	91.8	74.6	69.0	63.6	38.8
100%	85.8	92.5	74.7	69.6	63.9	39.6
100%+DO=8.5 mg/L	86.1	94.1	74.7	74.1	64.0	44.1

In general, the results show that pollutant removal at CSOs improves DO to a certain degree, but it still was not enough to bring DO concentrations equal to or higher than 5 mg/L for 90% of the time during wet weather periods at most locations on the CWS. As can be seen in Table 6.18, daily average discharges from gravity flow CSOs can reach significant amounts during storms. For most storms the total discharge coming from gravity flow CSOs is higher than the total discharge from the 3 pumping stations. Since all CSOs are distributed along the CWS, their effect is diminished. Whereas pumping stations result in more stress on DO in the CWS since a huge amount of un-treated water with a high pollution load is discharged into the river system in a short period of time at a certain location. For example, on August 2, 2001, the Racine Avenue Pumping Station discharge is greater than both the NSWRP and Calumet WRP discharges. In addition, during the August 2, 2001 storm, the total amount of discharge from the pumping stations (44.8 m^3/s) is almost as great as the Stickney WRP discharge (48.3 m^3/s). The $CBOD_5$ and ammonia concentrations (39.3 mg/L; 1.1 mg/L, respectively) from the Racine Avenue Pumping Station are 6.6 and 2.4 times, respectively, higher than Stickney WRP $CBOD_5$ and ammonia concentrations (6 mg/L; 0.465 mg/L, respectively). Since the NSC flow is mostly dominated by the CSOs, pollutant removal at CSOs is most effective along the NSC.

Table 6.18 Daily average discharges (m^3/s) from Combined Sewer Overflows (CSOs), Pumping Stations, Water Reclamation Plants (WRPs) and at Romeoville during major storms in 2001.

Date-2001	7-25	8-2	8-25	8-31	9-19	9-21	9-23	10-5	10-14	10-23
Discharge (m^3/s)										
Romeoville	196.6	472	242.8	213.9	208.5	195.4	180.4	187	431.5	183.7
Stickney WRP	61.0	48.3	51.4	52.2	48.6	52.1	49.2	46.2	63.1	44.4
North Side WRP	19.4	17.0	17.7	22.1	20.9	21.7	19.8	18.3	21.9	21.7
Calumet WRP	18.4	16.1	15.8	14.3	10.6	15.8	11.2	10.6	19.5	10.3
Total gravity flow CSO	25.7	137.4	71.2	29.5	44	35.8	33.9	27.3	148.4	13.6
Total-Pumping Station	28.9	44.8	31.8	25	21.2	23.8	13.1	19.5	44.8	13.1
North Branch P.S	4.3	11.7	7.8	13.7	7.9	7.1	1.4	3.2	10.5	6.4
Racine Avenue P.S	20.5	27.2	14.5	11.2	13.3	16.6	11.6	16.3	22.4	6.7
125th Street P.S	4.2	5.8	9.4	0	0	0	0	0	11.8	0

Throughout the CWS simulations wet weather has been defined as extended periods when flow at Romeoville exceeds 100 m^3/s (3,530 cfs). Simulation results listed in Tables 6.4-6.17 show that pollutant removal at CSOs affects percentage compliances for both wet and dry weather. According to the results the Calumet-Sag Channel and Little Calumet River (North) locations are less affected than the CSSC locations by the discharge based wet-dry weather definition. This outcome suggests that effects of CSOs on the CWS can still be observed after the flows at Romeoville go back to dry weather flows.

6.2 Results of Simulations for the Pollutant Removal at Combined Sewer Overflows - May 1 – September 23, 2002

In this section, simulation results for the May 1-September 23, 2002 period are briefly presented. Like the 2001 simulation, pollutant removal at CSOs has a significant effect along the upper NSC. The DO concentration is greater than 5 mg/L for 40.5% of the time during wet weather periods for the baseline simulation, this percentage increases to 79.4% for 100% treatment with raised DO at Main Street (Table 19). Since a DO concentration of 3.48 mg/L is used for all NSC CSOs, a 5 mg/L increase in DO resulted in a big jump between 100% pollutant removal and 100% treatment (pollutant removal) with raised DO.

Table 6.19 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Main Street on the North Shore Channel for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	77.4	52.7	66.7	40.5	49.8	30.2
30%	78.3	54.7	69.4	43.9	55.0	35.0
60%	82.3	57.2	72.0	46.9	57.6	39.1
90%	90.4	64.5	73.9	50.3	61.3	43.8
100%	94.7	82.2	76.8	52.9	62.4	44.7
100%+DO=8.5 mg/L	94.9	94.3	78.7	79.4	62.4	62.0

In general 2002 water quality conditions are better than those for 2001. 2002 was a relatively dry year compared to 2001 and there were less storms and the storms had shorter durations in 2002 which resulted in less stress on the DO concentrations in the CWS. Although it is not possible to achieve the 5 mg/L target DO concentration 90% of the time during wet weather periods in 2001 at Kinzie Street, 5 mg/L is achieved 91.5%

of the time during wet weather periods for 100% CSO treatment in 2002 at Kinzie Street (Table 6.20).

Table 6.20 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Kinzie Street on the North Branch Chicago River for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	77.5	91.2	41.7	77.6	19.1	55.7
30%	95.4	96.8	46.1	81.6	18.5	52.5
60%	98.3	99.7	51.1	82.7	20.8	55.9
90%	99.0	99.7	57.4	88.7	22.6	61.9
100%	99.1	99.7	59.4	91.5	23.1	64.1
100%+DO=8.5 mg/L	99.1	100.0	59.8	95.4	23.1	69.5

The overall percentage compliance with the 4, 5, and 6 mg/L target DO concentrations resulting from different pollutant removal levels are listed in Tables 6.21-6.23 for the period of May 1 – September 23, 2002 for Jackson Boulevard (SBCR), Route 83 (CSSC), and Romeoville (CSSC). It is possible to see the positive effect of pollutant removal from CSOs along the CSSC down to Romeoville. Providing 100% $CBOD_5$ and ammonia removal from CSOs with raised DO can improve compliance with the 5 mg/L target concentration during wet weather periods by 16.3 percentage points at Romeoville (Table 6.23). Even with a 16.3 percentage point improvement in compliance with the 5 mg/L target DO concentration, complete pollutant removal from CSOs is not sufficient to bring DO concentrations to 5 mg/L or higher 90% of the time during wet weather periods along the CSSC.

Table 6.21 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Jackson Boulevard on the South Branch Chicago River for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	56.8	80.8	43.2	68.7	19.3	46.5
30%	60.7	81.3	45.5	69.1	18.1	46.5
60%	63.6	82.6	47.0	71.6	18.8	48.0
90%	67.8	85.9	49.9	76.7	19.5	51.0
100%	69.1	87.5	50.5	77.3	19.7	52.0
100%+DO=8.5 mg/L	69.2	91.3	50.6	80.0	19.7	54.7

Table 6.22 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Route 83 on the Chicago Sanitary and Ship Canal for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	54.1	63.7	30.1	50.2	4.8	17.4
30%	54.5	65.1	28.6	54.2	4.5	15.7
60%	55.4	68.3	30.8	57.8	5.1	19.0
90%	56.3	70.9	32.2	61.9	6.1	26.2
100%	56.9	71.6	32.6	62.4	6.3	28.4
100%+DO=8.5 mg/L	57.2	76.4	32.8	68.7	6.5	36.5

Table 6.23 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Romeoville on the Chicago Sanitary and Ship Canal for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	63.5	73.0	36.3	54.9	13.9	27.0
30%	62.4	73.1	36.0	57.5	13.0	22.9
60%	63.0	75.6	37.6	62.1	15.0	27.5
90%	63.3	79.4	38.2	65.8	15.5	32.2
100%	63.7	79.9	38.5	67.2	15.8	34.6
100%+DO=8.5 mg/L	63.8	80.9	38.8	71.2	15.9	42.5

Simulation results for pollutant removal at CSOs are listed in Tables 6.24-6.26 for Division Street, Harlem Avenue, and Route 83 on the Calumet-Sag Channel. The 5 mg/L DO target concentration is achieved 99.1% of the time during wet weather periods even for the baseline simulation at Division Street (Table 6.24). Even just 30% $CBOD_5$ and ammonia removal at CSOs is sufficient to bring DO concentrations to 5 mg/L for 92.2% of the time during wet weather periods at Harlem Avenue (Table 6.25), and 100% removal of $CBOD_5$ and ammonia at CSOs with raised DO is necessary to obtain 5 mg/L for 89.2% of the time during wet weather periods at Route 83 (Table 6.26).

Table 6.24 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Division Street on the Calumet-Sag Channel for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

–	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	100.0	100.0	100.0	99.1	67.3	84.0
30%	100.0	100.0	100.0	100.0	66.7	78.3
60%	100.0	100.0	100.0	100.0	67.8	79.2
90%	100.0	100.0	100.0	100.0	68.1	82.2
100%	100.0	100.0	100.0	100.0	68.2	84.7
100%+DO=8.5 mg/L	100.0	100.0	100.0	100.0	68.2	92.6

Table 6.25 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Harlem Avenue on the Calumet-Sag Channel for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	100.0	95.7	92.4	87.8	57.9	72.8
30%	100.0	100.0	99.7	92.2	51.9	65.4
60%	100.0	100.0	99.8	96.2	53.2	65.7
90%	100.0	100.0	99.9	98.4	55.0	66.2
100%	100.0	100.0	99.8	98.4	55.3	66.8
100%+DO=8.5 mg/L	100.0	100.0	99.9	98.4	55.4	74.4

Table 6.26 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Route 83 on the Calumet-Sag Channel for May 1 – September 23, 2002 for different pollutant removal levels for the gravity flow combined sewer overflows.

–	4 mg/L		5 mg/L		6 mg/L	
Scenario	dry	wet	dry	wet	dry	wet
Baseline	99.5	85.9	72.8	75.0	40.3	56.6
30%	100.0	86.3	80.2	73.8	32.4	53.9
60%	100.0	89.3	81.5	77.0	32.4	55.9
90%	100.0	95.7	82.3	79.0	32.6	57.9
100%	100.0	95.7	82.2	80.2	32.7	58.1
100%+DO=8.5 mg/L	100.0	95.7	82.6	89.2	32.8	60.6

The simulations done here have shown that 100% removal of $CBOD_5$ and ammonia and increases in DO concentrations to 8.5 mg/L at the gravity flow CSOs are not sufficient to raise DO concentrations above the 4, 5, and 6 mg/L target concentrations for large percentages of the time during wet weather periods on the NSC, NBCR, SBCR, and CSSC. Compliance with these target DO concentrations is better for the Little Calumet River (North) and Calumet-Sag Channel. However, the most downstream locations on the Calumet-Sag Channel cannot achieve 90 % compliance with the 5 mg/L target concentration. The inability to treat the flows from the large pump stations and the stress placed on the WRPs during wet weather periods are the most likely cause of the ineffectiveness of the pollutant removal at gravity flow CSOs in substantially improving DO concentrations. Further, Field (1980) summarized the $CBOD_5$ and TSS removal efficiency of various methods that had been proposed for pollutant removal at CSOs as follows:

Control alternative	Design loading rate, in gallons per minute per square foot	$CBOD_5$ removal efficiency, %	TSS removal efficiency, %
Swirl concentrator	60	25-60	50
Microstrainer	20	40-60	70
High-rate filtration	24	60-80	90
Dissolved air flotation	2.5	50-60	80
Sedimentation	0.5	25-40	55

Among these alternatives only swirl concentrators have design loading rates that make them feasible alternatives for the CSOs along the CWS. In an analysis of alternatives for the UAA CTE Engineers selected vortex separators (which function similarly to swirl concentrators) for the CSO treatment alternative and reasoned that they could achieve removal efficiencies of 30 and 50 percent for $CBOD_5$ and TSS, respectively. The pollutant removal percentages that can be achieved with these devices resulted in minimal improvements in DO concentrations during wet weather periods in the simulations done here. Thus, at this time treatment of CSO flows does not appear to be a viable alternative for achievement of proposed DO standards throughout the CWS. Consideration of different DO standards during wet weather and dry weather periods may be necessary for the CWS.

Chapter 7 - FLOW AUGMENTATION FOR BUBBLY CREEK

Two sets of simulations considering diversion of a portion of the SBCR flow to the upstream end of the Bubbly Creek are presented in this chapter. The first set of simulations considers transferred flow without aeration and the second set of simulations considers aerated transferred flow. Six different (50, 100, 200, 400, 450, and 550 mgd) fixed amounts of flow transfer have been evaluated for the periods July 12 – September 14, 2001, September 15 – November 9, 2001, May 1-August 11, 2002 and August 12-September 23, 2002. The withdrawal point for flow augmentation for Bubbly Creek is the intersection of the SBCR and Throop Street. This point is slightly upstream (~0.4 mile) of the intersection of Bubbly Creek and the SBCR.

7.1 Flow Augmentation without Aeration for Bubbly Creek

Plots of simulated (baseline) discharges at Throop Street are given in Figure 7.1. Average discharges for July 12 to November 9, 2001 and May 1 to September 23, 2002 are 1,186 cfs (767 mgd) and 984 cfs (636 mgd), respectively. Six different augmentation flow transfer values (50, 100, 200, 400, 450, and 550 mgd) have been evaluated. For periods when the simulated discharge was less than the transfer amount, the flow in the SBCR was set to zero and the fixed amounts of flow still was transferred even though the available flow was not sufficient. This approach did not result in hydraulic problems in the computations. In the actual design of the augmentation scheme, more precise flow transfers (i.e. time series of flow for the periods when the simulated discharge is less than transfer amount and the total simulated discharge is transferred) should be used in the simulation to calculate percentage compliances especially if the desired transferred flow is much larger than the simulated discharge at Throop Street at a specific time.

The percentage of time that target DO concentrations of 3, 4, 5, and 6 mg/L are equaled or exceeded for the total period of July 12 – November 9, 2001 are listed in Tables 7.1-7.3 for Jackson Boulevard (SBCR), I-55 (Bubbly Creek), and Cicero Avenue (CSSC), respectively.

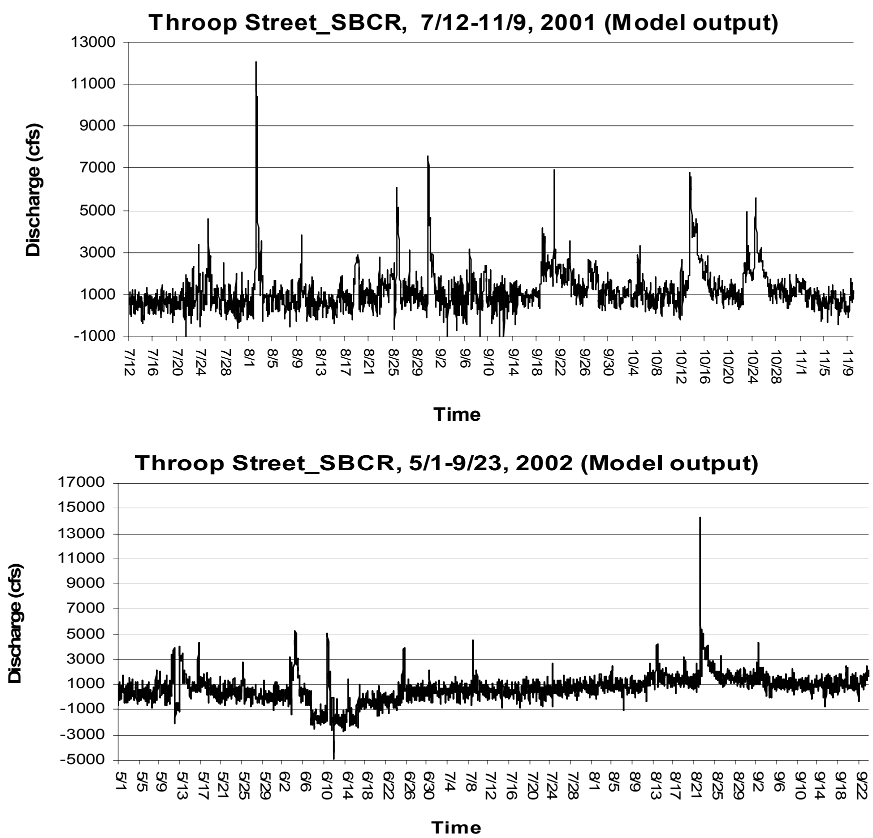


Figure 7.1 Simulated discharges at Throop Street for July 12 to November 9, 2001 and May 1 to September 23, 2002

Table 7.1 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Jackson Boulevard on the South Branch Chicago River for July 12 – November 9, 2001 for different withdrawal values for flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	Wet
Measured	98.2	92.9	91.4	82.5	67.6	54.0	41.9	16.9
Calibrated	90.7	94.0	78.1	85.6	63.3	70.7	41.8	35.8
50 mgd	91.3	94.3	78.6	87.0	64.7	72.1	43.1	36.3
400 mgd	91.3	94.3	78.7	87.0	64.8	72.1	43.2	36.3

Table 7.2 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at I-55 on Bubbly Creek for July 12 – November 9, 2001 for different withdrawal values for flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	Dry	wet
Measured	-*	-	-	-	-	-	-	-
Calibrated	71.2	66.1	56.6	41.0	41.8	31.6	25.9	20.3
50 mgd	71.3	66.2	56.6	41.0	41.9	31.6	25.9	20.4
400 mgd	71.8	66.4	56.6	41.4	42.0	31.9	26.0	20.5

* No measured dissolved oxygen data available for 2001

Table 7.3 The percentage of time that dissolved oxygen concentrations are higher than the target concentrations at Cicero Avenue on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 for different withdrawal values for flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	Dry	wet	dry	Wet
Measured	83.8	71.5	54.9	46.8	27.6	15.9	22.8	0.1
Calibrated	85.5	70.4	58.7	40.0	43.6	28.9	27.7	19.4
50 mgd	85.4	70.4	58.7	40.0	43.6	28.9	27.7	19.4
400 mgd	85.5	70.7	58.7	40.5	43.6	28.9	27.8	19.6

Even though simulations have been completed for all 6 different flow transfer values for 2001 and 2002, results of only 50 and 400 mgd flow transfer simulations for 2001 are presented here since simulation results show that different levels of augmentation without aeration do not affect the DO concentration at I-55.

Measured DO concentrations at Jackson Boulevard can get as low as 1.1 mg/L and mostly fluctuate between 4 and 6 mg/L (Figure 7.2). Measured DO concentrations at I-55 (Bubbly Creek) are always lower than Jackson Boulevard DO concentrations and get as low as 0 mg/L at certain periods. Simulated DO concentrations at Throop Street are usually lower than Jackson Boulevard DO concentrations.

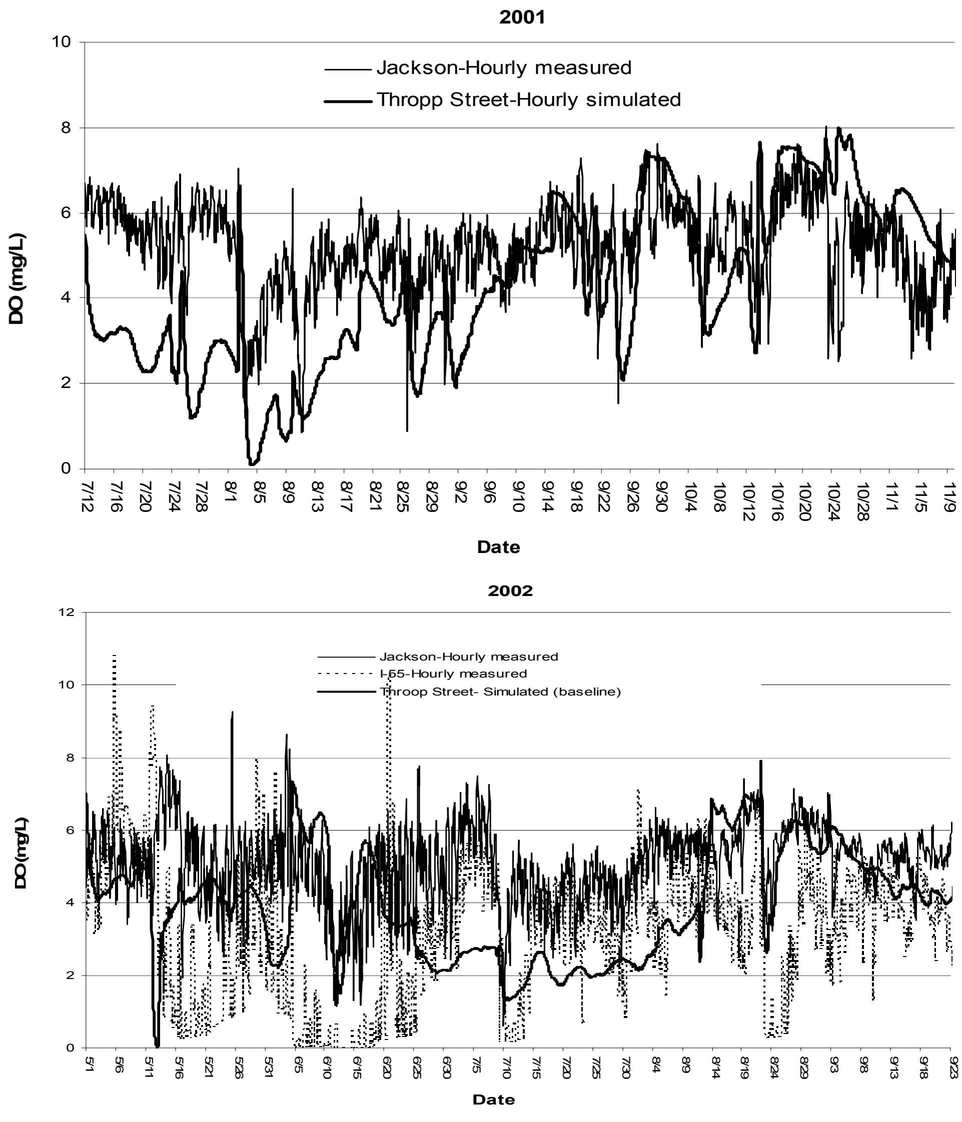


Figure 7.2 Dissolved oxygen (DO) concentrations measured at Jackson Boulevard on the South Branch Chicago River and I-55 on Bubbly Creek and simulated at Throop Street on the South Branch Chicago River for July 12 to November 9, 2001 and May 1 to September 23, 2002 (no measured DO concentrations are available for the 2001 period at I-55)

Comparison of measured hourly DO concentration plots for Jackson Boulevard and Cicero Avenue for 2001 and 2002 simulation periods are given in Figure 7.3. Comparison of the simulated (baseline) DO concentration at Throop Street and I-55 for the 2001 and 2002 simulation periods are given in Figure 7.4. Figures 7.3 and 7.4 show that DO concentrations at Cicero Avenue are always lower than Jackson Boulevard DO concentrations and simulated DO concentrations at Throop Street and I-55 are almost identical. The agreement between Throop Street and I-55 results because during periods of no flow in Bubbly Creek the ambient water quality in the SBCR and CSSC dominates the downstream reaches of Bubbly Creek, whereas when the Racine Avenue Pumping Station is operating water quality at the downstream end of Bubbly Creek has a large effect on water quality in the nearby portions of the SBCR and CSSC. Figures 7.3 and 7.4 also show that simulated DO concentrations at Throop Street show a very similar trend with Cicero Avenue DO concentrations. Since simulated DO concentrations just at the upstream and downstream of the junction of the SBCR and Bubbly Creek are very similar to Bubbly Creek DO concentrations, Bubbly Creek augmentation without aeration did not improve DO concentrations in Bubbly Creek.

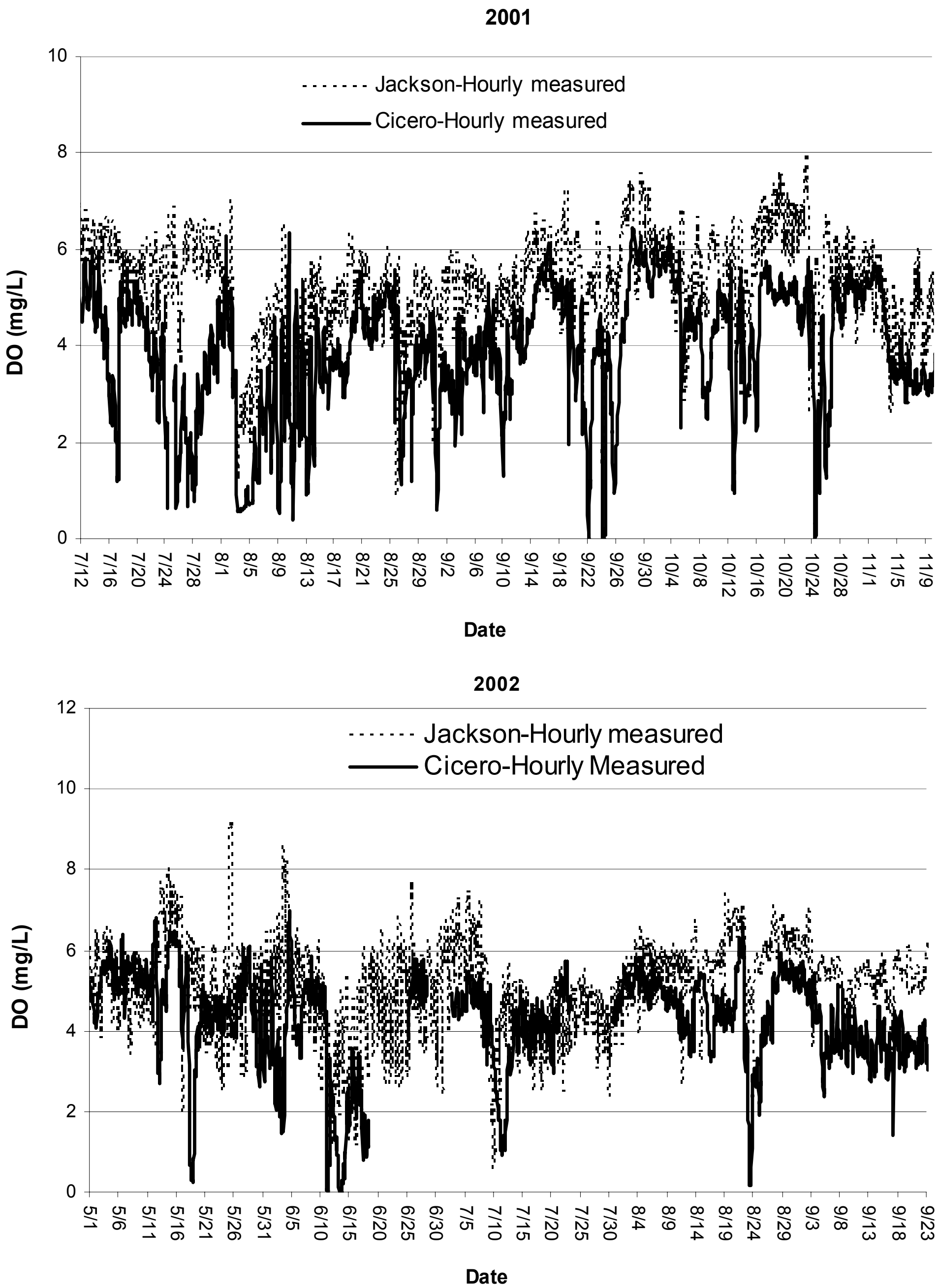


Figure 7.3 Measured dissolved oxygen (DO) concentrations at Jackson Boulevard on the South Branch Chicago River and Cicero Avenue on the Chicago Sanitary and Ship Canal for July 12 to November 9, 2001 and May 1 to September 23, 2002

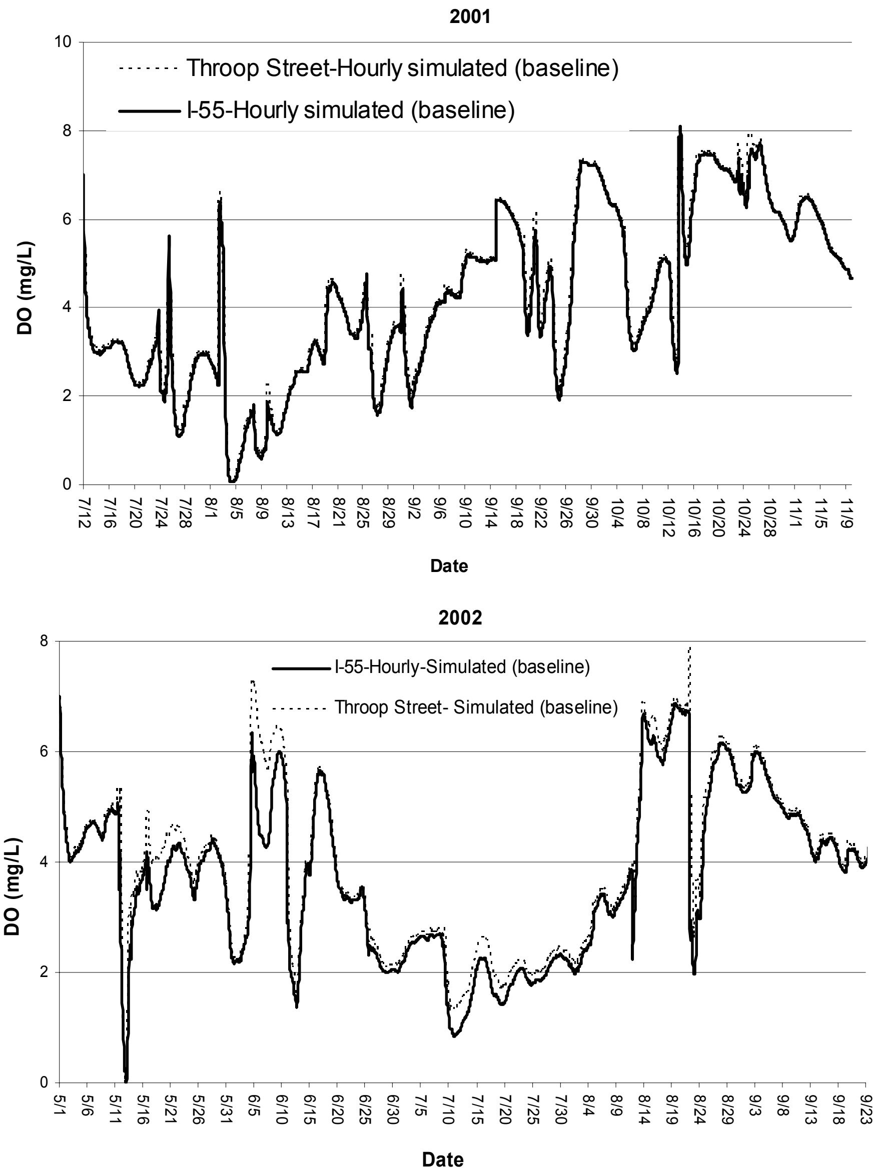


Figure 7.4 Simulated dissolved oxygen (DO) concentrations at I-55 on Bubbly Creek and Throop Street on the South Branch Chicago River for baseline conditions (no transfer) for July 12 to November 9, 2001 and May 1 to September 23, 2002

7.2 Flow Augmentation with Aeration for Bubbly Creek

In this section, results of simulations of scenarios of Bubbly Creek flow augmentation with aeration are presented. In these simulations, saturated DO concentrations were assigned to the augmented flow. The rest of the water quality variables were kept the same as the simulated Throop Street concentrations. Jackson Boulevard water temperatures were used to calculate saturation concentrations (Figures 7.5 and 7.6). This makes the following simulation results somewhat optimistic because the Midwest Generation Fisk Power Plant sits between Jackson Boulevard and Throop Street and comparison of monthly sample data at Madison Street and Damen Avenue indicates about a 1°C temperature increase primarily due to the Fisk Power Plant. Because only monthly data are available to estimate the temperature increase and this is a preliminary planning level analysis, no attempt was made to account for the temperature increase. In the actual design of a flow transfer scheme, the temperature increase resulting from the Fisk Power Plant should be considered.

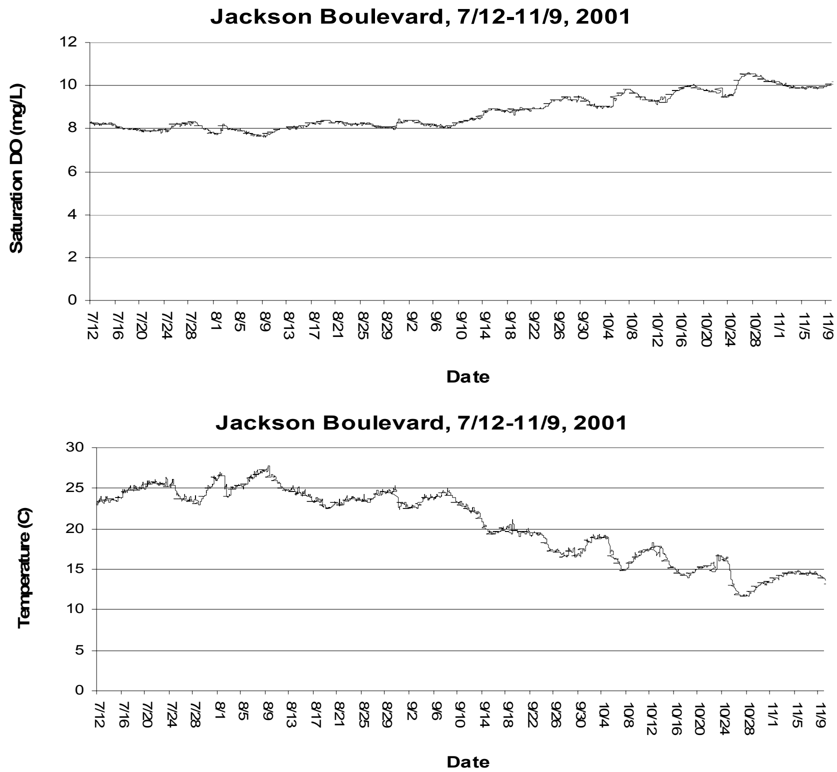


Figure 7.5 Temperature (°C) and calculated saturation dissolved oxygen (DO) concentrations at Jackson Boulevard for July 12 to November 9, 2001

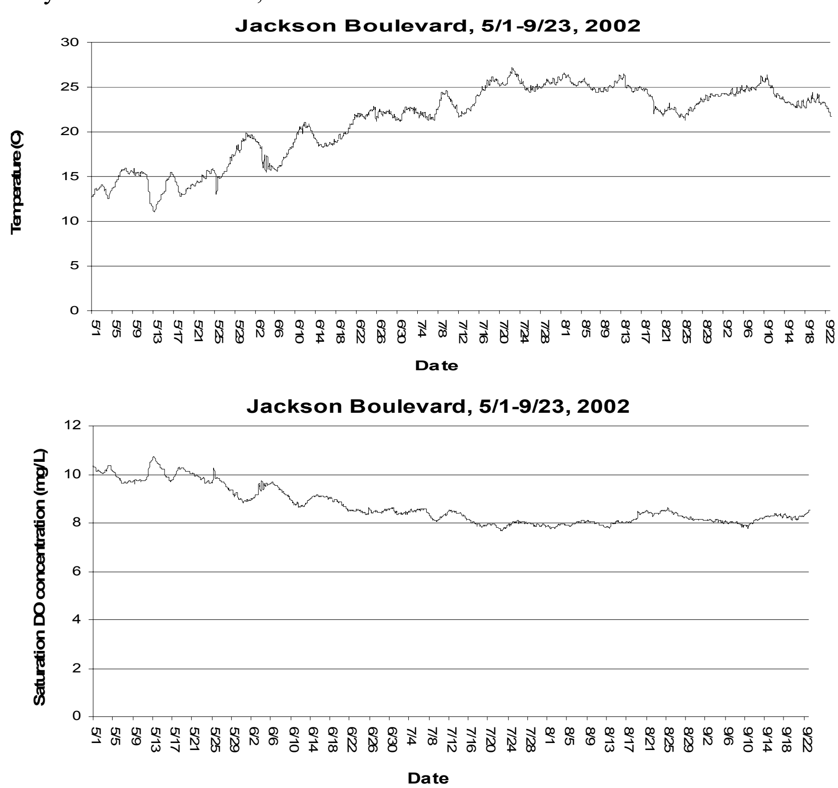


Figure 7.6 Temperature (°C) and calculated saturation dissolved oxygen (DO) concentrations at Jackson Boulevard for May 1 to September 23, 2002

7.2.1 Results of the Aerated Augmentation Simulations

The percentage of time that target DO concentrations of 3, 4, 5, and 6 mg/L are equaled or exceeded for July 12 – November 9, 2001 are listed in Tables 7.4-7.6 for Jackson Boulevard (SBCR), I-55 (Bubbly Creek), and Cicero Avenue (CSSC), respectively.

Table 7.4 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Jackson Boulevard on the South Branch Chicago River for July 12 – November 9, 2001 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	Wet
Measured	98.2	92.9	91.4	82.5	67.6	54.0	41.9	16.9
Calibrated	90.7	94.0	78.1	85.6	63.3	70.7	41.8	35.8
50 mgd	91.5	94.4	79.0	87.6	65.9	72.4	43.5	36.4
100 mgd	92.0	94.7	79.3	87.9	66.4	72.5	44.1	36.5
200 mgd	93.2	95.2	79.7	88.5	67.7	72.9	45.3	36.7
400 mgd	95.1	95.9	81.6	89.2	68.6	73.6	46.9	37.3
450 mgd	95.4	96.1	82.0	89.4	68.7	74.0	47.1	37.4
550 mgd	96.2	96.1	82.2	89.4	68.9	74.7	47.2	37.7

Table 7.5 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at I-55 on Bubbly Creek for July 12 – November 9, 2001 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Measured	-	-	-	-	-	-	-	-
Calibrated	71.2	66.1	56.6	41.0	41.8	31.6	25.9	20.3
50 mgd	83.0	73.0	60.4	44.6	45.5	33.7	29.7	22.7
100 mgd	87.3	81.4	65.5	55.9	48.2	35.6	33.0	24.0
200 mgd	91.5	91.5	84.3	72.8	60.1	40.9	44.5	28.7
400 mgd	**100.0**	96.2	92.9	91.2	86.2	72.8	56.0	36.3
450 mgd	**100.0**	97.0	96.6	93.1	87.8	75.8	60.6	39.6
550 mgd	**100.0**	**100.0**	99.7	95.4	90.5	81.9	70.2	49.5

Table 7.6 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Cicero Avenue on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Measured	83.8	71.5	54.9	46.8	27.6	15.9	22.8	0.1
Calibrated	85.5	70.4	58.7	40.0	43.6	28.9	27.7	19.4
50 mgd	88.4	75.3	60.8	45.7	45.2	29.4	30.2	21.0
100 mgd	89.5	79.7	67.9	50.8	47.0	29.8	32.6	21.8
200 mgd	91.3	82.4	81.8	60.6	55.1	30.6	36.4	25.0
400 mgd	96.0	90.9	89.0	72.8	67.4	41.0	44.8	26.8
450 mgd	96.3	91.7	89.9	75.2	72.5	44.5	45.3	26.9
550 mgd	98.7	93.7	91.3	77.8	81.3	52.9	48.4	27.3

Results of the aerated flow augmentation simulations show that aeration of the transferred flow improves the DO conditions in Bubbly Creek. It can be seen that the transfer of 550 mgd of aerated flow results in attainment of DO concentrations in excess of 3 mg/L at I-55 during dry and wet weather 100 percent of the time, whereas 3 mg/L DO concentrations are achieved 100 percent of the time during just dry weather for 400 and 450 mgd transfer simulations. More than 89% of the time the 4 mg/L DO target level is achieved with a transfer of 400 mgd both for wet and dry periods. Results also show that aerated flow augmentation influences the DO concentrations at locations downstream from the junction of Bubbly Creek and the SBCR (Table 7.6). At Cicero Avenue the percentage compliance with the 3 mg/L DO target level increased from 85.4 % and 70.4 % for wet and dry periods, respectively, during calibration to 98.7% and 93.7% for wet and dry periods, respectively, for a transfer of 550 mgd of aerated SBCR water. Even though aerated augmentation simulations have little effect on DO concentrations at Jackson Boulevard (Table 7.4) it is possible to see the effect of aerated augmentation operations along the CSSC until the downstream boundary (Romeoville) of the modeled section of the river system (Table 7.7).

Table 7.7 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Romeoville on the Chicago Sanitary and Ship Canal for July 12 – November 9, 2001 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	Dry	wet	dry	wet
Measured	93.5	67.7	74.0	38.0	30.7	12.0	21.5	0.2
Calibrated	79.5	86.0	63.9	60.9	42.5	33.4	28.5	20.8
50 mgd	80.3	86.5	66.1	62.4	45.5	34.9	29.6	22.3
100 mgd	81.3	87.2	68.7	64.2	46.7	35.4	30.7	22.9
200 mgd	82.8	87.8	71.6	70.7	51.2	38.4	32.2	24.3
400 mgd	84.8	90.1	72.9	73.7	57.1	43.2	33.5	26.3
450 mgd	85.3	90.4	73.2	74.1	58.2	44.2	33.7	26.6
550 mgd	86.1	91.1	73.7	75.3	59.7	46.6	34.7	27.0

The percentage of time that target DO concentrations of 3, 4, 5, and 6 mg/L are equaled or exceeded for the period of May 1-September 23, 2002 are listed in Tables 7.8-7.10 for Jackson Boulevard (SBCR), I-55 (Bubbly Creek), and Cicero Avenue (CSSC), respectively.

Table 7.8 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Jackson Boulevard on the South Branch Chicago River for May 1-September 23, 2002 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	Wet
Measured	97.3	92.2	85.9	81.5	59.6	60.7	15.8	23.9
Calibrated	91.4	88.0	57.5	80.8	44.0	69.6	20.0	47.5
50 mgd	94.1	88.6	59.1	80.8	45.0	69.9	20.3	47.8
100 mgd	96.3	89.0	60.6	81.0	46.6	70.7	20.9	48.9
200 mgd	98.3	90.1	67.8	81.7	47.8	72.6	23.0	53.4
400 mgd	99.7	91.1	71.4	84.7	49.6	75.7	25.7	56.4
450 mgd	**100**	91.8	72.0	85.8	50.2	76.0	26.5	56.6
550 mgd	**100**	92.8	73.3	86.8	51.8	76.8	27.6	57.0

Like the simulations for 2001, aerated transferred flow improved the DO concentrations in Bubbly Creek. The 3 mg/L DO target level is achieved for the 200, 400, 450, and 550 mgd augmentation scenarios at I-55 (Table 7.9) for dry periods, whereas 3 mg/L target level cannot be achieved even with the transfer of 550 mgd of aerated flow for wet periods at I-55. The 400, 450, and 550 mgd simulations result in achievement of 4 mg/L 100 % of the time for dry periods. Effects of aerated flow augmentation extend until Romeoville (Table 7.11).

Table 7.9 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at I-55 on Bubbly Creek for May 1-September 23, 2002 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	wet
Measured	62.20	37.8	31.8	29.0	9.8	17.9	2.8	7.8
Calibrated	62.40	69.8	43.3	48.0	18.2	24.4	4.6	10.7
50 mgd	68.86	78.4	51.7	56.6	24.4	36.2	6.7	16.5
100 mgd	87.64	82.8	60.0	65.1	35.4	46.8	10.6	19.5
200 mgd	99.72	87.7	79.7	77.6	55.5	58.3	22.0	36.6
400 mgd	**100**	97.6	100.0	89.1	82.0	76.7	49.8	59.6
450 mgd	**100**	98.0	100.0	94.0	94.6	78.7	53.9	64.3
550 mgd	**100**	98.8	100.0	95.0	100.0	83.8	67.3	73.0

Table 7.10 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Cicero Avenue on the Chicago Sanitary and Ship Canal for May 1-September 23, 2002 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	dry	wet	dry	Wet
Measured	92.9	79.4	66.8	61.5	28.0	35.2	0.5	7.8
Calibrated	67.4	78.2	52.4	58.2	23.9	40.1	5.9	10.1
50 mgd	76.4	81.9	55.3	61.0	29.6	45.2	7.1	11.9
100 mgd	87.0	82.6	57.8	65.6	35.8	46.8	8.5	14.4
200 mgd	97.6	85.0	68.9	76.3	46.2	50.8	15.4	31.9
400 mgd	**100**	90.6	93.1	80.7	58.0	65.3	25.2	44.1
450 mgd	**100**	91.6	96.6	81.6	63.7	70.3	27.5	46.3
550 mgd	**100**	92.5	99.3	83.1	71.1	73.3	32.1	49.4

Table 7.11 The percentage of time that dissolved oxygen concentrations are greater than the target concentrations at Romeoville on the Chicago Sanitary and Ship Canal for May 1-September 23, 2002 for different withdrawal values for aerated flow augmentation

Scenario	3 mg/L		4 mg/L		5 mg/L		6 mg/L	
	dry	wet	dry	wet	Dry	wet	dry	wet
Measured	85.7	82.5	54.2	64.5	20.7	34.5	3.7	10.9
Calibrated	98.2	85.4	63.5	73.0	36.3	54.8	13.9	27.0
50 mgd	99.1	86.1	67.5	73.8	38.6	57.8	16.2	29.6
100 mgd	99.5	86.6	70.7	74.3	40.9	59.4	17.2	32.1
200 mgd	99.8	87.3	75.8	76.9	43.0	61.2	17.9	35.5
400 mgd	**100**	88.4	87.5	79.0	47.9	65.5	19.9	41.8
450 mgd	**100**	88.7	89.5	79.5	49.2	66.2	20.2	42.5
550 mgd	**100**	89.3	92.4	79.7	52.7	67.9	21.2	43.7

For each flow transfer amount the overall percentage compliance for 4, 5, and 6 mg/L at I-55 are given in Table 7.12 and Figure 7.7. It can be seen from Figure 7.7, 90 % compliance for 4 mg/L is achieved with a transfer of approximately 340 mgd. A transfer of approximately 520 mgd is needed to attain 5 mg/L 90% of the time, and flows greater than the average flow at Throop Street may be needed to attain 6 mg/L 90% of the time. Therefore, an increase in the transferred flow of 180 mgd is needed to increase 90 % compliance from 4 mg/L to 5 mg/L. Since the average daily simulated flow at Throop Street for 2002 was only 636 mgd, this may be an impractical solution. Even though transfer of aerated flow can help to improve DO conditions in Bubbly Creek, it is still very hard to attain 6 mg/L 90 % of the time since Bubbly Creek water quality is still affected by the water quality of SBCR and CSSC. Hence, it is possible to expect more improvement in DO in Bubbly Creek if the water quality of the SBCR gets better.

Table 7.12 The percentage of time that dissolved oxygen (DO) concentrations are greater than the target concentrations at I-55 on Bubbly Creek for all periods during July 12 – November 9, 2001 and May 1 – September 23, 2002 for different withdrawal values for aerated flow augmentation

Scenario	4 mg/L	5 mg/L	6 mg/L
Calibrated	47.3	28.1	14.2
50 mgd	53.6	33.8	17.4
100 mgd	61.6	40.8	20.6
200 mgd	79.4	54.6	31.7
400 mgd	94.7	80.6	50.6
450 mgd	96.9	86.8	54.9
550 mgd	98.3	91.5	65.8

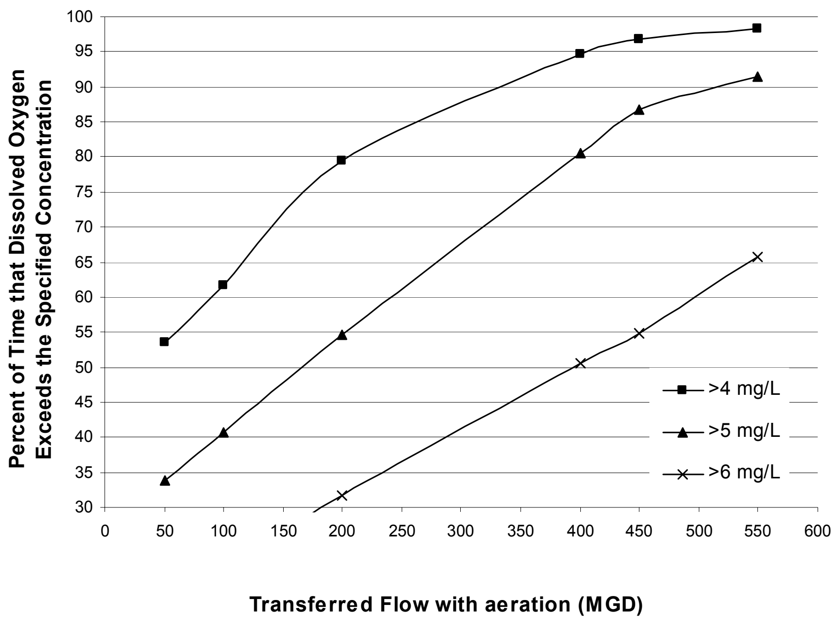


Figure 7.7 Relation between the amount of aerated transferred flow and percentage compliance with the dissolved oxygen concentration criteria for July 12 – November 9, 2001 and May 1 – September 23, 2002 at I-55 on Bubbly Creek.

Chapter 8 - CONCLUSIONS

An unsteady flow water-quality model for the Chicago Waterway System (CWS) has been calibrated to assist water-quality management and planning decision making. An extensive set of flow, stage, and water-quality data have been used for verification of the previously calibrated hydraulic model and for calibration of the unsteady-flow water-quality model for the CWS for the period of July 12 to November 9, 2001.

First, hydraulic verification of the previously calibrated hydraulic model (Shrestha and Melching, 2003) was done. Water-surface elevation data at several different locations along the CWS were used to test the power of the model, and it was observed that model could predict water levels at all locations with a high accuracy (two to three percent error relative to depth).

Boundary conditions, water reclamation plants (WRPs), SEPA stations, in-stream aeration stations, tributaries, CSOs, and pumping stations input constituents to the CWS. The water-quality model was calibrated using monthly grab sample data at 18 locations and hourly dissolved oxygen (DO) and temperature data at 25 locations all collected by the MWRDGC. The model was run at a 15-min. time step for the period of July 12 to November 9, 2001. Primarily hourly measured and simulated DO concentrations were compared.

Except for locations close to the boundaries (i.e. upstream of WRPs), the simulated DO concentrations agreed well with the observed concentrations. Simulated concentrations of other constituents such as $CBOD_5$, ammonia nitrogen, nitrate nitrogen, among others were compared to the mean and one standard deviation confidence bounds of historic data in order to detect and correct any unusual simulated concentrations. The simulated mean $CBOD_5$, ammonia nitrogen, and nitrate nitrogen concentrations are close to the measured mean concentrations and most of the simulated values are within ± 1 standard deviation of the mean of the long-term measured values. The calibrated model was verified for the period of May 1 to September 24, 2002 (Neugebauer and Melching, 2005). Since there were no detailed storm loading data available for the period of May 1 to September 24, 2002, different statistical methods were used to estimate the CSO event mean concentrations. Although at 10 of 24 (as opposed to 3 of 24 in the calibration) locations average absolute errors were greater than 30%, the model verification results were similar to the calibration results (Neugebauer and Melching, 2005). Therefore, the water-quality DUFLOW model can be considered satisfactory for DO simulation on the CWS. The DUFLOW model of the CWS is able to simulate water quality under unsteady flow conditions, and can be used to assist water-quality management and planning decision-making. The model then was applied to evaluate the effect of different management practices on the water quality in the CWS.

Flow augmentation without aeration along the North Shore Channel (NSC) was not effective enough to bring DO concentrations to target levels. Even transferring the complete NSWRP flow does not result in attainment of DO concentrations in excess of 4 mg/L at Simpson Street and 3 mg/L at Main Street during dry weather 100 % of the time. Since the DO concentration in the NSWRP effluent is 6 mg/L or less in summer 2001, there is a small margin between the effluent DO concentration and the 4 mg/L target, and the $CBOD_5$ and ammonia loads and sediment oxygen demand are sufficient to reduce DO concentrations below the 4 and 3 mg/L targets. Flow augmentation (no aeration) with two outlets was also evaluated. For complete (100 %) flow transfers the results with one or two outlets are nearly identical in terms of percentage of compliance. The results of the flow augmentation without aeration on the NSC indicate that if a transfer of NSWRP effluent is utilized a final design with multiple outlets would be most efficient as it would yield nearly identical DO concentrations at a smaller construction and operation cost. The flow augmentation with aeration results show that this practice can be a effective management alternative to increase DO concentrations to desired levels. A transfer of 170 mgd will result in 94.9 percent compliance with a 6 mg/L criterion at Main Street on the NSC.

The size and the locations of the additional aeration stations to bring the DO concentrations to target levels were determined. It was determined that total of 6 new aeration stations along the Chicago Waterway System distributed as 2 new aeration stations on the North Branch Chicago River (NBCR), 2 new aeration stations on the South Branch Chicago River (SBCR), and 2 new aeration stations on the Chicago Sanitary and Ship Canal (CSSC), could be enough to achieve 5 mg/L 100 % for the period of July 10-August 10, 2002 which was considered as the representative dry-weather period to determine the size and the locations of the new aeration stations. The oxygen loads from the new aeration stations vary between 30-80 g/s. Throughout the simulations, availability of the space was not taken into consideration. Hence, new simulations will be necessary if the final design requires proposed new aeration stations to be relocated. It was also found that raising the Stickney WRP effluent DO concentrations to saturation is nearly as effective as 2 new aeration station along the CSSC.

Simulations of the pollutant removal at combined sewer overflows (CSOs) resulted in interesting outcomes. Even tough it was found that pollutant removal at CSOs is most efficient at the locations on the NSC upstream from NSWRP, DO concentrations do not get higher than 5 mg/L even 60 % of the time during wet weather periods along the upper NSC. In addition, the simulations show that 100% removal of $CBOD_5$ and ammonia and increases in DO concentrations to 8.5 mg/L at the gravity flow CSOs are not sufficient to raise DO concentrations above the 4, 5, and 6 mg/L target concentrations for large percentages of the time during wet weather periods on the NSC, NBCR, SBCR, and CSSC.

Simulations considering diverting a portion of the SBCR flow to the upstream end of the Bubbly Creek are also evaluated in this study. Since water-quality conditions are already very poor along the SBCR, transferring a portion of the SBCR did not improve the water-quality conditions in Bubbly Creek. Hence, it was necessary to increase DO concentrations of the transferred flow to improve DO concentrations in Bubbly Creek. Results show that if DO concentrations of transferred flow is brought to the saturation, more than 90% of the time the 5 mg/L DO target level is achieved with a transfer of approximately 520 mgd at I-55 on Bubbly Creek. The other benefit of this practice is that it is possible to see the effect of aerated augmentation operations along the CSSC until the downstream boundary (Romeoville) of the modeled section of the river system.

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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

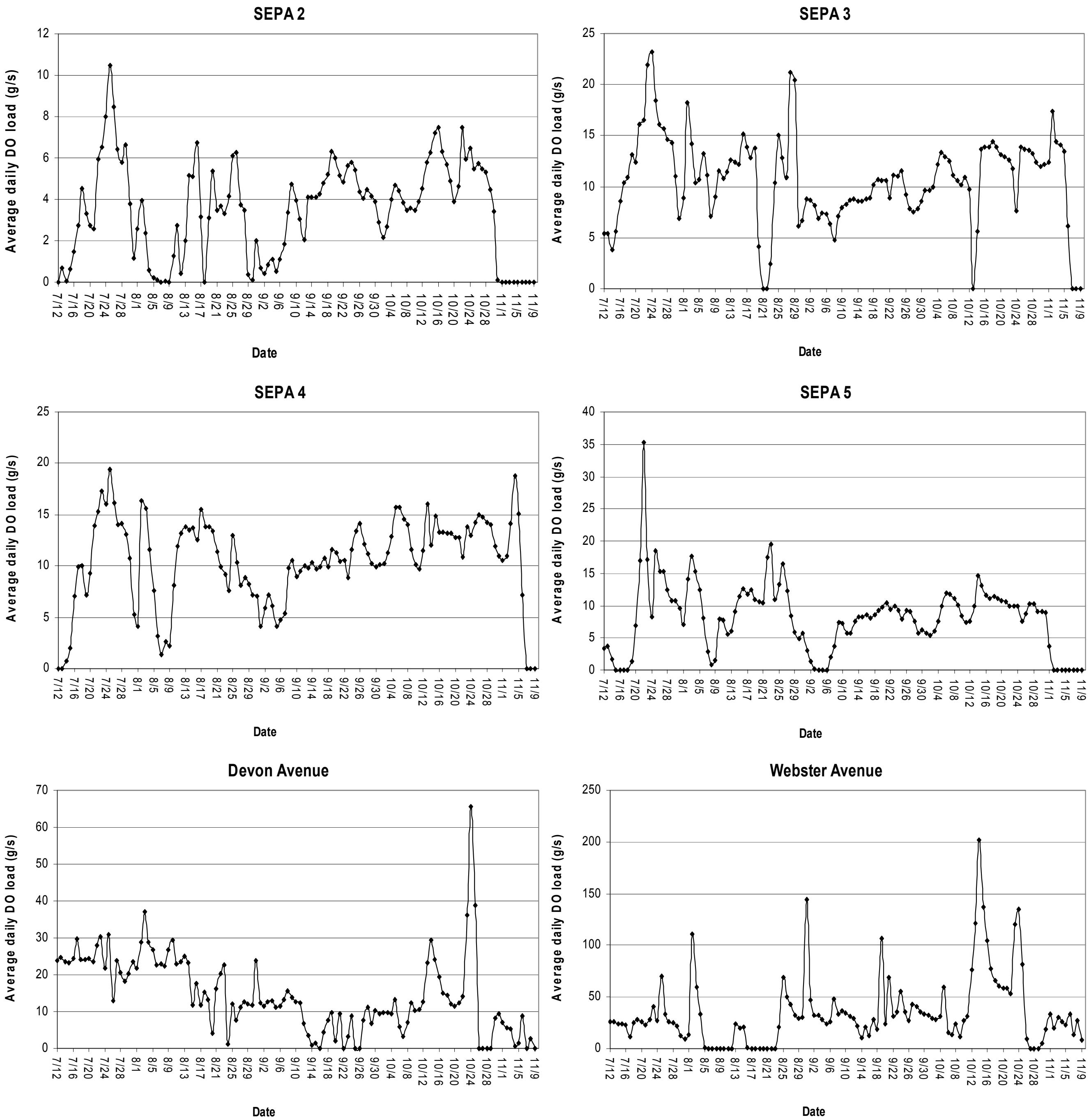

Figure B.1 Average Daily DO loads from SEPA and Aeration Stations (g/s) for July 12-November 9, 2001

APPENDIX-C Initial Conditions

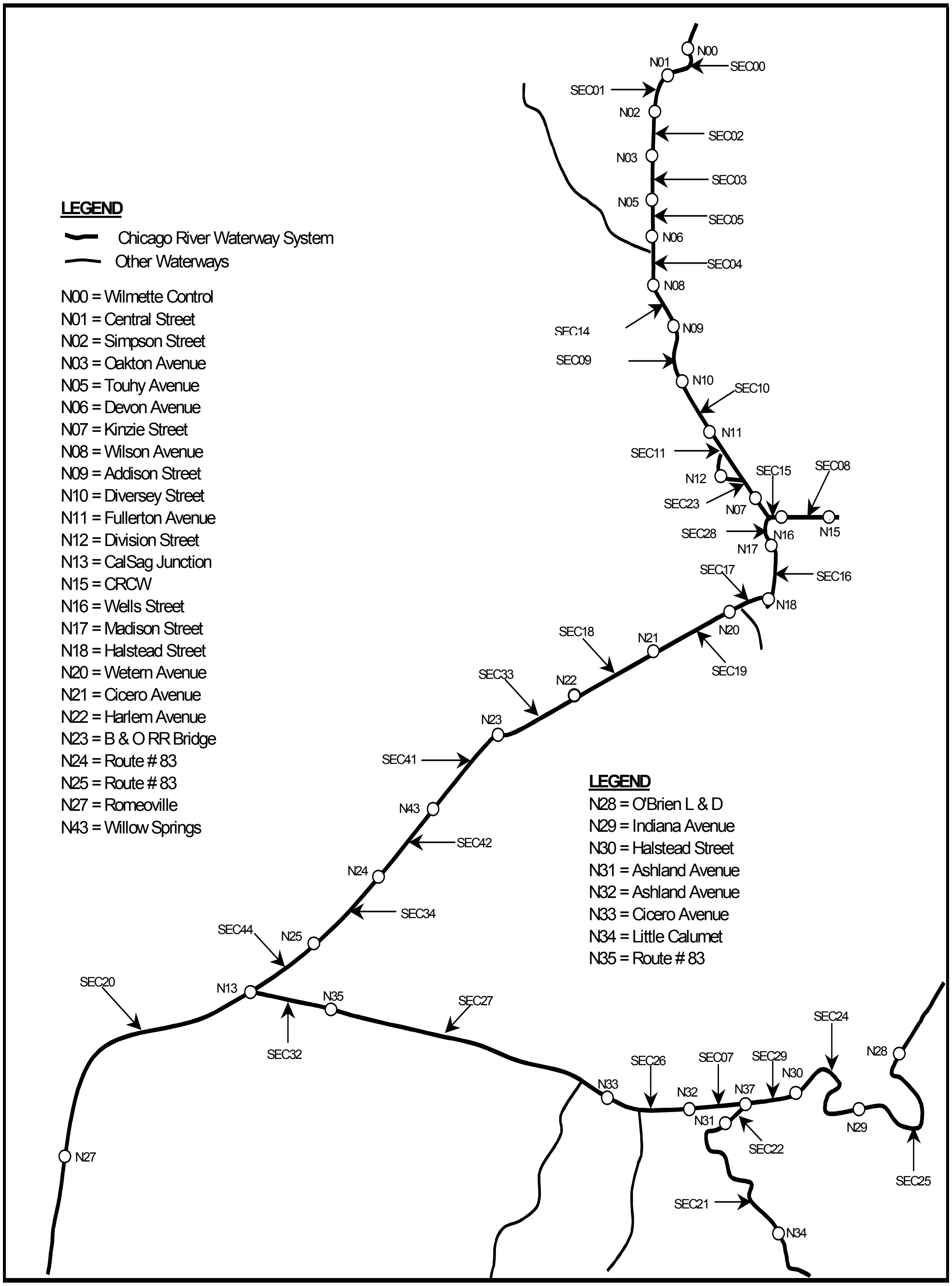

Figure C.1 Calculation nodes sections for the Chicago Waterway System

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

APPENDIX-D- WET WEATHER PERIODS

Table D.1 Wet Weather periods in for the periods of July 12-November 9, 2001

7/21/2001	8/1/2001	8/22/2001	9/18/2001	10/4/2001	10/11/2001	10/23/2001
7/22/2001	8/2/2001	8/23/2001	9/19/2001	10/5/2001	10/12/2001	10/24/2001
7/23/2001	8/3/2001	8/24/2001	9/20/2001	10/6/2001	10/13/2001	10/25/2001
7/24/2001	8/4/2001	8/25/2001	9/21/2001	10/7/2001	10/14/2001	10/26/2001
7/25/2001	8/5/2001	8/26/2001	9/22/2001		10/15/2001	10/27/2001
7/26/2001		8/27/2001	9/23/2001		10/16/2001	
		8/28/2001	9/24/2001		10/17/2001	
		8/29/2001	9/25/2001		10/18/2001	
		8/30/2001	9/25/2001			
		8/31/2001				
		9/1/2001				
		9/2/2001				

Table D.2 Wet Weather periods in for the periods of May 1-September 23, 2002

5/7/2002	6/2/2002	6/9/2002	7/8/2002	8/11/2002	8/21/2002
5/8/2002	6/3/2002	6/10/2002	7/9/2002	8/12/2002	8/22/2002
5/9/2002	6/4/2002	6/11/2002	7/10/2002	8/13/2002	8/23/2002
5/10/2002	6/5/2002	6/12/2002	7/11/2002	8/14/2002	8/24/2002
5/11/2002	6/6/2002	6/13/2002		8/15/2002	8/25/2002
5/12/2002	6/7/2002			8/16/2002	8/26/2002
5/13/2002					8/27/2002
5/14/2002					
5/15/2002					
5/16/2002					
5/17/2002					
5/18/2002					
5/19/2002					
5/20/2002					
5/21/2002					