Contract Report 586

Considerations in Water Use Planning for the Fox River

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Prepared for the
Illinois Department of Transportation, Division of Water Resources

September 1995

Illinois State Water Survey
Hydrology and Chemistry Divisions
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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ISSN 0733-3927

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INTRODUCTION

The Fox River basin in Illinois is located along the western fringe of suburban growth in the Chicago metropolitan area. It drains an area of 1,720 square miles (sq mi) in Illinois and 938 sq mi in Wisconsin, giving a total area of approximately 2,658 sq mi. Headwaters of the Fox River are in Wisconsin, and it runs for 115.1 miles from the McHenry County/ Wisconsin border to its junction with the Illinois River at Ottawa. The Fox River basin is unique relative to other streams similar in size and/or location within the state. Its natural and man-made physical characteristics and layout contribute significantly to this uniqueness. The river between the Stratton Dam (previously McHenry Dam) and the Wisconsin border (mile 98.9 to mile 115.1) runs through the Fox Chain of Lakes, a series of nine major lakes having a water surface area of 6,850 acres at normal pool level at the Stratton Dam. The pool level is controlled at the dam, but the lakes are natural and were formed during the last glacial period. The Fox River is the only river in Illinois that includes a large glacial lake system in its drainage area. This "headwaters" lake system, to a great degree, dictates water quantity and quality for many miles downstream.

The water quality of the river has improved significantly over the past 30 years. During the 1960s, most of the middle section of the river, from Carpentersville (mile 78.0) to Yorkville (mile 36.5), could be classified as polluted to grossly polluted. This is no longer the case, but significant water quality and water use problems are still manifest.

A unique feature influencing water quality, and to a lesser extent water quantity, along the Fox River is the presence of dams. Dams have been built along the river throughout the past 100 years at various temporal and spatial intervals to cater to a number of special interests. Included are a navigation/water level control dam, an active hydropower dam, and a multiplicity of channel or low-head dams. These channel dams range from vestiges of old saw, grist, and hydropower operations, to relatively modern installations built primarily for aesthetics and to improve water quality (albeit in a somewhat misguided fashion). These dams have actually contributed significantly to water quality degradation and/or lessened the ability of the river to purify itself naturally. More than 20 communities are located along the portion of the Fox River in Illinois. These communities have been experiencing significant population growth (an overall increase of about 25% during 1980-1990). High rates of population growth are expected to continue for several decades.

Throughout most of this century, the towns in the Fox River basin have relied almost entirely on ground water for their public water supplies. Excessive pumping from deep sandstone aquifers has led to continuous lowering of piezometric levels and water quality. To remedy the situation, Elgin and Aurora (the two largest users of deep aquifers in the basin) also made plans to use the Fox River as a supply source. In 1983 the city of Elgin began withdrawing water from the Fox River for most of its public water supply, and the city of Aurora began augmenting its ground-water supplies with water from the Fox River in 1993. It is expected that the magnitude of these withdrawals will grow along with the regional population.

Effluents from wastewater treatment plants currently discharging into the Fox River constitute a significant portion of low flows. Replacing a ground-water withdrawal by a corresponding withdrawal from the Fox River will reduce the low flow by a similar amount below the withdrawal point. This can reduce the dilution ratio (river flow/effluent discharge) at some locations to unacceptable values, affecting river water quality. Reduced water quality may adversely affect the aquatic habitat as well as lead to progressively greater treatment problems for downstream communities attempting to withdraw surface water for public use.

In addition to its potential as a source of public water supply and receptor for effluent discharges, the Fox River is highly valued for recreational activities such as fishing, boating, and canoeing. The value of the river as habitat for aquatic life also needs to be considered as a major benefit.

Objectives and Scope

The objectives of this study were to 1) identify locations along the Fox River where reductions in the flow rate and/or river water quality are likely to degrade any use of water along the river, 2) assess the prevailing water quality and ecology of a critical reach of the river, e.g., from one dam to the other, and 3) estimate and evaluate water supply and water quality conditions at present and in the future.

The study is divided into two main sections: one on water quality data analyses, population and water demand projections, and changes in effluent discharges and 7-day, 10-year low flow, Q(7,10) values. The other section deals with water quality and waste assimilative capacity of the St. Charles Pool of the Fox River.

Water quality data from the Illinois Environmental Protection Agency (IEPA) database, STORET, at five long-term stations on the Fox River (near Channel Lake and at Algonquin, South Elgin, Montgomery, and Dayton) were analyzed for dissolved oxygen, chemical oxygen demand, $NO_3 + NO_2$ nitrogen, $NH_3 + NH_4$ nitrogen, phosphorus, hardness, and fecal coliform. In addition to overall data analyses, the data at each station were split into four time periods for trend analyses, and for the four quarters of the year for seasonal analyses. The relationships with magnitude of river flow were also investigated.

The 2010 population projections for towns and cities in the Fox River basin were developed from historical census data, Illinois Bureau of the Budget (IBOB) county population projections, and 2010 population projections from the Northern Illinois Planning Commission (NIPC). Population projections were used in developing water demand projections as well as sources of water for meeting these demands.

Water demand projections, 1990 water use and effluent discharges, water withdrawals from the Fox River by Elgin and Aurora, and the allowable minimum low flow releases from Stratton Dam were used in developing Q(7,10) maps for 1990 and 2010 conditions with varying water withdrawals from the Fox River and minimum flow releases from Stratton Dam.

St. Charles Pool (between dams at South Elgin and St. Charles, river mile 68.18 to 60.65 upstream of the confluence with the Illinois River) was monitored during 1993 and 1994. Up to about two miles below South Elgin dam, the pool represents a free-flowing river condition during low to medium flows, and the remaining length a pool with increasing water depths downstream. Short-term intensive water quality data collections were made by installing Hydrolab DataSondes II to record ambient, light chamber, and dark chamber conditions. Sediment oxygen demands were monitored. Though the overall capacity has improved significantly over the last 30 years, the main stem of the river still has excessive algal growths in the pools created by the dams.

Acknowledgments

The study was jointly supported by the Division of Water Resources of the Illinois Department of Transportation and the Illinois State Water Survey Division of the Illinois

Department of Energy and Natural Resources. Gary Clark of the Division of Water Resources served in a liaison capacity during the course of this study. Ali Durgunoglu and Rajalingam Janarthanan helped in water quality data analyses. Linda Hascall prepared the illustrations and Kathleen Brown typed the manuscript. Eva Kingston edited the final report.

Part A. Water Quality, Population and Water Demand Projections, and Q(7,10) Values

WATER QUALITY OF THE FOX RIVER

The general water quality conditions on the Fox River have been described in two previous studies (Flemal, 1983; Broeren and Singh, 1987). Historically, the major water quality concern along the Fox River has been associated with wastewater effluents, most notably the high amounts of bacteria and nutrients associated with wastewater, and the resulting high levels of biochemical oxygen demand (BOD) and low levels of dissolved oxygen (DO). According to the Illinois Environmental Protection Agency (IEPA), Illinois Pollution Control Board (IPCB) phosphorus standards for lakes do not apply to seasonal pools (created during low-flow conditions) behind dams in the Fox River.

Phosphorus

There is no water quality standard for phosphorus in free-flowing streams. However, the IPCB has set a standard of 0.05 milligrams per liter (mg/L) for reservoirs or lakes with surface areas exceeding 20 acres and for streams as they enter such reservoirs or lakes. High concentrations of phosphorus can occur as the result of urban runoff, municipal wastewater discharges, and application of agricultural fertilizers, as well as by natural processes. All streams in the Fox basin have high phosphorus levels, with individual samples generally ranging from 0.0 to 0.6 mg/L. Flemal (l983) suggests that the background levels of phosphorus in the Fox basin are high and will remain significant even if all urban and agricultural contributions of phosphorus were greatly reduced.

Iron

Consistent measurements of dissolved iron concentration are available only for the Fox River, at Algonquin. The measurements at Algonquin indicate that dissolved iron has not exceeded the IPCB general use standard of 1000 micrograms per liter (μg/L). Concentrations of total iron in the tributaries to the Fox are occasionally above 2000 μg/L. Shallow ground water appears to be the source of the iron. High concentrations are generally, although not consistently, associated with high discharges from tributary streams (Broeren and Singh, 1987), because of velocities sufficient to scour the streambeds.

Dissolved Oxygen

The IPCB standard indicates that dissolved oxygen (DO) concentrations should not be below 5 mg/L. Data collected by the IEPA suggests general compliance with this standard on the Fox River. However, as discussed later in this section, DO concentrations can have considerable diurnal fluctuations, and some evidence indicates that nocturnal violations of the standard may be occurring frequently at locations along the Fox River.

Fecal Coliform Bacteria

IPCB standards indicate that fecal coliform counts in streams should not be above 200 per 100 milliliters (mL) for general use during the summer months (May-October), nor above 2000 counts per 100 mL when used for water supply. Broeren and Singh (1987) indicate that the general use standard is violated for a considerable number of samples taken on the Fox River in the more highly urbanized portion of Kane County.

Analysis of STORET Water Quality Data

The U.S. Environmental Protection Agency (USEPA) water quality database, STORET, contains water quality data for numerous locations on the Fox River. Table 1 is a selected list of the 32 locations at which data were measured over the greatest number of years. As noted, only six monitoring stations have been active since 1983. Periodic measurements have been taken at the following five stations since the early 1970s: near Channel Lake, Algonquin, South Elgin, Montgomery, and Dayton. Data from these five stations were selected for analysis. The drainage area above each of the five stations selected is 871 sq mi near Channel Lake, 1403 sq mi at Algonquin, 1556 sq mi at South Elgin, 1732 sq mi at Montgomery, and 2642 sq mi at Dayton. The corresponding river mileages are 113.6, 81.6, 67.2, 45.9, and 5.3, respectively, upstream of the confluence with the Illinois River.

The following seven parameters were monitored for most years at the five stations: dissolved oxygen (DO), chemical oxygen demand (COD), NO_2 + NO_3 nitrogen, NH_3 + NH_4 nitrogen, phosphorus, hardness, and fecal coliform. The IEPA data were analyzed to develop graphs showing water quality parameter values over time. For example, Figure 1 shows fecal

Table 1. Location of Selected Water Quality Stations on the Fox River

Location description	*River mile*	*Number of measurements*	*Years of measurement (through 1993)*
Wilmot, WI	116.6	189	1961-1976
Route 173 near Channel Lake*	113.6	237	1971-1993
Grass Lake Road	108.5	40	1972-1976
US Highway 12 at Nippersink Lake	106.4	46	1972-1978
Johnsburg	103.0	55	1964, 1972-1978
Route 120 at McHenry	100.4	81	1964-1983
Burtons Bridge (Route 176)	95.2	153	1964-1971, 1979-1993
Rawson Bridge	92.4	50	1964, 1972-1976
US Highway 14 near Fox River Grove	86.0	90	1964-1976
Route 62 at Algonquin*	81.6	831	1958-1993
Huntley Road at Carpentersville	76.7	51	1964-1971, 1982
Route 72 at West Dundee	75.7	31	1982-1983
Walnut Avenue at Elgin	70.1	53	1971-1977
State Street at South Elgin*	67.2	304	1960, 1964-1993
Route 64 at St. Charles	59.8	87	1964-1976
Route 38 at Geneva	57.8	83	1964, 1971-1983
Fabyan Park in Geneva	56.6	28	1982-1983
Weston Inlet at Batavia	55.5	89	1964, 1969-1971
Wilson Avenue at Batavia	55.2	475	1959-1976
Route 56 at North Aurora	51.9	60	1964-1965, 1971-1976
Illinois Avenue at Aurora	49.3	22	1964-1971
Route 65 at Aurora	48.4	76	1964, 1970
Mill Street at Montgomery*	45.9	272	1964-1993
US Highway 34 at Oswego	42.5	95	1958, 1964-1983
Route 47 at Yorkville	35.9	85	1964-1976
Millbrook bridge	28.6	59	1964, 1971-1983
Millington	25.2	48	1964, 1970-1976
Sheridan	19.1	478	1959-1976, 1982
US Highway 52 near Serena	15.5	55	1964, 1971-1976
Wedron	8.8	59	1964, 1971-1976 1982-1983
Dayton*	5.4	248	1974-1993
US Highway 6 at Ottawa	1.3	67	1961-1962, 1973

Notes:

* indicates water quality records selected for analysis in this study

The number of measurements listed for each water quality station is approximate and includes cases where multiple measurements were taken on the same day. The monitoring record for Algonquin, in particular, contains several short gaging periods in which measurements were taken continuously throughout the day. All types of measurements for which data are available are included, even when only one water quality parameter was measured. Therefore the number of measurements for a given parameter may be considerably lower than the total number of measurements.

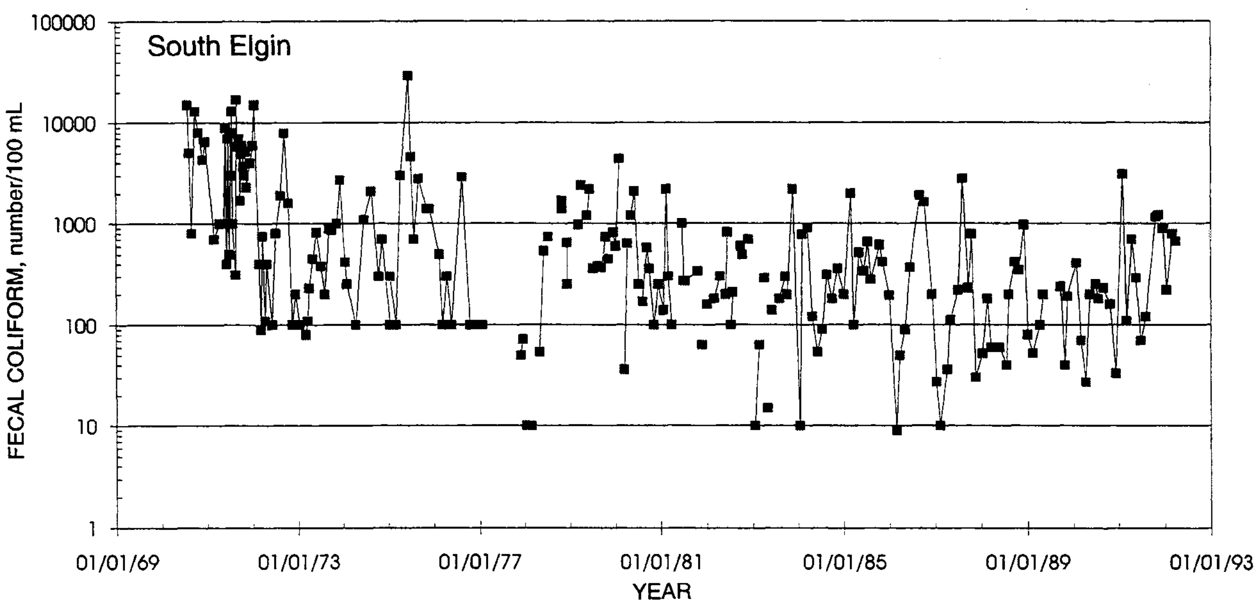

Figure 1. Fecal coliform counts measured at South Elgin, 1969-1992

coliform data plotted versus time for the Fox River at South Elgin. An examination of such plots for the selected water quality parameters at the five stations indicated the desirability of analyzing the data and developing cumulative frequency distributions at selected ranges of water quality parameter concentrations at each station using 1) the entire period of record, 2) four subperiods (1972 - 1976, 1977 - 1981, 1982 - 1986, and 1987 - 1992) to detect any time trends, 3) available record divided into four quarters of the year (January - March, April - June, July - September, and October - December) to assess any seasonal effects, and 4) any variation in parameter values with river discharge over the period of record.

Water Quality Parameter Statistics

In order to compare the overall statistics of selected water quality parameters from station to station, data collected at the five water quality stations in the Ambient Water Quality Monitoring Network (AWQMN) for the period 1972 to 1992 were used. These data sets were ranked from low to high, and cumulative percent values of observations were developed at various concentrations for each parameter. The results are summarized in Table 2. The total number of observations (N) for each parameter at a station are also included. The following inferences can be made:

DO: Overall concentrations do not vary significantly from station to station.

COD: The conditions near Channel Lake are better than at the other four stations, which do not differ significantly from one another.

$NO_2 + NO_3$: Overall conditions are better at Algonquin, followed in order by South Elgin, near Channel Lake, Montgomery, and Dayton. With the exception of Channel Lake, nitrate levels increase in the downstream direction. There are only isolated cases where the concentration exceeds the IEPA water supply standard of 10 mg/L.

$NH_3 + NH_4$: Overall conditions are better near Channel Lake and Dayton, followed in order by Algonquin, Montgomery, and South Elgin.

Phosphorus: Conditions are better near Channel Lake, followed in order by Algonquin, South Elgin, Montgomery, and Dayton. In other words, overall phosphorus

Table 2. Cumulative Percent Values of Observations at Various Concentrations of Water Quality Parameters

Range			*Cumulative percent values for Fox River*				
			near Channel Lake	*at Algonquin*	*at South Elgin*	*at Montgomery*	*at Dayton*
Dissolved oxygen (DO), mg/L							
4.0	to	6.0	3.1	5.5	2.2	0.0	3.1
4.0	to	10.0	39.8	45.5	41.9	41.2	33.9
4.0	to	12.0	66.4	66.8	65.4	65.6	64.6
4.0	to	16.0	96.9	95.5	98.5	100	98.5
4.0	to	>16.0	100	100	100		100
	N		128	202	136	131	65
Chemical oxygen demand (COD), mg/L							
5.0	to	20.0	18.7	12.7	12.4	11.7	18.8
5.0	to	40.0	83.3	56.3	62.1	57.9	61.9
5.0	to	60.0	99.3	93.0	94.1	94.5	88.1
5.0	to	>60.0	100	100	100	100	100
	N		150	142	153	145	160
NO3 + NO2 nitrogen, mg/L							
0.0	to	1.0	29.0	54.2	43.8	36.8	20.0
0.0	to	2.0	65.5	74.7	68.8	67.9	38.8
0.0	to	3.0	88.5	94.2	91.7	90.5	56.3
0.0	to	8.0	99.5	99.5	99.0	99.5	98.1
0.0	to	>8.0	100	100	100	100	100
	N		200	190	192	190	160
NH3 + NH4 nitrogen, mg/L							
0.0	to	0.1	55.8	48.4	29.7	40.6	70.2
0.0	to	0.3	88.4	73.2	66.2	74.8	87.0
0.0	to	0.8	98.8	93.5	90.3	94.4	98.8
0.0	to	1.2	100	99.4	95.2	97.2	99.4
0.0	to	1.6		99.4	97.2	97.9	99.4
0.0	to	>1.6		100	100	100	100
	N		163	153	145	143	161

Table 2. Concluded

Range			*Cumulative percent values for Fox River*				
			near Channel Lake	*at Algonquin*	*at South Elgin*	*at Mongomery*	*at Dayton*
Phosphorus, mg/L							
0.0	to	0.1	30.4	19.5	4.2	1.0	0.6
0.0	to	0.2	71.7	64.5	41.1	25.3	29.4
0.0	to	0.4	96.9	93.5	87.0	82.1	81.3
0.0	to	0.6	97.9	97.0	96.4	96.8	96.9
0.0	to	>0.6	100	100	100	100	100
N			194	200	192	190	160
Hardness, mg/L							
200	to	250	3.6	3.2	2.4		5.6
200	to	300	15.5	35.5	19.3		26.7
200	to	350	65.5	77.4	68.7		64.4
200	to	400	92.9	90.3	91.6		95.6
200	to	450	98.8	98.4	98.8		100
200	to	500	100	100	100		
N			84	62	83		90
Fecal coliform, #/100 mL							
5	to	100	52.0	73.2	27.0	7.9	40.0
5	to	300	80.6	86.1	54.1	30.5	64.4
5	to	1000	94.3	95.4	82.7	59.9	77.8
5	to	5000	98.9	98.5	97.8	92.1	90.0
5	to	>10,000	100	99.0	98.9	96.1	94.4
N			175	194	185	177	90

Note: N = number of observations

concentrations increase in the downstream direction or with increased drainage area.

Hardness: Overall hardness values do not vary significantly from station to station.

Fecal coliform: Better conditions or lower coliform levels occur at Algonquin followed in order by near Channel Lake, Dayton, South Elgin, and Montgomery. At all locations, fecal coliform counts are occasionally above the IPCB water supply standard (2000 counts per 100 mL) and frequently above the general use standard (200 counts per 100 mL) for stations considered in this study with the exception of Algonquin.

Water Quality Trends

The total period analysis sheds no light on any significant trends in water quality over time or any seasonal variability within the year. Such information is needed for optimal planning of water use, effluent discharges, and maintenance/improvement of river water quality. In order to detect any improvement or worsening of a water quality parameter at a station with respect to time, each data set containing the observations for the years 1972 - 1992 was divided into four time segments: 1972 - 1976, 1977 - 1981, 1982 - 1986, and 1987 - 1992. Data in each segment were ranked from low to high, and cumulative percent values of water quality observations were developed at various concentrations for each parameter (similar to those used for the entire data in Table 2). The results are given in Table 3. The following inferences can be drawn from the information presented:

DO: Concentrations have decreased slightly over time.

COD: Concentrations have increased slightly.

$NO_3 + NO_2$: Overall, there has been practically no change.

$NH_3 + NH_4$: There has been some decrease at all stations.

Phosphorus: There has been a steady, significant improvement at all stations except Montgomery.

Hardness: Overall, there is no consistent trend for hardness values.

Table 3. Cumulative Percent Values of Water Quality Observations
during Four Time Periods

Range	*Cumulative percent values* 1972-1976	1977-1981	1982-1986	1987-1992
Dissolved oxygen (DO), mg/L (IEPA Water Supply Standard = 5 mg/L min)				
Near Channel Lake				
4.0 to 6.0	5.0	2.2	2.3	
4.0 to 10.0	40.0	40.0	39.5	
4.0 to 12.0	62.5	62.2	74.4	
4.0 to 16.0	95.0	97.8	97.7	
4.0 to >16.0	100	100	100	
n	40	45	43	
At Algonquin				
4.0 to 6.0	6.0	10.9	0.0	5.0
4.0 to 10.0	50.0	41.3	47.8	43.3
4.0 to 12.0	62.0	60.9	76.1	68.3
4.0 to 16.0	90.0	97.8	97.8	96.7
4.0 to >16.0	100	100	100	100
n	50	46	46	60
At South Elgin				
4.0 to 6.0	0.0	6.8	0.0	
4.0 to 10.0	34.7	45.5	46.5	
4.0 to 12.0	61.2	70.5	65.1	
4.0 to 16.0	100	100	95.4	
4.0 to >16.0			100	
n	49	44	43	
At Montgomery				
4.0 to 6.0	0.0	0.0	0.0	
4.0 to 10.0	39.6	44.4	39.5	
4.0 to 12.0	64.6	66.7	65.8	
4.0 to 16.0	100	100	100	
n	48	45	38	
At Dayton				
4.0 to 6.0		4.0	2.5	
4.0 to 10.0		44.0	27.5	
4.0 to 12.0		56.0	70.0	
4.0 to 16.0		96.0	100	
4.0 to >16.0		100		
n		25	40	

Table 3. Continued

Range	*Cumulative percent values* 1972-1976	1977-1981	1982-1986	1987-1992
Chemical oxygen demand (COD), mg/L				
Near Channel Creek				
5.0 to 20.0		13.0	33.3	10.4
5.0 to 40.0		85.2	87.5	77.1
5.0 to 60.0		100	97.9	100
5.0 to >60.0			100	
n		54	48	48
At Algonquin				
5.0 to 20.0		10.0	17.4	11.3
5.0 to 40.0	100	55.0	56.5	54.6
5.0 to 60.0		92.5	95.7	90.5
5.0 to >60.0		100	100	100
n	3	40	46	53
At South Elgin				
5.0 to 20.0		14.5	13.3	8.7
5.0 to 40.0		51.6	75.6	63.1
5.0 to 60.0		93.6	100	89.1
5.0 to >60.0		100		100
n		62	45	46
At Montgomery				
5.0 to 20.0		11.3	11.6	12.2
5.0 to 40.0		54.7	67.4	53.1
5.0 to 60.0		96.2	95.3	91.8
5.0 to >60.0		100	100	100
n		53	43	49
At Dayton				
5.0 to 20.0		18.0	12.8	23.8
5.0 to 40.0		56.0	63.8	65.1
5.0 to 60.0		94.0	89.4	82.5
5.0 to >60.0		100	100	100
n		50	47	63

Table 3. Continued

Range	*Cumulative percent values* 1972-1976	1977-1981	1982-1986	1987-1992
<u>$NO_3 + NO_2$ nitrogen, mg/L</u> (IEPA Water Supply Standard = 10 mg/L)				
Near Channel Lake				
0.0 to 1.0	37.3	25.9	25.5	27.1
0.0 to 2.0	86.3	64.8	53.2	56.3
0.0 to 3.0	94.1	87.0	85.1	87.5
0.0 to 8.0	100	100	100	97.9
0.0 to >8.0				100
n	51	54	47	48
At Algonquin				
0.0 to 1.0	55.8	56.0	48.8	55.6
0.0 to 2.0	86.0	80.0	62.8	70.4
0.0 to 3.0	100	90.0	88.4	98.2
0.0 to 8.0		98.0	100	100
0.0 to >8.0		100		
n	43	50	43	54
At South Elgin				
0.0 to 1.0	57.1	47.1	35.6	34.0
0.0 to 2.0	79.6	74.5	60.0	59.6
0.0 to 3.0	98.0	90.2	82.2	95.7
0.0 to 8.0	100	100	95.6	100
0.0 to >8.0			100	
n	49	51	45	47
At Montgomery				
0.0 to 1.0	39.1	38.5	37.2	32.7
0.0 to 2.0	84.8	67.3	58.1	61.2
0.0 to 3.0	100	88.5	86.0	87.8
0.0 to >8.0		100	97.7	100
n	46	52	43	49
At Dayton		18.0	19.6	21.9
0.0 to 1.0				
0.0 to 2.0		40.0	43.5	34.4
0.0 to 3.0		64.0	52.2	53.1
0.0 to 8.0		96.0	100	98.4
0.0 to >8.0		100		100
n		50	46	64

Table 3. Continued

Range	*Cumulative percent values*			
	1972-1976	*1977-1981*	*1982-1986*	*1987-1992*
$NH_3 + NH_4$ nitrogen, mg/L (IEPA Standard = 1.5mg/L)				
Near Channel Lake		5.1		
0.0 to 0.1	53.3	67.3	47.9	52.1
0.0 to 0.3	100	82.7	83.3	95.8
0.0 to 0.8		100	95.8	100
0.0 to 1.2			100	
n	15	52	48	48
At Algonquin				
0.0 to 0.1	100	45.1	56.5	42.6
0.0 to 0.3		66.7	82.6	70.4
0.0 to 0.8		86.3	98.8	96.3
0.0 to 1.2		98.0	100	100
0.0 to 1.6		98.0		
0.0 to >1.6		100		
n	2	51	46	54
At South Elgin				
0.0 to 0.1	100	19.6	35.6	31.9
0.0 to 0.3		54.9	77.8	66.0
0.0 to 0.8		80.4	93.3	97.9
0.0 to 1.2		86.3	100	100
0.0 to 1.6		92.2		
0.0 to >1.6		100		
n	2	51	45	47
At Montgomery				
0.0 to 0.1		31.4	46.5	44.9
0.0 to 0.3		62.7	81.4	81.6
0.0 to 0.8		88.2	95.3	100
0.0 to 1.2		92.2	100	
0.0 to 1.6		94.1		
0.0 to >1.6		100		
n		51	43	49
At Dayton				
0.0 to 0.1		72.6	69.6	68.8
0.0 to 0.3		82.4	89.1	89.1
0.0 to 0.8		98.0	97.8	100
0.0 to 1.2		98.0	100	
0.0 to 1.6		98.0		
0.0 to >1.6		100		
n		51	46	64

Table 3. Continued

Range	Cumulative percent values 1972-1976	1977-1981	1982-1986	1987-1992
Phosphorus, mg/L (IEPA Standard for Reservoirs =0.05 mg/L)				
Near Channel Lake				
0.0 to 0.1	9.4	23.9	44.7	45.8
0.0 to 0.2	41.5	71.7	83.0	93.7
0.0 to 0.4	98.1	97.8	91.5	100
0.0 to 0.6	100	97.8	93.6	
0.0 to >0.6		100	100	
n	53	46	47	48
At Algonquin				
0.0 to 0.1	3.9	19.6	26.1	28.1
0.0 to 0.2	39.2	63.1	82.6	73.7
0.0 to 0.4	84.3	95.6	97.8	98.5
0.0 to 0.6	92.1	95.6	100	100
0.0 to >0.6	100	100		
n	51	46	46	57
At South Elgin				
0.0 to 0.1	-	3.9	8.9	4.3
0.0 to 0.2	12.2	43.1	57.8	53.2
0.0 to 0.4	69.4	90.2	95.6	93.7
0.0 to 0.6	91.8	98.0	100	95.7
0.0 to >0.6	100	100		100
n	49	51	45	47
At Montgomery				
0.0 to 0.1	0.0	4.1	0.0	0.0
0.0 to 0.2	4.1	24.5	41.9	32.6
0.0 to 0.4	67.4	85.7	93.0	83.74
0.0 to 0.6	95.9	98.0	95.3	98.0
0.0 to >0.6	100	100	100	100
n	49	49	43	49
At Dayton				
0.0 to 0.1		-	-	1.6
0.0 to 0.2		20.0	28.3	37.5
0.0 to 0.4		72.0	87.0	84.4
0.0 to 0.6		98.0	93.5	98.4
0.0 to >0.6		100	100	100
n		51	46	64

Table 3. Continued

Range	*1972-1976*	*1977-1981*	*1982-1986*	*1987-1992*
	Cumulative percent values			
Hardness. mg/L				
Near Channel Lake				
200 to 250		-	8.0	2.0
200 to 300		-	20.0	16.3
200 to 350		60.0	68.0	65.3
200 to 400		90.0	96.0	91.8
200 to 450		90.0	100	100
200 to 500		100		
n		10	25	49
At Algonquin				
200 to 250	-	5.9	4.8	-
200 to 300	66.7	23.5	42.9	33.3
200 to 350	100	65.7	81.0	81.0
200 to 400		82.4	90.5	95.2
200 to 450		94.1	100	100
200 to 500		100		
n	3	17	21	21
At South Elgin				
200 to 250		-	4.8	2.1
200 to 300		20.0	28.7	14.9
200 to 350		60.0	76.2	68.1
200 to 400		80.0	90.5	95.8
200 to 450		93.3	100	100
200 to 500		100		
n		15	21	47
At Montgomery				
200 to 250		20.0	4.3	
200 to 300		20.0	34.8	
200 to 350		60.0	87.0	
200 to 400		80.0	100	
200 to 450		100		
n		5	23	
At Dayton				
200 to 250		20.0	4.8	4.7
200 to 300		20.0	33.3	25.0
200 to 350		80.0	71.4	60.9
200 to 400		100	95.2	95.3
200 to 450			100	100
n		5	21	64

Table 3. Concluded

Range	Cumulative percent values 1972-1976	1977-1981	1982-1986	1987-1992
Fecal coliform, #/100 mL (IEPA Water Supply Standard = 2000 count/100ml)				
Near Channel Lake				
5 to 100	50.0	64.1	56.5	39.6
5 to 300	81.0	82.1	91.3	68.8
5 to 1,000	92.9	92.3	95.7	95.8
5 to 5,000	100	94.9	100	100
5 to 10,000		100		
n	42	39	46	48
At Algonquin				
5 to 100	69.4	71.7	72.3	78.9
5 to 300	85.7	87.0	80.9	90.4
5 to 1,000	89.8	95.7	97.9	98.1
5 to 5,000	95.9	100	100	98.1
5 to 10,000	95.9			100
5 to >10,000	100			
n	49	46	47	52
At South Elgin				
5 to 100	24.0	25.0	24.4	34.8
5 to 300	42.0	43.2	60.0	71.7
5 to 1,000	70.0	79.5	91.1	91.3
5 to 5,000	92.0	100	100	100
5 to 10,000	96.0			
5 to >10,000	100			
n	50	44	45	46
At Montgomery				
5 to 100	8.3	9.3	0.0	12.0
5 to 300	27.1	25.6	13.9	50.0
5 to 1,000	54.2	46.5	66.7	72.0
5 to 5,000	95.8	88.4	97.2	88.0
5 to 10,000	100	95.3	97.2	96.0
5 to >10,000		100	100	100
n	48	43	36	50
At Dayton				
5 to 100		40.0	36.4	47.6
5 to 300		64.0	61.4	71.4
5 to 1,000		76.0	75.0	85.7
5 to 5,000		80.0	95.5	90.5
5 to 10,000		88.0	100	90.5
5 to >10,000		100		100
n		25	44	21

Note: n = number of observations in a time period

Fecal coliform: There is practically no change near Channel Lake and at Algonquin, some reduction at Algonquin and Dayton, and a steady reduction at South Elgin and at Montgomery.

Seasonal Change in Water Quality Parameters

Water quality data at each of the five stations and for each of the seven parameters at a station were segmented into four quarters: January - March, April - June, July - September, and October - December. Data for each quarter were ranked from low to high and stored on the computer together with corresponding discharges (where available). Cumulative percent values for each parameter were developed for various ranges of values similar to those in Tables 2 and 3, and these are given in Table 4. The tabulated information can be used to describe seasonal differences in the parameters and define the relatively best and worst quarters at a station for each parameter. It can also be used to compare parameter values for a particular quarter from the most upstream station (near Channel Lake) to the most downstream station (at Dayton). The information will be helpful in overall water use planning and river water quality maintenance/improvement endeavors.

Results in Table 4 are interpreted below in terms of relatively best and worst quarters for various water quality parameters for the Fox River near Channel Lake.

DO: The DO conditions are assumed to be better when the cumulative percent values in the low ranges are low. [The limitations of this assumption are discussed in the next section.] Overall, quarter 4 or 1 is the best, and quarter 3 is the worst.

COD: The higher the cumulative percent values for low ranges, the better the COD conditions. Overall, quarter 1 is the best, and quarter 3 is the worst.

$NO_3 + NO_2$: The higher the cumulative percent values for low ranges, the better the $NO_3 + NO_2$ conditions. Overall, quarter 3 is the best, and quarter 1 is the worst.

$NH_3 + NH_4$: The higher the cumulative percent values for low ranges, the better the $NH_3 + NH_4$ conditions. Overall, quarter 2 or 3 is the best, and quarter 1 is the worst.

Phosphorus: The higher the cumulative percent values for low ranges, the better the phosphorus conditions. Overall, quarter 1 or 4 is the best, and quarter 3 is the worst.

Table 4. Cumulative Percent Values of Water Quality Observations during Four Quarters of the Year

Range	*Cumulative percent values for quarters* 1	2	3	4
Dissolved oxygen, DO, mg/L				
Near Channel Lake				
4.0 to 6.0	0.0	2.7	10.7	0.0
4.0 to 10.0	26.7	43.2	60.7	30.3
4.0 to 12.0	63.3	81.1	78.6	42.4
4.0 to 16.0	96.7	97.3	96.4	97.0
4.0 to >16.0	100	100	100	100
n'	30	37	28	33
At Algonquin				
4.0 to 6.0	1.9	5.7	15.2	0.0
4.0 to 10.0	21.2	49.1	91.3	21.6
4.0 to 12.0	50.0	69.8	100	52.9
4.0 to 16.0	96.2	100		86.3
4.0 to >16.0	100			100
n'	52	53	46	51
At South Elgin				
4.0 to 6.0	2.6	0.0	7.1	0.0
4.0 to 10.0	15.8	48.6	96.4	20.0
4.0 to 12.0	29.0	80.0	100	62.9
4.0 to 16.0	94.7	100		100
4.0 to >16.0	100			
n'	38	35	28	35
At Montgomery				
4.0 to 6.0	0.0	0.0	0.0	0.0
4.0 to 10.0	8.6	50.0	93.3	15.2
4.0 to 12.0	20.0	94.1	96.7	57.6
4.0 to 16.0	100	100	100	100
n'	35	34	30	33
At Dayton				
4.0 to 6.0	0.0	0.0	12.5	0.0
4.0 to 10.0	0.0	47.4	62.5	18.8
4.0 to 12.0	21.4	79.0	93.8	56.3
4.0 to 16.0	92.9	100	100	100
4.0 to >16.0	100			
n'	14	19	16	16

Table 4. Continued

Range	*Cumulative percent values for quarters* 1	2	3	4
Chemical oxygen demand (COD), mg/L				
Near Channel Creek				
5.0 to 20.0	50.0	6.8	3.0	18.0
5.0 to 40.0	100	79.6	57.6	94.9
5.0 to 60.0		100	97.0	100
5.0 to >60.0			100	
n'	34	44	33	39
At Algonquin				
5.0 to 20.0	45.7	0.0	0.0	5.6
5.0 to 40.0	100	37.1	0.0	80.6
5.0 to 60.0		97.1	75.8	97.2
5.0 to >60.0		100	100	100
n'	35	35	33	36
At South Elgin				
5.0 to 20.0	36.8	0.0	3.2	5.6
5.0 to 40.0	94.7	63.9	19.4	77.8
5.0 to 60.0	100	88.9	83.9	100
5.0 to >60.0		100	100	
n'	38	36	31	36
At Montgomery				
5.0 to 20.0	38.5	0.0	0.0	2.9
5.0 to 40.0	97.4	39.5	17.6	73.5
5.0 to 60.0	97.4	100	79.4	100
5.0 to >60.0	100		100	
n	39	38	34	34
At Dayton				
5.0 to 20.0	54.1	4.9	2.3	18.9
5.0 to 40.0	91.9	51.2	27.3	86.5
5.0 to 60.0	94.6	92.7	72.7	97.3
5.0 to >60.0	100	100	100	100
n'	37	41	44	37

Table 4. Continued

Range	Cumulative percent values for quarters 1	2	3	4
$NO_3 + NO_2$ nitrogen, mg/L				
Near Channel Lake				
0.0 to 1.0	0.0	40.7	61.0	17.3
0.0 to 2.0	27.1	79.7	90.2	65.4
0.0 to 3.0	83.3	91.5	95.1	84.6
0.0 to 8.0	100	100	95.1	100
0.0 to >8.0			100	
n'	48	59	41	52
At Algonquin				
0.0 to 1.0	1.9	70.2	95.1	63.3
0.0 to 2.0	34.0	89.4	100	85.7
0.0 to 3.0	88.7	97.8		98.0
0.0 to 8.0	100	100		100
0.0 to >8.0				
n'	53	47	41	49
At South Elgin				
0.0 to 1.0	0.0	56.3	75.0	51.1
0.0 to 2.0	28.9	79.2	95.5	78.7
0.0 to 3.0	86.5	93.8	97.7	91.5
0.0 to 8.0	100	100	100	97.9
0.0 to >8.0				100
n'	52	48	44	47
At Montgomery				
0.0 to 1.0	0.0	43.1	79.6	31.9
0.0 to 2.0	23.5	82.4	97.7	74.5
0.0 to 3.0	76.5	98.0	97.7	89.4
0.0 to 8.0	98.0	100	100	100
0.0 to >8.0	100			
n'	51	51	44	47
At Dayton				
0.0 to 1.0	0.0	9.8	51.2	13.2
0.0 to 2.0	0.0	34.2	74.4	39.5
0.0 to 3.0	24.3	48.8	88.4	57.9
0.0 to 8.0	100	95.1	97.7	100
0.0 to >8.0		100	100	
n'	37	41	43	38

Table 4. Continued

Range	*Cumulative percent values for quarters* 1	*2*	*3*	*4*
NH_3+ NH_4 nitrogen, mg/L				
Near Channel Lake				
0.0 to 0.1	10.5	80.0	75.6	55.8
0.0 to 0.3	63.2	97.8	97.3	93.0
0.0 to 0.8	94.7	100	100	100
0.0 to 1.2	100			
n'	38	45	37	43
At Algonquin				
0.0 to 0.1	5.3	79.0	58.3	53.7
0.0 to 0.3	36.8	89.5	86.1	82.9
0.0 to 0.8	84.2	94.7	97.2	97.6
0.0 to 1.2	100	97.4	100	100
0.0 to 1.6		97.4		
0.0 to >1.6		100		
n'	38	38	36	41
At South Elgin				
0.0 to 0.1	10.5	44.4	36.4	29.0
0.0 to 0.3	31.6	77.8	84.9	73.7
0.0 to 0.8	79.0	88.9	93.9	100
0.0 to 1.2	89.5	94.4	97.0	
0.0 to 1.6	94.7	94.4	100	
0.0 to >1.6	100	100		
n'	38	36	33	38
At Montgomery				
0.0 to 0.1	5.3	68.4	58.8	30.6
0.0 to 0.3	36.8	94.7	90.9	75.0
0.0 to 0.8	81.6	97.4	100	100
0.0 to 1.2	89.5	100		
0.0 to 1.6	92.1			
0.0 to >1.6	100			
n'	38	38	33	36
At Dayton				
0.0 to 0.1	32.4	82.9	88.6	73.7
0.0 to 0.3	56.8	95.1	100	94.7
0.0 to 0.8	94.6	100		100
0.0 to 1.2	97.3			
0.0 to 1.6	97.3			
0.0 to >1.6	100			
n'	37	41	44	38

Table 4. Continued

Range	Cumulative percent values for quarters 1	2	3	4
<u>Phosphorus, mg/L</u>				
Near Channel Lake				
0.0 to 0.1	55.3	22.4	2.4	39.6
0.0 to 0.2	87.2	70.7	41.5	83.3
0.0 to 0.4	97.9	96.6	92.7	100
0.0 to 0.6	97.9	96.6	97.6	
0.0 to >0.6	100	100	100	
n'	47	58	41	48
At Algonquin				
0.0 to 0.1	38.5	9.4	2.2	28.3
0.0 to 0.2	76.9	67.9	28.3	84.8
0.0 to 0.4	92.3	94.3	95.7	93.5
0.0 to 0.6	100	96.2	97.8	95.7
0.0 to >0.6		100	100	100
n'	52	53	46	46
At South Elgin				
0.0 to 0.1	7.7	0.0	2.3	6.3
0.0 to 0.2	59.6	33.3	11.4	56.3
0.0 to 0.4	92.3	89.6	70.5	93.8
0.0 to 0.6	98.1	95.8	93.2	97.9
0.0 to >0.6	100	100	100	100
n'	52	48	44	48
At Montgomery				
0.0 to 0.1	0.0	0.0	0.0	4.2
0.0 to 0.2	46.0	18.0	4.6	31.2
0.0 to 0.4	94.0	86.0	45.5	97.9
0.0 to 0.6	98.0	100	88.6	100
0.0 to >0.6	100		100	
n'	50	50	44	48
At Dayton				
0.0 to 0.1	2.7	0.0	0.0	0.0
0.0 to 0.2	46.0	31.7	9.1	35.1
0.0 to 0.4	78.4	90.2	72.7	86.5
0.0 to 0.6	91.9	100	97.7	97.3
0.0 to >0.6	100		100	100
n'	37	41	44	37

Table 4. Continued

Range	*Cumulative percent values for quarters* 1	2	3	4
Hardness, mg/L				
Near Channel Lake				
200 to 250	5.6	0.0	10.5	0.0
200 to 300	16.7	12.5	36.8	0.0
200 to 350	50.0	83.3	84.2	40.9
200 to 400	77.8	100	100	90.9
200 to 450	100			95.5
200 to 500				100
n'	18	24	19	22
At Algonquin				
200 to 250	7.7	0.0	5.0	0.0
200 to 300	23.1	28.6	50.0	21.4
200 to 350	30.8	92.9	100	71.4
200 to 400	53.9	100		100
200 to 450	92.3			
200 to 500	100			
n'	13	14	20	14
At South Elgin				
200 to 250	4.6	0.0	5.0	0.0
200 to 300	4.6	15.0	50.0	9.5
200 to 350	31.8	95.0	95.0	57.1
200 to 400	72.7	100	100	95.2
200 to 450	95.5			100
200 to 500	100			
n'	22	20	20	21
At Montgomery				
200 to 250	0.0	0.0	8.3	0.0
200 to 300	13.0	25.0	58.3	0.0
200 to 350	52.2	90.0	100	65.0
200 to 400	82.6	100		90.0
200 to 450	87.0			100
200 to 500	100			
n'	23	20	24	20
At Dayton				
200 to 250	0.0	4.6	16.0	0.0
200 to 300	5.3	18.2	68.0	8.3
200 to 350	36.8	77.3	92.0	45.8
200 to 400	84.2	95.5	100	100
200 to 450	100	100		
n'	19	22	25	24

Table 4. Concluded

Range	*Cumulative percent values for quarters* 1	2	3	4
<u>Fecal coliform, #/100 mL</u>				
Near Channel Lake				
5 to 100	58.5	52.0	48.7	48.9
5 to 300	85.4	92.0	74.4	68.9
5 to 1,000	97.6	100	94.5	86.7
5 to 5,000	100		97.4	97.8
5 to 10,000			100	100
n'	41	50	39	45
At Algonquin				
5 to 100	77.4	64.6	66.7	83.3
5 to 300	84.9	81.3	82.2	95.8
5 to 1,000	96.2	91.7	93.3	100
5 to 5,000	98.1	97.9	97.8	
5 to 10,000	100	97.9	97.8	
5 to >10,000		100	100	
n'	53	48	45	48
At South Elgin				
5 to 100	45.3	29.6	7.3	21.3
5 to 300	67.9	56.8	48.8	40.4
5 to 1,000	88.7	81.8	80.5	78.7
5 to 5,000	96.2	97.7	97.6	100
5 to 10,000	98.1	97.7	100	
5 to >10,000	100	100		
n'	53	44	41	47
At Montgomery				
5 to 100	20.0	2.1	4.6	2.3
5 to 300	50.0	27.7	16.3	25.6
5 to 1,000	70.0	80.8	55.8	58.1
5 to 5,000	98.0	93.6	81.4	95.4
5 to 10,000	100	97.9	90.7	100
5 to >10,000		100	100	
n'	50	47	43	43
At Dayton				
5 to 100	52.6	26.1	37.5	45.8
5 to 300	73.7	47.8	62.5	75.0
5 to 1,000	84.2	73.9	75.0	79.2
5 to 5,000	94.7	82.6	87.5	95.8
5 to 10,000	100	87.0	91.7	100
5 to >10,000		100	100	
n'	19	23	24	24

Note: n' = number of observations in a quarter

Hardness: The higher the cumulative percent values for low ranges, the lower the overall hardness. Overall, quarter 3 is the best, and quarter 1 is the worst.

Fecal coliform: The higher the cumulative percent values for low ranges, the better the conditions. Generally, fecal coliform counts are higher in quarters 2 and 3. However, there is no consistent seasonal trend.

Seasonal water quality changes in terms of relatively best and worst quarters are given in Table 5. It is obvious that relatively worst conditions occur in the third quarter for water quality parameters DO, COD, and phosphorus and in the first quarter for $NO_2 + NO_3$, $NH_3 + NH_4$, and hardness. The relatively worst fecal coliform conditions occurred in quarters 4, 2, 3, 3, and 2 near Channel Lake, at Algonquin, South Elgin, Montgomery, and Dayton, respectively.

The observed DO and COD concentrations for the relatively best and worst quarters are shown in Figures 2 and 3. For DO, conditions are better when levels are higher and worse when they are lower. Figure 2 shows that in terms of relatively best DO conditions, the five stations can be ranked as Montgomery, Dayton, South Elgin, Algonquin, and Channel Lake (in descending order) though the respective quarters are 1 for Dayton, Montgomery, and South Elgin, and 4 for Algonquin and Channel Lake. In terms of relatively worst conditions, the ranking is South Elgin, Algonquin, Montgomery, Dayton, and Channel Lake (all occurring in the third quarter); DO conditions for the Fox River near Channel Lake are better than at Montgomery, and so on.

Figure 3 shows the relatively best and worst quarters for COD at the five stations; conditions are better when COD levels are lower. The relatively best COD conditions occur in the first quarter at all five stations though upstream stations (Channel Lake and Algonquin) have somewhat better conditions than downstream stations. The relatively worst COD condition occurs in the third quarter at all five stations though the relative ranking is Channel Lake, South Elgin, Montgomery, Dayton, and Algonquin.

Seasonal Water Quality and Discharge Relationships

Dissolved oxygen (DO) versus discharge observations at the four stations are plotted in Figure 4 for the best quarter (high DO values) and Figure 5 for the worst quarter (low DO values). Figure 4 shows that 1) the Fox River near Channel Lake has DO in the general range of 8 to 16 milligrams per liter (mg/L) and there is practically no correlation with discharge, 2) at

Table 5. Relatively Best and Worst Quarters for Various Water Quality Parameters

Water quality parameter	*near Channel Lake*		*at Algonquin*		*at South Elgin*		*at Montgomery*		*at Dayton*	
	Best	*Worst*	*Best*	*Worst*	*Best*	*Worst*	*Best*	*Worst*	*Best*	*Worst*
DO	4	3	4	3	1	3	1	3	1	3
COD	1	3	1	3	1	3	1	3	1	3
NO_2+NO_3-N	3	1	3	1	3	1	3	1	3	1
NH_3+NH_4-N	2	1	2	1	4	1	2	1	3	1
Phosphorus	4	3	1,4	3	1,4	3	1,4	3	1,2,4	3
Hardness	3	4	3	1,4	3	1	3	1,4	3	1
Fecal coliform	2	4	4	2,3	4,1	2,3	1	3	1,4	2

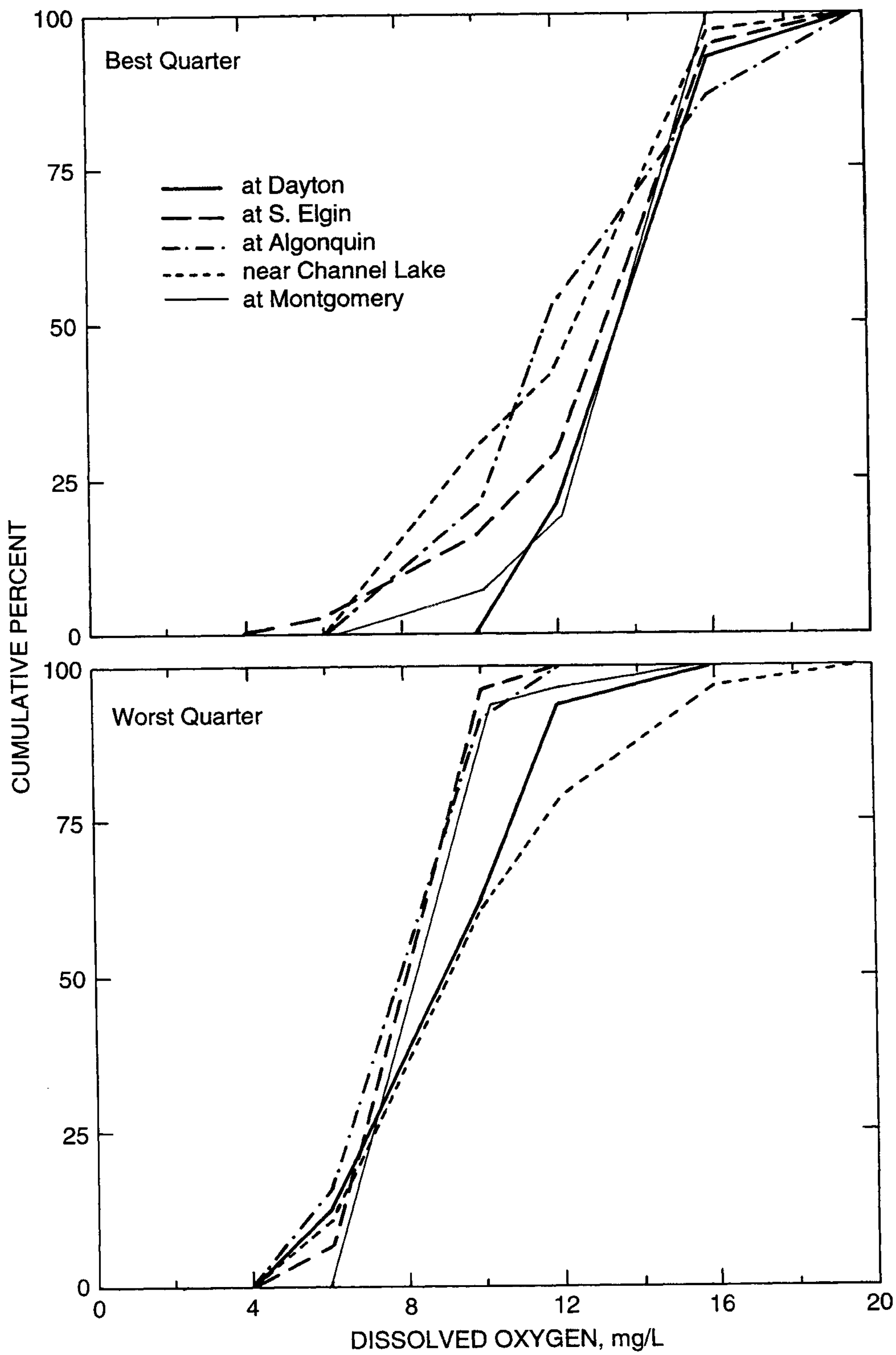

Figure 2. Cumulative percent graphs for dissolved oxygen (DO) in best and worst quarters

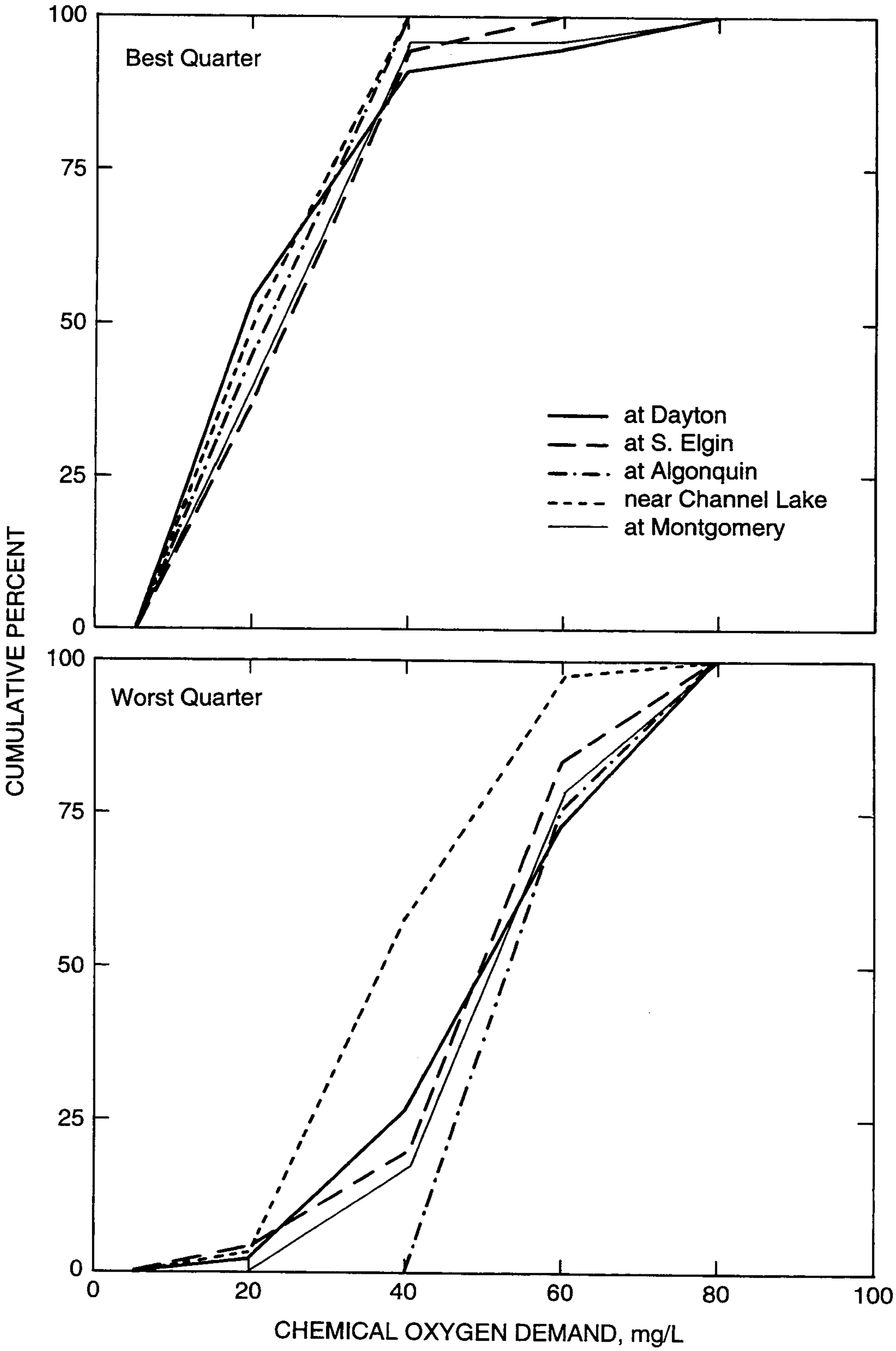

Figure 3. Cumulative percent graphs for chemical oxygen demand (COD) in best and worst quarters

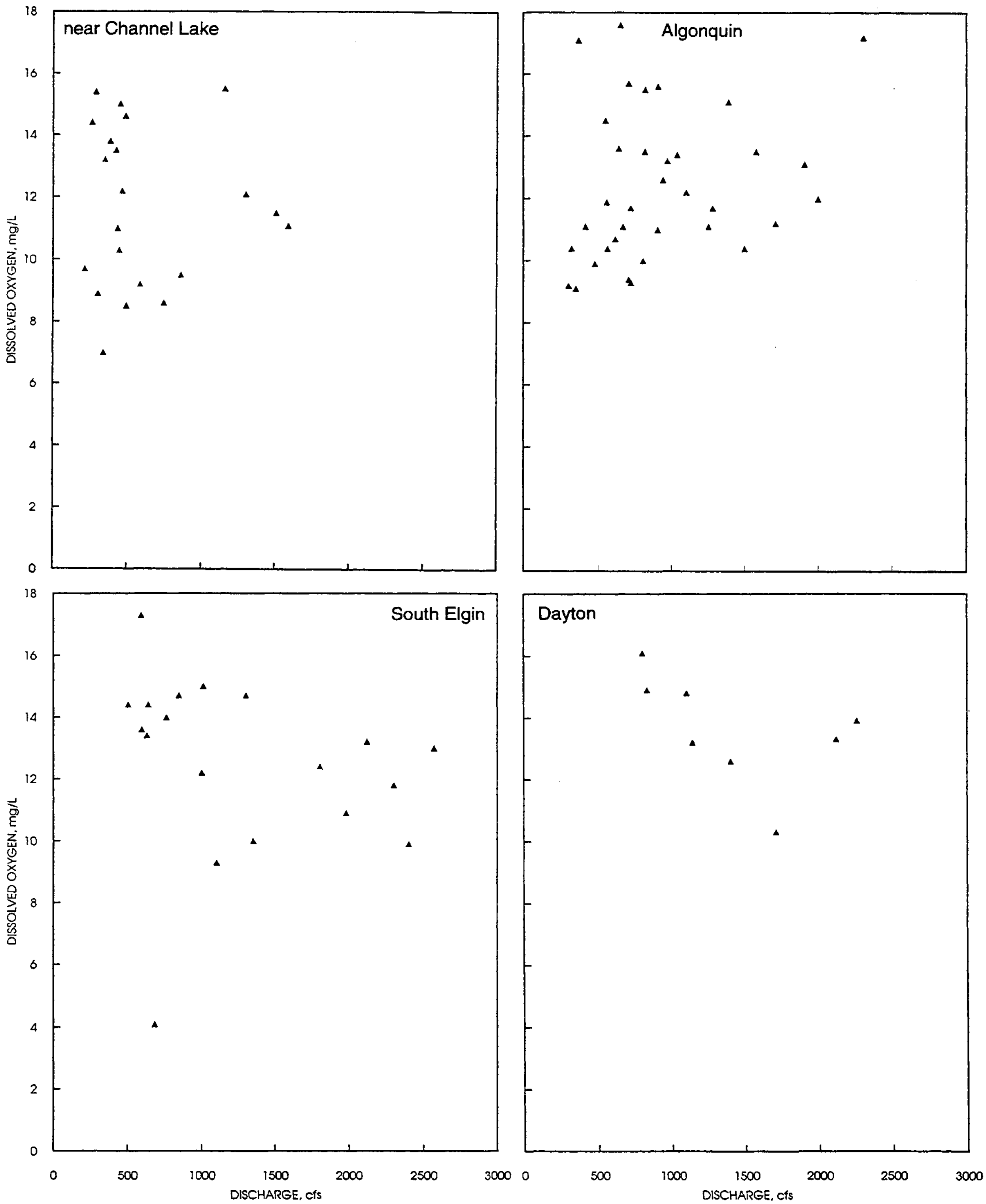

Figure 4. Plots of dissolved oxygen versus discharge observations in the best quarter at four stations along the Fox River

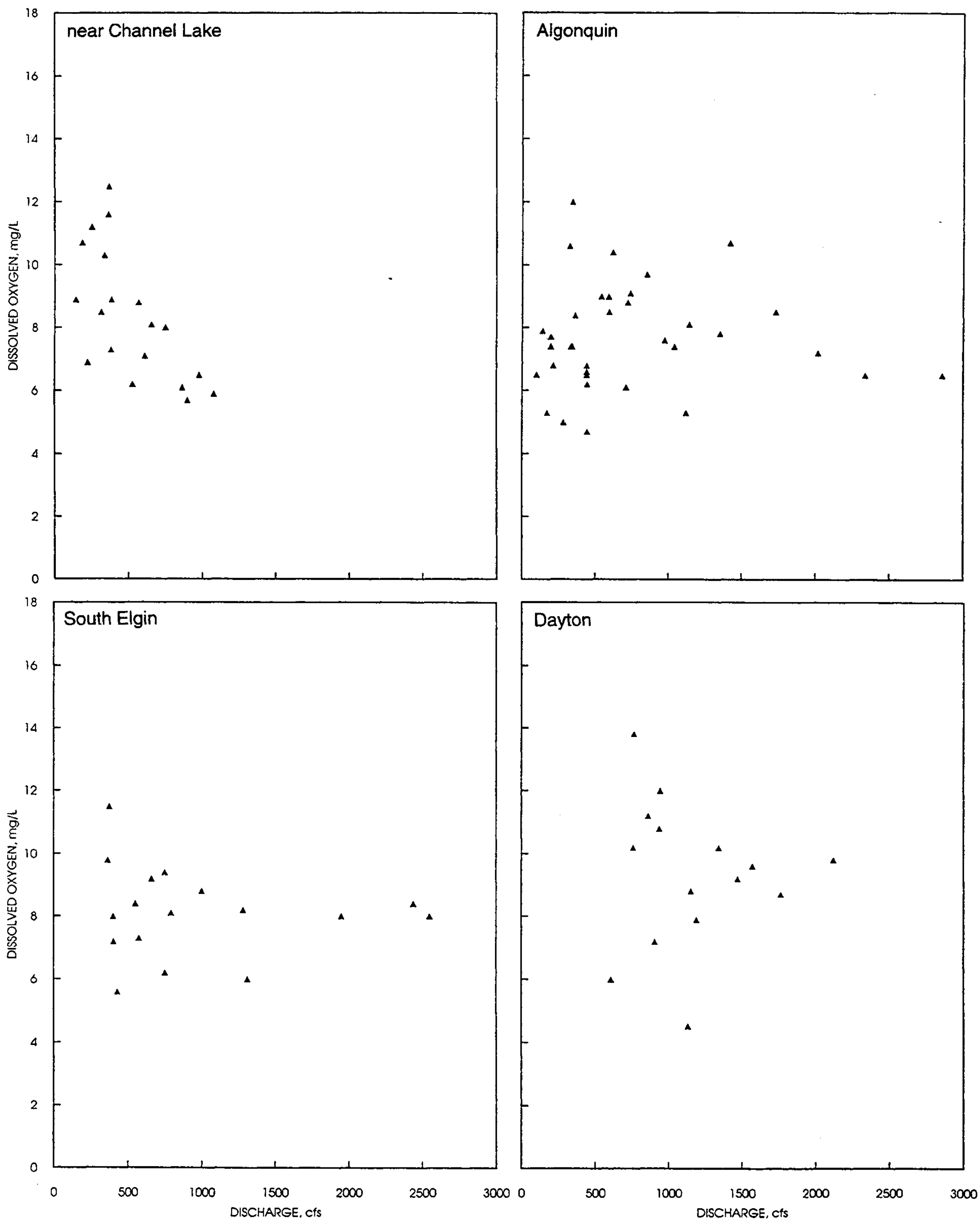

Figure 5. Plots of dissolved oxygen versus discharge observations in the worst quarter at four stations along the Fox River

Algonquin the DO generally is in the range of 9 to 18 mg/L and there is practically no correlation with discharge, 3) at South Elgin the DO range is still high, with one observation showing DO of 4 mg/L, and there seems to be a slight decrease in DO with increase in discharge, and 4) at Dayton (with less observations than at the three stations upstream) the DO ranges from 10 to 16 mg/L. Figure 5 shows that not only are the DO ranges significantly lower than in Figure 4, but also there is some tendency for reductions in DO levels with increases in discharge.

Chemical oxygen demand (COD), versus discharge observations at the four stations are plotted in Figure 6 for the best quarter (low COD values) and Figure 7 for the worst quarter (high COD levels). Figure 6 shows 1) COD in the general range of 10 - 30 mg/L near Channel Lake and practically no correlation with discharge, 2) the range substantially remains unchanged at Algonquin, 3) at South Elgin, the COD range remains about the same as at the two upstream stations but with about 10 percent values being much higher, and 4) the COD range remains about the same, but a few higher values do occur. Figure 7 shows that the COD range widens and rises: near Channel Lake it is 20 - 60 mg/L, and it increases with discharge; at Algonquin the range is 40 to 90 mg/L with a tendency for COD to decrease with an increase in discharge; at South Elgin the range becomes lower (about 35-70 mg/L) with practically no correlation with discharge; and at Dayton the COD ranges from 25-80 mg/L, and there is a marked decrease in COD with increase in discharge.

Changes in Water Quality with Streamflow, Water Temperature, and Time of Day

The occurrence of seasonal differences in water quality usually indicates that a more basic physical relationship is present, such as that between water quality and either streamflow or water temperature, both of which also display strong seasonal trends. Water temperature has a significant impact on DO, fecal coliform, and phosphorus concentrations (Figures 8 and 9). Figure 8 illustrates that DO concentrations decrease with increasing water temperature, and fecal coliform increases with increasing temperature, while figure 9(a) indicates that phosphorus concentrations increase with water temperature. It is believed that the streamflow magnitude also influences DO, COD, and phosphorus. However, the impact is only detected in the data for phosphorus as shown in Figure 9(b). It can be expected that water quality problems associated with all three parameters will be greatest during hot, dry summers.

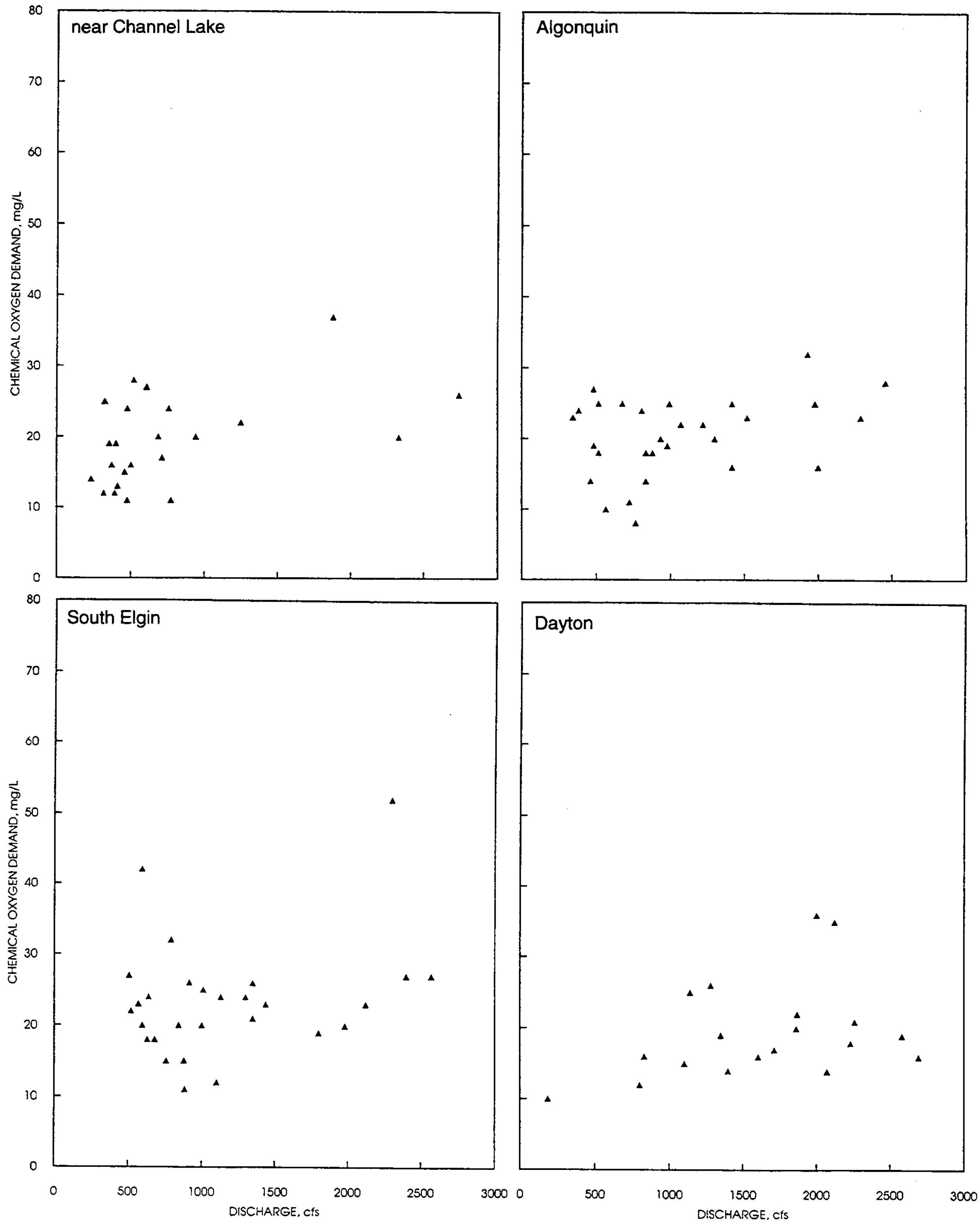

Figure 6. Plots of chemical oxygen demand versus discharge observations
in the best quarter at four stations along the Fox River

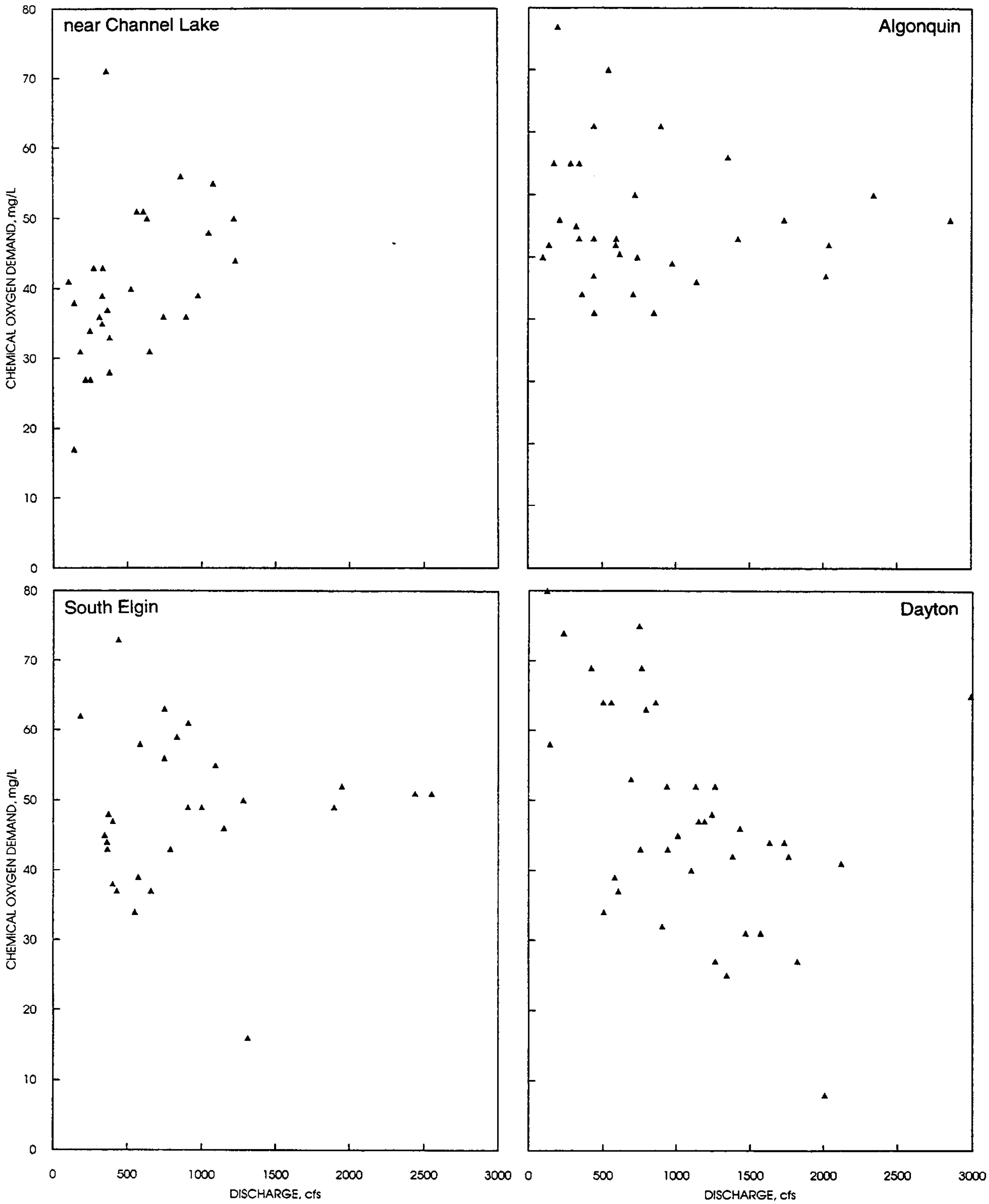

Figure 7. Plots of chemical oxygen demand versus discharge observations in the worst quarter at four stations along the Fox River

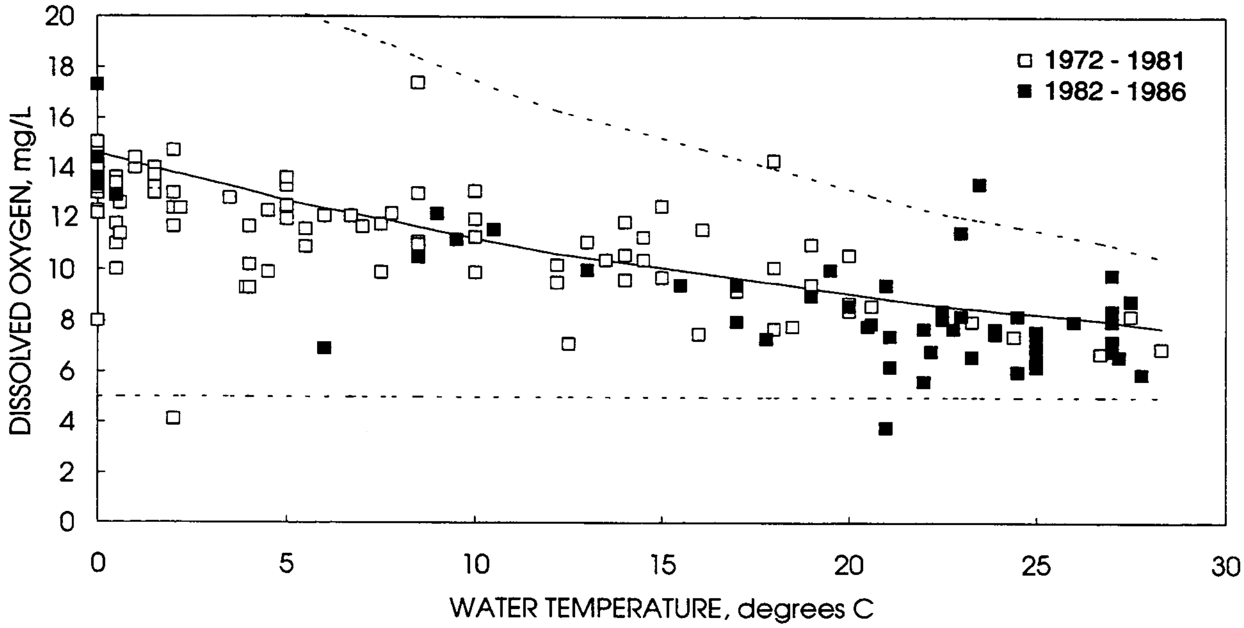

Figure 8a. Relationship between water temperature and dissolved oxygen concentrations: Fox River at South Elgin, 1972-1986

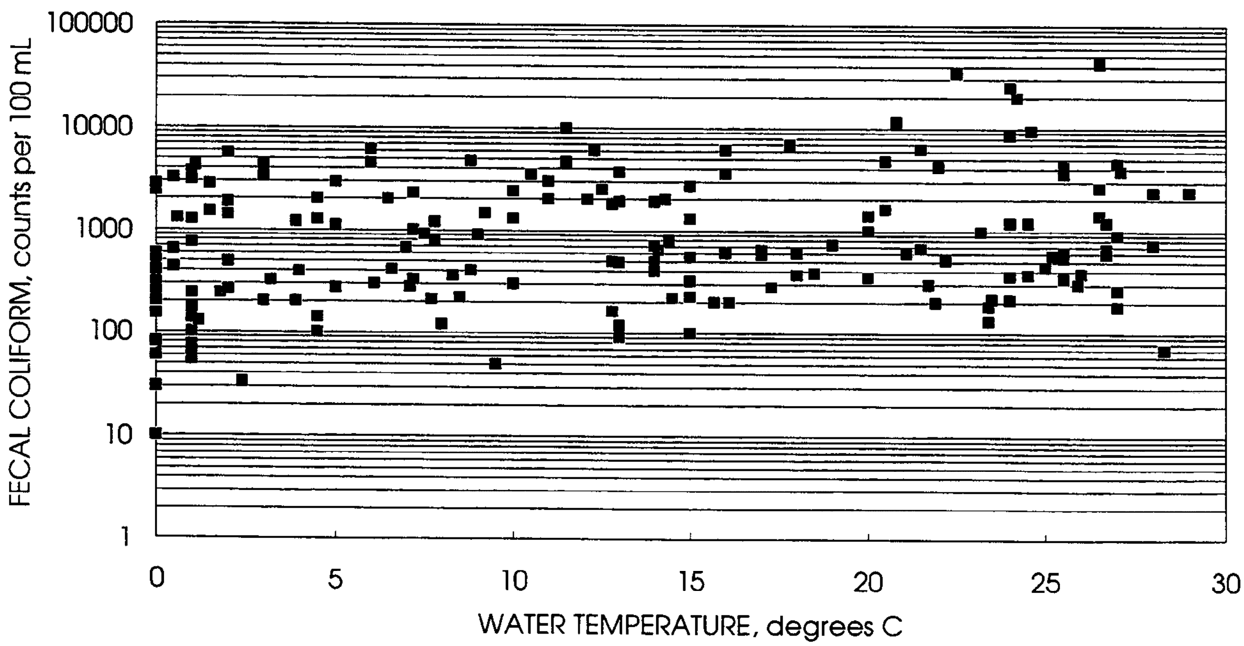

Figure 8b. Relationship between temperature and fecal coliform counts: Fox River at Montgomery, 1972-1992

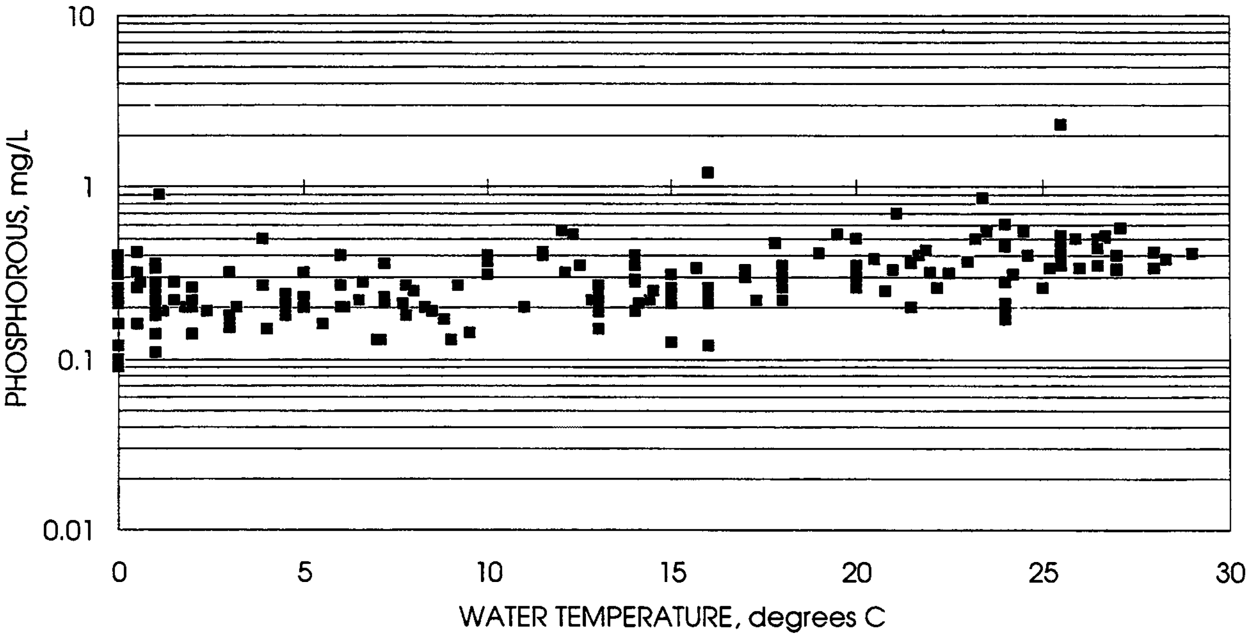

Figure 9a. Relationship between water temperature and phosphorus concentrations:
Fox River at Montgomery, 1972-1992

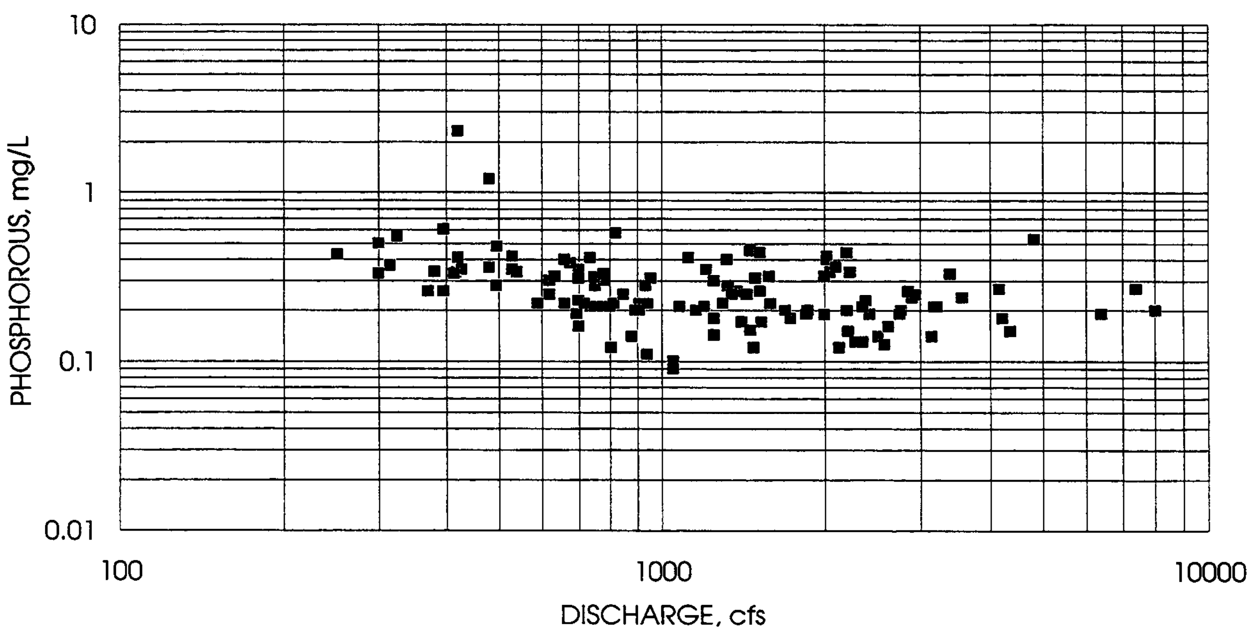

Figure 9b. Relationship between stream discharge and phosphorus concentrations:
Fox River at Montgomery, 1972-1992

Dissolved Oxygen. The bottom, middle, and top lines in Figure 8 represent the 5 mg/L general use standard for DO, the saturation level of DO, and the point at which the amount of supersaturation is greater than the difference between the saturation level and the 5 mg/L standard, respectively. The saturation level of dissolved oxygen decreases significantly with increasing temperature. As explained by Butts and Shackleford in Part B of this report, with pronounced algal activity the concentration of dissolved oxygen may become supersaturated during daylight photosynthetic oxygen production, but then drop well below saturation during nighttime algal respiration. The amount of supersaturation during the day is representative of the saturation deficit expected to occur at night. Thus, for those cases where the DO concentration is above the top line in Figure 8(a), it can be expected that a violation of the DO standard will occur during the night.

The diurnal fluctuation in DO concentrations is not evident from the water quality records, primarily because most water quality measurements are gathered in late morning and early afternoon. Figure 10 illustrates that over 61% of the measurements from the five locations under study were gathered between 10:00 a.m. and 3:00 p.m., and 95% were gathered between 8:00 a.m. and 6:00 p.m. Less than 2% of all measurements were gathered before sunrise or after sunset.

Measurements of DO during nighttime are available from STORET only for only a few days on the Fox River at Algonquin. Figure 11(a) shows the DO measurements at Algonquin for July 28-July 29, 1978. The bottom, middle, and top lines in this figure are the same as explained for Figure 8(a). As shown in Figure 11(a), the supersaturated DO concentrations during the afternoon are high and, as expected, nighttime violations of the IEPA standard occur. At water depths below the surface, the fluctuations in DO are not as great. Figure 11(b) illustrates that DO levels below the surface varied between 4 mg/L and 6 mg/L for much of the two-day sampling period in July 1978.

Additional examples of strong diurnal changes in dissolved oxygen are presented in Part B of this report by Butts and Shackleford for the St. Charles Pool on the Fox River. Butts and Shackleford indicate that the diurnal cycle in DO is most prominent directly behind the low channel dams on the Fox River, where the flow velocities are lower and algal growth reaches its greatest concentrations. However, the fluctuation in DO is also great enough in the free-flowing

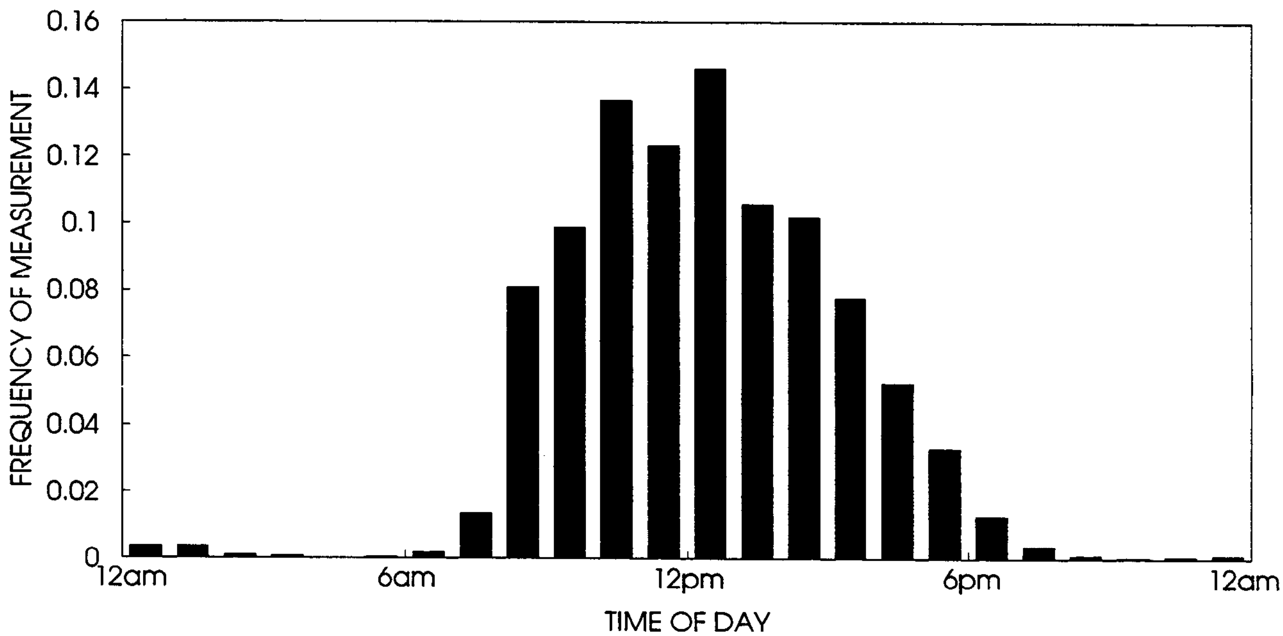

Figure 10. Frequency of dissolved oxygen measurements versus time of measurements: Fox River water quality stations

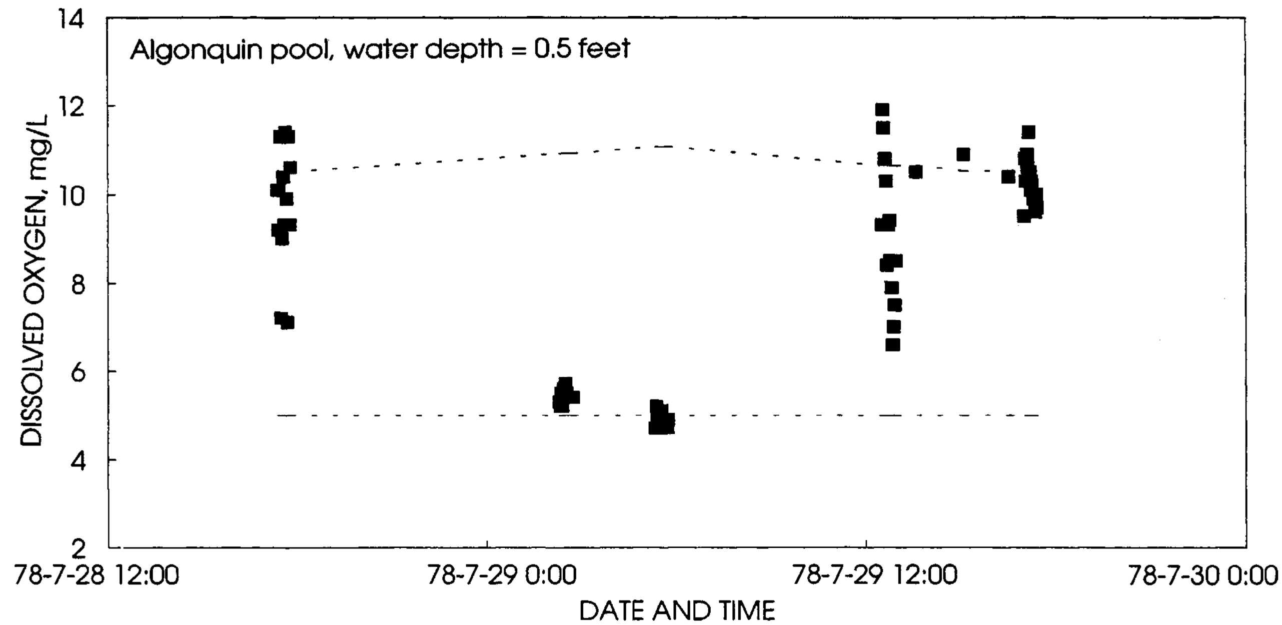

Figure 11a. Dissolved oxygen concentrations measured at Algonquin near water surface, July 28-29, 1978

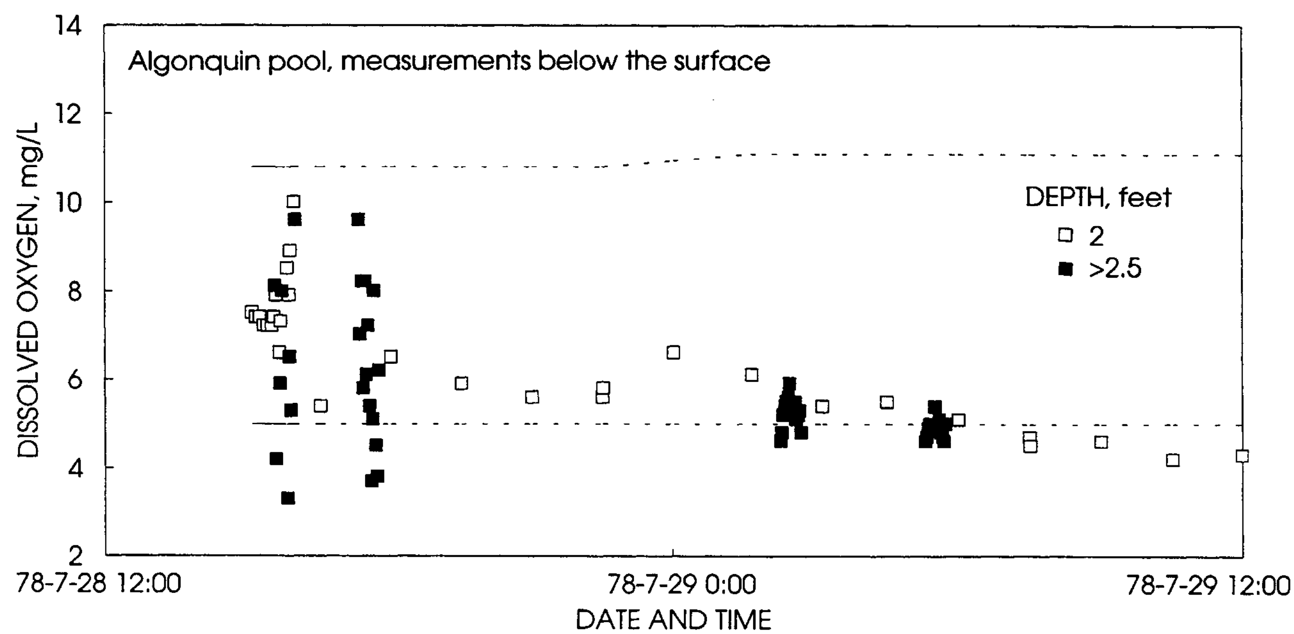

Figure 11b. Dissolved oxygen concentrations measured at Algonquin at least 2 feet below water surface, July 28-29, 1978

reaches of the stream to cause nocturnal violations of the 5 mg/L standard. The DO measurements taken at Algonquin and near Channel Lake are from pooled areas. The DO measurements from South Elgin, Montgomery, and Dayton were taken downstream of dams in relatively free-flowing reaches of the river. The latter three stations may not have as much variability in DO as nearby pooled areas.

Figure 8(a) also shows that the more recent DO measurements (from 1982 to 1986) were taken during periods of high water temperature. The analysis of the water quality records, presented earlier, indicates that DO concentrations have been decreasing over time. But it is apparent from Figure 8(a) that this decrease is related to the period during which the samples were taken, and is not necessarily the result of a major change in the river water quality.

Discussion

As indicated earlier, significant reductions in phosphorus concentrations and fecal coliform counts have occurred during the past twenty years. During the same period of time there have been increases in COD. Changes in DO are less difficult to identify, not only because of the complicating influences of time of measurement and water temperature, but also because the only measurements of DO taken on the Fox River since 1986 have been at Algonquin (Table 3). Nevertheless, it is apparent that the DO concentrations in the Fox River have not improved, and that nocturnal violations of the IEPA standard may be occuring, and are likely to be particularly frequent during warm weather behind the low channel dams along the river.

POPULATIONS AND WATER DEMANDS

The Fox River basin covers major portions of Kane, Kendall, and McHenry Counties, and some portions of Lake, Cook, DuPage, Grundy, LaSalle, Lee, and DeKalb Counties (Figure 12). The majority of the population centers along the Fox River lie in Kane, the lower part of McHenry, and western Lake Counties. Population growth is continuing at a rapid pace in these areas mostly because of a population shift from the metropolitan Chicago area to the west.

Populations, water demands, and present sources of water supply and their adequacy were analyzed for towns and cities in the Fox River basin and nearby areas to determine the present use of the Fox River for municipal water supplies as well as the possibility of some more municipalities withdrawing water from the river if their increased future demands cannot be met from ground-water resources. However, the forthcoming new U.S. Environmental Protection Agency (USEPA) regulations that require testing of various chemicals, organics, contaminants, microbes, etc., so as not to exceed the permissible limits, will greatly increase the water treatment costs. These regulations will primarily affect surface water supplies. Big supply systems such as the city of Chicago and other Lake Michigan regional systems benefit from economies of scale. However, individual and relatively small surface water supply systems, serving at least 10,000 people, will see their treatment costs increase greatly. Ground-water supplies will be affected to a minor extent.

Historical and Projected Populations

The relevant information was developed and compiled on a countywise basis. Some towns cover two or three counties. Total population figures as well as population in an individual county are included in the tables. Kane and McHenry county populations and future forecasts are given in Tables 6 and 7. Similar information for western Lake County, Cook (Barrington and Hanover townships), western DuPage, Kendall, DeKalb, and LaSalle Counties is given in Table 8. The Northern Illinois Planning Commission (NIPC) 2010 population projections or forecasts are also included in the tables.

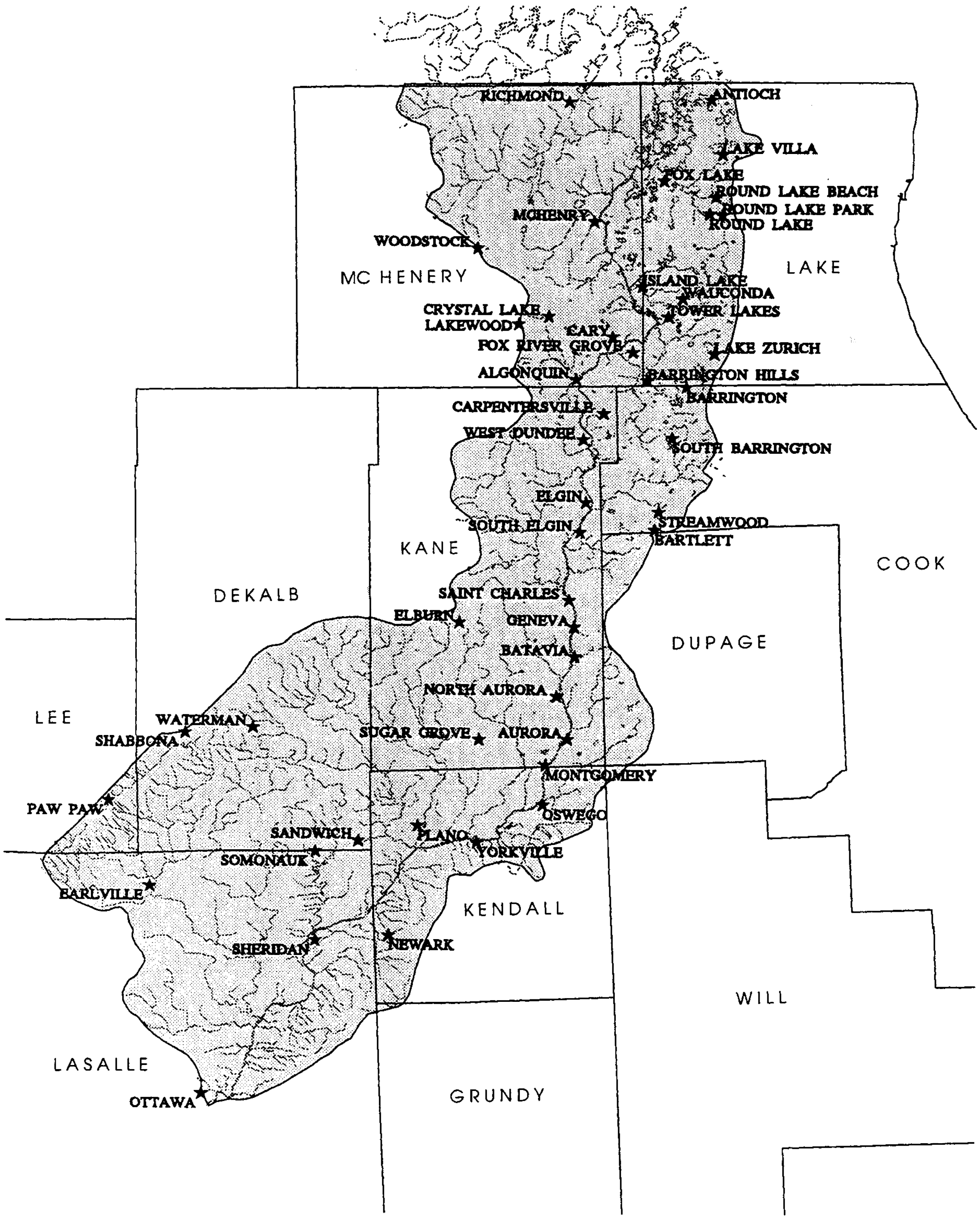

Figure 12. Location map of Fox River basin, drainage network, and towns

Table 6. Kane County: Census Populations and Future Estimates

Town		*Census population*				*NIPC 2010 forecast*
		1960	*1970*	*1980*	*1990*	
Algonquin		-	-	258	1,469	5,000*
	T	2,014	3,513	5,834	11,663	20,321
Aurora		63,715	74,389	79,610	84,770	97,890*
	T	63,715	74,389	81,293	99,581	148,317
Barrington Hills		-	91	105	151	300*
	T	1,726	2,805	3,631	4,202	5,942
Bartlett		-	-	-	11	70*
	T	1,540	3,501	13,254	19,373	41,912
Batavia		7,496	9,060	12,574	17,076	23,581
Burlington		360	456	442	400	495
Carpentersville		17,424	24,059	23,272	23,049	33,790
East Dundee		2,221	2,920	2,618	2,721	2,758
Elburn		960	1,122	1,224	1,275	6,167
Elgin		46,579	50,344	52,778	61,610	73,820*
	T	49,447	55,691	63,798	77,010	99,755
Geneva		7,646	9,049	9,881	12,617	20,985
Gilberts		238	336	405	987	3,069
Hampshire		1,309	1,611	1,735	1,843	4,226
Maple Park		592	660	637	637	823
	T	592	660	637	641	840*
Montgomery		2,122	3,258	3,329	3,675	6,431
	T	2,122	3,278	3,369	4,267	7,650*
North Aurora		2,088	4,833	5,205	5,940	10,519
Pingree Grove		173	174	183	138	277
St. Charles		9,269	12,928	17,471	22,491	35,500*
	T	9,269	12,945	17,492	22,501	35,547
Sleepy Hollow		311	1,729	2,000	3,241	3,631
South Elgin		2,624	4,289	6,218	7,474	10,479
Sugar Grove		326	1,230	1,366	2,005	7,214
Valley View		1,741	1,723	2,112	2,600*	3,200*
Wayne		-	111	480	823	1,841*
	T	373	572	960	1,541	7,941
West Dundee		2,530	3,295	3,551	3,728	6,000*

Table 6. (concluded)

	Census population				*NIPC 2010 forecast*
	1960	*1970*	*1980*	*1990*	
Total in county	169,724	207,667	227,454	260,731	358,066
County population	208,246	251,005	278,405	317,471	426,100
% population in towns	81.5	82.7	81.7	82.1	84.0
Population (unincorporated areas)	38,522	43,338	50,951	56,740	68,034

Notes: * = estimated town population; where NIPC total population estimate is not available, a population figure is determined from past trends and information on nearby communities

T = total population in town in two or more counties

Illinois Bureau of the Budget 2010 population estimate = 396,686

NIPC 2010 population estimate = 426,100

Table 7. McHenry County: Census Populations and Future Estimates

Town		Census population				NIPC 2010
		1960	1970	1980	1990	forecast
Algonquin		2,014	3,515	5,576	10,194	15,321*
	T	2,014	3,515	5,834	11,663	20,321
Barrington Hills		335	550	1,022	1,223	1,842*
	T	1,726	3,805	3,631	4,202	5,942
Bull Valley		-	-	509	574	1,311
Cary		2,530	4,358	6,640	10,043	16,563
Crystal Lake		8,314	14,541	18,590	24,512	48,517
Fox Lake		-	-	207	48	200*
	T	3,700	4,511	6,831	7,478	12,978
Fox River Grove		1,866	2,245	2,515	3,551	4,994
Fox River Valley		-	428	520	566	2,105*
	T	-	428	520	660	3,105
Harvard		4,248	5,177	5,126	5,975	6,304
Hebron		701	781	786	809	889
Holiday Hills		-	-	802	807	2,025
Huntley		1,143	1,432	1,646	2,453	4,458
Island Lake		509	578	724	2,466	5,900*
	T	1,639	1,973	2,293	4,449	10,667
Lake in the Hills		2,046	3,240	5,651	5,866	17,619
Lakemoor		736	797	723	1,061	3,400*
	T	736	797	723	1,322	5,410
Lakewood		635	782	1,254	1,609	2,679
McCullom Lake		759	873	947	1,033	1,406
McHenry		3,336	6,772	10,908	16,177	24,988
Marengo		3,568	4,235	4,361	4,768	6,526
Oakwood Hills		213	476	1,255	1,498	2,209
Pistake Highlands CDP				3,623	3,848	4,400
Prairie Grove		-	-	680	654	2,077
Richmond		855	1,153	1,068	1,016	1,407
Spring Grove			348	571	1,066	1,922
		301				
Sunnyside (Johnsburg)		303	367	1,432	1,529	3,443
Union		480	579	622	542	866
Wonder Lake, CDP		3,543	4,806	5,917	6,664	7,000*
Woodstock		8,897	10,226	11,725	14,353	19,379

Table7. (concluded)

	Census population				*NIPC 2010 forecast*
	1960	*1970*	*1980*	*1990*	
Total in county	47,332	68,259	95,400	124,905	209,750
County population	84,210	111,555	147,897	181,595	266,850⌖
% population in towns	56.2	61.2	64.5	68.8	78.6
Population (unincorporated areas)	36,878	43,296	52,497	56,690	57,100

Notes: *= estimated town population; where NIPC total population estimate is not available, a population figure is determined from past trends and information nearby communities

T = total population in town in two or more counties

⌖ = estimated using NIPC 2010 town populations (in McHenry County) and expected % population in towns.

Illinois Bureau of the Budget 2010 population estimate = 216,570
NIPC 2010 population estimate = 235,800

Table 8. Western Lake, Cook, Western DuPage, Kendall, DeKalb, and LaSalle Counties: Census Populations and Future Estimates

Town		*Census population* 1960	1970	1980	1990	*NIPC 2010 forecast*
Western Lake County						
Antioch		2,268	3,189	4,419	6,105	9,416
Barrington		1,958	3,450	4,074	4,345	6,248*
	T	5,434	8,581	9,029	9,504	12,496
Barrington Hills		293	368	524	698	1,188*
	T	1,726	2,805	3,631	4,202	5,942
Channel Lake CDP		-	-	1,613	1,660	
Fox Lake		3,700	4,511	6,624	7,430	12,900*
	T	3,700	4,511	6,831	7,478	12,978
Fox River Valley Gardens		-	-	-	94	1,000*
	T	-	428	520	660	3,105
Island Lake		1,130	1,395	1,569	1,983	4,767*
	T	1,639	1,973	2,293	4,449	10,667
Lake Barrington		172	347	2,320	3,855	4,903
Lake Catherine CDP		-	1,219	1,335	1,515	
Lake Villa		903	1,090	1,462	2,857	7,955
Lake Zurich		3,458	4,082	8,225	14,947	20,116
Lakemoor		-	-	-	261	2,010*
	T	736	797	723	1,322	5,440
Long Lake CDP		-	-	2,201	2,888	
North Barrington		282	1,411	1,475	1,787	3,503
Round Lake		997	1,531	2,644	3,541	7,298
Round Lake Beach		5,011	5,717	12,921	16,434	19,533
Round Lake Heights		-	1,144	1,192	1,251	1,955
Round Lake Park		2,565	3,148	4,032	4,045	14,601
Third Lake		216	199	222	1,248	1,849
Tower Lake		-	932	1,177	1,333	1,392
Wauconda		3,227	5,460	5,688	6,294	10,067
Cook County (Barrington & Hanover townships)						
Barrington		3,476	5,131	4,955	5,159	6,248*
	T	5,434	8,581	9,029	9,504	12,496
Barrington Hills		1,098	1,796	1,980	2,130	2,496*
	T	1,726	2,805	3,631	4,202	5,942
Bartlett		1,540	2,510	4,705	7,276	16,790*
	T	1,540	3,501	13,254	19,373	41,912
Elgin		2,868	5,347	11,020	15,400	25,935*
	T	49,447	55,691	63,798	77,010	99,755

Table 8. (continued)

Town		*Census population* 1960	*1970*	*1980*	*1990*	*NIPC 2010 forecast*
Hanover Park		451	11,735	18,158	18,662	18,900*
	T	451	11,735	28,850	32,895	37,914
Hoffman Estates		8,296	22,238	37,292	46,561	51,217
Inverness		-	1,674	4,046	6,503	9,201
Schaumburg	T	986	18,531	53,288	68,576	86,700*
		986	18,531	53,305	68,586	86,959
SouthBarrington		473	348	1,168	2,937	4,791
Streamwood		4,821	18,176	22,456	30,987	39,380
WesternDuPage County						
Aurora		-	-	1,683	14,811	50,427*
	T	63,715	74,389	81,293	99,581	148,317
Bartlett		-	991	8,549	12,086	25,122*
	T	1,540	3,501	13,254	19,373	41,912
Carol Stream		836	4,434	15,472	31,716	39,100
Hanover Park		-	-	10,692	14,233	19,014*
	T	451	11,735	28,850	32,895	37,914
Naperville		12,933	22,794	41,429	72,931	95,054*
	T	12,933	22,794	42,330	86,331	126,738
Schaumburg		-	-	17	10	259*
	T	986	18,531	53,305	68,586	86,959
Warrenville		-	3,281	7,519	11,333	13,700
Wayne		373	461	460	718	6,100*
	T	373	572	940	1,541	7,941
West Chicago		6,854	9,988	12,550	14,796	23,300
Winfield		1,575	4,285	4,422	7,096	10,600
Kendall County (Fox River watershed)						
Newark		489	590	798	840	1,020⌖
Oswego		1,510	1,862	3,021	3,876	5,800⌖
Plano		3,343	4,664	4,875	5,104	5,550⌖
Sandwich		-	10	3	1	
	T	3,842	5,056	5,244	5,567	6,180⌖
Yorkville		1,565	2,049	3,422	3,925	5,300⌖
DeKalb County (Fox River watershed)						
Hinckley		940	1,053	1,447	1,682	2,000⌖
Sandwich		3,842	5,046	5,241	5,566	
	T	3,842	5,056	5,244	5,567	6,180⌖

Table 8. (concluded)

Town	*Census population 1960*	*1970*	*1980*	*1990*	*NIPC 2010 forecast*
Shabbona	690	730	851	897	970⌖
Somonauk	899	1,012	1,107	1,031	
T	899	1,112	1,344	1,263	1,840⌖
Waterman	916	990	943	1,074	1,170⌖
LaSalle County (Fox River watershed)					
Earlville	1,420	1,410	1,382	1,435	1,490⌖
Sheridan	704	724	719	738	900⌖
Somonauk	-	100	237	232	
T	899	1,112	1,344	1,263	1,840⌖
Ottawa	19,408	18,716	18,166	17,451	

Notes: * = estimated town population; where NIPC total population estimate is not available, a population figure is determined from past trends and information on nearby communities

T = total population in town in two or more counties

⌖ = estimated population from historical trends

Kane County

The county census populations, Illinois Bureau of the Budget (IBOB) population projections, and NIPC 2010 population forecast for Kane County are given below.

	Census populations			
Year	1960	1970	1980	1990
Population	208,246	251,005	278,405	317,471

	IBOB population projections			*NIPC forecast*
Year	2000	2010	2020	2010
Population	364,019	396,686	419,894	426,100

Census populations and NIPC 2010 forecast for towns in Kane County are given in Table 6. Combined population of the towns as a percent of total Kane County population was 81.5, 82.7, 81.7, and 82.1% in 1960, 1970, 1980, and 1990, respectively. Over this 30-year period the percentage has stayed close to 82%. The total of NIPC 2010 forecast for towns in Table 6 is 84% of the corresponding NIPC county population forecast. An increase from 82 to 84% over 20 years (Figure 13) is justifiable because of westward movement of people from Cook and DuPage Counties.

County populations (census, IBOB, and NIPC) are plotted in Figure 13. The 2010 NIPC forecast is about 7.4% higher than the corresponding IBOB projection. Many towns (e.g., Aurora, Carpentersville, Geneva, North Aurora, St. Charles, and West Dundee) show a population increase of 50 to 100% over the period 1990-2010. A significant part of the increase has already occurred in the last three years. Inquiries made to many municipalities confirmed the overall suitability of NIPC forecasts though some towns expected increases in population beyond NIPC estimates. The available IBOB projections are only for the county population, and there is no satisfactory and viable procedure available to develop individual town population estimates when rate of population growth in an individual town is a function of so many factors with rather uncertain future values.

McHenry County

The county populations, IBOB population projections, and NIPC 2010 population forecast for McHenry County are given below.

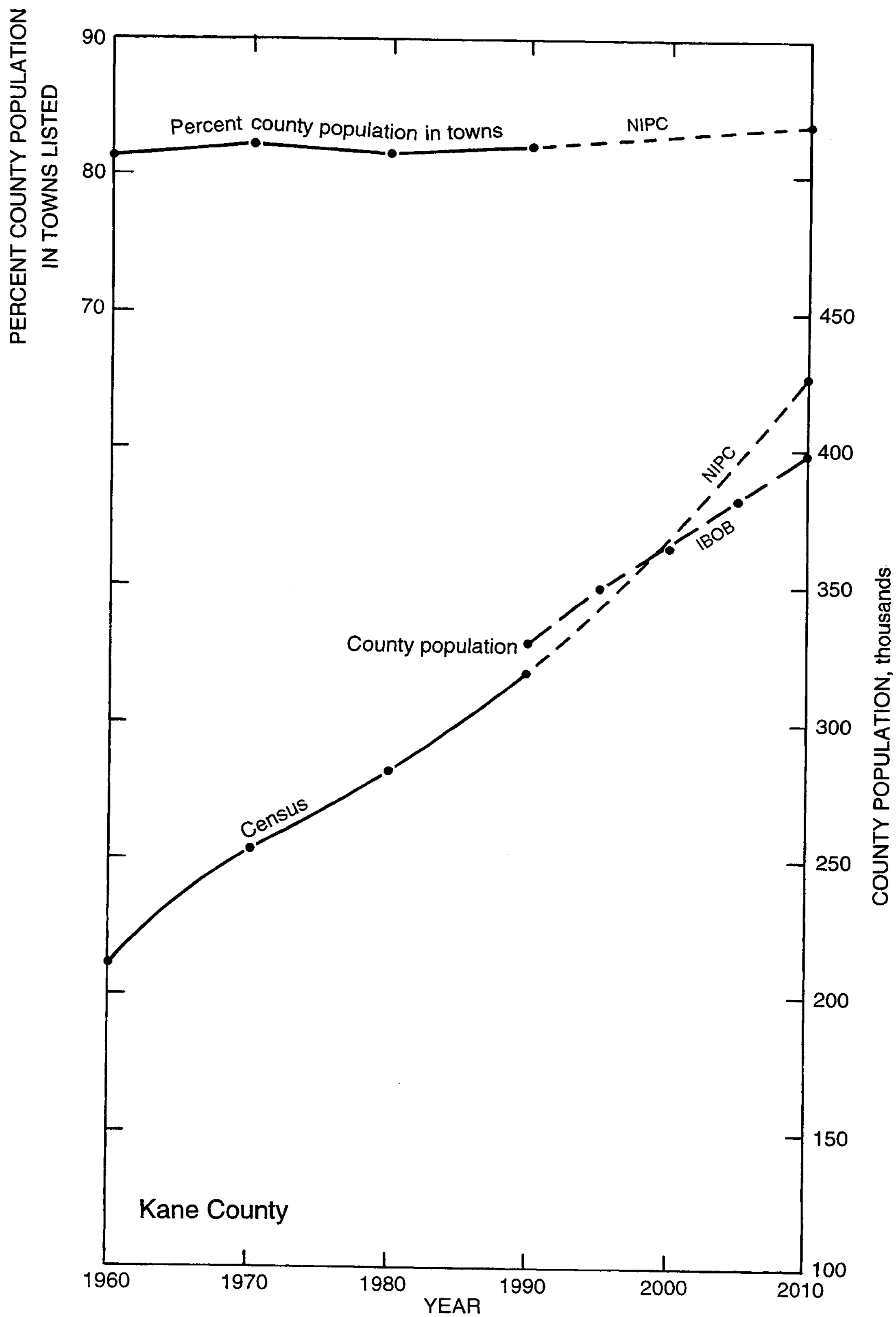

Figure 13. Kane County census populations and future projections

			Census populations		
Year	1960	1970	1980	1990
Population	84,210	111,555	147,897	181,595

	IBOB population projections			*NIPC forecast*
Year	2000	2010	2020	2010
Population	196,920	216,570	228,399	235,800

Census populations and NIPC 2010 forecast for towns in McHenry County are given in Table 7. Combined population of the towns as a percent of total McHenry County population was 56.2, 61.2, 64.5, and 68.8% in 1960, 1970, 1980, and 1990, respectively. There has been a steady, significant rise in percentage. Total of NIPC 2010 forecast for towns in Table 7 is 78.6% of the corresponding NIPC county population forecast. This increase is in line with the historical trend (Figure 14), which gives an estimated population of 266,850 in 2010.

County populations (census, IBOB, and NIPC) are plotted in Figure 14. The 2010 NIPC forecast is about 8.9% higher than the IBOB projection. Some towns such as Algonquin, Crystal Lake, Island Lake, and Lake in the Hills show a great increase in population during the period 1990 to 2010. A significant part of the increase has already occurred in the last three years. Inquiries made to many towns confirmed the overall suitability of NIPC forecasts though some towns expected to increase in population beyond NIPC estimates. The available IBOB projections are only for the county population, and there is no satisfactory and viable procedure available to develop individual town population estimates when rate of population growth in an individual town is a function of so many factors with relatively uncertain future values.

Other Counties

Other towns in the Fox River basin and in the vicinity of Fox River lie in western Lake County, Barrington and Hanover Townships of Cook County, western DuPage County, Kendall, DeKalb, and LaSalle Counties. Census populations for these towns are given in Table 8. Available NIPC 2010 forecasts are also included (excluding Kendall, DeKalb, and LaSalle Counties).

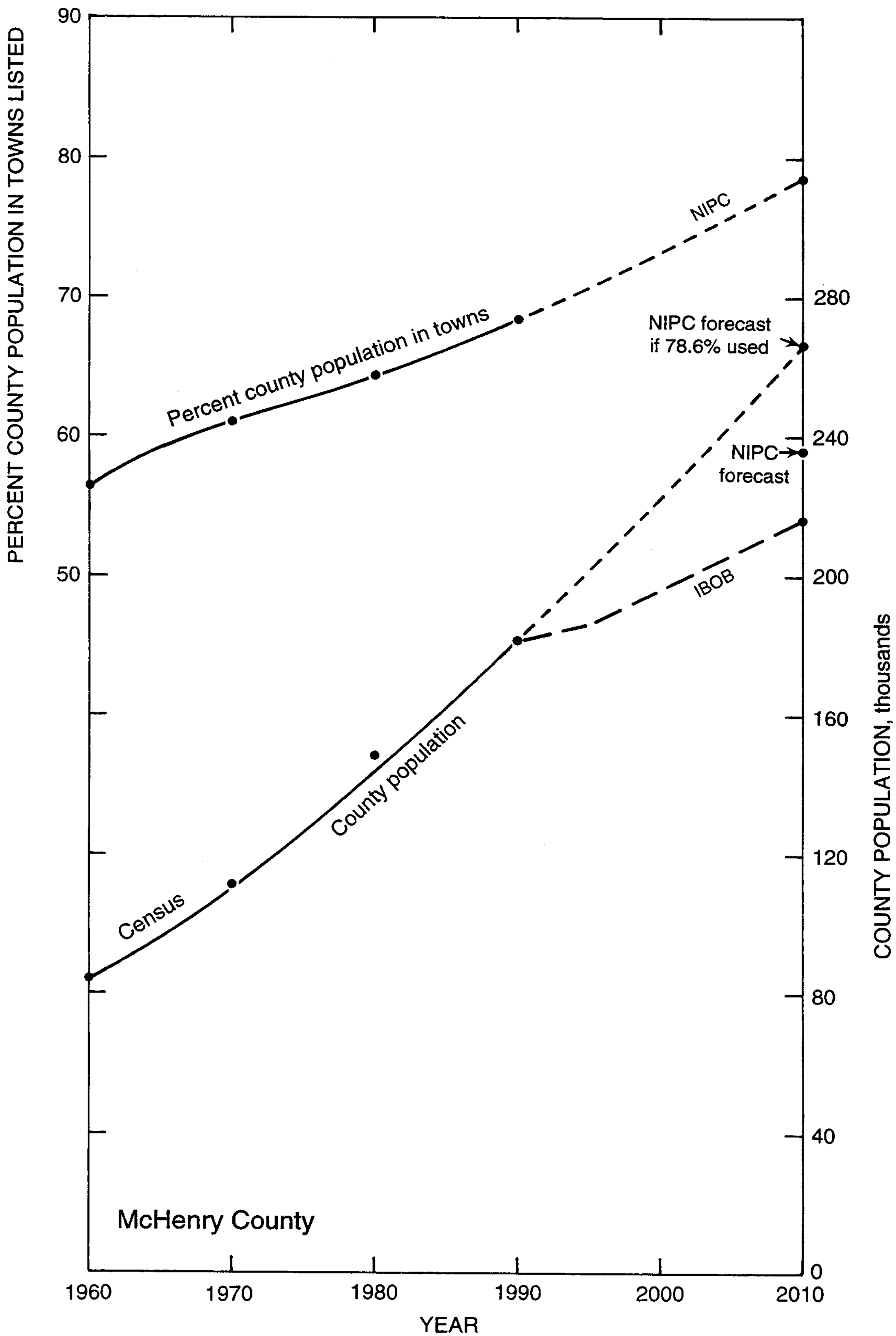

Figure 14. McHenry County census populations and future projections

Estimated Water Demands and Source Adequacy

Water demands for the year 2010 for various towns in the Fox River basin were developed using the NIPC 2010 forecasts of population and estimates, and gallons per capita day use (gpcd) derived from the historic data for each town (Table 9). There are three main sources of water: Lake Michigan, Fox River, and ground-water aquifers (shallow sand and gravel and upper bedrock, and deep sandstone). In order to reduce the mining of deep sandstone aquifer (mining means water withdrawals exceed the recharge to the aquifer), many towns to the north and west of Chicago have been connected to systems supplying Lake Michigan water directly or from the Chicago water supply system. There is a possibility of more towns to the west being connected to lake water supply if the local water sources are inadequate, serious water quality problems, or both. A continual search for shallow aquifers in Kane and McHenry Counties has greatly increased the estimated potential yield from these aquifers.

Lake Michigan Water Supply

In order to reduce overpumping of the deep sandstone aquifer, the following towns (in the Fox River basin and nearby) have been moved to the Lake Michigan water system, either from Chicago or from the lake directly.

Town	*County*	*Water supply system*
Carol Stream	DuPage	Chicago to DuPage Water Commission
Valley View	Kane	Chicago to DuPage Water Commission
Naperville	DuPage/Will	Chicago to DuPage Water Commission
Warrenville	DuPage	Chicago to DuPage Water Commission
Hanover Park	Cook/DuPage	Chicago to Northwest Surburban Joint Action Water Agency
Hoffman Estates	Cook	Chicago to Northwest Surburban Joint Action Water Agency
Schaumburg	Cook	Chicago to Northwest Surburban Joint Action Water Agency
Streamwood	Cook	Chicago to Northwest Surburban Joint Action Water Agency
Round Lake	Lake	Central Lake County Joint Action Water Agency
Round Lake Beach	Lake	Central Lake County Joint Action Water Agency
Round Lake Park	Lake	Central Lake County Joint Action Water Agency

Table 9. Estimated 2010 Water Demands in mgd (Fox River Basin)

Town	*Demand*
Kane County	
Aurora (f+b)	18.73
Batavia (c)	3.07
Carpentersville (a)	4.05
East Dundee (a)	0.40
Elburn (c)	0.62
Elgin (f+b)	15.08
Geneva (c)	3.15
Montgomery (c)	1.70
North Aurora (b)	1.68
St. Charles (c)	5.48
Sleepy Hollow (d)	0.27
South Elgin (a)	1.26
Sugar Grove (a)	1.03
West Dundee (a)	1.20
McHenry County	
Algonquin (a)	2.85
Cary (c)	2.32
Crystal Lake (b)	6.79
Fox River Grove (a)	0.65
Hebron (a)	0.10
Lake in the Hills (a)	1.76
Lakemoor private wells	
Lakewood (c)	0.27
McHenry (a)	3.00
Richmond (a)	0.16
Sunnyside (Johnsburg) (a)	0.31
Woodstock (a)	2.91
Western Lake County	
Antioch (a)	1.32
Barrington (a)	2.30
Fox Lake (c)	1.04
Island Lake (a)	0.75
Lake Barrington private wells	
Lake Villa (a)	0.72
Lake Zurich (b)	2.31
Round Lake*	0.66
Round Lake Beach*	2.16
Round Lake Park*	1.63
Tower Lake (a)	0.14
Wauconda (a)	1.11
Northwestern Cook County	
Barrington Hills private wells	
Hanover Park*	3.41
South Barrington private wells	
Streamwood*	4.33
Kendall County	
Newark (a)	0.07⌖
Oswego (c)	0.58⌖
Plano (a)	0.88⌖
Yorkville (b)	0.69⌖
DeKalb County	
Hinckley	0.19⌖
Sandwich (a)	0.83⌖
Shabbona (a)	0.10⌖
Somonauk (a)	0.25⌖
Waterman (a)	0.13⌖
LaSalle County	
Earlville (a)	0.15⌖
Sheridan (a)	0.20⌖
Lee County	
Paw Paw	0.07⌖

Notes: a = water supply mainly/entirely from shallow aquifers
b = water supply mainly/entirely from deep sandstone aquifer
c = water supply from both a and b
d = water supply from other towns
f = water supply from Fox River
* = Lake Michigan water from Chicago or a new system
⌖ = 1992 water use in mgd

The towns in the Fox River basin are Round Lake, Round Lake Beach, Round Lake Park, Streamwood, and Valley View. Some towns near the eastern fringe of the basin in McHenry and Kane Counties may get Lake Michigan water in the future if further reduction in pumping from deep sandstone aquifer is desired.

Ground Water and Other Supplies

Table 9 gives the 2010 estimated average demand for towns in the Fox River basin. In Kane County, Elgin and Aurora are the main users of water from the Fox River. Average ground-water use for Elgin is only 0.95 mgd and for Aurora 6.75 mgd from the deep sandstone aquifer. The rest of the water demand is met from the Fox River. Many other towns using deep sandstone aquifer have gradually moved to shallow aquifers over the last 10 years. The reasons for this continuing change are 1) the presence of radium alpha and beta particle activity and costly treatment for their removal and disposal (Singh and Adams, 1980), 2) barium concentrations exceeding 5 mg/L in a large portion of northeastern Kane County, southeastern McHenry, southwestern Lake, and northwestern Cook counties (Gilkeson et al., 1983), and 3) desirable reduction in ground-water mining of the deep sandstone aquifer. Visocky (1990) estimates potential yield of shallow aquifers in Kane County at 63 mgd. Thus most of the towns (excluding Elgin and Aurora) will get their water from shallow aquifers. Use of 0.95 mgd of ground water (from deep sandstone aquifer) by Elgin is to keep the well fields active. As more shallow wells are drilled into the shallow aquifer, Aurora may shift the ground-water supply from deep to shallow aquifers.

Most of the towns in McHenry County, with the exception of Crystal Lake, have shallow ground-water aquifers as their primary source. Potential yield of shallow aquifers with primary development in sand and gravel in townships comprising McHenry County, and Crystal Lake, Cary, Lake in the Hills, and Algonquin, are 12.7 and 10.5 mgd (Singh and Adams, 1980), respectively. Lake in the Hills and Crystal Lake can develop wells in the shallow aquifers in the adjoining township to the west with 5.1 mgd potential yield and/or in the adjacent township to the north with 11.4 mgd potential yield. Towns in McHenry County within the Fox River basin can meet their 2010 demands without pumping water from the Fox River as well as decrease deep sandstone aquifer water withdrawals to practically zero.

Round Lake, Round Lake Beach, and Round Lake Park get their water from the Central Lake County Joint Action Water Agency, with an independent uptake from Lake Michigan. For most of the towns in the Lake County portion in the Fox River basin, with the exception of Lake Zurich, the shallow aquifers are the source of water. Yield potential of these aquifers in four townships adjoining McHenry County varies from 7.2 mgd in the northernmost township to 3.2 mgd in the southernmost township. Lake Zurich can gradually shift to shallow aquifers.

The water demands for parts of towns in northwestern Cook County have been considered under such towns in adjoining Lake, Kane, and DuPage Counties such as Barrington has been considered in western Lake County, Bartlett in DuPage County, Elgin in Kane County. Hoffman Estates, Inverness and Schaumburg are outside of the Fox River basin (though Hoffman Estates and Schaumburg are served by Northwest Suburban Joint Action Water Agency receiving Lake Michigan water from Chicago). Bartlett and West Chicago have wells in shallow and deep aquifers. Winfield has wells in shallow aquifers.

Water use for 1992 was given in Table 9 for towns in portions of Kendall, DeKalb, and LaSalle Counties in the Fox River basin.

Fox River Water Supply

Only Elgin and Aurora are using water from the Fox River, and they will probably continue to do so in the future. Present and future demands are given below.

	1993 water pumped, mgd		*2010 water demand, mgd*	
Town	*Fox River*	*Ground water*	*Fox River*	*Ground water*
Elgin	10.69	0.95	14.13	0.95
Aurora	6.70	6.75	11.98	6.75

Water demand corresponds to water pumped, which is about 10-30% higher than water billed depending on water system losses and nonbilled water. During a drought year, average demand may be 20 to 30% higher than that for a normal year.

MUNICIPAL EFFLUENTS FOR THE YEARS 1990 AND 2010

The Illinois State Water Survey (ISWS) conducts an annual survey of surface and ground-water withdrawals for all municipal and major self-supplied industries in the state. These data are stored in the Illinois Water Inventory Program (IWIP). The yearly use for 1990 for the towns contributing effluent discharge to the Fox River and its tributaries was obtained from the IWIP and modified slightly if the preceding and succeeding years of water use indicated some adjustment to the 1990 figure. Water use for the year 2010 was estimated using information on historical per capita use and projected 2010 populations.

1990 and 2010 Effluent Discharges

The locations of effluent outfall and magnitudes of effluent discharge (under the 7-day, 10-year low flow conditions) relevant to the year 1990 are given by Singh and Ramamurthy (1993). The locations of effluent outfall were obtained from the Illinois Environmental Protection Agency (IEPA) offices and by direct telephone inquiries to the wastewater treatment plants.

The 7-day, 10-year low flow, Q(7, 10), is defined as the lowest average flow during a 7-day consecutive period, occurring at an average of once in 10 years. The effluent flow is usually 70 to 90 percent of water use because of consumptive uses, leakage from collection and conveyance system, etc. It is assumed that the natural hydrologic regime of the Fox River and its tributaries in 2010 will essentially remain the same as in 1990. Future changes in Q(7,10) will mostly be attributed to changes in the magnitude of effluent discharges because of increasing population and water use, and use of Fox River water by Elgin and Aurora.

The effluent discharges for 2010 7-day, 10-year low flow conditions were estimated using two methods:

1. Multiplying the 1990 effluent discharge with the ratio of 2010 water use to 1990 water use (est- 1).
2. Converting the difference between 2010 and 1990 water uses to cfs and then adding this amount to the 1990 effluent (est-2).

The first estimate will be lower and the second estimate higher than the 2010 effluent discharge under 7-day, 10-year low flow conditions. Thus, an average of the two estimates was used in delineating effluent discharges on the Q 7.10 maps.

Table 10 contains the counties, towns within each county, 1990 population and water use in mgd, 1990 effluent discharge in cfs, 2010 population and water use, and 2010 est-1 and est-2 effluent discharge. Usually effluent discharge is less than water use (both in same units). However, some towns in Table 10 show more effluent discharge than water use; a few glaring examples are Aurora and Elgin. The Aurora Sanitary District (ASD) serves not only Aurora but also North Aurora, Montgomery, and many unincorporated areas (all with independent ground-water supplies). Fox River Water Reclamation District (WRD) plants serve Elgin, West Dundee, Bartlett, South Elgin, and some unincorporated areas. Water use for Aurora and Elgin is shown for their respective water departments serving Aurora and Elgin and areas directly connected to their water supply system.

7-Day, 10-Year Low Flow Maps

The values of 7-day 10-year low flow, Q(7, 10), along the Fox River and its tributaries as well as the values of 1990 municipal and industrial effluents discharged to them during 7-day 10-year low flow conditions were developed by Singh and Ramamurthy (1993) and are shown in map 1-1990 (in Appendix C). The Q(7,10) flow from Stratton Dam near McHenry was estimated as 94 cfs, which corresponds to a minimum gate opening of 0.10 feet (Knapp, 1988).

Elgin and Aurora already supplement their ground-water supplies with water withdrawals from the Fox River. Their average ground-water withdrawal in 1993 was only 0.95 mgd and 6.75 mgd, respectively. In developing the 1990 Q(7,10) values for the Fox River, it was understood that Aurora and Elgin would shift completely to ground-water supplies whenever the Fox River flow becomes equal to or less than the 7-day, 10-year low flow for the condition of no withdrawals from the river. However, recent discussions with the IDOT's Division of Water Resources personnel, as well as with water authorities in Elgin and Aurora, indicate that no such withdrawal restrictions are specified in their water use permits. Accordingly, a modified map (map 2:1990 in Appendix C) was prepared showing water

Table 10. Municipal Effluents Discharged to Fox River and Its Tributaries, 1990 and 2010

		1990			*2010*			
County	*Towns*	*Population*	*Water use (mgd)*	*Effluents (cfs)*	*Population*	*Water use (mgd)*	*Effluentest – 1 (cfs)*	*Effluentest - 2 (cfs)*
Lake	Antioch	6105	0.87	0.90	9416	1.32	1.37	1.60
	Barrington	9504	1.75	2.70	12496	2.30	3.55	3.55
	Fox Lake Regional WTP			6.00			12.00	12.00
	Island lake	4449	0.31	0,48	10667	0.75	1.16	1.16
	Lake Barrington H. 0	3855	Private wells	0.35	4903		0.45	0,45
	Lake Villa[2]	2857	0.26	0.29	7955	0.72		
	Lake Zurich	14947	1.72	1.69	20116	2.31	2.27	2.60
				0.75 + 0.94			1.01 +1.26	1.15+1.45
	Wauconda	6294	0.69	0.65	10067	1.11	1.05	1.30
McHenry	Algonquin	11663	1.63	1.40	20321	2.85	2.45	3.29
	Cary	10043	1.41	1.50	16563	2.32	2.47	2.91
	Crystal Lake	24512	3.43	2.69	48517	6.79	5.33	7.89
				2.3 + 0.39			4.56+0.77	6.75+1.14
	Fox River Grove	3551	0.46	0.65	4994	0.65	0.91	0.94
	Hebron	809	0.09	0.10	889	0.10	0.11	0.11
	Lake in the Hills	5866	0.59	0.60	17619	1.76	1.80	2.41
	McHenry	16177	1.94	2.3	24988	3.00	3.56	3.94
	Richmond	1016	0.12	0.12	1407	0.16	0.16	0.18
	Sunnyside (Johnsburg)	1529	Private wells	septic tanks	3443			
	Woodstock	14353	2.15	1.90	19379	2.91	2.57	3.08

Table 10. Continued

County	Towns	1990 Population	1990 Water use (mgd)	1990 Effluents (cfs)	2010 Population	2010 Water use (mgd)	2010 Effluent est (cfs)	2010 Effluent est - : (cfs)
Kane	Aurora [3]	99581	12.45	29.00	148317	18.73	43.63	43.63
	Batavia	17076	2.22	1.80	23581	3.07	2.49	3.11
	Carpentersville	23049	2.77	2.40	33790	4.05	3.51	4.38
				2.3+0.10			3.36+0.15	4.19+.19
	East Dundee	2721	0.39	0.49	2758	0.40	0.50	0.51
	Album	1275	0.13	0.16	6167	0.62	0.76	0.92
	Elgin	77010	11.64	20.974	99755	15.085	27.174	27.174
				16.2 +4.3 +			20.99 + 5.57+	20.99 + 5.57+
				0.47			0.61	0.61
	Geneva	12617	1.89	2.20	20985	3.15	3.67	4.15
	Mooseheart Home	600	0.17	0.11	600	0.17	0.11	0.11
	St. Charles	22501	3.53	5.00	35547	5.48	7.76	8.02
	St. Charles Skyline	300	0.10	0.10	1500	0.12	0.12	0.12
	Sugar Grove6	3105	0.34	0.44	9214	1.03	1.33	1.51
	West Dundee [7]	3728			6000			
Kendall	Newark	840	0.06	0.04	1020	0.07	0.05	0.06
	Oswego	3876	0.39	0.27	5800	0.58	0.40	0.56
	Piano	5104	0.82	0.67	5550	0.88	0.72	0.76
	Valley Water Co	2200	0.16	0.22	4400	0.34	0.47	0.50
	rkville-Bristol SD	3925	0.49	0.70	9300	1.15	1.64	1.72

Table 10. Concluded

County	Towns	1990 Population	1990 Water use (mgd)	1990 Effluents (cfs)	2010 Population	2010 Water use (mgd)	2010 Effluent est – 1 (cfs)	2010 Effluent est-2 (cfs)
LaSalle	Earlville	1435	0.15	0.13	1490	0.15	0.13	0.13
	Sheridan	738	0.16	0.21	900	0.20	0.26	0.27
DeKalb	Hinckley	1682	0.16	0.24	2000	0.19	0.29	0.29
	Sandwich	5567	0.75	0.56	6180	0.83	0.62	0.68
	Shabbona	897	0.10	0.06	970	0.10	0.06	0.06
	Somonauk	1263	0.17	0.13	1840	0.25	0.19	0.25
	Waterman	1074	0.12	0.06	1170	0.13	0.07	0.08
Lee	Paw Paw	860	0.07	0.04	860	0.07	0.04	0.04

Notes:

1. Fox Lake Regional WTP (wastewater treatment plant) serves Fox Lake, Round Lake, Round Lake Beach, Round Lake Park, Hainesville, Round lake Heights, Ingleside, Lake Villa (since 1993), and considerable unincorporated areas.

2. Lake Villa effluents go to Fox Lake Regional WTP since November 1993.

3. Aurora Sanitary District serves Aurora, North Aurora, Montgomery, and many unincorporated areas

4. Fox River Water Reclamation District (WRD) plants served Elgin, West Dundee, Bartlett, South Elgin, and some unincorporated areas in 1990. The effluent volume is assumed to increase in the same proportion as the water use for Elgin.

5. Elgin supplies water to about 20,000 people outside the city. It is assumed that this number will increase proportionately with increase in population of Elgin. Water demand for the year 2010 is accordingly estimated.

6. Sugar Grove population also includes Prestbury population (1990 : 1100, 2010 : 2000).

Table 10. Concluded

8. Yorkville-Bristol Sanitary District (YBSD) serves Yorkville, Bristol and some unincorporated areas.

- Effluent Estimate-l for 2010 = 1990 effluents/1990 water use x 2010 water use
- Effluent Estimate-2 for 2010 = (2010 water use - 1990 water use) x 1.547 + 1990 effluents
- Lake Zurich, Carpentersville, Crystal Lake, and Elgin have more than one location of wastewater plant outfalls. The amounts for each location for these towns are given in the columns below the corresponding totals.

withdrawals by Elgin and Aurora from the Fox River, as well as reduction in Q(7,10) values below Elgin to the confluence with the Illinois River.

The Q(7,10) maps for the year 2010 have been prepared considering the change in effluent flows as listed in Table 10 as well as the change in water withdrawals from the Fox River.

	1990 water pumped, mgd		*2010, water pumped, mgd*	
Town	*Fox River*	*Ground water*	*Fox River*	*Ground water*
Elgin	10.69	0.95	14.13	0.95
Aurora	5.70	6.75	11.98	6.75

The 2010 Q(7,10) at Wilmot gaging station 05546500 has been taken as 80 cfs (Knapp, 1988). Considering increased effluent discharges in 2010, the Q(7,10) near Stratton Dam is estimated as 111 cfs (instead of 94 cfs for the 1990 conditions). If the present gate operation is continued, the release from the dam will be limited to 94 cfs. Hence the Q(7,10) maps for the year 2010 are developed for four scenarios.

Scenario	*Withdrawal from Fox River*		*Flow release from Stratton Dam*		*Map number*
	a	*b*	*111 cfs*	*94 cfs*	
1	X		X		1-2010-1
2		X	X		2-2010-1
3	X			X	1-2010-2
4		X		X	2-2010-2

Note: *a* denotes no withdrawals from the Fox River when flow is equal to or less than the relevant Q(7,10)
b denotes no restrictions on stipulated withdrawals even in low flow conditions like the Q(7,10) or lower

Completed Q(7,10) maps for the Fox River basin (two for the 1990 conditions and four for the 2010 conditions) are contained in Appendix C.

Some Anticipated Water Quality Problems

It will be interesting to look at the dilution ratios [Q(7,10) to effluent flow discharge] just upstream of the Fox River WRD South and Aurora Sanitary District (ASD) outfalls, under the above four scenarios.

	Fox River WRD South			*Aurora Sanitary District, ASD*		
Scenario	*Q(7,10)*	*Effluent*	*Dilution ratio*	*Q(7,10)*	*Effluent*	*Dilution ratio*
1	165	21.0	7.86	218	43.6	5.00
2	143	21.0	6.81	178	43.6	4.08
3	148	21.0	7.05	201	43.6	4.61
4	126	21.0	6.00	161	43.6	3.69

Fox River WRD North is about three miles upstream of WRD South and its 2010 effluent discharge is 5.6 cfs. If it is combined with 21.0 cfs from the South plant, the total effluent discharge of 26.6 cfs will make dilution ratios of 6.20, 5.38, 5.56, and 4.74. For dilution ratios of less than 5.0, improved wastewater treatment may be required.

The 2010 Q(7,10) values do not significantly affect the 1990 conditions in the tributaries joining the Fox River upstream of Stratton Dam. However, the effluent discharges are greatly increased from 1990 to 2010 conditions for the Crystal Creek. The towns of Crystal Lake and Lake in the Hills discharge 7.8 cfs effluent in 2010 instead of 2.9 cfs to Crystal Creek.

Part B. Water Quality and Waste Assimilative Capacity of St. Charles Pool

FIELD MEASUREMENTS AND WATER QUALITY MONITORING

Although the Fox River is located in the most densely populated region of Illinois and has been subjected to severe environmental abuse over the past 100 years, no systematic investigation had previously been made to ascertain its water use potential, water quality, and waste assimilative capacity characteristics associated with any increase in water demands and related water resource development.

Dams of any type placed on a waterway can exacerbate existing water quality problems and create a number of new ones as summarized as below:

1. Reduce natural waste assimilative capacity via:
    a. Reduced natural atmospheric reaeration
    b. Increased bacterial oxygen usage in the water column due to biochemical oxygen demand (BOD) including the stabilization of dissolved carbonaceous organic material and dissolved ammonia/nitrite nitrogen
    c. Increased oxygen consumption in the sediments in the form of gross sediment oxygen demand (SOD)
2. Create excess algae growth resulting in:
    a. Wide swings in dissolved oxygen (DO) concentrations on a daily basis
    b. DO stratification in the vertical water column
    c. Organic enrichment of bottom sediments via the settling of dead algae cells, thereby increasing SOD
    d. A shift to less desirable quiet water-dwelling blue-green algae species that create taste and odor problems in drinking water and create unaesthetic "green paint" scum on water surfaces and riverbanks
    e. Increased chemical and physical costs for treating potable water, chemical, process water, and cooling water
3. Accelerate sedimentation resulting in:
    a. Streambed siltation and filling in of backwater areas
    b. Increased SOD rates

Various dams along the Fox River in Illinois are listed in Table 11. Inherently, dams reduce stream velocities and increase depth. Reaeration is reduced because reaeration rates are

Table 11. Fox River Dam Sites

Dam	*Location*	*Type / Function*
Stratton (prev. McHenry)	98.94	Navigation, Pool Control
Algonquin	82.61	Channel
Carpentersville	78.85	Channel
Elgin	71.85	Channel (Old Hydropower)
South Elgin	68.18	Channel (Old Hydro)/Water Supply
St. Charles	60.65	Channel
Geneva	58.67	Channel
North Batavia	56.26	Channel
South Batavia	54.90	Channel
North Aurora	52.60	Channel/Reaeration
Stolp Island, Aurora	48.91	Channel
Hurds Island, Aurora	48.37	Channel
Montgomery	46.56	Channel/Reaeration/Water Supply
Yorkville	36.54	Channel
Dayton	5.60	Hydropower

Table 12. Water Surface Elevations for Selected Flows
at the USGS South Elgin Gage (Gage Datum: 688.05)

			Water Surface Elevation, ft msl at South Elgin Dam	
Date	*Measurement number*	*Discharge (cfs)*	*Headwater*	*Tailwater*
11/14/89	83	708	700.47	694.19
01/03/90	84	328	700.13	693.81
08/07/90	90	522	700.34	694.00
09/17/90	91	447	700.25	693.91
01/15/91	96	883	700.61	694.31
07/10/91	100	286	700.09	693.77
08/21/91	101	284	700.09	693.78
05/27/92	106	474	700.33	693.97
07/14/92	107	624	700.42	693.05

directly proportional to stream velocity and indirectly proportional to water depth, i.e. deep, slow stream reaches absorb oxygen from the atmosphere at a much lower rate than do shallow turbulent reaches. Reduced velocities, in turn, increase travel time, thereby increasing incubation times and depleting the dissolved oxygen resources.

The standard for dissolved oxygen availability as developed by the Illinois Environmental Protection Agency (State of Illinois, 1990), in particular, subpart B, Section 302.206 specifies that, "Dissolved oxygen shall not be less than 6.0 mg/L at least 16 hours of any 24-hour period, nor less than 5.0 mg/L at any time."

Site Selection

The St. Charles pool is an excellent reach of the Fox River to study for several reasons. One is that it is 7.53 miles long, somewhat longer than the average Fox River pool length, and it has a well-defined shallow, free-flow reach (with many riffles) extending about two miles below the South Elgin Dam before transforming into a backwater pool. This situation affords one to examine and/or compare the waste assimilative capacity of a relatively long shallow free-flowing stretch of the river to that of a relatively deep, pooled stretch.

A second reason is that the head of the pool is the recipient of treated wastewater from a major source (the 13 mgd Elgin South Plant) and two significant but lesser sources (the 2 mgd Elgin North Plant and the 0.6 mgd Elgin State Hospital plant). A much smaller plant (less than 0.2 mgd) serving the Fox River Estates/Valley View area discharges effluent directly into the pool at approximately river mile 64.0

Another factor that contributes to the desirability of studying this pool is that, historically, the Water Survey has conducted some water quality studies (albeit limited) along this reach. During 1976, the reaeration characteristics of the South Elgin and St. Charles dams were analyzed (Butts and Evans, 1978a). This involved collecting DO and temperature measurements at 15-minute intervals over 8-hour periods. Also, sediment oxygen demand measurements were conducted within the pool at miles 61.27 and 64.39 (Butts and Evans, 1978b). Benthos and sediment samples were analyzed in conjunction with these SOD measurements. Some of the highest DO concentrations ever observed in Illinois streams were recorded above the St. Charles dam on July 28, 1976.

Sampling Stations

Two methods are available to compute estimates of travel time through the study reaches. The first of these is the volume-displacement method, while the second method employs hydraulic geometry equations developed by Stall and Fok (1968) for the Fox River basin.

The volume-displacement method requires knowledge of the cross sections and water surface elevations throughout the study reach. The Division of Water Resources provided cross-sectional data for 22 locations between the South Elgin and St. Charles dams from which water surface elevations were developed. They also provided water elevations at the South Elgin Dam for several flow events. The gaging station information is summarized in Table 12.

Hydraulic geometry formulas developed by Stall and Fok (1968) give the average discharge, cross-sectional area, velocity, width, and depth as a function of drainage area and flow duration. The equations are of the general form

$$\ln(var) = a + b \times F + c \times \ln(A_d) \quad (1)$$

where

var = the parameter to be estimated,

F = the decimal flow duration,

A_d = drainage area in sq mi, and

a, b, and c = regression coefficients.

The specific equations for the Fox River basin are:

$$\ln(Q) = -0.24 - 3.33 \times F + 1.13 \times \ln(A_d) \quad (2)$$

$$\ln(A) = -0.35 - 1.94 \times F + 0.97 \times \ln(A_d) \quad (3)$$

$$\ln(V) = 0.11 - 1.39 \times F + 0.16 \times \ln(A_d) \quad (4)$$

$$\ln(W) = 0.56 - 0.39 \times F + 0.64 \times \ln(A_d) \quad (5)$$

$$\ln(V) = -0.91 - 1.55 \times F + 0.33 \times \ln(A_d) \quad (6)$$

where

Q = discharge in cfs,

V = velocity in fps,

W = stream width at the water surface in feet, and

D = average stream depth in feet

A_d = drainage area in sq mi

Both methods were used to estimate travel time at 284 cfs and 883 cfs. Incremental comparisons between the hydraulic geometry derived values and those computed using the volume-displacement method are presented in Figure 15. Note the excellent agreement in the upstream, free-flowing portion of the reach, but the increasing divergence downstream of river mile 66.6, where the depth in the pool portion of the reach increases. The hydraulic geometry formulas were developed by Stall and Fok (1968) with data from free-flowing reaches only, thus results would not apply to reaches with significant backwater effects from a dam.

The travel time values obtained using the volume-displacement method (Table 13) were used to locate the five DataSonde stations. The river mile locations of the stations are listed in Table 14, along with the estimated travel time between stations for the 284 and 883 cfs flow values. Their locations are also shown schematically in Figure 16. The unequal distances between stations 2 and 3, 3 and 4, and 4 and 5 reflect the use of equal travel times for the 284 cfs flow.

Field Procedures

Short-term intensive water quality data collections were made during two separate time periods (events). Event 1 ran for three days, (August 17 - August 20, 1993), while event 2 ran for six days (June 21 - June 27, 1994). The second event was planned to run for only three days, similar to event 1, but heavy rainfall and subsequent high flows during the second day of the event prompted the extension to 6 days. Hydrolab DataSonde II model 2070-DS water quality monitoring units were used at each of the five fixed-stations to collect data for temperature, DO, conductivity, and pH at 15-minute intervals. DataSondes were installed at all five fixed-stations by two crews. Stations 1 and 2 were set by wading, while stations 3, 4, and 5 were set by boat.

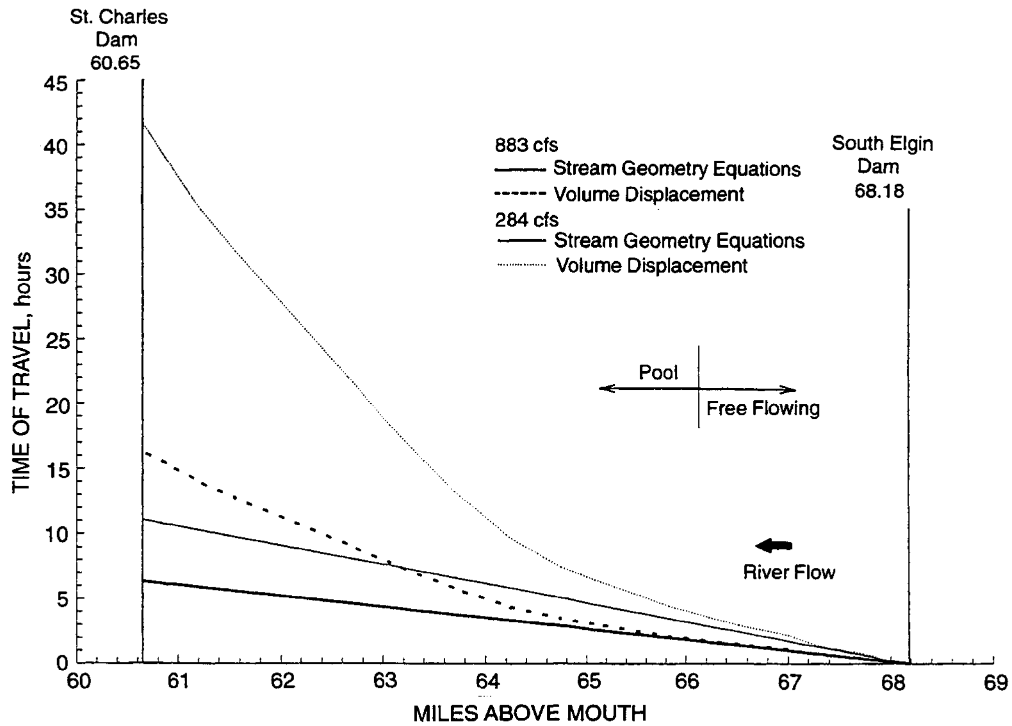

Figure 15. Computed times of travel for low and medium flows

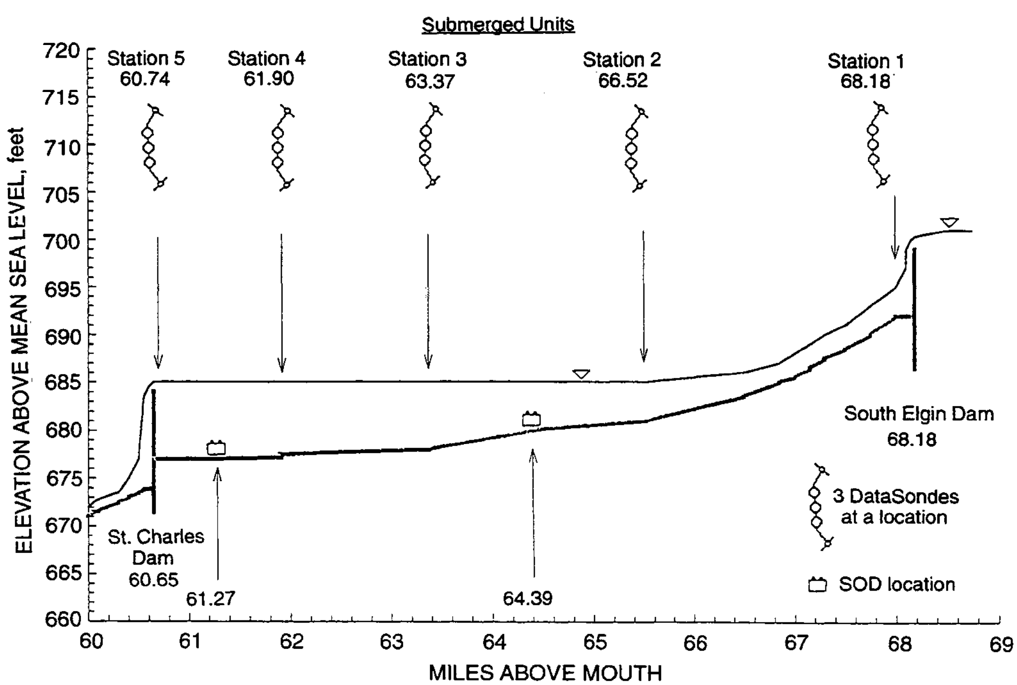

Figure 16. Profile showing locations and types of monitoring installations

Table 13. Computed Time of Travel with Volume-Displacement Method

Stream Mile	*Average Depth (ft)* 284	*Average Depth (ft)* 883	*Average Width (ft)* 284	*Average Width (ft)* 883	*Average Velocity (fps)* 284	*Average Velocity (fps)* 883	*Time of Travel (hours) Incremental* 284	*Time of Travel (hours) Incremental* 883	*Time of Travel (hours) Cumulative* 284	*Time of Travel (hours) Cumulative* 883
68.18										
	1.34	1.83	338	343	0.63	1.40	0.047	0.021	0.047	0.021
68.16										
	1.44	2.05	305	315	0.65	1.40	0.181	0.084	0.228	0.105
68.08										
	0.99	1.58	368	378	0.90	1.71	0.586	0.301	0.795	0.407
67.73										
	1.11	1.79	250	265	1.02	1.86	0.330	0.181	1.125	0.588
67.50										
	1.34	1.74	125	273	1.69	2.63	0.104	0.067	1.229	0.655
67.38										
	1.47	1.77	278	343	0.70	1.46	0.253	0.121	1.483	0.776
67.26										
	1.40	2.00	385	398	0.53	1.11	0.698	0.331	2.181	1.107
67.01										
	1.44	1.58	213	300	0.93	1.86	0.776	0.386	2.957	1.493
66.52										
	1.74	1.70	235	325	0.70	1.61	1.457	0.628	4.415	2.121
65.83										
	1.36	1.83	393	408	0.53	1.19	1.872	0.841	6.287	2.962
65.15										
	1.53	1.98	226	358	0.53	1.25	1.129	0.482	7.416	3.445
64.74										
	2.56	3.11	340	488	0.33	0.82	2.244	0.898	9.660	4.342
64.24										

Table 13. Concluded

Stream Mile	*Average Depth (ft)*		*Average Width (ft)*		*Average Velocity (fps)*		*Time of Travel (hours)*			
							Incremental		*Cumulative*	
	284	*883*	*284*	*883*	*284*	*883*	*284*	*883*	*284*	*883*
64.24										
	2.46	3.01	518	525	0.22	0.56	3.544	1.415	13.204	5.757
63.70										
	2.91	3.45	533	540	0.18	0.47	5.038	1.949	18.241	7.706
63.07										
	3.69	4.22	485	490	0.16	0.43	3.789	1.408	22.031	9.114
62.66										
	3.82	4.33	448	453	0.17	0.45	9.709	3.576	31.740	12.690
61.56										
	3.18	3.66	575	588	0.16	0.41	3.206	1.213	34.946	13.903
61.22										
	3.77	4.20	598	615	0.13	0.34	4.066	1.503	39.012	15.407
60.87										
	5.86	6.16	405	413	0.12	0.35	2.574	0.887	41.586	16.293
60.66										
	6.30	6.61	350	350	0.13	0.38	0.114	0.039	41.700	16.331
60.65										

Table 14. Preliminary Sampling Station Locations and Time of Travel for 284 cfs and 883 cfs Flows

Station Number	*Mile*	*Incremental Distance (miles)*	*Time of Travel (hours)* *Incremental* *284*	*883*	*Total* *284*	*883*
1	68.18	-	-	-	-	-
2	66.52	1.66	2.957	1.493	2.957	1.493
3	63.37	3.15	12.914	5.285	15.871	6.778
4	61.90	1.47	12.914	4.802	28.785	11.580
5	60.65	1.25	12.914	4.751	41.700	16.331

Note: Final Field Location of Station 5 was at Mile 60.74.

Table 15. Continuous Monitoring - Start and Stop Times (CST) for Events 1 and 2

Station	*Event 1* *8/17/93* *Start*	*8/20/93* *Stop*	*Event 2* *6/21/94* *Start*	*6/27/94* *Stop*
1	1415	1215	1245	0530
2	1300	1315	1445	0530
3	1530	1030	1445	0530
4	1445	1045	1330	0530
5	1345	1130	1245	0530

Table 16. Datasonde Placement Depths and Available DO Concentrations

	Station 1		*Station 2*		*Station 3*		*Station 4*		*Station 5*	
Depth (ft)	*1993*	*1994*	*1993*	*1994*	*1993*	*1994*	*1993*	*1994*	*1993*	*1994*
1	X	X	X	X						
2					(X)	(X)	(X)	(X)	(X)	(X)
3					X	X	(X)	(X)	(X)	(X)
4										
5							X			
6								X		
7										X
8									X	

Notes: X = depths at which DataSondes were located
(X) = depths with calculated DO concentrations

Record rainfall over the area on June 23-24 during event 2 delayed the removal of monitoring units from the fixed-stations until June 27. All of the dataloggers had ceased recording data at 0530 Central Standard Time (CST) on June 27 because unit memory banks were full. Table 15 gives the inclusive times that the DataSondes were used for each event.

Three DataSonde units were installed at each of the fixed-stations to record ambient, light chamber, and dark chamber conditions. The dark chambers consisted of screw-capped 40-inch lengths of 6-inch diameter white PVC pipe. The light chambers consisted of 35-inch lengths of 6 1/2-inch diameter clear plastic tubing permanently sealed at one end, with access provided by clear Plexiglas plates with clear plastic gaskets bolted to flanges glued to the tubings. The ambient monitors were protected inside 36-inch long, open-ended lengths of 6-inch diameter PVC pipe. The monitor/chamber systems were attached to harness arrangements in submerged prone positions in line with river flow at each location.

Attendant to installation of the fixed-stations, grab samples were collected, stored, and preserved for physical, chemical, and biological analyses in the laboratory in accordance with Standard Methods guidelines (APHA, 1992) with the exception of long-term biochemical oxygen demand (BOD) samples. BOD samples were collected and processed for running long-term laboratory BODs using an ISWS modification of the jug-aeration technique (Elmore, 1955). Water samples were analyzed for turbidity, suspended solids, volatile suspended solids, ortho-phosphate, ammonia, nitrite, nitrate, chlorophylls *a,b,c,* pheophytin *a,* and 20-day BOD. Samples were also collected for the identification and enumeration of algal species. Secchi disk and pH readings were taken at the time of the laboratory sample collections, and temperature/DO vertical profiles were run at the cross sections at each station using YSI model 59 temperature/DO meters. Cross-sectional temperature/DO vertical profiles were run at each station when the DataSondes were retrieved.

During June 22 and 23, 1994, sediment oxygen demand (SOD) measurements were taken in concert with an attempt to determine the periphytonic respiration rates at mile points 64.39, 63.37 (station 3), 61.90 (station 4), 61.27, and 60.74 (station 5), see Figure 16. Sediment samples were collected with a petite PONAR dredge for the determination of moisture content and volatile solids and for the identification/enumeration of benthic macroinvertebrates. Collections for the macroinvertebrates consisted of three PONAR grabs, washed and sieved through a 30-mesh screen, and then combined and preserved with 95% ethanol for transport to the laboratory. Algae samples were also collected for identification and enumeration.

Time of travel for the St. Charles pool was determined during each of the intensive data collection periods. The fluorescent tracer dye Rhodamine WT was injected in the vicinities of stations 1, 2, 3, and 4 between the hours of 12:00 a.m. and 6:00 a.m. on August 18, 1993 (event 1) and June 22, 1994 (event 2). A Turner Designs model 10-005 fluorometer was used to monitor the tracer dye at each subsequent station. This work was directed by personnel from the Water Survey Office of Surface Water Resources: Systems, Information & GIS.

Data Reduction and Analyses

Continuous Monitoring

DataSonde DO readings need to be adjusted for flow conditions and corrected for instrument drift over the duration of a run. Combined adjustment/correction factors were developed using DO values recorded using finely calibrated YSI DO meters at each DataSonde location at the beginning and the end of each event. Ratios of the YSI readings to the appropriate beginning and ending time-interval DataSonde readings were developed. Linear slope adjustments were then applied to the incremental DataSonde values in proportion to the difference between the beginning and ending ratios and the time element involved.

The water depths vary significantly within the pool as shown by Figure 16. Since all stations were continuously monitored at the river bottom, the shallow station DO results are influenced to a much greater degree by algal photosynthetic oxygen production (primary productivity) than are the deeper stations. To account for these differences, shallow-water DO readings were estimated from the deep-water DataSonde data. The continious deep water readings were adjusted by the ratio of the YSI readings taken at the 2- to 3-foot depth to the YSI readings taken at the depth of the DataSonde. Table 16 presents the locations where these conversions were calculated. Note that the placements of the monitoring units at stations 4 and 5 differed slightly etween the two events.

Biological Indices and Factors

Algae were enumerated and identified in the laboratory, and the data were used in assessing the effects of primary productivity on the DO resources of the river at the time of the field work. A biological diversity index, which provides a means of evaluating the richness of species within a biological community using a mathematical computation, was calculated for each site and monitoring event. A community consisting solely of one species has no diversity or richness and takes on the value of unity. As the number of species increases and as long as each species is relatively equal in number, the diversity index increases numerically. A diversity index would approach infinity when a large number of individual organisms are present with each belonging to a different species.

The Shannon-Weiner diversity index formula, as given by Smith (1980), was used to evaluate algal conditions. The formula is:

$$S = 3.222 \left[\log N - \left(\sum_{i=1}^{k} n_i \times \log n_i \right) / N \right] \qquad (7)$$

where

S = Shannon-Weiner diversity index

N = total number of all organisms

n_i = number of organisms for a given species

i = 1, 2, ... k where k is the number of species

Both algae productivity/respiration (P/R) and SOD are biologically associated factors that are normally expressed in terms of grams per square meter per day (g/m²/day). Conversion of these areal rates to mg/L for use in computing the physical reaeration (REA) was accomplished using the following expression:

$$G' = \frac{3.28\ G \times t}{H} \qquad (8)$$

where

G' = DO usage per reach, mg/L

G = SOD or P/R rates, g/m²/day

t = time of travel through reach ($t_1 - t_2$), days

H = average depth, feet

Biochemical Oxygen Demand

Generally, the long-term biochemical oxygen demand or DO usage in a stream is modeled as a first-order exponential reaction, i.e., the rate of biological oxidation of organic matter is directly proportional to the remaining concentration of unoxidized material. The integrated mathematical expression representing this reaction is:

$$L = L_a \left[1 - e^{-K_1 t} \right] \tag{9}$$

where

L = oxygen demand exerted up to time t

L_a = ultimate oxygen demand

K_1 = reaction rate per day

t = incubation time, days

e = base of the natural logarithm, 2.7183

When a delay occurs in the oxygen uptake at the onset of a BOD test, a lag time, t_0 is included and the equation becomes:

$$L = L_a \left[1 - e^{-K_1 (t - t_0)} \right] \tag{10}$$

However, at times, neither Equation 9 nor 10 provides a good model for observed BOD progression curves generated for samples collected in some streams and wastewaters. The BOD often consists primarily of high-profile, second-stage or nitrogenous BOD (NBOD), and the onset of the exertion of this NBOD is often delayed by one or two days. The delayed NBOD curve and the total BOD (TBOD) curve when dominated by the NBOD fraction, often exhibit an S-shaped configuration. The general mathematical model used to simulate the S-shaped curve is:

$$L = L_a \left[1 - e^{-K_1 (t - t_0)^x} \right] \tag{11}$$

where x is a power factor.

Butts et al. (1975) used statistical procedures to show that a power factor of 2.0 in Equation 11 best represents S-shaped BOD curves generated for the ammonia-laden waters of the upper reaches of the Illinois waterway. Substituting x = 2 in Equation 11 yields:

$$L = L_a \left[1 - e^{-K_1 (t - t_0)^2} \right] \tag{12}$$

The strength of organic wastes in water is usually measured indirectly in terms of BOD, which represents the amount of dissolved oxygen required to stabilize dissolved and collodial material in water by microbial processes. Heterotrophic bacteria and protozoa consume carbonaceous material resulting in what is referred to as CBOD. The biochemical utilization (oxidation) of ammonia-N by autotrophic bacteria as a source of energy to convert carbon dioxide to cellular material is referred to NBOD and can be determined by either subtracting measured CBOD from the measured total BOD (TBOD) or computed by measuring the progressive reduction in NH_3-N concentration during the BOD incubation time period.

Historically, the ISWS added the Hach Chemical Company nitrification inhibitor Formula 2533 [or its precusor N-Serve, 2-chloro-6-(trichloromethyl)pyridine] to a BOD sample to prevent ammonia oxidation. This supposedly provides a measure of CBOD. Therefore, the subtraction of the DO used in a CBOD sample from the DO used in an uninhibited (TBOD) sample should provide an estimate of the NBOD. Recent experimental work by the ISWS indicates that microbial activity besides just that associated with the nitrifiers is retarded by the Formula 2533 inhibitor. This results in an overestimation of NBOD. Consequently, for this study NBOD was determined stoichometrically by testing for the reduction in ammonia-N concentrations at 1-, 3-, 5-, 10-, 15-, and 20-day incubation periods and converting these incremental ammonia-N losses to equivalent dissolved oxygen losses.

This conversion process involves a two-stage biochemical reaction referred to as nitrification. The nitifier *Nitrosomonas* sp. oxidizes ammonia-N to nitrite-N as shown by Equation 13 while the nitrfier *Nitrobacter* sp. oxidizes nitrite-N as shown by Equation 14.

$$2NH_3 + 3O_2 \xrightarrow[\textit{Nitrosomonas}\ \text{sp.}]{\text{Nitrite Formers}} 2NO_2^- + 2H^+ + 2H_2O \tag{13}$$

$$2NO_2^- + O_2 \xrightarrow[\textit{Nitrobactor}\ \text{sp.}]{\text{Nitrate Formers}} 2NO_3^- \tag{14}$$

Theoretically, a total of 4.57 mg/L of DO is required to complete both reactions, and this is the figure used in this study to compute NBOD. Of the total, 3.45 mg/L is due to *Nitrosomonas* sp. while 1.14 mg/L is due to *Nitrobacter* sp.

Reaeration Coefficient Analysis

The physical reaeration computational procedure is based upon estimating inputs relative to basic reaeration theory succinctly expressed by the formula:

$$\frac{dD}{dt} = \frac{\Delta D}{\Delta t} = -K_2 D \tag{15}$$

where ΔD is the change in the DO deficit, D, over an increment of time Δt due to the atmospheric exchange of oxygen at the air/water interface, their ratio denotes the reaeration coefficient K_2 Integrating Equation 15 from time t_1 to t_2 gives:

$$\log_e \frac{D_2}{D_1} = -K_2 (t_2 - t_1)$$

$$= -K_2 \Delta t$$

therefore

$$K_2 = -\frac{\log_e \frac{D_2}{D_1}}{\Delta t} \tag{16}$$

Input approximations and computations using observed data are:

$$\Delta D = \text{Reaeration (REA) in mg/L} = C_2 - C_1 - POP - PAP + TBOD + SOD \tag{17}$$

Δt = reach time of travel (t_2 - t_1) in days

D = DO deficit in mg/L

where

C_2 and C_1 = observed DO concentrations in mg/L at t_1 and t_1, respectively.

POP = net periphytonic (attached algae) oxygen production (mg/L) for $\Delta t = t_2 - t_1$.

PAP = net planktonic algae (suspended algae) oxygen production (mg/L) for $\Delta t = t_2 - t_1$

TBOD = total biochemical oxygen usage (mg/L) for $\Delta t = t_2 - t_1$.

SOD = net sediment oxygen demand (mg/L) for $\Delta t = t_2 - t_1$.

The combined effect of TBOD + SOD - POP - PAP is represented by the gross output of the clear periphytonic respiration chamber when employed; or when the clear periphytonic chamber is not employed (periphytonic productivity/ respiration deemed insignificant; i.e., POP = 0), the combined effect of TBOD - PAP is represented by the gross output of the light chamber, and the SOD is equal to the gross SOD chamber output less the dark chamber output.

$$D = \frac{S_1 + S_2}{2} - \frac{C_1 + C_2}{2} \qquad (18)$$

where: S_1 and S_2 are the DO saturation concentrations (mg/L) at t_1 and t_2, respectively, for the average water temperature (T) in the reach.

Equation 15 shows that natural physical reaeration of water occurs at a rate proportional to the DO saturation deficit, i.e., water nearly devoid of DO will add oxygen at a much faster rate than will water that is nearly saturated with DO. Similarly, water containing supersaturated DO concentrations due to algal productivity will lose DO at a rate proportional to the excess up to 200 percent of saturation. This means that water containing 200 percent of saturation will lose DO at the same rate that oxygen is gained when the water is totally devoid of DO (0% saturation). Butts and Evans (1978a) have shown that any supersaturation above 200 percent is lost immediately upon disturbance. Consequently, water saturated at 250 percent will be immediately reduced to 200 percent when any physical disturbance is encountered.

RESULTS AND DISCUSSION

A summary of the parameters for which field and laboratory data were collected or generated is presented in Table 17. The resultant BOD curves are presented in Figure 17; the BOD-curve constants and coefficients derived using the method of steepest descent are summarized in Table 18. Summary statistics for the continuous data generated by the DataSondes are tabulated in Table 19. Daily statistics computed from the continuous monitoring are presented in Appendix A. Plots of the DataSonde - generated data are presented according to parameter and event: DO for the 2-foot, 3-foot, and bottom depths in Figures 18 and 19; temperature in Figure 20; pH in Figure 21; and conductivity in Figure 22.

Hydrologic/Hydraulic Considerations

Hydrologic/hydraulic conditions varied considerably between 1993 and 1994 events. In addition, conditions varied greatly over the duration of the 1994 event, as shown in Table 20. The flows and attendant flow durations (the percent of time a given flow is equalled or exceeded) are given in Table 20a, while the times of travel recorded using the dye tracer are given in Table 20b. Stable, medium-level flows persisted over the three-day 1993 event while the 1994 event started under moderately low-flow conditions that quickly changed to medium-level flows within 24 hours. Flood conditions persisted by June 24 and prevented the removal of the monitoring equipment after the planned 72-hour placement time period had elapsed. Consequently, the units were left in place an additional three days until retrieval was affected on June 27, 1994.

The 1994-event high flows resulted from intense rainfall that fell in northeastern Illinois during the night of June 23 and early morning of June 24. Chicago O'Hare Airport recorded 3.80 inches of rain during this period. On the morning of June 24, ISWS personnel measured approximately 7 inches of rainwater in a 5-gallon bucket that had been left overnight in a motel parking lot in St. Charles. Luckily, all water sampling, SOD measuring, and time of travel work were able to be completed before the effects of the rainfall increased the flow in the mainstem of the Fox River significantly. However, as previously mentioned, the scheduled removal of the monitors was delayed.

Existing extremes in hydrologic/hydraulic conditions prevented exploring the possibility of using the information and data derived for developing a USEPA QUAL-2EU type water quality

Table 17. Summary of Ambient Water Quality Conditions at Time of DataSonde Placement

Parameter		*Station 1*		*Station 2*		*Station 3*		*Station 4*		*Station 5*	
		8/17/93	*6/21/94*	*8/17/93*	*6/21/94*	*8/17/93*	*6/21/94*	*8/17/93*	*6/21/94*	*8/17/93*	*6/21/94*
Turbidity (NTU)		46	19	55	18	38	22	45	25	48	54
Suspended solids (mg/L)		42	35	63	42	37	48	45	54	46	81
Volatile suspended solids (mg/L)			18		21		27		24		35
Secchi disk (in)		11	11	11	12	14	12	13	12	12	14
PH (units)		8.34	9.11	8.46	8.75	8.48	9.04	8.51	8.42	8.44	9.13
Ortho-PO_4 -P (mg/L)		0.48	0.19	0.34	0.20	0.25	0.09	0.15	0.15	0.11	0.07
NH_3 -N (mg/L)		0.16	<0.02	0.11	<0.02	0.15	<0.02	0.06	<0.02	0.05	<0.02
NO_2 -N (mg/L)		0.05	0.09	0.05	0.07	0.04	0.07	0.06	0.07	0.05	0.06
NO_3 -N (mg/L)		0.71	0.87	0.83	0.77	0.84	0.20	0.97	0.35	0.91	0.12
Chlorophyll (mg/m^3)	*a*	40	145	10	92	29	164	22	146	19	116
	b	9	9	4	2	5	2	4	3	5	2
	c	5	21	<2	15	2	30	2	56	3	17
Pheophytin (mg/m^3)	*a*	16	25	8	2	6	5	7	4	9	2
Dissolved Oxygen (mg/L)											
0’		11.75	12.82	10.36	16.89	12.81	25.72	11.28	18.62	10.52	28.80
1’		11.53	12.82	10.32	16.89	12.78	26.06	11.17	18.52	11.51	24.00
2’		11.50				12.75	22.44	11.13	18.42	10.45	26.60
3’						12.60	23.62	11.08	17.94	10.42	22.00
4’								11.08	16.84	10.13	14.50
5’								11.08	15.02	10.11	12.80
6’										10.09	11.60
7’										10.01	11.09
Temperature (°C)											
0’		26.5	28.5	26.8	31.6	27.9	30.6	26.3	29.6	26.2	30.6
1’		26.5	28.5	26.7	31.6	27.9	30.5	26.3	29.6	26.2	30.6
2’		26.5				27.9	29.8	26.3	29.6	26.2	30.4
3’						27.9	30.0	26.3	29.5	26.1	28.6
4’								26.3	29.3	26.1	28.1
5’								26.3	29.0	26.1	27.7
6’										26.1	27.6
7’										26.0	27.5
*DO saturation 0’ (mg/L)		7.95	7.65	7.90	7.21	7.77	7.35	7.95	7.49	7.99	7.19

*(ASCE, 1960)

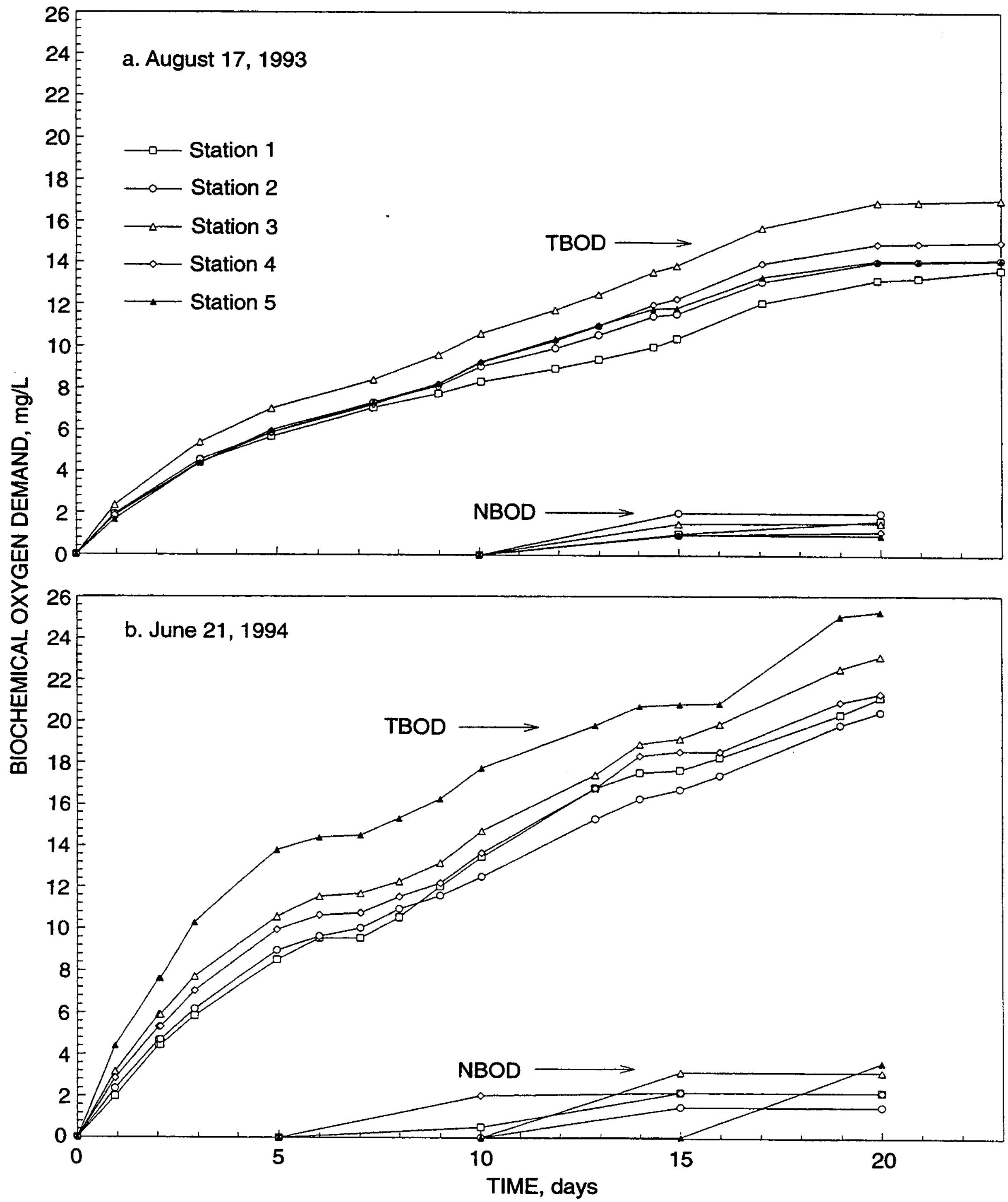

Figure 17. Total (TBOD) and nitrogenous (NBOD) biochemical oxygen demand during 1993 and 1994 monitoring events

Table 18. TBOD Coefficients Derived for Equation 9 and Equation 12 Using the Method of Steepest Descent

		Equation 9			*Equation-12 Best-Fit*				
Event	*Station*	*Standard Deviation(mg/L)*	*K_1 (1/day)*	*L_a (mg/L)*	*Standard Deviation*	*x*	*t_o (days)*	*K_1 (1/day)*	*L_a (mg/L)*
1	1	0.707	0.0896	14.74	0.538	2	-7.067	0.0538	14.47
	2	0.555	0.0896	15.91	0.405	2	-5.992	0.0602	14.94
	3	0.677	0.0822	19.75	0.475	2	-7.047	0.0546	18.34
	4	0.683	0.0836	17.15	0.552	2	-4.750	0.0663	15.28
	5	0.478	0.0925	15.09	0.397	2	-4.872	0.0678	14.65
2	1	0.695	0.0771	25.77	0.605	2	-4.948	0.0656	21.98
	2	0.844	0.0911	22.52	0.563	1	-0.795	0.0634	26.68
	3	1.090	0.0932	25.74	0.729	1	-1.147	0.0642	29.68
	4	1.000	0.0971	23.69	0.716	1	-0.971	0.0663	27.80
	5	1.460	0.1384	24.77	1.010	1	-1.603	0.0874	28.15

Notes: K = deoxygenation rate constant, per day
L = ultimate oxygen demand, mg/L
x = power factor
t_o = lag time, days

Table 19. Continuous Monitoring - Summary Statistics

		8/17 - 20/1993					6/21 - 27/1994				
Station	*Parameter*	*n*	*Min*	*Avg*	*Max*	*S.D.*	*n*	*Min*	*Avg*	*Max*	*S.D.*
1	Temp °C	281	25.05	26.136	27.37	0.571	548	19.47	24.036	29.99	3.018
	pH units	281	8.11	8.330	8.65	0.120	548	7.49	7.885	8.78	0.320
	S.C. ms/cm	281	0.713	0.726	0.740	0.008	548	0.640	0.746	0.849	0.068
	DO-1' (mg/L)	281	7.13	9.178	12.09	1.304	548	7.89	9.880	14.92	1.688
2	Temp °C	290	24.92	26.563	28.17	0.696	540	19.68	24.084	31.89	3.113
	pH units	290	7.94	8.216	8.59	0.165	540	7.38	7.899	8.99	0.435
	S.C. ms/cm	290	0.666	0.683	0.703	0.006	540	0.638	0.741	0.849	0.061
	DO-1' (mg/L)	290	6.14	8.348	12.19	1.606	540	2.83	7.178	18.86	3.493
3	Temp °C	269	24.96	26.426	28.55	1.007	540	19.39	23.849	29.65	3.006
	pH units	269	8.02	8.326	8.62	0.195	540	7.58	8.139	8.99	0.483
	S.C. ms/cm	269	0.685	0.705	0.715	0.008	540	0.507	0.691	0.788	0.070
	DO-2' (mg/L)	269	4.97	9.271	17.37	3.533	540	4.58	11.702	26.67	6.019
	DO-3' (mg/L)	269	4.93	9.176	17.18	3.493	540	4.80	12.290	28.06	6.346
4	Temp °C	273	25.09	26.271	27.37	0.627	545	18.84	23.711	29.27	3.221
	pH units	273	8.00	8.252	8.49	0.141	545	7.40	8.004	8.92	0.471
	S.C. ms/cm	273	0.746	0.754	0.761	0.003	545	0.403	0.682	0.826	0.118
	DO-2' (mg/L)	273	4.87	9.798	14.99	3.102	545	3.64	10.769	26.52	4.310
	DO-3' (mg/L)	273	4.58	9.485	14.56	3.057	545	3.48	10.309	25.41	4.133
	DO-5' (mg/L)	273	4.58	9.485	14.56	3.057	545	2.63	7.760	19.01	3.081
5	Temp °C	280	25.39	26.182	26.95	0.425	548	18.75	23.312	27.67	2.957
	pH units	280	8.09	8.301	8.44	0.083	548	7.64	8.061	8.74	0.387
	S.C. ms/cm	280	0.691	0.742	0.758	0.008	548	0.396	0.689	0.856	0.132
	DO-2' (mg/L)	280	5.82	9.027	11.75	1.738	548	3.06	8.820	26.24	4.975
	DO-3' (mg/L)	280	5.69	8.883	11.68	1.749	548	3.06	8.084	21.87	3.214
	DO-8' (mg/L)	280	5.58	8.658	11.26	1.666	548	3.06	6.800	14.58	2.795

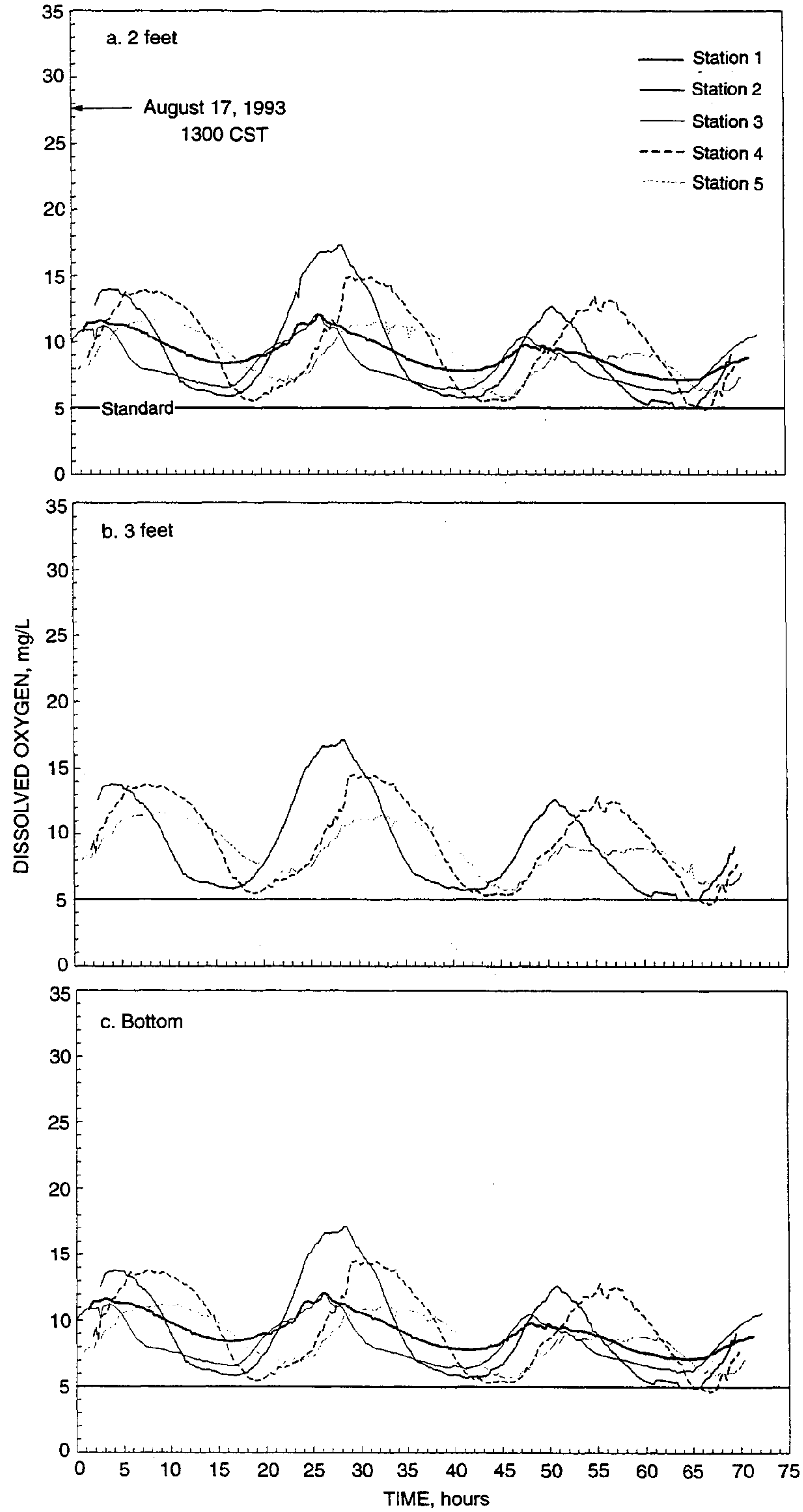

Figure 18. Ambient dissolved oxygen (DO) at a) 2 feet, b) 3 feet, and c) bottom for the 1993 event

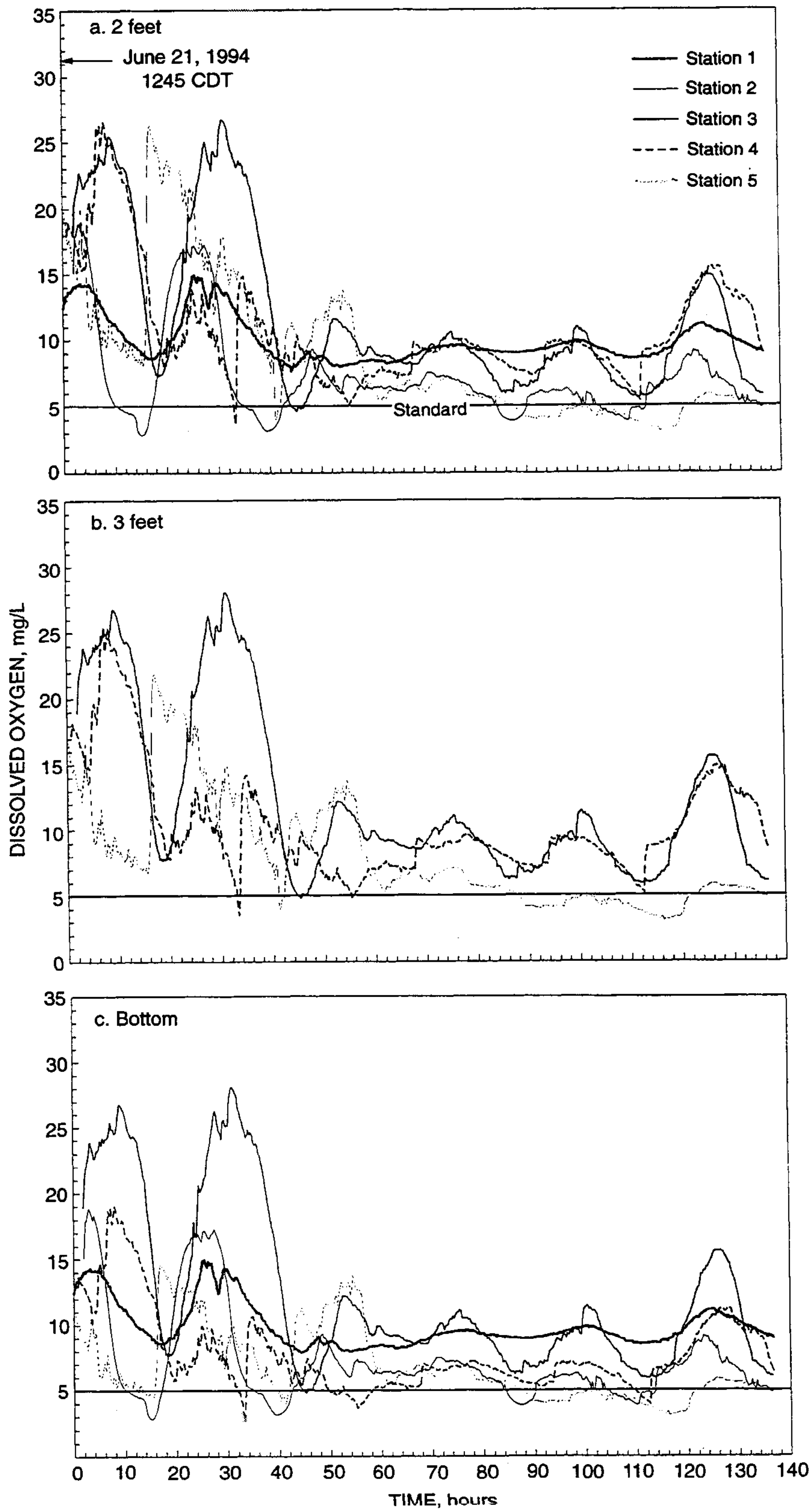

Figure 19. Ambient dissolved oxygen (DO) at a) 2 feet, b) 3 feet, and c) bottom for the 1994 event

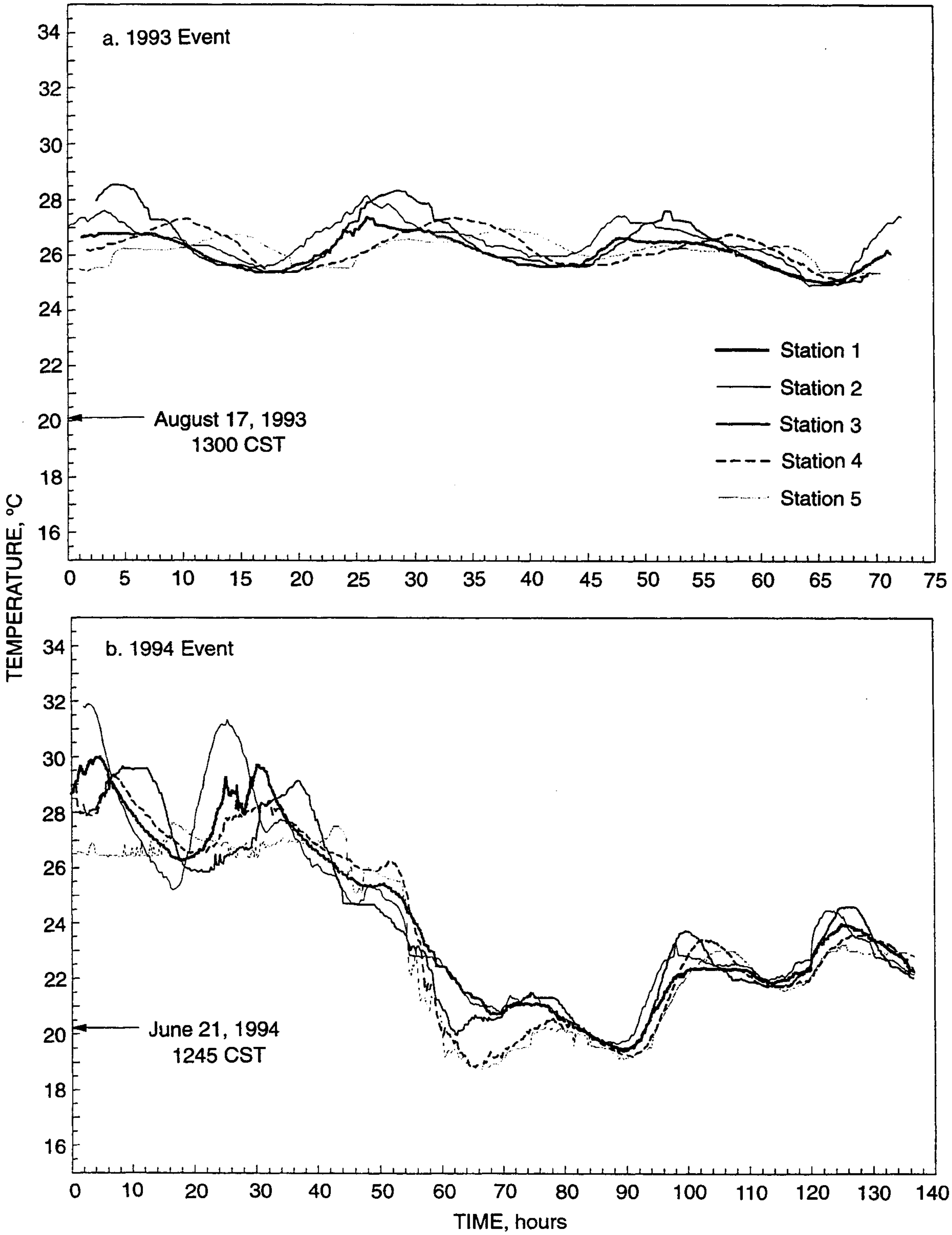

Figure 20. Ambient temperature at the bottom during the 1993 and 1994 events

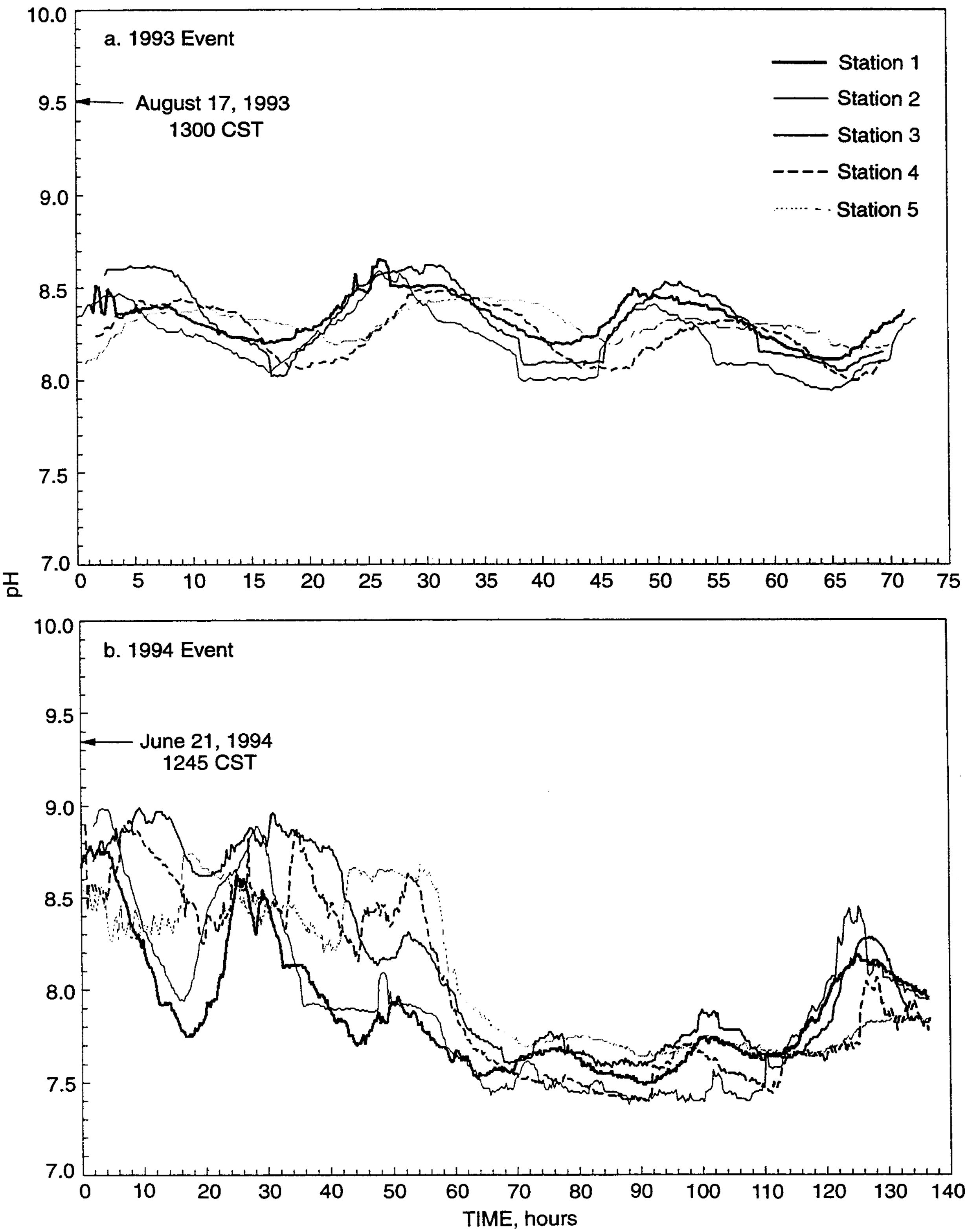

Figure 21. Ambient pH at the bottom during the 1993 and 1994 events

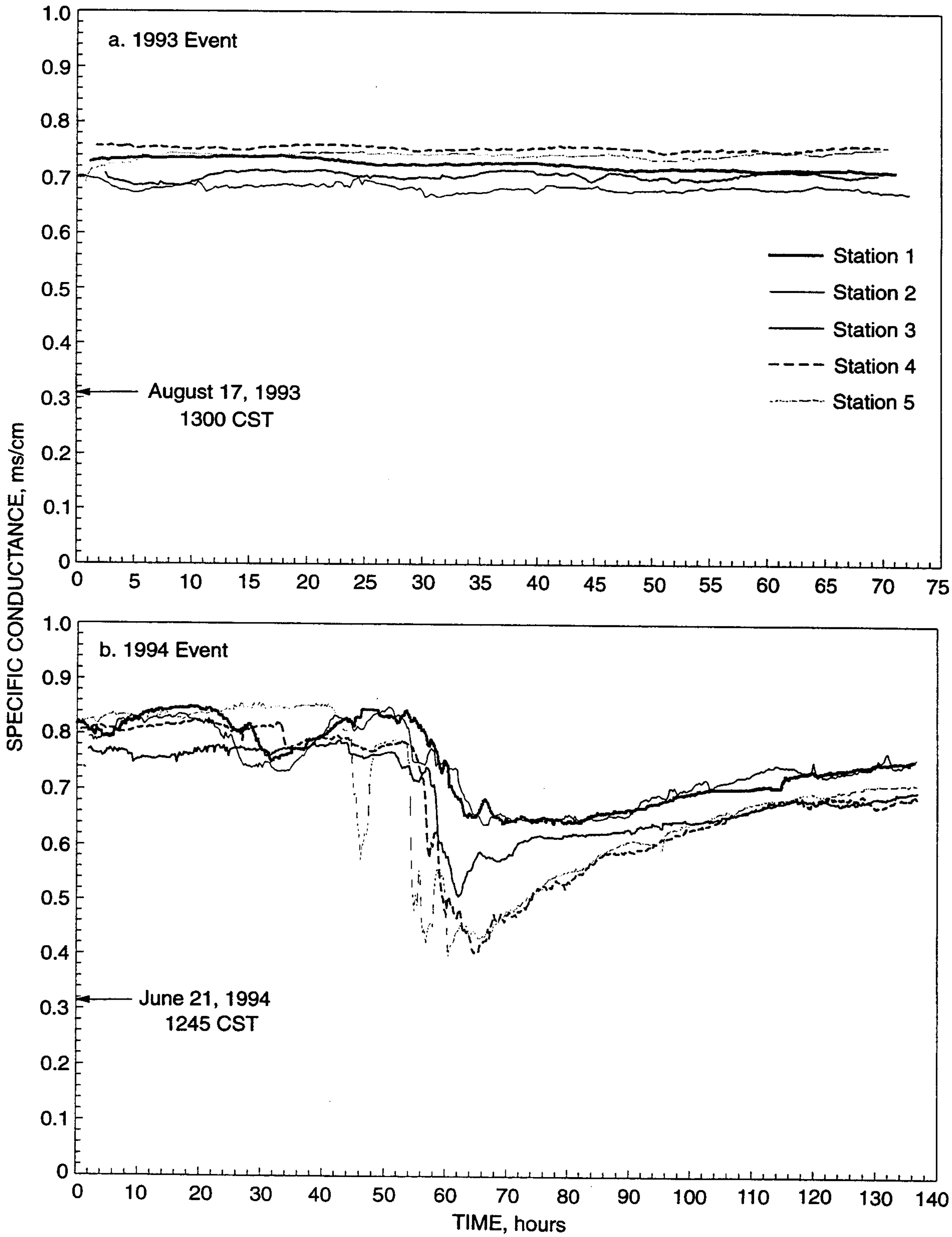

Figure 22. Ambient specific conductance at the bottom during the 1993 and 1994 events

Table 20. Measured and Recorded Hydrological/Hydraulic Data and Information

a. Flow Data at Station 2

Event	*Date*	*Flow (cfs)*	*Flow Duration (%)*
1	8/18/93	810	43
	8/19/93	818	43
2	6/22/94	305	81
	6/23/94	835	42

b. Time of Travel and Velocity

					Time of Travel (hrs)			
		Incremental			*Incremental*		*Cumulative*	
	River	*Distance*	*Velocity (fps)*					
Station	*Mile*	*(miles)*	*Event 1*	*Event 2*	*Event 1*	*Event 2*	*Event 1*	*Event 2*
1	68.18							
		1.66	1.007	0.673	2.42	3.62	2.42	3.62
2	66.52							
		3.15	1.130	0.695	4.09	6.65	6.51	10.27
3	63.37							
		1.47	0.408	0.116	5.28	18.52	11.79	28.79
4	61.90							
		1.16	0.473	0.128	3.88	14.33	15.67	43.12
5	60.74							
Cumulative Totals - Volume Displacement							17.30	37.81

model for the St. Charles pool. Persistent low-flow conditions are needed for such modeling. The 1993 flows were marginally excessive to produce meaningful results. The initial flow (81 percent duration using the ILSAM Model for the Fox River (Knapp, 1988) - Table 20a) during June 22, 1994 was within acceptable low-flow, steady-state conditions for model development, but this changed dramatically when the storms moved over the area and caused unsteady, high-flow conditions to develop.

The information contained in Table 20b and Figure 23 show that the total time of travel values through the length of the pool measured using the dye tracer during both events are in good agreement with those computed using theoretical volume displacement methodology. The higher flows experienced during event 1 produced a measured time of travel that was within 9.4% of the theoretical (from volume displacement model) value, whereas the measured event-2 value was within 14.0% of the theoretical value. Time of travel values computed using volume displacement, when compared to values measured using a dye tracer, appear to provide hydraulic information sufficiently accurate for use in developing a predictive water quality model or in forecasting the downstream progress of contaminants released during accidental spills or from wastewater treatment plants.

Although limited to a collection at each station during the initiation of each event, the grab sampling phase of this study produced some interesting results. These results, when examined either alone or in conjunction with continuous monitoring data, reveal some interesting and provocative features and characteristics of present-day Fox River water quality. Over the past 30 years, the water quality of the river has shown marked improvement. However, the metamorphosis from a grossly polluted stream to a "clean" stream is not complete. Some chronic problems that plagued the river in the past still persist today, namely, those associated with excessive algal growth and its attendant effects on general water quality.

Ambient Water Quality Parameters: Discussion

A discussion of the ambient water quality parameters, as listed in Table 17, will be presented. Some references and discussions will be rather pointed and brief, whereas others, especially those associated with algal activity, will be given in more detail.

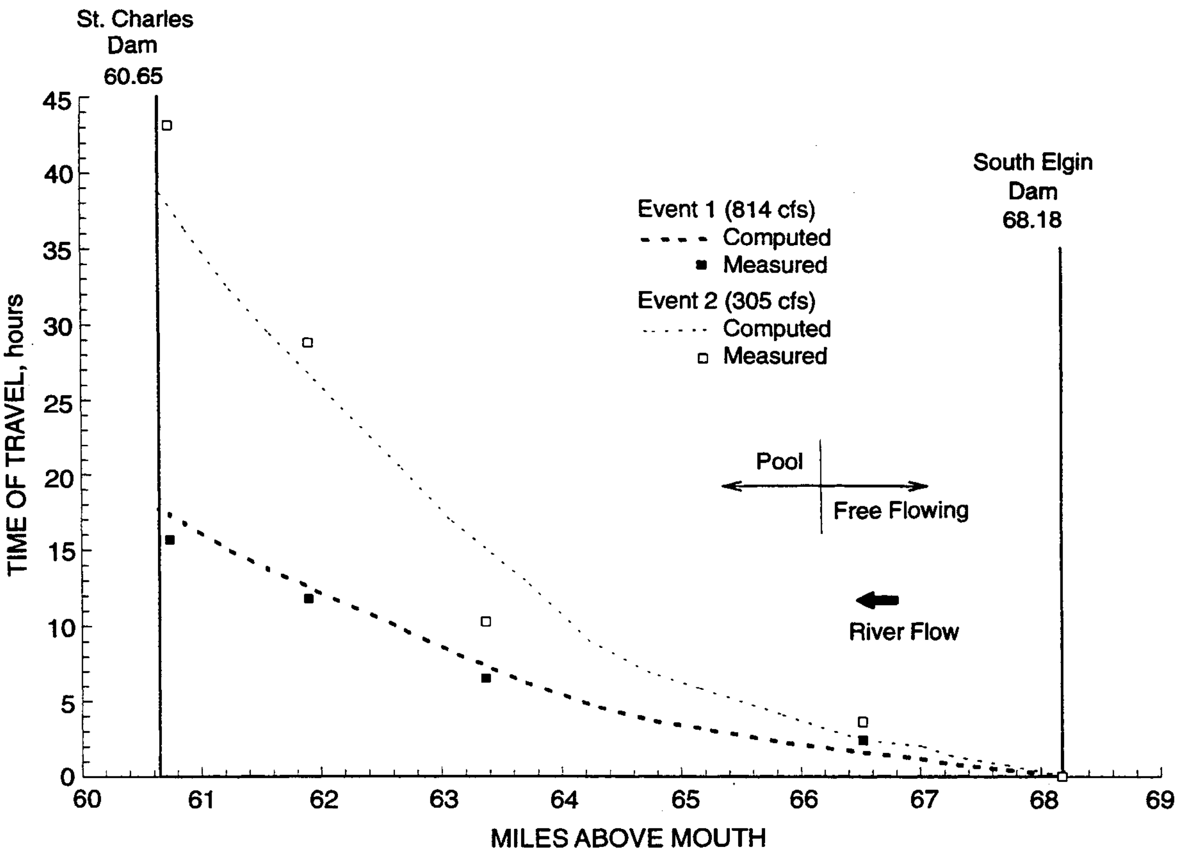

Figure 23. Comparison of travel times measured in the field with those computed by the volume-displacement method

Turbidity. The turbidity levels were significantly higher during the 1993 than the 1994 event at four of the five stations. At station 5, immediately above the dam, the 1994 turbidity was slightly higher than the 1993 value. The overall pool level was higher during event 1 because of the higher flows and the fact that bank-flow conditions had persisted for several months prior to this event. Turbidities of 40 NTU's and above would tend to suppress algal activity somwhat, especially when such turbidities are associated with antecedent bank-flow or flood-flow conditions. Turbidities observed during both events of a similar study recently conducted on the Sangamon River (Larson et al., 1994), were almost identical to those observed during event 1 of this study. Sangamon River primary productivity is low. As will be discussed in detail later, algal productivity was much lower during event 1 than event 2.

The higher turbidity during 1994 at station 5 appears to be an anomaly that is not readily explainable. It cannot be attributed to any great degree to increased algal biomass since the ratio of 1994 algal counts to 1993 counts were higher at stations 2, 3, and 4. Also, the absolute algal numbers were higher at station 1 than at station 5 during both events (Table 21).

Suspended Solids (SS); Volatile Suspended Solids (VSS). Although the overall pool turbidities were higher during 1993 because of the high flows associated with this event, suspended solids that are normally highly positively correlated to turbidity, were not commensurately higher. The SS values at stations 3, 4, and 5 were higher during event 2 and were essentially equal at station 1 because of the three- to sevenfold increase in the number of suspended algal cells (Table 21). This, in turn, is supported by the fact that roughly 50% of the 1994 suspended solids consisted of volatile material (probably algal cells). This is an inordinately high ratio of VSS to SS for surface waters of Illinois.

Secchi Disk. The Secchi disk readings represent subjective water clarity measurements taken by observing the disappearance of a standard disk with alternating black - and - white quadrants as the disks are lowered over the side of a boat into the water. The disappearance distance exceeding 10 inches represents relatively clear water for most flowing Illinois streams. Illinois River readings may fall as low as two or three inches during high flows or during barge passage. Secchi disk water clarity measurements were essentially equal for both periods. During 1993, however, higher flows probably dictated water clarity conditions, whereas suspended algae cells probably influenced clarity to a great degree during 1994.

Table 21. Algae Identification and Enumeration (cells/mL)

Classification	Genus/Species	*Station 1* 8/17/93	*Station 1* 6/21/94	*Station 2* 8/17/93	*Station 2* 6/21/94	*Station 3* 8/17/93	*Station 3* 6/21/94	*Station 4* 8/17/93	*Station 4* 6/21/94	*Station 5* 8/17/93	*Station 5* 6/21/94
Blue green	*Anabaena flos-aquae*	168									
	Anacystis thermalis					168		630			
	Aphanizomenon flos-aqua	252	84	210	189	452	137	242	179	378	252
	Oscillatoria sp.	73									
Green	*Actinastrum hantzschis*	158		116	74		231	221	200		
	Coelastrum microporum				315		452		221		
	Crucigenia retangularis	5103	84	2909	504	2615	378	2709	1166	2079	935
	Crucigenia tetrapdia				63						
	Micractircium pusillum	168	74		137		137		126		
	Oocystis borgei	137	32		74	200	105	63	84	158	168
	Pediastrum duplex	147	641	189	914	242	641		704	200	452
	Pediastrum simplex	95		105		116		95		63	
	Pediastrum tetra	53	116							116	95
	Polyedriopsis spinosa						210	32			189
	Scenedesmus dimorphus	126	326		662		536	84	305		431
Diatom	*Caloneis amphisbaena*	126									
	Cyclotella atomus		14658		17714		13766		14763		
	Cyclotella meneghiniana	1901	14049			1607		1922	16769	1775	14837
	Cymatopleura solea			21							
	Diatoma vulgare									95	
	Gyrosigma kutzingii							11		63	32
	Gyrosigma macrum	53	32				32	63	95		200
	Gyrosigma obtusatum									32	
	Mastogloia braunii	168								158	
	Melosira binderana		63		305		531	189	2184		1953
	Melosira granulata	1376	12989	1218	13661	1397	13524	1397	882	1166	11687
	Navicula cryptocephala	1292									

Table 21. Concluded

Classification	Genus/Species	*Station 1*		*Station 2*		*Station 3*		*Station 4*		*Station 5*	
		8/17/93	*6/21/94*	*8/17/93*	*6/21/94*	*8/17/93*	*6/21/94*	*8/17/93*	*6/21/94*	*8/17/93*	*6/21/94*
	Navicula gastrum	84	32								
	Stephanodiscus niagarae		11					32		53	
	Synedra acus						63				116
	Tabellaria fenestrata									147	
Flagellate	*Ceratium hirundinella*	2069	11	347		137		179			
	Chlamydomonas pertusa									42	
	Dinobryon sertularia	294				63	53	116	420	189	
	Euglena gracilis		137	200	2247		1691		924		767
	Euglena viridis	662		84							
	Phacus pleuronectes	105	11		53				21	84	
	Trachelomanas crebea									21	
Desmid	*Staurastrum cornutum*	53	11	53			32		168	74	42
Class Totals											
	Blue Green	493	84	210	189	620	137	872	179	378	252
	Green	5987	1273	3319	2743	3173	2459	3214	2827	2816	2270
	Diatom	5000	41834	1239	31680	3004	27816	3614	34693	3469	28825
	Flagelate	3130	159	631	2300	200	1744	295	1365	336	767
	Desmid	53	11	53	0	0	32	0	168	74	42
Grand Total		*14663*	43361	5452	36912	6997	32188	7995	39232	7093	32156
Total # taxa		23	18	11	14	10	16	16	17	20	15
Shannon - Weiner Index		3.2	1.9	2.2	1.9	2.6	1.8	3.5	2.1	3.3	2.0

pH. The flux in pH in the St. Charles pool is dictated primarily by algal photosynthetic oxygen production and respiration. During photosynthesis, carbon dioxide (CO_2), either as a free gas or in its half-bound state as a bicarbonate (HCO_3), is extracted from the water and used in conjunction with water to manufacture cellular material:

$$6CO_2 + 6H_2O \xrightarrow{light} C_6H_{12}O_6 + 6O_2 \qquad (19)$$

Dissolved CO_2 produces acid conditions in water via carbonic acid. When CO_2 is biologically extracted, the pH of the aquatic environment is raised in proportion to phytoplanktonic activity. During algal respiration, the reverse is true, i.e., CO_2 is released into the water column resulting in lower pH values. This phenomenon will be aptly illustrated later with the presentation of the continuous monitoring data. The "grab-sample" values recorded during both events are elevated above normal surface water conditions of 7.0 to 7.5. However, the 9.0+ values recorded during event 2 are extremely elevated due to intense algal activity.

Ortho-Phosphorus. Phosphorus availability is a critical factor governing biological productivity in an aquatic system. Evans and Schnepper (1974) emphatically state that phosphorus is the nutrient that limits algae growth in Illinois waters. Inorganic phosphorus levels as low as 0.01 mg/L, in conjunction with inorganic nitrogen levels of 0.3 mg/L, have been shown to produce algal blooms in Wisconsin lakes (Sawyer, 1952). IPCB rules and regulations (State of Illinois, 1990) do not provide a phosphorus standard for flowing streams. However, for lakes and streams flowing into lakes, the standard is 0.05 mg/L as P. Ortho-phosphorus is free, dissolved phosphorus, and it is the form that is most readily available for biological assimilation.

The ortho-P values at all stations during both events are very high relative to those needed for algal growth. At all stations with the exception of station 4, the 1993 values are significantly higher than the 1994 values. Futhermore, during both events in years, the concentrations decrease significantly downstream. These inter-year and intra-year differentials are due to algal growth and algal densities. As Table 21 shows, 1994 total densities (cells/mL) were three to seven times higher than those observed during 1993. As a consequence, more ortho-P was extracted from the water by algal cells during 1994, and during both years, downstream values were reduced because of this extraction and assimilation process.

Nitrogen. Ammonia-N (NH_3-N), nitrite-N (NO_2-N), and nitrate-N (NO_3-N) are the three forms of dissolved inorganic nitrogen that are readily available for phytoplanktonic uptake and assimilation. Nitrite-N is usually found in low concentrations since it is a transient intermediary in the biological oxidation (nitrification) of ammonia-N. Nitrate-N is the stable end-product of nitrification. Of the three forms of nitrogen, Wang et al. (1973) found that ammonia-N is more readily assimilated during algal biosynthesis than the other two forms.

The IPCB rules and regulations (State of Illinois, 1990) for general use water quality standards limit NH_3-N concentrations to 1.5 mg/L when warm weather conditions persist in concert with pH levels above 8.0.

The ammonia-N standard was not close to being violated during the initiation of either event. In fact, during event 2, the NH_3-N concentrations were below the minimum detection limit of 0.02 mg/L at all five stations. Although the NH_3-N levels were somewhat higher during event 1, the concentrations were still very low. Additionally, the total of the three inorganic nitrogen components are generally low for Illinois streams and rivers. Public health limits of 10.0 mg/L for NO_3-N have been set to prevent methemoglobinemia in infants ("blue babies"). The probability of Fox River water exceeding this public health limit appears to be very low during summer warm weather.

Similar to phosphorus, much of the nitrogen in the study reach of the Fox River appears to be "tied up" in algal biomass. Two similar studies on two widely separate reaches of the Sangamon River (Broeren et al., 1991, Larson et al., 1994) found total inorganic nitrogen concentrations ranging from 2.13 mg/L to 9.89 mg/L at six sampling stations for two weeks while the algal densities ranged from only 71 cells/mL to 837 cells/mL. This contrasts with the present study, which generated total nitrogen values ranging from only 0.18 mg/L to 1.09 mg/L in concert with algal counts ranging from 5,452 cells/mL to 39,232 cells/mL (Table 20).

Winter sampling probably would provide results that better reflect the true magnitude of ammonia-N concentrations in the Fox River as derivatives of wastewater treatment plant discharges. For example, during the summer of 1971, the average ammonia-N concentration in the Illinois River at Peoria was 0.67 mg/L, however, during the winter of 1971-72 it ballooned to 5.13 mg/L (Butts, 1983). Cold weather inhibits both bacterial nitrification and primary productivity permitting the ammonia to be transported in the inorganic form and not in a biologically tied-up state.

Chlorophyll/ Pheophytin/ Algae. Chlorophyll *a* is found in all plants, whereas chlorophylls *b* and *c* and pheophytin *a* are specific to phytoplankton. Pheophytin *a* is a degradation product of chloroplyll *a.* Consequently, the higher the ratio of pheophytin *a* to chlorophyll *a,* the less viable the plankton community. For the 1993 event, this ratio averaged 0.44 and ranged from a high of 0.80 at station 2 to a low of 0.21 at station 3 (Table 17). The 1994 ratio averaged only 0.053 and ranged from a high of 0.172 at station 1 to a low of 0.017 at station 5.

Based on chlorophyll/pheophytin results as given in Table 17 and the algal data tabulated in Table 21, several conclusions can be reached relative to the phytoplanktonic activity in the two events and in Fox River phytoplankton activity in general. The most obvious is that algal activity was much more pronounced and viable during 1994 than 1993. This, however, does not mean that the 1993 algal activity was suppressed or low. It merely means that the 1994 activity was extremely high. This inference can be put into perspective by noting that a widely espoused limnological "rule of thumb" sets the lower limit for potentially nuisance algal blooms at 500 cells/mL.

According to standard Methods (APHA, 1992), various types of photosynthetic pigments can be used to separate the major algal groups. A cursory attempt was made to do this for the limited data generated during this study by statistically correlating the three types of chlorophyll to the four major algae classifications plus desmids (conjugated, filamentous algae). The most apparent conclusion reached is that diatoms are highly correlated to chlorophyll a and c (Table 22). Any further interpretation of the data is limited by dominance of diatoms in the 1994 samples. Diatoms accounted for 80% of the 43,361 algal cells counted in the 1994 samples, but only 18% of the 6997 algal cells in the 1993 samples.

The fact that diatoms predominate and that blue green densities appear in less than "bloom" proportions is encouraging from general use and potable water use perspectives. Diatoms reflect good overall water quality conditions, whereas blue greens (and to a lesser degree, greens) indicate poor or degraded aquatic conditions. However, high algal densities of any type could cause filter clogging and other operational problems associated with potable water treatment processes. Also, taste and odor problems associated with some species of green and

Table 22. Correlation Coefficients (r) Relating Types of Chlorophyll to Algal Class Cell Counts (cells/mL)

Type of Chlorophyll	*Algal Classification*					*Total*
	Blue Green	*Green*	*Diatom*	*Flagellate*	*Desmid*	*All Classes*
a	-0.6394	-0.5152	0.9747	0.3075	-0.2474	0.9672
b	0.1843	0.1295	-0.3722	-0.3964	-0.3178	-0.3263
c	-0.6708	-0.4593	0.9584	0.3906	-0.0382	0.9558
a + c			0.9736	0.3581		
a & c			0.9768	0.4741		
Range (cells/mL)						
low	84	1273	1239	159	0	6997
high	620	5987	34,693	3130	168	43,361

Notes: *a + c* = arithmetically combined
a & c = stepwise regression combined

blue green algae could become a reality if the Fox River becomes a major source of domestic water for communities in the area.

While the overall water quality of the Fox River has improved tremendously over the past 30 years, the main stem of the river still has excessive algal growths. The numbers really have not changed significantly, but the dominant species have changed from a blue green - green mix to those identified as diatoms.

Large blooms are likely to persist and remain unchecked during summer low flows for three reasons: (1) the Fox Chain of Lakes provide an almost unlimited source of "seed" cells and nutrients to the river proper (Kothandaraman et al., 1977), (2) a number of nutrient point sources exist along the main stem and tributaries and, (3) the pools created by the channel dams make environmental conditions more lenitic than lotic in nature during warm-weather, low-flow conditions. Lenitic or lakelike conditions are more conducive to phytoplankton growth than are riverine conditions. To achieve any noticeable improvements, phosphorus reduction at point sources has to be undertaken and the channel-dam pools must be subjected to the same stringent phosphorus IPCB water quality standard as lakes and reservoirs, i.e., 0.05 mg/L (State of Illinois, 1990). Channel-dam pools, especially those in the Fox River, should be treated as a lake or reservoir and not exempted as stated in Section 302.205 of the IPC Rules and Regulations (State of Illinois, 1990) when these types of surface waters are subjected to intense recreational activities and are used as sources of domestic water supplies.

Dissolved Oxygen/ Temperature. The dissolved oxygen and temperature results presented in Table 17 are those taken on a vertical at the DataSonde installations. Dissolved oxygen and temperature results and conditions will be discussed in greater detail later. However, several interesting observations can be made from the "grab sampling" DO/temperature results presented in Table 17. As with the previously discussed parameters, great differences exist between event-to-event DOs as well as station-recorded DOs during each event.

Supersaturated DO concentrations persisted throughout the pool during both events; supersaturation levels were much greater at stations 2 - 5 during event 2. This is reflective of the greater algal counts observed during event 2 throughout the study reach. However, station-1 DOs differed little between events. The DOs in this reach of the pool tend to be equalized over a wide range of conditions because of the aeration/deaeration effects of the South Elgin Dam.

wide range of conditions because of the aeration/deaeration effects of the South Elgin Dam. Water supersaturated with oxygen above the dam will be consistently deaerated as it flows over the dam to some broad baseline exceeding the saturation concentration. Conversely, variable oxygen deficiencies above the dam will be reaerated and elevated to some basic level less than the saturation concentration.

If a dam is a good aerator/deaerator, highly supersaturated DO concentrations in waters above these structures are reduced to levels downstream that differ little from those which would result downstream when the above-dam DO concentrations are only slightly above saturation. During events 1 and 2, the average above-dam (station-5) DOs computed from Table 17 are 10.41 mg/L and 19.05 mg/L, respectively. The aeration/deaeration coefficient for the St. Charles dam is high (Butts and Evans, 1978a). Consequently, a large loss of DO is expected to occur at the St. Charles Dam during periods when upstream DO is highly supersaturated. Based on dam aeration/deaeration theory, the predicted downstream DO concentration is only 9.47 mg/L for event 2, which differs little from the value of 8.79 mg/L predicted for event 1.

The higher flows during 1993 produced well mixed conditions as evidenced by the small differentials in DOs and temperatures between the surface and the bottom waters, even at station 5, the deepest location. The low flows that persisted at the onset of event 2 produced markedly stratified DOs and temperatures in the pooled area of the study reach. A 17.72 mg/L difference in DO and a 3.1°C difference in temperature occurred in water only seven-feet deep at station 5. This supports the contention that during low flows in Fox River, low-head dams create pools that act and react like mini-lakes and mini-reservoirs. The event-2 supersaturated surface DO at station 5 of 28.80 mg/L (401% of saturation) is the highest known DO to be recorded at any location in any lake or river in Illinois.

Biochemical Oxygen Demand. Because ambient (day 0) ammonia-N concentrations were very low at all stations for both events as shown in Table 23, little nitrification occurred during the first 10 days of incubation. The fact that the NH_3-N and NO_2-N concentrations actually increased gradually during this period for both events prevented a realistic fractionalization of the TBOD into CBOD and NBOD. Consequently, during the first 10 days of the incubation the TBOD curves shown in Figure 17 are essentially equal to the CBOD.

Table 23. BOD Aliquot Nitrogen Concentrations (mg/L)

Parameter	*Year*	*Station*	*Day*						
			0	*1*	*3*	*5*	*10*	*15*	*20*
NH3 -N	1993	1	0.16	0.04	0.12	0.19	0.38	0.16	0.02
		2	0.11	0.05	0.13	0.17	0.46	0.02	0.02
		3	0.15	0.04	0.13	0.21	0.36	0.03	0.02
		4	0.06	0.04	0.11	0.22	0.27	0.06	0.02
		5	0.05	0.05	0.14	0.21	0.23	0.02	0.02
	1994	1	0.07	0.02	0.02	0.48	0.37	0.02	0.02
		2	0.05	0.02	0.13	0.31	0.35	0.02	0.02
		3	0.02	0.02	0.25	0.51	0.71	0.02	0.02
		4	0.02	0.04	0.37	0.54	0.05	0.02	0.02
		5	0.02	0.02	0.18	0.45	0.82	0.81	0.02
NO2 -N	1993	1	0.05	0.05	0.05	0.05	0.04	0.09	0.01
		2	0.05	0.04	0.04	0.05	0.01	0.04	0.01
		3	0.04	0.04	0.04	0.04	0.09	0.20	0.01
		4	0.06	0.06	0.05	0.05	0.10	0.04	0.02
		5	0.05	0.05	0.05	0.05	0.14	0.01	0.01
	1994	1	0.09	0.11	0.12	0.14	0.34	0.73	0.01
		2	0.07	0.08	0.08	0.08	0.25	0.58	0.01
		3	0.07	0.07	0.08	0.08	0.18	0.90	0.02
		4	0.07	0.07	0.07	0.08	0.32	0.47	0.02
		5	0.05	0.06	0.05	0.04	0.05	0.16	1.08
NO3 -N	1993	1	0.71	0.67	0.69	0.69	0.74	0.99	1.40
		2	0.83	0.63	0.64	0.65	0.74	1.14	1.33
		3	0.84	0.58	0.55	0.56	0.57	0.92	1.38
		4	0.97	0.81	0.82	0.83	0.91	1.31	1.55
		5	0.91	0.79	0.79	0.81	0.87	1.37	1.51
	1994	1	0.83	0.84	0.89	0.79	0.86	1.13	2.02
		2	0.95	0.80	0.78	0.78	0.80	1.04	1.82
		3	0.48	0.24	0.21	0.20	0.22	0.38	1.47
		4	0.44	0.37	0.37	0.36	0.39	0.85	1.55
		5	0.38	0.08	0.09	0.07	0.08	0.07	0.22

Close examination of Table 23 shows that, for each station during event 1, the ammonia-N levels gradually increased during the first 10 days of incubation after which nitrification appeared to commence to such an extent that virtually all the ammonia-N became oxidized by day 20. Also, with the exception of station 2, 1993 ambient nitrite-N concentrations increased, peaking sometime between 10 and 15 days, after which nitrification commenced and became virtually completed by day 20. Event 1 nitrate-N concentrations also ran counter to the norm in that levels decreased the first 10 days at all stations. This biochemical reduction process would be expected to release oxygen into the BOD bottle thereby tending to cause slight underestimates of BOD during this period. After approximately 10 days, increases in NO_3-N occurred in concert with the oxidation of NH_3-N and NO_2-N.

The 1994 BOD actions and reactions basically mirrored those of 1993. Extremely low ambient ammonia-N levels gradually increased and peaked at times ranging from 5 to 10 days. The low initial nitrite-N values gradually increased and peaked at 15 days for all stations but station 5 where they peaked dramatically at 20 days. Also, the nitrates appeared to be reduced reaching low levels somewhere between 5 and 10 days, after which concentrations increased in concert with nitrification with the exception of station 5 where the *Nitrobacter* sp. nitrifiers apparently needed more time to completely oxidize the exceptionally high 20-day NO_2-N value of 1.08 mg/L.

The increases in ammonia-N concentrations, which consistently peaked about 10 days after the BOD tests were started, probably are the result of the decomposition of algal cells that die under the dark conditions used in conducting BOD tests. Although algal growth appears to have a moderating effect on ammonia levels in the Fox River, some of this ammonia appears to be returned to the water column as cells die and deamination occurs. However, most releases will probably occur only in the last 10 miles of the Fox River during extremely low flows, such as 7-day, 10-year low flows. During higher flows, the release will occur after the Fox River enters the Illinois River. This supposition is based on the time of travel values presented in Table 20. In other words, at least 10 days are required for algal cells to die and release ammonia even under the most adverse conditions (with the exception of very low flows, e.g., 7-day 10-year low flow), and during most flow conditions, the time of travel between the St. Charles pool and the Illinois

River is less than 10 days. This in turn dictates that the Fox River in general experiences little oxygen depletion due to nitrification.

Figure 17 and Table 24 show that the $TBOD_{20}$ concentrations were significantly higher during the 1994 event than during the 1993 event at all stations. However, the $TBOD_{20}$ loads in terms of pounds per day were much higher during 1993 than 1994. In fact, the 1993 pool average load was approximately 77% greater. Since the 1993 sampling was done during relatively high summer flows (on the receding side of the flood hydrograph), about 43% of the 1993 BOD load appears to come from nonpoint sources.

Table 25 lists $TBOD_5$ and $TBOD_{20}$ results for samples collected during recent studies in Illinois along with those for event 2 of this study. Event 1 results are not listed because this event occurred during relatively high flows. Overall, long-term Fox River BODs appear to be significantly higher than those recorded for other northeastern Illinois streams and for two of the three stations listed for the Sangamon River. With the exception of station 1, the ratios of $TBOD_5/TBOD_{20}$ for each station were generally higher than those for other streams. The ratio of $TBOD_5/TBOD_{20}$ for the five study area stations progressively increased downstream during event 2 as shown in Table 25. This could be attributable to the large volume of treated wastewater discharged by Elgin immediately above station 1. During event 1, the ratio remained relatively constant throughout ranging only from 40 to 43%. The event-1, high flows and attendent nonpoint runoff probably tempered the point source influence on these ratios.

The results of fitting the TBOD curves to Equation 9 and 12 (Figure 17) are summarized in Table 18. The fitted parameters using both equations are given in Table 18. Results from Equation 9 have been included because it is most commonly used in classic water quality models such as the USEPA QUAL-2EU model. For event 1, the best fit was achieved at all stations when x was set at 2 and t_0 was computed, whereas for event 2, the best fit was achieved at all but station 1 when x was set at 1 and t_0 was computed. For the combined events 1 and 2, the average standard deviation with Equations 9 and 12 were 0.819 mg/L and 0.599 mg/L, respectively. Other parametric combinations, such as $x = 2$ and $t_0 = 0$ or letting $x = 1$ while computing t_0 produced much larger standard deviations than those presented in Table 18.

At each station, the computed lag times (t_0) were negative, indicating that biochemical oxygen demand in this reach of the river (and probably throughout the entire river) is in a very

Table 24. Comparison of Event 1 and 2 TBOD Concentrations and Loads

Station	*Concentration (mg/L)*		*Load (lbs/day)*		*Load Ratio*
	Event 1	*Event 2*	*Event 1*	*Event 2*	*E1/E2*
1	13.16	25.22	57,754	41,471	1.39
2	14.04	23.09	61,615	37,968	1.62
3	16.90	21.29	74,167	35,009	2.11
4	14.91	21.11	65,434	34,713	1.88
5	14.10	20.40	61,879	33,545	1.84
Average	14.62	22.22	64,170	36,541	1.76

Table 25. Comparison of Study Area TBOD and TBOD Values with Those of Other Central and Northeastern Illinois Streams for Warm-Weather, Low-Flow Conditions

Water Course	*$TBOD_5$ (mg/L)*	*$TBOD_{20}$ (mg/L)*	*$TBOD_5/TBOD_{20}$ (%)*
Illinois Waterway at Lockport	3.0	9.6	31
Des Plaines River*	4.1	10.9	38
DuPage River*	4.4	11.9	37
Kankakee River*	2.3	7.1	32
Fox River*	11.5	30.2	38
Vermilion River*	4.0	12.0	33
Sangamon River			
River Mile 124.5	4.5	15.2	30
Sangamon River			
River Mile 102.5	9.5	26.0	37
Sangamon River			
River Mile 59.9	8.0	15.6	51
Fox River Event 2			
Station 1	6.5	21.1	31
Station 2	9.0	20.4	44
Station 3	10.6	23.1	46
Station 4	10.0	21.3	47
Station 5	13.8	25.2	55

Note: * Above mouth of river

active state. In other words, the river contains a large resident bacterial population that immediately commences to use large amounts of dissolved oxygen when fed carbonaceous organic matter from point or nonpoint sources. The Equation 9 BOD reaction rate constants (K_1) were somewhat uniform throughout during 1993, whereas during 1994 the Equation 9 constants increased somewhat downstream. The difference between the two years can be attributed to the differences in hydraulic/hydrologic conditions. The much higher 1993 flows moderated the effects of the treated wastewaters discharged from Elgin immediately above the pool. The BOD "incubation" time in the pool was 2.75 times greater during 1994 than it was during 1993 (Table 20), which allowed the bacterial population to become very active in a short distance below the wastewater plant discharges.

Continuous Monitoring Data

Continuous, 15-minute interval data from DataSonde monitors/dataloggers produces a wealth of information over short periods of time that permits some in-depth assessments of water quality conditions that normally cannot be done using grab sampling and/or monitoring even when such sampling/monitoring is extended over long time periods. The DataSonde units recorded dissolved oxygen, temperature, pH, and specific conductance (conductivity corrected to 25°C) data for approximately 72 hours starting at 1:00 p.m. CST on August 17, 1993, and for approximately 130 hours starting at 12:45 p.m. CST on June 21, 1994. Specific time settings for each station are given in Table 15.

Only the ambient DataSonde monitors yielded quantifiable data over the entire 72- and 130-hour time periods. All event-1 and event-2 dark chambers became depleted of oxygen within 30 hours of use as depicted in Figure 24. Event-1 light chambers, at all stations, experienced either complete or nearly complete oxygen depletion as depicted in Figure 24; i.e., algal productivity (P) was less than algal respiration (R).

During 1994, P was so much greater than R that in the shallow upper end of the pool the light chamber DO concentrations exceeded the 20 mg/L recording limit of the DataSondes during most of the daylight hours (23 to 38 hrs - Figure 24) prior to the rain and subsequent high flows. Oxygen production was so great at station 1 that DO concentrations remained high at night and even during the entire period of high-flows, which created turbid conditions that commenced

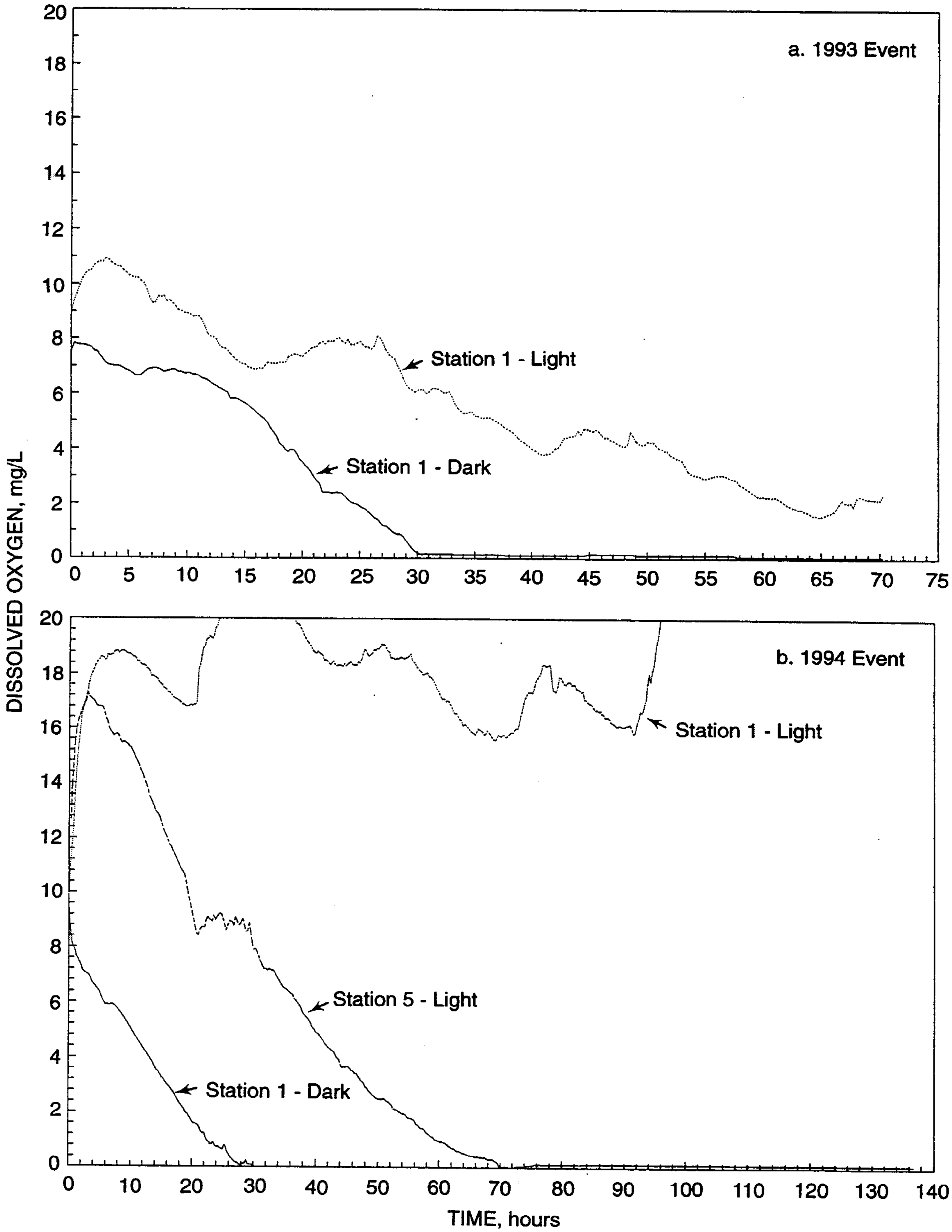

Figure 24. Typical light and dark chamber dissolved oxygen (DO) concentrations during the 1993 and 1994 events

about 40 hours later after the deployment of DataSone units. However, light penetration was reduced to such an extent at the deep station 5 during the high flows that the light chamber DO became totally depleted in 70 hours (Figure 17b).

Note from Figure 17b, that after the high flows began to subside significantly, at around the 90-hour mark, the light-chamber DO rose sharply and quickly exceeded 20 mg/L and remained above this value until the units were retrieved 48 hours later. This contrasts sharply with the ambient DO conditions depicted in Figure 19. During the high-flow, turbid conditions, photosynthetic oxygen production was curtailed and did not recover significantly after the flows subsided before the units were retrieved. The flood flows not only limited light penetration, but the flows also "washed out" the standing algal communities. This fact, plus the contrasting hydraulic/hydrologic conditions between events 1 and 2, and the rapid change in these conditions during event 2, precluded any attempt to compute reaeration coefficients (K_1) using Equations 15 - 17. Also, these conditions rendered impossible the development of a QUAL-2EU water quality model even on a cursory basis. However, these unexpected occurrences provided an unusual opportunity to observe the effects of dramatic, sudden changes in weather and hydraulic/hydrologic conditions on ambient Fox River water quality.

Data reviews of dissolved oxygen, temperature, pH, and specific conductance, the four parameters that were continuously recorded during each event, are presented individually. The interactive relationship between a given parameter and one or more of the others will be discussed where appropriate.

Dissolved Oxygen. Short-term DO pulses or cycles represent a complex combination of physical and biochemical reactions and activities along this reach of the Fox River. Extreme variations in DO occurred temporally and spatially. The relatively uniform sinuosity for all event-1 DO curves (Figures 18a, b, and c) for all the stations, over the 72-hour monitoring period, and throughout the water column are indicative of the relatively high flow and well-mixed conditions that persisted.

The sinusoidal nature of these curves denotes pronounced algal activity. The peaks represent periods of daylight photosynthetic oxygen production while the valleys represent periods of nighttime algal respiration (DO usage). Algal respiration caused DOs to fall to levels near or below the minimum 5.0 mg/L standard (State of Illinois, 1990) at all five stations. The standard was violated for a short period of time at station 4 on August 20, 1993, during which a minimum concentration of 4.58 mg/L was reached at the 3- and 5-foot depths (Appendix A, Figures 18b and 18c). A minimum DO of 4.93 mg/L was also recorded at station 3 on this same date. The disturbing fact about this is that the standard violations, albeit minor in nature, occurred during a flow of a relatively high duration of 43% (Table 20) during event 1.

The 1994 monitoring period was approximately twice as long - six days versus three days for 1993 - and within this six-day period significant changes occurred in all four of the water quality parameters. The effects of runoff from the heavy rains that began on June 23, 1994 resulted in a sharp drop in DO approximately 40 hours into the run. The DO drop was less marked at station 1 because of the aforementioned stabilizing effect of the South Elgin dam on DO levels in the riffle-pool reach immediately below the dam. The pre-rain period supersaturated concentrations exceeded 20 mg/L at stations 3, 4, and 5. Quality control adjustments to the DataSonde recorded data account for values exceeding 20 mg/L. As evident from Figure 18, event-1 DO levels never exceeded 20 mg/L at any station, although daylight DO concentrations reached supersaturated levels.

The minimum DO standard of 5.0 mg/L was violated throughout the pool during event-2 for both the low-flow and high-flow periods. Violations were most significant at stations 1 and 5. The station-1 bottom DO fell below 5.0 mg/L for approximately 15 hours over two time periods during the 40 hours of low flow and for approximately 16 hours over two time periods during the 96 hours of high flow (Figure 19c). The bottom DO remained below the standard at station 5 for almost 36 straight hours during the high-flow period. The lowest DO recorded during either event was 2.63 mg/L during low flow on June 22, 1994 at the bottom of station 4. The minimum DO during the high-flow segment of event 2 was 3.06 mg/L on June 26 at the bottom of station 5. All station minimums are presented in appendix A by date. Serious and extensive violations of the DO standards appear to occur during a wide range of flows.

Temperature. During event 1, daily water temperature variations were relatively small as shown by Figure 20a. The maximum variability occured on August 18, 1993 at station 3 when it ranged from 25.34°C to 28.34°C. Sunny, hot weather persisted during this event, but the relatively high flows minimized diel fluctuations.

In contrast to event 1, the extreme variability in flows during event 2 caused extreme temperature variabilities diurnally and over the course of the whole event as shown by Figure 20b. During the low-flow period, station-2 temperatures ranged from 25.22°C to 31.34°C during the normal June 23, 1994 diel cycle (Figure 20b, Appendix A). The initial surge of runoff caused the average daily water temperature to drop to 21.21°C on June 24 from an antecedent daily average of 28.05°C recorded during low-flow conditions on June 22, 1994. Cold rain, cloudy skies, and cool air temperatures caused this dramatic drop. Such a large temperature drop over such a short time period, coupled with low DOs, could be stressful to the Fox River fishery.

pH. The sinusoidal shapes of the event-1 pH curves (Figure 21a) mirror those of the event-1 DO curves. Both represent pronounced photosynthetic activity that persisted throughout this high, but stable-flow event. Diel highs occured during the day when algal productivity extracted carbon dioxide from the water, and diel lows occurred at night when carbon dioxide was released back into the water column due to respiratory processes.

The extreme amplitudes during low-flow, and lesser-defined sinusoidal curves which developed at some event-2 stations are indicative of the extremely high rate of phytoplanktonic activity which was occurring at that time. A pH of 8.99 occurred on June 21 at station 2, and it approaches the maximum pH that can be expected to be biologically induced in surface waters.

The event-2 rains washed-out and diluted algal activity, thereby causing the pH to drop dramatically and to remain stable in the mid-sevens for approximately 60 hours (Figure 21b). Near the end of the event, algal photosynthesis and respiration began to increase. The pH responded by rising and regaining sinuosity mirroring that which occurred for the DO curves as shown in Figure 19.

Specific Conductance. For each station, temporal variations in specific conductance were small during event 1, however, spatial water station variations were discernible and significant as shown in Figure 22a. Station 2 values were persistently the lowest; the values fell within a narrow range of 0.666 ms/cm to 0.703 ms/cm. Station 5 displayed the highest values where the values ranged from 0.691 ms/cm to 0.758 ms/cm.

As was the case for DO, temperature, and pH, specific conductance was also greatly affected by the torrential rains, which fell early during event 2, as indicated by Figure 22b. Specific conductance can be significantly elevated in streams during low flows when a significant portion of the stream flow consists of treated domestic wastewater. This was clearly evident from the specific conductance results reported by Larson et al. (1994) for the Sangamon River water quality study below Decatur. The average 72-hour, low-flow specific conductance values for Sangamon River monitoring sites, one immediately below the Decatur wastewater discharge point and another 65 miles downstream, were 3.100 ms/cm and 0.880 ms/cm, respectively. The influence of the treated Elgin wastewater discharges on the Fox River is not nearly as dramatic, but the effects are measurable. The event-1, 72-hour average specific conductance for station 1 was 0.725 ms/cm, whereas during the event-2 low-flow period it was 0.813 ms/cm. During the high-flow period station 1 values drop to 0.640 ms/cm. Station 5, the monitoring site farthest downstream of Elgin, exhibited very diluted values falling as low as 0.396 ms/cm.

Sediment Oxygen Demand (SOD)

Table 26 summarizes the SOD results and attendant sediment and benthos data. Details of the benthos and phytoplankton sample analyses are presented in Appendix B. The total algal counts presented in Appendix B are only 50 to 60 percent of those collected one or two days before (Table 21). These differences primarily result from the fact that the SOD - plankton samples were collected from bottom water at the SOD chamber placement, whereas the earlier ones were collected at the surface. Included in Table 26 are the results of the two SOD settings and benthos samplings conducted in the St. Charles pool during the summer of 1976 (Butts and Evans, 1978b).

Some important water quality and ecological related information can be derived from this limited information. The SOD rate in the deep-pool area near the dam (station 5) is high. A rate as high as 6.88 $g/m^2/day$ at 25°C is indicative of grossly polluted sediment (Butts and Evans, 1978b). The SOD rates become progressively less upstream as indicated by the 1.14 $g/m^2/day$ at 25°C at mile 64.39. This rate represents slightly degraded conditions according to Butts and Evans (1978b). The 1994 rates at miles 61.27 and 64.39 were significantly less than those observed during 1976, indicating sediment conditions have improved significantly over the past 18 years throughout most of the pool with the possible exception of the bottoms immediately above the dam. The lower moisture and volatile solid contents of the 1994 samples, versus the 1976 samples at miles 61.27 and 64.39, are also indicative of improved sediment quality.

Table 26. Benthic Sediment and Benthos Characteristics

Station	*Year*	*Mile*	*Solids (%)* *Dried*	*Volatile*	*T°C*	*SOD (g/m/day)* *T°C*	*20°C*	*25°C*	*Macroinvertebrates* *No.m*	*No. taxa*	*Shannon-Weiner*
5	1994	60.78	41.3	7.7	26.8	7.50	5.46	6.88	7.32	5	1.6
(10)*	1976	61.27	75.7	1.9	26.3	2.35	1.72	2.17	173	2	1.0
	1994		31.5	8.0	25.3	1.35	1.05	1.32	689	2	0.7
4	1994	61.90	67.3	3.6	27.5	4.50	3.25	4.09	388	1	0.0
3	1994	63.37	77.7	4.5	26.5	0.51	0.52	0.67	1248	2	0.4
(9) *	1976	64.39	83.5	1.6	22.8	2.64	2.32	2.92	517	2	0.6
	1994		61.5	3.6	24.1	1.10	0.90	1.14	1119	3	1.2

* (Butt and Evans, 1978b)

However, the type and number of benthic macroinvertebrates observed during 1994 indicate that the health of the benthos community in the pool has improved very little over the past 18 years. Most of the organisms found during 1994 are sludge worms (Tubificidae) as indicated in Appendix B and the diversity indexes are low. Shannon-Weiner values less than 1.0 are indicative of polluted sediments (Table 26). The number of organisms found during 1994 are higher than in 1976 at miles 61.27 and 64.39. However, this difference is due to an increase in the undesirable tubificid worm.

SUMMARY AND CONCLUSIONS

It is projected that most of the communities in the Fox River basin will continue to use ground water as the source for their entire water supply. Only the cities of Elgin and Aurora are expected to use the Fox River as a source of their water supply, as they are now doing. The cumulative water use for all these communities is expected to increase roughly 53% between 1990 and 2010. The cities of Elgin and Aurora accounted for 42.5% of water use in 1990 and their share will drop to 39.0% in the year 2010. They withdrew 17.39 mgd of water from the Fox River in 1990 and are expected to withdraw 26.11 mgd in 2010. The percentage of water supply coming from the Fox River will remain approximately 30 percent of the total use.

The volume of effluent discharge to Fox River during 7-day, 10-year low flow conditions increases by about 57% over 20 years. This is slightly more than the increase in total water use because of reduced losses from the increased flow to the streambeds and banks. The additional effluent discharges will increase the Q(7,10) low flow in the Fox River as shown in the maps for 2010. The increase in low flows from effluents would be higher below Elgin were it not for the simultaneous increase in water supply withdrawals from the Fox River by Elgin and Aurora.

In the year 2010 and even much earlier, the amount of effluent discharged from the Aurora Sanitary District treatment plant will be such that the IEPA's minimum standard of a 5:1 dilution ratio (the ratio between upstream flow and wastewater discharge at an outfall) for secondary treatment plants will be violated, even if minimum flow release from Stratton Dam is increased from 94 to 111 cfs. With 111 cfs release, dilution ratio is 5.0 only if withdrawals from the river are not permitted during very low flow conditions. With projected increases in discharges by the year 2010, the 5:1 dilution ratio can be maintained for Aurora effluent discharge only if both of the following two conditions occur: 1) the cities of Elgin and Aurora switch to ground-water sources during low-flow conditions, and 2) the flow releases from Stratton Dam are increased from 94 to 111 cfs during periods of low flow. For the second condition, it is not necessary for the 111 cfs release from Stratton Dam to be maintained on a full time basis. Q(7,10) is a once-in-10 years on the average event for a limited number of days. Increasing flow release from Stratton Dam even for a month may lower the lake level by less than 0.1 foot.

It appears doubtful that maintaining a 5:1 dilution ratio (using the two conditions listed above) will have much overall effect on the water quality problems in the Fox River. Algal blooms and depressed levels of dissolved oxygen are likely to continue as long as there exists the combined condition of high organic loading and low flow velocities in the backwater pools behind the dams in the river.

The study monitoring and sampling methods and procedures were initially designed to produce data that could be used to develop a cursory water quality model patterned after the USEPA QUAL-2EU. It was also intended to develop reaeration coefficients (from field studies) for use in the model. Neither endeavor was successful due to the extremely erratic nature of the water quality as experienced on a diel basis and to the extreme flow variations experienced between events 1 and 2 and within event 2. The following inferences can be drawn from this study.

1. Fox River water quality has improved greatly over the past 30 years, however, some major problems exist, one of which is persistent, excessive algal growth. Nuisance algal blooms often occur when cell counts exceed 500 per milliliter. During event-2 low-flow conditions, however, counts were recorded in excess of 43,000 cells/mL. Such high algal counts will create significant treatment problems if Fox River water is regularly withdrawn on a large scale for domestic use.
2. High nutrient inputs and still-water environments created by the numerous channel dams situated along the entire main stem of the Fox River in Illinois promote excessive algal growths. Very high phosphorus (P) levels appear to promote and sustain massive algal blooms along the Fox River. During both events, ortho-P (dissolved-P) exceeded the IEPA minimum lake-standard of 0.05 mg/L at all sampling stations. Total inorganic nitrogen levels are low. The ammonia-N fraction persists at barely detectable limits during warm-weather, low-flows because it is readily and quickly assimilated by algae.
3. Algal productivity probably can best be controlled by reducing phosphorus loadings to the river. However, a significant reduction in primary productivity could, in turn, create an ammonia-N problem since this chemical species appears to be suppressed to extremely low levels as a result of the burgeoning algal activity.

4) Phytoplanktonic activity dictates the diel levels of several basic water quality parameters in the Fox River during low-flow, warm-weather conditions. The continuous monitoring curves, generated for DO and pH, exhibit profound variability over the course of a day.

During event 2, daylight surface DOs exceed 400% of saturation near the St. Charles dam, while during the night, DOs persistently fall below the IEPA minimum standard of 5.0 mg/L. Daytime pHs exceed 9.0 while falling well below 8.0 at night.

5) Marked changes in virtually all the basic parameters used to gage or evaluate stream water quality occur rapidly in the Fox River during the onset of a heavy storm during the summer. This fact was clearly demonstrated during event 2 when torrential rains began to fall approximately 48 hours after the installation of the monitors. Within a day after the storms began, DOs dropped from daylight highs of approximately 28 mg/L to values in the low teens; temperatures dropped from daily highs of about 32°C to values lower than 20°C. Similarly, dramatic changes occurred with pH and conductivity. These marked changes resulted from the rapid flushing of the lakelike environment (attendant with its algal activity that dictated water quality conditions) by storm runoff and increased dilution of wastewater effluents with surface runoff. Such periodic occurrences could produce acute problems for potable domestic water treatment processes.

6) Benthic (bottom) sediment quality has improved throughout most of the pool (with the exception of the deep-pooled area immediately above the St. Charles dam) as gaged by the *in situ* sediment oxygen demand (SOD) measurements. SOD rates measured at two sites in the pool during 1994 were only 39% and 61% of the rates measured at these two locations in 1976. The 1994 sediments were more compact (less watery) and contained less organic (volatile) matter than sediments that were observed 18 years earlier. However, the deep-pooled area immediately above the dam acts as a sediment trap, consequently, sediments from this area are flocculent, contain large amounts of organics, exhibit high SOD rates, and could be classified as grossly polluted. The polluted and enriched nature of these sediments is probably maintained primarily as a result of algal death and deposition, not as a result of suspended solids in effluents discharged from wastewater treatment plants.

7) The biochemical oxygen demand (BOD) concentrations in the pool are relatively high compared to similar streams in central and northern Illinois. However, unlike many of the other comparable streams almost 100 percent of the demand is due to carbonaceous BOD (CBOD) with virtually none being attributable to ammonia-N oxidation (NBOD). This phenomenon appears to be the consequence of the rapid removal of ammonia-N from the

system through algae photosynthetic activity. In other words, the presence of algae with all its attendant water quality problems spares the river from suffering oxygen depletion due to bacterial nitrification.

8) Time of travel through the pool during low flows is very long. Dye tracers were used during both events to measure stream velocity and travel times. More than 14 hours were required for the dye to travel the final 1.16 miles of the pool during event 2 for an 81% duration flow. Based on these results, the times of travel through this reach and for the whole pool for Q(7,l0) flows are estimated to be 58 hours and 153 hours, respectively. This clearly demonstrates why Fox River pools act and react as minilakes. Large-scale withdrawal of water for domestic uses during summer, low-flow conditions would probably exacerbate existing instream water quality problems.

Water quality measurements conducted in this study are not sufficient to estimate the capacity of the river to assimilate additional wastewaters discharged into it -- to a great extent because the low flow condition in June 1994 was interrupted by a heavy rain event. Detailed monitoring of the river during an extended low flow period would provide sufficient data in the St. Charles pool such that a water quality model (for example, QUAL2-E) could be applied to estimate selected aspects of the river's assimilation capacity.

Given this, it is not presently possible to quantify the effect of additional effluents on water quality of the stream. However, several inferences can be made. If the treatment of wastewater is not changed over the next 15 years, it is likely that additional effluents may halt or reverse the declining trend in phosphorus and fecal coliform that has been observed over the last 20 years. COD concentrations appear to be increasing, and this trend is likely to continue. Dissolved oxygen levels should be further examined by monitoring, and should specifically include measurements at times when violations are likely to occur. Pronounced algal growth will continue to produce fluctuating DO levels behind the low channel dams unless significant reduction in phosphorus levels occurs. Winter sampling should also be considered to determine the magnitude of ammonia-N concentrations at times when bacterial nitrification and primary productivity are inhibited.

This study has concentrated on two aspects of water use along the Fox River: public water supply and assimilation of wastewaters. But the Fox River is also highly valued for recreational activities, including fishing, boating, and canoeing, and provides a valuable habitat for aquatic life. It is difficult to assess the impact of potential water supply changes on these other uses of the Fox River. The net changes in flow magnitude on the Fox River as a result of increased water use will be fairly small. As a result, the associated increases in water depth and flow velocity will probably not be sufficiently large to improve (or degrade) aquatic habitat. The major impact to recreation, the environment, and aquatic life will thus be limited to the increasing proportion of flow originating from wastewater. Continued use of the Fox River for effluent assimilation will thus require careful planning to avoid adverse impacts on the river quality and ecology.

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Appendix A. Continuous Data - Daily Statistics: 5 stations -- Events 1 and 2

n = number of observation in a day
S.C. = specific conductance, millisienners/cm
DO-1' = dissolved oxygen at 1 foot below the surface, mg/1;
Similarly 2', 3', 5', and 8''

Station 1

	1993						*1994*					
Parameter	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*
Temp °C	8/17	39	26.27	26.676	26.78	0.148	6/21	45	27.62	29.036	29.99	0.718
pH units		39	8.30	8.382	8.51	0.048		45	8.12	8.550	8.78	0.215
S.C. (ms/cm)		39	0.728	0.734	0.737	0.002		45	0.793	0.812	0.836	0.012
DO-1' (mg/L)		39	9.60	10.891	11.65	0.629		45	10.67	12.950	14.29	1.171
Temp °C	8/18	96	25.38	26.265	27.37	0.628	6/22	96	26.27	27.701	29.69	1.067
pH units		96	8.20	8.379	8.65	0.131		96	7.75	8.128	8.62	0.270
S.C. (ms/cm)		96	0.723	0.731	0.740	0.006		96	0.750	0.816	0.849	0.033
DO-1' (mg/L)		96	8.40	9.783	12.09	1.108		96	8.56	11.417	14.92	2.091
Temp °C	8/19	96	25.6	26.134	26.65	0.358	6/23	96	22.72	25.498	27.67	1.221
pH units		96	8.19	8.331	8.49	0.091		96	7.64	7.846	8.13	0.116
S.C. (ms/cm)		96	0.715	0.721	0.729	0.005		96	0.750	0.812	0.845	0.024
DO-1' (mg/L)		96	7.76	8.656	9.83	0.640		96	7.89	8.721	11.19	0.824
Temp °C	8/20	50	25.05	25.471	26.19	0.336	6/24	96	20.15	21.140	22.47	0.580
pH units		50	8.11	8.197	8.37	0.074		96	7.52	7.614	7.69	0.048
S.C. (ms/cm)		50	0.713	0.716	0.719	0.001		96	0.640	0.661	0.753	0.026
DO-1' (mg/L)		50	7.13	7.662	8.83	0.532		96	8.18	8.981	9.62	0.482
Temp °C							6/25	96	19.47	21.015	22.39	1.180
pH units								96	7.49	7.604	7.74	0.086
S.C. (ms/cm)								96	0.651	0.680	0.704	0.017
DO-1' (mg/L)								96	8.92	9.303	9.90	0.305
Temp °C							6/26	96	21.84	22.773	23.95	0.759
pH units								96	7.62	7.893	8.18	0.210
S.C. (ms/cm)								96	0.703	0.726	0.750	0.016
DO-1' (mg/L)								96	8.50	9.640	11.17	0.959
Temp °C							6/27	23	22.3	22.830	23.32	0.331
pH units								23	7.95	8.007	8.06	0.033
S.C. (ms/cm)								23	0.748	0.751	0.755	0.002
DO-1' (mg/L)								23	8.98	9.454	9.93	0.302

Continuous Data - Daily Statistics: 5 stations -- Events 1 and 2

Station 2

	1993						1994					
Parameter	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*
Temp°C	8/17	44	26.36	27.000	27.68	0.371	6/21	37	27.08	29.567	31.89	1.737
pH units		44	8.23	8.351	8.47	0.084		37	8.26	8.697	8.99	0.249
S.C. (ms/cm)		44	0.673	0.686	0.703	0.009		37	0.787	0.809	0.829	0.015
DO-1' (mg/L)		44	7.56	9.447	11.22	1.424		37	4.80	11.704	18.86	5.416
Temp°C	8/18	96	25.55	26.716	28.17	0.720	6/22	96	25.22	28.045	31.34	1.939
pH units		96	8.04	8.289	8.59	0.152		96	7.94	8.393	8.89	0.294
S.C. (ms/cm)		96	0.666	0.683	0.701	0.007		96	0.732	0.790	0.836	0.040
DO-1' (mg/L)		96	6.59	8.684	12.19	1.689		96	2.83	10.154	17.27	5.333
Temp °C	8/19	96	25.94	26.584	27.46	0.448	6/23	96	22.64	24.984	27.62	1.342
pH units		96	7.99	8.167	8.41	0.141		96	7.68	7.900	8.09	0.069
S.C. (ms/cm)		96	0.674	0.682	0.688	0.004		96	0.743	0.801	0.849	0.034
DO-1' (mg/L)		96	6.38	7.888	10.48	1.280		96	3.14	6.060	9.35	1.683
Temp °C	8/20	54	24.92	25.903	27.46	0.771	6/24	96	20.23	21.212	22.72	0.585
pH units		54	7.94	8.064	8.33	0.111		96	7.43	7.517	7.67	0.067
S.C. (ms/cm)		54	0.674	0.682	0.069	0.004		96	0.638	0.666	0.753	0.032
DO-1'(mg/L)		54	6.14	7.690	10.61	1.554		96	5.63	6.573	7.50	0.497
Temp °C							6/25	96	19.68	21.466	23.32	1.315
pH units								96	7.38	7.437	7.57	0.036
S.C. (ms/cm)								96	0.648	0.686	0.720	0.025
DO-1' (mg/L)								96	3.87	5.268	6.30	0.807
Temp °C							6/26	96	21.96	22.982	24.46	0.838
pH units								96	7.40	7.918	8.45	0.306
S.C. (ms/cm)								96	0.720	0.736	0.757	0.008
DO-1' (mg/L)								96	3.87	6.550	9.14	1.540
Temp °C							6/27	23	22.18	22.499	22.77	0.207
pH units								23	7.94	7.984	8.05	0.032
S.C. (ms/cm)								23	0.743	0.752	0.770	0.008
DO-1' (mg/L)								23	4.83	5.259	5.77	0.238

Continuous Data - Daily Statistics: 5 stations -- Events 1 and 2

Station 3

	1993						1994					
Parameter	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*
Temp °C	8/17	34	26.19	27.678	28.55	0.759	6/21	37	27.92	28.928	29.65	0.643
pH units		34	8.37	8.569	8.62	0.066		37	8.70	8.854	8.99	0.077
S.C. (ms/cm)		34	0.685	0.691	0.707	0.005		37	0.748	0.764	0.773	0.007
DO-2' (mg/L)		34	8.01	12.168	14.02	1.837		37	18.00	22.941	25.41	1.518
DO-3' (mg/L)		34	7.90	12.001	13.82	1.810		37	18.95	24.148	26.74	1.597
Temp°C	8/18	96	25.34	26.578	28.34	1.048	6/22	96	25.85	27.310	29.57	1.238
pH units		96	8.02	8.371	8.62	0.188		96	8.62	8.800	8.97	0.111
S.C. (ms/cm)		96	0.698	0.707	0.714	0.005		96	0.748	0.767	0.778	0.007
DO-2’ (mg/L)		96	5.91	10.772	17.37	4.123		96	7.28	18.201	26.67	6.365
DO-3’ (mg/L)		96	5.84	10.659	17.18	4.088		96	7.66	19.151	28.06	6.699
Temp °C	8/19	96	25.60	26.335	27.62	0.595	6/23	96	21.37	25.280	29.14	2.115
pH units		96	8.08	8.289	8.53	0.157		96	7.99	8.379	8.85	0.272
S.C. (ms/cm)		96	0.695	0.706	0.715	0.006		96	0.609	0.757	0.788	0.029
DO-2' (mg/L)		96	5.74	8.246	12.77	2.263		96	4.58	10.641	22.58	4.947
DO-3' (mg/L)		96	5.68	8.172	12.66	2.246		96	4.80	11.183	23.76	5.209
Temp °C	8/20	43	24.96	25.303	25.93	0.269	6/24	96	19.98	20.818	21.50	0.419
pH units		43	8.05	8.111	8.15	0.031		96	7.59	7.710	8.00	0.091
S.C. (ms/cm)		43	0.703	0.710	0.715	0.003		96	0.507	0.590	0.623	0.031
DO-2' (mg/L)		43	4.97	5.913	9.09	1.046		96	7.39	8.973	10.57	0.736
DO-3' (mg/L)		43	4.93	5.871	9.03	1.041		96	7.74	9.417	11.10	0.774
Temp °C							6/25	96	19.39	21.388	23.70	1.606
pH units								96	7.58	7.705	7.89	0.096
S.C. (ms/cm)								96	0.622	0.638	0.656	0.010
DO-2' (mg/L)								96	5.92	7.975	10.92	1.454
DO-3' (mg/L)								96	6.20	8.355	11.45	1.528
Temp °C							6/26	96	21.75	22.834	24.58	1.090
pH units								96	7.63	7.886	8.28	0.249
S.C. (ms/cm)								96	0.657	0.677	0.689	0.008
DO-2' (mg/L)								96	5.65	9.582	14.86	3.425
DO-3' (mg/L)								96	5.90	10.037	15.59	3.602
Temp °C							6/27	23	22.05	22.429	23.02	0.281
pH units								23	7.82	7.879	8.03	0.070
S.C. (ms/cm)								23	0.686	0.694	0.700	0.004
DO-2' (mg/L)								23	5.83	6.725	8.85	0.888
DO-3' (mg/L)								23	6.08	7.023	9.26	0.936

Continuous Data - Daily Statistics: 5 stations -- Events 1 and 2

Station 4

	1993						1994					
Parameter	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*
Temp °C	8/17	37	26.15	26.749	27.33	0.392	6/21	42	27.88	28.508	29.27	0.482
pH units		37	8.24	8.379	8.44	0.060		42	8.43	8.706	8.92	0.153
S.C. (ms/cm)		37	0.751	0.755	0.759	0.002		42	0.802	0.808	0.814	0.003
DO-2' (mg/L)		37	8.82	12.660	13.92	1.492		42	15.29	20.972	26.52	3.765
DO-3' (mg/L)		37	8.78	12.550	13.78	1.457		42	14.65	20.099	25.41	3.608
DO-5' (mg/L)		37	8.78	12.550	13.78	1.457		42	10.96	15.034	19.01	2.700
Temp °C	8/18	96	25.39	26.342	27.37	0.68	6/22	96	26.53	27.498	29.02	0.629
pH units		96	8.06	8.288	8.49	0.150		96	8.25	8.519	8.85	0.142
S.C. (ms/cm)		96	0.749	0.755	0.760	0.004		96	0.774	0.812	0.826	0.011
DO-2' (mg/L)		96	5.58	10.214	14.99	3.306		96	3.64	12.246	22.80	4.481
DO-3' (mg/L)		96	5.47	9.982	14.56	3.201		96	3.48	11.733	21.85	4.296
DO-5' (mg/L)		96	5.47	9.982	14.56	3.201		96	2.63	8.790	16.35	3.209
Temp °C	8/19	96	25.68	26.284	27.24	0.480	6/23	96	21.12	25.750	27.75	1.627
pH units		96	8.05	8.227	8.42	0.113		96	8.01	8.412	8.83	0.177
S.C. (ms/cm)		96	0.746	0.754	0.760	0.003		96	0.577	0.764	0.797	0.053
DO-2' (mg/L)		96	5.53	9.333	13.47	2.790		96	5.05	8.557	14.32	2.335
DO-3' (mg/L)		96	5.31	8.924	12.80	2.648		96	4.83	8.192	13.72	2.240
DO-5' (mg/L)		96	5.31	8.924	12.80	2.648		96	3.65	6.160	10.29	1.670
Temp °C	8/20	44	25.09	25.688	26.61	0.509	6/24	96	18.84	19.807	20.70	0.541
pH units		44	8.00	8.121	8.28	0.094		96	7.44	7.583	7.94	0.115
S.C. (ms/cm)		44	0.748	0.755	0.761	0.004		96	0.403	0.489	0.554	0.041
DO-2' (mg/L)		44	4.87	7.494	11.57	2.072		96	7.07	8.698	10.04	0.981
DO-3' (mg/L)		44	4.58	7.070	10.96	1.970		96	6.76	8.323	9.61	0.939
DO-5' (mg/L)		44	4.58	7.070	10.96	1.970		96	5.10	6.277	7.25	0.707
							6/25	96	19.22	21.090	23.40	1.617
								96	7.40	7.543	7.71	0.106
								96	0.561	0.610	0.659	0.025
								96	7.32	8.668	9.91	0.864
								96	7.00	8.290	9.48	0.828
								96	5.30	6.271	7.16	0.621
							6/26	96	21.71	22.502	23.57	0.701
								96	7.44	7.689	8.06	0.169
								96	0.656	0.679	0.693	0.009
								96	5.38	10.920	15.55	3.181
								96	5.13	10.444	14.88	3.048
								96	3.92	7.900	11.23	2.285
							6/27	23	22.26	22.923	23.36	0.358
								23	7.78	7.857	7.94	0.045
								23	0.673	0.684	0.696	0.006
								23	8.83	11.997	13.60	1.501
								23	8.44	11.473	13.01	1.439
								23	6.42	8.681	9.83	1.075

Continuous Data - Daily Statistics: 5 stations -- Events 1 and 2

Station 5

	1993						1994					
Parameter	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*	*Date*	*n*	*Min*	*Avg*	*Max*	*S.D.*
Temp °C	8/17	41	25.43	26.000	26.36	0.328	6/21	45	26.36	26.530	26.91	0.153
pH units		41	8.09	8.293	8.38	0.096		45	8.26	8.406	8.56	0.091
S.C. (ms/cm)		41	0.691	0.732	0.744	0.012		45	0.816	0.828	0.836	0.006
DO-2' (mg/L)		41	7.92	10.572	11.75	1.278		45	9.13	13.50	20.30	3.438
DO-3' (mg/L)		41	7.90	10.520	11.68	1.260		45	7.61	11.25	16.91	2.865
DO-8' (mg/L)		41	7.59	10.129	11.26	1.224		45	5.07	7.501	11.28	1.910
Temp °C	8/18	96	25.55	26.250	26.74	0.422	6/22	96	26.36	26.890	27.67	0.319
pH units		96	8.19	8.330	8.44	0.077		96	8.29	8.509	8.74	0.125
S.C. (ms/cm)		96	0.736	0.743	0.748	0.002		96	0.825	0.840	0.856	0.008
DO-2' (mg/L)		96	7.03	9.585	11.67	1.616		96	8.00	17.08	26.24	5.443
DO-3' (mg/L)		96	6.95	9.469	11.49	1.585		96	6.67	14.23	21.87	4.536
DO-8' (mg/L)		96	6.74	9.188	11.18	1.544		96	4.45	9.486	14.58	3.024
Temp °C	8/19	96	25.89	26.366	26.95	0.321	6/23	96	20.82	25.418	27.50	2.011
pH units		96	8.19	8.314	8.44	0.074		96	8.09	8.497	8.68	0.171
S.C. (ms/cm)		96	0.732	0.741	0.747	0.004		96	0.419	0.731	0.854	0.136
DO-2' (mg/L)		96	5.82	8.523	11.24	1.518		96	3.97	10.35	13.77	3.641
DO-3' (mg/L)		96	5.69	8.340	11.04	1.506		96	3.97	10.00	13.77	3.353
DO-8' (mg/L)		96	5.58	8.186	10.77	1.468		96	3.97	9.173	13.77	2.874
Temp °C	8/20	47	25.39	25.829	26.36	0.422	6/24	96	18.75	19.592	20.91	0.546
pH units		47	8.16	8.226	8.30	0.050		96	7.69	7.790	8.11	0.103
S.C. (ms/cm)		47	0.744	0.750	0.758	0.003		96	0.396	0.492	0.561	0.047
DO-2' (mg/L)		47	6.12	7.571	9.16	1.130		96	5.24	6.313	7.11	0.517
DO-3' (mg/L)		47	5.93	7.365	8.90	1.104		96	5.24	6.313	7.11	0.517
DO-8' (mg/L)		47	5.87	7.259	8.78	1.083		96	5.24	6.313	7.11	0.517
							6/25	96	19.13	20.819	23.02	1.467
								96	7.64	7.690	7.75	0.031
								96	0.562	0.619	0.664	0.027
								96	4.00	4.619	5.78	0.493
								96	4.00	4.619	5.78	0.493
								96	4.00	4.619	5.78	0.493
							6/26	96	21.58	22.425	23.19	0.557
								96	7.64	7.713	7.84	0.068
								96	0.660	0.691	0.711	0.012
								96	3.06	4.460	5.91	0.985
								96	3.06	4.460	5.91	0.985
								96	3.06	4.460	5.91	0.985
							6/27	23	22.81	22.919	22.98	0.049
								23	7.83	7.837	7.84	0.004
								23	0.710	0.711	0.714	0.001
								23	4.86	5.225	5.56	0.233
								23	4.86	5.225	5.56	0.233
								23	4.86	5.225	5.56	0.233

Appendix B. SOD Benthos and Phytoplankton Identification/Enumeration -- June 22-23, 91994

Type of organism	*Taxa*	*IEPA-MBI taxon tolerance value*	*Sampling station mile point* 60.65	61.27	61.91	63.37	64.39
Benthos	Diptera						
	Chironomus attentaus	10	86	129		86	301
	Oligochaeta						
	Tubifcidae	10	474	560	388	1162	732
	Hirudinea						
	Helobdella fusca	8	43				
	Bivalvia						
	Sphaerium transversum	5	86				
	Turbellaria						
	Dugesia tigrina	6	43				86
Phytoplankton	Blue Green						
	Aphanizomennon flos-aquae		95		200	116	
	Oscillatoria putride		63			168	105
	Green						
	Acinastrum hantzschis		63			74	53
	Coelastrum microporum		42	242		95	74
	Crucigenia rectangularis		189	725		525	452
	Micractinium pusillum		126	116	168	105	137
	Oocystis borgei		347	210	210	263	200
	Pediastrum duplex		399	746	525	389	462
	Pediastrum simplex			42			74
	Pediastrum tetras			63	74		
	Scenedesmus dimorphus		462		326	189	95
	Diatom						
	Cyclotella atomus		5229				
	Cyclotella meneghiniana		11865	14711	16937	11876	13608

Appendix B. (Concluded)

Type of organism	Taxa	IEPA-MBI taxon tolerance value	Sampling station mile point 60.65	61.27	61.91	63.37	64.39
	Diatoma vulgare					21	
	Gyrosigma kutzingii		11	74			
	Gyrosigma macrum		32	63	168	95	63
	Melosira binderana		168	1229		221	924
	Meosira granulata		1187	1691		641	
	Navicula adiosa				21		
	Navicula crytocephala		63				
	Navicula gastrum		21		63		21
	Stephanodiscus niagarae		74	11			21
	Synedra acus		32				189
	Synedra ulna				116		
	Tabellaria fenestrata				200		
Flagllate							
	Euglena gracilis		221	347	105	74	32
	Euglena oxyuris		21	11	11		
	Trachelomanas crebea					21	
Desmid							
	Glenodinium sp.		11	21	32	11	
	Staurastrum lornutum		32			11	
Total no. phytoplankton organisms (cells/mL)			20753	20313	19156	14895	16510
Total no. phytoplankton taxa			23	17	15	18	16

APPENDIX C

Fox River Basin Maps

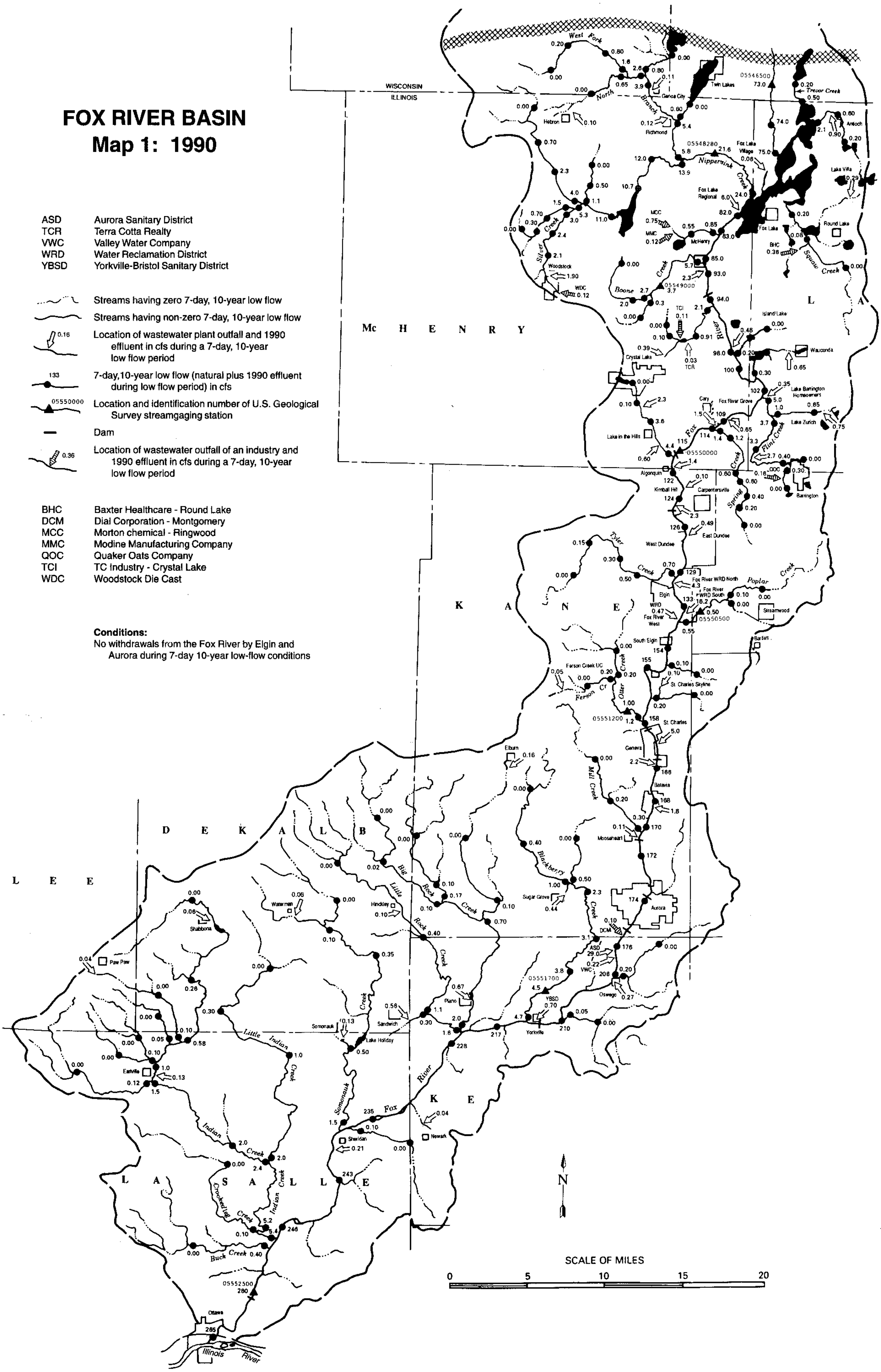
FOX RIVER BASIN
Map 1: 1990

ASD Aurora Sanitary District
TCR Terra Cotta Realty
VWC Valley Water Company
WRD Water Reclamation District
YBSD Yorkville-Bristol Sanitary District

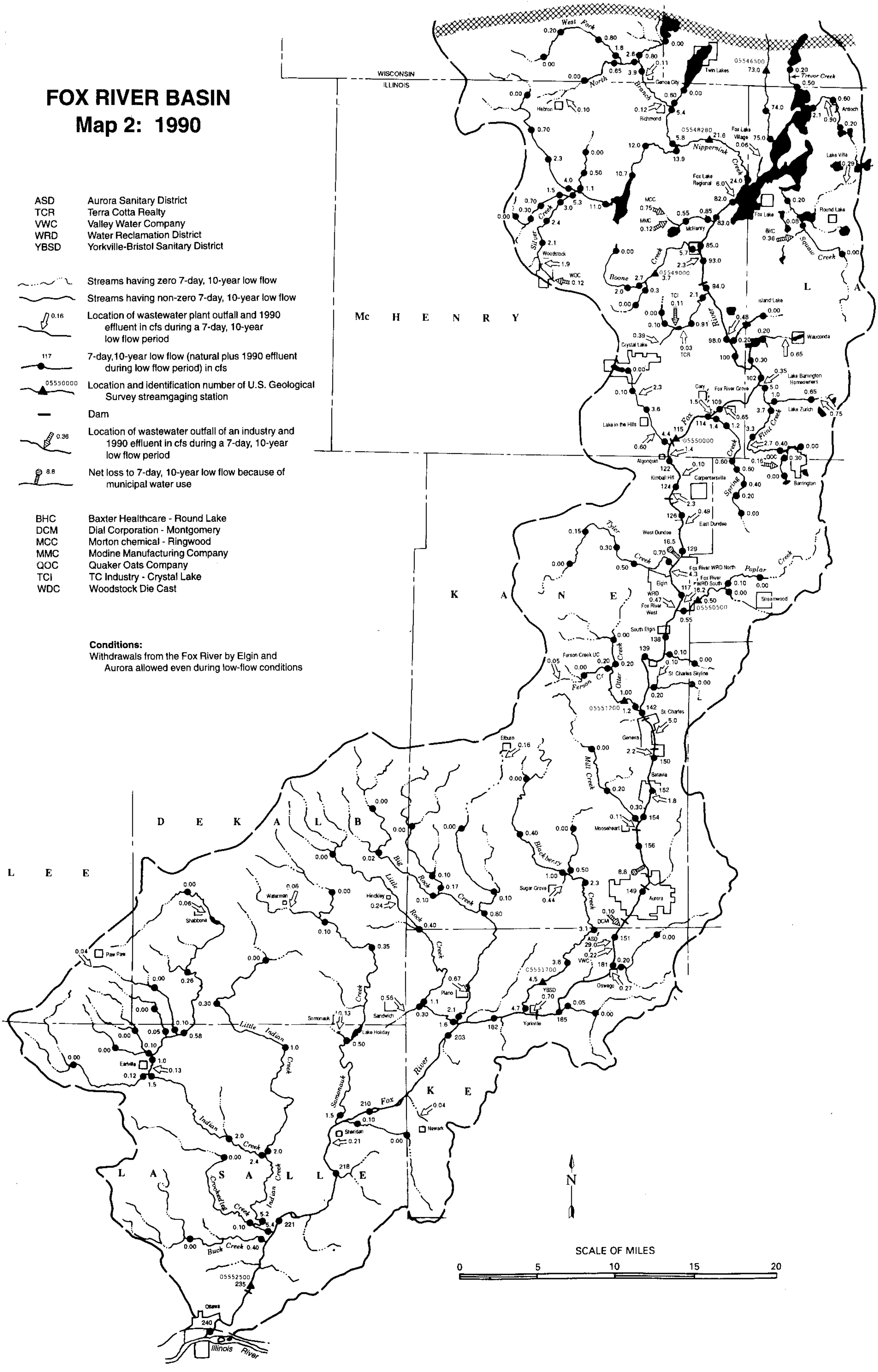
- Streams having zero 7-day, 10-year low flow
- Streams having non-zero 7-day, 10-year low flow
- 0.16 — Location of wastewater plant outfall and 1990 effluent in cfs during a 7-day, 10-year low flow period
- 133 — 7-day,10-year low flow (natural plus 1990 effluent during low flow period) in cfs
- 05550000 — Location and identification number of U.S. Geological Survey streamgaging station
- Dam
- 0.36 — Location of wastewater outfall of an industry and 1990 effluent in cfs during a 7-day, 10-year low flow period

BHC Baxter Healthcare - Round Lake
DCM Dial Corporation - Montgomery
MCC Morton chemical - Ringwood
MMC Modine Manufacturing Company
QOC Quaker Oats Company
TCI TC Industry - Crystal Lake
WDC Woodstock Die Cast

Conditions:
No withdrawals from the Fox River by Elgin and Aurora during 7-day 10-year low-flow conditions



FOX RIVER BASIN
Map 2: 1990



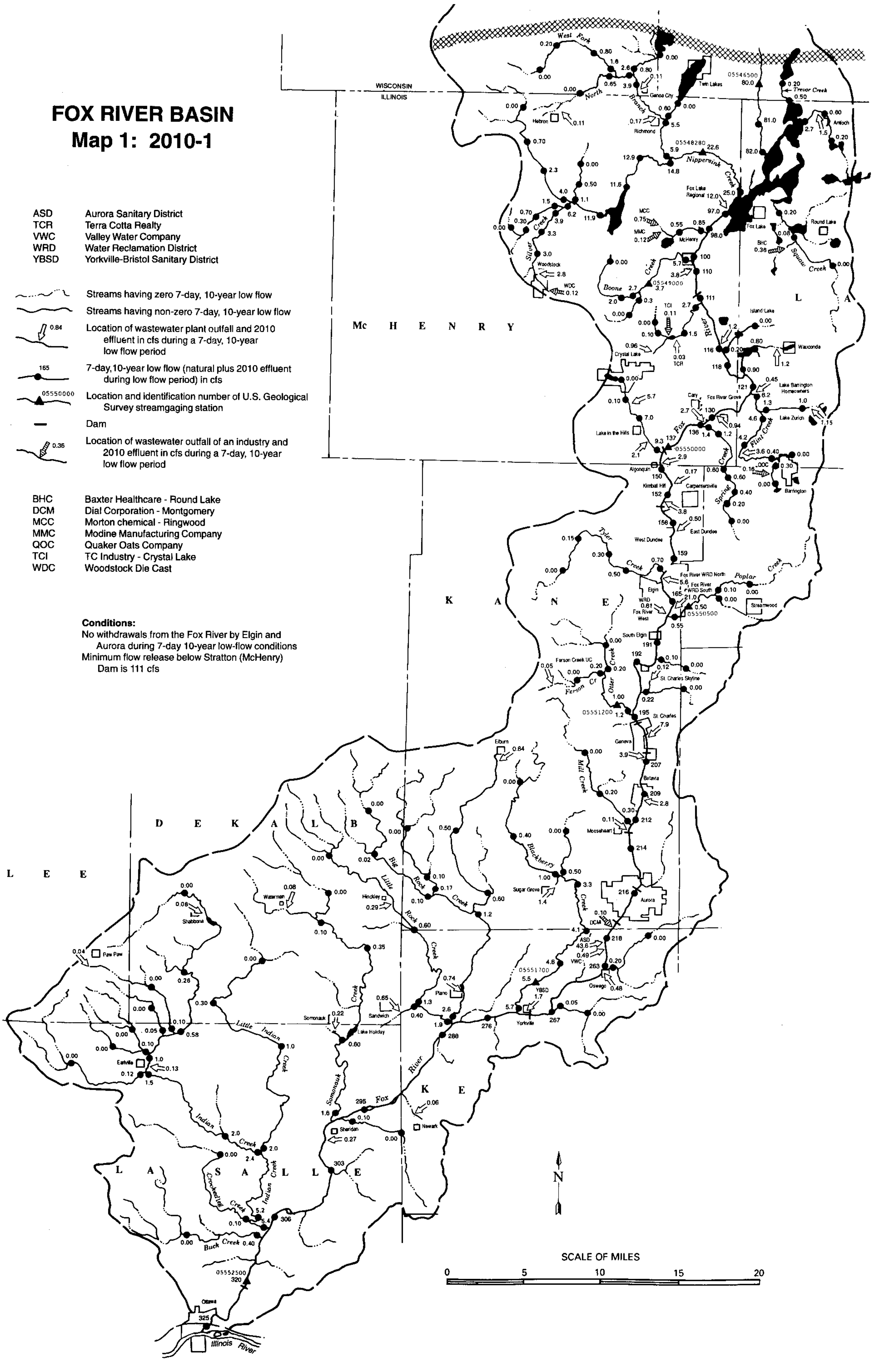
FOX RIVER BASIN
Map 1: 2010-1

ASD	Aurora Sanitary District
TCR	Terra Cotta Realty
VWC	Valley Water Company
WRD	Water Reclamation District
YBSD	Yorkville-Bristol Sanitary District

- Streams having zero 7-day, 10-year low flow
- Streams having non-zero 7-day, 10-year low flow
- 0.84 — Location of wastewater plant outfall and 2010 effluent in cfs during a 7-day, 10-year low flow period
- 165 — 7-day,10-year low flow (natural plus 2010 effluent during low flow period) in cfs
- 05550000 — Location and identification number of U.S. Geological Survey streamgaging station
- Dam
- 0.36 — Location of wastewater outfall of an industry and 2010 effluent in cfs during a 7-day, 10-year low flow period

BHC	Baxter Healthcare - Round Lake
DCM	Dial Corporation - Montgomery
MCC	Morton chemical - Ringwood
MMC	Modine Manufacturing Company
QOC	Quaker Oats Company
TCI	TC Industry - Crystal Lake
WDC	Woodstock Die Cast

Conditions:
No withdrawals from the Fox River by Elgin and Aurora during 7-day 10-year low-flow conditions
Minimum flow release below Stratton (McHenry) Dam is 111 cfs



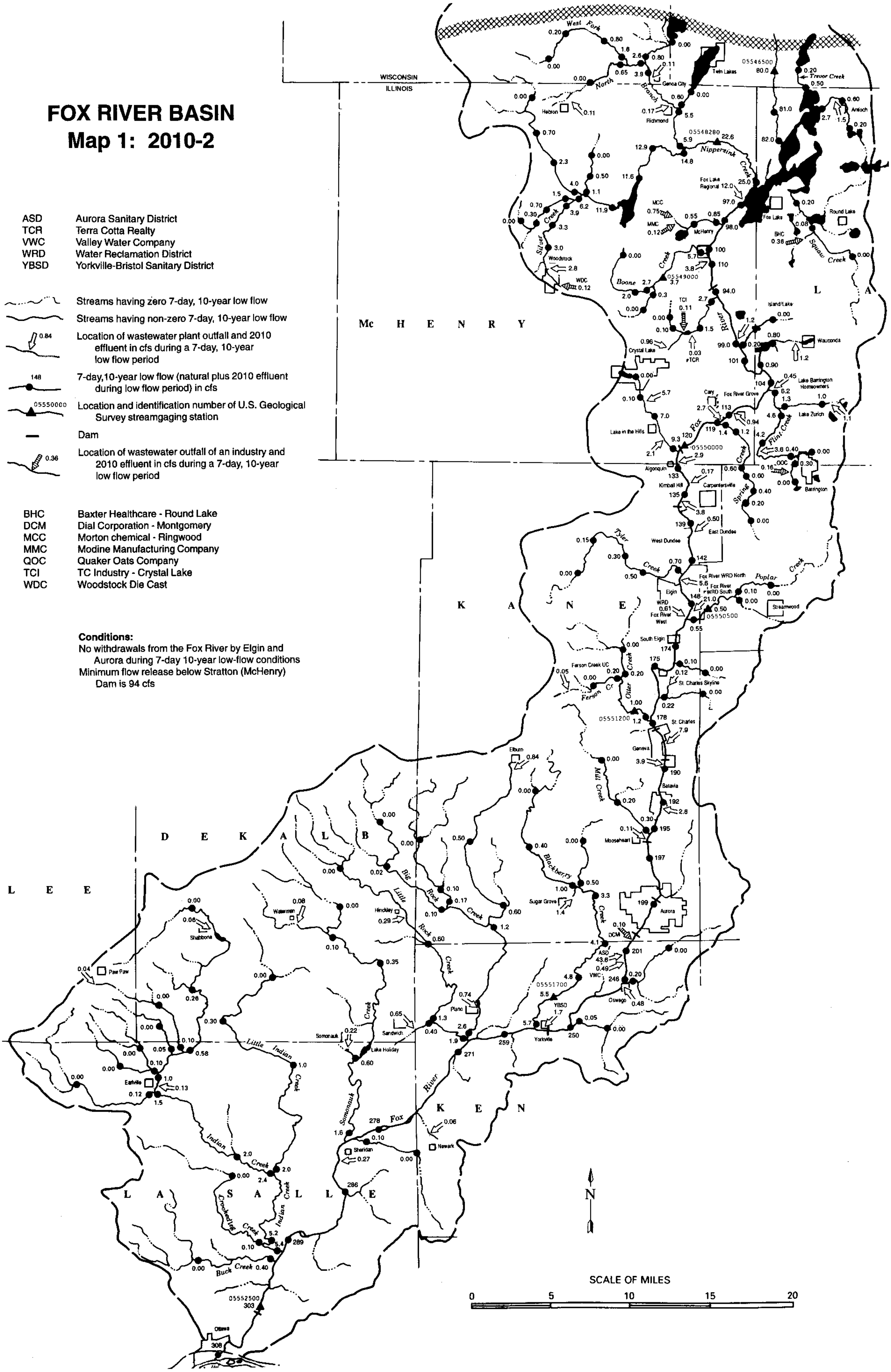
FOX RIVER BASIN
Map 1: 2010-2

ASD	Aurora Sanitary District
TCR	Terra Cotta Realty
VWC	Valley Water Company
WRD	Water Reclamation District
YBSD	Yorkville-Bristol Sanitary District

- Streams having zero 7-day, 10-year low flow
- Streams having non-zero 7-day, 10-year low flow
- 0.84 — Location of wastewater plant outfall and 2010 effluent in cfs during a 7-day, 10-year low flow period
- 148 — 7-day,10-year low flow (natural plus 2010 effluent during low flow period) in cfs
- 05550000 — Location and identification number of U.S. Geological Survey streamgaging station
- Dam
- 0.36 — Location of wastewater outfall of an industry and 2010 effluent in cfs during a 7-day, 10-year low flow period

BHC	Baxter Healthcare - Round Lake
DCM	Dial Corporation - Montgomery
MCC	Morton chemical - Ringwood
MMC	Modine Manufacturing Company
QOC	Quaker Oats Company
TCI	TC Industry - Crystal Lake
WDC	Woodstock Die Cast

Conditions:
No withdrawals from the Fox River by Elgin and Aurora during 7-day 10-year low-flow conditions
Minimum flow release below Stratton (McHenry) Dam is 94 cfs



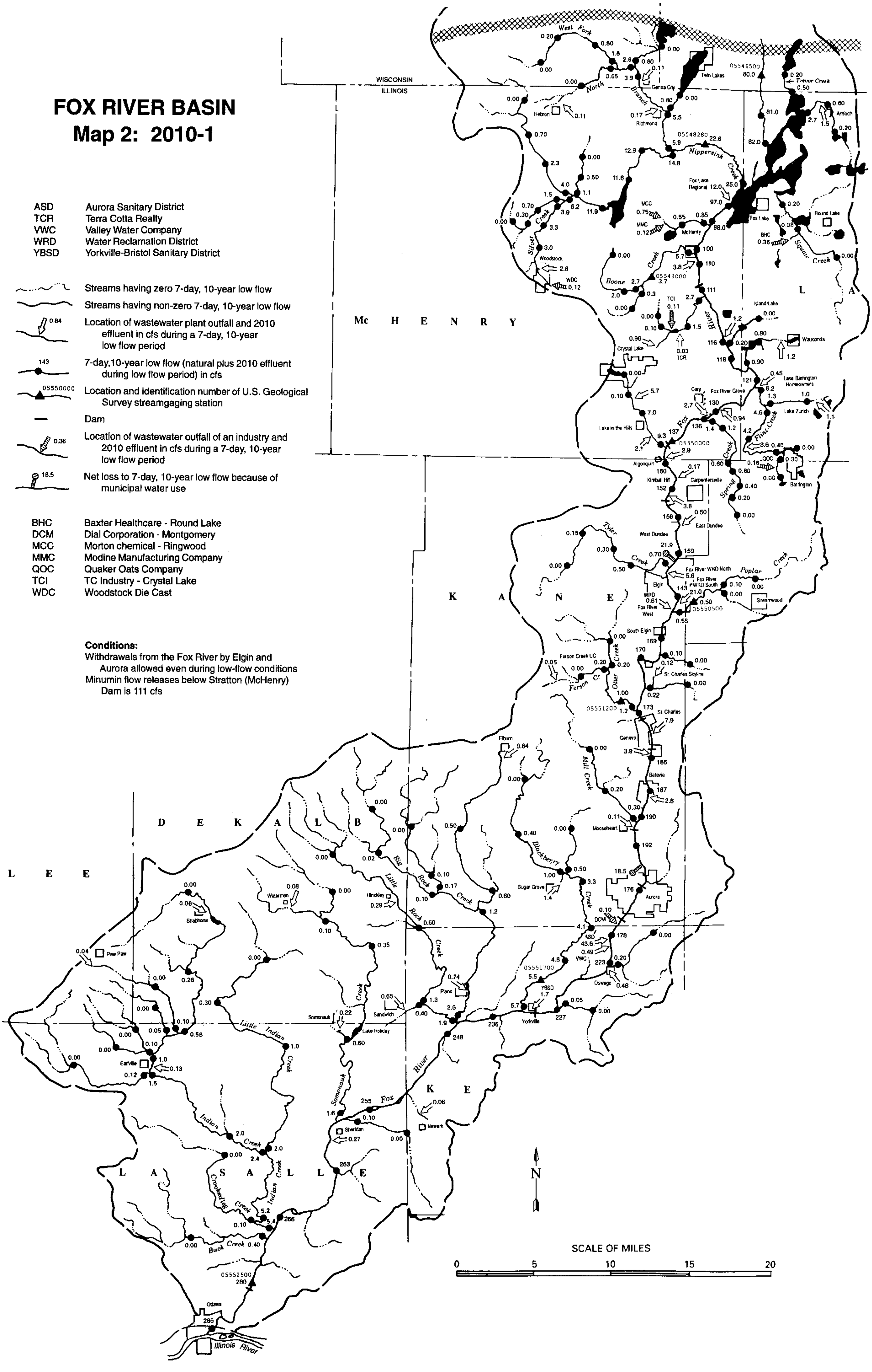
FOX RIVER BASIN
Map 2: 2010-1

ASD Aurora Sanitary District
TCR Terra Cotta Realty
VWC Valley Water Company
WRD Water Reclamation District
YBSD Yorkville-Bristol Sanitary District

Streams having zero 7-day, 10-year low flow
Streams having non-zero 7-day, 10-year low flow
0.84 Location of wastewater plant outfall and 2010 effluent in cfs during a 7-day, 10-year low flow period
143 7-day,10-year low flow (natural plus 2010 effluent during low flow period) in cfs
05550000 Location and identification number of U.S. Geological Survey streamgaging station
Dam
0.36 Location of wastewater outfall of an industry and 2010 effluent in cfs during a 7-day, 10-year low flow period
18.5 Net loss to 7-day, 10-year low flow because of municipal water use

BHC Baxter Healthcare - Round Lake
DCM Dial Corporation - Montgomery
MCC Morton chemical - Ringwood
MMC Modine Manufacturing Company
QOC Quaker Oats Company
TCI TC Industry - Crystal Lake
WDC Woodstock Die Cast

Conditions:
Withdrawals from the Fox River by Elgin and Aurora allowed even during low-flow conditions
Minumin flow releases below Stratton (McHenry) Dam is 111 cfs



FOX RIVER BASIN
Map 2: 2010-2

ASD	Aurora Sanitary District
TCR	Terra Cotta Realty
VWC	Valley Water Company
WRD	Water Reclamation District
YBSD	Yorkville-Bristol Sanitary District

- Streams having zero 7-day, 10-year low flow
- Streams having non-zero 7-day, 10-year low flow
- 0.84 — Location of wastewater plant outfall and 2010 effluent in cfs during a 7-day, 10-year low flow period
- 126 — 7-day,10-year low flow (natural plus 2010 effluent during low flow period) in cfs
- 05550000 — Location and identification number of U.S. Geological Survey streamgaging station
- Dam
- 0.36 — Location of wastewater outfall of an industry and 2010 effluent in cfs during a 7-day, 10-year low flow period
- 18.5 — Net loss to 7-day, 10-year low flow because of municipal water use

BHC	Baxter Healthcare - Round Lake
DCM	Dial Corporation - Montgomery
MCC	Morton chemical - Ringwood
MMC	Modine Manufacturing Company
QOC	Quaker Oats Company
TCI	TC Industry - Crystal Lake
WDC	Woodstock Die Cast

Conditions:
Withdrawals from the Fox River by Elgin and Aurora allowed even during low-flow conditions
Minumin flow releases below Stratton (McHenry) Dam is 94 cfs