WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN IN ILLINOIS, INDIANA, AND WISCONSIN: NUTRIENTS, DISSOLVED OXYGEN, AND FECAL-INDICATOR BACTERIA IN SURFACE WATER, APRIL 1987 THROUGH AUGUST 1990

by Paul J. Terrio

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95–4005

1995

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
ton, short	0.9072	megagram
ton per acre	0.0002241	megagram per square meter
ton per day (ton/d)	0.0105	kilogram per second
ton per year	0.9072	megagram per second
ton per square mile (ton/mi^2)	0.3503	tonne per square kilometer
ton per square mile per year [(ton/mi^2)/yr]	0.3503	tonne per square kilometer per year

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8(°C)+32$$

Abbreviated water-quality units used in this report

col/100 mL	colonies per 100 milliliters
mm	millimeter
mg/L	milligram per liter
μm	micrometer
μg/L	microgram per liter
μS/cm	microsiemen per centimeter at 25° Celsius

Water-Quality Assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin: Nutrients, Dissolved Oxygen, and Fecal-Indicator Bacteria in Surface Water, April 1987 through August 1990

By Paul J. Terrio

Abstract

Data collected during the pilot phase of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program in the upper Illinois River Basin were used to describe the presence, spatial distribution, and temporal variability of nutrients, dissolved oxygen (DO), and fecal-indicator bacteria in selected streams during 1987–90 and to identify, where possible, factors affecting in-stream concentrations and loads of these constituents.

Streams in the upper Illinois River Basin receive nutrient inputs from many different sources within the basin, including wastewater-treatment plants, agricultural runoff, urban runoff, ground-water discharge, diversions from Lake Michigan, eroded soils, and transported plant material.

Nutrient concentrations in the upper Illinois River Basin were larger than nutrient concentrations typically found in Midwestern streams, and most of the largest nutrient concentrations and loads were found in the urban areas of the basin. Median concentrations of total nitrogen at eight NAWQA fixed stations ranged from 2.2 to 9.7 mg/L (milligrams per liter). Most of the nitrogen in upper Illinois River Basin streams was in the form of nitrate, except at two sites where either ammonia nitrogen or organic nitrogen comprised a large part of the total nitrogen concentration. Median concentrations of total phosphorus at the fixed stations ranged from 0.06 to 0.84 mg/L. The spatial distribution of total phosphorus concentrations was similar to that of total nitrogen concentrations—the smallest concentrations were present in the agricultural Kankakee River Basin and the largest in the urban Des Plaines River Basin.

Total nitrogen concentrations were correlated with streamflow at all but one of the fixed stations. Positive correlations were found at stations in predominantly agricultural basins, and negative correlations were found at stations in urban areas.

Approximately 252,000 tons of nitrogen and 94,000 tons of phosphorus are input to streams in the upper Illinois River Basin annually. Only 74,730 tons of nitrogen and 3,850 tons of phosphorus are exported from the upper Illinois River Basin each year via the Illinois River. These figures correspond to 30 and 4 percent of the nitrogen and phosphorus inputs, respectively. During low-flow conditions, the nutrient load in streams in the Des Plaines River Basin accounted for virtually all of the low-flow nitrogen load in the upper Illinois River Basin, with other streams contributing a relatively minor load. Upward trends in total nitrogen concentrations from 1978–90 were found at three of the fixed stations, and downward trends in total phosphorus concentrations were found at two stations.

Median DO concentrations measured at the fixed stations during routine monthly sampling (daylight hours) ranged from 3.4 to 12.2 mg/L. During a low-flow synoptic sampling (measurements made prior to sunrise), all DO concentrations in the Fox River Basin

equaled or exceeded 5.0 mg/L, the Illinois water-quality standard for general-use waters. DO concentrations during the low-flow synoptic sampling at 59 percent of the sampled stream sites in the agricultural Kankakee River Basin and at 49 percent of the sites in the Des Plaines River Basin were less than 5.0 mg/L. Neither stream size nor land use appeared to affect DO concentrations at the synoptic sites significantly. Upward trends in DO concentrations were indicated at the two most downstream stations in the upper Illinois River Basin. The water quality at these two stations represents the aggregate water quality of streams draining the entire upper Illinois River Basin.

The NAWQA program used both fecal coliform and *Escherichia coli* to indicate bacterial contamination. Fecal-coliform densities at the fixed stations ranged from 1 to 45,000 colonies per 100 milliliters. Median fecal-coliform densities were one or two orders of magnitude larger at two stations in the Des Plaines River Basin than at the other fixed stations. From 30 to 100 percent of the stream-water samples collected at stations in the Des Plaines River Basin had *Escherichia coli* densities greater than the Federal criteria for a single sample for infrequently used, full-body-contact water. Trend analyses for bacteria indicated significant downward trends in bacteria densities at three fixed stations: Iroquois River near Chebanse, Ill., Fox River at Algonquin, Ill., and Fox River at Dayton, Ill.

INTRODUCTION

Beginning in 1986, the Congress appropriated funds for the U.S. Geological Survey (USGS) to test and refine concepts for a National Water-Quality Assessment (NAWQA) program. The goals of the program are to—

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources;
2. Define long-term trends (or lack of trends) in water quality; and
3. Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

Information from this program will be obtained on a continuing basis and will be made available to water managers, policy makers, and the public. This information will provide an improved scientific basis for evaluating the effectiveness of water-quality-management programs and for predicting the likely effects of contemplated changes in land- and water-management practices. A detailed description of the goals and concepts of the NAWQA program is presented by Hirsch and others (1988).

At present, the program is completing a pilot phase that lasted about 4 years. The upper Illinois River Basin in Illinois, Indiana, and Wisconsin was one of four surface-water basins selected to test and develop assessment concepts. The other surface-water pilot project areas were the Yakima River Basin in Washington, the lower Kansas River Basin in Kansas and Nebraska, and the Kentucky River Basin in Kentucky.

Some of the water-quality issues of concern in the upper Illinois River Basin are the presence and distribution of nutrients, dissolved oxygen (DO), and fecal-indicator bacteria. Nutrients discussed in this report include nitrogen and phosphorus compounds that are required for plant production. These nutrients can also stimulate excessive algal growth and subsequent eutrophication if present in excessive concentrations. Sampling efforts were conducted to address the following questions:

1. Where do these constituents present problems in the upper Illinois River Basin and what are the causes of these problems?
2. What are the concentrations and loads of nutrients and the concentrations of DO and fecal-indicator bacteria in the upper Illinois River Basin, and what are the effects of these concentrations and loads on the aquatic ecosystem and uses of the stream water?
3. How have the distributions and concentrations of these constituents changed over time in the upper Illinois River Basin?
4. How do the various point and nonpoint sources in the upper Illinois River Basin affect the concentrations of these constituents?

Purpose and Scope

This report describes the presence, spatial distribution, and temporal variability of nutrients, DO, and fecal-indicator bacteria in streams in the upper Illinois River Basin during 1987–90, and identifies, where possible, factors affecting in-stream concentrations and loads of these constituents. Monthly data collected during April 1987 through August 1990 at 8 fixed-station sampling sites and data collected during synoptic surveys in 1988 and 1990 at approximately 70 surface-water sampling sites are used to determine distributions, seasonality, and variability of constituent concentrations and loads. The monthly NAWQA data for 1987–90 are combined with monthly Illinois Environmental Protection Agency (IEPA) data for 1978–86 to analyze long-term trends.

Description of the Upper Illinois River Basin

A brief description of the upper Illinois River Basin is presented here, and the reader is referred to Mades (1987) for a more complete description of the study area. The upper Illinois River Basin is located in northeastern Illinois, northwestern Indiana, and southeastern Wisconsin. The upper Illinois River Basin is drained by the Illinois River at a point just downstream from the mouth of the Fox River near Ottawa, Ill. (fig. 1). The basin includes an area of 10,949 mi^2 and coincides with hydrologic subregion 0712 as defined by the Water Resources Council (Seaber and others, 1987).

The upper Illinois River Basin includes three principal streams: the Kankakee, Fox, and Des Plaines Rivers. The Kankakee River drains 5,165 mi^2, or 47.2 percent of the upper Illinois River Basin area, and flows westerly from its headwaters in St. Joseph County, Ind., to its confluence with the Des Plaines River. The Kankakee River is 130 mi long. In Indiana, the Kankakee River and its tributaries have been dredged and straightened to facilitate drainage of wetland areas for conversion to farmland.

The Fox River originates in Waukesha County, Wis., and flows southerly for 180 mi where it discharges to the Illinois River near Ottawa, Ill. The Fox River has a drainage area of 2,658 mi^2, or 24.3 percent of the upper Illinois River Basin.

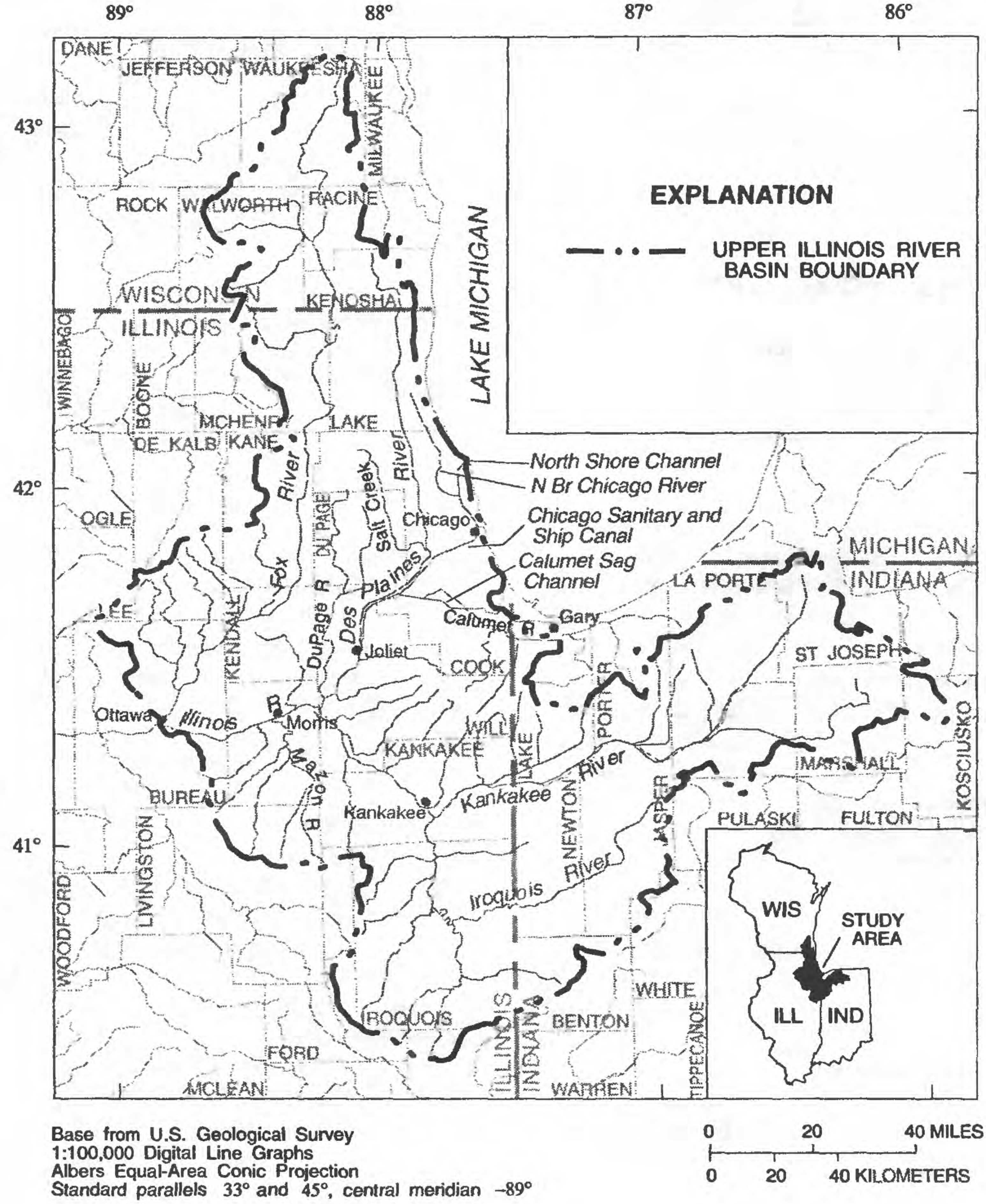
The Des Plaines River is 130 mi long, and its headwaters are in Kenosha County, Wis. The Des Plaines River flows southward, through the Chicago metropolitan area, to its confluence with the Kankakee River. The Des Plaines River Basin includes 2,111 mi^2, or 19.3 percent of the upper Illinois River Basin. Included in the Des Plaines Basin is the Calumet River system, which historically drained to Lake Michigan but was altered in the early 1900's to drain to the Des Plaines River. The Chicago Sanitary and Ship Canal (CSSC), which conveys water diverted from Lake Michigan, is included in the Des Plaines River Basin.

The Illinois River originates at the confluence of the Kankakee and Des Plaines Rivers. The Illinois River flows south and southwest for 273 mi where it discharges to the Mississippi River; only the most upstream 33 mi are included in the upper Illinois River Basin. The area drained directly by the Illinois River includes 1,015 mi^2, or 9.2 percent of the upper Illinois River Basin.

The major land uses in the upper Illinois River Basin are agricultural (77 percent), urban and industrial (18 percent), and forest (5 percent). Figure 2 shows level I land-use classifications in the upper Illinois River Basin, as defined by Anderson and others (1976). Most of the upper Illinois River Basin is used for row-crop agriculture, primarily the production of corn and soybeans. Some areas in the northern part of the basin are used for pasture. The two principle urbanized areas in the upper Illinois River Basin are the greater Chicago metropolitan area and a corridor of urban development along the middle reach of the Fox River. The Kankakee River Basin is 90 percent agricultural, 5 percent urban, and 5 percent forest. The Fox River Basin is 85 percent agricultural and 15 percent urban. In contrast to the Kankakee and Fox River Basins, the Des Plaines River Basin is 60 percent urban, 30 percent agricultural, and 10 percent forest.

The upper Illinois River Basin has a continental climate, and significant variations in temperature and precipitation can occur in any given year. Summers generally are hot and humid, with July temperatures averaging around 25°C and humidity often more than 75 percent. Winters are cold, with an average January temperature of –6°C. An average of 162 days spans the time between the last 0°C day in the spring and the first 0°C day in the fall.

Average annual precipitation in the upper Illinois River Basin varies geographically. The average (1951–80) annual precipitation in the northern parts of the basin was 32 in., and the average annual precipitation for the eastern parts of the upper Illinois River Basin was 40 in. (Moody and others, 1986). Approximately 50 percent of the annual precipitation falls during the growing season, from May through October.



Base from U.S. Geological Survey
1:100,000 Digital Line Graphs
Albers Equal-Area Conic Projection
Standard parallels 33° and 45°, central meridian −89°

Figure 1. Location of the upper Illinois River Basin.

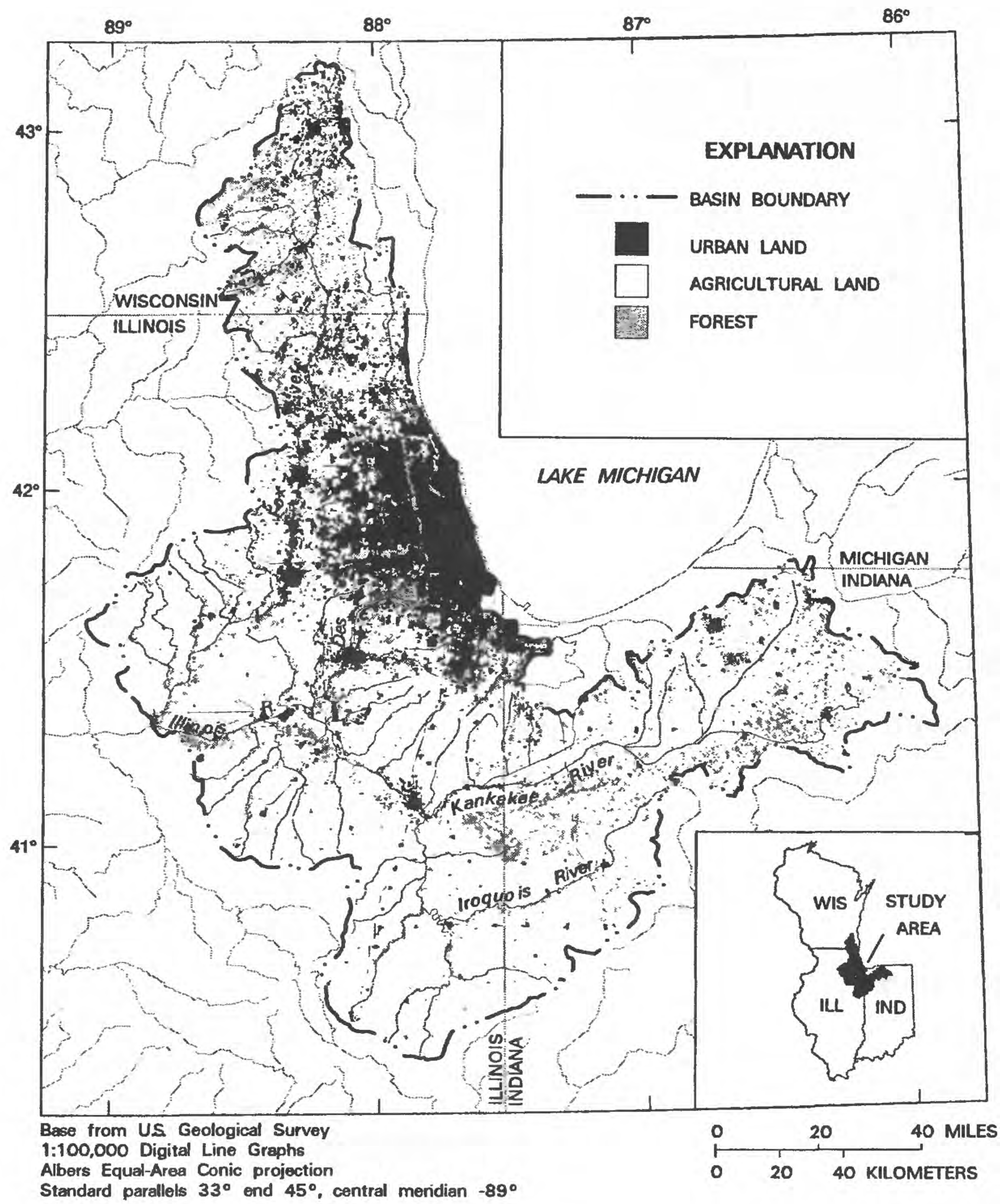


Figure 2. Land use in the upper Illinois River Basin, 1970.

Several sources of streamflow are found in the upper Illinois River Basin, including precipitation and runoff, ground-water flow, return flows, and water diverted from Lake Michigan. Return flow is water discharged to streams after use. An example of return flow is ground water withdrawn for domestic use and returned to a stream after wastewater treatment. In the upper Illinois River Basin, water is diverted or pumped from Lake Michigan for water supply, wastewater dilution, and commercial purposes. In the Des Plaines River Basin, a large percentage of the total streamflow is attributed to return flows and Lake Michigan diversions. Over half of the streamflow in the CSSC can be return flow. Streamflow in the other river basins, however, is derived primarily from runoff and ground-water flow.

DATA COLLECTION AND SOURCES

The upper Illinois River Basin NAWQA program included extensive water-quality-data collection at a network of 8 sampling stations (fixed stations) and at approximately 70 synoptic-survey sampling sites. Sample collection for nutrient, DO, and fecal-indicator bacteria analyses began at the fixed stations in April 1987 and continued through August 1990. Samples were collected at synoptic sites in 1988 and 1990. Data from the IEPA ambient water-quality-monitoring network were available for 38 sites throughout the Illinois part of the upper Illinois River Basin for 1978–90. Data on the quality of wastewater-treatment-plant effluent were available from individual treatment-plant operators.

Fixed-Station Sampling

The upper Illinois River Basin NAWQA program incorporated a network of eight fixed stations for the purposes of—

1. Describing the seasonal variations and the frequency of occurrence of selected water-quality constituents;
2. Estimating loads of constituents past the stations and attempting mass balances of selected target constituents between stations; and
3. Defining long-term trends in water quality.

The eight fixed stations were selected based on basin hydrology, land use, geographical location, and stream characteristics. Most of the fixed stations were in a downstream segment of a major river or tributary. Two of the fixed stations were selected to provide information on stream-water-quality characteristics from specific land-use areas, including areas of potential pollution. The locations of the eight fixed stations are shown in figure 3, and information about each of the stations is given in table 1.

Monthly water-quality samples were collected at the eight fixed stations from April 1987 through August 1990. Samples were collected on a fixed frequency in order to provide a data set suitable for trend analysis. The fixed frequency sampling also provided samples from low-, medium-, and high-flow periods during 1987–90. Water-quality samples collected at the fixed stations were analyzed for physical properties and chemical constituents including nutrients, metals, ions, sediment, bacteria, and organic compounds. The physical properties and nutrient forms analyzed in the fixed-station samples that are discussed in this report are listed in table 2.

Except for water used for bacteria analyses, water samples for constituents discussed in this report were collected using depth- and width-integrating techniques (Illinois Environmental Protection Agency, 1987; Ward and Harr, 1990). These techniques provide a sample representative of the entire stream. Samples for bacteriological analyses were collected as grab samples about 1 ft below the water surface at the center of the stream. Physical properties (temperature, DO concentration, pH, and specific conductance) were measured in situ with a portable multi-parameter water-quality meter.

Several different laboratories were used to analyze the water-quality samples collected at the fixed stations. Nutrient concentrations were analyzed by both the USGS National Water-Quality Laboratory (NWQL) and IEPA laboratories because the agencies apply different nutrient preservatives for stream-water samples. The USGS preserves nutrient samples by adding mercuric chloride to the sample and chilling the samples to 4°C (Timme, 1994). The IEPA uses sulfuric acid and chilling to 4°C for nutrient sample preservation (Illinois Environmental Protection Agency, 1987). Except for long-term trend analyses, nutrient data in this report were from samples preserved with mercuric chloride. Data used for long-term trend analyses included nutrient data from samples preserved with both sulfuric acid and mercuric chloride. Fecal-coliform bacteria analyses were

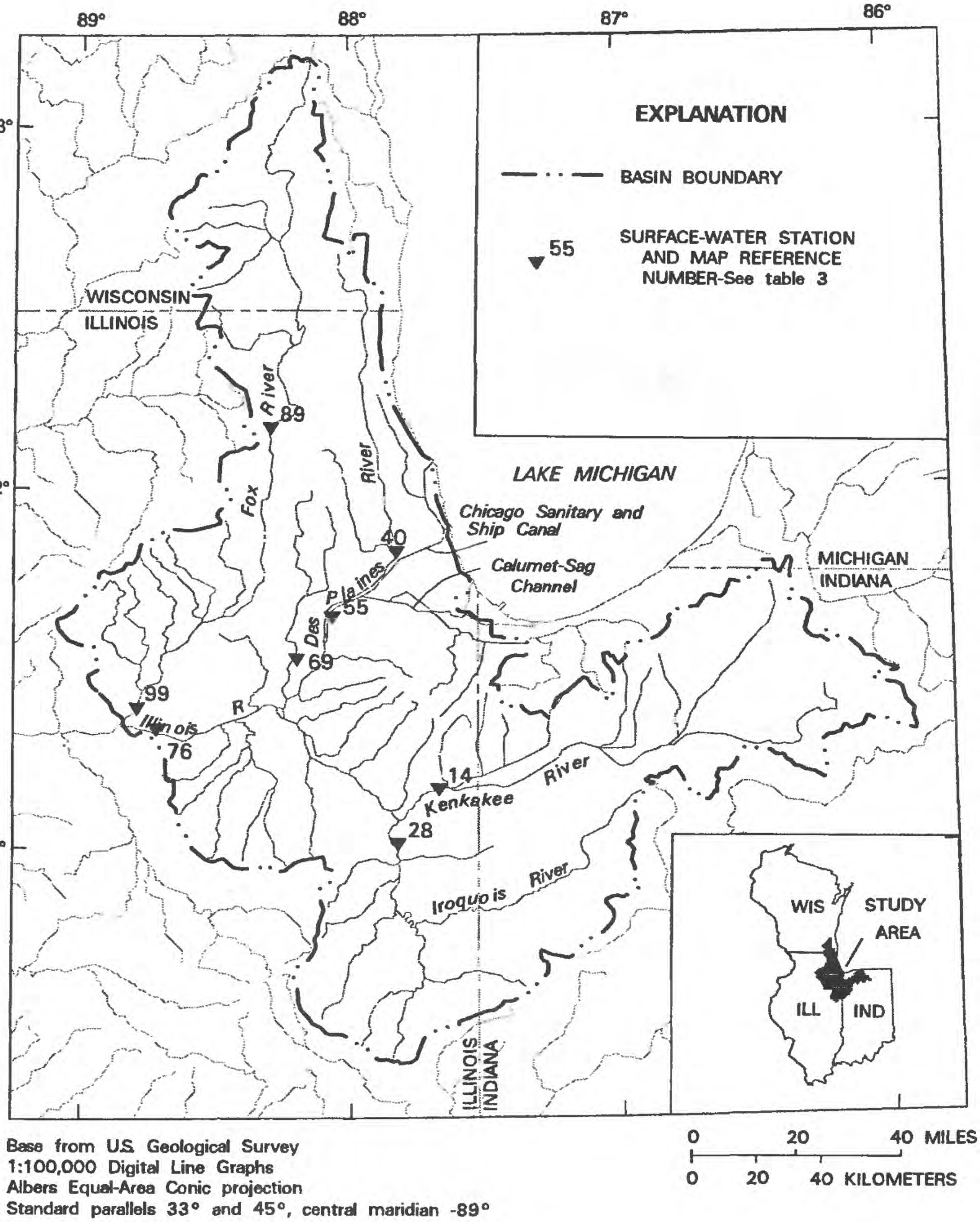


Figure 3. Locations of the eight fixed surface-water stations in the upper Illinois River Basin.

Table 1. Selected information for the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990

[mi^2, square mile; ft^3/s, cubic feet per second; <, less than]

Station number	Station name and latitude and longitude	Drainage area (mi^2)	Through 1990 water year: Years surface-water record	Through 1990 water year: Yeara water-quality record	Through 1990 water year: Mean discharge (ft^3/s)	Mean discharge 1987–90 (ft^3/s)	Land use (percentage of drainage area): Agriculture	Urban	Forest	Other
05520500	Kankakee River at Momence, Ill. Lat 41° 09′ 36″, long 87° 40′ 07″	2,294	75	15	1,998	2,224	88	3	6	3
05526000	Iroquois River near Chebanse, Ill. Lat 41° 00′ 32″, long 87° 49′ 27″	2,091	67	13	1,664	1,554	96	1	3	<1
05532500	Des Plaines River at Riverside, Ill. Lat 41° 49′ 20″, long 87° 49′ 15″	630	47	8	508	680	44	45	6	5
05536995	Chicago Sanitary and Ship Canal at Romeoville, Ill. Lat 41° 38′ 26″, long 88° 03′ 38″	739	6	8	3,788	3,707	22	65	8	5
05540500	Du Page River at Shorewood, Ill. Lat 41° 31′ 20″, long 88° 11′ 35″	324	50	26	270	330	51	37	4	8
05543500	Illinois River at Marseilles, Ill. Lat 41° 19′ 40″, long 88° 43′ 10″	8,259	71	16	10,688	9,377	78	14	5	3
05550000	Fox River at Algonquin, Ill. Lat 42° 09′ 59″, long 88° 17′ 25″	1,403	75	13	863	950	64	13	12	11
05552500	Fox River at Dayton, Ill. Lat 41° 23′ 12″, long 88° 47′ 26″	2,642	75	13	1,743	1,964	74	11	8	7

Table 2. Physical properties, nutrient forms, and bacteria species analyzed in water samples collected in the upper Illinois River Basin, April 1987 through August 1990
[--, no data]

Constituent (WATSTORE[1] code)	Fixed stations	Low-flow synoptics 1987	Low-flow synoptics 1988	Storm-event synoptic
Streamflow (00060 or 00061)	X	X	X	X
Temperature (water) (00010)	X	X	X	--
Specific conductance (00095)	X	X	X	--
pH (00400)	X	X	X	--
Dissolved oxygen (00300)	X	X	X	--
Nitrogen, organic, dissolved (00607)	X	--	--	--
Nitrogen, ammonia, dissolved (00608)	X	X	X	X
Nitrogen, ammonia, total (00610)	X	--	--	--
Nitrogen, nitrite, dissolved (00613)	X	X	X	X
Nitrogen, ammonia, un-ionized (00619)	X	--	--	--
Nitrogen, ammonia plus organic, dissolved (00623)	X	X	--	--
Nitrogen, ammonia plus organic, total (00625)	X	--	X	--
Nitrogen, nitrite plus nitrate, total (00630)	X	--	--	X
Nitrogen, nitrite plus nitrate, dissolved (00631)	X	X	X	X
Phosphorus, total (00665)	X	X	X	--
Phosphorus, dissolved (00666)	X	X	X	--
Phosphorus, orthophosphate, dissolved (00671)	X	X	X	X
Solids, residue on evaporation, 180°C, dissolved (70300)	X	--	--	--
Suspended sediment, percent finer than 0.062 mm (70331)	X	--	X	X
Suspended sediment (80154)	X	X	X	X
Carbon, organic, total (00680)	X	X	X	--
Carbon, organic, dissolved (00681)	X	--	--	--
Carbon, organic, suspended (00689)	X	--	--	--
Fecal coliform, 0.45 micron filter (31616)	X	--	--	--
Escherichia coli (31648)	X	--	X	--
Chlorophyll-*a* (32209)	X	--	--	--
Chlorophyll-*a*, phytoplankton (70953)	--	X	X	--

[1]National WATer Data STOrage and REtreival System.

performed either by USGS field personnel or by IEPA laboratory personnel. *E. Coli* analyses were performed only by USGS personnel.

The quality-assurance and quality-control (QA/QC) practices used during the fixed-station sampling program included duplicate samples, split samples, blanks, and standard reference samples. Duplicate samples were discrete samples collected from the same location at about the same time. These samples were used to determine the variation in concentrations because of sample-collection and field-processing techniques. A split sample was a sample that was collected and subsequently divided into two separate samples for processing and analysis. The results of split samples provided information on the variation in concentrations attributed to sample processing and laboratory analysis. Blanks were samples of the distilled or deionized water used in the sample processing. The blank samples were used to determine the constituent concentrations in the processing water and the contamination from processing equipment. Standard reference samples consisted of water prepared by the NWQL with known nutrient concentrations. This water was processed and analyzed in the same manner as the stream-water samples. The results of standard reference samples were used to show whether contamination or constituent loss resulted from the processing, shipping, and analysis procedures. Sullivan and Blanchard (1994) discuss the NAWQA sampling program design, data-collection methods, laboratory analyses, and QA/QC procedures used in the fixed-station sampling program.

Synoptic Sampling

In addition to the fixed-station sampling program, water-quality samples were collected during several synoptic surveys. Synoptic surveys were designed to collect data from a large number of sites throughout the upper Illinois River Basin, or a specific part thereof, during a brief period of time and during specific flow or climatic conditions. The purposes of these synoptic surveys were to (1) provide a finer degree of spatial resolution for selected water-quality conditions than attainable from the fixed-station sampling network, and (2) document the spatial distribution of concentrations and loads of selected target variables in relation to land and water uses and to land- and waste-management practices. Hirsch and others (1988) provide an overview of the concepts for the NAWQA program including a discussion of the synoptic sampling strategy.

Three synoptic surveys were scheduled as part of the upper Illinois River Basin NAWQA project. These surveys included low-flow surveys in 1987 and 1988, and a storm survey in the Kankakee River Basin in 1990. The 1987 low-flow synoptic survey was cancelled because of heavy rainfall after some of the sites were sampled. The analyses of water samples collected during the 1987 synoptic survey are not included in this report, but the 1987 QA/QC results are included because they are applicable to sampling methods used for the 1988 synoptic survey and the fixed-station sampling methods. The low-flow synoptic survey in 1988, which targeted nutrients, DO, and fecal-indicator bacteria, was conducted during a warm, dry period when problems associated with these constituents commonly occur. The sites sampled during the low-flow synoptic survey were selected by several criteria, as discussed in Hirsch and others (1988). Sites sampled included locations along the main stems of the major streams in the upper Illinois River Basin, locations downstream from known or suspected nutrient-enrichment sources (enriched sites), and locations representing the major land uses in the basin—agricultural, urban, and forest. Fifty-nine sites were sampled throughout the upper Illinois River Basin from July 25 through August 13, 1988. The names and station numbers of the synoptic sites are listed in table 3, and the locations of the sites are shown in figure 4. The constituents sampled during each of the synoptic surveys varied, as shown in table 2. Samples collected during the synoptic surveys also were collected using documented USGS methods (Ward and Harr, 1990). All samples collected during the synoptic surveys were analyzed by USGS field personnel or by the NWQL.

The 1990 storm synoptic survey targeted agricultural organic compounds but also included analyses for total nitrite plus nitrate concentrations. Samples were collected before, during, and after storms to determine changes in concentrations related to changes in runoff and streamflow. The samples were collected from May through July 1990 at 17 sites in the Kankakee River Basin (fig. 5; table 3). Samples were collected as near as possible to the runoff peak and during the duration of the runoff hydrograph at stations on the Iroquois River and Sugar Creek. At Iroquois River at Chebanse, samples were collected

Table 3. Names and numbers for surface-water sites sampled during the low-flow and storm synoptic surveys in the upper Illinois River Basin
[USGS, U.S. Geological Survey]

Map reference number	USGS station number	Station name
1	05515000	Kankakee River near North Liberty, Ind.
3	05515500	Kankakee River at Davis, Ind.
4	05516500	Yellow River at Plymouth, Ind.
5	05517000	Yellow River at Knox, Ind.
7	05517500	Kankakee River at Dunns Bridge, Ind.
8	05517530	Kankakee River near Kouts, Ind.
10	05517890	Cobb Ditch near Kouts, Ind.
11	05518000	Kankakee River at Shelby, Ind.
12	05519000	Singleton Ditch at Schneider, Ind.
13	05520150	Singleton Ditch at County Road 52 near Illiana Heights, Ind.
14	05520500	Kankakee River at Momence, Ill.
15	05521000	Iroquois River at Rosebud, Ind.
16	05522500	Iroquois River at Rensselaer, Ind.
18	05523500	Slough Creek near Collegeville, Ind.
19	05524500	Iroquois River near Foresman, Ind.
20	05525000	Iroquois River at Iroquois, Ill.
21	05525290	Sugar Creek near Stockland, Ill.
22	05525500	Sugar Creek at Milford, Ill.
23	05525540	Iroquois River near Watseka, Ill.
26	05525600	Spring Creek near Gilman, Ill.
28	05526000	Iroquois River near Chebanse, Ill.
29	05526130	Kankakee River near Bourbonnais, Ill.
30	05526410	Rock Creek at Highway 102 near Deselm, Ill.
31	05527500	Kankakee River near Wilmington, Ill.
32	05527800	Des Plaines River at Russell, Ill.
33	05528000	Des Plaines River near Gurnee, Ill.
34	05529000	Des Plaines River near Des Plaines, Ill.
37	05531175	Salt Creek at Wood Dale, Ill.
38	05531500	Salt Creek at Western Springs, Ill.
40	05532500	Des Plaines River at Riverside, Ill.
41	05533020	Flag Creek at 91st Street near Willow Springs, Ill.
42	05534050	Des Plaines River at Lockport, Ill.
44	05535172	Skokie River at Happ Road at Northfield, Ill.
45	05536000	North Branch Chicago River at Niles, Ill.
47	05536108	North Shore Channel at Devon Avenue at Chicago, Ill.
48	05536142	Chicago Sanitary and Ship Canal at Forest View, Ill.
51	05536290	Little Calumet River at South Holland, Ill.
52	055363252	Little Calumet River at Halsted Avenue at Harvey, Ill.
54	05536700	Calumet Sag Channel at Sag Bridge, Ill.
55	05536995	Chicago Sanitary and Ship Canal at Romeoville, Ill.
58	05538008	Des Plaines River above Brandon Road Dam at Joliet, Ill.
61	05539360	Des Plaines River below Lock and Dam at Rockdale, Ill.
62	05539900	West Branch Du Page River near West Chicago, Ill.
67	05540290	Du Page River near Naperville, Ill.
69	05540500	Du Page River at Shorewood, Ill.

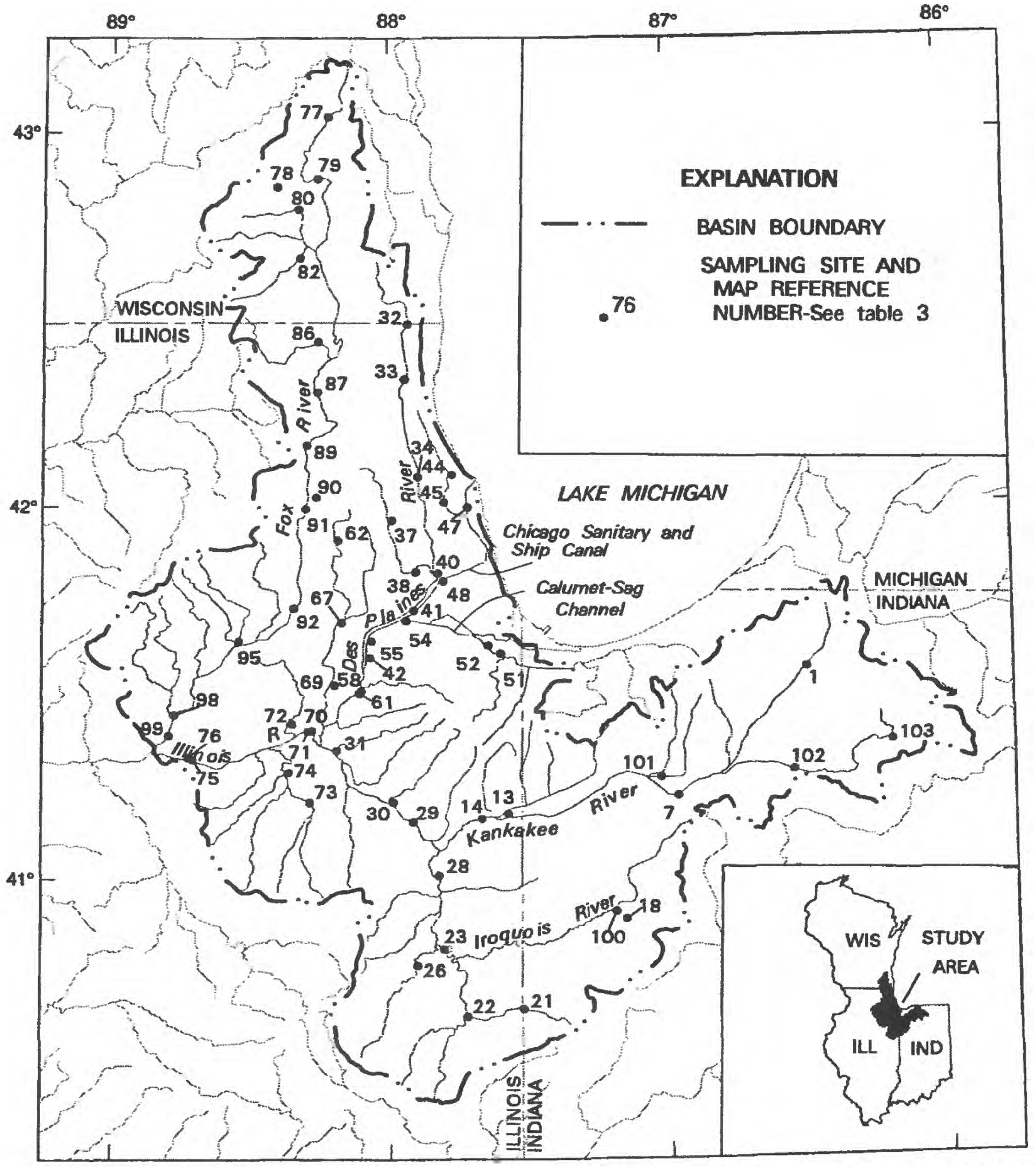
Table 3. Names and numbers for surface-water sites sampled during the low-flow and storm synoptic surveys in the upper Illinois River Basin—*Continued*

Map reference number	USGS station number	Station name
70	05541498	Illinois River above Dresden Island Dam near Minooka, Ill.
71	05541508	Illinois River below Dresden Island Dam near Minooka, Ill.
72	05541710	Aux Sable Creek near Morris, Ill.
73	05541745	Mazon River near Gardner, Ill.
74	05542000	Mazon River near Coal City, Ill.
75	05543484	Illinois River above Marseilles Dam at Marseilles, Ill.
76	05543500	Illinois River at Marseilles, Ill.
77	05543814	Pewaukee River at State Route 164 at Waukesha, Wis.
78	05544090	Mukwonago River at Marsh Road near Mukwonago, Wis.
79	05544315	Fox River near Big Bend, Wis.
80	05544908	Honey Creek at Bell School Road near East Troy, Wis.
82	05545300	White River near Burlington, Wis.
86	05548280	Nippersink Creek near Spring Grove, Ill.
87	05549500	Fox River near McHenry, Ill.
89	05550000	Fox River at Algonquin, Ill.
90	05550500	Poplar Creek at Elgin, Ill.
91	05551000	Fox River at South Elgin, Ill.
92	05551540	Fox River at Montgomery, Ill.
95	05551937	Big Rock Creek at Route 276 near Plano, Ill.
98	05552400	Indian Creek at Route 258 at Wedron, Ill.
99	05552500	Fox River at Dayton, Ill.
100	405443087112800	Iroquois River above Slough Creek near Rensselaer, Ind.
101	411616087013100	Reeves Ditch at State Route 49 near Kouts, Ind.
102	411714086325600	Yellow River above State Route 8 near Knox, Ind.
103	412147086113700	Yellow River at North Hickory Road near Inwood, Ind.

by an automatic sampler actuated by an increase in stream stage. Samples collected by the automatic sampler were analyzed only for dissolved nitrite plus nitrate.

Quality-assurance and quality-control practices implemented during the low-flow synoptic surveys were similar to those used for the fixed-station sampling program and consisted of duplicate samples, split samples, blanks, and standard reference samples. No nutrient QA/QC samples were collected during the 1990 storm synoptic survey. Sample collection and processing methods used during the synoptic surveys were comparable to the methods used for the fixed-station sampling, and the QA/QC samples used for the fixed-station program also are applicable to the synoptic samples (Sullivan and Blanchard, 1994).

The results of the QA/QC samples for the 1987 and 1988 low-flow synoptic surveys are given in tables 4–7. The results of the standard reference samples processed during the synoptic surveys (table 4) showed several dissolved nitrite and nitrate concentrations and one dissolved orthophosphate concentration slightly below the mean standard reference concentrations for these constituents. This is an indication that some of the analyses for these nutrient forms might indicate concentrations slightly less than the true concentrations. The blank analyses (table 5) indicated that there were some concentrations of nitrogen species that were larger than desirable in sample-processing water. Other analyses of water from the same source were performed as part of the NAWQA fixed-station program and did not indicate concentrations at these levels. The analysis of the sample-processing water during the synoptic survey, however, indicated some contamination was present in the water or was being introduced by the sampling equipment or processing personnel. Depending on the stream sample concentration, the contributions of nitrogen from the sample-processing water ranged



Base from U.S. Geological Survey
1:100,000 Digital Line Graphs
Albers Equal-Area Conic projection
Standard parallels 33° and 45°, central meridian -89°

0 20 40 MILES
0 20 40 KILOMETERS

Figure 4. Locations of the low-flow synoptic-survey surface-water sampling sites in the upper Illinois River Basin, July 25 through August 13, 1988.

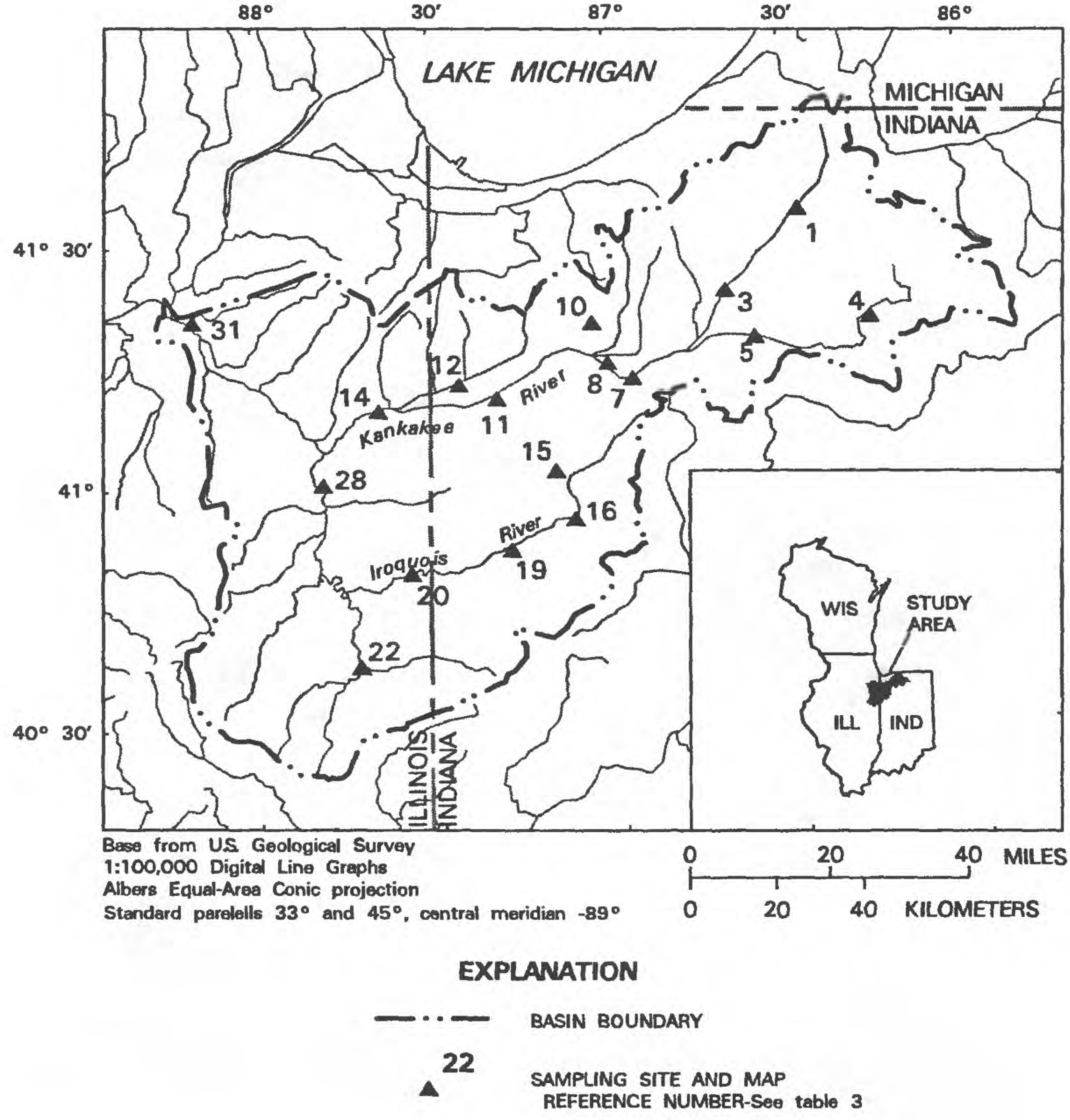


Figure 5. Locations of the 1990 storm synoptic-survey surface-water sampling sites in the Kankakee River Basin.

Table 4. Results of analyses for nutrient concentrations in standard reference samples processed during the 1987 and 1988 low-flow synoptic surveys in the upper Illinois River Basin
[mg/L, milligrams per liter]

Constituent	Mean standard reference concentration	Standard deviation for reference samplea	Measured sample concentration
		August 24, 1987, at 10:00 a.m.	
Nitrogen, organic, dissolved (mg/L)	0.62	0.27	0.49
Nitrogen, ammonia, dissolved (mg/L)	.67	.10	.71
Nitrogen, nitrite, dissolved (mg/L)	.07	.01	.07
Nitrogen, nitrate, dissolved (mg/L)	1.13	.08	1.03
Nitrogen, ammonia plus organic, total (mg/L)	1.29	.37	1.20
Phosphorus, total (mg/L)	.63	.05	.67
Phosphorus, orthophosphate, dissolved (mg/L)	.28	.02	.25
		August 24, 1987, at 11:00 a.m.	
Nitrogen, organic, dissolved (mg/L)	.62	.27	.61
Nitrogen, ammonia, dissolved (mg/L)	.67	.10	.69
Nitrogen, nitrite, dissolved (mg/L)	.07	.01	.07
Nitrogen, nitrate, dissolved (mg/L)	1.13	.08	1.13
Nitrogen, ammonia plus organic, total (mg/L)	1.29	.37	1.30
Phosphorus, total (mg/L)	.63	.05	.67
Phosphorus, orthophosphate, dissolved (mg/L)	.28	.02	.26
		July 26, 1988, at 5:40 a.m.	
Nitrogen, organic, dissolved (mg/L)	.68	.29	.58
Nitrogen, ammonia, dissolved (mg/L)	.70	.08	.72
Nitrogen, nitrite, dissolved (mg/L)	.12	.04	.05
Nitrogen, nitrate, dissolved (mg/L)	.85	.08	.85
Nitrogen, ammonia plus organic, total (mg/L)	1.38	.21	1.30
Phosphorus, total (mg/L)	.66	.04	.66
Phosphorus, orthophosphate, dissolved (mg/L)	.49	.03	.48
		August 4, 1988, at 7:50 a.m.	
Nitrogen, organic, dissolved (mg/L)	.68	.29	.76
Nitrogen, ammonia, dissolved (mg/L)	.70	.08	.74
Nitrogen, nitrite, dissolved (mg/L)	.12	.04	.05
Nitrogen, nitrate, dissolved (mg/L)	.85	.08	.86
Nitrogen, ammonia plus organic, total (mg/L)	1.38	.21	1.50
Phosphorus, total (mg/L)	.66	.04	.66
Phosphorus, orthophosphate, dissolved (mg/L)	.49	.03	.48

from almost insignificant to comprising the entire concentration determined for the sample. The results of the duplicate samples (table 6) showed little variation in concentrations that could be attributed to sample processing and analysis for most constituents. There were some significant differences in the concentrations of total phosphorus and total organic carbon. The results of the split sample analyses (table 7) showed some small differences in most constituent concentration analyses. The largest differences between duplicate samples were for those constituents associated with particulate matter. Concentrations of these constituents are typically more variable than dissolved forms because they are affected to a greater degree by physical differences and forces in the streams. None of the differences was considered to be so large as to identify any problem in the sample collection or analyses.

Data Compiled From Other Sources

The IEPA has operated an ambient water-quality-monitoring network throughout the State since 1975. This network includes 38 sites in the upper Illinois River Basin where water-quality samples are

Table 5. Results of analyses for nutrient concentrations in sample-processing water (blanks), at 6:00 a.m., August 2, 1988
[mg/L, milligrams per liter]

Constituent	Concentration (mg/L)
Nitrogen, organic, dissolved	0.17
Nitrogen, ammonia, dissolved	.03
Nitrogen, nitrite, dissolved	.01
Nitrogen, nitrate, dissolved	.09
Nitrogen, ammonia plus organic, dissolved	.20
Nitrogen, ammonia plus organic, total	.30
Nitrogen, nitrite plus nitrate, dissolved	.10
Phosphorus, total	.02
Phosphorus, dissolved	.02
Phosphorus, orthophosphate, dissolved	.02
Carbon, organic, total	.20

collected on a 6-week frequency using sample-collection methods comparable to those used by the USGS. As mentioned, the IEPA uses sulfuric acid to preserve nutrient samples, whereas the USGS uses mercuric chloride. Six of the eight NAWQA fixed stations were located at IEPA water-quality-monitoring sites. Because data were available at these stations since 1978, the IEPA data were combined with the data collected through the NAWQA program to determine long-term trends in nutrient concentrations. The IEPA incorporates standard QA/QC procedures into the ambient water-quality-monitoring program, including equipment blanks, duplicate samples, sample splits, QC field visits, and standard-reference samples. A discussion of the IEPA's field QA/QC practices is included in IEPA (1987).

Approximately 180 wastewater-treatment plants are located in the upper Illinois River Basin. Requests for treatment-plant-effluent flow rates and water-quality data for periods coinciding with the 1988 synoptic survey were sent to personnel at each treatment plant. Approximately two-thirds of the personnel at the treatment plants responded. The data aided in assessing the effect of effluents on stream-water quality during low-flow periods. The available data generally were limited to those constituents required for the treatment plant to fulfill regulatory requirements and seldom included any associated in-stream water-quality data. Because data from the wastewater-treatment plants were used only for background information and were not used in calculations or computations, the QA/QC information for these data were not determined.

NUTRIENTS, DISSOLVED OXYGEN, AND FECAL-INDICATOR BACTERIA

This section presents results of analyses and interpretation of nutrient, DO, and fecal-indicator bacteria data from the upper Illinois River Basin NAWQA program, April 1987 through August 1990. Sources of nutrients, DO, and bacteria in the upper Illinois River Basin are identified, and contributions of the constituents from these sources to streams in the upper Illinois River Basin are estimated. Characteristics of these constituents and water-quality conditions in the upper Illinois River Basin related to the constituents are examined.

Nutrients

Nutrients affect aquatic environments because they are required for plant growth. Aquatic plants provide food, oxygen, and habitat for fish and other aquatic fauna and are required for a healthy aquatic system. Excessive nutrient levels, however, can cause prolific algal growth and eutrophic conditions, resulting in subsequent decomposition of plant and organic matter, increased oxygen demand, foul odors, and fish kills.

The nutrients of primary importance in most stream environments are nitrogen and phosphorus. Carbon, silica, and trace elements also function as nutrients, but these elements usually are available in sufficient quantities to meet the metabolic needs of the aquatic organisms. Both nitrogen and phosphorus are found in the environment at several oxidation states and in several different forms.

Nitrogen is present in water as nitrite and nitrate anions, in cationic form as ammonium, and at intermediate oxidation states as part of organic solutes (Hem, 1985). Organic nitrogen includes nitrogen present in peptides, proteins, nucleic acids, urea, and synthetic organic materials. The sum of organic nitrogen and ammonia may be determined analytically and is referred to as kjeldahl nitrogen. Wastewaters may contain other forms of nitrogen, such as cyanide.

Nitrite is an intermediate state of nitrogen, present either during the oxidation of ammonia to nitrate or during the reduction of nitrate. Nitrite generally is detected only in trace quantities in surface waters. Nitrate is easily leached from soils and can be found in large concentrations in agricultural areas

Table 6. *Results of analyses of duplicate surface-water samples collected at Kankakee River near Wilmington, Ill., August 4, 1988*

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; NO_2+NO_3, nitrite plus nitrate; diam., diameter; %, percent; mm, millimeters; µg/L, micrograms per liter; USGS, U.S. Geological Survey; <, less than; Numbers in parentheses are National Water Data Storage and Retrieval System parameter codes]

Time (hour)	Agency collecting sample	Agency analyzing sample	Streamflow instantaneous (ft^3/s) (00061)	Number of sampling points (count) (00063)	Gage height (feet) (00065)	Nitrogen, ammonia dissolved (mg/L as N) (00608)
0545	USGS	USGS	E420	10	0.62	0.07
0715	USGS	USGS	E414	10	.62	.07

Nitrogen, nitrita dissolved (mg/L as N) (00613)	Nitrogen, ammonia + organic dissolved (mg/L as N) (00623)	Nitrogen, ammonia + organic total (mg/L as N) (00625)	Nitrogen, $NO_2 + NO_3$ dissolved (mg/L as N) (00631)	Phoephorus total (mg/L as P) (00665)	Phosphorus dissolved (mg/L as P) (00666)
0.01	0.3	0.3	<0.1	0.18	0.11
.01	.2	.2	.1	.18	.12

Phosphorus ortho, dissolved (mg/L as P) (00671)	Carbon, organic totsl (mg/L ss C) (00680)	Sediment suspended sieve diam. % finer than .062 mm (70331)	Chlorophyll-*a* phytoplankton chromofluorom (µg/L) (70953)	Chlorophyll-*b* phytoplankton chromofluorom (µg/L) (70954)	Sediment, suspended (mg/L) (80154)
0.09	6.5	92	11	1.9	18
.09	7.0	99	11	2.1	15

E, Estimated

where nitrogen fertilizers are used. Ammonium, on the other hand, adsorbs to soil particles and clays because of its positive charge and is not leached readily from soils (American Public Health Association and others, 1985). Ammonium and organic nitrogen are converted to nitrite and nitrate by nitrifying bacteria, and the presence of these nitrogen forms generally indicates a nearby pollutant source.

Phosphorus is not as abundant in the environment as nitrogen and often is the limiting element for plant growth in aquatic systems (Hem, 1985). Phosphorus is usually found as phosphate (fully oxidized phosphorus) in natural waters. For most stream waters, the H_2PO_4 and HPO_4 orthophosphate species are the predominant dissolved phosphorus forms. Organophosphates (organically bound phosphates) also are common in stream systems. Phosphate is found in solution, as part of detritus, attached to sediment particles and in the bodies of aquatic organisms. Much of the phosphorus in stream systems adsorbs to particulate matter and is not directly available for uptake by plants and algae.

Five nutrient forms were selected to represent nutrient conditions in the upper Illinois River Basin: total nitrogen as nitrogen (total nitrogen), dissolved nitrite plus nitrate as nitrogen ($NO_2 + NO_3$), dissolved ammonia nitrogen as nitrogen (ammonia), total organic nitrogen as nitrogen (organic nitrogen), and total phosphorus as phosphorus (total phosphorus). Total nitrogen concentrations were calculated as the sum of dissolved $NO_2 + NO_3$ concentration and total organic plus ammonia concentration. Dissolved $NO_2 + NO_3$ concentrations were used rather than total $NO_2 + NO_3$ concentrations because the number of dissolved analyses was larger than the number of total analyses and the concentrations of dissolved

Table 7. Results of analyses of split surface-water samples collected at Fox River at Montgomery, Ill., July 29, 1988

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; NO_2+NO_3, nitrite plus nitrate; diam., diameter; %, percent; mm, millimeters; µg/L, micrograms per liter; USGS, U.S. Geological Survey; <, less than; Numbers in parentheses are National Water Data Storage and Retrieval System parameter codes]

Time (hour)	Agency collecting sample	Agency analyzing sample	Streamflow instantaneous (ft^3/s) (00061)	Number of sampling points (count) (00063)	Nitrogen, ammonia dissolved (mg/L as N) (00608)
0730	USGS	USGS	E258	11	<0.01
0731	USGS	USGS	E258	11	<.01

Nitrogen, nitrite dissolved (mg/L as N) (00613)	Nitrogen, ammonia + organic dissolved (mg/L as N) (00623)	Nitrogen, ammonia + organic total (mg/L as N) (00625)	Nitrogen, $NO_2 + NO_3$ dissolved (mg/L as N) (00631)	Phosphorus total (mg/L as P) (00665)	Phosphorus dissolved (mg/L as P) (00666)
<0.01	1.2	2.4	<0.1	0.38	0.17
<.01	1.4	2.6	<.1	.42	.16

Phosphorus ortho, dissolved (mg/L as P) (00671)	Carbon, organic total (mg/L as C) (00680)	Sediment suspended sieve diam. % finer than .062 mm (70331)	Chlorophyll-*a* phytoplankton chromofluorom (µg/L) (70953)	Chlorophyll-*b* phytoplankton chromofluorom (µg/L) (70954)	Sediment, suspended (mg/L) (80154)
0.13	16	92	59	8.9	27
.13	19	94	59	8.9	28

E, Estimated

$NO_2 + NO_3$ were virtually always the same or slightly greater or less than corresponding concentrations of total $NO_2 + NO_3$. Concentrations of nutrients in this report are expressed as concentrations of elemental nitrogen and phosphorus in milligrams per liter, unless otherwise indicated.

Sources of Nutrients in the Upper Illinois River Basin

In-stream nutrient concentrations and loads in the upper Illinois River Basin are affected by a number of sources including wastewater-treatment-plant effluents, agricultural runoff, urban runoff, ground-water contribution, diversions from Lake Michigan, soil erosion, and plant material. The primary sources of nutrients to the upper Illinois River Basin are wastewater-treatment-plant effluents and agricultural fertilizers. In the early 1980's, approximately 46 percent of the total nutrient load in upper Illinois River Basin streams was attributed to point sources and about 54 percent of the load was from nonpoint sources (Gianessi, 1986).

Most domestic and many industrial wastewaters have relatively large concentrations of ammonia, nitrate, and phosphorus in comparison to stream-water concentrations. Approximately 1,815 Mgal/d, or about 2,810 ft^3/s, of effluent is discharged to upper Illinois River Basin streams by 181 wastewater-treatment plants (Zogorski and others, 1990). Seventy-two of these treatment plants have capacities of 1 Mgal/d or more, and three treatment plants have capacities greater than 300 Mgal/d. Wastewater-treatment-plant effluents comprised about 30 percent of the total streamflow from the upper Illinois River Basin in 1988.

The water quality of treatment-plant effluent varies, depending on the type of treatment. Discharges from the three largest treatment plants comprised about 75 percent (2,100 ft^3/s) of the total treatment-plant effluent discharged in the upper Illinois River Basin. These three plants only provide secondary treatment. Flow-weighted average nutrient concentrations of the effluents from the three largest treatment plants in the upper Illinois River Basin were calculated for 1988. The flow-weighted average nutrient concentrations for the treatment-plant effluents for 1988 were derived by multiplying the 1988 average nutrient concentration for each treatment plant by the average effluent discharge from the treatment plant in 1988, summing the products from the three treatment plants, and dividing by the cumulative discharge for all three treatment plants. The average nitrogen concentration was 8.40 mg/L, and the average phosphorus concentration was 0.90 mg/L. Jerri Davis (U.S. Geological Survey, written commun., 1993) estimated that approximately 26,000 tons per year of nitrogen and 5,410 tons per year of phosphorus are discharged annually to streams from treatment plants in the upper Illinois River Basin.

Because nearly 75 percent of the upper Illinois River Basin is active agricultural land, the input of nutrients to streams from agricultural activities is substantial. Gianessi (1986) estimated that nonurban (agricultural) land contributed about 55,500 tons per year of kjeldahl nitrogen and 7,340 tons per year of phosphorus to upper Illinois River Basin streams. The water chemistry of runoff from agricultural land depends on a number of factors including the specific agricultural use, topography, soil type, climate, and hydrologic conditions. These factors vary temporally and spatially throughout the upper Illinois River Basin. In addition, the quality of water from overland runoff can differ substantially from that of tile drainage. Most forms of nutrients are found in agricultural runoff, but, because nitrate is both a relatively stable form and soluble in water, it is generally the most prevalent form of nitrogen in streams. Concentrations of total nitrogen in agricultural runoff have been found to range from 4.9 to 35 mg/L (Dornbush and others, 1974; Uttormark and others, 1974; Donigian and Crawford, 1976; and Roseboom and others, 1990). The same studies found concentrations of total phosphorus in agricultural runoff to range from 0.02 to 3.45 mg/L. Nutrient concentrations in feedlot runoff can be orders of magnitude larger than concentrations in field runoff. Approximately 132 feedlots of various sizes are located in the upper Illinois River Basin. High concentrations of nutrients in runoff from these feedlots typically are found after relatively small, local storms (Roseboom and others, 1990).

Application of fertilizers on agricultural fields is a major source of nutrients in the upper Illinois River Basin. Amounts of nutrients in fertilizers sold in Illinois counties in the upper Illinois River Basin in 1988 were available from the Illinois Department of Agriculture (1988a, 1988b). An average quantity of nitrogen and phosphorus was calculated for the Illinois part of the upper Illinois River Basin, and this average was assumed for the parts of the upper Illinois River Basin in Indiana and Wisconsin. Assuming that all of the fertilizer purchased was applied to fields in 1988, approximately 215,000 tons per year of nitrogen and 87,000 tons per year of phosphorus were introduced into streams draining the upper Illinois River Basin through fertilizer application.

Approximately 13 percent (1,425 mi^2) of the upper Illinois River Basin is urbanized. Urban runoff can have large nutrient concentrations. Many factors, including antecedent conditions, local land use, drainage-system design, climatic season, and street-cleaning practices affect nutrient concentrations in runoff from urban areas. Ammonia and phosphorus often are found in urban areas because of their domestic and industrial uses. Results from several studies (Uttormark and others, 1974; Donigian and Crawford, 1976; and Manning and others, 1977) show that concentrations of total nitrogen and total phosphorus in runoff from urban areas were found to range from 0.5 to 33 mg/L and from less than 0.2 to 5.0 mg/L, respectively. Uttormark and others (1974) found that 0.60 ton/mi^2 of nitrogen and 0.88 ton/mi^2 of phosphorus were exported in runoff from urban areas in Madison, Wis. Assuming that these yields apply to urban areas of the upper Illinois River Basin, approximately 855 tons per year of nitrogen and 1,250 tons per year of phosphorus are conveyed to upper Illinois River Basin streams in runoff from urban areas.

Data for concentrations and loads of nitrate and ammonium ions in precipitation were available from the National Atmospheric Deposition Program for five sites in, or near, the upper Illinois River Basin for 1988 (National Atmospheric Deposition Program, 1989). Concentration and load data from these five sites were averaged to obtain values representative of the entire upper Illinois River Basin. The average concentrations of nitrate and ammonia were 0.37 and 0.31 mg/L, respectively. Precipitation varies throughout the upper Illinois River Basin both spatially and temporally, but 36 in. per year is an approximate annual average for the upper Illinois River Basin. Atmospheric deposition contributes approximately 10,600 tons of nitrate and 8,850 tons of ammonia to the upper Illinois River Basin land surface each year. How much of the atmospheric depositional load of ammonium and nitrate is conveyed to upper Illinois River Basin streams is not known, but this deposition could represent a significant contribution of nutrients to the upper Illinois River Basin.

In 1985, an average of 650 ft^3/s of ground water was withdrawn from aquifers in the upper Illinois River Basin (Mades, 1987). Ground-water withdrawals comprised about 7 percent of the total median annual discharge from the upper Illinois River Basin. Water-quality data for public water-supply wells in Illinois were available for 1985–87 (Voelker and others, 1987). Total nitrite plus nitrate concentrations typically were less than or equal to 0.10 mg/L, concentrations of total ammonia nitrogen generally were about 0.40 mg/L, and phosphorus concentrations typically were about 0.02 mg/L. Contributions of nutrient loads from ground-water withdrawals are included in the estimates for wastewater-treatment-plant effluents. Water also was conveyed to upper Illinois River Basin streams through ground-water flow. Ground-water flow in the upper Illinois River Basin was estimated by two methods. One method assumed that streamflow during dry weather conditions (the drought of 1988) at sites unaffected by return flows or diversions was derived primarily from ground-water flow. Streamflow yields calculated for these sites were used to estimate the basin-wide ground-water flow. The second method determined ground-water flow as the difference between streamflow out of the upper Illinois River Basin and the known qualities of ground-water withdrawals (subsequently return flows) and diversions from Lake Michigan. These methods derived estimates of ground-water flow of 876 and 1,176 ft^3/s, respectively. From the average of these two estimates, ground-water flow contributes about 102 tons per year of nitrite plus nitrate, 408 tons per year of ammonia, and 20 tons per year of phosphorus to upper Illinois River Basin streams (unpublished data on file in Urbana office of the U.S. Geological Survey, 1989).

Approximately 3,470 ft^3/s of water were withdrawn or diverted from Lake Michigan during 1981–85 and subsequently contributed to the streamflow in the upper Illinois River Basin (U.S. Army Corps of Engineers, 1990). Of this total, about 1,660 ft^3/s were pumped from Lake Michigan for water-supply purposes and about 1,810 ft^3/s were diverted from the lake via channels. Approximately 33 percent of the streamflow at Illinois River at Marseilles consists of water diverted or withdrawn from Lake Michigan.

Nutrient concentrations in Lake Michigan generally are smaller than nutrient concentrations at most of the fixed stations. Table 8 shows concentrations of selected nutrient species in water samples collected in southwestern Lake Michigan near the three principal diversion locations. The concentrations in table 8 and the estimates of Lake Michigan diversions were used to derive estimated nutrient loads in water diverted from Lake Michigan. Approximately 1,100 tons per year of nitrogen and 180 tons per year of phosphorus are conveyed to the upper Illinois River Basin in water diverted from Lake Michigan.

Soil erosion is a conveyance mechanism for the transport of nutrients from the land surface to streams. Soil erosion can result wherever soil is exposed to wind, rain, or other forms of disturbance. Several different forms of erosion convey soil particles to streams in the upper Illinois River Basin, but the most important process in terms of the total quantity of soil transported is sheet and rill erosion. Sheet and rill erosion occurs in almost all agricultural areas (U.S. Department of Agriculture, 1980). Sediment—the erosion, transport, and deposition in streams and lakes—is a major contamination problem in Illinois and is often cited as the primary

Table 8. Concentrations of selected nutrient forms in water samples from nearshore locations in southwestern Lake Michigan[1]
[Data from Torrey, 1976]

Nutrient	Concentration, in milligrams per liter	
	Range	Average
Nitrogen, ammonia, total, as N	0.01 –0.23	0.15
Nitrogen, nitrite, total, as N	.005– .007	.006
Nitrogen, nitrate, total, as N	.08 – .24	.15
Nitrogen, organic, total, as N	.20 – .50	.30
Phosphorus, total, as P	.01 – .78	.10

[1]Data from locations in Lake Michigan near the Wilmette, Chicago, and Calumet diversions.

nonpoint-source-contamination concern (Illinois Environmental Protection Agency, 1992). An IEPA assessment found that sediment and turbidity were the primary nonpoint-source contaminants in 85 percent of the assessed streams (Illinois Environmental Protection Agency, 1986).

The Soil Conservation Service estimated that the total annual sheet and rill erosion in the Illinois portion of the upper Illinois River Basin was 20,498,000 tons, or 3,052 tons/mi^2 (U.S. Department of Agriculture, 1980). This estimate corresponds with an IEPA estimate of 4.9 tons per acre, or 3,136 tons/mi^2 annually (Illinois Environmental Protection Agency, 1979). Using these figures, approximately 34,000,000 tons per year of sediment are eroded annually in the upper Illinois River Basin.

Reliable estimates of the amounts of eroded sediment that is actually conveyed to streams have not been made (Illinois Environmental Protection Agency, 1979). Sediment delivery ratios (the ratio of sediment delivered to a stream in relation to the total amount of erosion in the watershed above the particular point in the stream) generally are unknown and variable. Delivery ratios for several lakes in central Illinois ranged from 0.24 to 0.34 (Illinois Environmental Protection Agency, 1979), but ratios in other areas of the State might vary substantially.

Only a rough approximation of the amounts of nitrogen and phosphorus delivered to upper Illinois River Basin streams can be made. Approximately 34 million tons per year of sediment are eroded in the upper Illinois River Basin. Using a sediment delivery ratio of 0.25, about 8.5 million tons per year of sediment are delivered to upper Illinois River Basin streams. Manning and others (1977) found that soils in the upper Illinois River Basin were about 25 percent nitrogen and about 15 percent phosphorus, by weight. Using these percentages, about 2.1 million tons per year of nitrogen and about 1.3 million tons per year of phosphorus are transported to upper Illinois River Basin streams with the eroded soil. These figures include nutrients that are washed off of agricultural fields in association with sediment particles.

Nutrients also can be conveyed to stream water from plant material. As plants decompose or are consumed by aquatic fauna and microbial organisms, nutrients are released to the stream water. Some plant materials that might be important in upper Illinois River Basin streams are leaf litter, aquatic flora, and crop residue. Estimates of the contributions of nutrients to streams in the upper Illinois River Basin from plant material are unknown and amounts likely vary widely from year to year. In addition, nitrogen fixation of atmospheric nitrogen by certain bacteria and blue-green algae also can contribute to the nitrogen in streams in the upper Illinois River Basin, although the quantity of nitrogen contributed by these processes is undetermined.

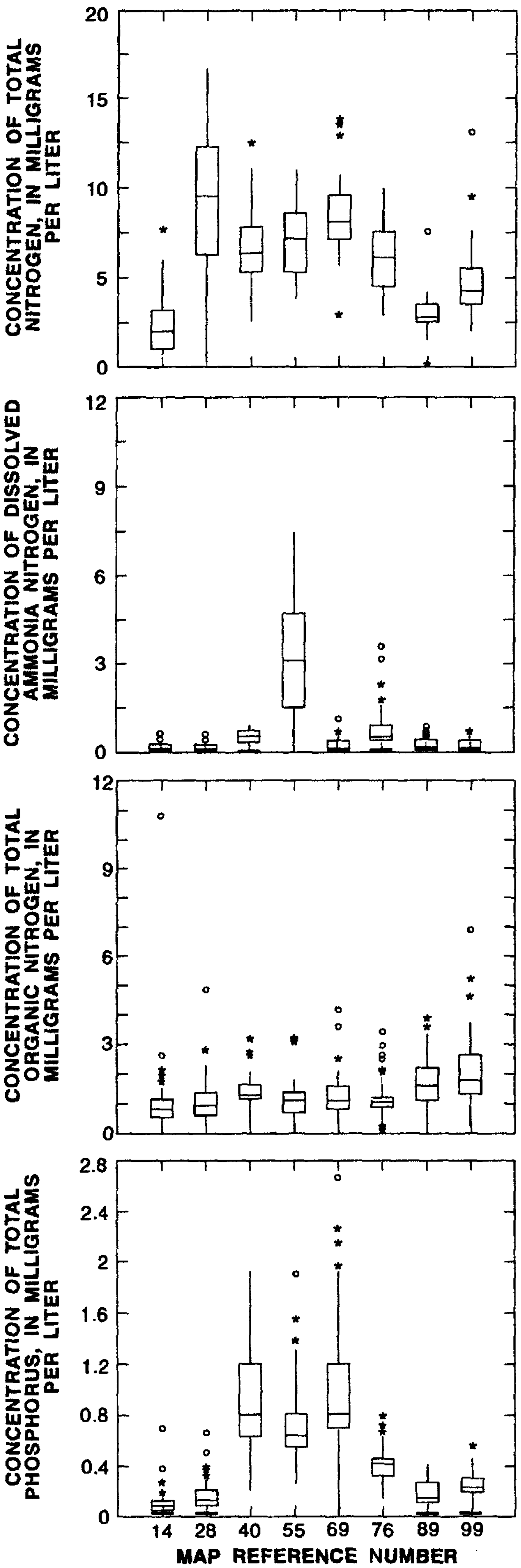
Data Analysis

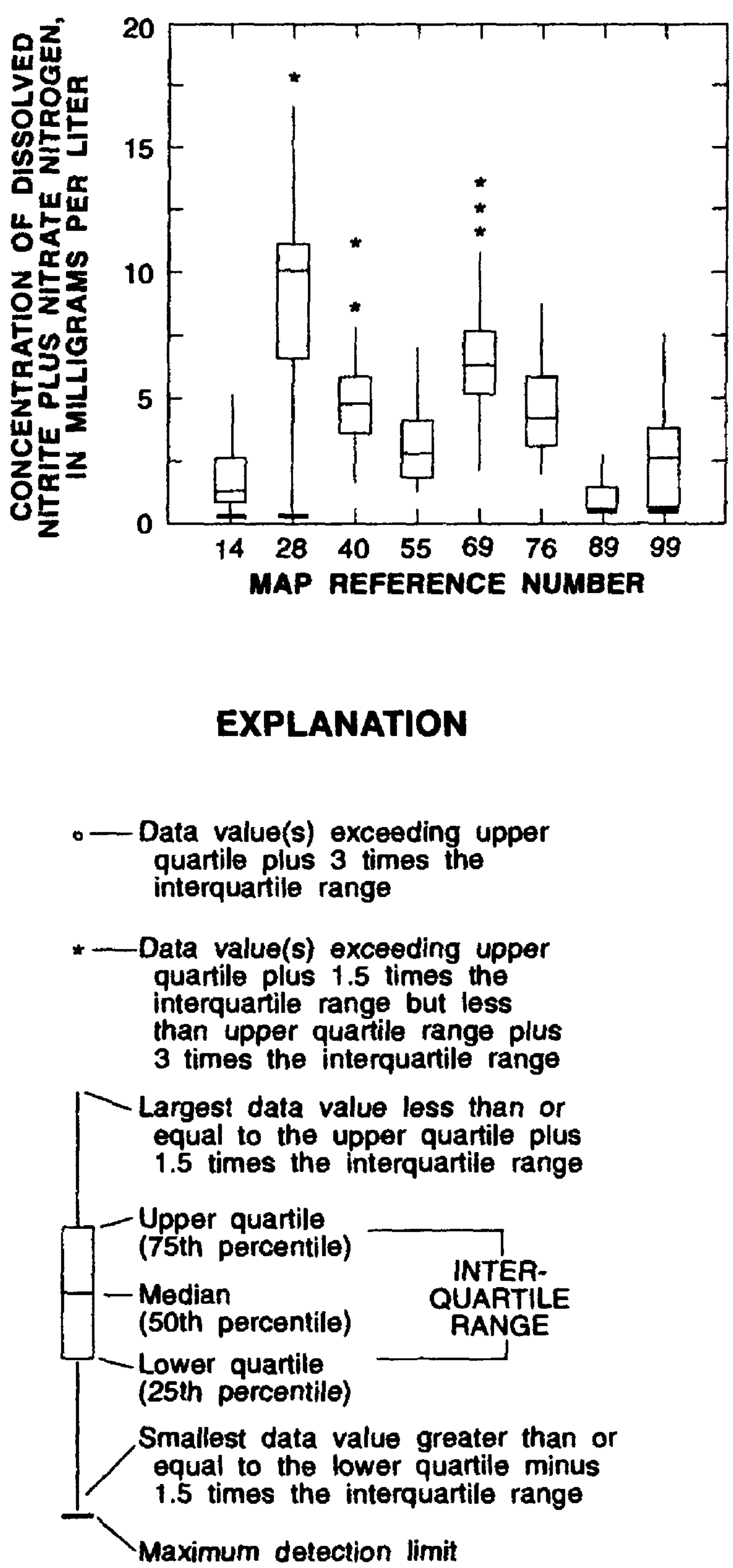
Data collected in the NAWQA program were analyzed to determine spatial distributions and temporal variability of nutrient concentrations and loads in streams in the upper Illinois River Basin. The effects of nutrient sources and other factors on the concentration of nutrients in streams in the upper Illinois River Basin was also investigated.

Boxplots of concentrations of the five indicator nutrient forms at the fixed stations are shown in figure 6. Boxplots graphically summarize and portray the characteristics of one or more data sets. Chambers and others (1983) provide a comprehensive description of boxplot construction and attributes.

The contributions of individual nutrient forms to the total nutrient concentration varied among the fixed stations. Approximate percentages of total nitrogen and total phosphorus concentrations attributed to specific nutrient forms at each of the fixed stations is given in table 9.

Nutrient loads were computed using all data collected by the USGS from 1987 through 1990, including data from the fixed-station sampling program and the synoptic surveys. Instantaneous loads at the fixed stations were calculated as the product of concentration and streamflow at the time the sample was collected. Regression equations relating instantaneous loads and streamflows were determined for each station. The regression equations were then used to estimate daily loads from mean daily streamflows. A comprehensive discussion of the procedures and equations used to calculate constituent loads at the fixed stations is presented by Smoot and others (1991). Some discrepancies between $NO_2 + NO_3$ loads and total nitrogen loads were found at Iroquois River near Chebanse and Fox River at Dayton. These inconqruities might be because total nitrogen concentrations were calculated from monthly samples, whereas concentrations of dissolved $NO_2 + NO_3$ were determined from monthly samples, plus samples





MAP REFERENCE NUMBER	STATION NAME
14	Kankakee River at Momence, Ill.
28	Iroquois River near Chebanse, Ill.
40	Des Plaines River at Riverside, Ill.
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.
69	Du Page River at Shorewood, Ill.
76	Illinois River at Marseilles, Ill.
89	Fox River at Algonquin, Ill.
99	Fox River at Dayton, Ill.

Figure 6. Distribution of nutrient concentrations at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990.

Table 9. Percentage of total nitrogen and total phosphorus concentrations in the upper Illinois River Basin attributed to specific nutrient forms at the eight fixed surface-water stations

Station name (map reference number[1])	Average percentage of total nitrogen concentration from indicated nitrogen form				Average percentage of total phoaphorus concentration from indicated phosphorus form	
	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Total organic nitrogen	Total un-ionized ammonia nitrogen	Dissolved phosphorus[2]	Dissolved ortho-phosphorus
Kankakee River at Momence, Ill. (14)	69	6	22	0.1	29	27
Iroquois River near Chebanse, Ill. (28)	88	2	8	.03	54	44
Des Plaines River at Riverside, Ill. (40)	73	6	21	.1	84	77
Chicago Sanitary and Ship Canal at Romeoville, Ill. (55)	56	26	16	.2	82	72
Du Page River at Shorewood, Ill. (69)	83	2	12	.08	88	84
Illinois River at Marseilles, Ill. (76)	72	7	18	.1	75	66
Fox River at Algonquin, Ill. (89)	27	4	60	.3	15	10
Fox River at Dayton, Ill. (99)	59	2	37	.2	29	26

[1]See table 3 and figure 4.

[2]Dissolved phosphorus concentration includes phosphorus present as orthophosphorus.

collected during the low-flow and storm synoptic surveys. Inclusion of dissolved $NO_2 + NO_3$ analyses from the synoptic-survey data provided more complete coverage of extreme low-flow conditions and conditions during storm runoff. Regrettably, low-flow and storm-runoff data were not available for all of the nutrient forms. Estimates of the total nutrient loads leaving the upper Illinois River Basin were made using the sum of the loads at Illinois River at Marseilles and Fox River at Dayton. Mean annual loads of nutrients at the fixed stations are given in table 10. Treatment of data with concentrations below the detection limit can affect computed loads. Load estimates in table 10 include estimates when data below the detection limit were set to the detection limit, to one-half of the detection limit, and to zero.

Yields are defined as the load divided by the upstream drainage area. Yields are used to compare contributions of constituents from different areas on a per-unit basis. In this report, yields are expressed as tons per square mile per year. The calculation of yields for CSSC at Romeoville was not appropriate because most of the streamflow in the CSSC is return flow or water diverted from Lake Michigan. The mean annual yields at the other fixed stations are given in table 10.

Spearman's rank correlation test (Conover, 1980) was used to determine the extent of mutual dependence among the different nutrient forms and among nutrient concentrations and other properties of the stream water. The correlation test identified nutrient concentrations and physical properties that increased or decreased similarly. A correlation was considered significant only if Spearman's rho, r_s, was greater than or equal to 0.50, if there were at least 10 data pairs, and if the level of significance of the test was less than or equal to 0.10. In all instances when r_s was greater than or equal to 0.5, the level of significance was much less than 0.1. The results of the correlation tests are given in table 11.

Data from the low-flow synoptic surveys provided a greater degree of spatial resolution than the fixed-station data but represent nutrient concentrations during warm weather and low-flow conditions only. Statistical summaries of physical properties and nutrient concentrations in samples collected during the 1988 low-flow synoptic survey are given in table 12. A comprehensive presentation of the data collected during the low-flow synoptic survey can be found in Coupe and others (1989). Boxplots of nutrient concentrations for synoptic sites representing several land-use categories are shown in figure 7. Enriched sites are locations downstream from known or suspected sources or inputs of nutrients. The spatial distributions for concentrations of the five indicator nutrient forms during the low-flow synoptic survey are shown in figures 8–12.

Table 10. Mean annual nutrient loads and yields at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990

[$(ton/mi^2)/yr$, tons per square mile per year; n.a., not applicable; --, no data]

Map reference number[2]	Station name	Number of observations	Mean annual load (tons): Censored data set to highest detection limit	Mean annual load (tons): Censored data set to one-half detection limit	Mean annual load (tons): Censored data set to zero	Mean annual yield[1] [$(ton/mi^2)/yr$]	Standard error in percent	Discharge ratio[3]
	Total nitrogen							
14	Kankakee River at Momence, Ill.	43	7,060	7,067	7,067	3.29	37.08	1.28
28	Iroquois River near Chebanse, Ill.	33	21,720	22,010	22,010	8.52	52.00	1.53
40	Des Plaines River at Riverside, Ill.	41	3,528	3,528	3,528	5.83	21.55	1.00
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	40	24,420	24,420	24,420	n.a.	18.58	1.01
69	Du Page River at Shorewood, Ill.	41	2,570	2,570	2,570	8.04	18.19	1.23
76	Illinois River at Marseilles, Ill.	46	63,420	63,420	63,420	[4]7.74	17.72	3.43
89	Fox River at Algonquin, Ill.	33	2,581	2,579	2,579	2.04	30.59	1.40
99	Fox River at Dayton, Ill.	33	9,930	9,940	9,940	4.10	30.64	1.08
	Dissolved nitrite plus nitrate nitrogen							
14	Kankakee River at Momence, Ill.	44	5,440	5,680	8,616	2.37	37.84	1.28
28	Iroquois River near Chebanse, Ill.	48	23,150	25,570	84,690	13.5	133.0	1.53
40	Des Plaines River at Riverside, Ill.	45	2,350	2,350	2,350	3.73	21.64	1.00
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	46	10,840	10,840	10,840	n.a.	34.32	1.01
69	Du Page River at Shorewood, Ill.	47	1,970	1,970	1,970	6.09	20.02	1.23
76	Illinois River at Marseilles, Ill.	53	48,040	48,040	48,040	[4]5.80	21.61	3.43
89	Fox River at Algonquin, Ill.	46	1,215	1,327	8,688	.86	51.61	1.40
99	Fox River at Dayton, Ill.	45	11,330	13,700	135,200	4.24	125.20	1.08
	Total organic nitrogen							
14	Kankakee River at Momence, Ill.	20	1,940	1,950	1,950	.921	43.63	1.28
28	Iroquois River near Chebanse, Ill.	20	--	--	--	1.25	64.36	1.53
40	Des Plaines River at Riverside, Ill.	39	924	925	925	1.45	31.57	1.00
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	40	4,570	4,570	4,570	n.a.	52.56	1.01
69	Du Page River at Shorewood, Ill.	29	522	524	524	1.57	76.65	1.23
76	Illinois River at Marseilles, Ill.	48	11,320	11,330	11,330	[4]1.33	31.47	3.43
89	Fox River at Algonquin, Ill.	34	1,345	1,353	1,353	.929	28.68	1.46
99	Fox River at Dayton, Ill.	34	3,120	3,380	3,380	1.30	28.21	1.08

Table 10. Mean annual nutrient loads and yields at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990—Continued

Map reference number[2]	Station name	Number of observa-tions	Mean annual load (tons): Censored data set to highest detection limit	Mean annual load (tons): Censored data set to one-half detection limit	Mean annual load (tons): Censored data set to zero	Mean annual yield[1] [(ton/mi²)/yr]	Standard error in percent	Discharge ratio[3]
			Total ammonia nitrogen					
14	Kankakee River at Momence, Ill.	45	291	231	231	.116	66.03	1.28
28	Iroquois River near Chebanse, Ill.	42	239	200	200	.113	45.66	1.53
40	Des Plaines River at Riverside, Ill.	41	290	290	282	.451	69.61	1.00
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	42	8,800	8,800	8,800	n.a.	56.12	1.01
69	Du Page River at Shorewood, Ill.	46	92.8	97.6	97.6	.306	74.25	1.23
76	Illinois River at Marseilles, Ill.	50	6,040	6,310	6,310	[4].766	70.75	3.43
89	Fox River at Algonquin, Ill.	43	166	166	166	.118	82.96	1.40
99	Fox River at Dayton, Ill.	43	264	264	264	.100	117.7	1.08
			Dissolved ammonia nitrogen					
14	Kankakee River at Momence, Ill.	44	264	228	228	0	89.45	1.28
28	Iroquois River near Chebanse, Ill.	42	228	207	207	0	105.0	1.53
40	Des Plaines River at Riverside, Ill.	41	284	283	383	.012	128.8	1.00
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	40	8,790	8,790	8,790	n.a.	135.0	1.01
69	Du Page River at Shorewood, Ill.	44	99	102	102	.011	149.0	1.23
76	Illinois River at Marseilles, Ill.	47	6,420	6,520	6,520	[4].011	92.25	3.43
89	Fox River at Algonquin, Ill.	40	166	159	159	.010	120.2	1.40
99	Fox River at Dayton, Ill.	43	264	241	241	.008	152.9	1.08
			Total phosphorus					
14	Kankakee River at Momence, Ill.	50	204	204	204	.089	45.82	1.28
28	Iroquois River near Chebanse, Ill.	47	338	338	338	.178	51.71	1.53
40	Des Plaines River at Riverside, Ill.	45	441	441	441	.700	32.81	1.00
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	46	2,680	2,680	2,680	n.a.	35.73	1.01
69	Du Page River at Shorewood, Ill.	50	282	282	282	.870	33.92	1.23
76	Illinois River at Marseilles, Ill.	53	3,390	3,390	3,390	[4].412	24.59	3.43
89	Fox River at Algonquin, Ill.	46	126	126	126	.0896	37.38	1.40
99	Fox River at Dayton, Ill.	48	443	443	443	.168	38.66	1.08

Table 10. Mean annual nutrient loads and yields at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990—Continued

Map reference number[2]	Station name	Number of observations	Mean annual load (tons): Censored data set to highest detection limit	Mean annual load (tons): Censored data set to one-half detection limit	Mean annual load (tons): Censored data set to zero	Mean annual yield[1] [(ton/mi^2)/yr]	Standard error in percent	Discharge ratio[3]
	Dissolved phosphorus							
14	Kankakee River at Momence, Ill.	49	64.2	68.9	68.9	.028	46.36	1.28
28	Iroquois River near Chebanse, Ill.	46	155	159	159	.078	53.36	1.53
40	Des Plaines River at Riverside, Ill.	45	310	310	310	.491	31.04	1.00
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	46	1,800	1,800	1,800	n.a.	31.74	1.01
69	Du Page River at Shorewood, Ill.	50	202	202	202	.625	21.71	1.23
76	Illinois River at Marseilles, Ill.	53	2,200	2,200	2,200	[4].267	24.95	3.43
89	Fox River at Algonquin, Ill.	46	28.3	26.5	26.5	.020	108.5	1.40
99	Fox River at Dayton, Ill.	48	157	157	157	.060	97.59	1.08
	Dissolved orthophosphorus							
14	Kankakee River at Momence, Ill.	42	57.0	68.2	68.2	.025	51.22	1.28
28	Iroquois River near Chebanse, Ill.	44	137	142	142	.066	53.15	1.53
40	Des Plaines River at Riverside, Ill.	42	279	279	279	.443	29.78	1.66
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	40	1,650	1,650	1,650	n.a.	38.84	1.01
69	Du Page River at Shorewood, Ill.	42	191	191	191	.588	23.07	1.23
76	Illinois River at Marseilles, Ill.	50	2,000	2,000	2,000	[4].242	25.07	3.43
89	Fox River at Algonquin, Ill.	41	16.7	13.7	13.7	.012	72.30	1.40
99	Fox River at Dayton, Ill.	41	128	130	130	.049	105.3	1.08

[1]Yield computed from load calculated with censored data set to the highest detection limit.

[2]See table 3 and figure 4.

[3]Ratio of largest instantaneous discharge used in estimating transport to largest daily discharge observed during data collection.

[4]Includes water diverted from Lake Michigan and ground-water return flows.

Table 11. Results of the Spearman rank correlation test for physical properties and nutrient forms at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990

[r_s, Spearman's rho; n, number of observations; shading, correlation is significant according to criteria specified in the text; --, insufficient number of observations to determine correlation]

Constituent		Total nitrogen	Dissolved nitrite plus nitrate nitrogen	Totel ammonia nitrogen	Total organic nitrogen	Total phosphorus
Kankakee River at Momence, Ill. (14)						
Total nitrogen	r_s	1.0000				
	n	121				
Dissolved nitrite + nitrate	r_s	0.9477	1.0000			
	n	40	85			
Dissolved ammonia	r_s	.2432	.4096	1.0000		
	n	40	85	86		
Total organic nitrogen	r_s	.6168	.3385	.1008	1.0000	
	n	66	21	21	67	
Total phosphorus	r_s	.2759	.0889	.2291	.5613	1.0000
	n	121	81	82	67	169
Discharge	r_s	.7292	.9091	.3604	.2469	.1141
	n	114	85	86	61	162
Temperature, water	r_s	−.2877	−.6261	−.0787	.3271	.4430
	n	121	43	43	66	129
Specific conductance	r_s	−.2580	−.3104	−.0087	−.2366	−.3496
	n	121	81	81	67	164
Suspended sediment	r_s	--	.2100	.3236	--	.2305
	n	0	37	38	1	35
Chlorophyll-*a*, phytoplankton	r_s	--	−.4030	−.0968	--	.4424
	n	1	33	34	1	32
Iroquois River near Chebanse, Ill. (28)						
Total nitrogen	r_s	1.0000				
	n	55				
Dissolved nitrite + nitrate	r_s	.9600	1.0000			
	n	40	287			
Dissolved ammonia	r_s	.0916	.2534	1.0000		
	n	40	97	97		
Total organic nitrogen	r_s	.1531	−.2060	.0502	1.0000	
	n	37	25	25	40	
Total phosphorus	r_s	.1463	.0056	.3141	.7030	1.0000
	n	55	93	93	40	158
Discharge	r_s	.6932	.4557	.2844	.5035	.3370
	n	55	286.	97	40	156
Temperature, water	r_s	−.3063	−.4921	−.2373	.2571	.2859
	n	55	57	49	38	113
Specific conductance	r_s	−.1415	.1231	−.0820	−.8173	−.6519
	n	55	101	91	40	152
Suspended sediment	r_s	--	.1204	.2170	--	.5535
	n	0	47	47	2	44
Chlorophyll-*a*, phytoplankton	r_s	--	−.4729	−.5541	--	−.0605
	n	1	34	34	2	33

Table 11. Results of the Spearman rank correlation test for physical properties and nutrient forms at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990—*Continued*

Constituent		Total nitrogen	Dissolved nitrite plus nitrete nitrogen	Total ammonia nitrogen	Total organic nitrogen	Total phosphorus
Des Plaines River at Riverside, Ill. (40)						
Total nitrogen	r_s	1.0000				
	n	43				
Dissolved nitrite + nitrate	r_s	.9353	1.0000			
	n	43	87			
Dissolved ammonia	r_s	.3051	.2222	1.0000		
	n	43	87	87		
Total organic nitrogen	r_s	.3558	.1280	.0333	1.0000	
	n	41	42	42	42	
Total phosphorus	r_s	.8038	.7587	.0805	.4874	1.0000
	n	43	82	82	42	82
Discharge	r_s	−.7649	−.7730	−.0331	−.3094	−.7385
	n	43	87	87	42	82
Temperature, water	r_s	.0510	−.0578	−.2393	.6152	.3566
	n	43	43	43	41	43
Specific conductance	r_s	.5522	.5775	.4355	−.1305	.2037
	n	43	84	84	42	80
Suspended sediment	r_s	--	−.4751	−.0065	--	−.1675
	n	0	40	40	1	36
Chlorophyll-*a*, phytoplankton	r_s	.4000	−.0386	−.4933	.9000	.3544
	n	4	29	29	5	27
Chicago Sanitary and Ship Canal at Romeoville, Ill. (55)						
Total nitrogen	r_s	1.0000				
	n	43				
Dissolved nitrite + nitrate	r_s	.3332	1.0000			
	n	42	111			
Dissolved ammonia	r_s	.7249	−.5370	1.0000		
	n	42	104	104		
Total organic nitrogen	r_s	.4979	−.0264	.3657	1.0000	
	n	43	42	42	43	
Total phosphorus	r_s	.6236	.3535	.1058	.4167	1.0000
	n	43	106	99	43	107
Discharge	r_s	−.3558	−.3746	−.0734	.2024	−.2000
	n	42	108	101	42	104
Temperature, water	r_s	−.6630	−.4966	−.3381	−.2325	−.2905
	n	42	41	41	42	42
Specific conductance	r_s	.7416	.3749	.5289	.2338	.3229
	n	42	84	83	42	80
Suspended sediment	r_s	--	−.1716	.0226	--	.1130
	n	0	41	41	0	37
Chlorophyll-*a* phytoplankton	r_s	--	−.2007	−.1300	--	.0905
	n	0	31	31	0	29

Table 11. Results of the Spearman rank correlation test for physical properties and nutrient forms at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990—Continued

Constituent		Total nitrogen	Dissolved nitrite plus nitrate nitrogen	Total smmonia nitrogen	Total orgsnic nitrogen	Total phosphorus
Du Page River at Shorewood, Ill. (69)						
Total nitrogen	r_s	1.0000				
	n	53				
Dissolved nitrite + nitrate	r_s	.9013	1.0000			
	n	46	120			
Dissolved ammonia	r_s	.0887	.0378	1.0000		
	n	46	115	115		
Total organic nitrogen	r_s	−.3318	−.6326	−.2355	1.0000	
	n	38	33	33	40	
Total phosphorus	r_s	.3511	.4092	−.1917	.0910	1.0000
	n	53	109	109	40	161
Discharge	r_s	−.3607	−.5712	.4079	.3469	−.6921
	n	52	118	115	39	160
Temperature, water	r_s	−.4258	−.3560	−.5016	.4202	.0992
	n	53	59	57	38	104
Specific conductance	r_s	.4788	.5485	−.3623	−.4331	.5088
	n	53	94	90	40	136
Suspended sediment	r_s	--	−.4311	.1894	--	−.2036
	n	0	43	43	2	40
Chlorophyll-*a*, phytoplankton	r_s	−.5000	−.5909	−.2981	−.5000	.0342
	n	3	34	34	3	33
Illinois River at Marseilles, Ill. (76)						
Total nitrogen	r_s	1.0000				
	n	143				
Dissolved nitrite + nitrate	r_s	.8214	1.0000			
	n	69	154			
Dissolved ammonia	r_s	.3802	.1273	1.0000		
	n	67	147	148		
Total organic nitrogen	r_s	.3355	.1728	−.2190	1.0000	
	n	137	84	83	157	
Total phosphorus	r_s	−.1327	−.3685	.1436	.0285	1.0000
	n	143	145	143	157	219
Discharge	r_s	.3900	.4469	.0002	.1897	−.4176
	n	136	148	146	149	211
Temperature, water	r_s	−.5565	−.5162	−.5397	.0144	.0656
	n	142	101	99	148	174
Specific conductance	r_s	.4153	.3567	.4596	−.0470	.0843
	n	142	146	142	152	212
Suspended sediment	r_s	.0553	−.0019	−.3305	.2765	.0459
	n	37	82	80	51	99
Chlorophyll-*a*, phytoplankton	r_s	−.6000	−.6410	−.4799	−.6669	.2107
	n	5	32	31	5	32

Table 11. Results of the Spearman rank correlation test for physical properties and nutrient forms at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990—Continued

Constituent		Total nitrogen	Dissolved nitrite *plus* nitrate nitrogen	Total ammonia nitrogen	Total organic nitrogen	Total phosphorus
Fox River at Algonquin, Ill. (89)						
Total nitrogen	r_s	1.0000				
	n	119				
Dissolved nitrite + nitrate	r_s	.5621	1.0000			
	n	35	113			
Dissolved ammonia	r_s	.3024	.3256	1.0000		
	n	35	113	113		
Total organic nitrogen	r_s	–.1171	–.6197	–.1913	1.0000	
	n	113	35	35	122	
Total phosphorus	r_s	–.2084	–.7051	–.0576	.6649	1.0000
	n	119	108	108	122	202
Discharge	r_s	.0684	.4788	–.0014	–.3114	–.3397
	n	118	113	113	121	200
Temperature, water	r_s	–.4501	–.8982	–.4226	.7154	.6755
	n	119	59	59	122	150
Specific conductance	r_s	.2917	.3556	.3173	–.4026	–.2886
	n	117	83	83	120	171
Suspended sediment	r_s	--	–.4480	–.4867	--	.3271
	n	0	41	41	0	36
Chlorophyll-*a*, phytoplankton	r_s	--	–.7529	–.4245	--	.3599
	n	1	30	32	1	28
Fox River at Dayton, Ill. (99)						
Total nitrogen	r_s	1.0000				
	n	117				
Dissolved nitrite + nitrate	r_s	.9352	1.0000			
	n	32	86			
Dissolved ammonia	r_s	.3385	.3882	1.0000		
	n	32	85	85		
Total organic nitrogen	r_s	–.0591	–.7546	–.4848	1.0000	
	n	110	34	34	120	
Total phosphorus	r_s	–.1836	–.5301	–.0079	.3080	1.0000
	n	117	80	80	120	179
Discharge	r_s	.5905	.6942	.2369	–.1521	–.1659
	n	117	85	85	120	178
Temperature, water	r_s	–.3687	–.7569	–.5245	.5990	.3055
	n	116	55	55	118	150
Specific conductance	r_s	–.0574	.2554	.3103	–.3939	–.1046
	n	115	84	83	118	174
Suspended sediment	r_s	--	–.2777	–.2606	--	–.1067
	n	0	39	39	1	34
Chlorophyll-*a*, phytoplankton	r_s	--	–.6593	-4735	1	.1147
	n	2	34	34	3	31

Table 12. Statistical summary of physical properties and nutrient concentrations from surface-water samples collected during the low-flow synoptic survey in the upper Illinois River Basin, July 26 through August 13, 1988

[Data less than the detection level were set to the detection level. µS/cm, microsiemen per centimeter at 25° Celsius; ft^3/s, cubic foot per second; mm, millimeters; ≤, less than or equal to]

Constituent name	Number of observations	Minimum	Percentile[1] (milligrams per liter unless otherwise noted) 10	25	50	75	90	Maximum
Temperature, water (°C)	59	18.0	21.82	23.79	25.43	27.26	28.46	30.0
Specific conductance (µS/cm)	59	485	559	648	714	950	1,200	1,816
pH (standard units)	58	6.6	7.29	7.50	7.71	8.04	8.56	9.5
Streamflow (ft^3/s)	64	0	.66	8.85	56.50	315.50	3,920	4,370
Dissolved oxygen	58	1.6	3.2	5.2	6.7	9.1	11.1	16
Total nitrogen, as N[2]	60	.30	.65	1.10	3.24	5.70	10.26	16.2
Dissolved nitrite, as N	61	.01	.01	.01	.03	.09	.19	.40
Dissolved orthophosphorus, as P	61	.01	.01	.03	.09	.35	1.18	2.60
Dissolved nitrite plus nitrate, as N	60	.10	.10	.10	1.06	3.80	8.11	15.0
Dissolved ammonia, as N	61	.01	.02	.04	.10	.23	.73	4.20
Total phosphorus, as P	64	.01	.07	.14	.29	.80	1.50	4.00
Dissolved phosphorus, as P	64	.01	.02	.05	.14	.60	1.35	3.80
Total kjeldahl nitrogen, as N	62	.20	.40	.70	1.40	2.00	2.84	5.40
Dissolved kjeldahl nitrogen, as N	61	.20	.22	.40	.90	1.35	1.94	5.00
Total organic carbon	60	1.0	4.81	6.70	8.20	11.00	16.90	24
Chlorophyll-*a*, phytoplankton	59	.60	2.20	4.90	23	52	130	390
Suspended sediment	58	7	15	22	45	69	123	499
Percent suspended sediment ≤ 0.063mm	58	15	55	76	86	95	98	100

[1]Percentage of samples with values less than or equal to the value shown.
[2]Total nitrogen calculated as the sum of dissolved nitrite plus nitrate and total kjeldahl nitrogen.

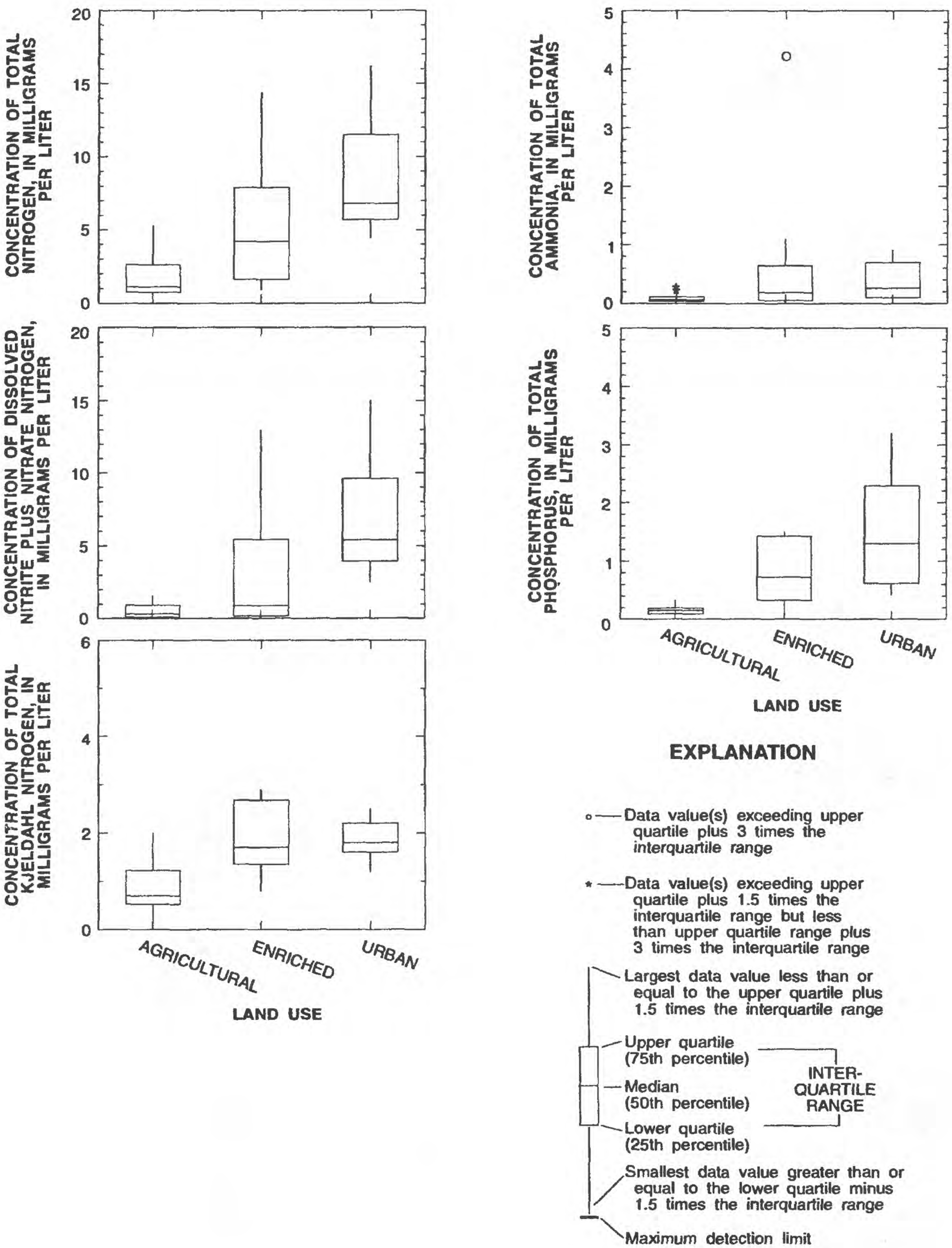


Figure 7. Distribution of nutrient concentrations, by land-use classification, in surface-water samples collected at the low-flow synoptic-survey sites in the upper Illinois River Basin, July 26 through August 13, 1988.

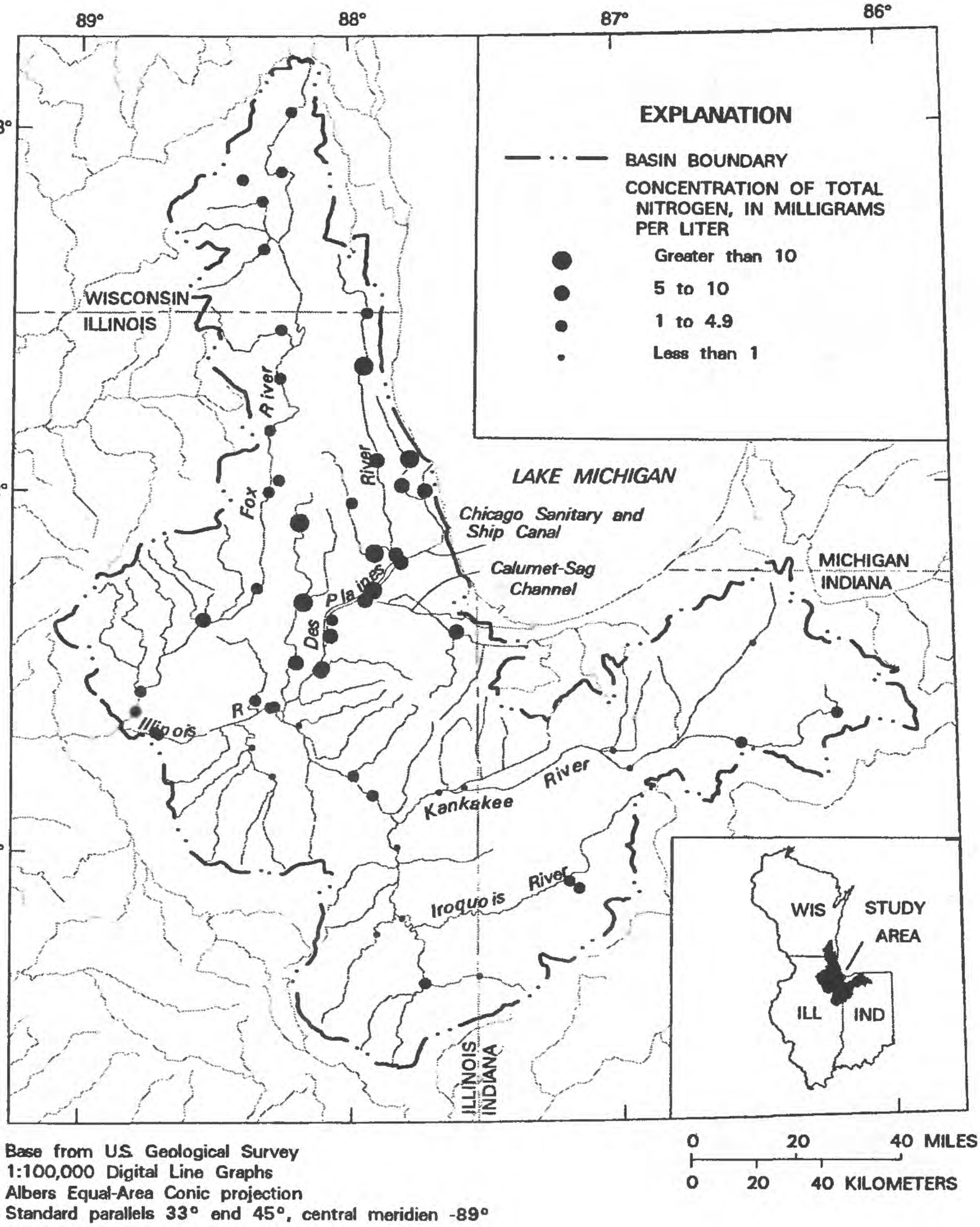


Figure 8. Spatial distribution of total nitrogen concentrations at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

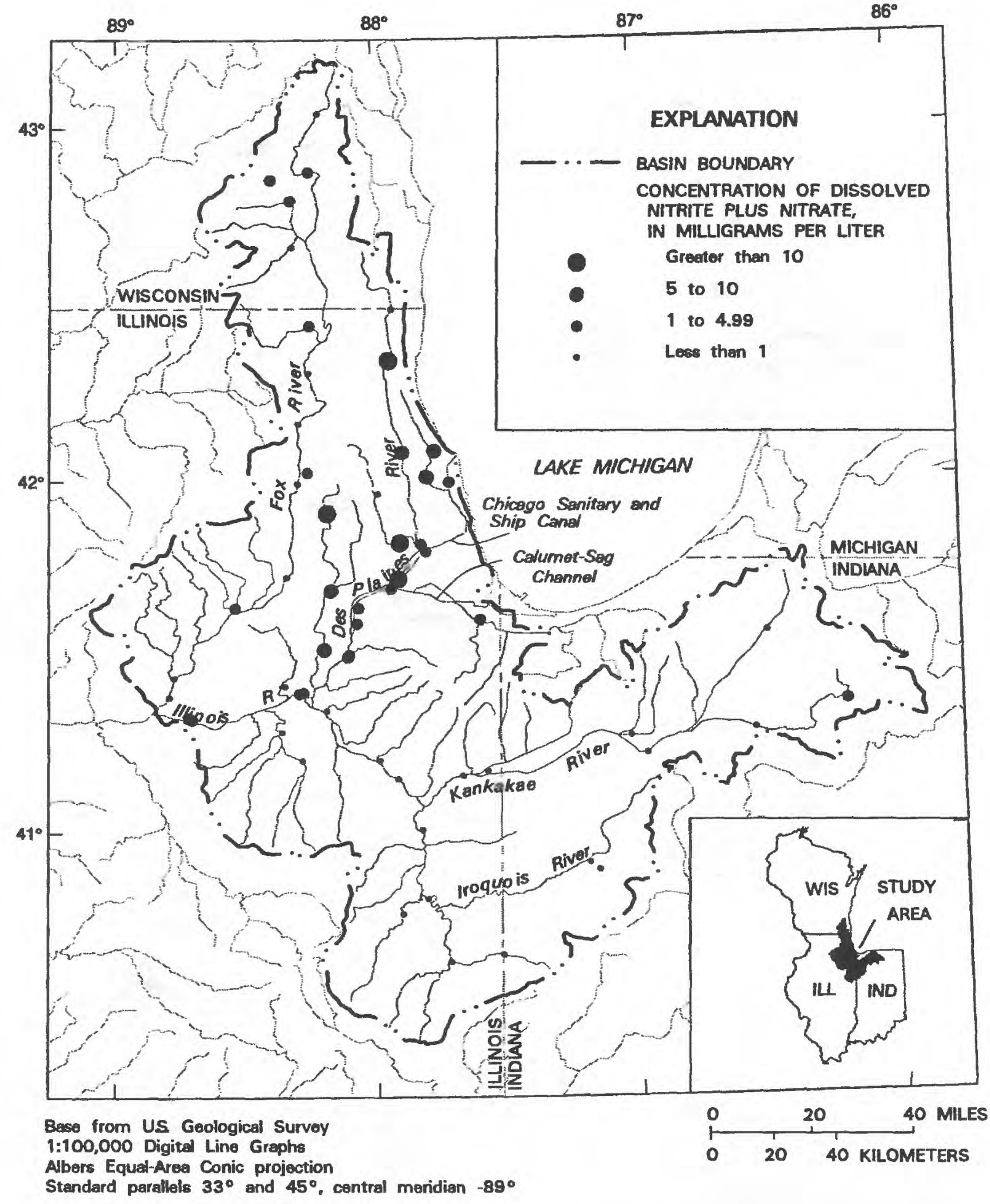


Figure 9. Spatial distribution of dissolved nitrite plus nitrate concentrations at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

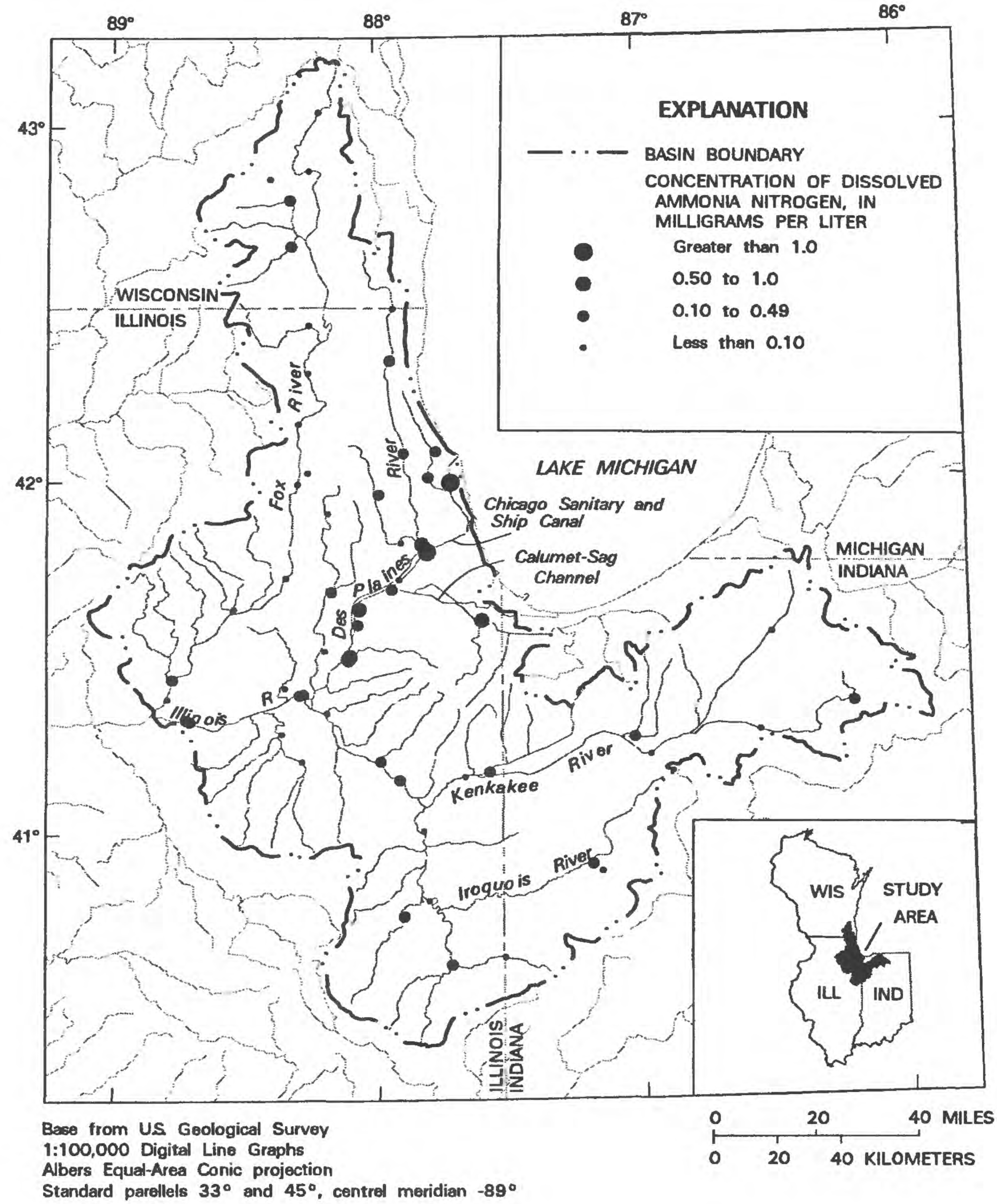


Figure 10. Spatial distribution of dissolved ammonia nitrogen concentrations at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

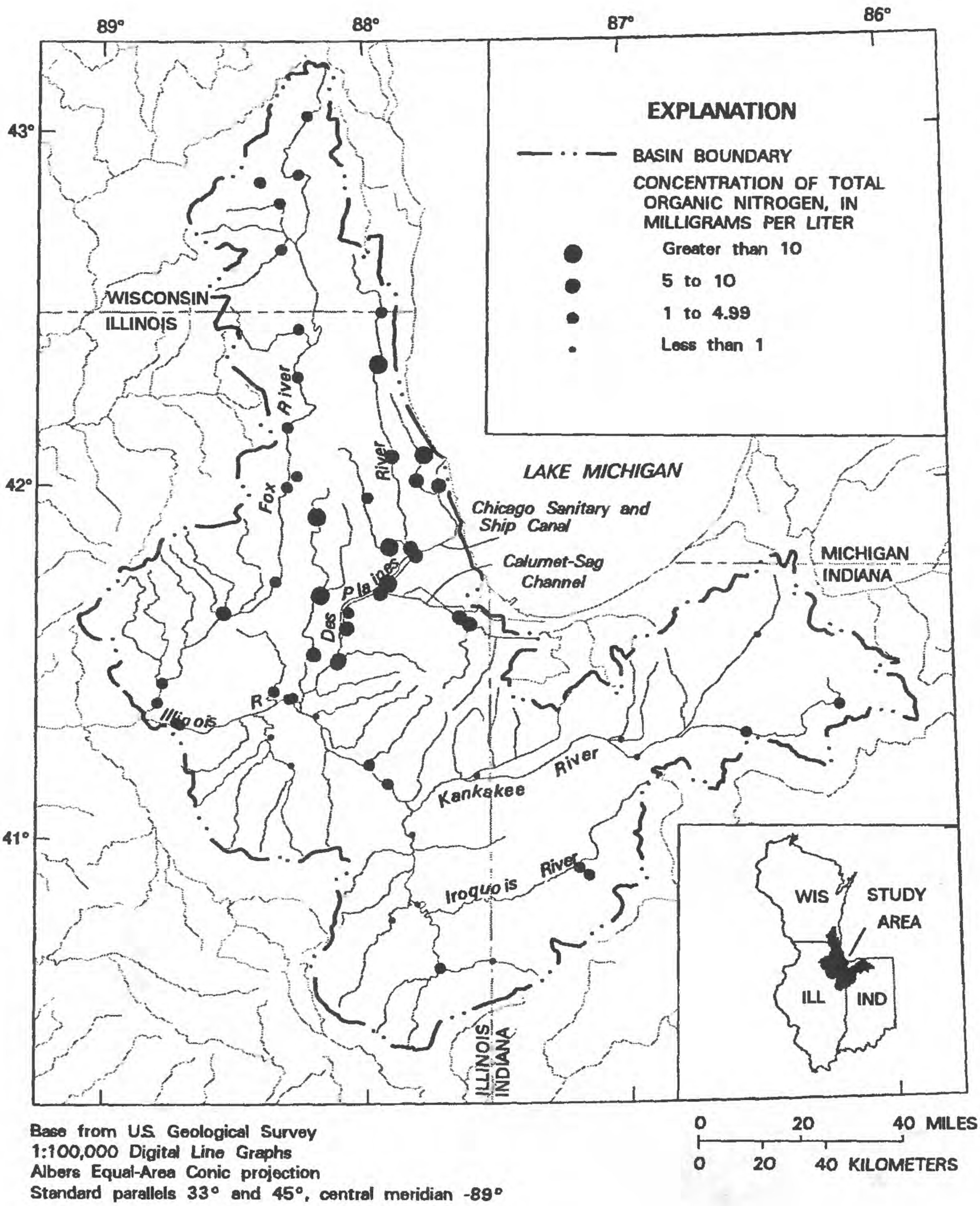


Figure 11. Spatial distribution of total organic nitrogen concentrations at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

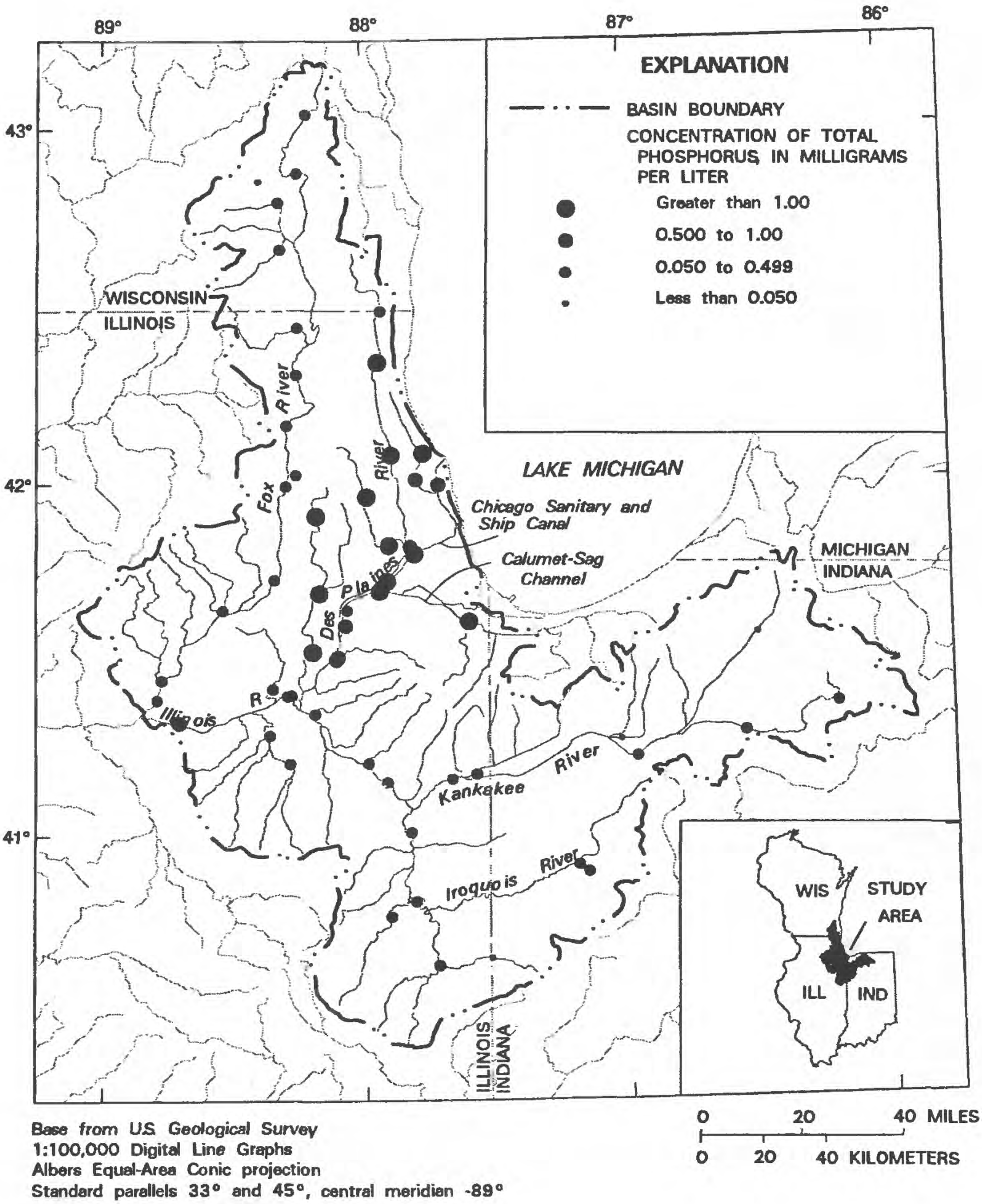


Figure 12. Spatial distribution of total phosphorus concentrations at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

Loads also were computed for samples collected during the low-flow synoptic survey. These loads were computed from single measurements of concentration and streamflow. The calculation used to compute the instantaneous constituent load was

$$L = C*Q*K,$$

where L = constituent load, in tons per day;
C = measured constituent concentration, in milligrams per liter;
Q = instantaneous discharge, in cubic feet per second; and
K = a conversion factor of 0.002714 to convert units to tons per day.

The estimated loads at the 1988 low-flow synoptic sites for the five indicator nutrient forms are given in table 13. The spatial distribution of loads for several selected nutrient forms are shown in figures 13–17.

Temporal variability in water chemistry can be described in different ways, including abrupt changes, long-term changes, diurnal variations, and seasonal changes. Because the NAWQA program provided only 3 years of data, trend analyses on these data alone would have been of little benefit. Consequently, data collected monthly at the fixed stations was combined with historical (1978–86) data collected through the IEPA monitoring program and long-term trend analyses were done using the combined 1978–90 data set. Water-quality data were not collected at Des Plaines River at Riverside or CSSC at Romeoville prior to the NAWQA program, and the trends for these two stations represent trends from April 1987 through September 1990.

Trends in nutrient concentrations and loads were determined using the seasonal Kendall trend test (Hirsch and others, 1982). Trends in measured constituent concentrations were determined first. Regressions between concentrations and streamflow were then determined for each constituent. The regression was considered statistically significant if the p-value was less than or equal to 0.10 and the coefficient of determination, R^2, was greater than or equal to 0.2. If the regressions were significant, the regression equations were used to factor out the effects of streamflow on concentration and flow-adjusted concentrations (residuals) were calculated. Trend tests were then done on the residuals. The results of the trend analyses are given in table 14.

Changes in climatic season often promulgate changes in stream-water quality. The effects of climatic season on nutrient concentrations can be substantially different among land-use areas and nutrient sources. Boxplots were used to determine whether there were substantial differences in nutrient concentrations among the four climatic seasons. The four seasons used were defined as groups of three consecutive months. Winter included December, January, and February; spring included March, April, and May; summer was defined as June, July, and August; and fall included September, October, and November. Several notable instances of seasonal variation in nutrient concentrations at the fixed stations are shown in figure 18.

Summer thunderstorms in the upper Illinois River Basin can produce large amounts of precipitation in short periods, resulting in runoff with large constituent concentrations. Data from the 1990 storm synoptic survey were used to examine relations between streamflow and nitrite plus nitrate concentrations in an agricultural basin during storms. Correlations between $NO_2 + NO_3$ concentrations and streamflow were made for six stations where 10 or more samples were collected. The results of these correlation analyses are given in table 15.

Because streamflow affects in-stream nutrient concentrations and the transport of chemical constituents in a stream system, a brief discussion of the streamflow characteristics at the eight fixed stations during 1987–90 follows. An additional discussion of the hydrology of the upper Illinois River Basin is provided in Mades (1987).

Boxplots of streamflow at the eight fixed stations for 1987–90 are presented in figure 19. The symmetry of the boxes shows that the distribution of the streamflow data was not markedly different from a normal distribution at the fixed stations. Greater than 99 percent of the entire upper Illinois River Basin drainage area is represented by two stations—Fox River at Dayton and Illinois River at Marseilles. The cumulative streamflows from these two stations are an approximation of the total discharge from the upper Illinois River Basin. Using these two stations to represent the basin, the median streamflow for the upper Illinois River Basin for 1987–90 was about 8,230 ft^3/s, and the mean annual streamflow was approximately 11,300 ft^3/s. Approximately 50 percent of the total upper Illinois River Basin streamflow was from the Des Plaines River Basin; the Fox and Kankakee River Basins contributed approximately 15 and 35 percent, respectively.

Table 13. Estimated nutrient loads during low flow at the synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988

[Loads are expressed as tons per day. Load estimates of 0.00 denote negligible load because of low streamflow, small concentrations, or both]

Map reference number[1]	Total nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Total organic nitrogen	Total phosphorus
1	0.06	0.04	0.00	0.01	0.00
7	.26	.08	.06	.11	.15
13	.02	.01	.00	.00	.00
14	(2)	(2)	.04	.43	.06
18	.00	.00	.00	.00	.00
21	.00	.00	.00	.00	.00
22	.00	.00	.00	.00	.00
23	.13	.01	.00	.11	.02
26	.00	.00	.00	.00	.00
28	.05	.00	.00	.04	.00
29	1.2	.09	.44	.64	.31
30	.00	.00	.00	.00	.00
31	.39	.11	.07	.20	.20
32	.00	.00	.00	.00	.00
33	4.1	3.52	.04	.53	.56
34	1.18	1.28	.01	.28	.21
37	.21	.03	.01	.16	.37
38	2.22	1.94	.01	.27	.49
40	2.90	2.09	.38	.42	.31
41	.37	.34	.00	.02	.06
42	6.4	3.06	.24	3.08	1.21
44	.64	.51	.00	.12	.08
45	.47	.38	.01	.08	.06
47	9.0	1.74	5.65	1.61	.67
48	63	2.65	2.03	8.74	2.03
51	.50	.30	.05	.14	.28
52	16.99	9.59	3.28	4.11	3.28
54	13.98	8.52	.67	4.78	3.27
55	48.24	7.41	.08	.74	4.60
58	59.55	2.84	7.94	8.77	6.47
61	60.60	1.79	6.58	2.22	5.43
62	.42	.38	.00	.04	.04
67	3.49	3.03	.03	.41	.42
69	1.89	1.40	.00	.48	.28
70	46.56	2.48	2.38	1.69	4.98
71	49.81	.56	.87	11.37	4.33
72	.00	.00	.00	.00	.00
73	.00	.00	.00	.00	.00
74	.01	.00	.00	.01	.00
75	47.06	.99	1.72	4.35	6.42
76	48.62	33.20	1.18	14.23	4.74
77	.00	.00	.00	.00	.00
78	.05	.02	.00	.02	.00
79	1.35	.40	.00	.94	.06
80	.15	.08	.00	.06	.00

Table 13. Estimated nutrient loads during low flow at the synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988—Continued

Map reference number[1]	Total nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Total organic nitrogen	Total phosphorus
82	0.07	0.02	0.00	0.04	0.00
86	.21	.10	.00	.11	.01
87	.90	.02	.00	.87	.05
89	1.79	.05	.00	1.73	.13
90	.00	.00	.00	.00	.00
91	1.92	.27	.00	1.64	.19
92	1.82	.07	.00	1.74	.28
95	.24	.20	.00	.03	.00
98	.02	.00	.00	.01	.00
99	.47	.01	.00	.45	.05
100	.03	.00	.00	.02	.00
101	.05	.01	.01	.02	.00
102	.25	.17	.01	.06	.02
103	.06	.04	.00	.01	.00

[1]See table 3 and figure 4.

[2]Nitrite plus nitrate concentration not determined, load calculation not possible.

During high-flow periods, the relative percentages of total streamflow from the major river basins in the upper Illinois River Basin were similar to the percentages during average flow conditions. At low flows, however, the Des Plaines River contributed a much larger percentage of the total upper Illinois River Basin streamflow. During the 1988 low-flow synoptic survey, the Des Plaines River Basin contributed about 97 percent of the total streamflow in the upper Illinois River Basin. The factors affecting this are (1) most of the point sources of return flow in the upper Illinois River Basin are in the Des Plaines River Basin, and (2) the water diverted from Lake Michigan helps to maintain streamflow in the CSSC (a tributary to the Des Plaines River) during dry periods.

Streamflow characteristics in the different river basins of the upper Illinois River Basin can be described by streamflow data from the eight fixed stations. Flow-duration curves for the fixed stations are shown in figure 20. The curves for the period of record show the historical streamflow characteristics at each station, and the curves for 1987–90 depict the streamflow characteristics during the NAWQA fixed-station sampling period. The differences between the curves show the effects of changes in the drainage areas, land use, sources of streamflow, or channel modification in recent decades.

The boxplots of streamflow at the fixed stations (fig. 19) show that the variability of streamflow increased as the quantity of streamflow increased. The Iroquois River had a large number of high streamflows. Although streamflow in the CSSC was larger, the variability of streamflow in the CSSC was similar to that for the stations in the Kankakee and Fox River Basins. The relatively small variability in the CSSC is likely a result of the comparatively consistent inputs from point sources and Lake Michigan diversions that comprise a large part of the total streamflow in the CSSC. Because streamflow directly affects nutrient nonpoint-source input and in-stream concentrations and loads, understanding the variability in streamflow at the fixed stations will aid in understanding the variability of nutrient concentrations and loads.

Significant variations in climatic conditions occurred during 1987–90 (National Oceanic and Atmospheric Administration, 1987–90) (fig. 21). Mean annual precipitation in northeastern Illinois in 1987 was about 5 in. more than the long-term

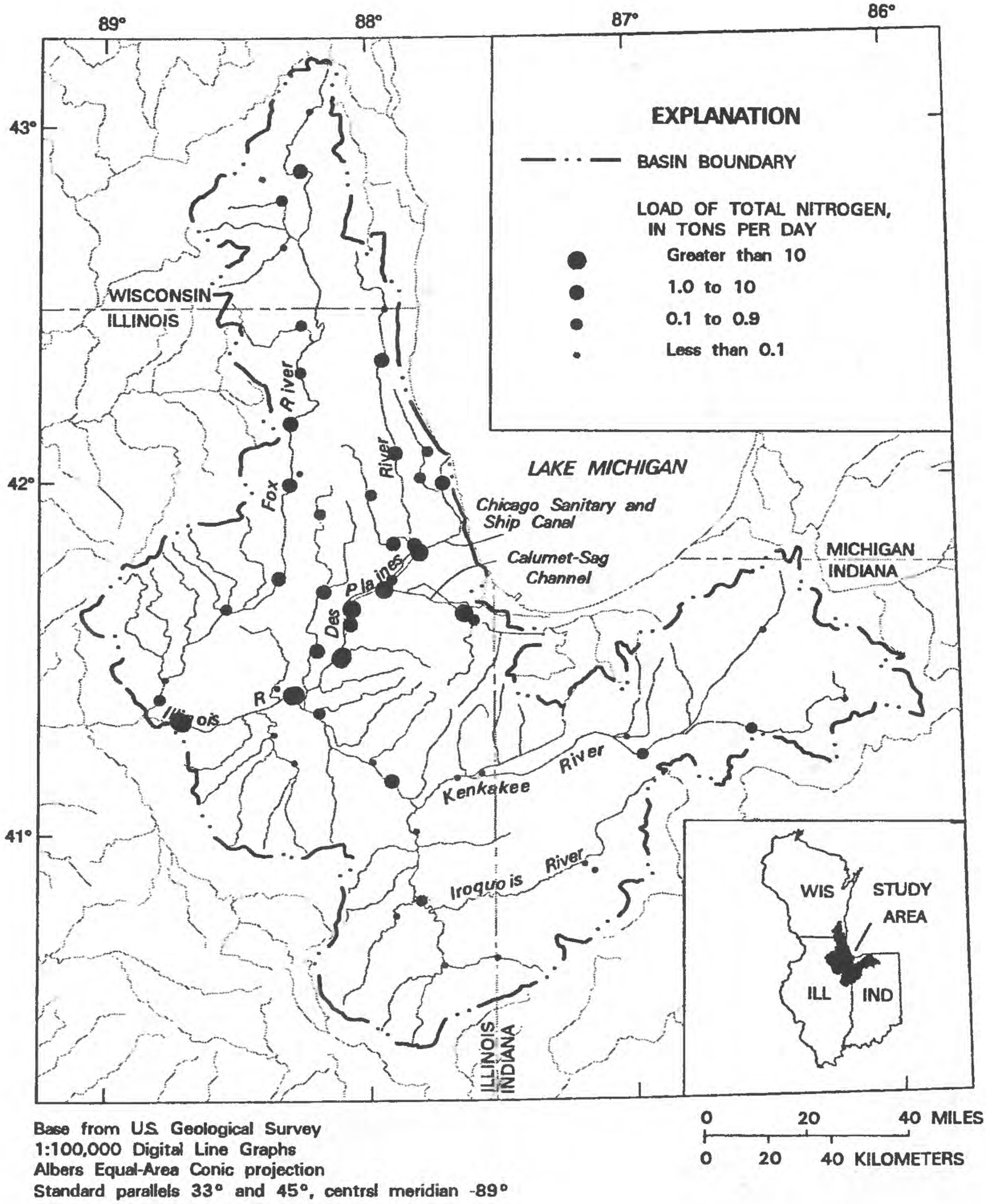


Figure 13. Spatial distribution of total nitrogen loads at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

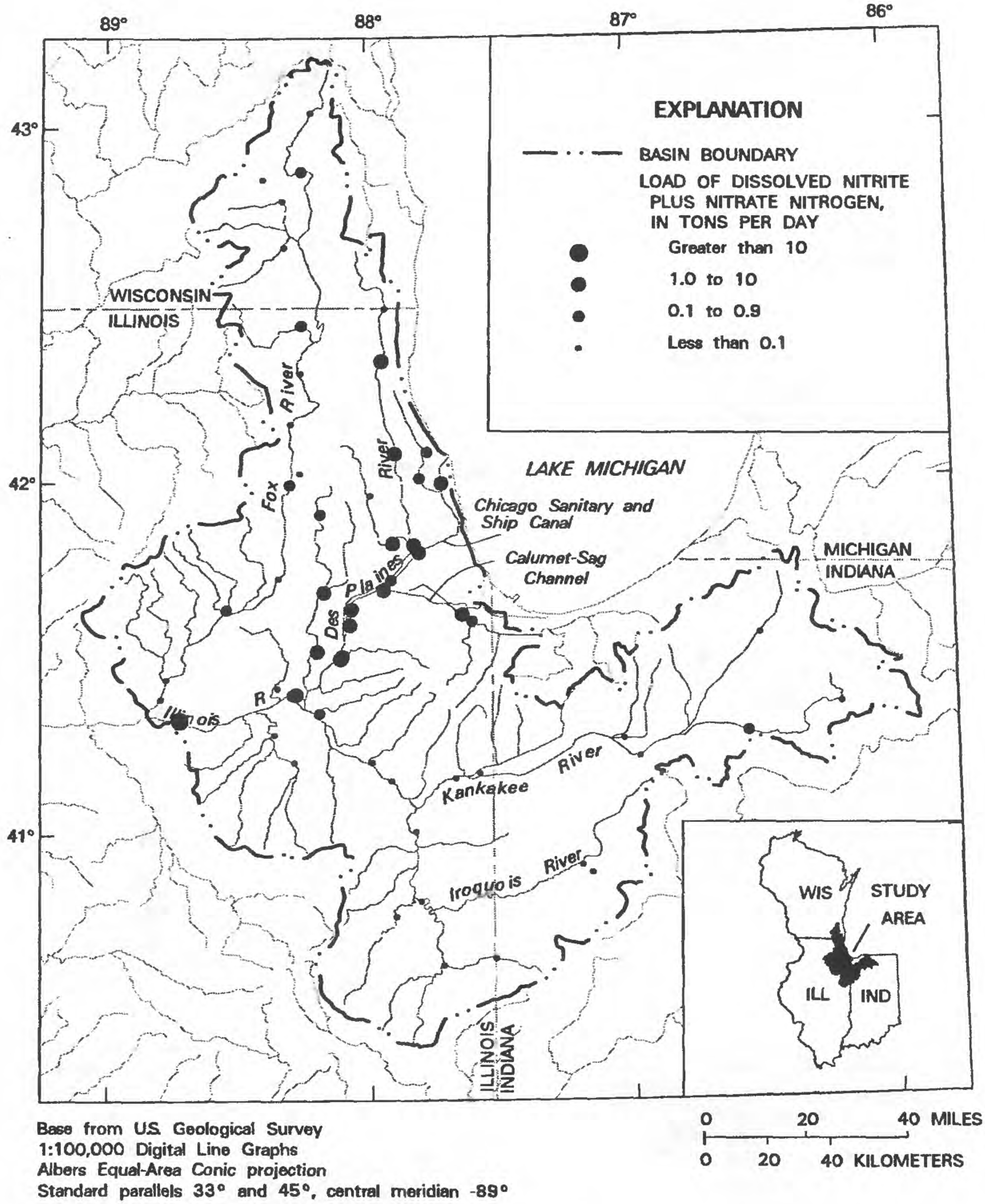


Figure 14. Spatial distribution of dissolved nitrite plus nitrate nitrogen loads at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

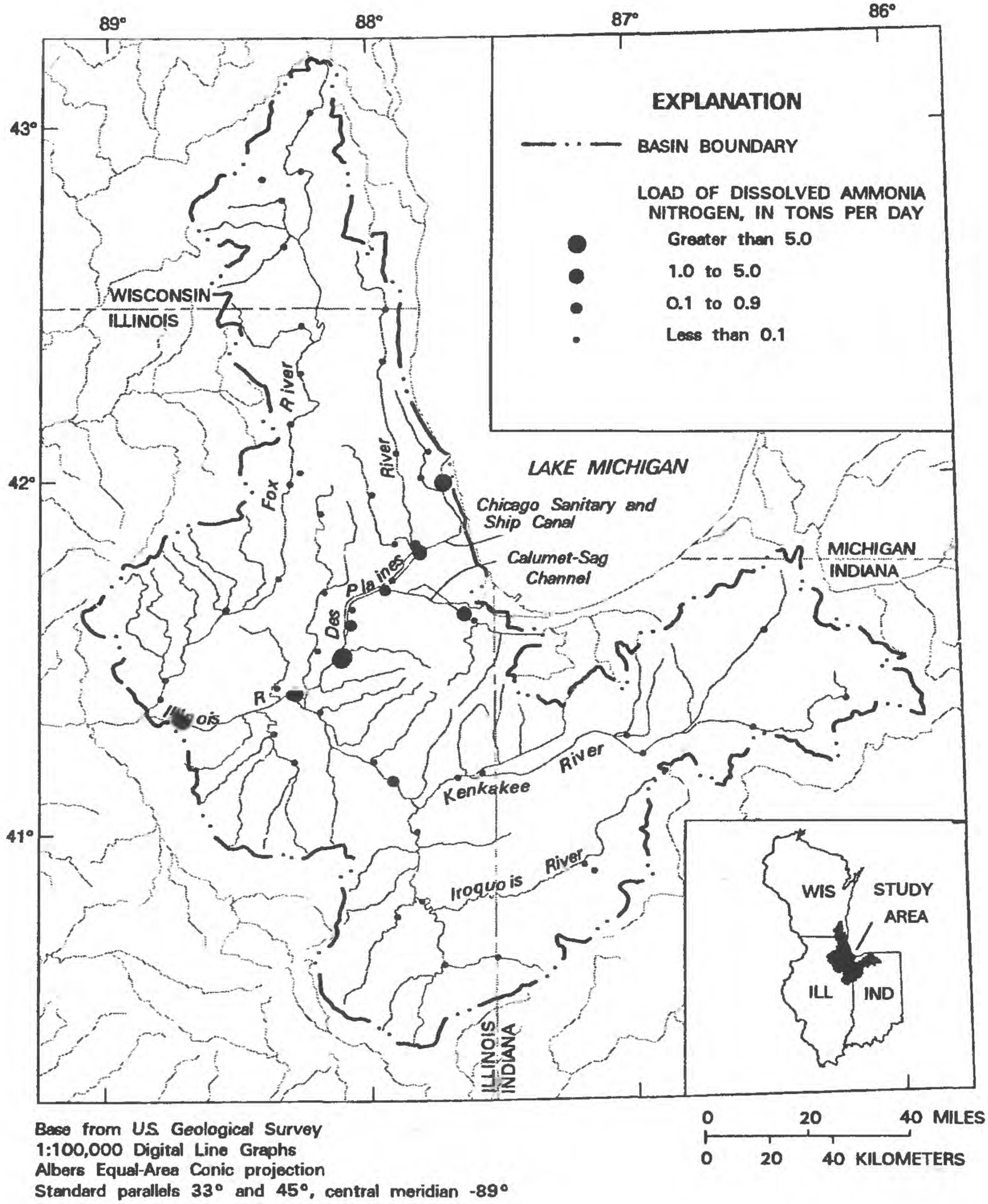
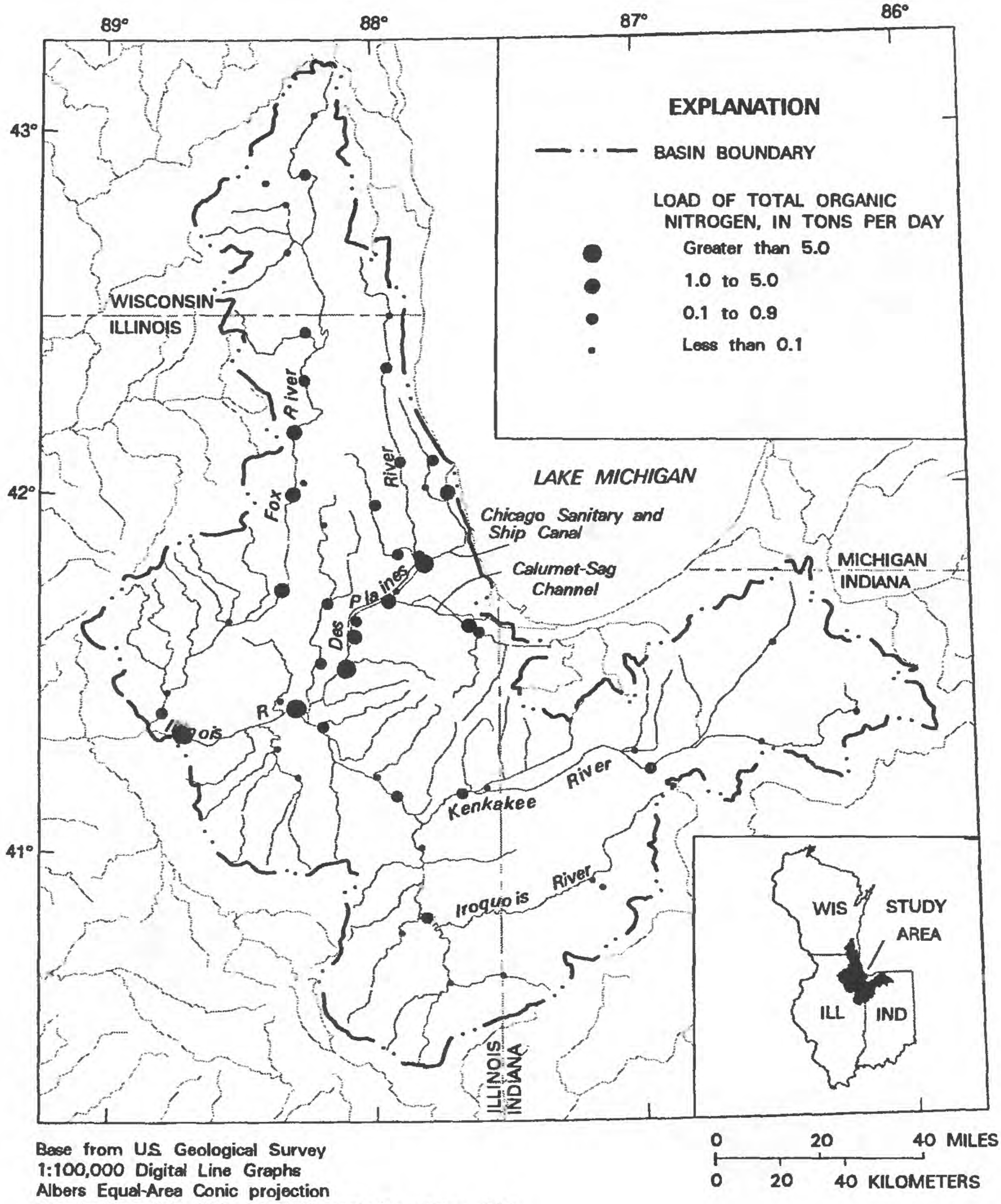


Figure 15. Spatial distribution of dissolved ammonia nitrogen loads at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.



Base from U.S. Geological Survey
1:100,000 Digital Line Graphs
Albers Equal-Area Conic projection
Standard parallels 33° and 45°, central meridian -89°

Figure 16. Spatial distribution of total organic nitrogen loads at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

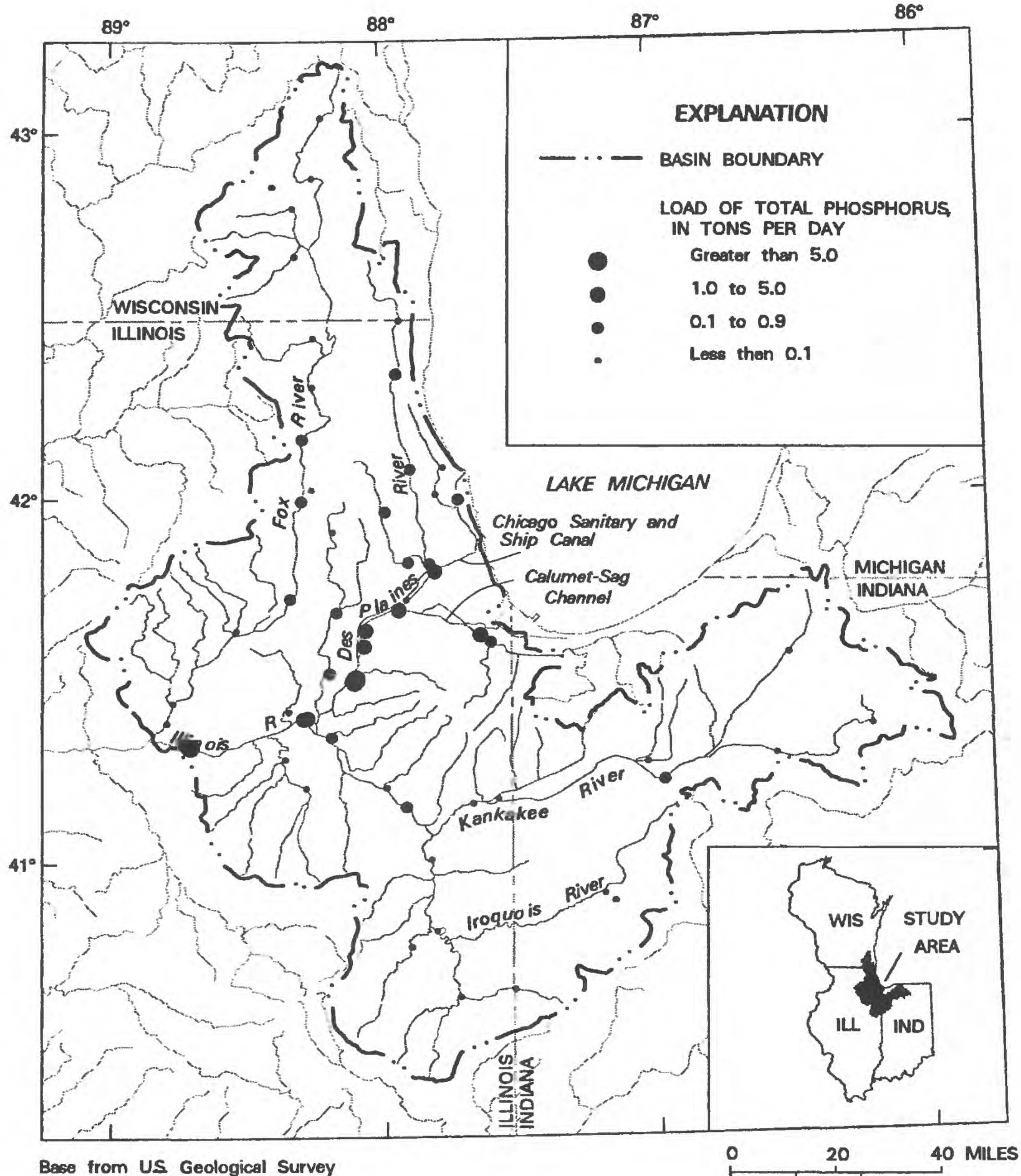


Figure 17. Spatial distribution of total phosphorus loads at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

Table 14. Results of the seasonal Kendall trend test for nutrient concentrations at the eight fixed surface-water stations in the upper Illinois River Basin, January 1978 through August 1990

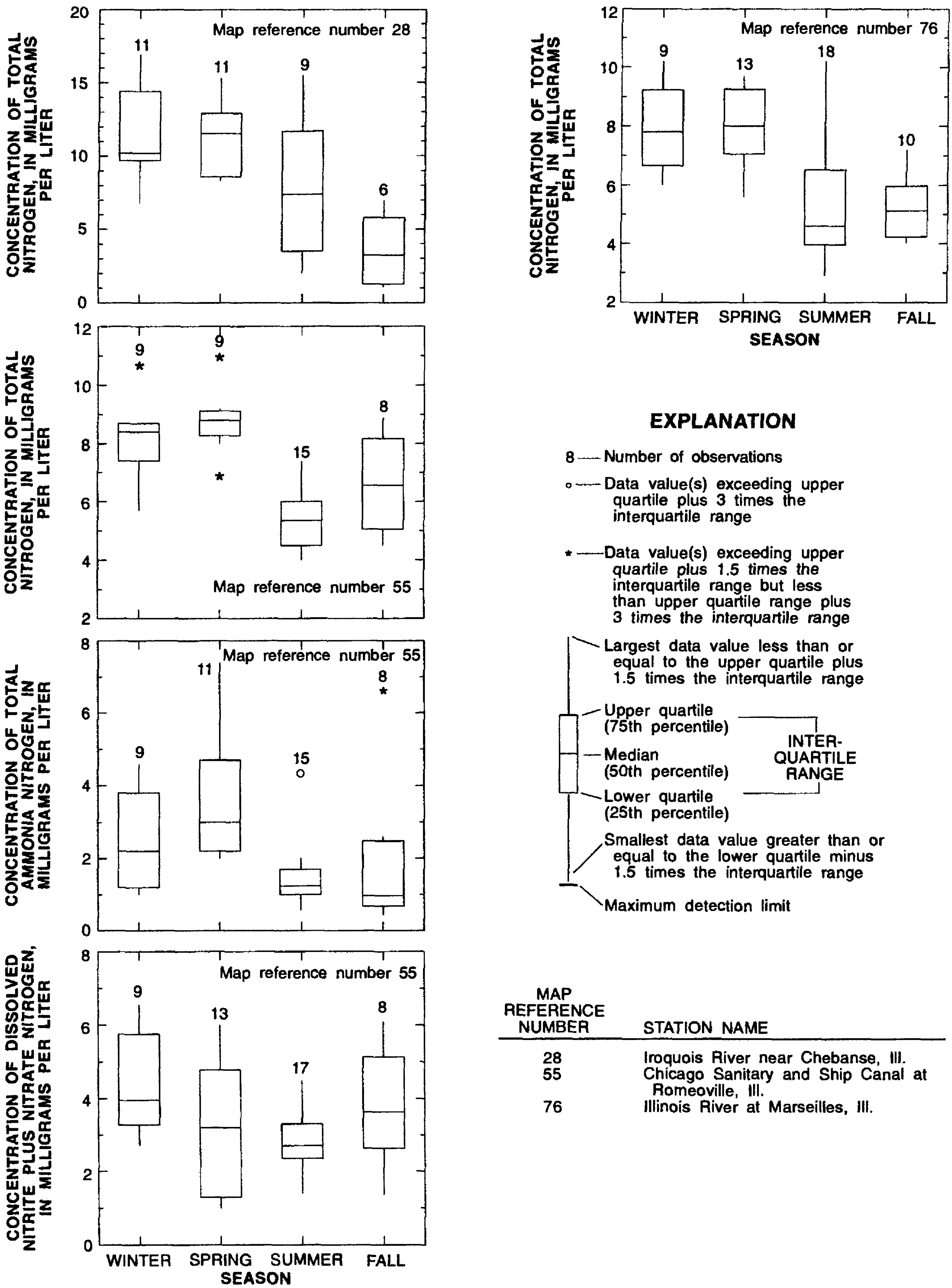
[Underlining indicates a trend with a p-value less than or equal to 0.1 or a regression with a correlation coefficient greater than or equal to 0.2 and a p-value less than or equal to 0.1; --, a trend with a p-value greater than 0.2 or a regression with a correlation coefficient less than 0.2 and a p-value greater than 0.1; n.a., regression and flow-adjustment not applicable to discharge, no flow-adjustment done when the regression analysis was not statistically significant]

Map reference number[1]	Number of observations	Concentration: Level of significance (p-value)	Concentration: Slope: Units per year[2]	Concentration: Slope: Percent of median concentration per year	Regression analyses: Coefficient of determination (R^2)	Regression analyses: Level of significance (p-value)	Flow-adjusted concentration: Level of significance (p-value)	Flow-adjusted concentration: Slope: Units per year[2]	Flow-adjusted concentration: Slope: Percent of median concentration per year
Discharge									
14	132	1	--	--	n.a.	n.a.	n.a.	n.a.	n.a.
28	130	.8724	--	--	n.a.	n.a.	n.a.	n.a.	n.a.
[3]40	94	.3395	--	--	n.a.	n.a.	n.a.	n.a.	n.a.
[3]55	39	.5232	--	--	n.a.	n.a.	n.a.	n.a.	n.a.
69	132	.2515	--	--	n.a.	n.a.	n.a.	n.a.	n.a.
76	127	.2358	--	--	n.a.	n.a.	n.a.	n.a.	n.a.
89	128	.0057	−37.2	−4.5	n.a.	n.a.	n.a.	n.a.	n.a.
99	134	.0297	−63.3	−3.6	n.a.	n.a.	n.a.	n.a.	n.a.
Total nitrogen									
14	107	1	--	--	0.3244	<0.0001	0.7551	--	--
28	47	.4350	--	--	.5825	<.0001	.0790	0.356	4.2
[3]40	37	.0865	.600	9.0	.6292	<.0001	.2531	--	--
[3]55	37	.4705	--	--	.1961	<.0001	n.a.	n.a.	n.a.
69	43	.0204	.469	5.7	.3160	<.0001	.0111	.454	5.5
76	111	.3452	--	--	.1432	<.0001	n.a.	n.a.	n.a.
89	105	.0067	.088	2.9	.0038	.056	n.a.	n.a.	n.a.
99	104	.4767	--	--	.2174	<.0001	.1088	--	--
Dissolved nitrite plus nitrate nitrogen									
14	41	.2751	--	--	.8132	<.0001	1	--	--
28	41	.2286	--	--	.6518	<.0001	1	--	--
[3]40	40	.0608	.625	14	.6405	<.0001	.0336	.311	7.0
[3]55	40	.0007	.842	26	.2130	<.0001	.0014	.568	20.0
69	41	.0302	.650	9.0	.4537	<.0001	.0039	.458	8.0
76	86	.0088	.192	4.8	.2017	<.0001	.0049	.193	5.0
89	40	.4497	--	--	.3049	<.0001	.0049	.193	28
99	39	1	--	--	.4027	<.0001	.4347	--	--

Table 14. Results of the seasonal Kendall trend test for nutrient concentrations at the eight fixed surface-water stations in the upper Illinois River Basin, January 1978 through August 1990—Continued

		Concentration			Regression analyses		Flow-adjusted concentration		
			Slope					Slope	
Map reference number[1]	Number of observations	Level of significance (p-value)	Units per year[2]	Percent of median concentration per year	Coefficient of determination (R^2)	Level of significance (p-value)	Level of significance (p-value)	Units per year[2]	Percent of median concentration per year
Total organic nitrogen									
14	60	.6814	--	--	.0243	<.0001	n.a.	n.a.	n.a.
28	34	.3348	--	--	.2236	<.0001	.1296	-.04	-4.0
[3]40	35	1	--	--	.1221	<.0001	n.a.	n.a.	n.a.
[3]55	37	.1123	-.20	-18	.2914	<.0001	.0397	-.13	-12
69	32	1	--	--	.3310	<.0001	.7780	--	--
76	108	.4400	--	--	.0573	<.0001	n.a.	n.a.	n.a.
89	107	.7857	--	--	.1589	<.0001	n.a.	n.a.	n.a.
99	103	.7746	--	--	.1934	<.0001	n.a.	n.a.	n.a.
							n.a.	n.a.	n.a.
Total ammonia nitrogen									
							n.a.	n.a.	n.a.
14	125	<.0001	.006	35.7	.0220	<.0001	n.a.	n.a.	n.a.
28	123	<.0001	.002	2.5	--	--	n.a.	n.a.	n.a.
[3]40	37	.7721	--	--	.0209	.0010	n.a.	n.a.	n.a.
[3]55	38	.0097	-.574	-29	.0676	<.0001	n.a.	n.a.	n.a.
69	122	.5627	--	--	--	--	n.a.	n.a.	n.a.
76	110	.0003	-.061	-8.6	.0676	<.0001	n.a.	n.a.	n.a.
89	125	.0719	.005	5.0	--	--	n.a.	n.a.	n.a.
99	125	.1978	.001	2.9	.0303	<.0001	n.a.	n.a.	n.a.
Total phosphorus									
14	114	.7398	--	--	.0095	.0070	--	--	--
28	98	.3352	--	--	.3221	<.0001	--	--	--
[3]40	40	.0608	.061	7.1	.5721	<.0001	--	--	--
[3]55	40	.7077	--	--	.2599	<.0001	--	--	--
69	85	.9331	--	--	.3600	<.0001	--	--	--
76	126	<.0001	-.013	-3.3	.2206	<.0001	.0001	-.009	-.02
89	122	.1595	-.004	-2.6	.0740	<.0001	n.a.	n.a.	n.a.
99	125	.0105	-.008	-3.2	.1253	<.0001	n.a.	n.a.	n.a.

[1]See table 3 and figure 4.
[2]Units are cubic feet per second for discharge, milligrams per liter for nutrient concentrations.
[3]Trends at these stations are from 1987–90.



MAP REFERENCE NUMBER	STATION NAME
28	Iroquois River near Chebanse, Ill.
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.
76	Illinois River at Marseilles, Ill.

Figure 18. Distribution of nutrient concentrations, by season, at selected fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990.

Table 15. Results of the Spearman rank correlation test for streamflow and total nitrite plus nitrate concentrations during the 1990 storm synoptic survey at six surface-water sites in the upper Illinois River Basin
[<, less than]

Station name (map reference number[1])	Number of samples	Correlation coefficient	Level of significance
Iroquois River at Rosebud, Ind. (15)	12	0.9702	<0.0001
Iroquois River at Rensselaer, Ind. (16)	13	.9036	<.0001
Iroquois River near Foresman, Ind. (19)	20	.8476	<.0001
Iroquois River at Iroquois, Ill. (20)	25	.6071	.0006
Sugar Creek at Milford, Ill. (22)	45	−.1282	.2007
Iroquois River near Chebanse, Ill. (28)	[2]102	−.3074	.0008

[1]See table 3 and figure 4.
[2]Correlation done using dissolved nitrite plus nitrate concentrations.

(1951–80) average of 35.37 in. In 1988 and 1989, the annual precipitation totals were over 6 in. less than long-term average. Total annual precipitation in 1990 was 10.65 in. more than the long-term average. Mean annual temperatures also fluctuated somewhat but were within a few degrees of normal each year.

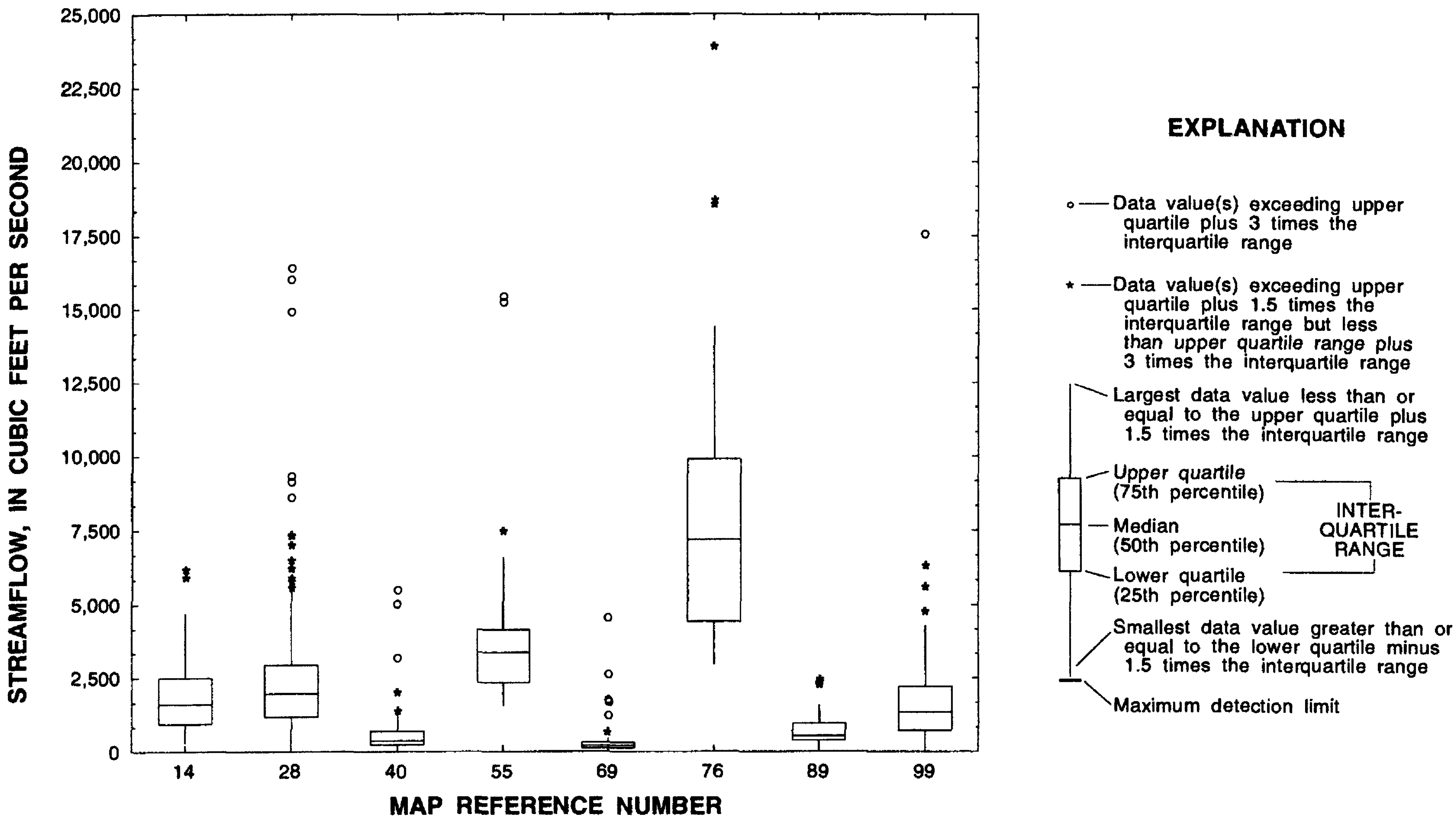
Nutrient Conditions in the Upper Illinois River Basin

The upper Illinois River Basin is a large and diverse area with numerous factors that affect in-stream nutrient conditions. These factors interact with each other and the processes change spatially and temporally. Nutrient concentrations in the upper Illinois River Basin generally were larger than concentrations typically found in natural waters (McNeely and others, 1979; Briggs and Ficke, 1978). Large nutrient concentrations were generally found in the urban areas of the upper Illinois River Basin—the Des Plaines River Basin, in particular. Point-source inputs often increased nutrient concentrations of receiving streams.

Median concentrations of total nitrogen at the eight fixed stations ranged from 2.20 mg/L at Kankakee River at Momence to 9.78 mg/L at Iroquois River near Chebanse (fig. 6). Total nitrogen concentrations in the Des Plaines River Basin ranged from 6.50 to 13.85 mg/L and generally were larger than in the rest of the upper Illinois River Basin, except at Iroquois River near Chebanse.

Total nitrogen and dissolved nitrite plus nitrate concentrations typically were smallest at Kankakee River at Momence and largest at Iroquois River near Chebanse (fig. 6). These two stations represent areas of comparable size and agricultural land use. Fertilizer application rates between the two basins are not substantially different. Significant differences in soil types, however, are found. Soils in the Kankakee River Basin are predominantly sand and gravel; whereas till, clay, and silt are found in most of the Iroquois River Basin. The sand and gravel in the Kankakee River Basin results in adequate field drainage through natural infiltration and percolation to drainage ditches. Because of the coarse soils in the Kankakee River Basin, precipitation is likely to percolate to ground water or to a stream. Conversely, precipitation in the Iroquois River Basin is more apt to be conveyed to the stream as surface runoff or through tile-drainage systems after limited percolation through the soil. Nitrogen transformation and consumption processes reduce concentrations as water passes through soil. Field-tile systems, such as those used throughout the Iroquois River Basin, provide rapid conveyance of water to streams after limited percolation, effectively reducing the transformation and consumption of nitrogen in soils and allowing larger concentrations and loads to reach the streams.

Most of the nitrogen in upper Illinois River Basin streams is in the form of nitrate. Median concentrations of dissolved $NO_2 + NO_3$ in the upper Illinois River Basin ranged from 0.22 mg/L at Fox River at Algonquin to 9.80 mg/L at Iroquois River near Chebanse (fig. 6). The spatial distribution of dissolved $NO_2 + NO_3$ concentrations was similar to the distribution for total nitrogen, except at CSSC at Romeoville, where ammonium made up a large part of the total nitrogen concentration, and at Fox River at Algonquin, where organic nitrogen was predominant.



MAP REFERENCE NUMBER	STATION NAME
14	Kankakee River at Momence, Ill.
28	Iroquois River near Chebanse, Ill.
40	Des Plaines River at Riverside, Ill.
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.
69	Du Page River at Shorewood, Ill.
76	Illinois River at Marseilles, Ill.
89	Fox River at Algonquin, Ill.
99	Fox River at Dayton, Ill.

Figure 19. Distributions of streamflow at the eight fixed surface-water stations in the upper Illinois River Basin, 1987–90 water years.

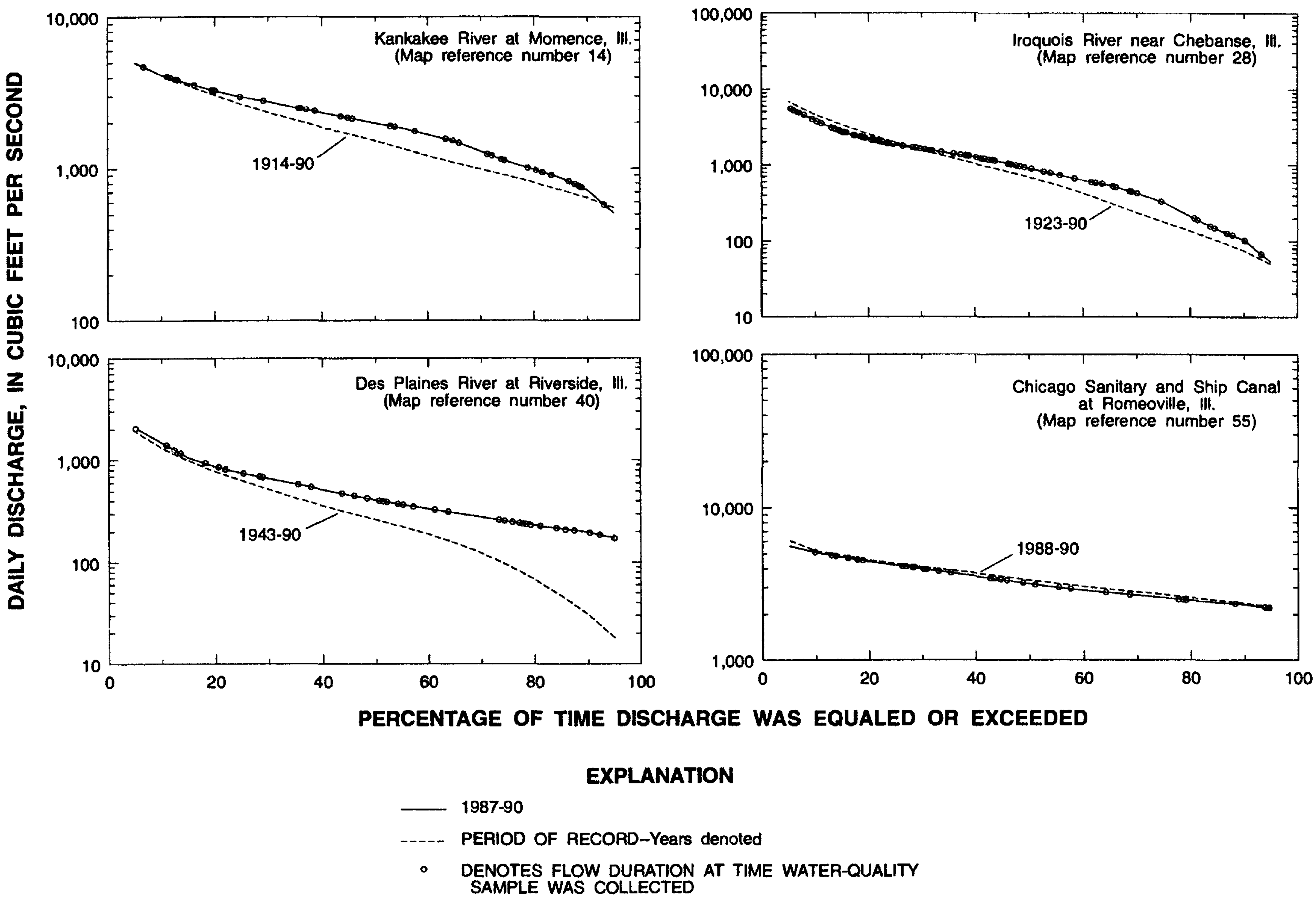


Figure 20. Flow-duration curves at the eight fixed surface-water stations in the upper Illinois River Basin for the period of record and for the 1987–90 water years.

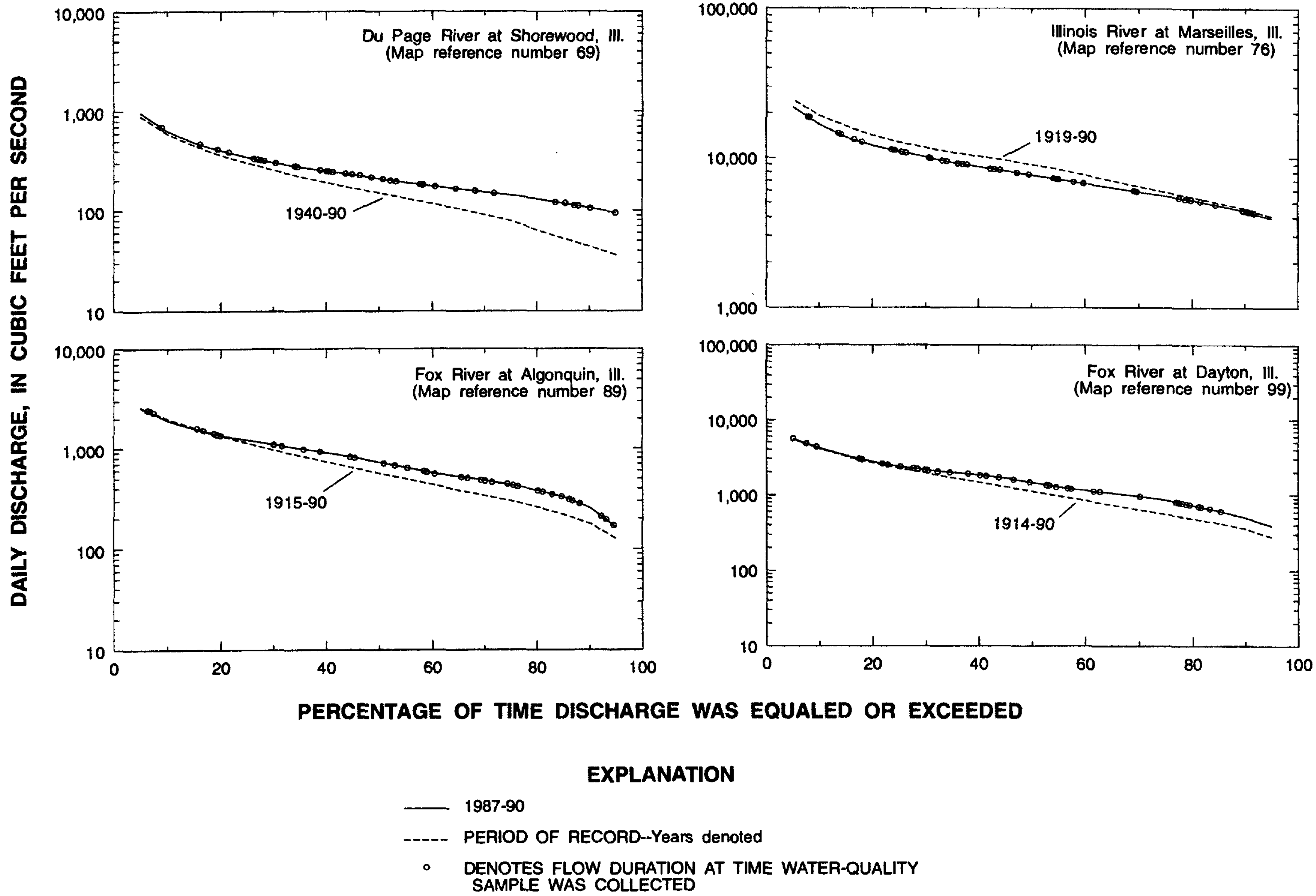


Figure 20. Continued.

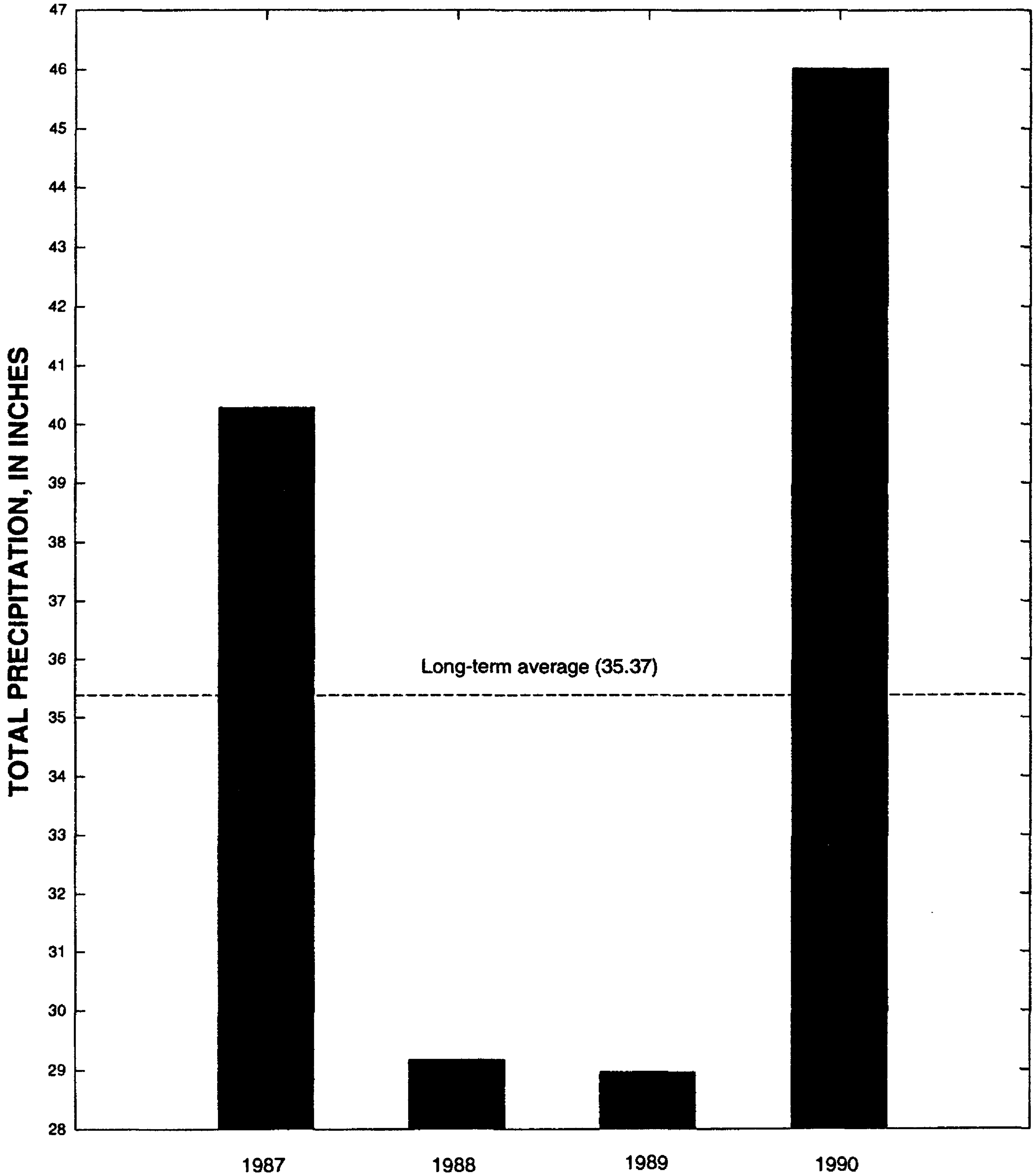


Figure 21. Averaged annual precipitation totals for precipitation monitoring sites in northeastern Illinois, 1987–90. [Data from National Oceanic and Atmospheric Administration, 1987–90]

Concentrations of ammonia at the fixed stations ranged from less than 0.01 to 7.40 mg/L (fig. 6). Ammonia concentrations were largest at Des Plaines River at Riverside, CSSC at Romeoville, and Illinois River at Marseilles. These larger concentrations were likely due to urban land uses and wastewater-treatment-plant effluents. The concentrations at Illinois River at Marseilles are likely results of the elevated concentrations in the Des Plaines River Basin.

Median concentrations of total organic nitrogen in the upper Illinois River Basin ranged from 0.87 mg/L at Kankakee River at Momence to 1.76 mg/L at Fox River at Dayton (fig. 6). Organic nitrogen comprised a larger portion of the total nitrogen concentration in the Fox River than in the other major upper Illinois River Basin rivers (table 9). Numerous dams are found in the Fox River Basin, both on the Fox River and on tributary streams. Aquatic plant growth in the pools behind the dams might be a cause for the relatively large organic nitrogen concentrations in the Fox River. During the low-flow conditions of the 1988 synoptic survey, stations in the Fox River Basin did not have large organic nitrogen concentrations, but concentrations as large as 14.2 mg/L were found in the Des Plaines River Basin (fig. 11).

Median concentrations of total phosphorus at the fixed stations ranged from 0.06 to 0.84 mg/L (fig. 6). The spatial distribution of total phosphorus concentrations was similar to that for total nitrogen; the smallest concentrations were in streams in the Kankakee River Basin and the largest concentrations were in streams in the Des Plaines River Basin. Unlike nitrogen concentrations, however, phosphorus concentrations were not large at Iroquois River near Chebanse. If tile-drainage systems in the Iroquois River Basin provide rapid conveyance of water and fertilizer components to streams (as evidenced by large $NO_2 + NO_3$ concentrations), correspondingly large phosphorus concentrations also might be expected because phosphorus also is commonly applied to agricultural fields. Large phosphorus concentrations, however, were not detected in the Iroquois River Basin. Phosphorus adsorption to sediment particles might be one reason why phosphorus concentrations in streams in the Iroquois River Basin were not large. Phosphorus commonly associates with sediment particles and, therefore, is not mobile in soils (Hem, 1985; Brown and Johnson, 1993). Similar adsorption processes take place with in-stream sediments and bottom material. Total phosphorus and suspended-sediment concentrations were correlated (rho = 0.5535) (table 11) at Iroquois River near Chebanse. This correlation was the only significant correlation between total phosphorus and suspended sediment at any of the fixed stations. Small sediment particles have more surface area per unit mass (Horowitz, 1991) and more potential sites for phosphorus adsorption. About 97 percent of the suspended sediment at Iroquois River near Chebanse was smaller than 63 µm, the smallest particle size classified as sand. The median suspended-sediment concentration at Iroquois River near Chebanse was 81 mg/L; almost twice as large as median concentrations at other fixed stations in agricultural areas and up to six times the concentration at fixed stations in urban areas. The relatively large suspended-sediment concentrations, compared to concentrations at other upper Illinois River Basin areas, indicate likely substantial adsorption of phosphorus to sediment in the Iroquois River Basin and the fine-sized sediments in the Iroquois River Basin.

Spatial distributions of nutrient concentrations might be considerably different during contrasting hydrologic or climatic conditions. The spatial distributions of nutrient concentrations in stream water samples collected during the 1988 synoptic survey are summarized in figures 8–17. Low-flow nutrient concentrations, in general, were largest in streams in the Des Plaines River Basin and smallest in streams in the Kankakee River Basin. Many of the largest concentrations were found at enriched sites downstream from point sources and often on small tributary streams. Large concentrations from point sources or smaller streams generally were attenuated in larger streams in a relatively short distance downstream. Elevated phosphorus concentrations, however, were found to persist in the stream system for a longer time and a greater distance than concentrations of nitrogen forms; possibly because of the association with particulate matter.

Total nitrogen concentrations and streamflow were found to be correlated at most of the unregulated fixed stations (table 11). The streamflow in the CSSC is regulated and is composed mostly of water diverted from Lake Michigan or of return flows, many of which have been routed through wastewater-treatment plants. Streamflow at Illinois River at Marseilles, Fox River at Algonquin, and Fox River at

Dayton is affected, to some extent, by dam operations. At Algonquin, organic nitrogen comprises a large part of the total nitrogen concentration. Organic nitrogen is derived primarily from plant and animal matter, and dilution of these sources typically occurs during high-flow periods. Many physical, hydrologic, biological, and chemical processes affect the correlations between streamflow and nitrogen concentrations, and these processes are different at each station. Positive correlations between streamflow and nitrogen concentrations were indicated at stations in predominantly agricultural basins and negative correlations were indicated for stations in urban areas, indicating that nitrogen is conveyed to streams in agricultural areas during storms, whereas point sources are major contributors of nitrogen in urban areas. Because point-source inputs generally are not affected by hydrologic conditions, they have a pronounced effect on in-stream concentrations during low-flow periods when nonpoint-source inputs are typically reduced. Nutrient concentrations at fixed stations in agricultural areas increased during high-flow periods but generally did not surpass concentrations at stations in urban areas.

Phosphorus concentrations were correlated with streamflow at five of the fixed stations; the only positive correlation was at Iroquois River near Chebanse. The positive correlation between phosphorus and streamflow in the Iroquois River is probably a result of the large concentrations and transport of suspended particulate matter and associated phosphorus during high-flow periods. Wastewater-treatment-plant effluents, the major source of phosphorus in urban locations, typically are diluted during high-flow periods. Negative correlations between phosphorus and streamflow were found at the three stations in the urban areas and the two mixed land-use stations.

Approximately 247,000 tons of nitrogen and 94,000 tons of phosphorus enter streams in the upper Illinois River Basin annually. A summary of the estimated contributions of nutrients from the major sources in the upper Illinois River Basin is given in table 16. These estimates are compiled and extrapolated from the many different data sources referenced in a previous section and are meant only to provide a gross approximation of the nutrient input to the upper Illinois River Basin and to give an indication of the relative contributions from the different sources. Only 74,730 tons of nitrogen and 3,850 tons of phosphorus are exported from the upper Illinois River Basin each year via the Illinois River. These figures correspond to 30 percent and 4 percent of the nitrogen and phosphorus inputs, respectively. The mean annual load of total nitrogen discharged from

Table 16. Estimated annual nutrient inputs to the upper Illinois River Basin from various sources
[--, insufficient data]

Source	Contribution, in tons per year	
	Nitrogen	Phosphorus
Wastewater-treatment plants[1]	26,000	5,400
Fertilizers[2]	210,000	87,000
Urban runoff[3]	860	1,200
Atmospheric deposition[4]	7,500	--
Ground water[5]	260	16
Lake Michigan diversions[6]	2,100	340
Total inputs to upper Illinois River Basin	247,000	94,000
Exported load in streams estimated from concentration measurements	74,730 (30 percent of input)	3,850 (4 percent of input)
Surplus storage in upper Illinois River Basin	172,000	90,000

[1]Jerry Davis, U.S. Geological Survey, written commun., 1993.
[2]Illinois Department of Agriculture, 1988a, 1988b.
[3]Uttormark and others, 1974; Donigian and Crawford, 1976; and Manning and others, 1977.
[4]National Atmospheric Deposition Program, 1989.
[5]Mades, 1987; Voelker and others, 1987.
[6]U. S. Army Corps of Engineers, 1990.

the upper Illinois River Basin from 1987–90 was approximately 74,700 tons per year, and the corresponding nitrogen yield was 6.82 (tons/mi^2)/yr. The Des Plaines River Basin contributed about 41 percent of the total nitrogen load, and the Kankakee and Fox River Basins contributed about 39 and 13 percent of the load, respectively (table 10). The large contribution from the Des Plaines River Basin was due to the nitrogen load in the CSSC—about 24,400 tons per year, or 33 percent of the total upper Illinois River Basin load. The spatial distribution of total nitrogen yields was similar to the distribution for total nitrogen concentrations. The distribution of total nitrogen loads, however, was considerably different and resembled the distribution of streamflow.

Stream loads during low-flow conditions were estimated as the product of measured discharge and constituent concentrations for samples collected during the 1988 low-flow synoptic survey. Because low-flow loadings represent a temporary condition and were based on a single measurement, low-flow loads are expressed in units of tons per day. The total nitrogen load exported from the upper Illinois River Basin under low-flow conditions was about 49 tons/d. The Fox and Kankakee River Basins each contributed only about 1 percent of the total upper Illinois River Basin nitrogen load during the low-flow synoptic survey (table 13 and fig. 13). The Des Plaines River Basin supplied virtually all of the low-flow nitrogen load. The estimated low-flow load in the CSSC was about 48.2 tons/d, and the Des Plaines River above the mouth of the CSSC provided an additional 8.3 tons/d. Some loss of in-stream nitrogen occurs between the mouth of the CSSC and Illinois River at Marseilles during low-flow conditions (table 13 and fig. 13). These losses are likely due to consumptive and depositional processes and denitrification.

The mean annual load of phosphorus from the upper Illinois River Basin was 3,850 tons per year, and the basin-wide yield was 0.35 (ton/mi^2)/yr. As with ammonia, most of the phosphorus load was in the CSSC. The spatial distribution of phosphorus was similar to that for ammonia, and wastewater-treatment-plant effluents are likely the major source of phosphorus to streams in the upper Illinois River Basin although agricultural practices are the greatest source of phosphorus into the drainage basin. The cumulative phosphorus loads from tributaries to the Illinois River were larger than the load at Illinois River at Marseilles, indicating that not all of the phosphorus load introduced into the streams is transported through the upper Illinois River Basin under normal conditions.

Total nitrogen loads decreased by 70 to 80 percent in the lower reaches of the Fox and Kankakee Rivers. Except for $NO_2 + NO_3$, loads for all forms of nitrogen and for total phosphorus decreased in the lower reaches of these rivers during low-flow conditions (figs. 13–17). Loads of $NO_2 + NO_3$ increased in the lower Kankakee River.

Temporal variability in water quality can be described in different ways, including abrupt changes, diurnal variations, seasonal changes, and long-term trends. This variability can be caused by many factors, but changes in climatic season, constituent sources, and land use are the most common causes. Long-term trend analyses can provide information on changes in water quality over time and can indicate future changes or problems.

The trend analyses for the fixed stations indicated significant upward trends in total nitrogen concentrations at three stations (table 14). Two of the upward trends were for flow-adjusted concentrations and one was for nonadjusted concentrations. The drainage areas and hydrologic characteristics of these three stations are different, and the causes for the upward trends are likely different as well. Iroquois River near Chebanse represents a predominantly agricultural drainage area with substantial nitrogen-fertilizer use and large concentrations of $NO_2 + NO_3$. Du Page River at Shorewood is in an urban watershed with inputs from wastewater-treatment plants upstream. Fox River at Algonquin represents a somewhat mixed land-use area and a regulated stream with large backwater areas. Organic nitrogen is a major form of nitrogen at this station (table 9). The trends in nonadjusted and flow-adjusted concentrations at Du Page River at Shorewood were comparable, indicating that although there was a correlation between total nitrogen concentrations and streamflow, streamflow did not have a large effect on the upward trends in nitrogen concentrations. Elder (in press) found a downward trend in total nitrogen concentrations from 1978–86 at Illinois River at Marseilles and an upward trend at Fox River at Algonquin. Many causes for the trends in nitrogen and phosphorus in the upper Illinois River Basin are possible, including increases in fertilizer use, changes in land use (primarily urbanization), the implementation of Chicago's Tunnel and Reservoir plan (a combined flood-control and water-quality-improvement project), decreased use of phosphate cleaning agents, increases in population, and variations in climatic conditions.

For total phosphorus, downward trends in flow-adjusted concentrations at Illinois River at Marseilles and in nonadjusted concentrations at Fox River at Dayton (table 14) were found. These two stations are the stations that collectively represent the entire upper Illinois River Basin. The downward trend at Illinois River at Marseilles also was found by Elder (in press), as was a downward trend at Des Plaines River at Riverside.

Trends in $NO_2 + NO_3$ concentrations were found at five stations; all were upward trends (table 14). The largest upward trend in $NO_2 + NO_3$ concentrations was in the Des Plaines River Basin (at CSSC at Romeoville). Concentrations of $NO_2 + NO_3$ in the CSSC increased by 0.568 mg/L per year, or 20 percent of the 1978–90 median concentration per year. The upward trends in $NO_2 + NO_3$ concentrations could have resulted from a variety of causes, including progressive urbanization. The only trend in $NO_2 + NO_3$ concentrations identified by Elder (in press) was an upward trend in nonadjusted concentrations at Du Page River at Shorewood.

The only significant trend in organic nitrogen concentrations was a downward trend at CSSC at Romeoville (table 14). The magnitude of this trend was –0.13 mg/L per year, or 12 percent of the 1978–90 median concentration per year. An upward trend at Fox River at Algonquin from 1978–86 was identified by Elder (in press), but no trend was found from 1978–90 at this station.

No flow-adjusted ammonia concentrations were determined because there were no statistically significant regressions between streamflow and ammonia concentrations at any of the fixed stations. Upward trends in nonadjusted ammonia concentrations were found for the stations in the Kankakee River Basin and for Fox River at Algonquin. Downward trends were found at CSSC at Romeoville and at Illinois River at Marseilles. The downward trend at CSSC at Romeoville contributed to the decrease at Illinois River at Marseilles. The only trend in ammonia concentrations found by Elder (in press) was downward at Du Page River at Shorewood.

Some of the factors that can change with climatic season and can affect in-stream nutrient concentrations and loads include precipitation, streamflow, temperature, water use, biological activity, erosion, and land-use practices. Several notable instances of seasonal variation in nutrient concentrations at the fixed stations were noted (fig. 18). Seasonal variations in total nitrogen concentrations were found at Iroquois River near Chebanse, CSSC at Romeoville, and Illinois River at Marseilles. In all instances, total nitrogen concentrations were large in the winter and spring and small in the summer and fall. This seasonality was seen in both agricultural and urban drainage areas, showing that land-use activities were not the only factor affecting the seasonality of total nitrogen concentrations. Changes in temperature, precipitation, and biological activity associated with climatic season were likely the key factors promulgating seasonal changes in total nitrogen concentrations. Most agricultural fields in the upper Illinois River Basin are barren during the nongrowing season, and nutrient and sediment transport from the fields is unrestricted by vegetation.

The seasonal variations of $NO_2 + NO_3$ concentrations at the fixed stations were similar to those of total nitrogen, except at CSSC at Romeoville, where concentrations were smallest in the spring (fig. 18). The difference between the seasonality of total nitrogen and nitrite plus nitrate was accounted for by the seasonality of ammonia. Ammonia comprises a large part of the total nitrogen concentration at CSSC at Romeoville, and ammonia concentrations were largest in the spring and smallest in the summer and fall. This seasonality might be a result of reduced efficiency of nitrogen transformation processes at cold temperatures.

Seasonality of nutrient loads was noted at some of the fixed stations and for some nutrient forms. Seasonality of nutrient loads typically was caused by seasonal variation of streamflow, but differences were found among stations. At the stations in agricultural basins, the largest loads, streamflows, and nutrient concentrations typically were found in the spring and also were often large in the winter. At Du Page River at Shorewood, a station with substantial upstream inputs from treatment plants and urban influences, no large seasonal differences in streamflow, nutrient concentrations, or nutrient loads were found. For CSSC at Romeoville, streamflow and loads of total nitrogen, $NO_2 + NO_3$, and ammonia were larger in the summer —the opposite seasonality found at most of the other fixed stations.

Data from the 1990 storm synoptic survey were used to determine $NO_2 + NO_3$ concentrations during summer storms and to examine relations between these concentrations and streamflow in an agricultural basin. Correlation analyses of $NO_2 + NO_3$ concentrations and streamflow were done for stations where 10 or more samples were collected during the storm synoptic survey (table 15). The variation explained by the correlations, as measured by rho, decreased from 0.9702 at Iroquois River at Rosebud, the most upstream station on the Iroquois River, to –0.3074 at Iroquois River near Chebanse, the most downstream station. At the three most upstream stations, concentrations of $NO_2 + NO_3$ increased notably with an increase in streamflow. At Iroquois River at Iroquois, the correspondence between $NO_2 + NO_3$ concentrations and streamflow was not as strong. At the two most downstream stations on the Iroquois River, $NO_2 + NO_3$ concentrations decreased at high streamflows. It appeared that $NO_2 + NO_3$ concentrations were diluted from streamflows greater than about 5,000 ft^3/s at Iroquois River near Chebanse.

Although the correlation tests determine relations between concentration and streamflow, the correlation analyses do not distinguish between samples collected from different parts of the runoff hydrograph; that is, no distinction was made between concentrations for samples collected before, during, and after the peak runoff for any particular storm. It is generally found that a sample collected before the runoff peak has a larger concentration than a sample collected after the peak runoff. These characteristics might vary at individual sites and might affect the strength of the correlations, or the effect of streamflow or nutrient concentrations at some sites.

Water-quality standards for Illinois, Indiana, and Wisconsin and Federal water-quality criteria for several nutrients are given in table 17. Federal water-quality criteria do not have a direct regulatory use, but they provide a basis for judgment for water-quality considerations (U.S. Environmental Protection Agency, 1976). Water-quality standards adopted by State regulatory agencies commonly are based on Federal criterion but are modified to reflect local conditions, concerns, and water uses. Except for CSSC at Romeoville, the Illinois general-use water standards are applicable for the fixed stations. General-use waters are suitable for aquatic life, primary (for example, swimming) and secondary (for example, boating) contact, agricultural, and industrial uses. The CSSC is designated as a secondary-contact water body (fig. 22). Secondary-contact waters are designated for industrial and less than full-body-contact use. Synoptic sites were located in all three States as well as on streams designated as secondary-contact waters. The Illinois water-quality standards are applicable to all of the fixed stations, while Indiana and Wisconsin standards and Illinois secondary-contact standards are applicable for some synoptic sites. For purposes of this discussion, however, the Illinois water-quality standards will be used.

Only five water samples collected at the fixed stations, all at Illinois River at Marseilles, were found to have ammonia nitrogen concentrations larger than the Illinois general-use standards (table 17). The total ammonia concentrations of these samples were less than 15 mg/L, but the un-ionized ammonia concentrations were larger than the water-quality standards allow. The large un-ionized ammonia concentrations were likely a result of large concentrations in the CSSC upstream from Marseilles.

At each of the fixed stations, from zero to five samples contained un-ionized ammonia concentrations larger than the water-quality standard of 0.04 mg/L. From 90 to 100 percent of the samples collected at the fixed stations had un-ionized ammonia concentrations that met the water-quality standard.

Phosphorus concentrations generally were larger than the Illinois general-use water-quality standard of 0.05 mg/L (table 17). The phosphorus standard, however, is applicable only to a stream at the point where it enters a lake or reservoir. This standard is not directly applicable to any of the fixed stations. Phosphorus concentrations at the fixed stations exceeded 0.05 mg/L in many of the samples collected. More than 90 percent of the samples collected at stations in the Des Plaines and Fox River Basins had phosphorus concentrations larger than the Illinois general-use water-quality standard.

Samples collected during the 1988 low-flow synoptic survey were collected during warm temperatures and low streamflows, generally considered to be indicators of drought conditions. Under these conditions, effects from point-source inputs were enhanced. Most of the point sources in the upper Illinois River Basin are in the Des Plaines River Basin, and the major point sources include several large wastewater-treatment plants that receive both domestic and industrial wastewater. No ammonia nitrogen or un-ionized ammonia concentrations larger than the Illinois general-use water-quality standard were found

Table 17. Federal water-quality criteria and State water-quality standards for nutrients in surface water in the upper Illinois River Basin

[mg/L, milligrams per liter; --, no applicable criteria or standard]

		Illinois[1]			Indiana[2]		Wisconsin[3]				U.S.
Nutrient	Units	General use	Public and food-processing water supply	Secondary contact and indigenous aquatic life	Aquatic life	Put-and-take trout water	Fish and aquatic life	Trout water	Recreational	Public-water supply	Environmental Protection Agency[4]
Ammonia nitrogen	mg/L	[5]1.5–15	[5]1.5–15	2.5 April–October 4.0 March–November	--	--	--	--	--	--	--
Nitrate nitrogen	mg/L	--	10.0	--	--	--	--	--	--	--	[6]10.0
Un-ionized ammonia	mg/L	.04	.04	--	Criteria depends on temperature and pH	Criteria depends on temperature and pH	0.04 warm water	0.06 cold water	--	0.04 warm water	Criteria depends on species, pH, and temperature[7]
Total phosphorus	mg/L	[8].05	.05	--	--	--	--	--	--	--	--

[1]Illinois Pollution Control Board, 1982.
[2]Indiana Stream Pollution Control Board, 1977.
[3]Wisconsin Department of Natural Resources, 1985.
[4]U.S. Environmental Protection Agency, 1986.
[5]Dependent upon pH and temperature. Ammonia nitrogen shall not be greater than 15 mg/L. If ammonia nitrogen is greater than or equal to 1.5 mg/L and less than or equal to 15 mg/L, then un-ionized ammonia shall not exceed 0.04 mg/L. Un-ionized ammonia is calculated based upon ammonia nitrogen concentration, pH, and temperature as documented in Illinois Environmental Protection Agency (1990).
[6]Maximum contaminant level for drinking water.
[7]Criteria specified in U.S. Environmental Protection Agency (1986).
[8]For a reservoir of lake with a surface area greater than or equal to 20 acres or any stream at the point where it enters any stem reservoir or lake.

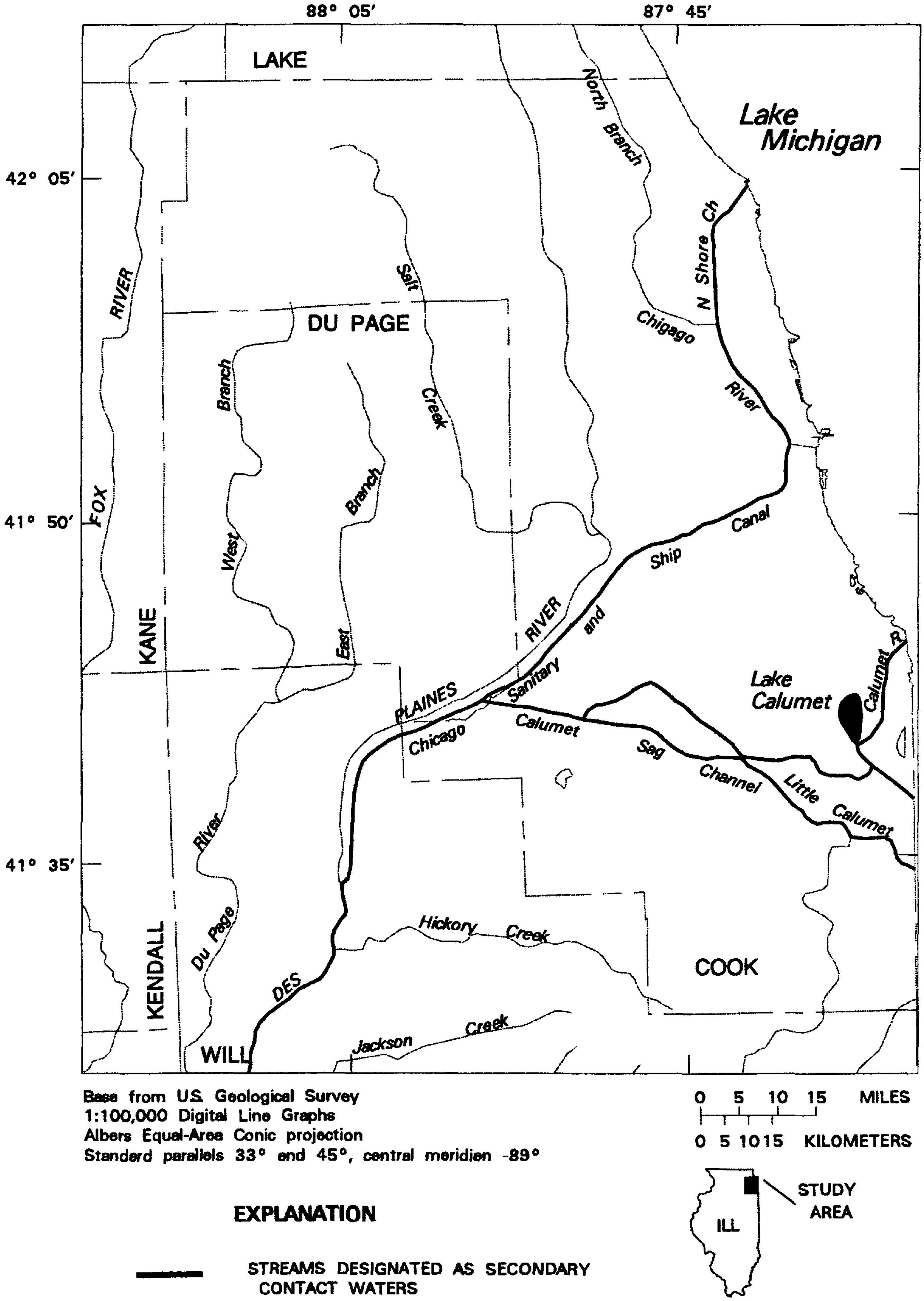


Figure 22. Streams in the upper Illinois River Basin designated as secondary-contact waters.

in samples collected during the synoptic survey. All but five phosphorus concentrations at the synoptic sites, however, exceeded the Illinois general-use water-quality standard of 0.05 mg/L. The largest total phosphorus concentration, 4.0 mg/L, was in a water sample collected at Salt Creek at Wood Dale, Ill.

Dissolved Oxygen

The sustenance of aquatic life depends upon the availability of oxygen. Although most anthropogenic water uses do not require large DO concentrations, the usefulness of water may be limited by low DO concentrations.

Oxygen is a moderately soluble gas present in most natural surface waters. Major sources of DO are limited to oxygen release during photosynthesis and the atmosphere. The DO concentration in streams is affected by plant growth, stream hydraulics, salinity, temperature, and barometric pressure. The amount of DO that can be stored in stream water depends on air pressure and temperature—the saturation concentration of DO decreases with decreasing atmospheric pressure and with increasing temperature. Oxygen is removed from aquatic systems by biological respiration, decomposition of organic material, and oxidation of inorganic waste. DO concentrations in natural waters typically are less than 10 mg/L (McNeely and others, 1979) and may approach zero under oxygen-demanding conditions.

Concentrations of DO often fluctuate diurnally and seasonally. DO concentrations typically are largest during the daylight hours, when sunlight is available and plant photosynthesis is producing oxygen. Because the ability of water to hold DO depends on temperature, concentrations typically are larger during the cold season when low temperatures increase the saturation level for dissolved oxygen in water.

Concentrations of DO vary widely in natural waters and in waters affected by anthropogenic activities. Statistical summaries of the DO concentrations at the fixed stations for 1987–90 are given in table 18. Median DO concentrations ranged from 3.4 mg/L at CSSC at Romeoville to 12.2 mg/L at Fox River at Dayton. Median concentrations at the other fixed stations were 8.7 to 9.7 mg/L.

Measurements of DO were typically made during daylight hours at the fixed stations, when plant photosynthesis is actively replenishing in-stream DO. During the 1988 synoptic survey, DO measurements were made just before sunrise, when DO concentrations are typically at the lowest point of the diurnal cycle.

The small DO concentrations at CSSC at Romeoville reflect the effects of wastewater-treatment-plant effluent and factors related to urbanization. As mentioned earlier, discharges from treatment plants in the Des Plaines River Basin contribute approximately 54 percent of the streamflow at CSSC at Romeoville. Concentrations of DO in the effluent

Table 18. Statistical summary of dissolved oxygen concentrations in surface-water samples collected at the eight fixed stations in the upper Illinois River Basin, April 1987 through August 1990

Station name (map reference number[2])	Number of observations	Percentile[1], in milligrams per liter: 10	25	50 (median)	75	90
Kankakee River at Momence, Ill. (14)	475	6.9	8.2	9.6	11.2	12.1
Iroquois River near Chebanse, Ill. (28)	816	3.4	6.2	8.8	11.4	12.3
Des Plaines River at Riverside, Ill. (40)	435	5.8	7.0	9.1	11.0	12.3
Chicago Sanitary and Ship Canal at Romeoville, Ill. (55)	615	2.0	2.9	3.4	4.9	7.0
Du Page River at Shorewood, Ill. (69)	491	7.0	8.2	9.7	12.3	15.0
Illinois River at Marseilles, Ill. (76)	509	6.7	7.6	9.7	11.8	13.2
Fox River at Algonquin, Ill. (89)	618	5.0	6.3	8.7	11.3	14.8
Fox River at Dayton, Ill. (99)	452	8.5	10.3	12.2	14.2	16.0

[1]Percentage of total observations with concentrations less than or equal to the value shown.

[2]See table 3 and figure 4.

from the three largest treatment plants upstream from Romeoville typically were 6 to 8 mg/L. Although the DO concentrations in the effluent were not small, the effluent could still have reduced DO concentrations in the CSSC because wastewater-treatment-plant effluent typically contains large concentrations of organic material, and the decomposition of organic matter requires oxygen; the oxygen used by the decomposition processes likely reduces the in-stream DO concentration. In addition, the physical characteristics of the CSSC are not conducive to large DO concentrations. The CSSC is a rectangular channel approximately 25 ft deep. Streamflow velocities in the CSSC typically are low (less than 1 ft/s). Turbulence and atmospheric interaction in the CSSC are limited except for that caused by barge traffic. The water quality, shipping activity, and physical characteristics of the CSSC limit aquatic-plant growth in the CSSC and limit associated DO production. The median concentration of chlorophyll-*a* at CSSC at Romeoville was 2.80 mg/L, indicating minimal DO production by aquatic plants in the CSSC. The relatively large DO concentrations at Fox River at Dayton are likely attributed to DO production by plants in a large backwater area created by a dam just upstream from the station. Although DO in this backwater was not measured, similar pooled areas along the Fox River had chlorophyll-*a* concentrations of almost 200 mg/L during the low-flow synoptic survey in 1988. Much of the time, the DO concentrations at Fox River at Dayton indicate that the water is supersaturated with respect to DO. With the exception of these two stations, no substantial differences among median DO concentrations were found at the fixed stations.

Data collected at the low-flow synoptic sites provided additional information on the spatial distribution of DO during warm weather and low-flow conditions (fig. 23). All DO concentrations in the Fox River Basin exceeded 5.0 mg/L, the minimum allowed by the Illinois water-quality standard for general-use waters; some exceeded 9.0 mg/L. The three sites where DO concentrations exceeded 9.0 mg/L were in or downstream from slow-moving stream reaches where plant photosynthesis supplies oxygen to the stream water. In the Kankakee River Basin, a basin with few urban areas, DO concentrations at 59 percent (35) of the sites were less than 5.0 mg/L, and less than 3.0 mg/L at 3 percent (2) of the sites. Some, but not all, of the stations where DO concentrations in the Kankakee River Basin were small were a couple of miles downstream from wastewater-treatment plants. Wastewater-treatment-plant effluents, low streamflow, and hot weather are all factors that likely contributed to the relatively low DO concentrations in the Kankakee River Basin. DO concentrations were less than 5 mg/L at 49 percent (29) of the sites in the Des Plaines River Basin. Neither stream size nor land use appeared to be prevailing factors affecting DO concentrations at the synoptic sites. Streamflow, channel characteristics, aquatic flora, and local contaminant sources were site-specific characteristics that affected DO concentrations.

Federal water-quality criteria for DO are temperature and water-use specific. State water-quality standards for DO and the number of DO measurements at the fixed stations not meeting the water-quality standards are shown in table 19. These data include measurements made during the fixed-station sampling, the low-flow synoptic surveys, and some storm-runoff-sampling efforts. The Illinois water-quality standard for DO in general-use waters states that DO shall not be less than 5.0 mg/L at any time. This standard is applicable for all of the fixed stations except for the CSSC, which is classified as a secondary-contact water body.

In 1987, 36-hour sampling efforts were done at three of the fixed stations to determine the diurnal variation of selected properties, including the DO concentration in the streams. These efforts were done at CSSC at Romeoville, Du Page River at Shorewood, and Fox River at Algonquin. These stations were selected because they represent the variety of drainage areas and water-quality conditions in the upper Illinois River Basin. The CSSC at Romeoville represents an urban drainage area with substantial wastewater input, and Du Page River at Shorewood represents a small stream that drains an area with mixed land use and receives some wastewater. Fox River at Algonquin represents a predominantly agricultural basin with some urban development and some channel modification. DO concentrations and water temperature measured over 36-hour periods are shown in figure 24. DO concentrations at CSSC at Romeoville were small, ranging from 1.8 to 4.1 mg/L. Larger DO concentrations (8.1–9.5 mg/L) were measured at Du Page River at Shorewood. The DO concentrations measured at Fox River at Algonquin were the most variable over the diurnal cycle and ranged from 3.8 to 11.9 mg/L. The chlorophyll-*a* concentration measured at Fox

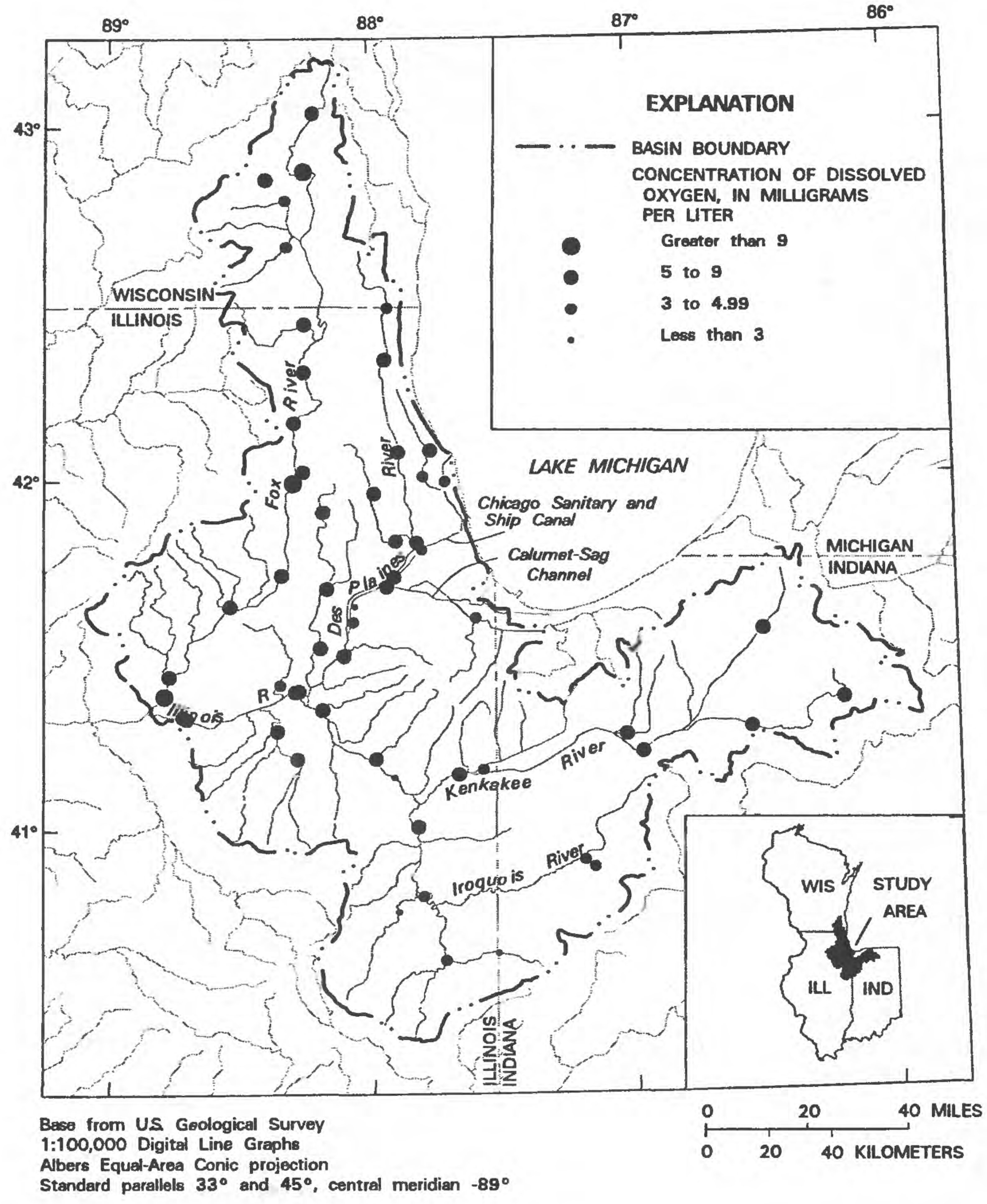


Figure 23. Spatial distribution of dissolved oxygen concentrations at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

Table 19. Number of samples collected at the eight fixed surface-water stations in the upper Illinois River Basin and number of samples with dissolved oxygen concentrations that were less than the Illinois, Indiana, or Wisconsin water-quality standards
[mg/L, milligrams per liter]

		Number of samples with concentrations less than State water-quality standards for dissolved oxygen			
		Illinois[1]		Indiana[2]	Wisconsin[3]
Station name (map reference number)	Number of samples[4]	General use, 5.0 mg/L minimum	Secondary-contact and indigenous aquatic life, 4.0 mg/L minimum	Aquatic life, 5.0 mg/L average per day	Fish and aquatic life, 5.0 mg/L minimum
Kankakee River at Momence, Ill. (14)	55	0	0	0	0
Iroquois River near Chebanse, Ill. (28)	62	2	1	2	2
Des Plaines River at Riverside, Ill. (40)	48	1	0	1	1
Chicago Sanitary and Ship Canal at Romeoville, Ill. (55)	48	32	23	32	32
Du Page River at Shorewood, Ill. (69)	53	1	0	1	1
Illinois River at Marseilles, Ill. (76)	57	0	0	0	0
Fox River at Algonquin, Ill. (89)	48	5	0	5	5
Fox River at Dayton, Ill. (99)	49	0	0	0	0

[1]Illinois Pollution Control Board, 1982.
[2]Indiana Stream Pollution Control Board, 1977.
[3]Wisconsin Department of Natural Resources, 1985.
[4]Average of multiple measurements made across the stream.

River at Algonquin during the 1988 synoptic survey was 200 mg/L, indicating significant plant production that might have a substantial effect on the diurnal DO variation.

Diurnal variations in DO concentrations at CSSC at Romeoville were small, probably because of (1) the large percentage (50 percent) of the total streamflow composed of treatment-plant effluents, (2) the lack of aquatic plant life in the CSSC, and (3) the hydraulics and geometry of the CSSC. Similarly, DO concentrations fluctuated little at Du Page River at Shorewood for unknown reasons. Median total organic carbon concentrations, an indicator of oxygen-demanding substances, were 6.50 to 12.0 mg/L at the fixed stations.

DO concentrations commonly vary seasonally with aquatic-plant growth, temperature, streamflow, and sunlight. In the upper Illinois River Basin, significant seasonal variations in DO concentrations were observed at most of the fixed stations. At all stations, the largest concentrations were measured during the winter months, and the smallest concentrations were measured during the summer months. Seasonal variation in DO concentration generally was less in the Des Plaines River Basin than other parts of the upper Illinois River Basin and was likely because of urban factors and the presence of point sources of surface-water contamination. Stream-water temperature in the CSSC at Romeoville was warmer than that in natural streams in the area in the winter months because of wastewater-treatment-plant inputs.

Correlations were done to determine the relations among DO concentrations and streamflow, water temperature, and chlorophyll-*a* concentrations. The results of the correlation analyses are given in table 20. DO concentrations were not correlated with streamflow at the fixed stations, with the exception of CSSC at Romeoville where a weak negative correlation was indicated. The negative correlation is likely caused by small DO concentrations in urban runoff, the reduction in DO by organic oxygen-demanding wastewater inputs, and by overflows from combined-sewer systems during storms.

A negative correlation also was determined between concentrations of DO and chlorophyll-*a*. This result was surprising because the presence of plant biomass, estimated from chlorophyll-*a* concentration, was assumed to be indicative of plant photosynthesis and DO production. The negative correlation might result from a couple of processes: (1) Samples collected for the determination of chlorophyll-*a* concentrations were collected along with the water used for the water-quality analyses using depth-

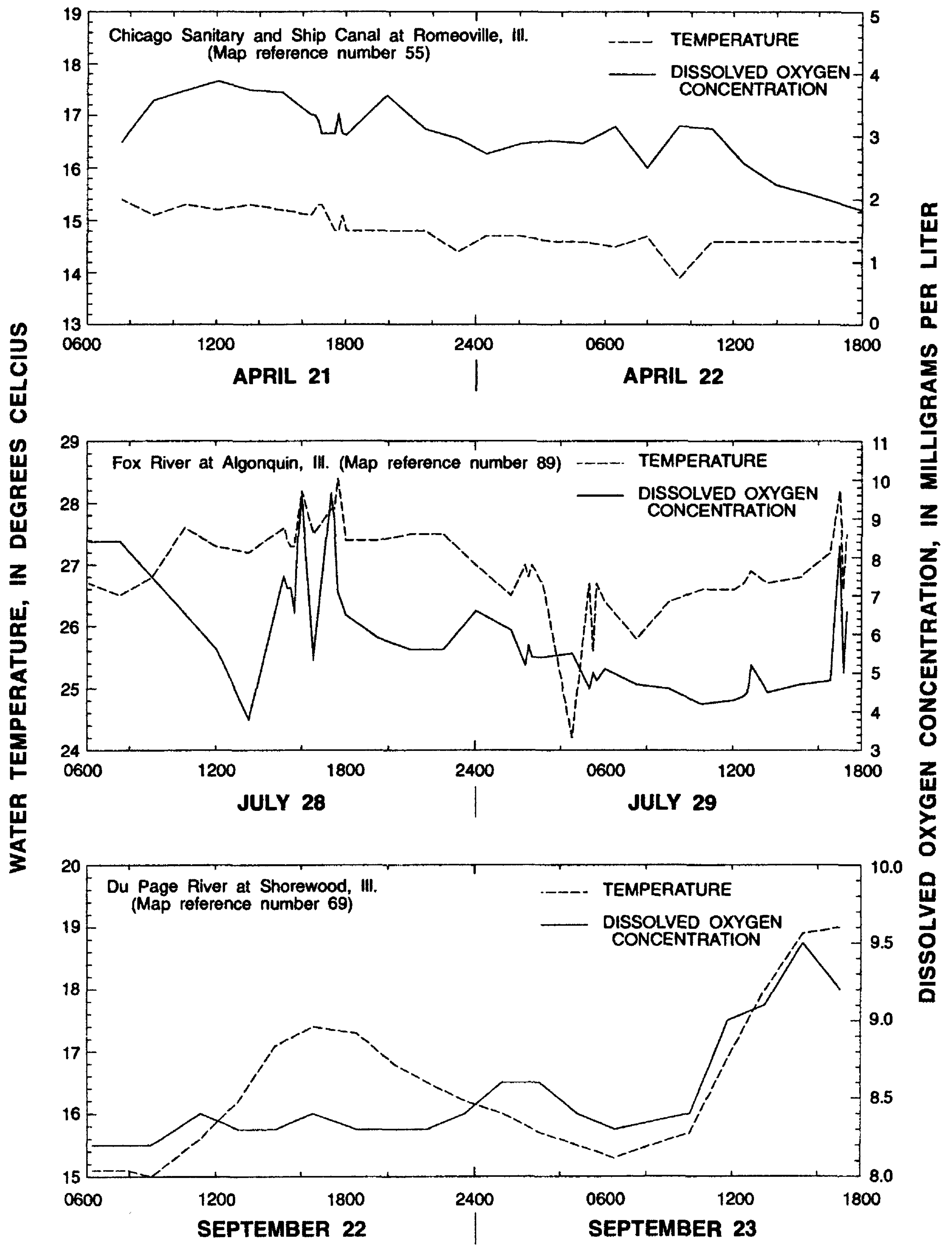


Figure 24. Variations in temperature and dissolved oxygen concentrations at selected fixed surface-water stations in the upper Illinois River Basin during 36-hour perioda.

Table 20. Results of the Spearman rank correlation test between dissolved oxygen concentrations and streamflow, water temperature, and chlorophyll-*a* concentrations at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990

[Underlining indicates results with a correlation coefficient equal to or greater than 0.20 and a p-level less than or equal to 0.10; <, less than]

Station name (map reference number)	Streamflow			Water temperature			Chlorophyll-a		
	Number of observations	Spearman correlation coefficient	p-level	Number of observations	Spearman correlation coefficient	p-level	Number of observations	Spearman correlation coefficient	p-level
Kankakee River at Momence, Ill. (14)	126	−0.0165	0.4274	557	−0.6471	<0.0001	54	−0.4648	0.0002
Iroquois River near Chebanse, Ill. (28)	137	.0032	.4850	893	−.5219	<.0001	52	−.2705	.0262
Des Plaines River at Riverside, Ill. (40)	44	−.1503	.1650	434	−.7727	<.0001	50	−.5487	<.0001
Chicago Sanitary and Ship Canal at Romeoville, Ill. (55)	42	−.3143	.0213	615	−.4988	<.0001	35	−.5664	.0002
Du Page River at Shorewood, Ill. (69)	149	−.1679	.0203	575	−.4840	<.0001	39	−.4136	.0044
Illinois River at Marseilles, Ill. (76)	171	.0599	.2181	706	−.8919	<.0001	31	−.5490	.0007
Fox River at Algonquin, Ill. (89)	144	.2501	.0012	706	−.7295	<.0001	33	−.5834	.0002
Fox River at Dayton, Ill. (99)	118	−.2166	.0092	522	−.4016	<.0001	47	−.0448	.3825

and width-integrating techniques. The samples, therefore, included only suspended and free-floating plant matter and did not include biomass from periphyton, macrophytes, or any rooted or attached plants. (2) The suspended matter collected was a combination of phytoplankton and detached parts of plants and might have included both living and dead plant material. Some of the measured chlorophyll-*a* concentration, therefore, might represent decaying plant material that could be contributing to the consumption of oxygen rather than oxygen production. The inverse relation also might represent the effect of temperature. Although substantial quantities of DO might be produced by plants in the summer, warm water temperatures reduce the solubility of the oxygen in water.

Chlorophyll-*a* concentrations also were measured at most of the synoptic survey sites in 1988. In general, the largest chlorophyll-*a* concentrations were found in the large streams and were associated with low-velocity reaches and pooled areas. These environments are suitable for substantial plant growth and the production of oxygen. These areas, however, also are susceptible to depletion of oxygen from the subsequent decay of plant material.

No apparent relations between concentrations of chlorophyll-*a* and DO were found for measurements made during the synoptic survey. At those sites where chlorophyll-*a* concentrations exceeded 100 µg/L, DO concentrations ranged from 3.38 mg/L (one of the lowest concentrations measured) to 11.08 mg/L (one of the largest concentrations measured). Sites where large chlorophyll-*a* concentrations and correspondingly large DO concentrations were found are mostly in the Fox River Basin. Sites where large chlorophyll-*a* concentrations and small DO concentrations were found are in the Iroquois River Basin. Flow conditions, temperature, and channel morphology, as well as differences in the types of aquatic plants in the two basins, the stage of development and maturity of the plant communities at the time the synoptic survey was conducted, and differences in the turbidity of the streams also contribute to the differences in river basins. Many low-head dams are located along the length of the Fox River and on other streams in the Fox River Basin, but these dams were found to both aerate and deaerate the water, depending on local conditions in the pooled areas above the dams, dam geometry, and other stream characteristics (Butts and Evans, 1978).

Trends in DO concentrations at the fixed stations from 1978–90 also were determined by combining data collected at the fixed stations with data collected by the IEPA during 1978–86. Because water-quality data were not collected at CSSC at Romeoville prior to the NAWQA program, only 4 years of record were available for this station. The IEPA collected DO-concentration data at CSSC at Lockport, Ill., about 5 mi downstream from Romeoville. Trend analyses for the CSSC were done by combining the 1978–90 IEPA data and the NAWQA data collected during 1987–90. Because regressions between DO concentrations and streamflow were not significant at the 0.10 level at any of the fixed stations, flow-adjusted concentrations were not used in the trend analyses.

The only statistically significant trends in DO concentrations were upward trends at Illinois River at Marseilles and Fox River at Dayton. These are the two most downstream stations in the upper Illinois River Basin, and the water quality at these stations represents the composite water quality of streams draining the entire upper Illinois River Basin. The upward trend at Illinois River at Marseilles had a slope of 0.15 mg/L (1.5 percent of the median concentration) per year, and the upward trend at Fox River at Dayton had a slope of 0.20 mg/L (1.7 percent of the median concentration) per year. The upward trend at Illinois River at Marseilles was similar to the trend identified by Kammerer and Blanchard (in press) for 1978–86; they did not find a trend in DO concentrations at Fox River at Dayton.

Fecal-Indicator Bacteria

Stream water often carries pathogenic organisms that can limit the use of the water and cause illness to persons contacting or ingesting the water. Some illnesses that can be conveyed through water include typhoid, cholera, gastroenteritis, hepatitis, and dysentery. The presence of pathogenic organisms can limit or preclude fish and shellfish consumption, recreational activities, and other water uses. The determination of the presence of specific pathogenic organisms in water is difficult, expensive, and impractical for most monitoring programs. Instead, indicator organisms that are not pathogenic, but are found coincidently with many pathogens, are used to identify conditions that might pose human-health problems.

The indicator bacteria used to identify potential pathogenic pollution are bacteria native to the gastrointestinal tract of humans and other warm-blooded animals. The presence of these organisms in stream water indicates contamination by fecal matter. Types of fecal-indicator bacteria generally used for monitoring and regulatory purposes include several members of the coliform group—namely, total coliform, fecal coliform, and *Escherichia coli* (*E. coli*), and the streptococcal group. Some specific sources of these bacteria include wastewater-treatment-plant effluents; runoff from feedlots, rendering plants and food-processing facilities; and septic drainage.

In the NAWQA program, fecal coliform and *E. coli* are used to indicate bacterial contamination. Fecal coliform is the traditional indicator used by the USGS and by many Federal and State monitoring and regulatory agencies. *E. coli* is a subspecies of the coliform group and is used as an indicator organism by the USEPA and by an increasing number of monitoring agencies. Analyses for *E. coli* at the fixed stations began in July 1988 in conjunction with the low-flow synoptic survey.

Statistical summaries for fecal coliform and *E. coli* densities in water samples collected at the fixed stations are given in table 21. Fecal-coliform densities ranged from 1 to 45,000 col/100 mL at the fixed stations. The largest fecal-coliform densities were found at urban stations and at Du Page River at Shorewood and CSSC at Romeoville, in particular. The median fecal-coliform densities in NAWQA water samples collected during 1987–90 were one or two orders of magnitude larger at Des Plaines River at Riverside and at CSSC at Romeoville than at the other fixed stations. The spatial distribution of *E. coli* densities at the fixed stations was similar to that of fecal-coliform densities. Some of the largest fecal-coliform densities were found in water samples collected in 1987, before *E. coli* analyses were done.

The Wilcoxon matched-pairs signed-ranks test was used to determine whether the fecal-coliform and *E. coli* density data were comparable for samples that were analyzed for both species of bacteria. Most of the coliforms present were *E. coli*, and no statistically significant differences in the density data from the two bacteria tests were found.

Federal water-quality criteria and State water-quality standards for fecal-indicator bacteria differ. The Federal criteria are based on *E. coli* densities,

Table 21. Statistical summary of bacteria densities at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990
[Densities in colonies per 100 milliliters]

Map reference number[2]	Mean	Minimum	Maximum	Number of samples	Percentile[1] 10	25	50 (median)	75	90
				Fecal coliform (April 1987 through August 1990)					
14	587	10	10,100	68	40	60	150	260	637
28	604	4	9,500	66	10	22	93	282	1,760
40	8,600	220	45,000	58	720	1,280	3,050	12,000	24,800
55	3,970	60	45,000	51	284	430	1,000	2,250	12,100
69	1,360	3	14,000	65	19	75	250	860	3,880
76	216	1	3,100	85	16	28	60	115	318
89	82	5	610	54	9	11	40	76	205
99	629	9	12,182	52	19	31	77	175	664
				***Escherichia coli* (July 1988 through August 1990)**					
14	514	24	8,000	22	31	53	135	220	511
28	630	8	8,000	26	11	45	91	422	1,660
40	8,150	600	45,000	24	835	1,180	2,800	7,630	35,500
55	1,450	200	5,600	23	358	531	1,060	1,670	4,300
69	2,170	3	15,000	24	11	36	181	1,480	13,300
76	367	16	2,916	22	22	25	97	250	1,930
89	90	6	833	23	8	21	37	80	198
99	119	10	600	20	15	30	47	162	373

[1]Percentage of data less than or equal to the value indicated.
[2]See table 3 and figure 4.

whereas most State standards continue to reference fecal-coliform densities.

In the NAWQA program, water samples are generally collected at the fixed stations on a monthly basis. Because most bacteriological criteria and standards are based on analyses of multiple samples collected during a specific time period (typically a 30-day period), most Federal criteria and State standards are not directly applicable to specific samples collected as part of the NAWQA program. Table 22 relates the bacteriological densities at the fixed stations to Federal water-quality criteria and State standards.

Bacteria densities greater than the water-quality criteria and standards were measured at all of the fixed stations, but densities larger than the criteria and standards were found most often at stations in the Des Plaines River Basin. All of the water samples analyzed for *E. coli* from Des Plaines River at Riverside contained densities that exceeded the single-sample criterion for infrequently used full-body-contact recreation. Approximately 70 percent of the water samples from CSSC at Romeoville had densities exceeding this criterion, as did about 29 percent of the samples from Du Page River at Shorewood. About 5 percent of the water samples collected at stations in the Fox River Basin and 9 to 15 percent of the water samples collected at the stations in the Kankakee River Basin exceeded the *E. coli* criterion. Similar percentages were found for fecal-coliform densities greater than the Illinois general-use water-quality standard of 200 col/100 mL (as a monthly geometric mean of more than five samples), except at CSSC at Romeoville, where the percentage of samples exceeding the Illinois standard for fecal-coliform densities was substantially less than the percentage of samples exceeding the Federal criterion for *E. coli* densities.

The IEPA (1992) identified municipal wastewater, urban runoff, and combined sewer overflows as primary causes for less than full-use support (the water body is not suitable for all intended uses) of many streams in the Des Plaines River Basin. The presence of pathogens, as evidenced by indicator bacteria, was indicated to have been the cause for less

Table 22. Relations of Federal water-quality criteria and State water-quality standards to bacteria densities at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990

Station name (map reference number[5])	Number of samples: *E. coli*	*E. coli*, U.S. Environmental Protection Agency criteria for *E. coli* (colonies per 100 milliliters)[4]: [6]126	[7]235	[8]296	[9]406	[10]576	Number of samples: Fecal coliform	Fecal coliform, State water-quality standards for fecal coliform (colonies per 100 milliliters): Illinois[1] General-use waters and public and food-processing water supply[11]	Indiana[2] Domestic and industrial use[12]	Indiana[2] Recreational use[13]	Wisconsin[3] Public water supply[14]
Kankakee River at Momence, Ill. (14)	22	15	5	3	2	2	68	15	3	4	8
Iroquois River near Chebanse, Ill. (28)	26	22	9	7	5	4	66	15	2	3	8
Des Plaines River at Riverside, Ill. (40)	22	22	22	22	22	22	58	40	13	24	38
Chicago Sanitary and Ship Canal at Romeoville, Ill. (55)	23	21	21	20	20	16	51	37	9	13	31
Du Page River at Shorewood, Ill. (69)	24	22	11	9	7	7	65	22	3	9	14
Illinois River at Marseilles, Ill. (76)	22	18	6	4	3	2	85	9	0	3	5
Fox River at Algonquin, Ill. (89)	23	19	1	1	1	1	54	3	0	0	2
Fox River at Dayton, Ill. (99)	20	16	3	3	1	1	52	10	2	3	7

[1]Illinois Pollution Control Board, 1988.
[2]Indiana Stream Pollution Control Board, 1987.
[3]Wisconsin Department of Natural Resources, 1985.
[4]U.S. Environmental Protection Agency, 1986.
[5]See table 3 and figure 4.
[6]Steady-state geometric mean.
[7]Designated beach area, single sample.
[8]Moderate full-body-contact recreation, single sample.
[9]Lightly used full-body-contact recreation, single sample.
[10]Infrequently used full-body-contact recreation, single sample.
[11]200 col/100 mL monthly average for 5 samples.
[12]Less than 5,000 col/100 mL monthly average and less than 5,000 col/100 mL in 2 percent of samples and 20,000 col/100 mL in less than 5 percent of samples.
[13]1,000 col/100 mL monthly average for 5 samples and 2,000 col/100 mL maximum.
[14]Less than 400 col/100 mL in 90 percent of samples and less than 200 col/100 mL in more than 5 samples per month.

than full-use support in approximately 45 percent of the assessed river miles in the Des Plaines River Basin.

Prior to the 1988 low-flow synoptic survey, stream-water samples were collected at two sites in the upper Illinois River Basin over a 24-hour period to determine the extent of diurnal variation in *E. coli* densities. These two sites were downstream from known wastewater-treatment-plant discharges and were selected to show water-quality conditions at such locations. Water-quality samples were collected at approximately 2-hour intervals, and continuous records of streamflow and discharge from the treatment plants were obtained. The *E. coli* densities during these sampling efforts are given in table 23. The results of these two 24-hour diurnal studies showed that bacteria densities in the streams were variable but that the variability could not be related to either wastewater-treatment-plant discharge or streamflow at these sites.

The ability of bacteria to survive in water depends on several critical factors, including temperature, energy (food) supply, and toxicity of the environment. Changes in climatic season in the upper Illinois River Basin affect each of these factors. Cold-water temperatures retard bacteriological growth and slow down the decay processes that supply food to bacteria.

Plots of bacteria densities, by month, at the eight fixed stations are given in figure 25. The available data do not provide a conclusive determination of the seasonality of fecal-indicator bacteria densities; however, densities in urban drainage areas appear to be slightly larger in the summer and fall. These large densities might result from the intense thunderstorms characteristic of this season and the flushing of bacteria from surfaces by runoff.

Little seasonal variation in bacteria densities was found at the three stations in predominantly agricultural drainage areas. The variation in densities

Table 23. *Escherichia coli* densities in water samples collected at selected sites downstream from wastewater-treatment plants in the upper Illinois River Basin, June 28–30, 1988
[ft^3/s, cubic feet per second]

Station name (map reference number[1])	Date	Time (hour)	Stream discharge (ft^3/s)	Wastewater-treatment-plant discharge (ft^3/s)	Density in colonies per 100 milliliters
Du Page River at Shorewood, Ill. (69)	June 28	1430	82.4	—Multiple wastewater-treatment	383
		1600	79.3	plants upstream, cumulative	97
		1800	79.3	discharge is unknown—	66
		2000	76.1		112
		2200	79.3		410
		2400	79.3		390
	June 29	0200	82.4		61
		0500	82.4		440
		0600	79.3		2,500
		0800	79.3		270
		1000	79.3		250
		1200	82.4		1,333
Fox River at South Elgin, Ill. (91)	June 29	1500		20	4,700
		1700	Daily mean	19	460,000
		1900	discharge[2]	23	7,670
		2100	= 182 ft^3/s	17	133,000
		2300		19	380,000
	June 30	0100		15	173,000
		0300	Daily mean	9	6,360
		0500	discharge[2]	11	69,700
		0700	= 196 ft^3/s	21	1,790
		0900		17	1,650
		1100		18	2,300
		1300		17	500

[1]See table 3 and figure 4.

[2]Daily mean discharge estimated from regression with measured discharge at Fox River at Algonquin, Ill. (89).

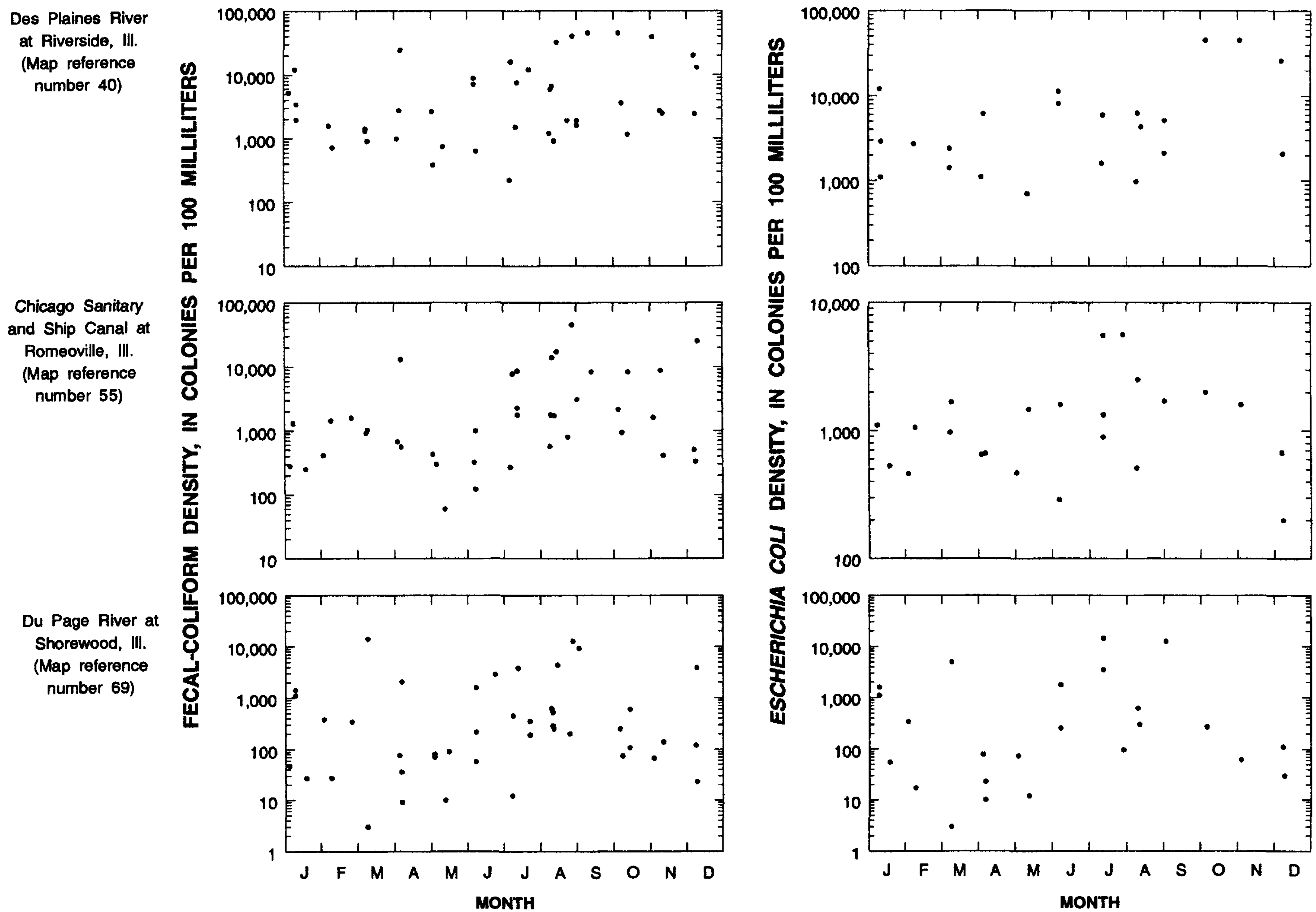


Figure 25. Temporal variation of fecal coliform and *Escherichia coli* densities at the eight fixed surface-water stations in the upper Illinois River Basin, April 1987 through August 1990.

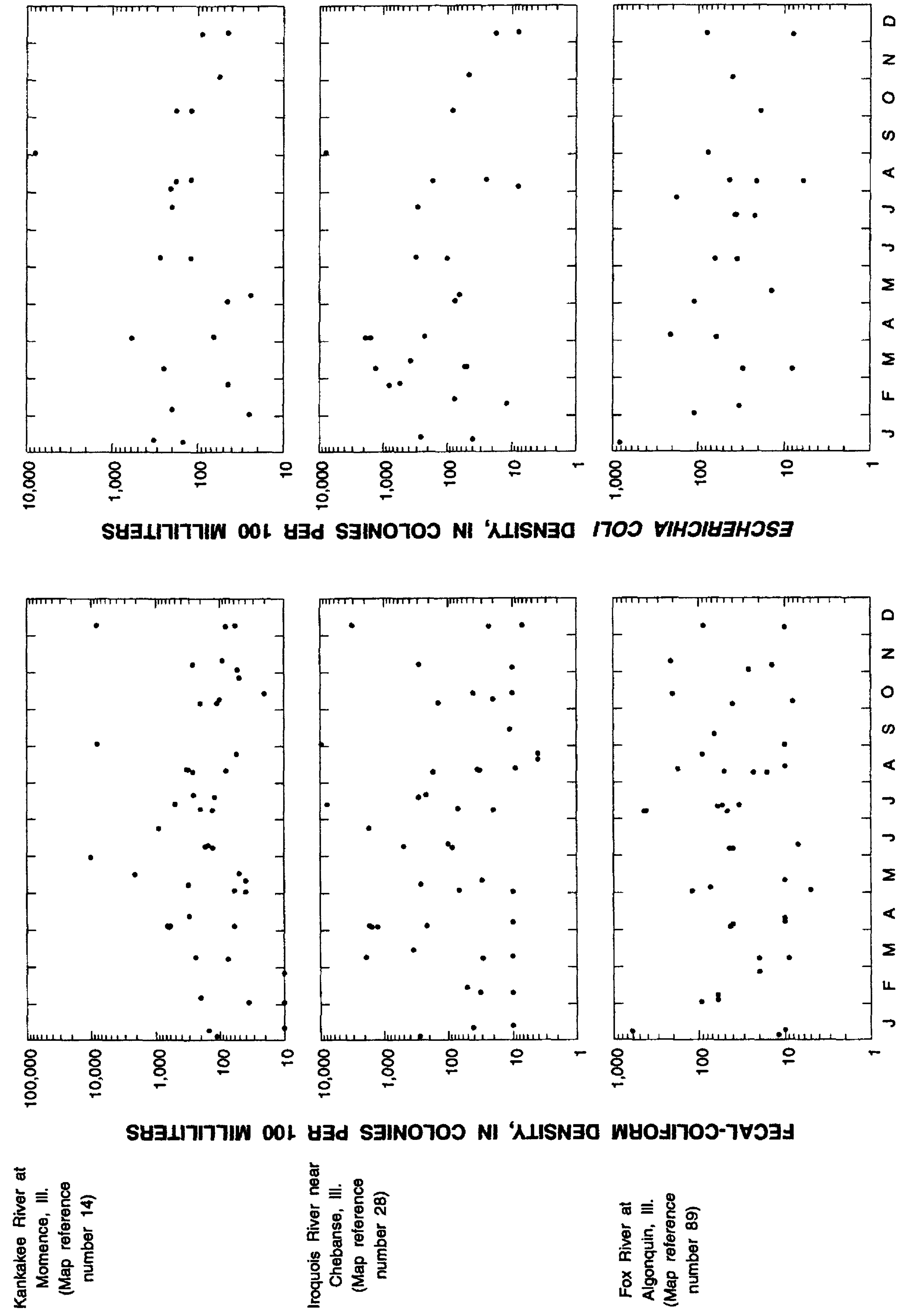


Figure 25. Continued.

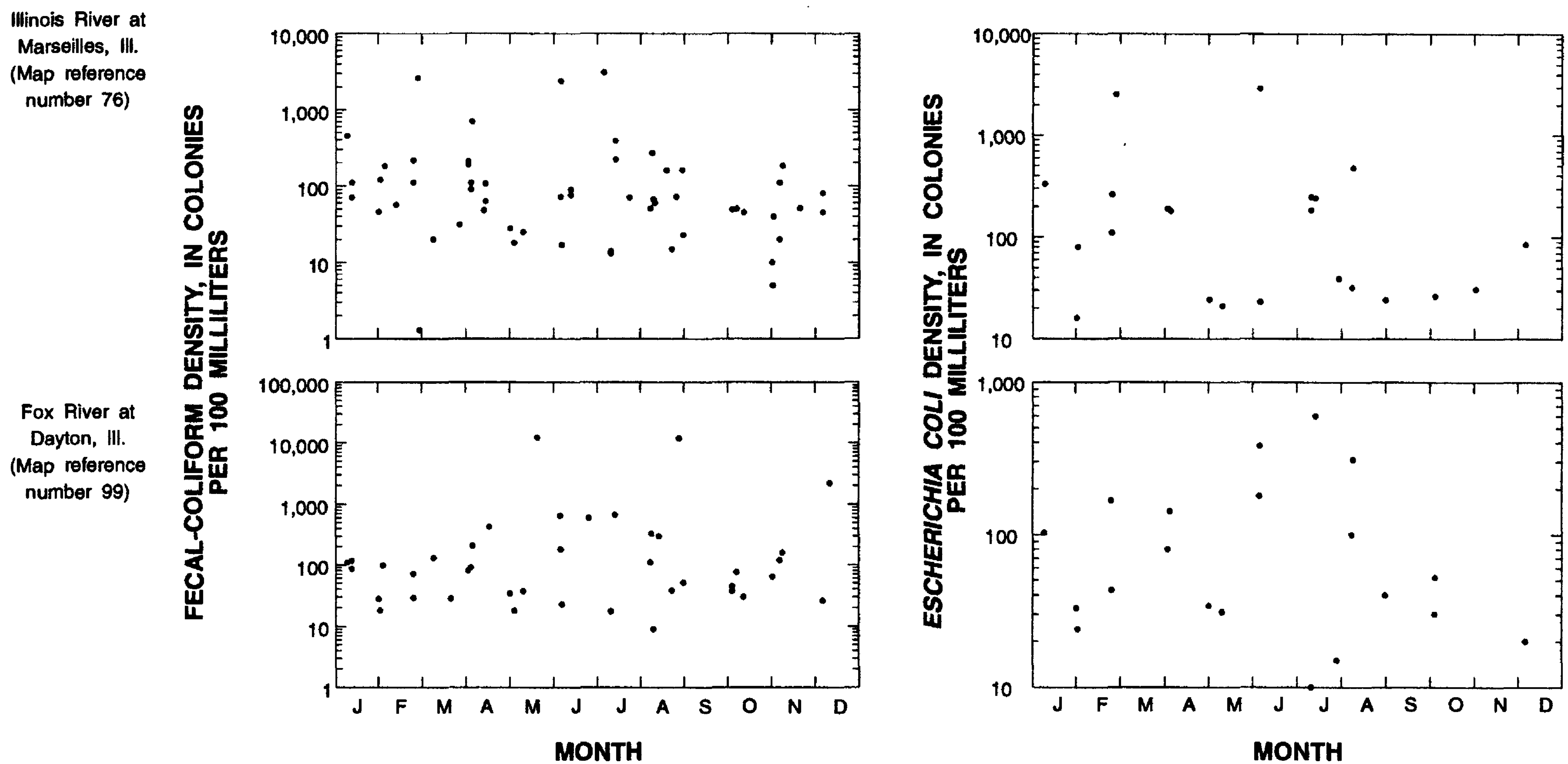


Figure 25. Continued.

among samples collected at these stations typically was as large or larger than any seasonal variation in densities.

E. coli densities were measured in water samples collected during the low-flow synoptic survey in 1988. During these conditions, point-source inputs and effects of these inputs are enhanced because of low natural streamflow and limited dilution potential. *E. coli* densities larger than Federal criteria for moderately and infrequently used full-body-contact recreation were measured at sites in every major river basin in the upper Illinois River Basin (fig. 26). The largest densities, up to 54,000 col/100 mL, were measured at sites on the secondary-contact designated streams and canals in the Chicago area. These large densities result from the discharge of wastewater to the streams. Although the low-flow synoptic survey was done during drought conditions, streamflow in many of the canals is maintained by water diverted from Lake Michigan to provide for the dilution of wastewater. Most of the sites with large *E. coli* densities were downstream from wastewater-treatment plants, although some sites were up to 10 mi downstream from some of the smaller treatment plants and the effect of the effluent on these densities this far from treatment plants is undetermined. At the two most downstream sites in the upper Illinois River Basin, Fox River at Dayton and Illinois River at Marseilles, *E. coli* densities were among the smallest in the basin. The combined streamflows at these two stations represent the total stream-water outflow from the upper Illinois River Basin, and the measured *E. coli* densities indicated that the large densities at some sites in the upper Illinois River Basin are attenuated before the streamflow leaves the basin.

No significant trends in fecal-coliform densities were found for 1987–90 at any of the fixed stations. Because *E. coli* data were not collected until the latter part of 1988, no trend analyses of *E. coli* data were done. Fecal-coliform-density data collected during the NAWQA program were combined with data collected by the IEPA during 1978–86 to form a data set of monthly values for 1978–90. No significant regressions between fecal-coliform densities and streamflow were found at any of the fixed stations; therefore, no flow adjustment of bacteria densities was done. Significant downward trends in fecal-coliform densities for this period were identified at three of the fixed stations: Iroquois River near Chebanse, Fox River at Algonquin, and Fox River at Dayton (table 24). Kammerer (in press) found a downward trend in flow-adjusted fecal-coliform densities at Iroquois River near Chebanse for 1978–86.

SUMMARY

Data collected by the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) program were used to describe the presence, spatial distribution, and temporal variability of nutrients, dissolved oxygen (DO), and fecal-indicator bacteria in the upper Illinois River Basin in Illinois, Indiana, and Wisconsin from 1987 through 1990.

Table 24. Results of the seasonal Kendall trend test for fecal-coliform bacteria densities at the eight fixed surface-water stations in the upper Illinois River Basin, 1978–90

[Underlining indicates those test results considered to be statistically significant based on a probability level of 0.1000]

Station name (map reference number[1])	Number of observations	Probability level	Units per year	Percent of median per year
Kankakee River at Momence, Ill. (14)	94	0.4959	–6.7	–4.4
Iroquois River near Chebanse, Ill. (28)	91	.0025	–20.0	–13.5
Des Plaines River at Riverside, Ill.[2] (40)	31	1.0000	50.0	1.8
Chicago Sanitary and Ship Canal at Romeoville, Ill.[2] (55)	32	.3407	–335	–33.0
Du Page River at Shorewood, Ill. (69)	91	.1543	–11.6	–4.0
Illinois River at Marseilles, Ill. (76)	62	.8643	–1.0	–1.0
Fox River at Algonquin, Ill. (89)	104	.0693	–4.5	–7.0
Fox River at Dayton, Ill. (99)	92	.0082	–22.8	–14.2

[1]See table 3 and figure 4.

[2]Trends at these stations are from 1987–90.

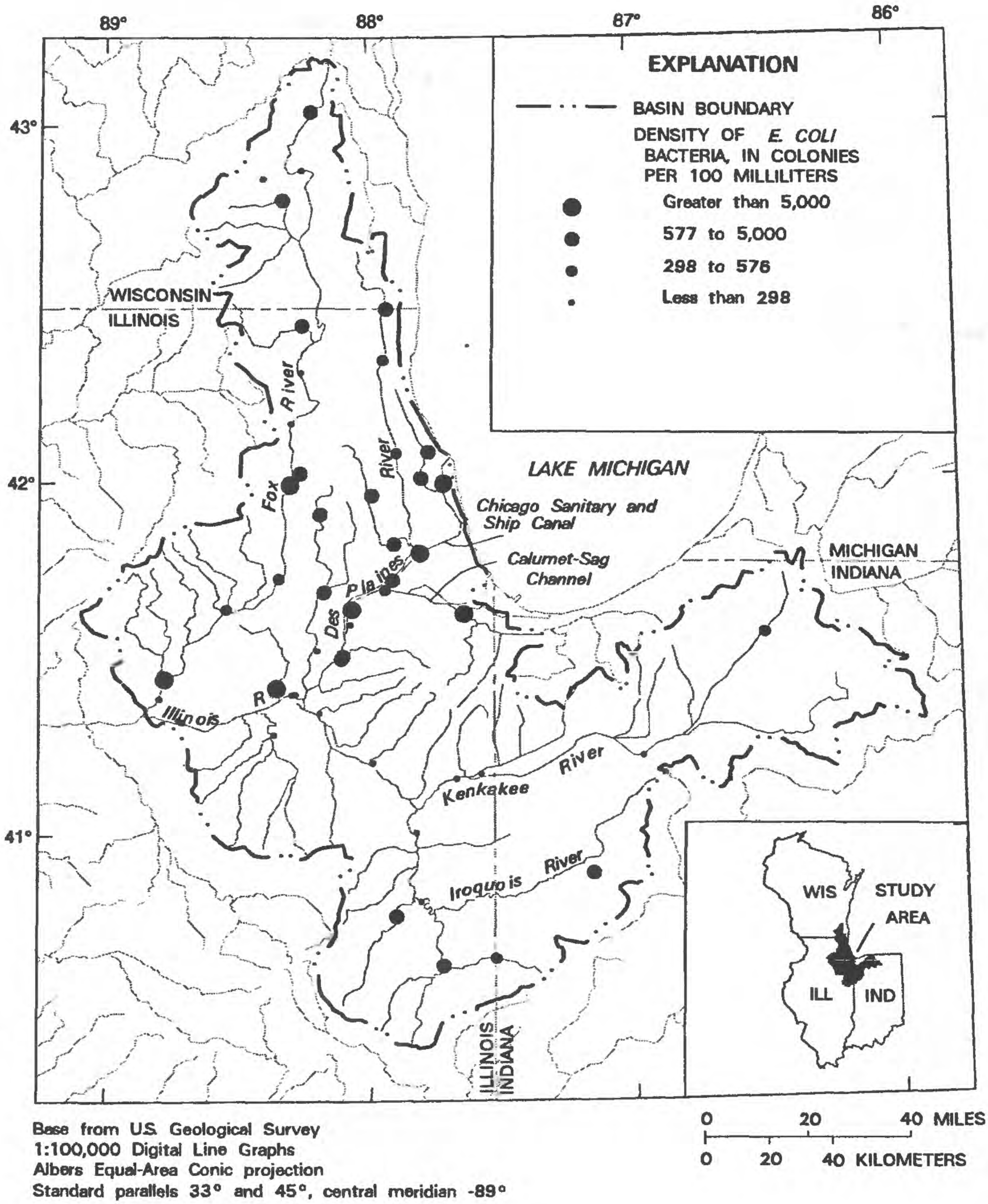


Figure 26. Spatial distribution of *Escherichia coli* densities at the low-flow synoptic-survey surface-water sites in the upper Illinois River Basin, July 26 through August 13, 1988.

Data from 1978 through 1986 were available from the Illinois Environmental Protection Agency (IEPA) and were used in conjunction with USGS data to assess long-term trends in concentrations. Five nutrient forms—total nitrogen, dissolved nitrite plus nitrate ($NO_2 + NO_3$), total ammonia, total organic nitrogen, and total phosphorus—were used to represent nutrient conditions in the upper Illinois River Basin.

Numerous sources of nutrient inputs to the upper Illinois River Basin, including wastewater-treatment plants, agricultural runoff, urban runoff, precipitation, ground water, Lake Michigan withdrawals and diversions, soil erosion, and plant material were found. These sources supplied an estimated 247,000 tons of nitrogen and 94,000 tons of phosphorus to streams in the upper Illinois River Basin each year. The quantities of nutrients input to upper Illinois River Basin streams from these sources is unknown. Approximately 74,730 tons of nitrogen and 3,850 tons of phosphorus are exported from the upper Illinois River Basin each year by the Illinois River.

Nutrient concentrations in streams in the upper Illinois River Basin generally were larger than concentrations typically found in natural waters. Nutrient concentrations in streams in urban areas, particularly in the Des Plaines River Basin, generally were larger than in streams in other areas of the upper Illinois River Basin. Median concentrations of total nitrogen at the fixed stations ranged from 2.20 to 9.78 mg/L. Small concentrations of total nitrogen were found at Kankakee River at Momence, and large concentrations were found at Iroquois River near Chebanse. Although both of these stations are in agricultural areas, differences in soil types between the drainage areas necessitate different drainage techniques for agricultural fields. Extensive tile drainage in the Iroquois River Basin provides efficient field drainage, resulting in larger nitrogen concentrations in the stream water.

Most of the nitrogen in upper Illinois River Basin streams was present as nitrate, and concentrations of $NO_2 + NO_3$ ranged from 0.22 to 9.80 mg/L at the fixed stations. Median concentrations of ammonia at the fixed stations ranged from 0.01 to 7.40 mg/L. Ammonia concentrations were large at sites used to monitor urban drainage areas and at sites where substantial upstream inputs from wastewater-treatment plants occur. Organic nitrogen concentrations ranged from 0.87 to 1.70 mg/L at the fixed stations. Organic nitrogen comprised a large fraction of the total nitrogen concentration at the stations in the Fox River Basin. During the low-flow synoptic survey, the largest organic nitrogen concentrations (up to 14.2 mg/L) were found in water samples from streams in the Des Plaines River Basin. Point-source inputs were the suspected cause of elevated concentrations of organic nitrogen in streams in the Des Plaines River Basin during low-flow periods.

Median concentrations of total phosphorus ranged from 0.06 to 0.84 mg/L at the fixed stations, and the spatial distribution of phosphorus concentrations was similar to the distribution for total nitrogen. Adsorption of phosphorus to fine-sized sediment particles is suspected as one reason why large phosphorus concentrations are not found in the Iroquois River Basin.

Total nitrogen concentrations were found to be correlated with streamflow at most of the fixed stations. Positive correlations of streamflow and total nitrogen concentrations were found at most stations in agricultural areas, whereas negative correlations were found at most stations in urban areas. These correlations indicate that runoff is a major source of nitrogen to streams in agricultural areas, whereas point-source inputs are a major source of nitrogen in urban areas.

Phosphorus concentrations and streamflow were negatively correlated at four of the fixed stations and positively correlated at Iroquois River near Chebanse. This positive correlation was likely related to the suspension and transport of sediment-related phosphorus during periods of increased streamflow. The negative correlations at the other stations reflect dilution at high streamflow and, in some cases, effects of wastewater inputs at low flows.

The Des Plaines River Basin contributed approximately 41 percent of the total nitrogen load to streams in the upper Illinois River Basin, whereas streams in the Kankakee and Iroquois River Basins contributed about 34 and 14 percent of the total load, respectively. About 30 percent of the total nitrogen load in streams in the upper Illinois River Basin was measured in the Chicago Sanitary and Ship Canal (CSSC).

During low-flow conditions, virtually all of the total nitrogen load was found in streams in the Des Plaines River Basin. Most of this load was attributed to the CSSC, which receives substantial wastewater inputs. The CSSC also was found to convey most ammonia and phosphorus loads under low-flow conditions.

Upward trends in total nitrogen concentrations during 1978–90 were found at three of the fixed stations: Iroquois River near Chebanse, Du Page River at Shorewood, and Fox River at Algonquin. Downward trends in phosphorus concentrations were found at the two most downstream fixed stations, Illinois River at Marseilles and Fox River at Dayton. The upward trends might be caused by increases in the use of fertilizers and increases in urbanization, whereas the downward trends in phosphorus might be a result of decreases in the use of phosphate cleansers and improvements to wastewater-treatment practices.

Seasonal variations in nutrient concentrations were found at several of the fixed stations. Nutrient concentrations typically were large in the winter and small in the summer. Because these variations were detected downstream from different types of land uses, changes in physical, chemical, and biological processes associated with climatic season were likely the key factors responsible for seasonal changes in nutrient concentrations. In addition, changes in nutrient inputs to the streams can vary with climatic season and hydrologic conditions.

Median DO concentrations at the fixed stations ranged from 3.4 mg/L at CSSC at Romeoville to 12.2 mg/L at Fox River at Dayton. Median concentrations at the other fixed stations were 8.7 to 9.7 mg/L. The small DO concentrations in the CSSC are due, in part, to the large amount of wastewater in the CSSC. The relatively large DO concentrations at Fox River at Dayton are likely caused by algae and plant photosynthesis in the pooled area behind a dam upstream from the station.

During the low-flow synoptic survey, 50 to 60 percent of the sites in the Des Plaines and Kankakee River Basins had DO concentrations below the State standard of 5.0 mg/L. All DO concentrations in the Fox River Basin exceeded 5.0 mg/L, and some exceeded 9.0 mg/L.

Diurnal variations in DO concentrations were examined at three of the fixed stations. Substantial variations were found at Fox River at Algonquin, some variations were found at Du Page River at Shorewood, and no variations were found at CSSC at Romeoville. The diurnal changes were driven by plant photosynthesis. The sparsity of aquatic plants in the CSSC, the hydraulic characteristics of the channel, and the large percentage of wastewater limited DO production and reaeration in the CSSC resulted in increases in oxygen demand in the water.

The only significant trends in DO concentrations at the fixed stations during 1978–90 were upward trends at Illinois River at Marseilles and Fox River at Dayton. Water quality measured at these two stations, the two most downstream stations in the upper Illinois River Basin, collectively represent the water quality in streams in the entire upper Illinois River Basin.

In the upper Illinois River Basin NAWQA program, fecal coliform and *Escherichia coli* (*E. coli*) were used to indicate bacterial contamination. Fecal-coliform densities at the fixed stations ranged from 1 to 45,000 col/100 mL. The largest densities were found at stations in urban areas in the Des Plaines River Basin. Median densities for Des Plaines River at Riverside and CSSC at Romeoville were two orders of magnitude larger than the median densities at any of the other fixed stations and are likely results of wastewater inputs to these streams.

Bacteria densities larger than Federal criteria and State standards were found in 30 to 75 percent of the samples collected at the fixed stations in urban areas. In contrast, only 5 to 20 percent of the water samples collected at stations in agricultural areas were found to have bacteria concentrations larger than the Federal *E. coli* criteria for infrequently used full-body-contact recreational waters.

Significant downward trends in fecal-coliform densities during 1978–90 were found at three fixed stations draining largely agricultural basins: Iroquois River near Chebanse, Fox River at Algonquin, and Fox River at Dayton. No significant trends were found at stations in urban areas for 1978–90.

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