

SURFACE-WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN IN ILLINOIS, INDIANA, AND WISCONSIN—RESULTS OF INVESTIGATIONS THROUGH APRIL 1992



U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96-4223

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by Arthur R. Schmidt and Stephen F. Blanchard



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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 specific contamination problems; 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 U.S. 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.

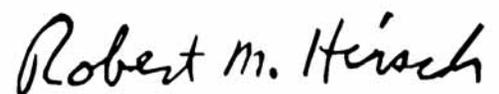
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

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 VERTICAL DATUM

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi ²)	2.590	square kilometer
Flow rate		
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
inch per year (in/yr)	25.4	millimeter per year
Mass		
pound per acre (lb/acre)	1.121	kilogram per hectare
ton per year (ton/yr)	907.2	kilograms per year

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Concentrations of chemical constituents in sediment are given in micrograms per gram (µg/g). Concentrations of fecal-coliform bacteria are given in colonies per 100 milliliters (col/100 mL).

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Abstract

A water-quality assessment of the upper Illinois River Basin (10,949 square miles) was conducted during water years 1987–91. This assessment involved interpretation of available data; 4 years of intensive data collection, including monthly sample collection at eight fixed-monitoring stations in the basin; and synoptic studies of selected water-quality constituents at many sites.

The number of exceedances of water-quality criteria for chromium, copper, lead, mercury, silver, and zinc in water was essentially the same at similar stations between 1978–86 and 1987–90. For water and sediment, a large signature for many trace inorganic constituents was observed from the Chicago metropolitan area, mainly from the Des Plaines River Basin and continuing down the Illinois River. Loads of trace inorganic constituents in water were 2–13 times greater from the Chicago metropolitan area than from rural areas in the upper Illinois River Basin.

Concentrations of cadmium, mercury, nickel, selenium, and zinc appeared to be relatively enriched in biota in the upper Illinois River Basin compared to other river basins. Biota from some urban sites were enriched with respect to several elements. For example, relatively large concentrations of cadmium, chromium, copper, lead, and nickel were observed in biota from sites in the Chicago River in the metropolitan area and the Calumet River.

Results of pesticide sampling in 1988 and 1989 identified the pesticides bromacil, diazinon, malathion, prometon, and simazine as urban related and alachlor, atrazine, cyanazine, metolachlor, and metribuzin as agricultural related.

Phenol concentrations never exceeded general-use and secondary-contact water-quality standards of 100 and 300 micrograms per liter, respectively. Pentachlorophenol concentrations observed at the Illinois River at Marseilles, Ill., between 1981 and 1992 decreased beginning in 1987.

A breakdown product of the organochlorine pesticide dichloro-diphenyl-trichloroethane (DDT), *p,p'*-DDE was the most commonly detected organic compound in biota in both 1989 and 1990. In the nine fish-fillet samples collected in 1989, exceedances of U.S. Environmental Protection Agency (USEPA) fish tissue concentrations were noted for *p,p'*-DDE in all nine fillets and for dieldrin in five of the nine fillets.

Nutrient concentrations in water in the study area generally were larger than concentrations typically found in natural waters. The Des Plaines River Basin contributed approximately 41 percent of the total nitrogen load to the upper Illinois River Basin, whereas the Kankakee River and Iroquois River Basins contributed about 34 and 14 percent of the total load, respectively.

Dissolved oxygen concentrations measured during a 1988 synoptic sampling exceeded State water-quality standards at 76 percent of the

sampled sites. Bacteria densities greater than water-quality standards were observed at all of the fixed-monitoring stations, but densities greater than water-quality criteria and standards were observed more often at stations in the Des Plaines River Basin.

Results from the analysis of changes in water quality following changes in wastewater-treatment practices indicated that current monitoring programs, although sufficient for their intended purposes, are not suitable for this type of retrospective assessment in large-scale water-quality assessments. Changes were not indicated in fish-community structure and population following changes in wastewater-treatment practices.

A strong relation between the quality of the fish community and overall water-quality conditions was observed, although USEPA acute criteria for the protection of freshwater aquatic life were rarely exceeded. Analyses of fish-community data clearly showed that water quality in the urbanized parts of the study area were degraded relative to those in agricultural areas. Total chromium in streambed sediments and total recoverable sodium in water were highly correlated with the fish community.

INTRODUCTION

Background

In 1985, 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 NAWQA Program is designed to address a wide range of water-quality issues, which include chemical contamination, acidification, eutrophication, salinity, sedimentation, sanitary quality, and degradation of the aquatic ecosystems. The long-term 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 current conditions and trends in water

quality. This information will provide an improved scientific basis for evaluating the effectiveness of water-quality management programs and determining the likely effects of contemplated changes in land- and water-management practices to water managers, policy makers, and the public.

The NAWQA Program began as a pilot program in 1986 to test and refine assessment concepts for a fully implemented national program. The upper Illinois River Basin was one of four river basins used to refine the concepts for assessing surface water. A water-quality assessment of the upper Illinois River Basin started in 1986. The first 2 years involved interpretation of available data and planning of future activities, followed by 4 years of intensive data collection. Data-collection activities included monthly sampling at a small number of stations to document temporal variability of constituent concentration. Synoptic studies were conducted at many sites to document the spatial variability of constituent concentrations under specific hydrologic conditions. Concentrations of selected constituents were determined for various media, including water, suspended sediment, streambed sediment, and fish tissues to provide multiple types of assessment. Additional special studies were done to (1) determine the availability and suitability of information on municipal wastewater-treatment practices for large-scale water-quality assessments; (2) identify changes in stream-water quality that could be related to changes in wastewater collection and treatment; and (3) develop protocols for sampling and analysis of fish and macro-invertebrate communities, and relating these communities to water quality.

In this report, station refers to those locations where a USGS identification number was assigned and, generally, more than one sample was collected for analysis of water quality during the study period. Site refers to those locations where no USGS identification number was assigned and, generally, only one sample was collected for analysis of water quality, usually as part of a synoptic survey.

Purpose and Scope

This report summarizes the results of data collected and analyzed as part of the upper Illinois River Basin NAWQA pilot study in Illinois, Indiana, and Wisconsin from 1986 to 1995. As a summary of the study, this report is limited to selected important results. Details about data collection and interpretation

are presented in other reports completed as part of this study (Blanchard and Schmidt, in press; Colman and Sanzalone, 1991; Colman and Sanzalone, 1992; Fitzpatrick and others, 1995; Fitzpatrick and Colman, 1993; Marron and Blanchard, 1995; Maden, 1987; Ruhl, 1995; Steffek and Striegl, 1989; Sullivan and Blanchard, 1994; Sullivan and others, in press; Sullivan and Terrio, 1994; Terrio, 1994a; Terrio, 1994b; Zogorski and others, 1990).

DESCRIPTION OF THE UPPER ILLINOIS RIVER BASIN

The upper Illinois River Basin drains 10,949 mi² of Illinois, Indiana, and Wisconsin and has a mean annual discharge of 12,500 ft³/s. The upper Illinois River Basin is composed of four principal river systems (fig. 1): The Kankakee, which drains 5,165 mi² and contributes 36 percent of the mean annual discharge from the basin; the Fox, which drains 2,658 mi² and contributes 14 percent of the mean annual discharge from the basin; the Des Plaines (except the Chicago Sanitary and Ship Canal), which drains 1,371 mi² and contributes 8 percent of the mean annual discharge from the basin; and the Chicago Sanitary and Ship Canal, which drains 740 mi² and contributes 42 percent of the mean annual discharge from the basin. The high percentage of discharge contributed by the Chicago Sanitary and Ship Canal is the result of water that is diverted from Lake Michigan and returned to the canal. Land use in the basin is 75 percent agricultural, 20 percent urban, and 5 percent forest (fig. 2).

The population in 1990 in the upper Illinois River Basin was 7.6 million. Census data from all counties in the study area (not corrected for the portion of each county outside the study area) indicate that the population in the study area increased by about 1.5 percent from 1980 to 1990. The data also indicated a shift in population from the metropolitan areas to outlying areas. For example, the population of Cook County, Ill., which contains the city of Chicago, decreased by 150,000 from 1980 to 1990, while the population in the four adjacent counties (Du Page, Kane, Lake, and McHenry) increased by a total of 270,000.

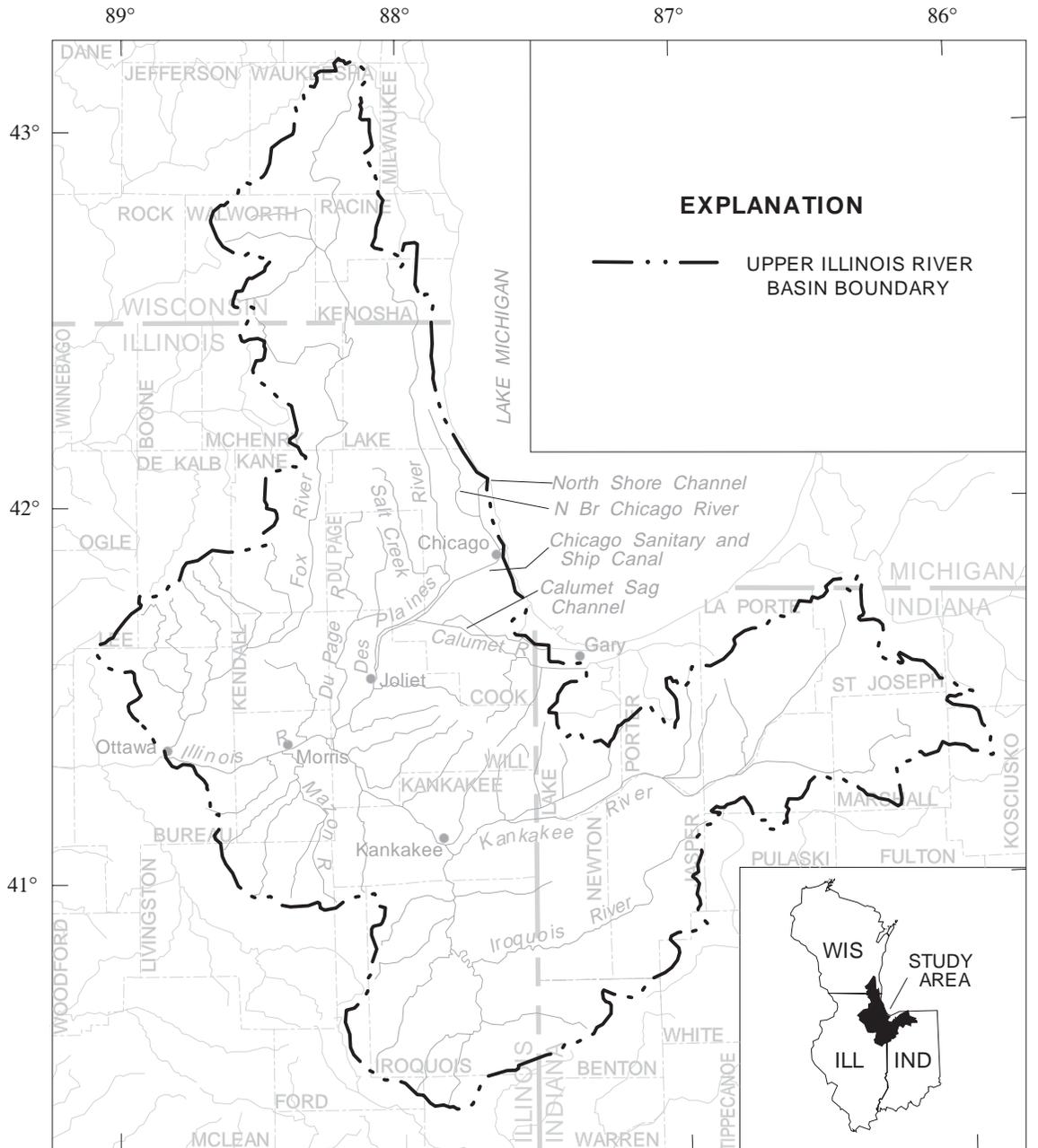
Surface-Water Hydrology and Climate, 1987–90

Runoff in the study area ranges from 8 in/yr in the Wisconsin part of the study area and increases to the south and east to 12 in/yr in parts of Illinois and Indiana. Mean-annual precipitation in the study area ranges from 32 in/yr in Wisconsin and increases to the south and east to 40 in/yr in parts of Indiana (Moody and others, 1986, p. 215–236, 485–492).

Mean discharges observed during the period of this study (water years¹ 1987–91) were greater than those observed over the period of record but were not as large as during the period used for the analysis of available data (water years 1978–86). Data from water years 1948–91 corresponded with the period of record for the precipitation stations and were used in the analysis of available data. The flow-duration curves for water years 1948–91, 1978–86, and 1987–91 for flow from four stations measuring the major subbasins of the upper Illinois River Basin (Kankakee River near Wilmington, Ill., 05527500; Des Plaines River at Riverside, Ill., 05532500; Illinois River at Marseilles, Ill., 05534500; and Fox River at Dayton, Ill., 05552500) are shown for comparison in figures 3 and 4. The curves for water years 1987–91 generally fall between the curves for water years 1948–91 and 1978–86 indicating that discharges during water years 1987–91 were smaller than during 1978–86 but larger than during 1948–91. The greatest differences between the curves were for lower discharges, those that were exceeded more than 50 percent of the time. The curves show that the low flows during water years 1978–86 and 1987–91 were greater than the low flows from the period of record. This especially applies to the stations with a large percentage of urban land use in their drainage basin as shown by the curves for the Des Plaines River at Riverside (05532500).

Precipitation observed during the period of this study (water years 1987–91) was not significantly different from that observed during the period of record (1948–91) and the period used for the analysis of available data (1978–86). The discharge and precipitation analyses indicate that precipitation in the upper Illinois River Basin has not changed appreciably over the

¹The water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.



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 1. Location of the upper Illinois River Basin.

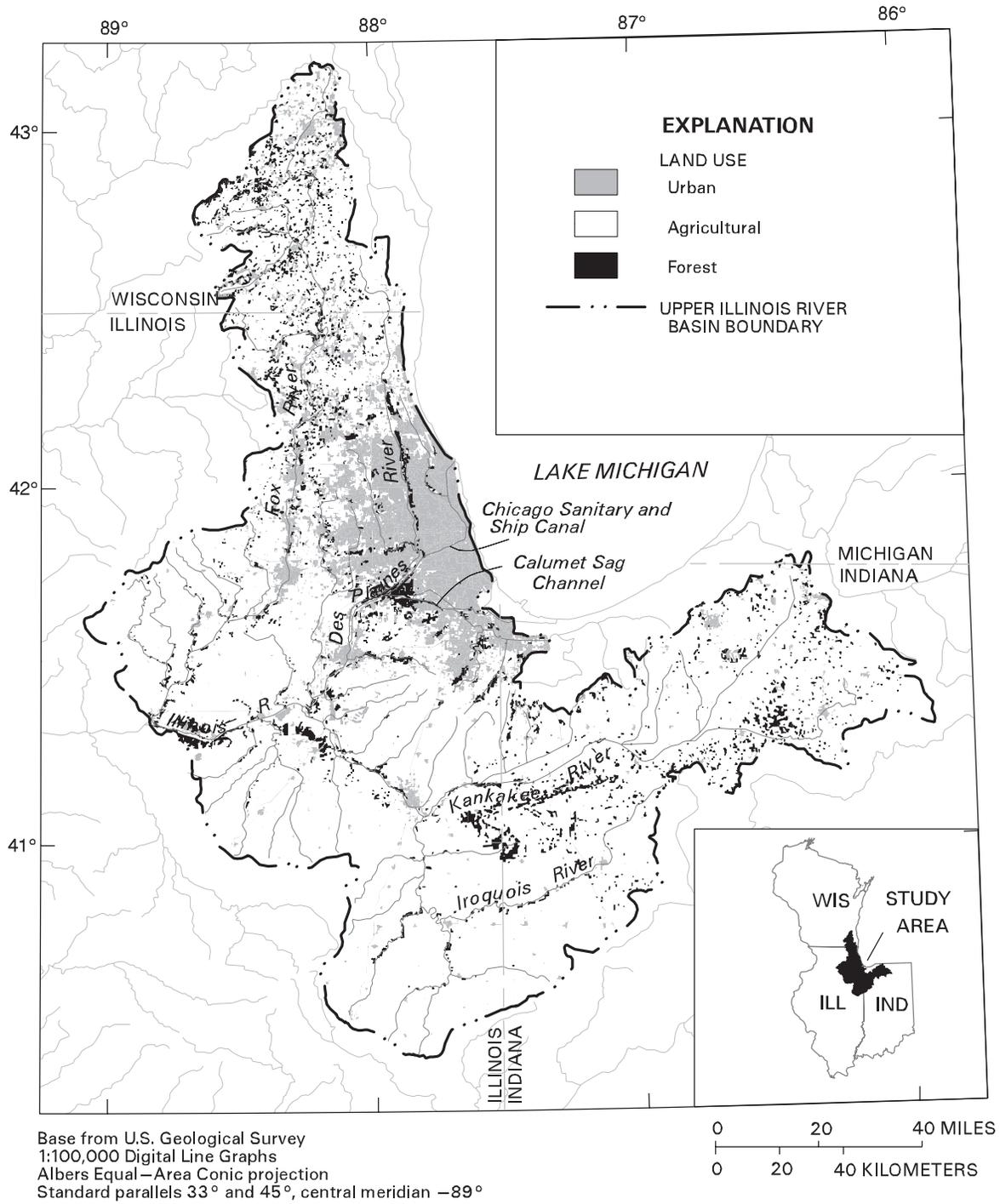


Figure 2. Land use in the upper Illinois River Basin.

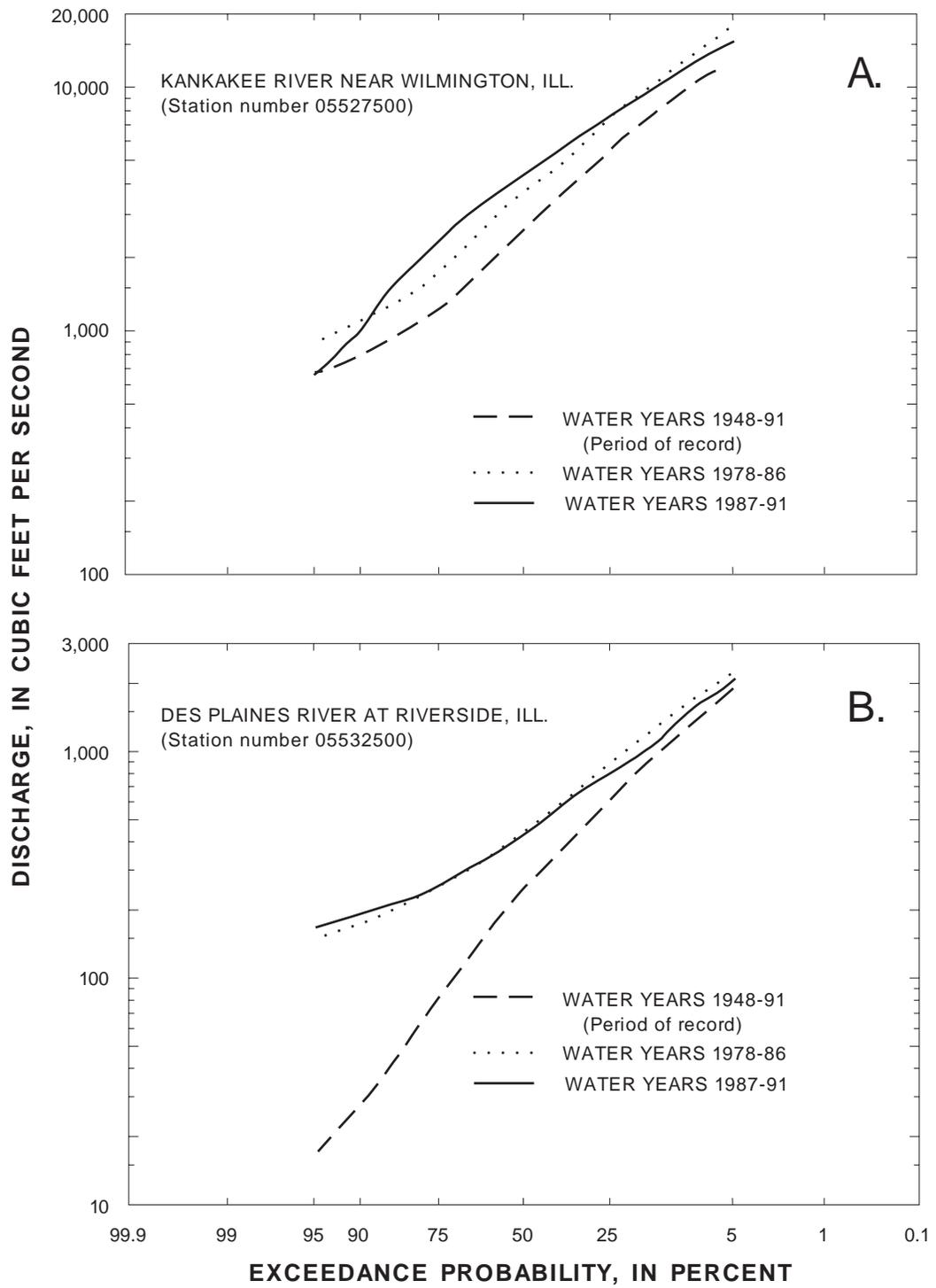


Figure 3. Flow-duration curves for water years 1948–91, 1978–86, and 1987–91 for (A) Kankakee River near Wilmington, Ill. and (B) Des Plaines River at Riverside, Ill.

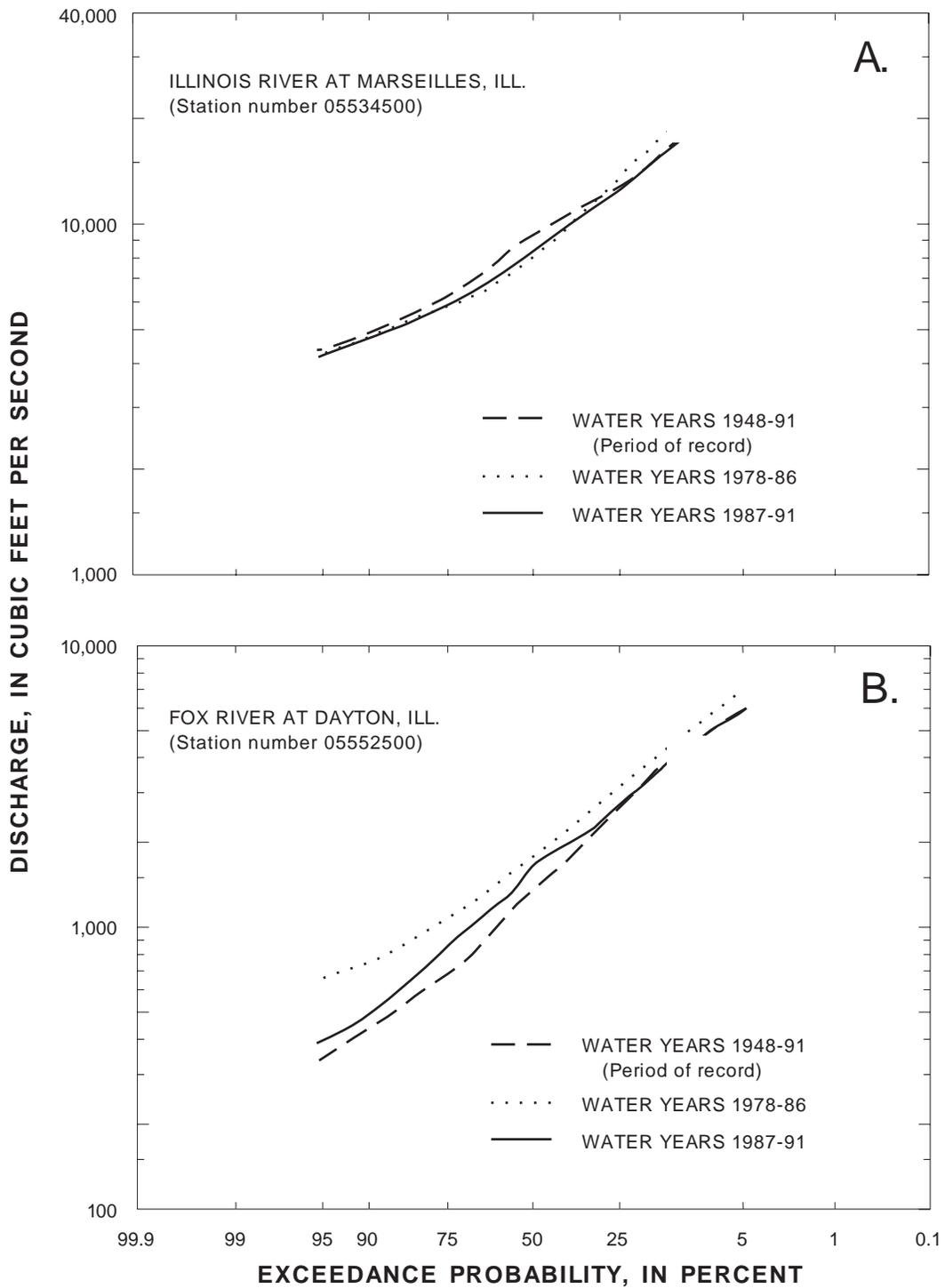


Figure 4. Flow-duration curves for water years 1948–91, 1978–86, and 1987–91 for (A) Illinois River at Marseilles, Ill., and (B) Fox River at Dayton, Ill.

period of record, but the discharge in the basin has increased appreciably over the same period.

Water Use, 1987–90

Average daily water use in the study area in 1985 was about 9,000 Mgal/d. About 19 percent of the water used is withdrawn from Lake Michigan, 76 percent is from surface waters other than Lake Michigan, and 5 percent is ground water from aquifers. Withdrawals from Lake Michigan and aquifers represent water imported to the surface-water system in the study area that contributes to the large amount of return flow.

Several communities in the Chicago metropolitan area changed from ground water to Lake Michigan as their primary water supply in the late 1970's and 1980's. The withdrawals for public water supply for Cook County, Ill., for 1978, 1986, and 1990 water years are listed in table 1. Approximately 80 percent of the total water withdrawals for the public water supply for the study area are from Cook County. Total water withdrawals for the whole study area for public water supply remained essentially unchanged between 1978 and 1990—ground-water withdrawals were reduced by 75 percent, whereas surface-water withdrawals increased.

SUMMARY OF SAMPLING PROGRAMS, APRIL 1987–APRIL 1992

Water and suspended-sediment samples were collected at 40 fixed-monitoring stations between 1987 and 1991. The Illinois Environmental Protection Agency (IEPA) collected water samples from 38 of the 40 stations in the upper Illinois River Basin from 1978 to 1991. Eight of the 40 stations were sampled monthly,

whereas the rest were sampled every 6 weeks. Water samples from all 40 of these sampling stations were analyzed by the IEPA laboratory. Suspended-sediment samples and periodic quality-assurance water samples were analyzed by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo. The location of the eight more intensely monitored stations, operated as part of the NAWQA study of the upper Illinois River Basin, and the additional 32 stations, operated by the IEPA, are shown in figure 5. Additional information for these 32 stations is given in Blanchard and Schmidt (in press).

Water, streambed sediment, suspended sediment, and fish-tissue samples were collected during several synoptic studies performed between 1988 and 1990 (table 2). Streambed-sediment samples were collected at 238 randomly selected sites on low-order streams and 134 sites spaced at regular intervals on high-order streams during fall 1987 (fig. 6) (Colman and Sanzalone, 1991). Fish-tissue samples were collected at 12 stations during the summer of 1989 and at 22 stations during the summer of 1990. Streambed-sediment samples were collected in 1989 and 1990 in conjunction with the fish-tissue sampling. The NAWQA synoptic sampling of trace inorganic constituents in streambed sediment significantly extended the coverage of available data for these constituents. The available data for 77 sites and stations on the main stem streams in Illinois were extended to 436 main stem and first- and second-order stream sites in Illinois, Indiana, and Wisconsin, and increased the coverage from 10 to 46 elements. The NAWQA sampling program for organic compounds was designed to augment available data; sampling was expanded to include locations and compounds not previously sampled. Sampling periods, sampling media, target constituents, and sampling frequencies used in this assessment are listed in table 2.

Table 1. Public water supply withdrawals in Cook County, Ill., for water years 1978, 1986, and 1990

[Data from aggregated water use data system (AWUDS), Stephen R. Tarte, U.S. Geological Survey, written commun., January 12, 1994; Mgal/d, million gallons per day]

Water year	Ground-water withdrawals (Mgal/d)	Surface-water withdrawals (Mgal/d)	Total public water supply withdrawals (Mgal/d)
1978	79.7	1,046	1,125
1986	40.9	1,083	1,124
1990	20.0	1,103	1,123

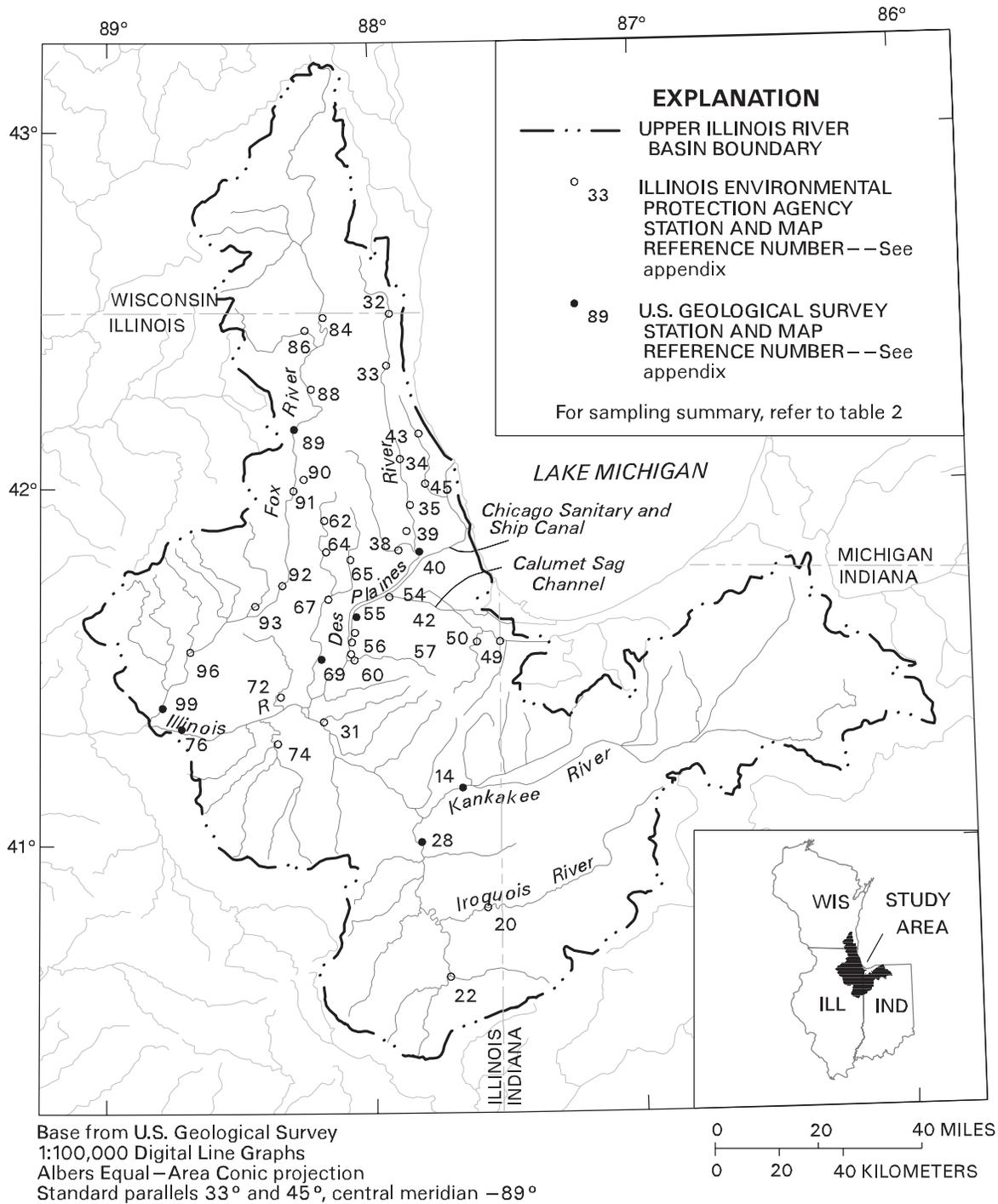


Figure 5. Location of fixed-monitoring stations operated by the Illinois Environmental Protection Agency and the U.S. Geological Survey in the upper Illinois River Basin, water years 1987–91.

Table 2. Summary of sampling performed for the water-quality assessment of the upper Illinois River Basin, water years 1987–92

[Bed, streambed sediment; VOC's, volatile organic compounds; BNA, base- neutral-, and acid-extractable organic compounds; DO, dissolved oxygen; fecal, fecal-indicator bacteria]

Number of sampling sites and stations	Period	Sampling frequency	Sampling type	Constituent category	Media sampled
Major- and Trace-Inorganic Constituents					
8	Apr. 1987–Aug. 1990	Monthly	Fixed station	Inorganic	Water
8	Apr. 1987–Aug. 1990	Monthly	Fixed station	Inorganic	Suspended sediment
4	Sept. 1990–Apr. 1992	Monthly	Fixed station	Inorganic	Water
4	Sept. 1990–Sept. 1991	Bimonthly	Fixed station	Inorganic	Suspended sediment
373	Fall 1987	Once	Synoptic	Inorganic	Bed
16	Summer 1989	Once	Synoptic	Inorganic	Water
16	Summer 1989	Once	Synoptic	Inorganic	Biota
25	Summer 1990	Once	Synoptic	Inorganic	Bed
25	Summer 1990	Once	Synoptic	Inorganic	Biota
Organic Compounds					
2	Aug. 1988–Mar. 1990	Monthly	Fixed station	Organic	Water
31	July 1988	Once	Synoptic	VOC's	Water
21	July 1988	Once	Synoptic	BNA	Water
16	Summer 1989	Once	Synoptic	Organic	Biota
83	Aug. 1989	Once	Synoptic	Organic	Bed
25	Summer 1990	Once	Synoptic	Organic	Bed
25	Summer 1990	Once	Synoptic	Organic	Biota
4	Summer 1988 and summer 1989	Variable ¹	Runoff event	Herbicides and insecticides	Water
17	Summer 1990	Variable ²	Runoff event	Herbicides	Water
Dissolved Oxygen, Nutrients, Fecal-Indicator Bacteria, and General³					
8	Apr. 1987–Aug. 1990	Monthly	Fixed station	General	Water
4	Sept. 1990–Apr. 1992	Monthly	Fixed station	General	Water
⁴ 32	Prior to 1986 to present	6 weeks	Fixed station	General	Water
20	Aug. 1987	Once	Synoptic	Nutrients and DO	Water
59	July 1988–Aug. 1988	Once ⁵	Synoptic	Nutrients, DO, and fecal	Water
Biological Survey					
12	Summer 1989	Twice ⁶	Synoptic	Community	Biota
22	Summer 1990	Twice ⁷	Synoptic	Community	Biota

¹Total of 25 samples collected during 4 storms and intervening low-flow periods.

²More than 400 samples collected during 3 major storms and intervening low-flow periods.

³Includes measurement of physical parameters, nutrients, fecal coliform and *Escherichia coli* bacteria, major ions, chemical oxygen demand, suspended solids, and 21 metals.

⁴Sampled by the Illinois Environmental Protection Agency.

⁵Four stations were sampled hourly for a 24-hour period.

⁶Fish-community samples collected at all stations; invertebrate-community and algae samples and habitat data also collected at selected stations.

⁷Fish-community samples collected at all stations; invertebrate-community and algae samples and habitat data also collected at selected stations.

Sampling stations included in the water-quality assessment of the upper Illinois River Basin are listed in the appendix. Synoptic sampling sites for organic compounds and trace elements in streambed sediment are not listed. The locations of the sampling sites and stations used in this assessment are shown in figures 6–11.

WATER-QUALITY CONDITIONS (1987–91) AND TRENDS (1978–91) IN THE UPPER ILLINOIS RIVER BASIN

The water-quality assessment of the upper Illinois River Basin targeted different groups of constituents for sampling and analysis. The observed water-quality conditions and trends in the study area for these constituent groups are described in this section. The spatial distribution of concentrations from three different media (water, sediment, and biota) is summarized and compared with water-quality standards and factors that may affect concentrations in the media. These factors include land use, location of point sources, and flow conditions.

Trace Inorganic Constituents

Trace inorganic constituents include alkaline-earth metals, transition metals, other metallic elements at the end of the transition series, and nonmetallic elements; many of these elements are naturally in low concentrations in surface water. Trace elements are defined as elements that normally are present in water at concentrations of less than 1 mg/L (Hem, 1985). Concentrations greater than 1 mg/L may result from weathering of ore-bearing rocks and sediments, industrial and municipal effluents, urban and agricultural runoff, and atmospheric deposition. Twelve of the trace inorganic constituents have been listed by the U.S. Environmental Protection Agency (USEPA) as priority pollutants. These are antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc.

Results of sampling three media indicate that many major and trace inorganic constituents are elevated or enriched (above background concentrations) in the upper Illinois River Basin. A description of the method for determining background concentrations is presented in Fitzpatrick and others (1995). However, those elements that were elevated at sites

in one media were not necessarily elevated in all three media at the same sites.

Concentrations in water and fine-grained (<62 micrometers) streambed sediment from 1978 to 1986 are similar to concentrations in water and fine-grained streambed sediment from 1987 to 1990. The number of exceedances of water-quality criteria for chromium, copper, lead, mercury, silver, and zinc in water were essentially the same at similar stations (mainly in the Des Plaines River Basin) between these periods (Fitzpatrick and others, 1995, p. 29). The results from this study are not adequate to evaluate whether exceedances in water affected the healthy propagation and distribution of biological communities.

Some of the most intensively used urban and industrial land within the basin is in the Chicago metropolitan area, although concentrations of many of the trace inorganic constituents in water were below the minimum reporting level, which limited the degree of analysis. Analytical techniques with lower minimum reporting levels are required to evaluate the occurrence and distribution of trace inorganic constituents in water in the basin, especially in nonurban areas. Minimum reporting levels used in this study were just low enough to adequately classify concentrations that exceeded water-quality criteria.

In general, the spatial distribution of trace inorganic constituents in the upper Illinois River Basin indicated enrichment from the urban areas. For water and fine-grained sediment, a large signature for many of the trace inorganic constituents was observed from the Chicago metropolitan area, mainly from the Des Plaines River Basin and continuing down the Illinois River. Loads of trace inorganic constituents in water were 2–13 times greater from the Chicago metropolitan area than from rural areas in the upper Illinois River Basin. The signature of elevated concentrations from the Chicago metropolitan area in water and sediment was observed in the Illinois River downstream from the confluence of the Des Plaines and Kankakee Rivers. The pattern of enrichment of normalized concentrations of trace inorganic constituents from the Chicago area is shown in figure 12. In the normalization, concentration values were converted to a zero-to-one scale by subtracting the lowest basin-wide concentration from each value and dividing the difference by the range in concentrations for the basin (highest concentration minus lowest concentration) (Colman and Sanzalone, 1991, p. 938).

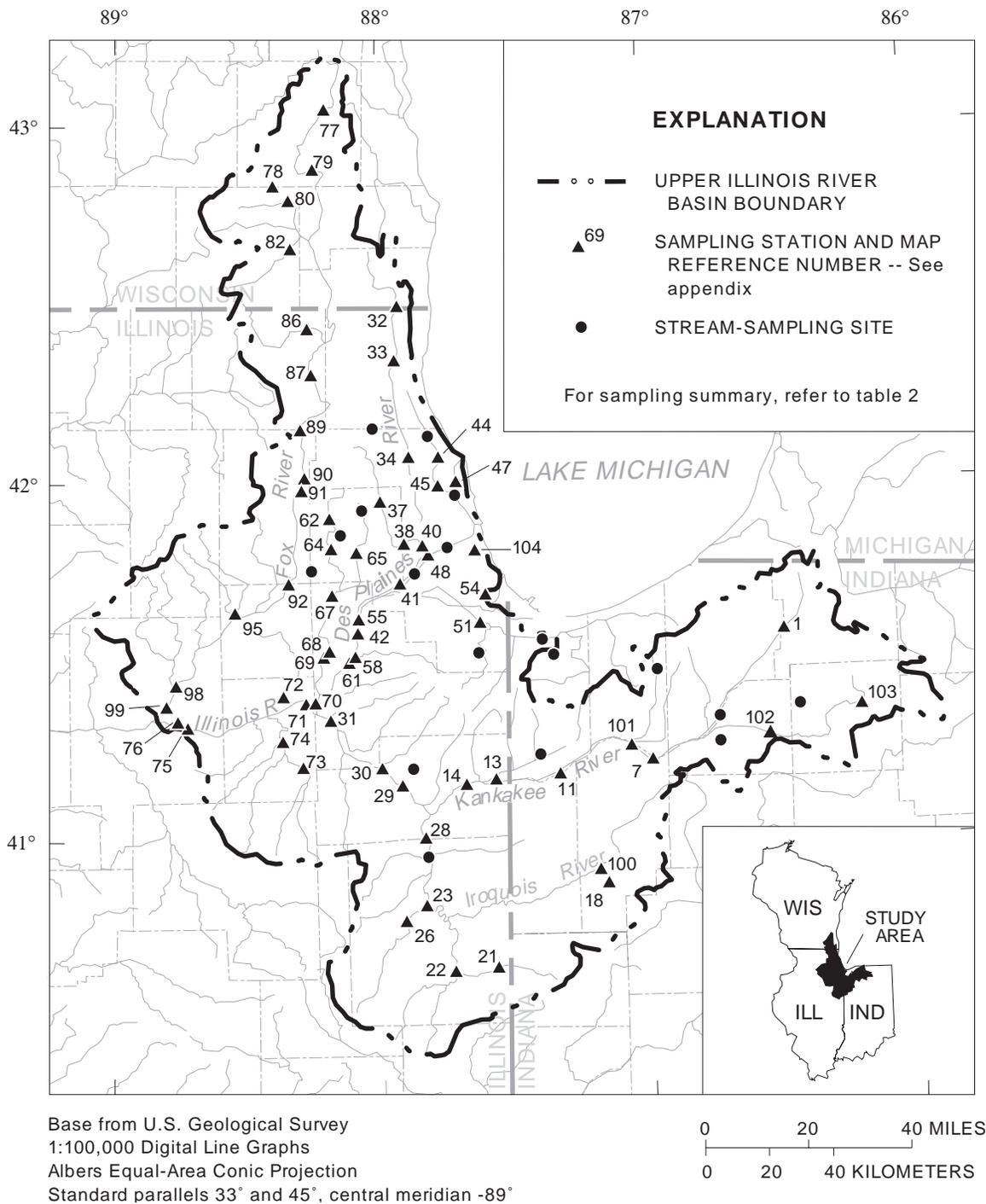


Figure 7. Sampling stations and sites used in the synoptic survey of organic compounds in streambed sediment in the upper Illinois River Basin, 1989.

The highest arsenic concentrations in water, sediment (Colman and Sanzalone, 1992), and biota were observed at sites in the upper Kankakee River Basin. Agricultural use of arsenic-based chemicals (insecticides, herbicides, algacides, and desiccants)

has resulted in the largest anthropogenic source of arsenic in the environment (Woolson, 1975, as cited in Eisler, 1988a). However, agricultural use of arsenic alone cannot explain the higher concentrations in the upper Kankakee River Basin because the Iroquois

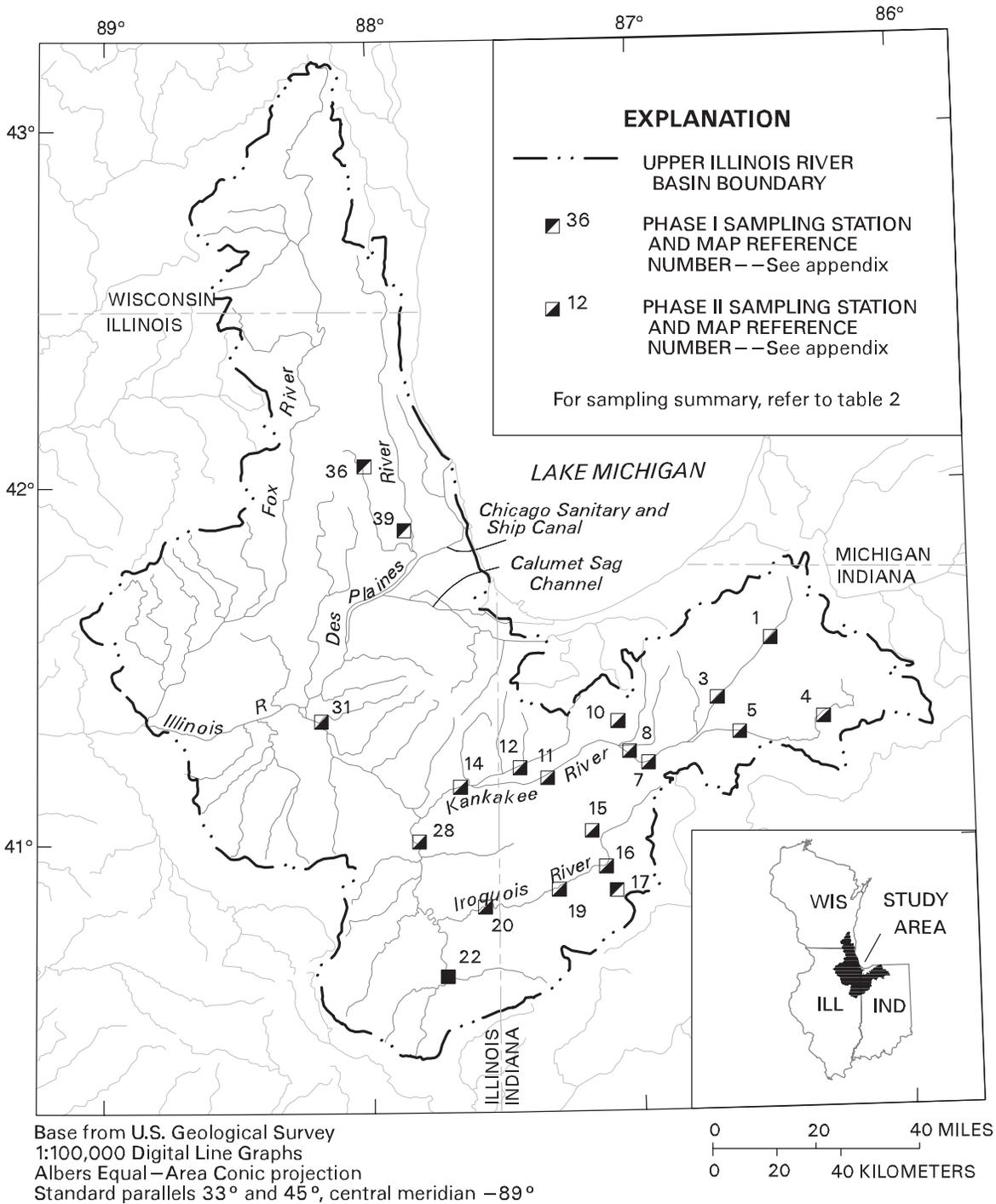


Figure 9. Sampling stations included in Phase I and Phase II pesticide in water sampling in the upper Illinois River Basin, 1988–89.

Kankakee River Basin has resulted in more arsenic associated with iron and manganese coatings, making arsenic more bioavailable. Gross and Berg (1981), however, found that whole-sediment samples from the Kankakee River between the mouth of the Iroquois

River and the city of Kankakee, Ill., contained only 1-4 percent clay-sized sediment, and concentrations of arsenic in whole-sediment samples from this same reach were lower than those from all other locations in the State included in their study (Gross and Berg, 1981,

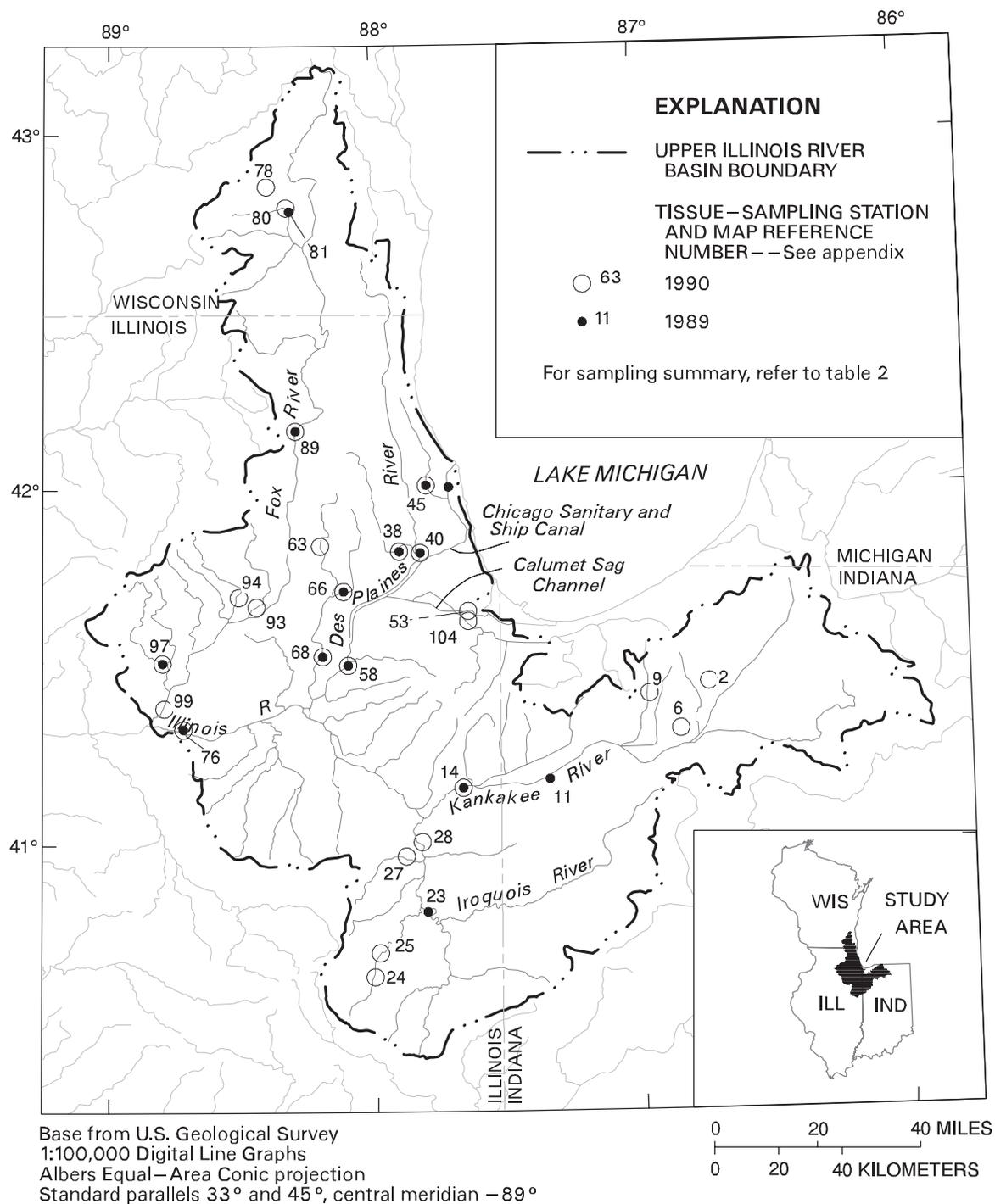


Figure 11. Sampling stations included in synoptic surveys for fish and macroinvertebrate tissue and communities in the upper Illinois River Basin, 1989–90.

three media differs. For example, elevated strontium concentrations were observed in water and biota in the Du Page River and Fox River Basin, whereas concentrations of strontium in streambed sediment

were elevated in the Fox River Basin but not in the Du Page River Basin.

Results from the synoptic sampling for trace inorganic constituents in fine-grained streambed

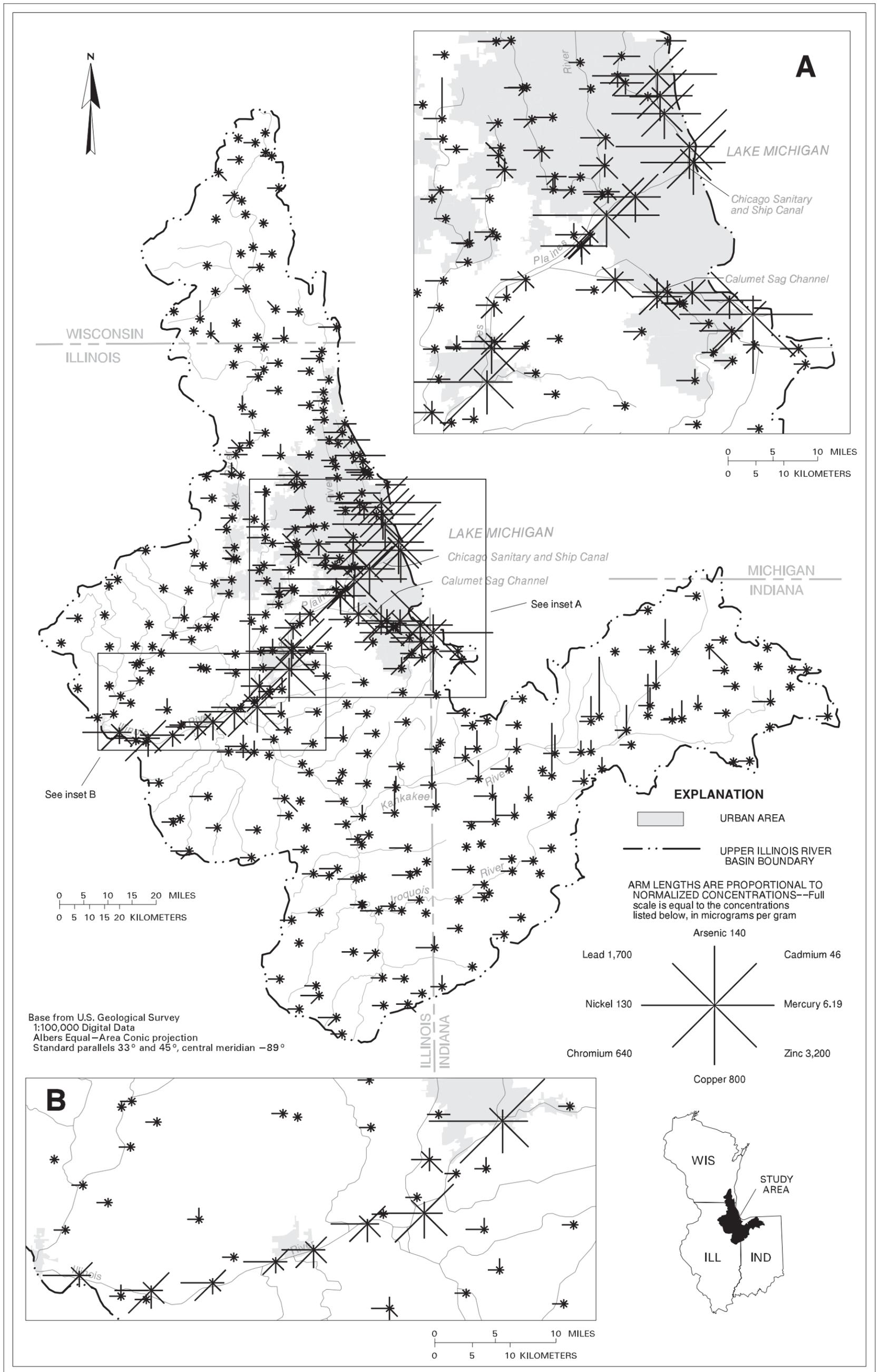


Figure 12. Normalized concentrations of selected trace inorganic constituents in the upper Illinois River Basin, 1989.

sediments indicate two distinctive patterns of enrichment: (1) Enrichment in the Chicago metropolitan area and in streams draining the urban area, relative to rural areas (fig. 12); (2) enrichment in high-order streams (monostems), relative to low-order streams (tributaries) (fig. 13). Ratios among trace inorganic constituents were variable in samples from the Chicago urban area, indicating that element sources were variable. Ratios among trace inorganic constituents in samples from the Illinois and lower Des Plaines Rivers (downstream from Chicago) were constant, but concentrations decreased downstream indicating that the upstream sediments were diluted downstream. Ratios and concentrations of these elements in the fine-fraction streambed sediments from the Illinois River (downstream from the confluence with the Kankakee River) indicate that sediments originating from the Chicago area are diluted to 35-40 percent of original concentrations by other sources of sediment.

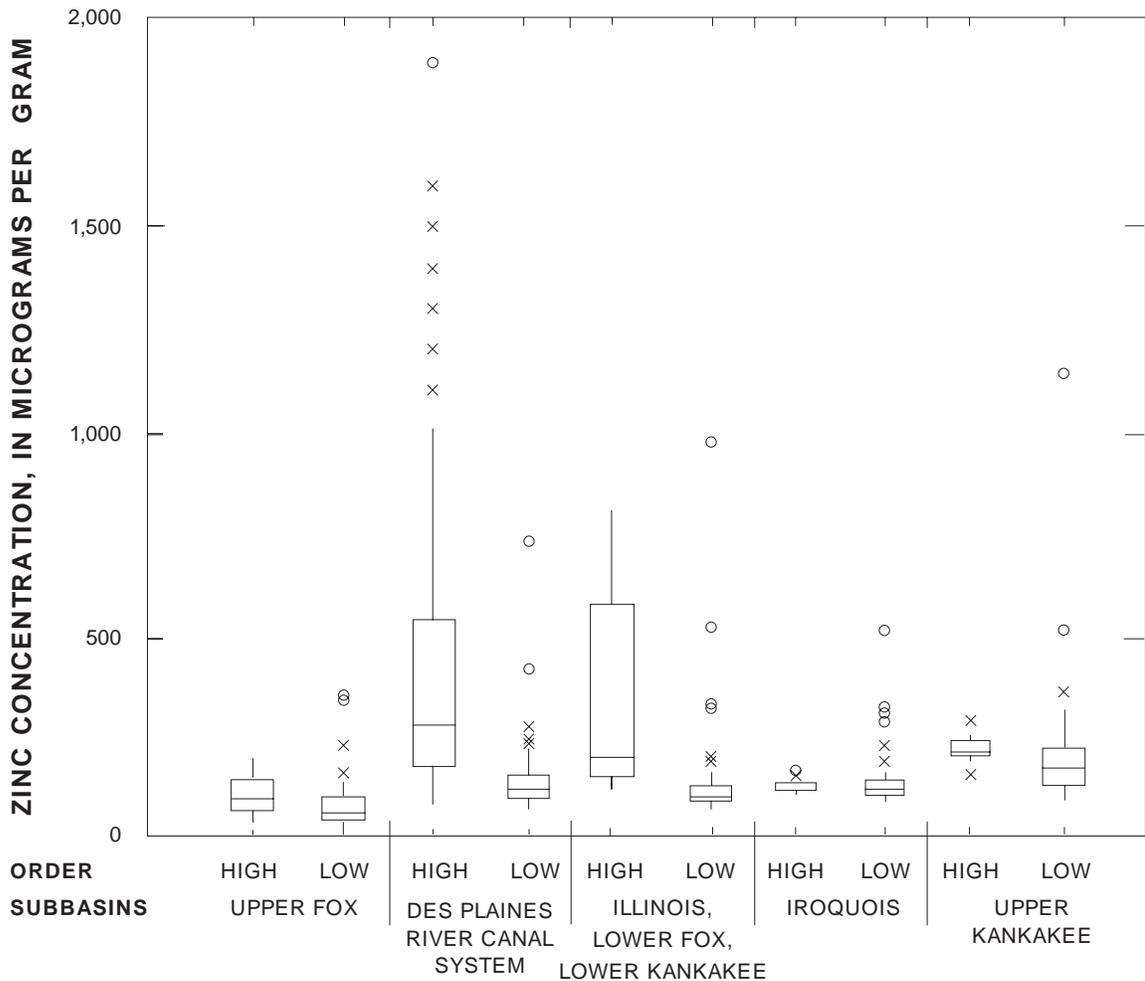
The exceedance probability for concentrations of chromium and lead in fine-grained streambed sediment is shown in figure 14. The curve for chromium from high-order streams breaks at 90 $\mu\text{g/g}$. All but one of the chromium concentrations observed in low-order streams were less than 90 $\mu\text{g/g}$. Concentrations greater than 90 $\mu\text{g/g}$ were mainly clustered in the Chicago metropolitan area. The curves for lead concentrations for high- and low-order streams break at 40 $\mu\text{g/g}$. Lead concentrations greater than 40 $\mu\text{g/g}$ in fine-grained streambed sediment were mainly in the Chicago metropolitan area and near other medium-sized urban areas outside of Chicago. Correlation of the trace inorganic constituents in sediments suggests that streams contain a well-mixed variety of elements from municipal wastewater-treatment plants (combined sewer overflows in Chicago); industrial point sources; and urban runoff from streets, parking lots, and buildings.

Concentrations of cadmium, mercury, nickel, selenium, and zinc appeared to be relatively enriched in biota for rural and urban sites across the upper Illinois River Basin compared to other river basins (Fitzpatrick and others, 1995). Several types of biota (clams, crayfish, fish, plants, and snails) were used because of the difficulty of obtaining one target taxa throughout the study area. Biota from some urban sites in the basin contained high concentrations of several elements. Relatively high concentrations of cadmium, chromium, copper, lead, and nickel were observed in whole snails from the North Shore Channel, Ill. (map

reference number 46), in 1989, and high concentrations of chromium and copper also were observed in Eurasian water milfoil collected from this industrial stream. Another industrial stream, the North Branch of the Chicago River at Niles, Ill. (map reference number 45), was enriched for copper and nickel in biota. Copper concentrations in water from this station have exceeded USEPA chronic water-quality criteria. Concentrations of chromium and lead also were relatively large in sago pondweed from the Little Calumet River at Calumet Park, Ill. (map reference number 53), a station located in a highly industrial area. Biota from Salt Creek at Western Springs, Ill. (map reference number 38), a stream in a residential area, contained relatively high concentrations of lead, manganese, nickel, and strontium. Total recoverable concentrations of lead in water from this station have exceeded USEPA chronic criteria.

Samples from the eight fixed-monitoring stations were analyzed for trends in concentrations of trace inorganic constituents between water years 1978 and 1991. Barium, boron, iron, manganese, and strontium concentrations in water decreased at many stations in the upper Illinois River Basin, and strontium concentrations in water increased at a number of other stations. No trends in streamflow were observed at the stations where these elements decreased. Trends in barium and strontium were probably caused by changes in ground-water sources used as water supplies in the Fox and Du Page River Basins. No trends were observed for concentrations of lead in water, which is contrary to what was expected, given the decrease in the use of leaded gasoline in the 1980's (Smith and others, 1987).

The lack of correlations among trace inorganic concentrations in biota and other media in this study emphasizes that concentrations in water and sediment cannot be used as surrogates for concentrations in biota; concentrations in biota cannot presently be estimated from concentrations in these media; and because of bioaccumulation, concentrations of trace elements in biota must be measured directly. A complex variety of chemical, physical, and biological variables affect the bioavailability of trace inorganic constituents from water and sediment. In addition, trace inorganic constituent concentrations in water are essentially instantaneous, whereas concentrations in biota may integrate the effects of water-quality conditions over time. Finally, in instances where ambient levels fall below current analytical detection limits for



EXPLANATION

- — Data value(s) exceeding upper quartile plus 3 times the interquartile range
 - × — Data value(s) exceeding upper quartile plus 1.5 times the interquartile range but less than the upper quartile plus 3 times the interquartile range
-
- Largest data value less than or equal to the upper quartile plus 1.5 times the interquartile range
 - Upper quartile (75th percentile)
 - Median (50th percentile)
 - Lower quartile (25th percentile)
 - Smallest data value greater than or equal to the lower quartile minus 1.5 times the interquartile range

Figure 13. Fine-grained streambed-sediment zinc concentrations, by stream order, in subbasins of the upper Illinois River Basin.

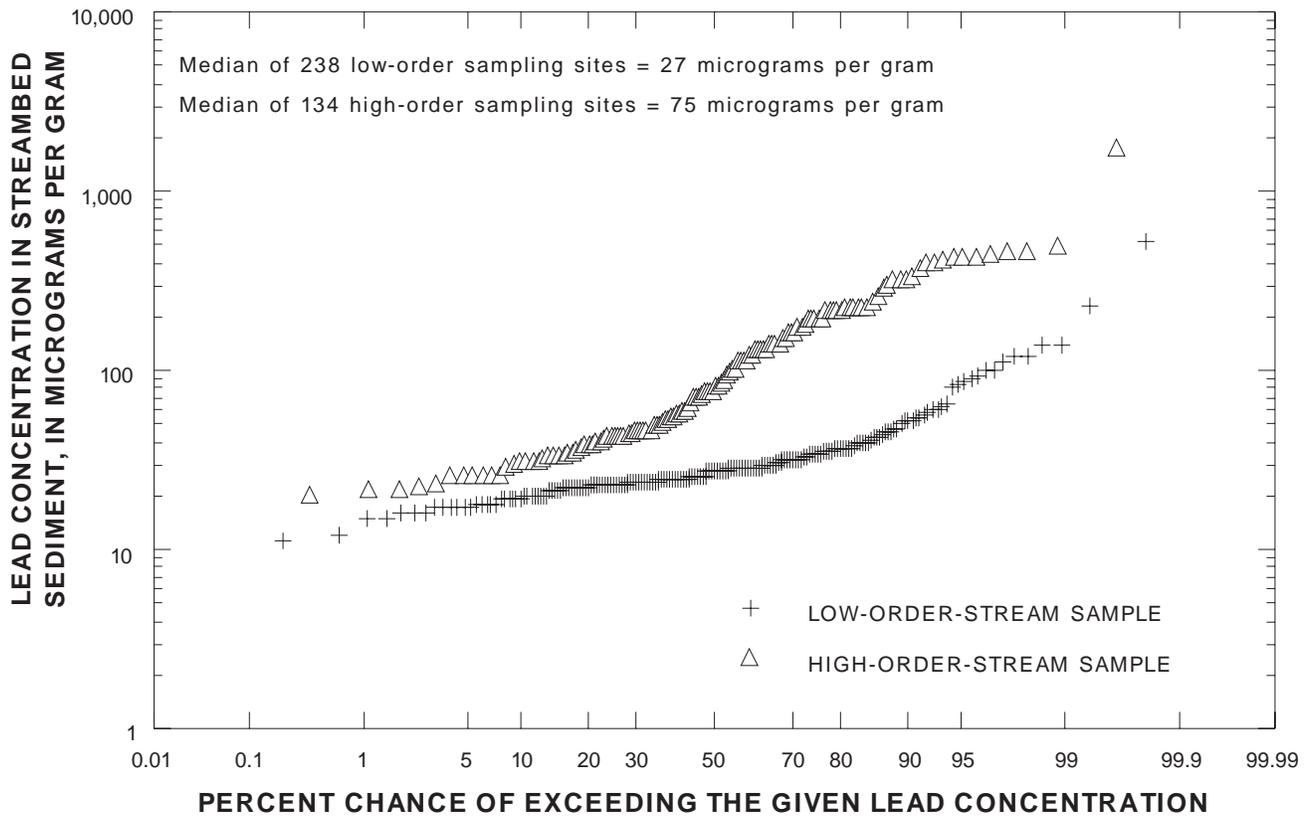
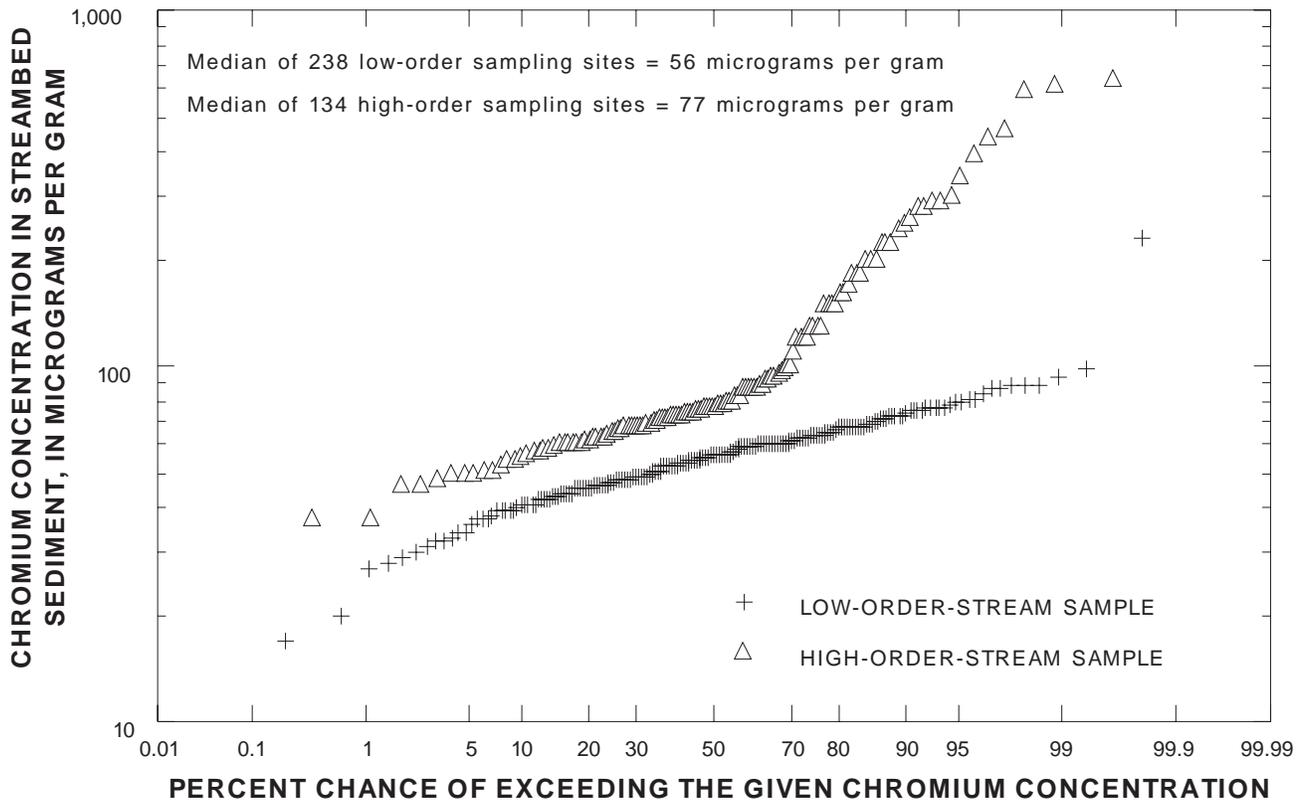


Figure 14. Exceedance probabilities for concentrations of chromium and lead in fine-fraction streambed-sediment samples from low- and high-order streams in the upper Illinois River Basin, 1989.

water, bioconcentration above ambient levels and concentration in sediment can provide valuable water-quality information. In the upper Illinois River Basin, total recoverable and dissolved concentrations of a number of trace inorganic constituents commonly were near or below minimum reporting levels but were measurable and sometimes elevated in sediment and biota. These constituents included arsenic, selenium, and zinc. Concentrations of mercury in sediment and biota were measurable and distinctly different among sites and stations, even though a large number of censored values were observed for total recoverable and dissolved mercury in water.

Organic Compounds

Pesticides and other synthetic organic compounds (SOC's) have been detected in the water, sediment, and biota of surface waters throughout the United States. The production and use of these compounds have increased greatly over the past 50 years, and the result has been a gradual decrease in the quality of the Nation's surface-water resources (Smith and others, 1988). Pesticides and other SOC's enter surface-water systems from a variety of sources, which include direct point-source discharges of municipal and industrial wastewater, and indirect nonpoint-source runoff. Many compounds with low solubility tend to bioaccumulate in organisms (Smith and others, 1988). Many pesticides and other SOC's have been shown to be potentially toxic, carcinogenic, and mutagenic (Commoner, 1979).

Agricultural areas in Illinois and neighboring States are among the most productive grain-growing regions in the world. Modern agriculture is heavily dependent on pesticides to ensure high productivity. In Illinois, in 1988, herbicides were applied to 97 percent of corn fields and 96 percent of soybean fields (Pike and others, 1990). Insecticides are applied to lower percentages of croplands. Herbicide applications in the upper Illinois River Basin are among the highest in the Nation (Koplin and others, 1994).

Pesticide loadings in urban areas also are high according to Ginsberg and Osborne (1984), who estimate that 75–90 percent of households apply pesticides. Home owners, land-management agencies, and other governmental agencies apply herbicides and insecticides at rates as high as 10 lb/acre. Therefore, extensive surface-water contamination by pesticides is possible in urban areas in the basin.

Extensive surface-water contamination by non-agricultural SOC's is possible in and near the large urban and industrial areas of Chicago. The major sources to streams of these SOC's are industrial effluent and municipal wastewater discharges (Moore and Ramamoorthy, 1984).

Analysis of historical data was utilized as a first step in describing the presence and extent of SOC's in the upper Illinois River Basin. Statistical analyses of historical data were limited because the data were combined from several sources, and collected and analyzed using unknown procedures. Analysis indicated that water-column sampling should be limited to relatively soluble (hydrophilic) compounds and sediment sampling to relatively insoluble (hydrophobic) compounds. This result guided the design of the organics sampling program of the NAWQA pilot study.

Intensive data-collection activities performed as part of the NAWQA study included pesticide sampling at four stations in 1988 and 1989. Two stations were on streams draining urban areas, and two stations were on streams draining agricultural areas. Bromacil, diazinon, malathion, prometone, and simazine were identified as primarily urban-related because they were detected more frequently or at higher concentrations from urban stations than from agricultural stations (figs. 15 and 16). Alachlor, atrazine, cyanazine, metolachlor, and metribuzin were detected more frequently or at higher concentrations at agricultural stations. However, several of the organic compounds typically associated with agriculture were frequently detected in the urban areas as high concentrations. Concentrations of atrazine exceeded the MCL² (3 µg/L) for drinking water in agricultural and urban land-use areas.

Sixty-eight herbicide samples were collected at 17 stations in the primarily agricultural Kankakee and Iroquois River Basins in 1990. Atrazine and metolachlor were detected in all samples. The atrazine breakdown products, desethylatrazine and desisopropylatrazine, were detected in 100 and 94 percent of samples, respectively. The data indicate that atrazine concentrations exceeded the MCL during runoff periods. The estimated total atrazine load from the Iroquois River Basin was less than 1 percent of the estimated amount of atrazine applied to the land. The

²Maximum contaminant level: enforceable, health-based National Primary Drinking Water Standards of the U.S. Environmental Protection Agency.

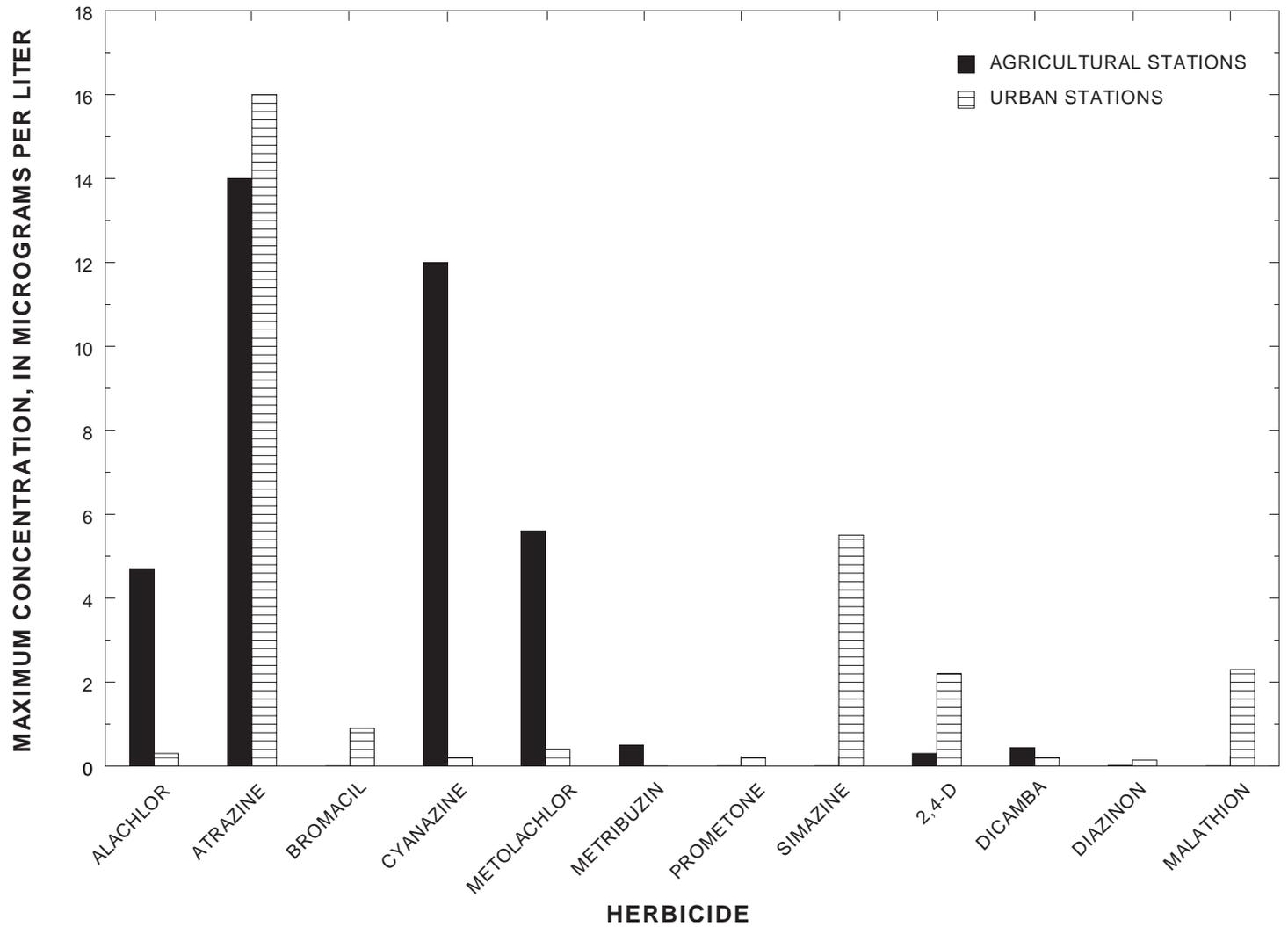


Figure 15. Maximum concentrations, by land use, of herbicides that were detected in at least 50 percent of samples from either urban or agricultural stations in the upper Illinois River Basin, 1988-89.

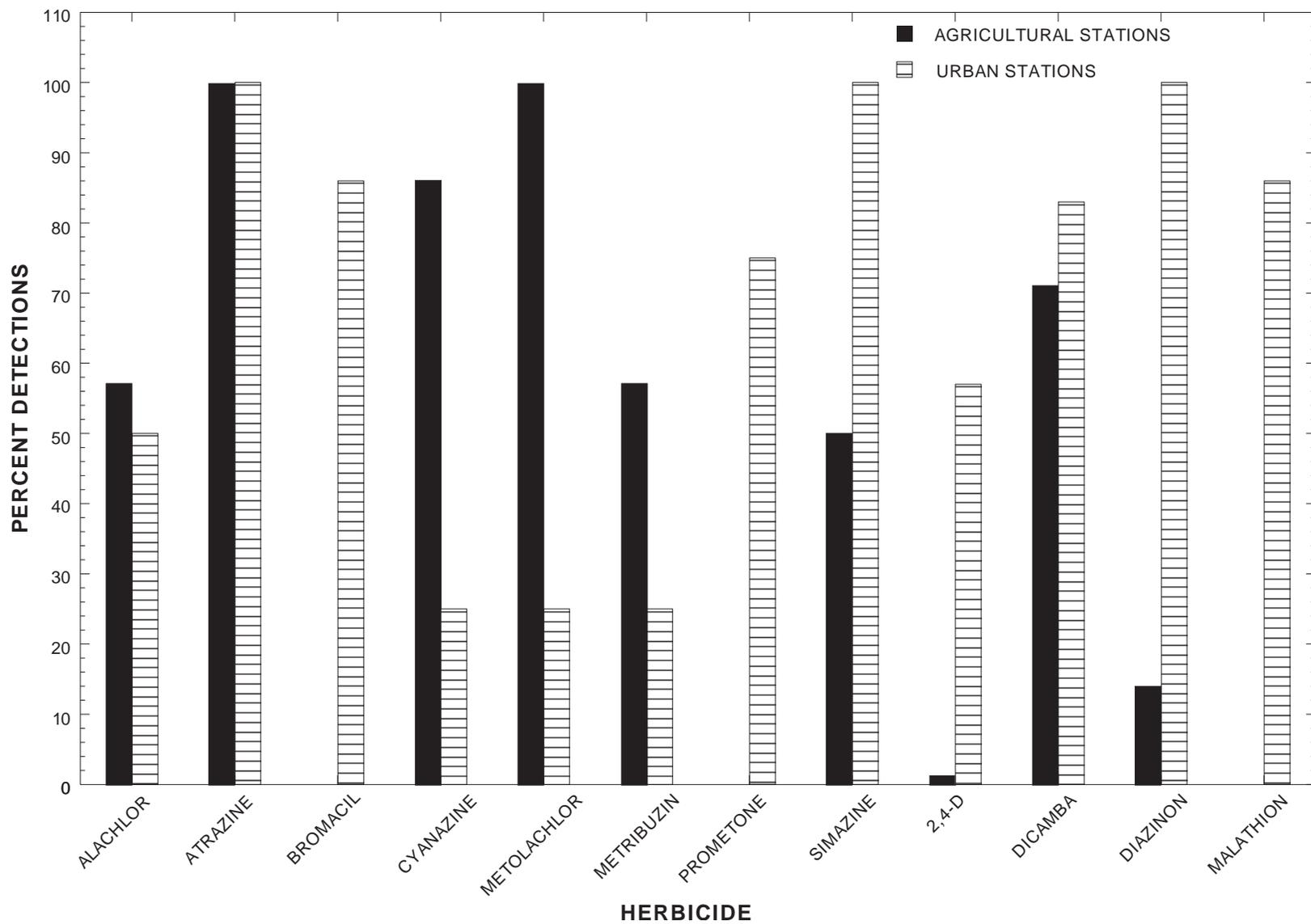


Figure 16. Percent detections, by land use, of herbicides that were detected in at least 50 percent of samples from either urban or agricultural stations in the upper Illinois River Basin, 1988–89.

time of year and magnitude of the runoff were the most important factors for estimating atrazine concentrations in streams. High correlation coefficients among most of the triazine herbicides indicate cooccurrence in the environment—when one triazine herbicide is detected, other triazine herbicides also are likely to be detected.

A low-flow synoptic survey for volatile organic compounds (VOC's) and semivolatile organic compounds (SVOC's) in water was conducted in 1988. The stations where two or more volatile organic compounds were detected are shown in figure 17. Results indicate that chloroform was the most commonly detected compound present in samples from 13 of 31 stations (42 percent). Commonly, chloroform is found in waters receiving chlorinated effluent. The next most commonly detected compounds, tetrachloroethylene and 1,1,1-trichloroethane, each were detected in samples from 9 of 31 stations (29 percent). A total of 21 different VOC's and one SVOC was detected at least once. All sites where more than one compound was detected were within the vicinity of a point source. Detections at two sites in the Chicago metropolitan area accounted for 37 percent (28 of 76) of the VOC detections. One exceedance of a drinking-water MCL was detected—tetrachloroethylene concentration was 5.5 mg/L at the Des Plaines River at Lockport, Ill. The detection of VOC's in stream waters is noteworthy; VOC's are not usually detected in stream water because these compounds volatilize out of the system rapidly.

Monitoring of VOC concentrations in water at two NAWQA fixed-monitoring stations was performed from June 1988 to March 1990. VOC's were detected, occasionally, at high concentrations. Results indicate three exceedances of MCL's during this time period.

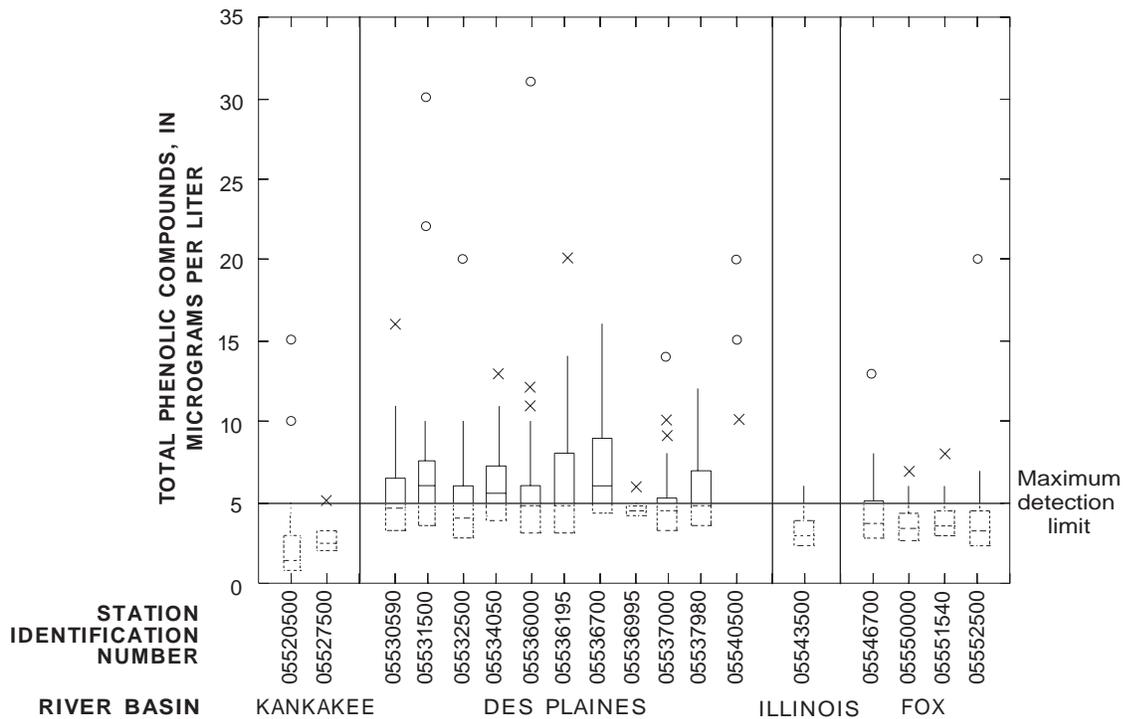
Phenolic compounds were detected most frequently in water from the Des Plaines River Basin; 251 of the 406 total detections (62 percent) were observed in the upper Illinois River Basin. Point-source discharges, such as wastewater-treatment plant and industrial effluents, are more predominant in the Des Plaines River Basin than in other subbasins of the upper Illinois River Basin. Concentrations of phenolic compounds were significantly different among the Des Plaines, Kankakee, and Fox River Basins (fig. 18). Phenolic compound concentrations at stations located within each basin were not significantly different, except in the Des Plaines River Basin, where source or natural spatial variability may be the cause for a significant difference among some stations. Median phenolic

compound concentrations, measured in samples taken during the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) 1989 survey, decreased with distance downstream from Chicago. Phenolic compound concentrations never exceeded the general-use and secondary-contact standards of 100 and 300 µg/L, respectively.

Pentachlorophenols were the most extensively used of the chlorophenolic compounds in the basin (Smith and others, 1988). The use of pentachlorophenol on nonwood products was banned by the IEPA in 1987. Concentrations of pentachlorophenols observed in the environment have been decreasing since the ban. Pentachlorophenols were detected most frequently in the Des Plaines River Basin with concentrations as high as 180 µg/L at the North Branch Chicago River at Niles, Ill. (map reference number 45). Pentachlorophenol concentrations detected at the Illinois River at Marseilles, Ill. (map reference number 76), from 1981 to 1992 show a decrease in concentrations beginning in 1987 (fig. 19); this was most likely associated with the ban. Pentachlorophenol concentration in water from the study area never exceeded the 1-µg/L drinking-water standard.

A survey of the presence and extent of SVOC's in streambed sediment was conducted in 1987, and a synoptic survey was conducted in 1989. Results from quality-assurance sampling indicate that data were adequate as a general indication of the detection of compounds but not for quantitative comparison among stations (Sullivan and others, in press). Results indicate that stations in the Chicago metropolitan area had the most detections of SVOC's. Of the 17 stations at which 10 or more compounds were detected in 1989, 14 were located in the Des Plaines River subbasin and 1 was downstream on the Illinois River mainstem. The remaining two stations were in urbanized areas of the Fox and Du Page Rivers (fig. 20). The most commonly detected compounds included the polycyclic aromatic hydrocarbons (PAH's), phenanthrene, fluoranthene, pyrene, fluorene, benzo(*a*)anthracene and benzo(*g,h,i*)perylene, and the plasticizer *bis*(2-ethylhexyl)phthalate. As with VOC's in water, each of these stations was located within 2 mi downstream from point sources.

Tissue samples from whole fish were collected and analyzed for organochlorines and PAH's in 1989 and 1990. A biodegradation-resistant metabolic-breakdown product of the organochlorine pesticide dichloro-diphenyl-trichloroethane (DDT), *p,p'*-DDE,



EXPLANATION

- — Data value(s) exceeding upper quartile plus 3 times the interquartile range
- × — Data value(s) exceeding upper quartile plus 1.5 times the interquartile range but less than the upper quartile plus 3 times the interquartile range
- (top whisker) — Largest data value less than or equal to the upper quartile plus 1.5 times the interquartile range
- (top box line) — Upper quartile (75th percentile)
- (middle box line) — Median (50th percentile)
- (bottom box line) — Lower quartile (25th percentile)
- (bottom dashed box line) — Most probable value (See note below)
- (bottom whisker) — Smallest data value greater than or equal to the lower quartile minus 1.5 times the interquartile range

NOTE: MOST PROBABLE VALUE--Tukey plots for stations having constituents with multiple detection limits were modified to display quartiles estimated by fitting the data to a log-normal distribution and applying a procedure outlined in Helsel and Cohn (1988)

Figure 18. Summary of available data for total phenolic compound concentrations at stations in the upper Illinois River Basin, water years 1987–90.

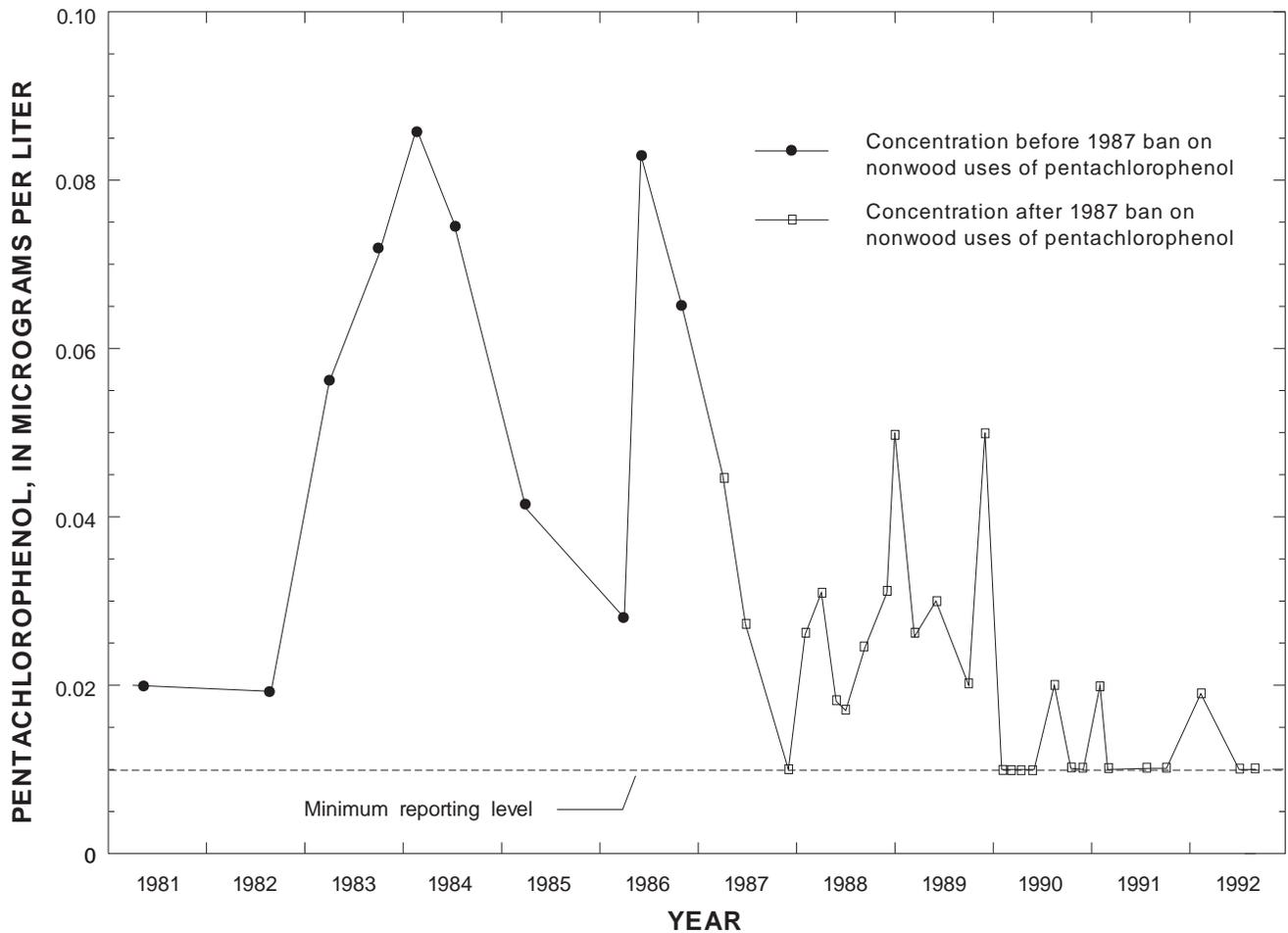
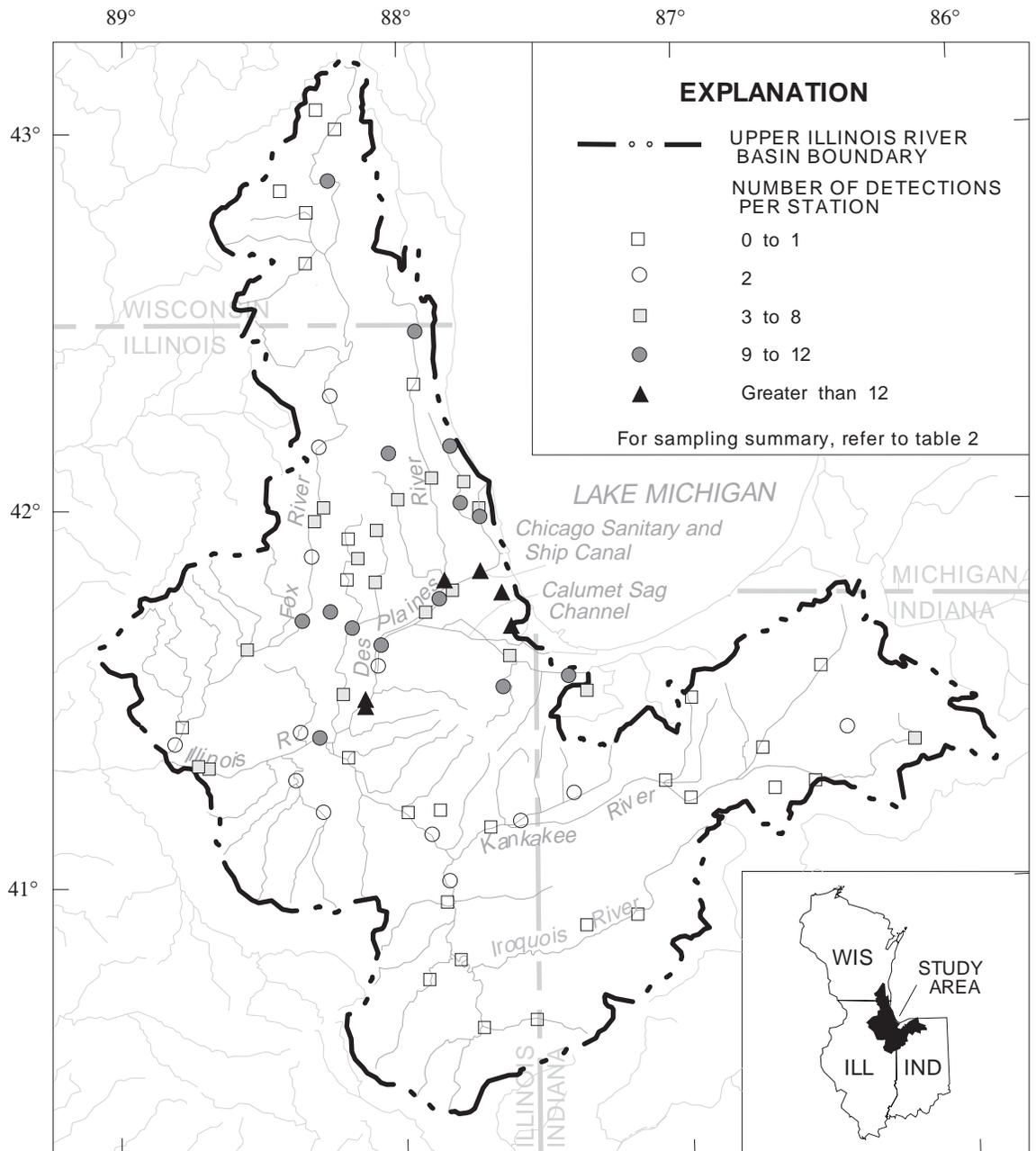


Figure 19. Concentrations of pentachlorophenol at the Illinois River at Marseilles, Ill. (05543500), water years 1981–92.

was the most commonly detected compound in 1989 and 1990. Concentrations of polychlorinated biphenyls (PCB's), *p,p'*-DDE, *p,p'*-DDD, and dieldrin were the highest (table 3). Correlations were observed among the chlordane components, among the DDT breakdown products, and between these two groups of compounds (table 4). Dieldrin was correlated to chlordane components but was not correlated to DDT breakdown products. Some correlation was observed between most of the compounds and the lipid content of the sample. Concentrations were lower in fish fillets than in whole fish. Lipid content is lower in fillets than in whole fish, indicating the strong tendency of these compounds to accumulate in the lipid portion of the fish. Normalizing organic-compound concentrations in whole fish for lipids reduced the differences between concentrations in whole fish and fillets.

Numerous exceedances of the National Academy of Science (1972) standards for protection of predatory animals were detected in fish from the upper Illinois River Basin; a total of 16 exceedances for chlordane and 8 exceedances for dieldrin, when 1989 and 1990 data were combined. Nine fillet samples were collected in 1989 and exceedances of USEPA (1992a) fish-tissue concentrations criteria in relation to the protection of human health were observed for *p,p'*-DDE in nine of nine fillets and for dieldrin in six of nine fillets.

Comparisons between SOC's in fine-grained streambed sediment and biota were limited to analyses of cooccurring compounds. There were 37 total detections of organochlorines in biota and 23 in streambed sediment, of which 14 compounds were detected in both media at a station. Total chlordane, PCB's, *p,p'*-DDE, and dieldrin each had 2–4.5 times



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 20. Spatial distribution of synthetic organic compounds in streambed sediment in the upper Illinois River Basin, 1989.

Table 3. Summary of concentrations of organochlorine compounds in whole-fish samples from the upper Illinois River Basin, 1989–90 (from Sullivan and others, in press)

[Data presented are for whole fish collected as part of the upper Illinois River Basin NAWQA project. Concentrations are in micrograms per gram, wet weight. NAWQA, National Water-Quality Assessment; NCBP, National Contaminant Biomonitoring Program; NSCRF, National Study of Chemical Residues in Fish; DDT, dichloro-diphenyl-trichloroethane; <, less than; NR, not reported; DDD, dichloro-diphenyl-dichloroethane; DDE, dichloro-diphenyl-trichloroethylene; PCB, polychlorinated biphenyl]

Compound	Upper Illinois River Basin			NCPB mean ¹	NSCRF mean ²
	Maximum	Mean	Median		
<i>o,p'</i> -DDT	0.05	<0.01	<0.01	NR	NR
<i>p,p'</i> -DDT	.07	<.01	<.01	0.03	NR
<i>o,p'</i> -DDD	.24	.04	.01	NR	NR
<i>p,p'</i> -DDD	1.5	.17	.03	.06	NR
<i>o,p'</i> -DDE	<.01	<.01	<.01	NR	NR
<i>p,p'</i> -DDE	.84	.15	.08	.19	0.30
DDT+DDE+DDD	2.56	.37	.15	.26	NR
Total PCB's	3.3	.73	.38	.39	7.6
Hexachlorobenzene	.02	<.01	<.01	NR	.006
α -Hexachlorocyclohexane	<.01	<.01	<.01	<.01	.002
β -Hexachlorocyclohexane	<.01	<.01	<.01	NR	NR
γ -Hexachlorocyclohexane (lindane)	<.01	<.01	<.01	<.01	.003
δ -Hexachlorocyclohexane	<.01	<.01	<.01	NR	NR
<i>cis</i> -Chlordane	.20	.05	.02	.03	.021
<i>trans</i> -Chlordane	.27	.03	.02	.02	.017
<i>cis</i> -Nonachlor	.04	.01	<.01	.02	.009
<i>trans</i> -Nonachlor	.11	.01	<.01	.03	.017
Oxychlordane	.02	<.01	<.01	.01	.005
Heptachlor epoxide	.03	.01	<.01	.01	.002
Chlordane-related compounds	.63	.14	.10	.12	NR
Toxaphene	<.01	<.01	<.01	.14	NR
Dieldrin	.52	.07	.05	.04	.028
Endrin	<.01	<.01	<.01	<.01	.002
Mirex	<.01	<.01	<.01	<.01	.004
Kepone	<.01	<.01	<.01	NR	NR
Dicofol	<.01	<.01	<.01	NR	.001
Octachlorostyrene	<.01	<.01	<.01	NR	.002

¹From Schmitt and others, 1990.

²From U.S. Environmental Protection Agency, 1992a.

as many detections in samples from biota as from fine-grained streambed sediment. Total detections of PAH's in biota and sediment were 39 and 41, respectively, of which 24 compounds were detected in both media at a station.

Future studies to determine the presence and extent of current-generation herbicides in the upper

Illinois River Basin would benefit from more precise information on pesticide use. Most of the information currently available is based roughly on use estimates of statewide average application rates. Sampling for agricultural pesticides also should be performed over a period of several years because rainfall timing and intensity can vary considerably, and important runoff

Table 4. Correlation coefficients of compounds detected in over 50 percent of fish samples in the upper Illinois River Basin, 1989–90 (from Sullivan and others, in press)

[DDE, dichloro-diphenyl-trichloroethylene; DDD, dichloro-diphenyl-dichloroethane; only those with $p \leq 0.05$ are shown, those with $p > 0.05$ are indicated with --]

Compound	<i>trans</i> -Nonachlor	<i>cis</i> -Chlordane	<i>p,p'</i> -DDE	Dieldrin	<i>p,p'</i> -DDD	Lipid content
1989 Samples						
<i>trans</i> -Nonachlor	1.00					
<i>cis</i> -Chlordane	.90	1.00				
<i>p,p'</i> -DDE	.66	.69	1.00			
Dieldrin	.58	.53	--	1.00		
<i>p,p'</i> -DDD	.54	.55	.66	.45	1.00	
Lipid Content	.80	.81	.64	.67	.48	1.00

Compound	Heptachlor epoxide	<i>trans</i> -Chlordane	<i>trans</i> -Nonachlor	<i>cis</i> -Chlordane	<i>p,p'</i> -DDE	Dieldrin	<i>o,p'</i> -DDD	<i>p,p'</i> -DDD	Lipid content
1990 Samples									
Heptachlor epoxide	1.00								
<i>trans</i> -Chlordane	--	1.00							
<i>trans</i> -Nonachlor	.36	.88	1.00						
<i>cis</i> -Chlordane	--	.95	.88	1.00					
<i>p,p'</i> -DDE	--	.78	.79	.82	1.00				
Dieldrin	.61	.62	.69	.54	--	1.00			
<i>o,p'</i> -DDD	--	.71	.65	.77	.80	--	1.00		
<i>p,p'</i> -DDD	--	.73	.67	.83	.86	--	.92	1.00	
Lipid content	--	.82	.73	.79	.68	.50	.55	.60	1.00

events may not be sampled. Sampling over several years would yield data from various hydrologic conditions, give a better indication of how often pesticide concentrations exceed health advisories, and give better information on loading and transport.

Concentrations of VOC's and SVOC's generally are low in the water column, often below the detection limit, and, as a result, few statistical analyses can be made. Locating sources of these compounds and monitoring outputs, if possible, and then modeling fate and transport to determine the possible outcomes of the actual loadings to the streams could be of great value in understanding the processes that control the concentration of these compounds in water.

Streambed sediment and biota sampling have the greatest potential value in determining distributions and concentrations of relatively insoluble SOC's. Although biota usually bioaccumulate compounds at higher concentrations, streambed-sediment samples generally are analyzed for a wider variety of compounds.

Nutrients, Dissolved Oxygen, and Fecal-Indicator Bacteria

The IEPA identified widespread violations of water-quality standards for fecal coliform, ammonia nitrogen, and dissolved oxygen in their 1979 water-quality-management plan (Illinois Environmental Protection Agency, 1979) as major water-quality issues in Illinois. This same report indicated that non-point sources are sufficient to cause the water-quality problems observed at most monitoring sites. More recent reports identified increased nutrients and decreased dissolved oxygen concentrations as primary causes for streams that were not fully supporting their designated uses (Illinois Environmental Protection Agency, 1988, p. 70). Point sources accounted for about 24 percent of the streams not fully supporting their designated uses, whereas agricultural, urban, and mining nonpoint sources accounted for about 55 percent of the streams not fully supporting their designated uses (Illinois Environmental Protection Agency, 1988, p. 70).

Data collected as part of the Survey's NAWQA program were utilized to describe the presence, spatial distribution, and temporal variability of nutrients, dissolved oxygen, and fecal-indicator bacteria in the upper Illinois River Basin in Illinois, Indiana, and Wisconsin from 1987 to 1990. Data from water years 1978–86, collected by the IEPA, were used in conjunction with USGS data to assess long-term trends in constituent concentrations. Five nutrient forms—total nitrogen, dissolved nitrite plus nitrate, total ammonia, total organic nitrogen, and total phosphorus—were used to represent nutrient conditions in the upper Illinois River Basin.

Approximately 74,730 tons of nitrogen and 3,850 tons of phosphorus are transported out of the upper Illinois River Basin each year in the Illinois River. Sources of nutrient inputs to the upper Illinois River Basin included wastewater-treatment plants, commercial and industrial sources, fertilizer application, atmospheric deposition, ground water, Lake Michigan withdrawals and diversions, soil erosion, and plant material. These sources supplied an estimated 247,000 tons of nitrogen and 94,000 tons of phosphorus to the upper Illinois River Basin each year.

The Des Plaines River Basin contributed approximately 41 percent of the total nitrogen load to the upper Illinois River Basin, whereas the Kankakee and Fox River Basins contributed about 39 and 13 percent of the total load, respectively (fig. 21). About 30 percent of the total nitrogen load in the upper Illinois River Basin was measured in the Chicago Sanitary and Ship Canal at Romeoville, Ill. (map reference number 55).

During low-flow conditions, almost all of the total nitrogen load was observed in the Des Plaines River Basin. Most of this load was attributed to the Chicago Sanitary and Ship Canal, which receives substantial inputs of wastewater effluents. The Chicago Sanitary and Ship Canal also transported the majority of ammonia and phosphorus loads during low-flow conditions.

During low-flow conditions in the upper Illinois River Basin, most of the load transported out of the basin was from the Des Plaines River Basin and primarily results from wastewater-treatment-plant effluent from the Chicago Sanitary and Ship Canal. The Chicago Sanitary and Ship Canal also was observed to carry the majority of ammonia and phosphorus loads during low-flow conditions.

Nutrient concentrations in the upper Illinois River Basin generally were higher than concentrations typically found in natural waters (Puckett, 1994; Mueller and Helsel, 1996). Nutrient concentrations in urban areas, particularly in the Des Plaines River Basin, were generally higher than in other areas of the upper Illinois River Basin. Median concentrations of the five nutrient forms at the eight fixed-monitoring stations from 1987 to 1991 are listed in table 5. Total nitrogen concentrations at the Kankakee River at Momence, Ill. (map reference number 14), were relatively low, and concentrations at the Iroquois River at Chebanse, Ill. (map reference number 28), were relatively high. Both stations drain areas of comparable size and land use with similar fertilizer application rates. Although both stations were in the Kankakee River Basin, differences in soil types necessitate different agricultural-drainage practices between the areas draining to these stations. Soils in the area draining to map reference number 14 typically are well drained, whereas soils in the area draining to map reference number 28 typically are poorly drained and, thus, extensively tile drained. Tile drainage in the Iroquois River Basin is a probable factor resulting in the higher nitrogen concentrations in the Iroquois River.

Although most of the nitrogen in the upper Illinois River Basin streams was in the form of nitrate, ammonia concentrations indicated differences between sites draining urban and rural areas. Median concentrations of nitrite plus nitrate ranged from 0.22 to 9.80 mg/L at the fixed-monitoring stations, and median concentrations of ammonia at the fixed-monitoring stations ranged from 0.01 to 7.40 mg/L. Concentrations of ammonia were higher at sites with urban drainage areas and substantial upstream inputs from wastewater-treatment plants. Most high ammonia concentrations were detected in the Des Plaines and Du Page Rivers; all concentrations greater than 10 mg/L were observed in the Des Plaines and Du Page Rivers. Concentrations in the Kankakee River were the lowest in the upper Illinois River Basin.

Median organic nitrogen concentrations ranged from 0.87 to 1.70 mg/L at the fixed-monitoring stations. Organic nitrogen composed a larger portion of the total nitrogen concentration at the stations in the Fox River Basin than at the other fixed-monitoring stations. During the low-flow synoptic survey, the highest organic nitrogen concentrations (up to 14.2 mg/L) were detected in the Des Plaines River Basin. Point-source inputs were the probable cause

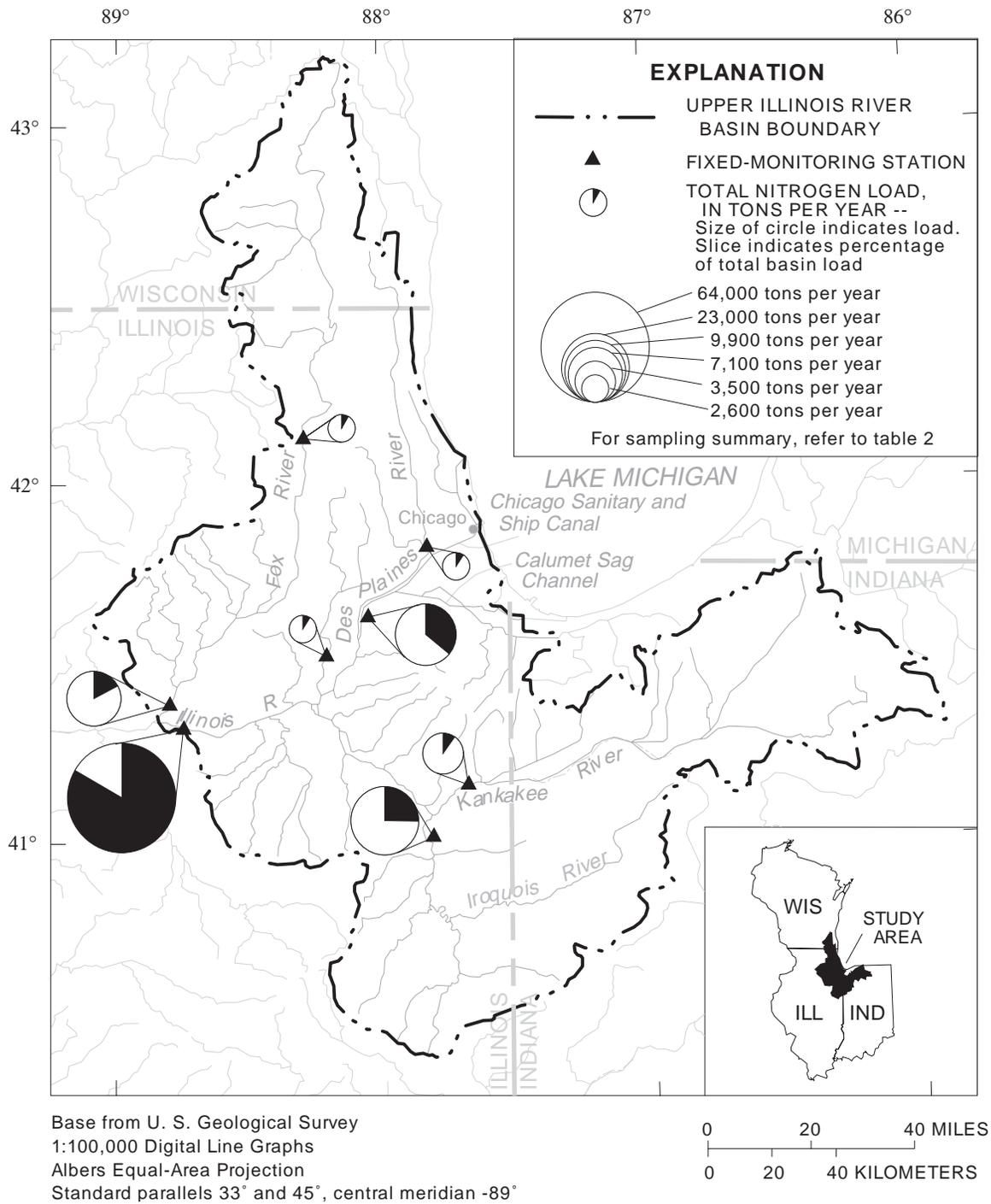


Figure 21. Loads of total nitrogen measured at the eight fixed-monitoring stations in the upper Illinois River Basin, water years 1987–91.

Table 5. Statistical summary of nutrient concentrations at the eight fixed-monitoring stations in the upper Illinois River Basin, water years 1987–91 (from Terrio, 1994a, p. 79)

[Number in parentheses is WATSTORE (WATER STORAGE and RETRIEVAL SYSTEM) parameter code; all concentrations are in milligrams per liter]

Map reference number (see fig. 5)	Station name	Number of observations	Percentile				
			10	25	50 (median)	75	90
Total nitrogen (00600)							
14	Kankakee River at Momence, Ill.	49	0.960	1.32	2.20	3.30	5.60
28	Iroquois River near Chebanse, Ill.	40	2.51	6.42	9.78	12.70	15.10
40	Des Plaines River at Riverside, Ill.	43	4.40	5.10	6.50	8.01	9.70
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	43	4.50	5.50	7.10	8.70	9.06
69	Du Page River at Shorewood, Ill.	48	6.00	7.30	8.30	9.50	10.6
76	Illinois River at Marseilles, Ill.	59	4.00	5.00	6.50	7.80	9.50
89	Fox River at Algonquin, Ill.	37	2.30	2.70	3.06	3.80	4.06
99	Fox River at Dayton, Ill.	35	3.16	4.00	4.60	6.00	7.82
Total ammonia nitrogen (00610)							
14	Kankakee River at Momence, Ill.	52	.093	.100	.100	.130	.177
28	Iroquois River near Chebanse, Ill.	53	.084	.100	.100	.160	.240
40	Des Plaines River at Riverside, Ill.	44	.105	.208	.395	.538	.710
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	68	.829	1.42	3.10	4.70	5.78
69	Du Page River at Shorewood, Ill.	75	.089	.100	.100	.280	.446
76	Illinois River at Marseilles, Ill.	73	.144	.235	.400	.920	1.70
89	Fox River at Algonquin, Ill.	71	.060	.100	.100	.160	.440
99	Fox River at Dayton, Ill.	46	.020	.040	.085	.200	.320
Dissolved nitrite plus nitrate nitrogen (00631)							
14	Kankakee River at Momence, Ill.	85	.540	.740	1.10	2.35	4.20
28	Iroquois River near Chebanse, Ill.	87	1.90	6.50	9.80	11.0	13.0
40	Des Plaines River at Riverside, Ill.	87	2.30	3.70	4.60	5.70	7.22
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	111	1.22	1.40	2.90	4.00	5.28
69	Du Page River at Shorewood, Ill.	120	4.50	5.02	6.30	7.77	9.30
76	Illinois River at Marseilles, Ill.	106	2.77	3.10	4.50	5.80	7.36
89	Fox River at Algonquin, Ill.	113	.100	.100	.220	1.45	2.30
99	Fox River at Dayton, Ill.	86	.100	.490	2.70	4.12	5.10
Total organic nitrogen (00605)							
14	Kankakee River at Momence, Ill.	25	.26	.54	.87	1.2	1.8
28	Iroquois River near Chebanse, Ill.	25	.49	.67	.98	1.4	2.5
40	Des Plaines River at Riverside, Ill.	42	.90	1.1	1.3	1.7	2.0
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	43	.44	.70	1.1	1.4	1.8
69	Du Page River at Shorewood, Ill.	35	.30	.80	1.1	1.6	2.9
76	Illinois River at Marseilles, Ill.	70	.73	.89	1.0	1.2	1.6
89	Fox River at Algonquin, Ill.	37	.94	1.2	1.7	2.2	3.1
99	Fox River at Dayton, Ill.	37	.86	1.3	1.8	2.7	3.2
Total phosphorus (00665)							
14	Kankakee River at Momence, Ill.	91	.040	.040	.060	.100	.170
28	Iroquois River near Chebanse, Ill.	97	.050	.066	.100	.170	.262
40	Des Plaines River at Riverside, Ill.	82	.423	.617	.840	1.18	1.48
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	107	.44	.530	.640	.850	1.10
69	Du Page River at Shorewood, Ill.	114	.615	.707	.820	1.20	1.70
76	Illinois River at Marseilles, Ill.	111	.272	.330	.410	.480	.570
89	Fox River at Algonquin, Ill.	110	.090	.120	.160	.250	.319
99	Fox River at Dayton, Ill.	83	.120	.170	.230	.310	.356

for elevated concentrations of organic nitrogen in the Des Plaines River Basin during low-flow periods.

The spatial distribution of phosphorus concentrations was similar to the distribution for total nitrogen. Median concentrations of total phosphorus ranged from 0.06 to 0.84 mg/L at the fixed-monitoring stations. During the low-flow synoptic survey, phosphorus concentrations greater than 1.0 mg/L were observed at 13 stations, which were in the Chicago metropolitan area. The highest phosphorus concentration detected was 4.0 mg/L in Salt Creek at Wooddale, Ill. (map reference number 37). The spatial distribution of total phosphorus concentrations was similar to that for total nitrogen, except concentrations were not high in the Iroquois River. Phosphorus tends to adsorb to fine-sized sediment particles, which generally would not be discharged from tile drains. This is probably why phosphorus concentrations in the Iroquois River Basin were not higher than in other parts of the study area, whereas nitrogen concentrations in the Iroquois River Basin were higher than in other parts of the study area.

Total nitrogen concentrations correlated with streamflow at most of the fixed-monitoring stations. Positive correlations of streamflow and total nitrogen concentrations were found at most agricultural stations, whereas negative correlations were found at most urban stations (table 6). A probable explanation for these correlations is that runoff was a major source of

nitrogen to streams in agricultural areas, whereas point sources, which are diluted by runoff, were the major nitrogen sources in urban areas.

Phosphorus concentrations and streamflow were negatively correlated at four of the fixed-monitoring stations and positively correlated at Iroquois River near Chebanse, Ill. (map reference number 28). A probable explanation of this positive correlation is that erosion, suspension, and transport of sediment-related phosphorus during periods of increased streamflow resulted in higher observed phosphorus concentrations during high flow. A probable explanation of the negative correlations at the other stations is that the high flows diluted the phosphorus from point sources.

Upward trends in total nitrogen concentrations from 1978 to 1990 were observed at three of the fixed-monitoring stations: Iroquois River near Chebanse, Ill. (map reference number 28), Des Plaines River at Riverside, Ill. (map reference number 40), and Du Page River at Shorewood, Ill. (map reference number 69); the upward trends ranged from 2.9 to 9.0 percent of median concentration per year. Downward trends in total phosphorus concentrations were observed at three fixed-monitoring stations: Des Plaines River at Riverside, Ill. (map reference number 40), Illinois River at Marseilles, Ill. (map reference number 76), and Fox River at Dayton, Ill. (map reference number 99). The trends ranged from -3.3 to 7.1 percent of median concentration per year. The uptrends in

Table 6. Correlation coefficients for nutrient concentrations and discharge at the eight fixed-monitoring stations in the upper Illinois River Basin, water years 1987–91 (from Terrio, 1994a)

[Number in parentheses is WATSTORE (WATER STORAGE and RETRIEVAL system) parameter code; n, number of observations; ρ^2 , Spearman's rho rank correlation coefficient; <, less than]

Map reference number (see fig. 6)	Station name	Total nitrogen (00600)		Total ammonia nitrogen (00610)		Dissolved nitrite plus nitrate nitrogen (00631)		Total organic nitrogen (00605)		Total phosphorus (00665)	
		n	ρ^2	n	ρ^2	n	ρ^2	n	ρ^2	n	ρ^2
14	Kankakee River at Momence, Ill.	114	0.73	86	0.36	85	0.91	61	0.25	162	0.11
28	Iroquois River near Chebanse, Ill.	55	.69	97	.28	286	.46	40	.50	156	.34
40	Des Plaines River at Riverside, Ill.	43	-.76	87	-.03	87	-.77	42	-.31	82	-.74
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	42	-.36	101	-.07	108	-.37	42	-.23	104	-.20
69	Du Page River at Shorewood, Ill.	52	-.36	115	.41	118	-.57	39	.35	160	-.69
76	Illinois River at Marseilles, Ill.	136	.39	146	<.01	148	.45	149	.19	211	-.42
89	Fox River at Algonquin, Ill.	118	.07	113	<.01	113	.48	121	-.31	200	-.34
99	Fox River at Dayton, Ill.	117	.59	85	.24	85	.69	120	-.15	178	-.16

nitrogen concentrations might be from increased application of fertilizers and urbanization. The down-trends in phosphorus (map reference numbers 76 and 99) might be from decreased use of phosphate cleansers and improved wastewater treatment in the basin.

Nutrient concentrations at several of the fixed-monitoring stations typically were high in the winter and low in the summer. Because these variations were observed at stations draining areas with different land uses, seasonal changes in physical, chemical, and biological processes were the likely factors causing seasonal changes in nutrient concentrations. Nutrient inputs to the streams also can vary with climatic season and hydrologic conditions.

Median dissolved oxygen concentrations at the fixed-monitoring stations ranged from 3.4 mg/L at the Chicago Sanitary and Ship Canal at Romeoville, Ill. (map reference number 55), to 12.2 mg/L at the Fox River at Dayton, Ill. (map reference number 99). Median concentrations at the other fixed-monitoring stations were from 8.7 to 9.7 mg/L (table 7). Dissolved oxygen concentrations at map reference number 55 were probably low in part because flow at this station during low-flow conditions is about 65 percent wastewater effluent. Velocities at this station during low-flow conditions are low (less than 0.5 ft/s), and depths are large (about 27 ft), resulting in little reaeration. Dissolved oxygen concentrations at map reference number 99 probably were high, in part, because of algae and plant photosynthesis in the pooled areas behind the dams upstream from this station.

Dissolved oxygen concentrations measured during a synoptic sampling for dissolved oxygen, nutrients, and fecal-indicator bacteria exceeded State water-quality standards at 76 percent of the sites sampled. Dissolved oxygen concentrations were measured in the early morning hours (generally 0500–0800) during the 1988 low-flow synoptic survey. This resulted in the measurement of minimum diel-varying concentrations. Dissolved oxygen concentrations were less than 5 mg/L at 20 of the 60 sites sampled (fig. 22). In the Kankakee River Basin, dissolved oxygen concentrations less than 5 mg/L were measured at 10 of the 17 stations, including map reference number 29 with the lowest measured concentration (1.85 mg/L). In contrast, dissolved oxygen concentrations at all stations measured in the Fox River were greater than 5 mg/L.

Diel variations in dissolved oxygen concentrations were measured at three of the fixed-monitoring stations (fig. 23). The diel variations are controlled primarily by plant photosynthesis and respiration. Chlorophyll-*a* concentrations for these stations (fig. 24) indicate that photosynthesis probably caused the large diel variations observed at map reference number 89.

Upward trends in dissolved oxygen concentrations from 1978 to 1990 were observed at the two most downstream stations in the upper Illinois River Basin (Illinois River at Marseilles, Ill. (map reference number 76), and Fox River at Dayton, Ill. (map

Table 7. Statistical summary of dissolved oxygen concentrations at the eight fixed-monitoring stations in the upper Illinois River Basin, water years 1987–91 (from Terrio, 1994a)

[All concentrations are in milligrams per liter]

Map reference number (see fig. 6)	Station name	Number of observations	Percentile				
			10	25	50 (median)	75	90
14	Kankakee River at Momence, Ill.	475	6.9	8.2	9.6	11.2	12.1
28	Iroquois River near Chebanse, Ill.	816	3.4	6.2	8.8	11.4	12.3
40	Des Plaines River at Riverside, Ill.	435	5.8	7.0	9.1	11.0	12.3
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	615	2.0	2.9	3.4	4.9	7.0
69	Du Page River at Shorewood, Ill.	491	7.0	8.2	9.7	12.3	15.0
76	Illinois River at Marseilles, Ill.	509	6.7	7.6	9.7	11.8	13.2
89	Fox River at Algonquin, Ill.	618	5.0	6.3	8.7	11.3	14.8
99	Fox River at Dayton, Ill.	452	8.5	10.3	12.2	14.2	16.0

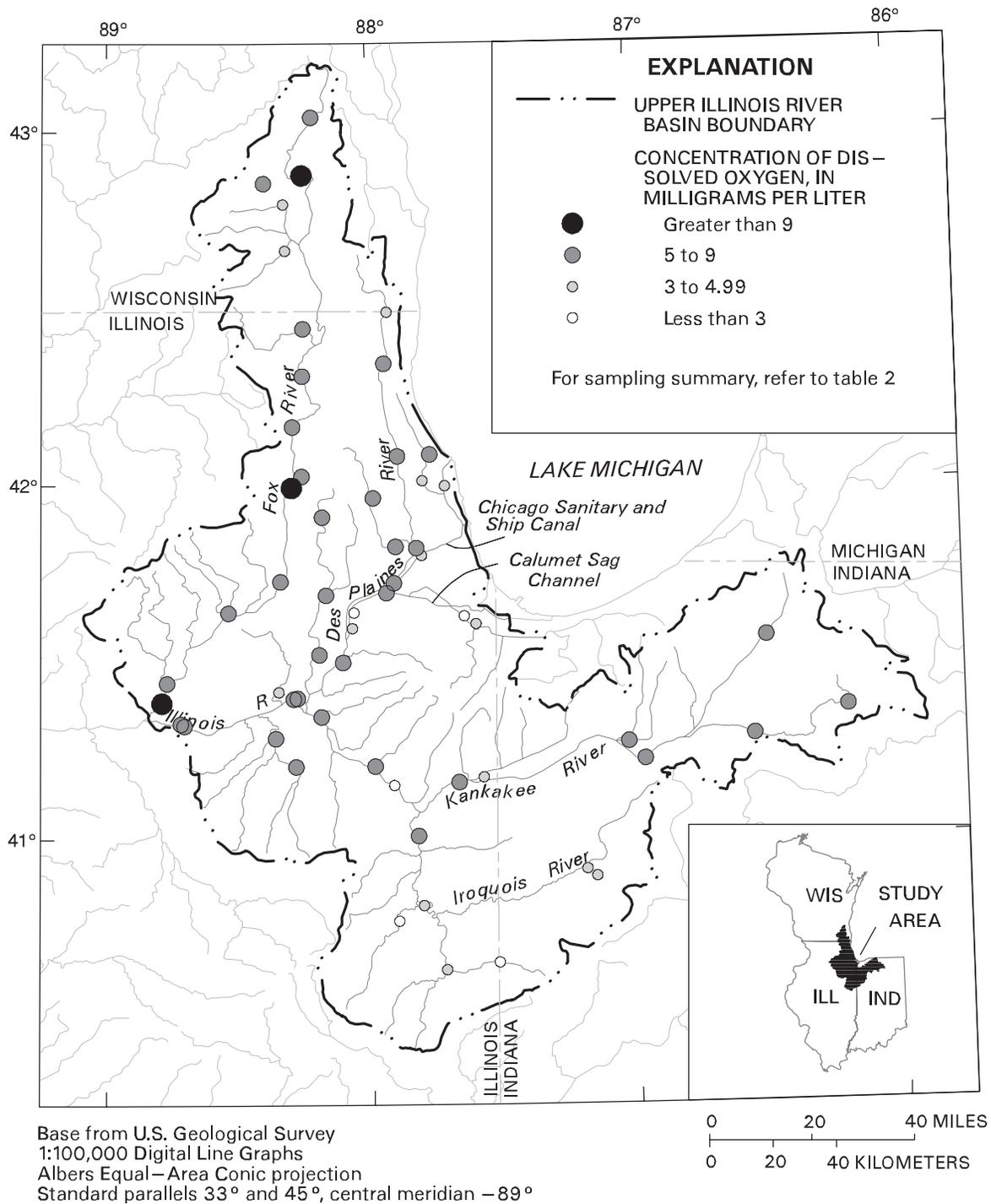


Figure 22. Spatial distribution of dissolved oxygen concentrations in water measured during the low-flow synoptic survey in the upper Illinois River Basin, July 25–August 13, 1988.

reference number 99)). The slope of the upward trend was 0.2 mg/L (2 percent of the median) per year.

Fecal coliform and *Escherichia Coli* (*E. Coli*) were used to indicate bacterial pollution in the upper Illinois River Basin. A statistical analysis of paired *E.*

Coli and fecal coliform data showed that there are no statistically significant differences in the density data from the two tests (Terrio, 1994a, p. 76). Density of *E. Coli* at the eight fixed-monitoring stations ranged from 1 to 45,000 col/100 mL (table 8). Median

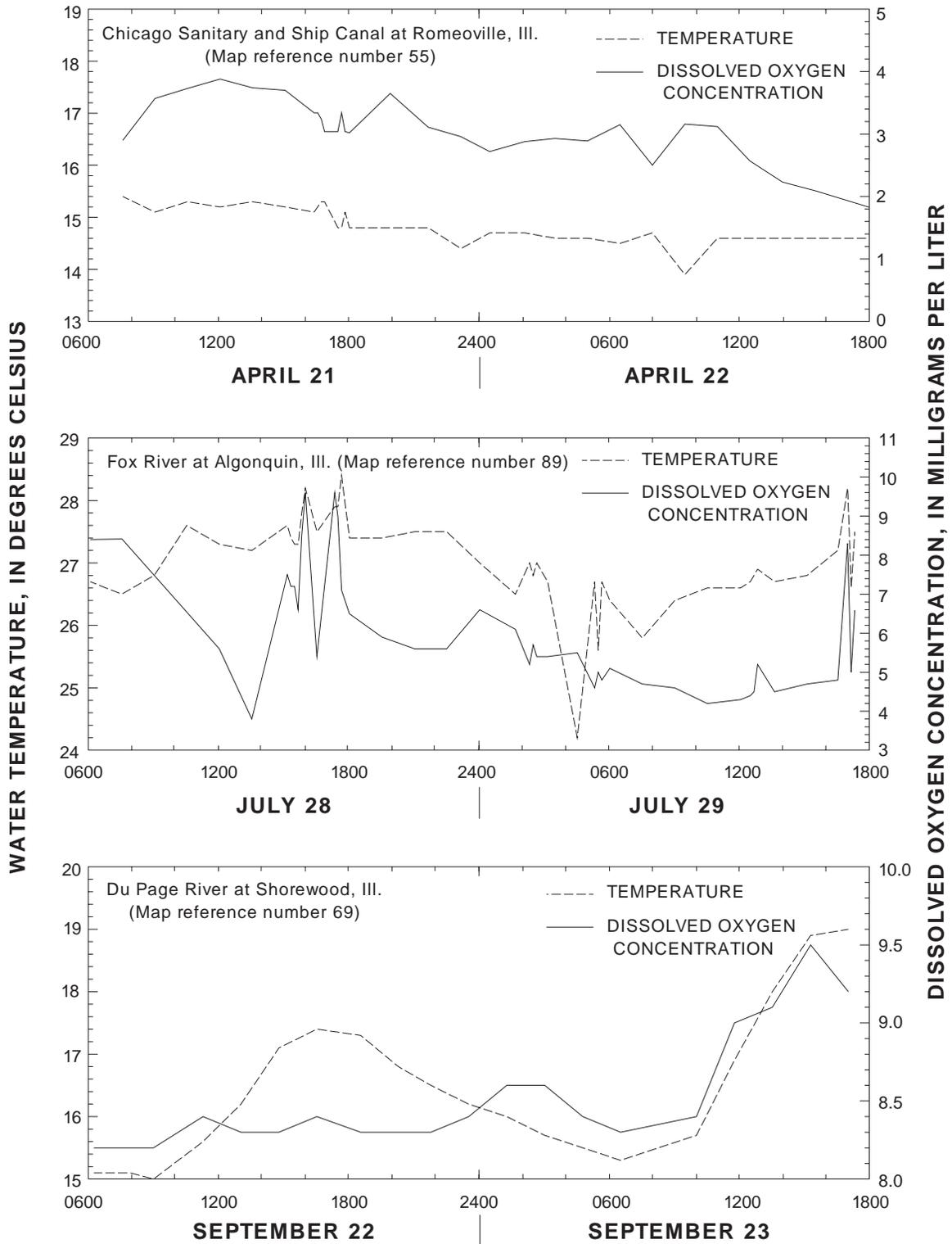
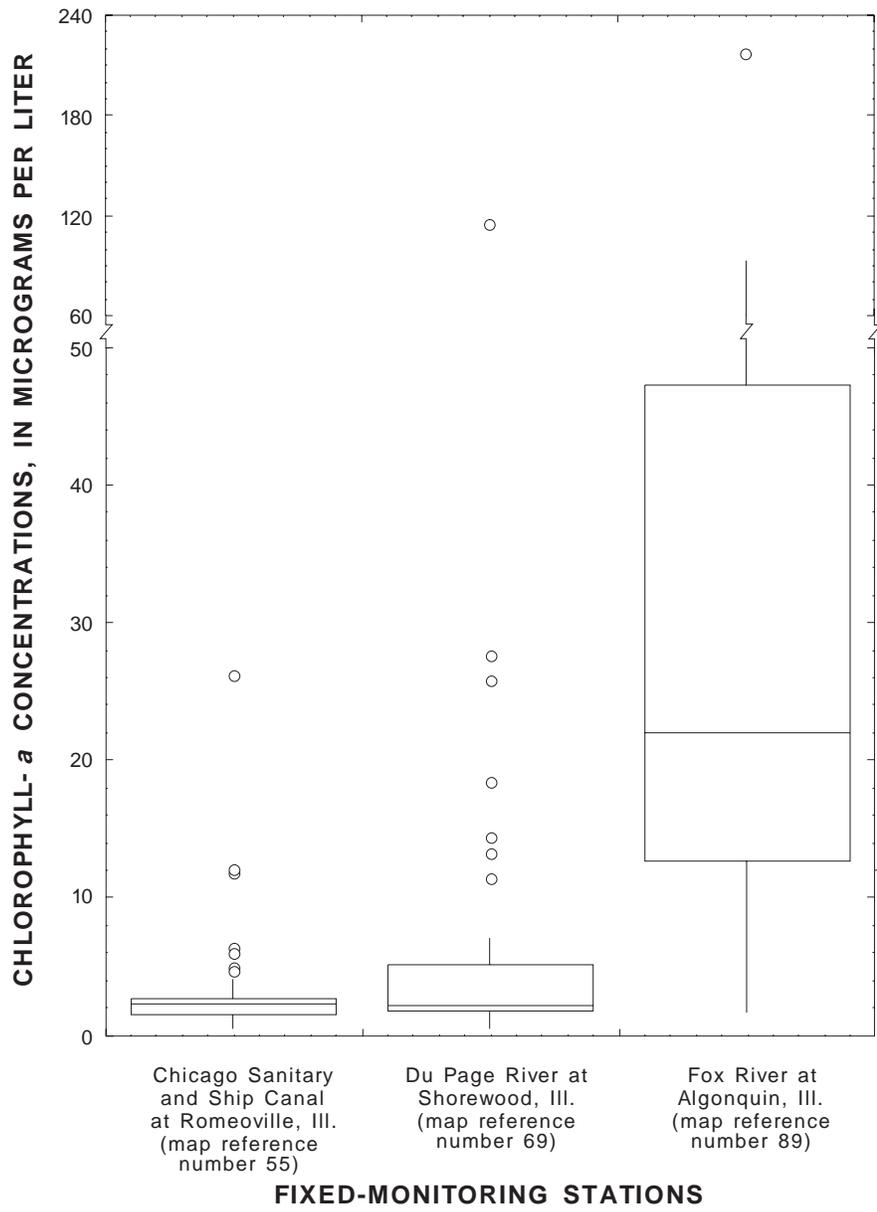


Figure 23. Diel-variations in temperature and dissolved oxygen concentrations at three fixed-monitoring stations during the low-flow synoptic survey in the upper Illinois River Basin, during 36-hour periods.



EXPLANATION

- — Data value(s) exceeding upper quartile
- Largest data value less than or equal to the upper quartile plus 1.5 times the interquartile range
- Upper quartile (75th percentile)
- Median (50th percentile)
- Lower quartile (25th percentile)
- Smallest data value greater than or equal to the lower quartile minus 1.5 times the interquartile range

Figure 24. Chlorophyll-a concentrations in water measured at three fixed-monitoring stations in the upper Illinois River Basin, water years 1987–91.

Table 8. Statistical summary of fecal-indicator bacteria densities at the eight fixed-monitoring stations in the upper Illinois River Basin, water years 1987–90 (from Terrio, 1994a, p. 79)

[All densities are in colonies per 100 milliliters; --, no data]

Map reference number (see fig. 6)	Station name	Number of observations	Minimum	Maximum	Percentile				
					10	25	50 (median)	75	90
Fecal coliform (April 1987–August 1990)									
14	Kankakee River at Momence, Ill.	68	10	10,100	40	60	150	260	637
28	Iroquois River near Chebanse, Ill.	66	4	9,500	10	22	93	282	1,760
40	Des Plaines River at Riverside, Ill.	58	220	45,000	720	1,280	3,050	12,000	24,800
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	51	60	45,000	284	430	1,000	2,250	12,100
69	Du Page River at Shorewood, Ill.	65	3	14,000	19	75	250	860	3,880
76	Illinois River at Marseilles, Ill.	85	1	3,100	16	28	60	115	318
89	Fox River at Algonquin, Ill.	54	5	610	9	11	40	76	205
99	Fox River at Dayton, Ill.	52	9	12,182	19	31	77	175	664
Escherichia Coli (July 1988–August 1990)									
14	Kankakee River at Momence, Ill.	0	--	--	--	--	--	--	--
28	Iroquois River near Chebanse, Ill.	26	8	8,000	11	45	91	422	1,660
40	Des Plaines River at Riverside, Ill.	24	600	45,000	835	1,180	2,800	7,630	35,500
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	23	200	5,600	358	531	1,060	1,670	4,300
69	Du Page River at Shorewood, Ill.	24	3	15,000	11	36	181	1,480	13,300
76	Illinois River at Marseilles, Ill.	22	16	2,916	22	25	97	250	1,930
89	Fox River at Algonquin, Ill.	23	6	833	8	21	37	80	198
99	Fox River at Dayton, Ill.	20	10	600	15	30	47	162	373

densities at the Des Plaines River at Riverside, Ill. (map reference number 40), and the Chicago Sanitary and Ship Canal at Romeoville, Ill. (map reference number 55), were 100 times higher than the median densities from the other fixed-monitoring stations.

Observations from the 1988 synoptic survey indicated that densities were higher than 126 col/100 mL at 44 sites and densities were higher than 576 col/100 mL at 30 stations. Densities were highest in the Des Plaines River Basin (fig. 25).

Bacteria densities higher than water-quality criteria and standards were observed at all fixed-monitoring stations, but densities higher than water-quality criteria and standards were observed more often at stations in the Des Plaines River Basin. Densities for all samples analyzed for *E. Coli* from the Des Plaines River at Riverside, Ill. (map reference number 40), were higher than the single-sample criteria for infrequently used full-body contact recreation. Densities for approximately 73 percent of the

samples collected from the Chicago Sanitary and Ship Canal at Romeoville, Ill. (map reference number 55), exceeded this criteria. Similar percentages were observed for fecal-coliform densities higher than Illinois' general-use water-quality standard of 200 col/100 mL for the monthly geometric mean of five or more samples from a specific site (table 9).

E. Coli densities were determined in samples collected during the low-flow synoptic survey in 1988. During these conditions, the effect of point-source inputs was enhanced because of limited dilution from streamflow. *E. Coli* densities higher than Federal criteria for moderately and infrequently used full-body contact recreation were measured at 47 percent of the sites; this included sites in every major subbasin in the study area (fig. 25). The highest densities, up to 54,000 col/100 mL, were measured at sites on streams and canals in the Chicago metropolitan area designated as secondary-contact waters. *E. Coli* densities that were among the lowest in the basin were detected at the two

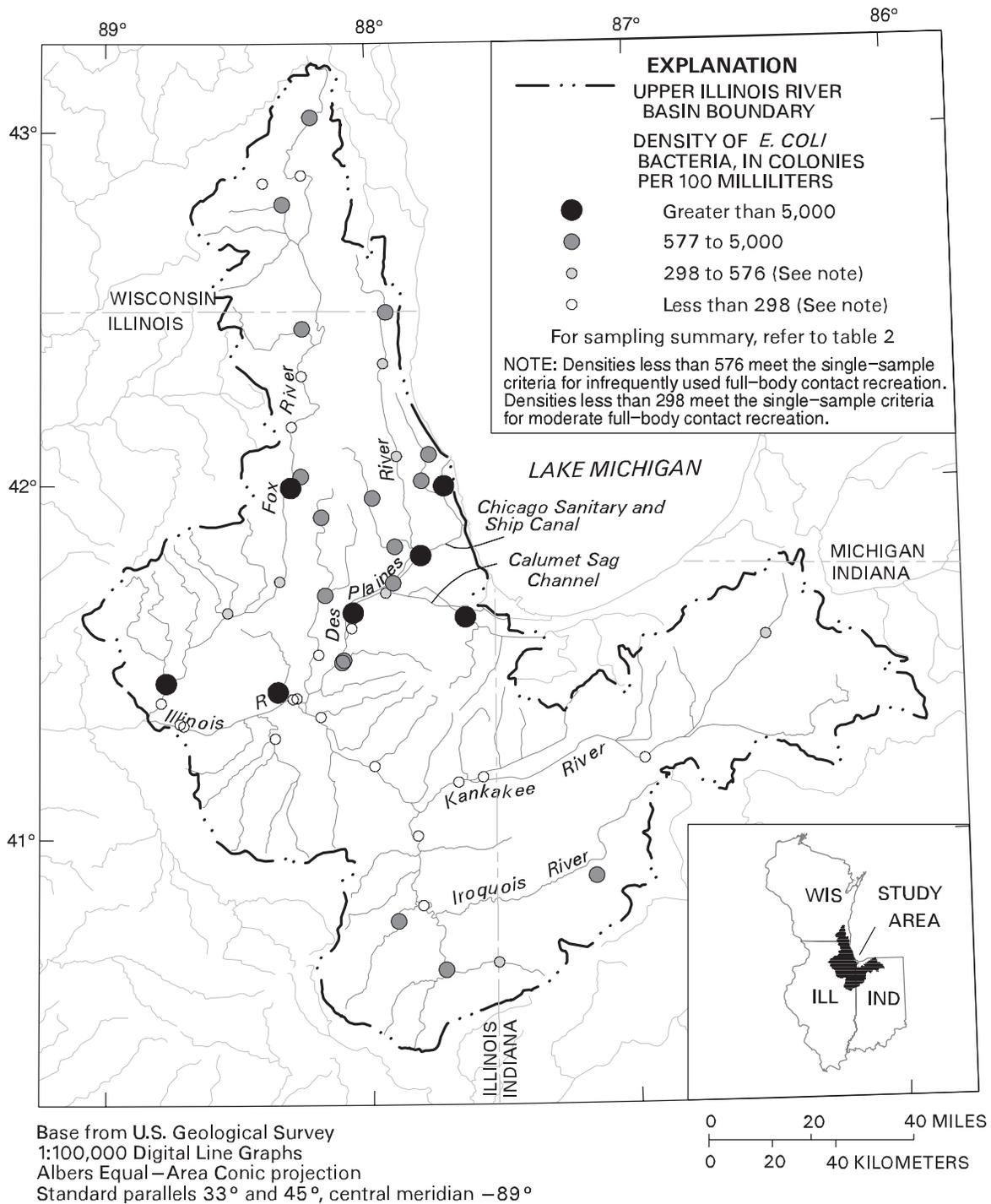


Figure 25. Spatial distribution of *Escherichia Coli* bacteria densities in water measured during the low-flow synoptic survey in the upper Illinois River Basin, July 25–August 13, 1988.

Table 9. Relations of Federal water-quality criteria and State water-quality standards to bacteria densities at the eight fixed-monitoring stations in the upper Illinois River Basin, April 1987–August 1990 (from Terrio, 1994a, p. 79)

[<, less than]

Map reference number (see fig. 6)	Station name	Number of samples	Number of samples with densities greater than indicated value U.S. Environmental Protection Agency criteria for <i>Escherichia Coli</i> (colonies per 100 milliliters)				
			¹ 126	² 235	³ 298	⁴ 406	⁵ 576
14	Kankakee River at Momence, Ill.	61	15	5	3	2	2
28	Iroquois River near Chebanse, Ill.	134	22	9	7	5	4
40	Des Plaines River at Riverside, Ill.	49	22	22	22	22	22
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	50	21	21	20	20	16
69	Du Page River at Shorewood, Ill.	57	22	11	9	7	7
76	Illinois River at Marseilles, Ill.	60	18	6	4	3	2
89	Fox River at Algonquin, Ill.	52	19	1	1	1	1
99	Fox River at Dayton, Ill.	50	16	3	3	1	1

Map reference number (see fig. 6)	Station name	Number of samples	Number of samples with densities greater than indicated value State water-quality standards for fecal coliform (colonies per 100 milliliters)			
			Illinois	Indiana	Wisconsin	
			⁶ 200 monthly average for 5 samples	<5,000 monthly average and <5,000 in 2 percent of samples and 20,000 in <5 percent of samples ⁷	1,000 monthly average for 5 samples and 2,000 maximum ⁸	<400 in 90 percent of samples and <200 in more than 5 samples per month ⁹
14	Kankakee River at Momence, Ill.	61	15	3	4	8
28	Iroquois River near Chebanse, Ill.	134	15	2	3	8
40	Des Plaines River at Riverside, Ill.	49	40	13	24	38
55	Chicago Sanitary and Ship Canal at Romeoville, Ill.	50	37	9	13	31
69	Du Page River at Shorewood, Ill.	57	22	3	9	14
76	Illinois River at Marseilles, Ill.	60	9	0	3	5
89	Fox River at Algonquin, Ill.	52	3	0	0	2
99	Fox River at Dayton, Ill.	50	10	2	3	7

¹Steady-state geometric mean.

²Designated beach area, single sample.

³Moderate full-body contact recreation, single sample.

⁴Lightly used full-body contact recreation, single sample.

⁵Infrequently used full-body contact recreation, single sample.

⁶General-use waters, and public and food-processing water supply.

⁷Domestic and industrial use.

⁸Recreational use.

⁹Public water supply.

sites most downstream in the study area—Fox River at Dayton, Ill. (map reference number 99), and Illinois River at Marseilles, Ill. (map reference number 76).

Significant downward trends in fecal-coliform densities from 1978 to 1990 were observed at three fixed-monitoring stations draining largely agricultural basins (Terrio, 1994a): Iroquois River near Chebanse,

Ill. (map reference number 28), Fox River at Algonquin, Ill. (map reference number 89), and Fox River at Dayton, Ill. (map reference number 99). The magnitude of the downward trends ranged from -7.0 to -14.2 percent of the median density per year. No significant trends were observed at stations in urban areas for 1978–90.

RESULTS OF STUDIES AND IMPLICATIONS FOR THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Studies were done in the upper Illinois River Basin to test the viability of using components of the NAWQA program to evaluate the effect of changes to wastewater-treatment practices on stream-water quality and using fish-community composition and structure as a measure of water quality. Study results are summarized in this section; details of these studies are given in Ruhl (1995), Terrio (1994b), and Zogorski and others (1990).

Availability and Suitability of Information on Municipal Wastewater-Treatment Practices for Large-Scale Water-Quality Assessments

A study was done to describe the availability and suitability of information on municipal wastewater treatment and effluent characteristics for use in the NAWQA program. The study addressed the question “What have been the effects of changes in municipal wastewater treatment on stream quality and ecosystem health?” (Zogorski and others, 1990).

Forty-eight of 118 wastewater-treatment plants in the upper Illinois River Basin were examined to determine the extent of available data on treatment and effluent characteristics. All 48 of the municipal wastewater-treatment plants maintained continuous records of effluent flow rates. No daily flow rates were entered into State or Federal data bases, but about 50 percent of the major wastewater-treatment plants entered their daily flow-rate data into a local computer data base. Except for wastewater-treatment plants operated by the MWRDGC, which monitors 43 constituents daily, only 8 water-quality characteristics—fecal-coliform bacteria, total chlorine residual, total phosphorus, ammonia nitrogen, suspended solids, carbonaceous

biochemical oxygen demand, biochemical oxygen demand, and pH—were commonly measured in effluent samples.

Although much information on wastewater-treatment and effluent characteristics is available, this information is of limited use for accomplishing the objectives of a national assessment. This information would be improved by (1) increasing the number of water-quality constituents routinely monitored in municipal effluent samples, (2) increasing the frequency of effluent monitoring at many locations and utilizing flow-weighted 24-hour composite samples for selected constituents, and (3) developing and utilizing a quality-assurance plan for effluent flow-rate determinations.

Evaluation of the Effects of Changes in Wastewater-Treatment Practices on Stream-Water Quality

Relations between changes in wastewater-treatment practices and stream-water quality were evaluated as part of the assessment of the upper Illinois River Basin (Terrio, 1994b). Relation of changes in the water chemistry in the Calumet Sag Channel to changes in practices at the MWRDGC's Calumet wastewater-treatment plant (design average discharge of 354 Mgal/d) and the implementation of Chicago's Tunnel and Reservoir Plan (TARP) system in the Chicago metropolitan area to capture overflow from combined sewers were examined. Relation of changes in the water chemistry in the Des Plaines River Basin to changes in practices at four large wastewater-treatment plants (design average discharge from 55 to 1,440 Mgal/d) also were examined.

Two major changes in wastewater-treatment practices between 1983 and 1986–88 were considered. In 1983, the Calumet wastewater-treatment plant, with approval from the IEPA, ceased effluent disinfection. In 1986–87, runoff from combined sewers in the service area of the wastewater-treatment plant were discharged to the TARP system. During 1987–88, additional blowers were installed, and diffusers were replaced, which increased the aeration in the secondary treatment at this plant. The effects of the TARP system and improved secondary-treatment aeration were considered to have occurred concurrently for this evaluation.

Fecal-coliform bacteria densities increased at sampling sites downstream from the Calumet

wastewater-treatment plant after disinfection of the effluent was discontinued. However, increases were limited to the vicinity of the wastewater-treatment plant. No change in bacteria densities was observed at sampling sites farther than 7 mi downstream, although effluent composed about 45–75 percent of the stream-flow.

Significant changes in concentrations of suspended solids and other constituents were observed in water samples from the effluent of the wastewater-treatment plant and from the Calumet Sag Channel after the TARP system began to collect overflow from combined sewers, and aeration was improved at the wastewater-treatment plant (table 10). Biochemical oxygen demand (BOD) decreased in the effluent and at all downstream sites. The BOD of effluent decreased from a median of 19 mg/L to a median of 15 mg/L, and median BOD at the downstream sites decreased by 3–4 mg/L. Median ammonia concentrations of effluent decreased from 12.4 to 3.6 mg/L. Downstream ammonia concentrations decreased about 3.5–4.5 mg/L. For BOD and ammonia, the probable causes for the decrease in effluent and downstream concentrations were the improvements in aeration made at the Calumet wastewater-treatment plant in 1987–88.

Other appreciable changes in concentrations of suspended solids and other constituents that may have resulted from the implementation of Phase I of the TARP system and improvements to aeration at the Calumet wastewater-treatment plant are shown in table 10. The decreases primarily were in samples with concentrations at the extreme high end of the distribution. The decreases are to be expected as the effects of the TARP system are limited to runoff periods, which would correspond to the extreme samples. The distribution of concentrations after the TARP system was implemented were significantly different from those before the TARP system. These differences are indicated in the percentile plots of the distribution of concentrations before and after the TARP system (fig. 26).

The effects of the changes in wastewater-treatment practices on the biota of the Little Calumet River and the Calumet Sag Channel were examined using fish-sampling data from electrofishing surveys performed in 1974–77 and 1985–90 by the MWRDGC for six sites in the Calumet River system. Three sites were located upstream from the Calumet wastewater-treatment plant, and three sites were located downstream from the Calumet wastewater-treatment plant. Changes in fish-community structure and population,

as summarized by the Index of Biotic Integrity (IBI) (Karr and others, 1986), did not indicate change following the changes in the wastewater-treatment practices. The low, high, and average IBI scores for the six fish-sampling sites for samples collected annually from 1974 to 1977 and from 2 to 3 times a year from 1985 to 1990 are shown in figure 27. All IBI scores for the sites were indicative of a poor to very poor capability of the Calumet River system to support fish communities. Although changes in IBI scores are shown in figure 27, they do not necessarily reflect major changes in the biota of the streams. The habitat in the Calumet River system is degraded, and although habitat is not directly included in determining IBI scores, a degraded habitat can affect fish-species ecosystem in such a way as to lower IBI scores.

Results indicate that current monitoring programs in Illinois, although sufficient for their intended purposes, could be enhanced for large-scale retrospective water-quality assessments. The lack of discharge data from the stream-monitoring program prevented constituent load and mass transport analyses that would have allowed for more quantitative analyses. These analyses could have provided important additional information regarding changes in stream-water quality resulting from changes in effluent quality.

Water-quality samples collected during and following storms could have been utilized to quantify the effects of nonpoint sources—such as those discharging to the TARP system—on effluent and stream-water quality. A more comprehensive analysis of the effects of changes to wastewater-collection and -treatment practices could be made with a few enhancements to the monitoring programs.

Fish-Community Composition and Structure as a Measure of Water-Quality Conditions

Many ecologists have used multivariate analysis to study patterns between fish-community structure and water-quality conditions (Gauch, 1982; Ter Braak, 1986). As part of the upper Illinois River Basin NAWQA study (Ruhl, 1995), a widely used multivariate ordination technique, detrended correspondence analysis (DCA), was evaluated for indirect gradient analysis of relations between community structure and water-quality conditions. Of particular interest was how this technique might be applied to the analysis of

Table 10. Statistical summary of concentrations of selected constituents and properties before and after implementation of the Tunnel and Reservoir Plan (TARP) system and improvements to aeration at the Calumet wastewater-treatment plant

[ft³/s, cubic feet per second; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; --, no data]

Property or constituent	Units	Percentiles									
		January 1985–August 1986					January 1987–December 1990				
		10	25	50 (median)	75	90	10	25	50 (median)	75	90
Effluent from Calumet wastewater-treatment plant											
Discharge	ft ³ /s	220	229	240	258	262	219	233	252	287	307
pH	units	7.4	7.4	7.5	7.6	7.7	7.0	7.1	7.1	7.2	7.3
Dissolved oxygen	mg/L	6.1	6.5	7.0	7.6	7.8	6.2	6.4	6.9	7.3	7.6
Chemical oxygen demand	mg/L	54	63	72	82	110	37	40	45	53	76
Biochemical oxygen demand	mg/L	13	17	19	21	27	7	10	15	20	29
Fecal-coliform bacteria	1,000 col/100 mL	53.9	180	365	670	1,900	8.89	18.9	32.1	83.4	257
Chloride	mg/L	115	124	138	178	215	91	120	141	173	212
Suspended solids	mg/L	11	17	20	23	32	7	9	12	16	23
Ammonia	mg/L	6.53	10.9	12.4	15.1	15.9	1.53	2.41	3.58	5.92	9.41
Phosphorus, total	mg/L	1.12	1.54	2.02	2.23	2.43	1.72	1.93	2.26	2.49	3.06
Cyanide	µg/L	10	30	50	90	140	20	20	30	30	40
Phenol	µg/L	4	4	5	6	9	3	4	5	7	9
Oil and grease	mg/L	4	4	6	6	8	5	6	7	10	12
1.5 Miles downstream from Calumet wastewater-treatment plant											
Discharge	ft ³ /s	--	--	--	--	--	--	--	--	--	--
pH	units	7.1	7.1	7.3	7.4	7.8	6.7	7.0	7.2	7.5	7.6
Dissolved oxygen	mg/L	0	1.1	3.6	4.4	4.9	.8	4.1	5.5	6.8	7.3
Chemical oxygen demand	mg/L	24	36	49	62	84	21	30	39	48	77
Biochemical oxygen demand	mg/L	4	6	9	11	13	2	3	5	8	11
Fecal coliform bacteria	1,000 col/100 mL	33	80	210	568	1,240	.39	4.2	13.5	165	270
Chloride	mg/L	58	67	107	151	211	46	66	94	138	216
Suspended solids	mg/L	9	14	19	26	40	10	11	17	21	26
Ammonia	mg/L	2.09	3.95	6.65	8.50	10.4	.80	1.32	2.15	3.90	6.50
Phosphorus, total	mg/L	.34	.64	.84	1.16	1.67	.35	.62	.81	1.13	1.42
Cyanide	µg/L	30	50	100	220	500	10	20	20	30	60
Phenol	µg/L	42	68	108	175	340	6	10	18	29	153
Oil and grease	mg/L	0	0	5	13	22	0	2	7	17	22

Water-Quality Conditions (1987–91) and Trends (1978–91) in the Upper Illinois River Basin

Table 10. Statistical summary of concentrations of selected constituents and properties before and after implementation of the Tunnel and Reservoir Plan (TARP) system and improvements to aeration at the Calumet wastewater-treatment plant—Continued

Property or constituent	Units	Percentiles									
		January 1985–August 1986					January 1987–December 1990				
		10	25	50 (median)	75	90	10	25	50 (median)	75	90
17.4 Miles downstream from Calumet wastewater-treatment plant											
Discharge	ft ³ /s	--	--	--	--	--	--	--	--	--	--
pH	units	7.0	7.2	7.3	7.5	7.8	6.8	7.1	7.3	7.5	7.6
Dissolved oxygen	mg/L	1.0	1.3	2.0	2.9	4.6	1.2	2.7	4.8	5.7	7.5
Chemical oxygen demand	mg/L	27	30	39	48	72	18	30	36	42	46
Biochemical oxygen demand	mg/L	2	3	6	7	10	1	2	3	7	8
Fecal coliform bacteria	1,000 col/100 mL	.678	2.02	13	85	161	.03	.25	2	4.82	85
Chloride	mg/L	60	62	87	147	208	53	72	106	147	202
Suspended solids	mg/L	9	13	24	35	74	9	14	23	34	47
Ammonia	mg/L	1.90	3.30	5.90	7.70	9.00	.65	1.17	2.49	4.67	7.18
Phosphorus, total	mg/L	.52	.59	.82	1.08	1.52	.60	.77	.87	1.55	1.84
Cyanide	µg/L	7	10	30	100	150	7	9	13	26	120
Phenol	µg/L	39	43	59	76	96	5	11	17	27	56
Oil and grease	mg/L	0	4	9	21	27	0	3	7	17	20

data collected for regional-scale, spatially oriented water-quality assessments.

Fish-community structure was summarized with DCA, a multivariate ordination technique, and with the Alternate Index of Biotic Integrity (AIBI). The AIBI is a modification of the IBI (Karr and others, 1986) that was specifically designed for Illinois streams (Hite and Bertrand, 1989). Relations between fish-community structure and water quality; streambed-sediment quality; and habitat in the Fox, Des Plaines, and Du Page River Basins in northeastern Illinois were examined with this technique to identify and describe some of the predominant environmental factors that affect the structure of fish communities within these river basins (Ruhl, 1995).

Fish communities were grouped with DCA and the AIBI. Streams in the predominantly agricultural Fox River Basin tended to have similar DCA scores, the highest AIBI scores, and relatively diverse fish communities that usually included several intolerant species. Streams in the more heavily urbanized Chicago, Calumet, Des Plaines, and Du Page River Basins tended to have lower AIBI scores and fish communities dominated by fewer, more tolerant species.

The relation between patterns in fish-community structure and patterns in the concentration of these constituents can be determined by comparing boxplots of the concentration of these constituents to boxplots of DCA and AIBI scores (fig. 28). The lowest DCA and AIBI scores, and the highest concentrations of these constituents are from sites in the most heavily urbanized basins (Chicago, Calumet, and Des Plaines River Basins). In contrast, the highest DCA and AIBI scores, and the lowest concentrations of these constituents are from stations in the agricultural Fox River Basin.

The results of the correlative and graphical analyses indicate that during the early 1980's fish-community structure within the study area was strongly related to patterns in water quality associated with differences between agricultural and urban land uses. Analyses of fish-community data clearly indicate that water-quality conditions in the urbanized parts of the study area were degraded relative to those in agricultural areas; for example, in highly urbanized areas, the fish community was entirely composed of extremely tolerant species, such as goldfish and common carp. The relations between fish-community structure and water quality were associated with assemblages of water-quality constituents. Results indicate a relation

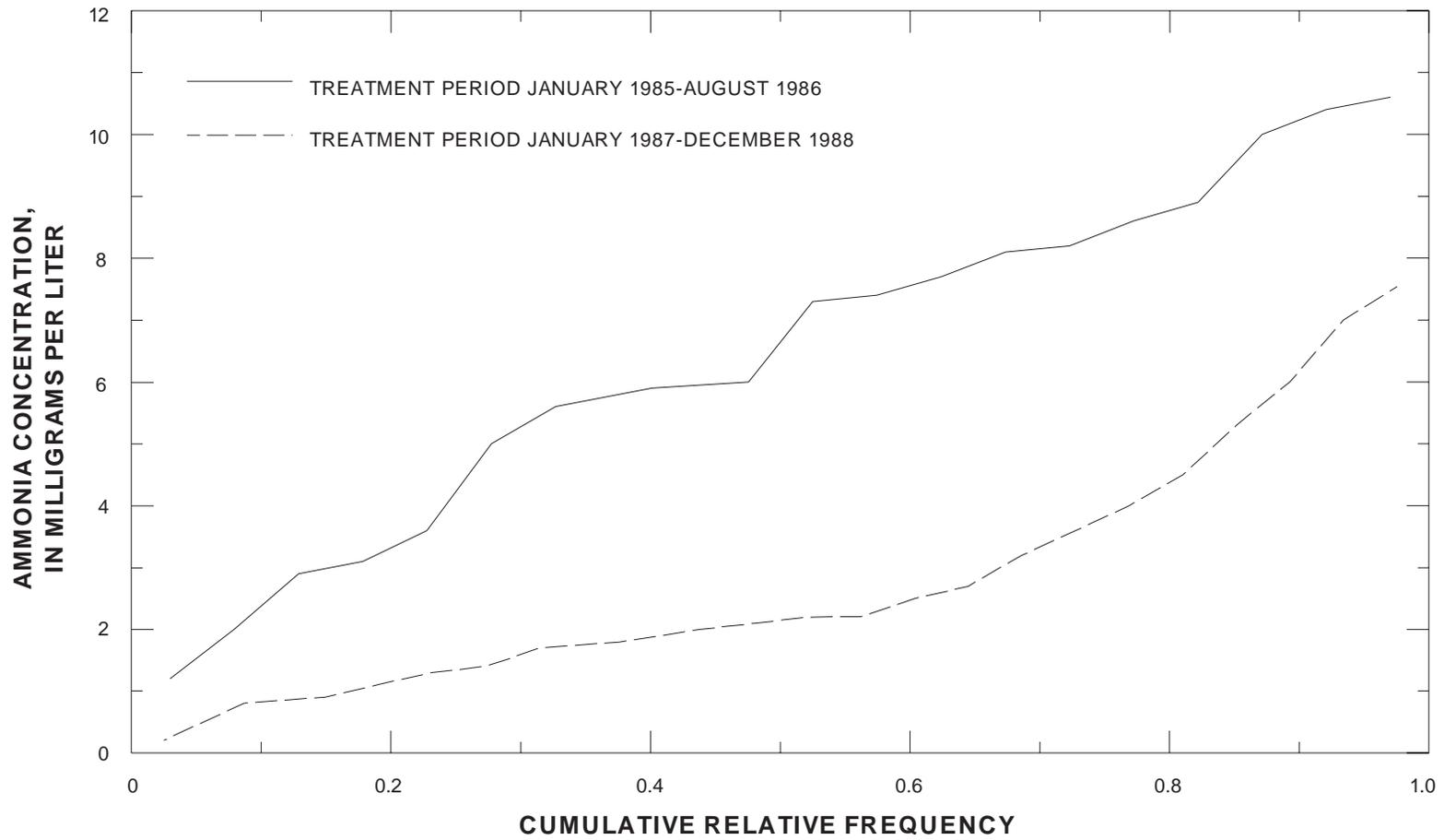


Figure 26. Exceedance probabilities for ammonia concentrations observed in the Calumet Sag Channel before and after implementation of the Tunnel and Reservoir Plan (TARP) system and improvements to aeration at the Calumet wastewater-treatment plant.

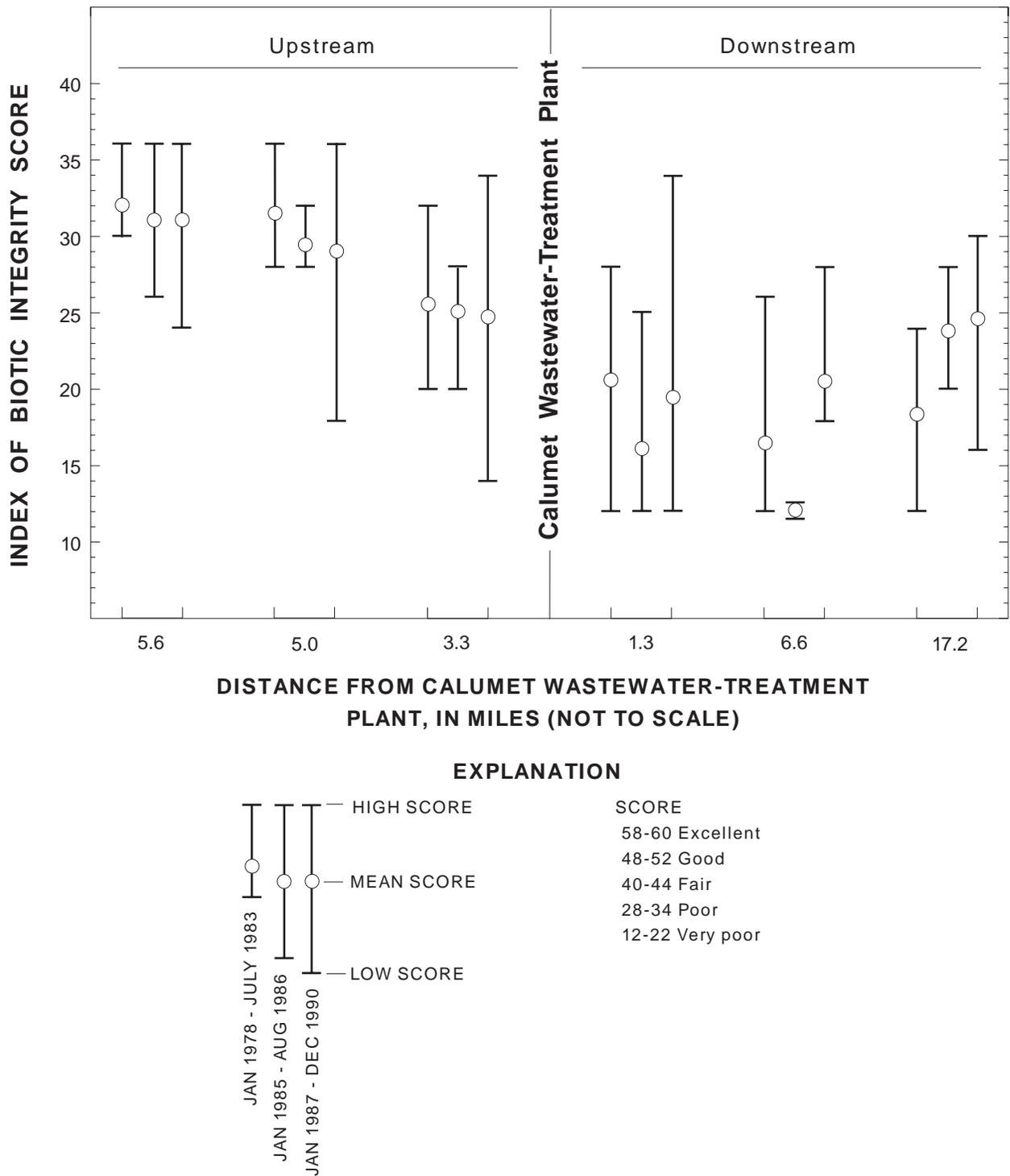
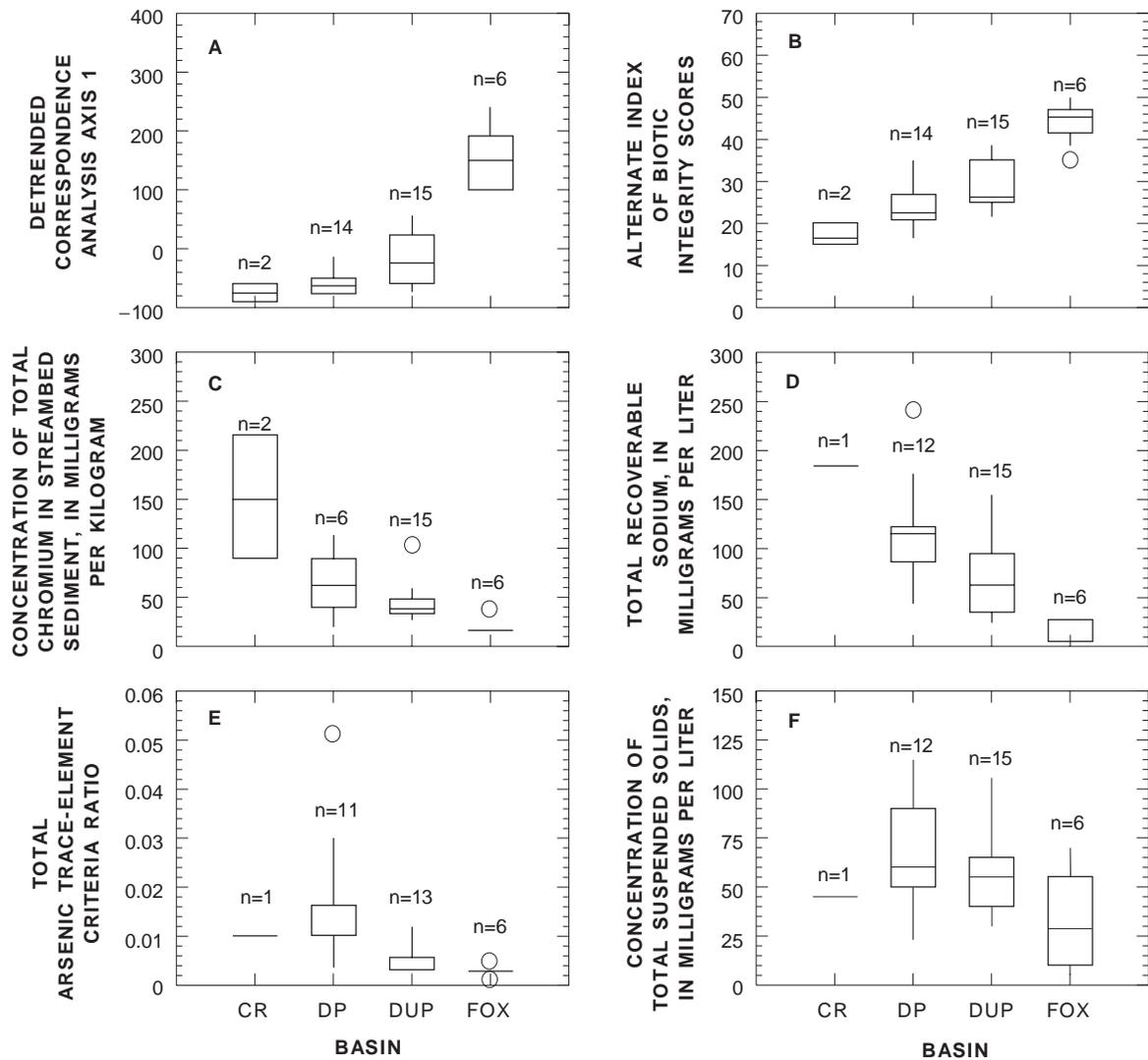


Figure 27. Index of biotic integrity (IBI) scores for six sites in the Calumet Sag Channel before and after implementation of the Tunnel and Reservoir Plan (TARP) system and improvements to aeration at the Calumet wastewater-treatment plant.



EXPLANATION

- n=11 — Number of samples
- — Data value(s) exceeding upper quartile
- Largest data value less than or equal to the upper quartile plus 1.5 times the interquartile range
- Upper quartile (75th percentile)
- Median (50th percentile)
- Lower quartile (25th percentile)
- Smallest data value greater than or equal to the lower quartile minus 1.5 times the interquartile range

- BASIN DESIGNATION
- CR Chicago/Little Calumet River Basin
 - DP Des Plaines River Basin
 - DUP Du Page River Basin
 - FOX Fox River Basin

Figure 28. Detrended correspondence analyses (DCA) axis 1 site scales, Alternate Index of Biotic Integrity (AIBI) scores, concentrated total chromium in streambed sediments, concentration of total recoverable sodium, trace-element criteria ratios (TECR) for total arsenic, and concentration of total solids at sites in the Chicago/Little Calumet, Des Plaines, Du Page, and Fox River Basins.

between the quality of the fish community and overall water-quality conditions.

USEPA acute water-quality criteria (U.S. Environmental Protection Agency, 1986) were exceeded for just four constituents: total cyanide, dissolved oxygen, total recoverable copper, and un-ionized ammonia (U.S. Environmental Protection Agency, 1986). Of the concentrations of constituents exceeding USEPA acute criteria, only the ratio of un-ionized ammonia to the USEPA criteria and the ratio of total recoverable copper to the USEPA criteria were significantly correlated with fish-community structure for wadable and nonwadable sites. For nonwadable sites, both ratios were significantly correlated with DCA and AIBI scores. For wadable sites, both ratios were significantly correlated with DCA scores, and the un-ionized ammonia criteria ratio was significantly correlated with AIBI scores.

Fish-community structure was not as strongly related to habitat as to water and streambed-sediment quality. Substrate particle size was weakly related to fish-community structure for wadable and nonwadable sites because the correlation coefficient was relatively small (wadable sites) or sampling was incomplete (nonwadable sites). For nonwadable sites, the percentage of the sampling reach containing logs and the percentage containing fish cover were weakly related to AIBI scores because sampling was incomplete. Fish-community structure for wadable sites was related to discharge, stream width, stream order, and current velocity but not as strongly as to water quality.

Results of analyses based on DCA and results of analyses based on AIBI are in general agreement. The similar DCA and AIBI results indicate that application of multivariate techniques for regional water-quality assessments is appropriate. Furthermore, multivariate techniques can be applied for validating the design of indices, such as the AIBI. Results from the two methods were similar probably because of the advanced development of the AIBI in Illinois. In other cases, however, where fully developed and tested biotic indices are not available, DCA may be utilized for design and testing.

Implications of results for the NAWQA study design are the following:

- Fish-community data are useful to identify long-term, low-level water-quality effects that would not be identified by comparing concentrations of constituents with water-quality criteria.

- Results from the DCA and AIBI methods were similar.

The NAWQA study of the upper Illinois River Basin provided data collected from several different media and for different groups of constituents. These data characterized not only the chemical quality of the water but also the quality of the streambed and suspended sediment; the concentration of selected constituents in tissue samples; and the composition and structure of fish, macroinvertebrate, and algal communities.

SUMMARY

A water-quality assessment of the 10,949 square miles upper Illinois River Basin during water years 1987–91 involved interpretation of available data, 4 years of intensive data collection including monthly sample collection at selected fixed-monitoring stations in the basin, and synoptic studies of selected water-quality constituents at many other stations and sites.

Discharges observed during the period of this study were greater than observed over the period of record but was not as large as during the period used for the analysis of available information (water years 1978–86). Precipitation observed during the period of this study was not appreciably different from that observed during the period of record for precipitation (1948–91) and the period used for the analysis of available information (water years 1978–86).

The number of exceedances of water-quality criteria for chromium, copper, lead, mercury, silver, and zinc in water was essentially the same at similar stations (mainly in the Des Plaines River Basin) between 1978–86 and 1987–90. Although the Chicago metropolitan area contains some of the most intensively urban and industrial land in the basin, concentrations of many of the trace inorganic constituents in water were below the minimum reporting level. Minimum reporting levels were just low enough to adequately classify concentrations that exceeded water-quality criteria.

In general, the spatial distribution of major and trace inorganic constituents in the upper Illinois River Basin indicated enrichment from the urban areas. For water and sediment, a large signature for many trace inorganic constituents was observed in the Chicago metropolitan area, mainly from the Des Plaines River Basin and continuing down the Illinois River. Loads of trace inorganic constituents in water were 2–13 times

greater from the Chicago metropolitan area than from rural areas in the upper Illinois River Basin.

Synoptic sampling for trace-inorganic constituents in fine-grained streambed sediments indicated two distinctive patterns of enrichment: (1) Enrichment in the Chicago metropolitan area and in streams draining the urban area, relative to rural areas; and (2) enrichment in high-order streams (main stems), relative to low-order stream (tributaries).

Concentrations of cadmium, mercury, nickel, selenium, and zinc appeared to be relatively enriched in biota from rural and urban stations scattered across the upper Illinois River Basin compared to other river basins in Illinois. Biota from some urban stations in the basin were enriched with respect to several elements. Relatively high concentrations of cadmium, chromium, copper, nickel, and lead were detected in biota from sites in the urban Chicago and Calumet Rivers.

Correlation analysis between element concentrations in tissues and other components in this study emphasizes that water and sediment cannot be used as surrogates for biota; concentrations in biota cannot presently be determined from concentrations in these components; and because of bioaccumulation, concentrations of trace elements in biota must be measured directly. It is clear that a combination of information from various components is optimum for achieving a more complete understanding of water quality in the upper Illinois River Basin.

Results of pesticide sampling in 1988 and 1989 indicate that bromacil, diazinon, malathion, prometon, and simazine were primarily urban related. Agricultural-related pesticides included alachlor, atrazine, cyanazine, metolachlor, and metribuzin. Concentrations of atrazine exceeded the maximum contaminant level (MCL) for drinking water in agricultural and urban areas. The atrazine breakdown products, desethylatrazine and desisopropylatrazine, were detected in 100 and 94 percent of samples, respectively.

Chloroform was the most commonly detected volatile organic compound, which was present in 42 percent of the samples collected during a 1988 synoptic survey. The next most commonly detected compounds—tetrachloroethylene and 1,1,1-trichloroethane—each were detected in 29 percent of the samples. With one exception, all stations at which more than one compound was detected were in the vicinity of a point source.

Phenols were detected most frequently in the Des Plaines River Basin with 62 percent of the total detections in the upper Illinois River Basin. Median phenol concentrations measured from samples taken during the Metropolitan Water Reclamation District of Greater Chicago 1989 survey decreased with distance downstream from Chicago. Phenol concentrations never exceeded the general-use and secondary-contact standards of 100 and 300 micrograms per liter ($\mu\text{g/L}$), respectively. Pentachlorophenols were detected most frequently in the Des Plaines River Basin. Pentachlorophenol concentrations detected at the Illinois River at Marseilles, Ill. (map reference number 76), between 1981 and 1992 showed a decrease beginning in 1987, which was most likely associated with the ban on the use of pentachlorophenols on nonwood products by the Illinois Environmental Protection Agency in 1987.

A breakdown product of the organochlorine pesticide dichloro-diphenyl-trichloroethane (DDT), *p,p'*-DDE, was the most commonly detected organic compound in biota in 1989 and 1990. Concentrations of polychlorinated biphenyls (PCB's), *p,p'*-DDE, *p,p'*-DDD, and dieldrin in biota had the most variability and highest median. In the nine fish-fillet samples collected in 1989, exceedances of U.S. Environmental Protection Agency fish-tissue concentrations were noted for *p,p'*-DDE in all nine fillets and for dieldrin in five of the nine fillets.

During low-flow conditions, almost all of the total nitrogen load measured in the upper Illinois River Basin was in the Des Plaines River Basin. The majority of this load was from the Chicago Sanitary and Ship Canal. The Chicago Sanitary and Ship Canal also was observed to carry most of the ammonia and phosphorus loads during low-flow conditions.

Nutrient concentrations in the upper Illinois River Basin generally were higher than concentrations typically found in natural waters. Nutrient concentrations in urban areas, particularly in the Des Plaines River Basin, generally were higher than in other areas of the upper Illinois River Basin. The Des Plaines River Basin contributed approximately 41 percent of the total nitrogen load to the upper Illinois River Basin, whereas the Kankakee River and Fox River Basins contributed about 39 and 13 percent of the total load, respectively. About 30 percent of the total nitrogen load in the upper Illinois River Basin was measured in the Chicago Sanitary and Ship Canal, Ill. (map reference number 55).

Although most of the nitrogen in the upper Illinois River Basin streams was in the form of nitrate, ammonia concentrations indicate differences between stations draining urban and rural areas. Concentrations of ammonia were higher at stations with urban drainage areas and substantial upstream inputs from wastewater-treatment plants. All ammonia concentrations higher than 10 mg/L were detected in the Des Plaines and Du Page Rivers.

Median dissolved oxygen concentrations at the fixed-monitoring stations ranged from 3.4 mg/L at the Chicago Sanitary and Ship Canal at Romeoville, Ill. (map reference number 55), to 12.2 mg/L at the Fox River at Dayton, Ill. (map reference number 99). Dissolved oxygen concentrations measured during a 1988 synoptic sampling did not meet the State water-quality standards at 76 percent of the stations sampled. In the Kankakee River Basin, 10 of the 17 stations contained water with dissolved oxygen concentrations less than 5 mg/L, including the site with the lowest measured concentration (1.85 mg/L). In contrast, dissolved oxygen concentrations in water at all stations measured in the Fox River Basin were greater than 5 mg/L.

Bacteria densities greater than water-quality criteria and standards were observed at all of the fixed-monitoring stations, but densities greater than water-quality criteria and standards were observed more often at stations in the Des Plaines River Basin. Densities of all the samples analyzed for *Escherichia Coli* from the Des Plaines River at Riverside, Ill. (map reference number 40), were greater than the single-sample criteria for infrequently used full-body contact recreation. Approximately 73 percent of the samples collected from the Chicago Sanitary and Ship Canal at Romeoville, Ill. (map reference number 55), contained densities exceeding this criteria.

Significant downward trends in fecal-coliform bacteria densities from 1978 to 1990 were observed at three fixed-monitoring stations draining largely agricultural basins. No significant trends were observed at stations in urban areas for 1978–90.

Fecal-coliform bacteria densities increased at sampling sites downstream from the Calumet wastewater-treatment plant after disinfection of the effluent was discontinued. However, these increases were limited to the vicinity of the wastewater-treatment plant. No change in bacteria densities was observed at sampling sites farther than 7 miles downstream, although effluent compose about 45 to 75 percent of the streamflow.

Significant changes in concentrations of suspended solids and other constituents were observed in water samples from the effluent of the wastewater-treatment plant and from the Calumet Sag Channel after overflow from combined sewers began discharging to Chicago's Tunnel and Reservoir Plan (TARP) system and aeration was improved. Median concentrations of biochemical oxygen demand (BOD) and ammonia decreased in the effluent and at all downstream sites. Changes in fish-community structure and population, as summarized by the Index of Biotic Integrity (IBI), did not indicate changes following changes in wastewater-treatment practices. Results from the analysis of changes in water quality following changes in wastewater-treatment practices indicate that current monitoring programs, although sufficient for their intended purposes, need to be enhanced for large-scale retrospective water-quality assessments. The lack of discharge data from the stream-monitoring program prevented constituent load and mass transport analyses.

Fish communities were grouped by river basin by Detrended Correspondence Analysis (DCA) and the Alternate Index of Biotic Integrity (AIBI). Streams in the predominantly agricultural Fox River Basin tended to have similar DCA scores, the highest AIBI scores, and relatively diverse fish communities that usually included several intolerant species. Streams in the more heavily urbanized Chicago, Calumet, Des Plaines, and Du Page River Basins tended to have lower DCA and AIBI scores, and fish communities dominated by fewer, more tolerant species. Analyses of fish-community data clearly indicate that water-quality conditions in the urbanized parts of the study area were degraded relative to those in agricultural areas. For example, in highly urbanized areas, the fish community was entirely composed of extremely tolerant species, such as goldfish and common carp.

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APPENDIX

APPENDIX: SELECTED WATER-SAMPLING STATIONS INCLUDED IN THE WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN, 1987–92

[Lat, latitude; Long, longitude; ND, no data]

Phase of study: Pest2, Phase II (1990) pesticide-sampling site; VOC, sampling site for nonagricultural volatile and semivolatile organic compounds; Nutr, nutrient-sampling site; Bio90, 1990 biology-sampling site; Bio89, 1989 biology-sampling site; Retro, analysis of available data; Ufix, fixed-monitoring station operated by the U.S. Geological Survey; Pest1, Phase I (1988–89) pesticide-sampling site; Ifix, fixed-monitoring station operated by the Illinois Environmental Protection Agency

Map reference number	Station number	Station name	Drainage area (square miles)	Phase of study
Kankakee River Basin				
1	05515000	Kankakee River near North Liberty, Ind. Lat 41°33'50" Long 86°29'50"	174	Pest2, VOC, Nutr
2	05515480	Mill Creek at Highway 39 near Kingsford Heights, Ind. Lat 41°27'04" Long 86°44'14"	ND	Bio90
3	05515500 ×	Kankakee River at Davis, Ind. Lat 41°24'00" Long 86°42'04"	537	Pest2
4	05516500	Yellow River at Plymouth, Ind. Lat 41°20'25" Long 86°18'16"	294	Pest2
5	05517000	Yellow River at Knox, Ind. Lat 41°18'10" Long 86°37'14"	435	Pest2
6	05517120	Pitner Ditch at State Highway 8 near La Crosse, Ind. Lat 41°19'13" Long 86°50'48"	ND	Bio90
7	05517500	Kankakee River at Dunns Bridge, Ind. Lat 41°13'17" Long 86°57'52"	1,350	Pest2, Nutr
8	05517530	Kankakee River near Kouts, Ind. Lat 41°15'14" Long 87°02'02"	1,380	Pest2
9	05517725	Crooked Creek at 100 South Road near Wanatah, Ind. Lat 41°25'12" Long 86°57'46"	ND	Bio90
10	05517890	Cobb Ditch near Kouts, Ind. Lat 41°20'19" Long 87°04'30"	30.3	Pest2
11	05518000	Kankakee River at Shelby, Ind. Lat 41°10'58" Long 87°20'33"	1,780	Bio89, Pest2
12	05519000	Singleton Ditch at Schneider, Ind. Lat 41°12'44" Long 87°26'44"	123	Pest2
13	05520150	Singleton Ditch at County Road 52 near Illiana Heights, Ill. Lat 41°10'25" Long 87°34'32"	242	Nutr
14	05520500	Kankakee River at Momence, Ill. Lat 41°09'36" Long 87°40'07"	2,290	Retro, Ufix, Bio89, Bio90, Pest2, VOC, Nutr

APPENDIX: SELECTED WATER-SAMPLING STATIONS INCLUDED IN THE WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN, 1987–92—CONTINUED

Map reference number	Station number	Station name	Drainage area (square miles)	Phase of study
Kankakee River Basin—Continued				
15	05521000	Iroquois River at Rosebud, Ind. Lat 41°02'00" Long 87°10'49"	35.6	Pest2
16	05522500	Iroquois River at Rensselaer, Ind. Lat 40°56'00" Long 87°07'44"	203	Pest2
17	05523000	Bice Ditch near South Marion, Ind. Lat 40°52'00" Long 87°05'32"	21.8	Pest1, VOC
18	05523500	Slough Creek near Collegeville, Ind. Lat 40°53'30" Long 87°09'17"	83.7	Nutr
19	05524500	Iroquois River near Foresman, Ind. Lat 40°52'14" Long 87°18'24"	449	Pest2
20	05525000	Iroquois River at Iroquois, Ill. Lat 40°49'25" Long 87°34'55"	686	Retro, Ifix, Pest2
21	05525290	Sugar Creek near Stockland, Ill. Lat 40°39'01" Long 87°31'34"	85.1	Nutr
22	05525500	Sugar Creek at Milford, Ill. Lat 40°37'50" Long 87°43'25"	446	Retro, Ifix, Pest1, Pest2, VOC, Nutr
23	05525540	Iroquois River near Watseka, Ill. Lat 40°48'44" Long 87°48'25"	ND	Bio89, VOC, Nutr
24	05525555	Spring Creek near Delrey, Ill. Lat 40°37'49" Long 88°00'22"	47.4	Bio90
25	05525570	Spring Creek at Road 730 East near Onarga, Ill. Lat 40°41'52" Long 87°59'09"	146	Bio90
26	05525600	Spring Creek near Gilman, Ill. Lat 40°46'08" Long 87°54'02"	221	Nutr
27	05525680	Langan Creek at Road 1300 East near Clifton, Ill. Lat 40°58'08" Long 87°53'04"	94.2	Bio90
28	05526000	Iroquois River near Chebanse, Ill. Lat 41°00'32" Long 87°49'27"	2,090	Retro, Ufix, Bio90, Pest2, VOC, Nutr
29	05526130	Kankakee River near Bourbonnais, Ill. Lat 41°09'08" Long 87°54'49"	4,630	VOC, Nutr
30	05526410	Rock Creek at Highway 102 near Deselm, Ill. Lat 41°12'23" Long 87°59'05"	120	Nutr

APPENDIX: SELECTED WATER-SAMPLING STATIONS INCLUDED IN THE WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN, 1987–92—CONTINUED

Map reference number	Station number	Station name	Drainage area (square miles)	Phase of study
Kankakee River Basin—Continued				
31	05527500	Kankakee River near Wilmington, Ill. Lat 41°20'48" Long 88°11'11"	5,150	Retro, Ifix, Pest2, VOC, Nutr
100	40544308	Iroquois River Above Slough Creek near Rensselaer, Ind. Lat 40°54'43" Long 87°11'28"	ND	Nutr
101	41161608	Reeves Ditch at State Road 49 near Kouts, Ind. Lat 41°16'16" Long 87°01'31"	ND	Nutr
102	41171408	Yellow River Above State Route 8 near Knox, Ind. Lat 41°17'14" Long 86°32'56"	ND	Nutr
103	41214708	Yellow River at North Hickory Road near Inwood, Ind. Lat 41°21'47" Long 86°11'37"	ND	Nutr
Des Plaines River Basin				
32	05527800	Des Plaines River at Russell, Ill. Lat 42°29'22" Long 87°55'32"	123	Retro, Ifix, VOC, Nutr
33	05528000	Des Plaines River near Gurnee, Ill. Lat 42°20'39" Long 87°56'18"	232	Retro, Ifix, Nutr
34	05529000	Des Plaines River near Des Plaines, Ill. Lat 42°04'55" Long 87°53'25"	360	Retro, Ifix, Nutr
35	05530590	Des Plaines River at Irving Park Road near Schiller Park, Ill. Lat 41°57'11" Long 87°51'15"	444	Retro, Ifix,
36	05530990	Salt Creek at Rolling Meadows, Ill. Lat 42°03'37" Long 88°00'59"	30.5	Pest1, VOC
37	05531175	Salt Creek at Wood Dale, Ill. Lat 41°57'51" Long 87°59'03"	74.7	VOC, Nutr
38	05531500	Salt Creek at Western Springs, Ill. Lat 41°49'35" Long 87°54'00"	115	Retro, Ifix, Bio89, Bio90, VOC, Nutr
39	05532000	Addison Creek at Bellwood, Ill. Lat 41°52'48" Long 87°52'07"	17.9	Retro, Ifix, Pest1, VOC
40	05532500	Des Plaines River at Riverside, Ill. Lat 41°49'20" Long 87°49'15"	630	Ufix, Bio89, Bio90, VOC, Nutr

APPENDIX: SELECTED WATER-SAMPLING STATIONS INCLUDED IN THE WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN, 1987–92—CONTINUED

Map reference number	Station number	Station name	Drainage area (square miles)	Phase of study
Des Plaines River Basin—Continued				
41	05533020	Flag Creek at 91st Street near Willow Springs, Ill. Lat 41°43'26" Long 87°54'28"	18.3	Nutr
42	05534050	Des Plaines River at Lockport, Ill. Lat 41°35'47" Long 88°04'07"	700	Retro, Ifix, VOC, Nutr
43	05534500	North Branch Chicago River at Deerfield, Ill. Lat 42°09'10" Long 87°49'07"	19.7	Retro, Ifix,
44	05535172	Skokie River at Happ Road at Northfield, Ill. Lat 42°05'11" Long 87°46'00"	31.5	Nutr
45	05536000	North Branch Chicago River at Niles, Ill. Lat 42°00'44" Long 87°47'45"	100	Retro, Ifix, Bio89, Bio90, Nutr
46	05536107	North Shore Channel at Touhy Avenue at Chicago, Ill. Lat 42°00'42" Long 87°42'37"	ND	Bio89
47	05536108	North Shore Channel at Devon Avenue at Chicago, Ill. Lat 41°59'51" Long 87°42'38"	20.4	VOC, Nutr
48	05536142	Chicago Sanitary and Ship Canal at Forest View, Ill. Lat 41°48'04" Long 87°48'06"	ND	VOC, Nutr
49	05536195	Little Calumet River at Munster, Ind. Lat 41°34'07" Long 87°31'18"	90.0	Retro, Ifix
50	05536275	Thorn Creek at Thornton, Ill. Lat 41°34'05" Long 87°36'30"	104	Retro, Ifix
51	05536290	Little Calumet River at South Holland, Ill. Lat 41°36'25" Long 87°35'52"	208	Nutr
52	05536325	Little Calumet River at Harvey, Ill. Lat 41°37'35" Long 87°38'05"	254	VOC
104	055363252	Little Calumet River at Halsted Avenue at Harvey, Ill. Lat 41°37'45" Long 87°38'30"	254	Bio90, Nutr
53	05536366	Little Calumet River at Calumet Park, Ill. Lat 41°39'26" Long 87°38'29"	24.3	Bio89, Bio90

APPENDIX: SELECTED WATER-SAMPLING STATIONS INCLUDED IN THE WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN, 1987–92—CONTINUED

Map reference number	Station number	Station name	Drainage area (square miles)	Phase of study
Des Plaines River Basin—Continued				
54	05536700	Calumet-Sag Channel at Sag Bridge, Ill. Lat 41°41'45" Long 87°56'11"	389	Retro, Ifix, Nutr
55	05536995	Chicago Sanitary and Ship Canal at Romeoville, Ill. Lat 41°38'26" Long 88°03'38"	739	Ufix, VOC, Nutr
56	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill. Lat 41°34'11" Long 88°04'42"	740	Retro, Ifix,
57	05537980	Des Plaines River at Route 53 at Joliet, Ill. Lat 41°32'12" Long 88°04'57"	1,500	Retro, Ifix
58	05538008	Des Plaines River above Brandon Road Dam at Joliet, Ill. Lat 41°30'24" Long 88°05'49"	1,510	Bio89, Bio90, VOC, Nutr
60	05539000	Hickory Creek at Joliet, Ill. Lat 41°31'10" Long 88°04'10"	107	Retro, Ifix
61	05539360	Des Plaines River below Lock and Dam at Rockdale, Ill. Lat 41°30'00" Long 88°06'12"	1,630	Nutr
62	05539900	West Branch Du Page River near West Chicago, Ill. Lat 41°54'39" Long 88°10'44"	28.5	Retro, Ifix, VOC, Nutr
63	05540066	West Branch Du Page River at Mack Road near West Chicago, Ill. Lat 41°50'33" Long 88°11'56"	80.6	Bio90
64	05540095	West Branch Du Page River near Warrenville, Ill. Lat 41°49'22" Long 88°10'23"	90.4	Retro, Ifix,
65	05540210	East Branch Du Page River at Route 34 Bridge near Lisle, Ill. Lat 41°48'02" Long 88°04'53"	51.4	Retro, Ifix,
66	05540258	East Branch Du Page River at Naperville, Ill. Lat 41°42'52" Long 88°06'44"	ND	Bio89, Bio90
67	05540290	Du Page River near Naperville, Ill. Lat 41°41'24" Long 88°09'58"	220	Retro, Ifix, VOC, Nutr
68	05540490	Du Page River at Hammel Woods at Shorewood, Ill. Lat 41°31'54" Long 88°11'34"	ND	Bio89, Bio90

APPENDIX: SELECTED WATER-SAMPLING STATIONS INCLUDED IN THE WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN, 1987–92—CONTINUED

Map reference number	Station number	Station name	Drainage area (square miles)	Phase of study
Des Plaines River Basin—Continued				
69	05540500	Du Page River at Shorewood, Ill. Lat 41°31'20" Long 88°11'35"	324	Retro, Ufix, VOC, Nutr
Illinois River Basin				
70	05541498	Illinois River above Dresden Island Dam near Minooka, Ill. Lat 41°23'58" Long 88°16'35"	ND	VOC, Nutr
71	05541508	Illinois River below Dresden Island Dam near Minooka, Ill. Lat 41°23'51" Long 88°17'59"	¹ 7,280	Nutr
72	05541710	Aux Sable Creek near Morris, Ill. Lat 41°25'02" Long 88°20'51"	172	Retro, Ifix, Nutr
73	05541745	Mazon River near Gardener, Ill. Lat 41°12'22" Long 88°17'01"	ND	VOC, Nutr
74	05542000	Mazon River near Coal City, Ill. Lat 41°17'10" Long 88°21'35"	455	Retro, Ifix, VOC, Nutr
75	05543484	Illinois River above Marseilles Dam at Marseilles, Ill. Lat 41°19'19" Long 88°42'19"	ND	VOC, Nutr
76	05543500	Illinois River at Marseilles, Ill. Lat 41°19'37" Long 88°43'03"	8,260	Retro, Ufix, Bio89, Bio90, VOC, Nutr
Fox River Basin				
77	05543814	Pewaukee River at State Route 164 at Waukesha, Wis. Lat 43°02'29" Long 88°12'39"	ND	Nutr
78	05544090	Mukwonago River at Marsh Road near Mukwonago, Wis. Lat 42°51'17" Long 88°23'44"	ND	Bio90, Nutr
79	05544315	Fox River near Big Bend, Wis. Lat 42°52'38" Long 88°14'53"	ND	VOC, Nutr
80	05544908	Honey Creek at Bell School Road near East Troy, Wis. Lat 42°47'43" Long 88°19'15"	ND	Bio90, Nutr
81	05544950	Honey Creek at Hill Valley Road near East Troy, Wis. Lat 42°47'03" Long 88°18'33"	ND	Bio89
82	05545300	White River near Burlington, Wis. Lat 42°39'57" Long 88°19'03"	110	Nutr

APPENDIX: SELECTED WATER-SAMPLING STATIONS INCLUDED IN THE WATER-QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN, 1987–92—CONTINUED

Map reference number	Station number	Station name	Drainage area (square miles)	Phase of study
Fox River Basin—Continued				
83	05546500	Fox River at Wilmot, Wis. Lat 42°30'40" Long 88°10'45"	868	Retro
84	05546700	Fox River near Channel Lake, Ill. Lat 42°28'45" Long 88°10'42"	² 871	Retro, Ifix
86	05548280	Nippersink Creek near Spring Grove, Ill. Lat 42°26'37" Long 88°14'51"	192	Retro, Ifix, Nutr
87	05549500	Fox River near McHenry, Ill. Lat 42°18'35" Long 88°15'05"	1,250	VOC, Nutr
88	05549600	Fox River at Burton's Bridge, Ill. Lat 42°16'44" Long 88°13'31"	1,280	Retro, Ifix
89	05550000	Fox River at Algonquin, Ill. Lat 42°09'59" Long 88°17'25"	1,400	Retro, Ufix, Bio89, Bio90, Nutr
90	05550500	Poplar Creek at Elgin, Ill. Lat 42°01'35" Long 88°15'20"	35.2	Retro, Ifix, Nutr
91	05551000	Fox River at South Elgin, Ill. Lat 41°59'40" Long 88°17'38"	1,560	Retro, Ifix, VOC, Nutr
92	05551540	Fox River at Montgomery, Ill. Lat 41°43'46" Long 88°20'19"	1,730	Retro, Ifix, VOC, Nutr
93	05551700	Blackberry Creek near Yorkville, Ill. Lat 41°40'18" Long 88°26'29"	70.2	Retro, Ifix, Bio90, VOC
94	05551933	Big Rock Creek above Henning Road near Plano, Ill. Lat 41°41'58" Long 88°30'30"	ND	Bio90
95	05551937	Big Rock Creek at Route 276 near Plano, Ill. Lat 41°38'28" Long 88°32'14"	182	Nutr
96	05551995	Somonauk Creek at Sheridan, Ill. Lat 41°32'37" Long 88°41'12"	83.3	Retro, Ifix,
97	05552200	Indian Creek near Harding, Ill. Lat 41°30'50" Long 88°47'50"	ND	Bio89, Bio90
98	05552400	Indian Creek at Route 258 at Wedron, Ill. Lat 41°26'33" Long 88°46'15"	265	Nutr
99	05552500	Fox River at Dayton, Ill. Lat 41°23'12" Long 88°47'26"	2,640	Retro, Ufix, Bio90, VOC, Nutr

¹Drainage area at Dresden Island Dam; Lat 41°23'53", Long 88°16'45".

²Water-discharge records for this station were from Fox River at Wilmot, Wis.

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