U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Nutrients and Suspended Solids in Surface Waters of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin, 1978–97

By Daniel J. Sullivan

Water-Resources Investigations Report 99–4275

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U.S. DEPARTMENT OF THE INTERIOR
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http://water.usgs.gov/nawqa/

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CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi2)	2.590	square kilometer
cubic foot per second (ft3/s)	0.02832	cubic meter per second
ton per year (ton/yr)	0.9072	megagram per second
ton per square mile per year [(ton/mi^2)/yr]	0.3503	tonne per square kilometer per year

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:
°F = 9/5 (°C) + 32.

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:
°C = 5/9 (°F-32).

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.

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Nutrients and Suspended Solids in Surface Waters of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin, 1978–97

By Daniel J. Sullivan

Abstract

A retrospective analysis of selected data on nutrients and suspended solids in surface waters of the upper Illinois River Basin was done as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Approximately 91 percent of the upper Illinois River Basin is drained by three principal rivers: the Kankakee (and its major tributary, the Iroquois), the Des Plaines, and the Fox. The data analyzed were collected by the Illinois Environmental Protection Agency (IEPA), which operates 39 monitoring sites in the study area as part of its Ambient Water-Quality Monitoring Network, and included analyses for total ammonia nitrogen, total nitrite-plus-nitrate nitrogen, total ammonia-plus-organic (total Kjeldahl) nitrogen, dissolved and total phosphorus, and total suspended solids and volatile solids. Nutrient and suspended-sediment data collected by the USGS as part of the upper Illinois River Basin NAWQA pilot study from 1987–90 were compared to IEPA data.

For the 1978–97 period, in general, nutrient concentrations, with the exception of nitrate, were highest at streams in the urban areas of the Des Plaines River Basin. Streams in the Kankakee and Fox River Basins generally had lower concentrations, although the data indicate that concentrations increased in a downstream direction in these basins. These spatial patterns in nutrient concentrations correspond closely with land use in the respective basins. The elevated concentrations of ammonia and phosphorus in the urbanized Des Plaines River Basin, with respect to other sites in the study area, indicate that municipal- and industrial-waste discharges into streams of the basin increase concentrations of these nutrients in the receiving streams. In contrast, nitrate concentrations were highest in agricultural areas. Relatively large ratios of nitrogen to phosphorus and nitrate to ammonia are characteristic of agricultural drainage. On the other hand, urban tributaries were characterized by smaller ratios of nitrogen to phosphorus and nitrate to ammonia. The apparent, but nonuniform, correspondence of nutrient concentrations to urban and agricultural land use in the upper Illinois River Basin was generally consistent with findings in other river basins. A seasonal pattern of nutrient concentrations characterized by high concentrations in the winter months, depletion during the spring and summer, and minimum levels in the late summer or early fall was observed in some of the data from the upper Illinois River Basin. Monthly median concentrations of total ammonia nitrogen and nitrite plus nitrate nitrogen were at minimum levels from July through October, whereas phosphorus concentrations did not display a strong seasonal trend.

The net result of nutrient inputs and transport through the river system were elevated nutrient concentrations at the most-downstream site in the study area on the Illinois River. At this site, the median concentrations of nitrate, total phosphorus, and orthophosphate were among the highest in the Mississippi River Basin, and the concentration of ammonia was the highest.

Suspended-solids concentrations do not indicate any particularly strong spatial patterns among major river basins in the study area. Instead, higher suspended-solids concentrations are observed at sites draining areas of low-permeability, easily eroded soils in agricultural and urban areas alike. Seasonal variation of suspended solids were consistent at sites across the study area. In general, suspended-solids concentrations were highest in the

summer and lowest in the winter. The increase during the summer can be attributed to higher streamflow and the associated increase in runoff and transport, as well as increased phytoplankton growth.

Because of the high nutrient concentrations in the upper Illinois River Basin, annual loads and yields also were relatively large; however, yields of phosphorus from the Fox and Kankakee River Basins were not unusually high. The major contributor of total ammonia nitrogen, total Kjeldahl nitrogen, and phosphorus loads to the total study-area output was the Des Plaines River Basin, the Chicago Sanitary and Ship Canal in particular. The high concentrations in this waterway, coupled with the relatively high volume of streamflow, contribute to the large load output. The high loads in the Ship Canal reflect the input from the three large Metropolitan Water Reclamation District of Greater Chicago treatment plants. In contrast, nitrate loads were higher from the agricultural Kankakee River Basin. Total suspended-solids loads were also greatest from agricultural areas, in particular the Iroquois River Basin and tributaries to the lower Fox River. These are areas of intensive row-crop agriculture and fine, easily erodable soils.

The total nitrogen export from the upper Illinois River Basin for 1978–97 was 91,800 ton/yr (tons per year). This figure corresponds well with estimates of loads from urban, agricultural, and other sources, and is about 30 percent of the estimated total nitrogen input to the basin of about 300,000 ton/yr. The total phosphorus export from the study area during 1978–97 was about 5,400 ton/yr, or about 6 percent of estimated phosphorus inputs of 94,000 ton/yr. Loads and yields of nutrients from the upper Illinois River Basin are among the very highest in the entire Mississippi River drainage system.

Significant downward trends in total-ammonia concentrations were observed at many sites during the period of analysis, along with correlative upward trends in nitrate. This opposite relation is consistent with the reversible capacity for transformation between the reduced form (ammonia) and the oxidized form (nitrate), and may be related to nitrification of wastewater effluents. Significant downward trends in total ammonia plus organic nitrogen were related to downward trends in ammonia concentrations. Few trends in phosphorus concentrations were observed, but upward trends were observed at 2 sites downstream of major wastewater-treatment plants.

INTRODUCTION

In 1986, Congress appropriated funds for the U.S. Geological Survey (USGS) to develop the pilot phase of the National Water-Quality Assessment (NAWQA) Program. In 1991, the NAWQA Program went into full implementation. The long-term goals of this 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 the observed water-quality conditions and trends (Hirsch and others, 1988). The upper Illinois River Basin was one of five pilot studies started in 1987; current investigations began in 1997 with the third round of NAWQA studies.

A fundamental component of the NAWQA Program is based on data collection and analysis within more than 50 study areas across the United States. The geographical extent of most of these study areas is based on surface-water drainage boundaries (fig. 1). These study areas cover about one-half of the conterminous United States, provide a water supply to about 65 percent of the population that uses public water supplies, and represent a variety of environmental settings and water-quality issues.

Purpose and Scope

The purposes of this report are to (1) update information assembled and analyzed during the pilot phase of the upper Illinois River Basin NAWQA study, (2) provide information to assist in the design of the data-collection components of the upper Illinois River Basin NAWQA study, (3) describe the spatial and temporal distribution of nutrients and suspended solids in the study area, (4) describe the natural factors and human activities affecting the spatial patterns in concentrations and loads within the study area, (5) describe long-term trends (or lack of trends) in water quality and provide

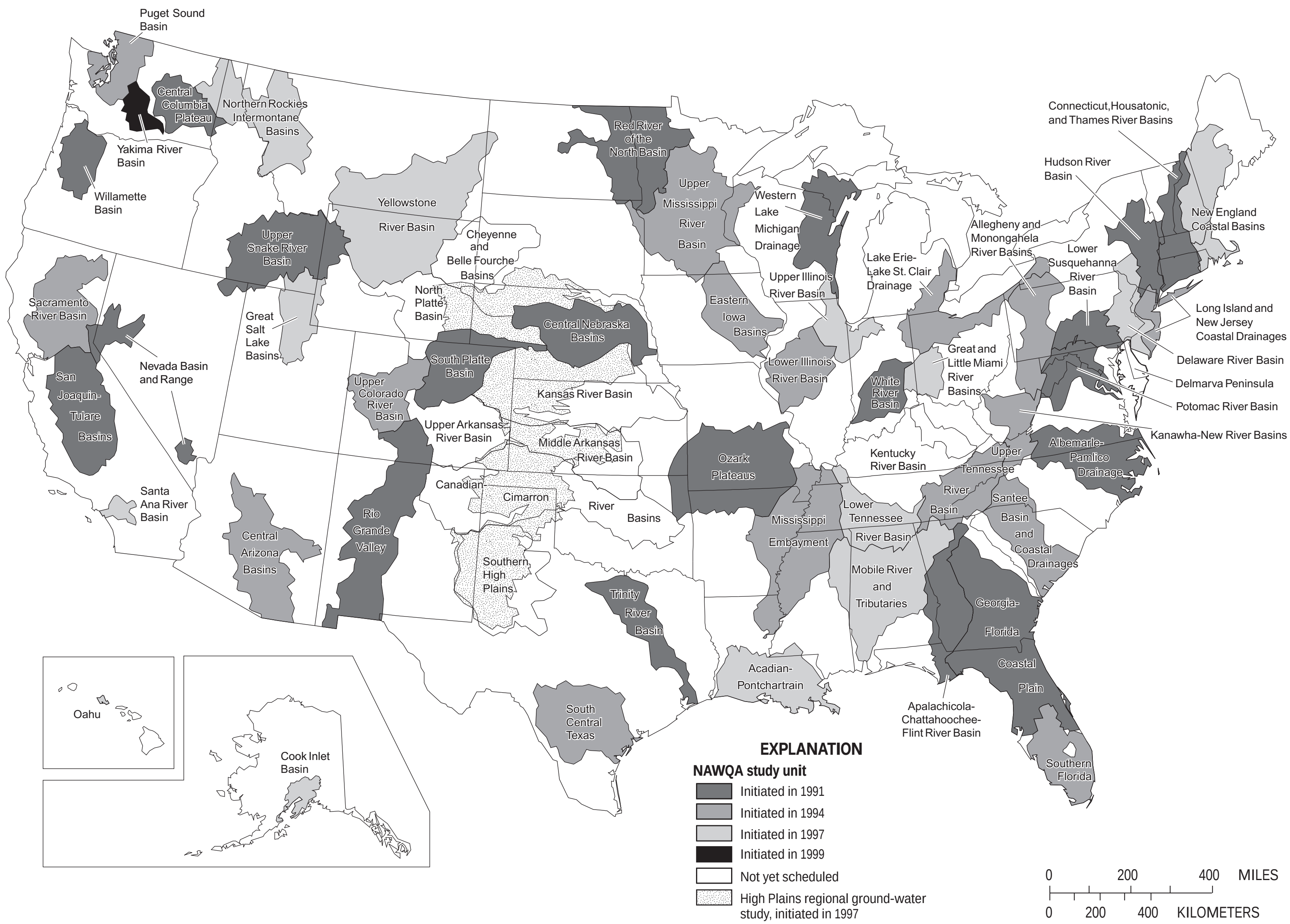


Figure 1. Location of National Water-Quality Assessment study areas.

data for future examinations for trends, and (6) provide data to the NAWQA National Synthesis Team, who will assemble data from the individual NAWQA study areas and interpret this information from a national perspective.

This report is limited to analysis of surface-water-quality data collected in the upper Illinois River Basin during 1978–97. Data used were from the Illinois Environmental Agency (IEPA) Ambient Water-Quality Monitoring Network (AWQMN), which includes 39 sites in the upper Illinois River Basin. Nutrient and suspended-solids data collected as part of the upper Illinois River Basin NAWQA pilot study during 1987–90 were compared to IEPA data (fig. 2). Nutrient data analyzed include ammonia, nitrite plus nitrate nitrogen, ammonia plus organic (total Kjeldahl) nitrogen, dissolved phosphorus, and total phosphorus.

Background

Nutrients are essential for algae and other plants in aquatic environments; but in sufficiently high concentrations, nutrients can adversely affect water quality by causing excess biological growth or, in some extreme cases, by being toxic to aquatic and terrestrial life (Rinella and others, 1992). The nutrient content of water affects its usefulness for municipal, industrial, and recreational purposes and affects the kinds and numbers of aquatic plants and animals present. Nutrients in excessive concentrations can degrade water quality by stimulating production of algal blooms. Algae contribute oxygen to the water, but excessive accumulation of algae results in an additional source of organic material that, when it decays, increases the oxygen demand. Many species of algae excrete waste products that can be toxic and commonly result in foul-smelling water. The nutrients usually of most concern for the biological quality of water are nitrogen and phosphorus. Not all forms of nitrogen and phosphorus are directly usable by biota; only nitrite, nitrate, ammonia, and orthophosphate are available for biotic uptake.

Suspended solids are virtually always present in streamwater. Like nutrients, however, excessive concentrations of suspended solids can be detrimental to aquatic life; when these solids settle, they can smother bottom-dwelling organisms or cover coarse streambed material that certain fish require for spawning. Downstream deposition of these solids in channels and harbors can be an impediment to navigation, and removal of the deposits can be costly. Transport of chemical constituents with the particulates to which they sorb is an important aspect of sediment-water interaction. Areas of sediment deposition are commonly areas of increased constituent concentration in water. Concentrations of elements and compounds in bottom sediments can be many times higher than the concentrations in the dissolved phase (Kelly and Hite, 1984; Horowitz, 1985). Constituents in bottom sediments may again be made available to the water column through resuspension caused by activities of aquatic animals, dredging, and flooding, among other processes.

Chicago is the third-largest metropolitan area in the United States and the largest city within the Mississippi River Basin, the largest watershed in the Nation. Thus, urban sources of nutrients and suspended solids are a major concern in the upper Illinois River Basin, especially in the Des Plaines River Basin, the most heavily populated subbasin in the study area. In the Des Plaines River Basin, the IEPA has identified the primary causes of water-quality problems to be nutrients, pathogens, siltation, and habitat alterations attributed to municipal point-source pollution, urban runoff, contaminated sediments, and hydrologic/habitat modifications. Excessive nutrients and siltation have been identified as the major causes of water-quality problems in Illinois (Illinois Environmental Protection Agency, 1996a). The major source of this pollution statewide is agriculture. In the Indiana and Wisconsin parts of the study area, major land uses are agriculture in Indiana and agriculture and suburban sprawl (Milwaukee suburbs) in Wisconsin.

DESCRIPTION OF THE STUDY AREA

A complete description of the environmental setting of the upper Illinois River Basin is given in Arnold and others (1999) and Mades (1987); selected information is repeated here. The upper Illinois River Basin drains 10,949 mi^2 of Illinois, Indiana, and Wisconsin (fig. 2). Approximately 91 percent of the upper Illinois River Basin is drained by three principal rivers: the Kankakee (and its major tributary, the Iroquois), the Des Plaines, and the Fox. The Kankakee and Des Plaines Rivers join near Morris, Ill., to form the Illinois River. The Fox River discharges to the Illinois River at the southwestern basin boundary near Ottawa, Illinois. The largest part of the basin, 5,165 mi^2 or 47.2 percent, is drained by the Kankakee River. The Fox River drains 2,658 mi^2 or 24.3 percent of the study area. The Des

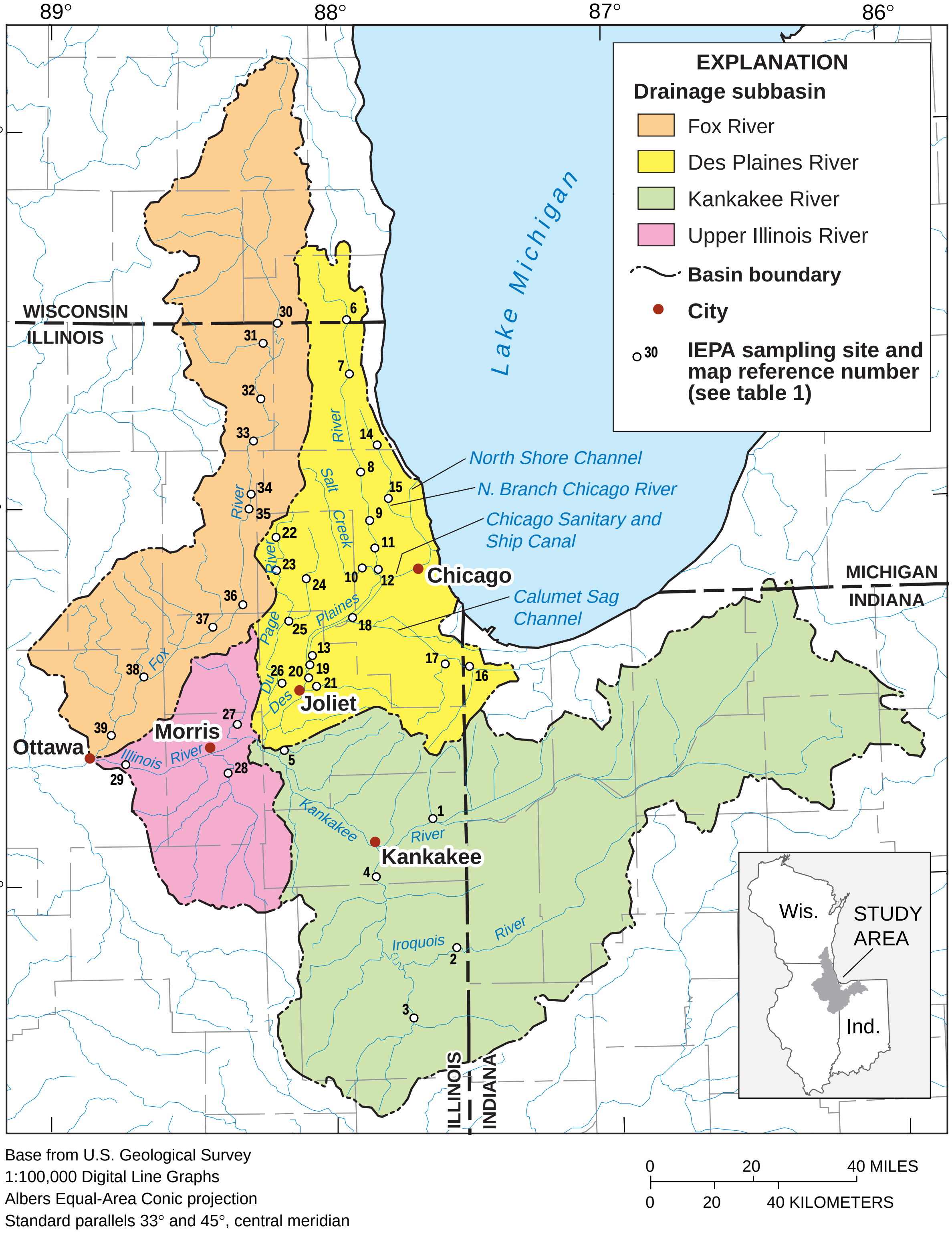


Figure 2. Subbasins and locations of Illinois Environmental Protection Agency water-quality monitoring sites within the upper Illinois River Basin.

Plaines River drains 2,111 mi^2 or 19.3 percent of the study area, and includes 673 mi^2 that originally drained to Lake Michigan through the Chicago and Calumet Rivers. The remaining 992 mi^2 or 9.2 percent is drained by tributaries that discharge to the 33-mi.-long main stem of the Illinois River between Morris and Ottawa, Ill. The Illinois River, the lower reaches of the Des Plaines River, and two canal systems in the Chicago metropolitan area provide a navigable link between Lake Michigan and the Mississippi River.

Five major changes in the upper Illinois River Basin have undoubtedly changed the quality of surface waters a great deal–construction of navigable waterways, diversion of Lake Michigan water, construction of wastewater-treatment plants, drainage of wetlands, establishment of farming and other agricultural activities, and most recently, the construction of the Tunnel and Reservoir Project (TARP), the Nation’s largest public works project for pollution and flood control. Some of the earliest activities were the development of transportation corridors. These corridors opened a passageway between the Great Lakes and the Mississippi River, first by the use of natural waterways and constructed canal systems and later by the use of railroads. With the ease of transportation came waves of immigrants. The basin population grew steadily, creating urban and industrial growth areas along the Lake Michigan shoreline and along major rivers such as the Illinois and Des Plaines. The rapid growth in the urban areas made wastewater disposal a serious issue. Agriculture also developed as farmers moved into the basin to supply the urban areas with food and other goods.

In 1990, agriculture, urban land, and forest accounted for about 75, 17, and 5 percent, respectively, of the land use in the basin (Arnold and others, 1999). Since the late 1970's, agriculture and forest has declined while urban land area has increased.

In addition to varied land use in the study area, soil types and bedrock geology also vary and may affect water quality, either directly or indirectly (fig. 3). As an aid in understanding how environmental factors affect water quality in the upper Illinois River Basin, the study area was subdivided into areas dominated by unique combinations of physiography, soil permeability, land use, and bedrock geology into areas dominated by unique combinations (Arnold and others, 1999). This subdivision, or stratification, was done by the use of a Geographic Information System to overlay these individual data layers.

Hydrology

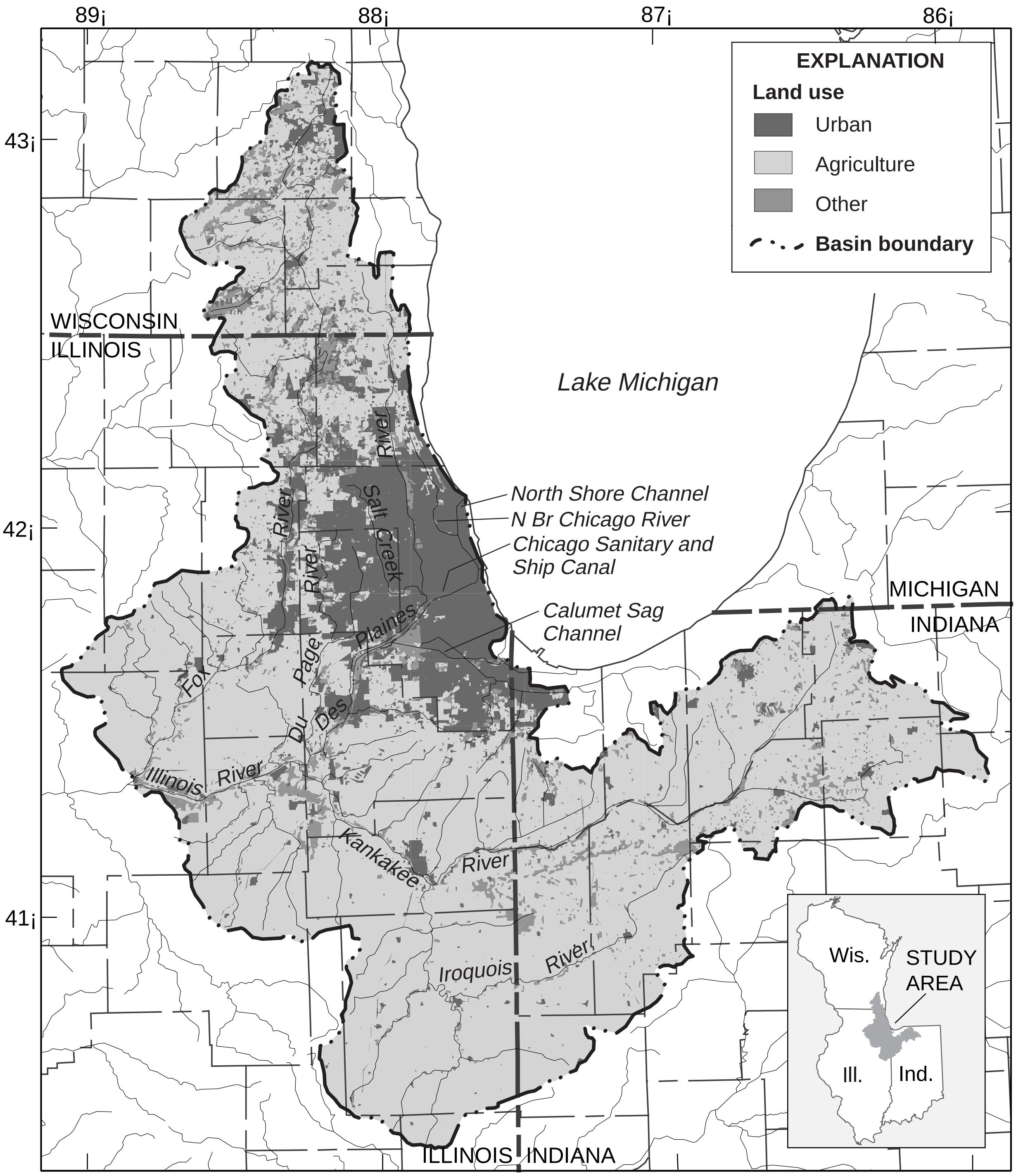
The hydrology of the study area has been greatly changed by human activity. The first major canal in the area, the Illinois and Michigan Canal, was opened to traffic in 1848 (Illinois Department of Public Works and Buildings, 1969). The 96-mi.-long canal connected the Illinois River 14 mi downstream from Ottawa (fig. 1) with Lake Michigan at Chicago. Competition with railroads led to further changes in the Illinois River for navigational purposes. The present navigable waterway, which includes the Chicago Sanitary and Ship Canal, was completed in 1939 (fig. 4).

As Chicago grew during the latter half of the 19th century, increasing amounts of untreated domestic sewage and industrial wastes were discharged to Lake Michigan, the city's principal water supply. These discharges were made directly to the lake and indirectly through tributaries such as the Chicago River. The concurrent increasing incidence of typhoid-related deaths and illnesses during this period of time was attributed to contaminated lake water and led to a proposal to divert the flow of the Chicago River from Lake Michigan to the Illinois River Basin.

The Chicago River was diverted by construction of the Chicago Sanitary and Ship Canal and diversion of Lake Michigan water through the Chicago River to this channel. Construction of the main channel was begun in 1892 and completed in 1907 when the Lockport Power House near Joliet (fig. 2) was put in operation.

Lake Michigan diversions were begun in 1900 at a rate of 3,000 ft^3/s (cubic feet per second). Of this amount, about 1,200 ft^3/s was withdrawn for water supply and 1,800 ft^3/s was diverted primarily to dilute domestic and industrial wastes discharged to the Chicago Sanitary and Ship Canal. Currently, the U.S. Supreme Court authorizes the State of Illinois a total diversion, including withdrawals for water supply, of an average 3,200 ft^3/s over a 40-year accounting period (Espey and others, 1981). Data from 1981–85 indicate that of 3,470 ft^3/s of total Lake diversion, 1,660 ft^3/s was pumped from the lake for water-supply purposes, and about 1,810 ft^3/s was diverted directly to the study area through canals (U.S. Army Corps of Engineers, 1990).

The Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) operates seven wastewater-treatment plants that serve an area of 872 mi^2 that includes the City of Chicago and 124 suburban communities. The MWRDGC serves an equivalent population



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

Figure 3. Land use in the upper Illinois River Basin.

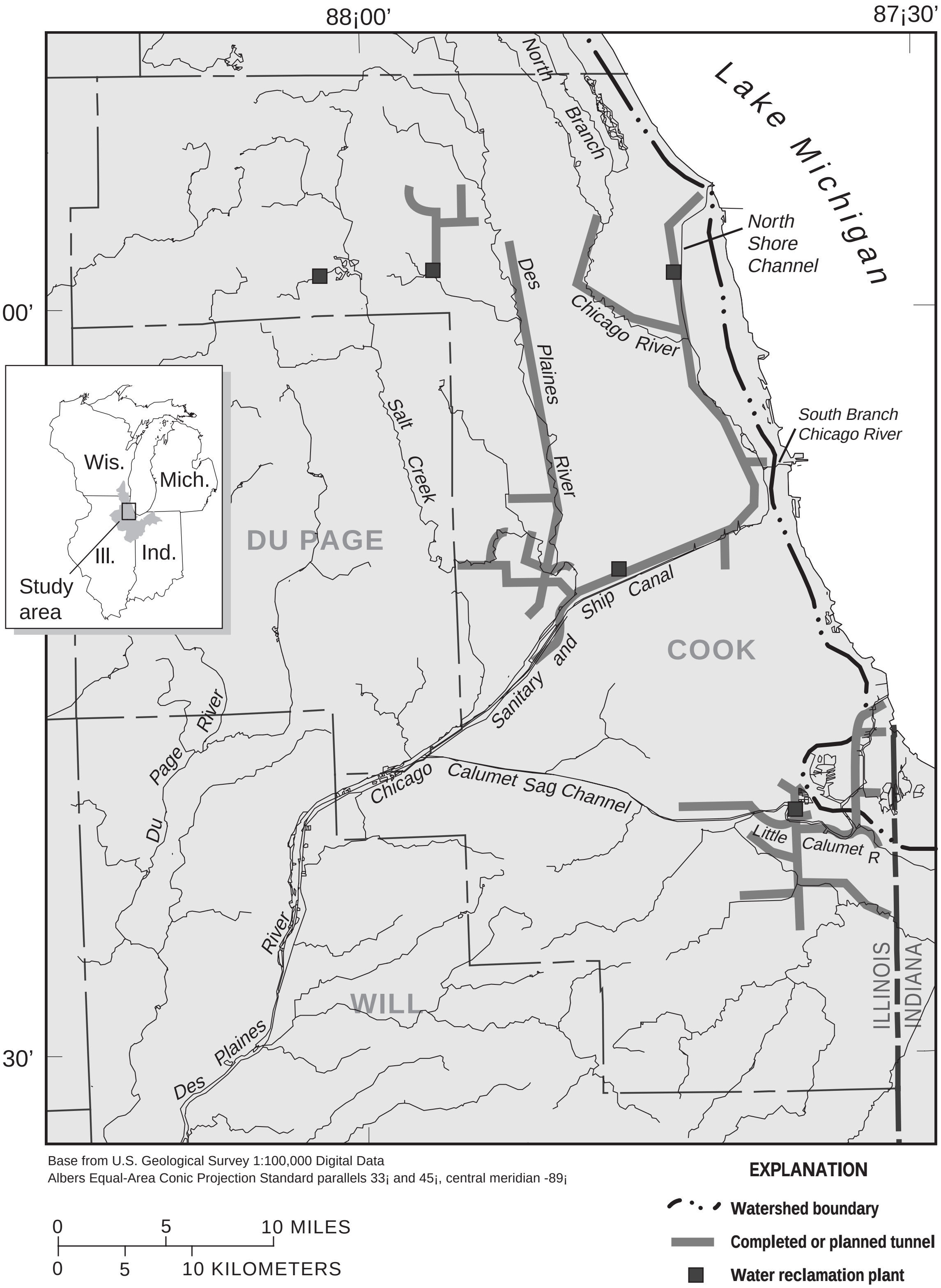


Figure 4. Location of canals, selected major wastewater-treatment plants, and completed Tunnel and Reservoir Project tunnels.

of 10.1 million people: 5.1 million residents, a commercial and industrial equivalent of 4.5 million people, and a combined-sewer-overflow equivalent of 0.5 million people. The MWRDGC has 547 mi of intercepting sewers that range in size from 12 in. to 27 ft in diameter and are fed by approximately 10,000 local sewer system connections. The return flow from its treatment operations averages about 2,200 ft^3/s (Metropolitan Water Reclamation District of Greater Chicago, 1995).

The two major sources of return flow in the study area are Lake Michigan water and ground water. Of the total flow leaving the study area, about 28 percent is contributed by the Chicago Sanitary and Ship Canal. The three largest wastewater-treatment plants in the study area discharge to the canal (or upstream from it) and contribute 73 percent of all effluent flow in the study area. Overall, wastewater-treatment plants in Illinois contribute about 97 percent of the effluent discharged to streams in the study area; wastewater-treatment plants in Indiana and Wisconsin contribute 1 and 2 percent, respectively (Zogorski and others, 1990).

Since 1985, runoff in the Chicago area has been diverted into a series of underground tunnels called the Tunnel and Reservoir Plan (TARP) (fig. 4), where the runoff is captured during intense precipitation and is stored until it can be treated and discharged as effluent. The TARP was designed to eliminate discharge of raw sewage during storms and thus decrease the resultant concentrations of pollutants discharged to streams (Metropolitan Water Reclamation District of Greater Chicago, 1999).

The average annual surface-water discharge from the upper Illinois River Basin is estimated to be 12,600 ft^3/s, on the basis of records from gaging stations near the terminus of the basin. These stations, the Fox River at Dayton, Ill. (site 39) and Illinois River at Marseilles, Ill. (site 29) are 2 of 81 active streamflow gaging stations in the study area as of 1997. The highest monthly streamflows in the study area typically are during June or July, and the lowest monthly streamflow is during November or December.

Trends in Streamflow

Long-term trends in streamflow were analyzed for seven stations that represent flow from major rivers in the study area. All of these stations had streamflow records dating back to at least 1950. Results of regression analyses indicate an upward trend in annual mean flows during 1950–97 at all seven stations (fig. 5).

The annual 7-day low flow also increased at five of the seven stations analyzed, whereas annual maximum flow increased at three of the seven stations. The most dramatic increases in all flow regimes were at stations draining urbanized land, although increases were noted at agricultural stations as well.

The most probable reasons for the increases in low flow are increased discharges of return flows to the streams as a result of urban growth and an upward trend in precipitation during the period. As a result, urban streams show a larger increase in flows than do agricultural streams. As population increases, more water is pumped from ground-water sources and discharged as effluent to the streams. Thus, for many of the rivers in areas that have undergone urban growth, some very low streamflows observed in the past may not occur again because point-source discharges now maintain a higher base rate of streamflow. This effect is further illustrated in flow-duration curves in Schmidt and Blanchard (1997), which show flows at the Des Plaines River at Riverside of below 20 ft^3/s for 1948–91, but no flows less than 100 ft^3/s for 1978–91.

A particularly large increase in annual mean flow was observed at the Des Plaines River site at Riverside, Ill., where data indicate an average increase in annual mean flow of almost 10 ft^3/s per year during 1950–97 (fig. 5); however, further analysis of mean annual streamflow data indicates a step increase around 1980. The two major treatment plants upstream from this site began operations in 1975 and 1980 and contributed an average of about 32 and 53 ft^3/s to the streamflow at this site during 1978–88 (Terrio, 1994). During 1975–97, mean annual streamflow was 682 ft^3/s, compared to 565 ft^3/s for the period 1950–97. Therefore, although there was increase above and beyond the additional discharge from the treatment plants, much of the streamflow increase was due to effluent flow. Prior to 1975, wastewater that is now routed to these two treatment plants was routed to treatment plants that discharged downstream from the Riverside site.

DESCRIPTION OF DATA USED IN REPORT

The streamwater constituents examined for this report include the following nutrients: ammonia, nitrite plus nitrate nitrogen ammonia plus organic (total Kjeldahl) nitrogen, dissolved and total phosphorus.

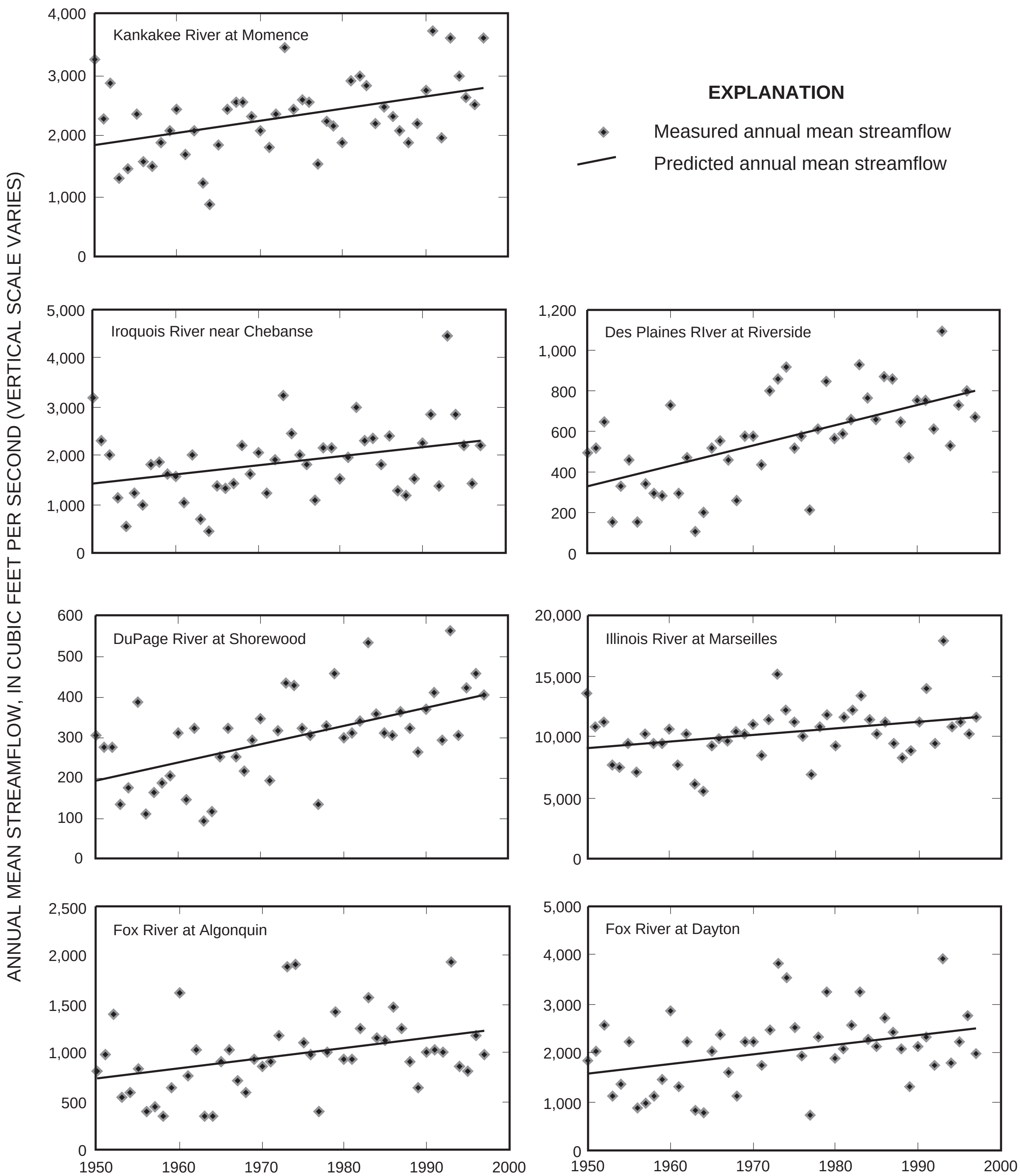


Figure 5. Annual mean streamflow at selected sites in the upper Illinois River Basin.

Also examined were total suspended solids and volatile solids.

In surface waters, the primary component of nitrite plus nitrate nitrogen is nitrate; thus, in this report, this constituent will be referred to as “nitrate”. Ammonia plus organic nitrogen is also known as Kjeldahl nitrogen and will be referred to as such. Because most of the data used in this report were for suspended solids, that is the term that will be used for describing sediment (as opposed to “suspended sediment,” which is the reporting term for a different analytical method). Total suspended solids refers to both volatile and nonvolatile matter suspended in the water column. Volatile suspended solids are organic in nature (algae, plant detritus) while nonvolatile solids are generally inorganic or organics resistant to volatilization.

Data for three constituents that describe sediment concentrations were available for statistical analysis. Concentration data for total suspended solids and volatile suspended solids were available for the 39 IEPA sites. Data for suspended-sediment and suspended-solids concentration were available from eight sites that were sampled during the upper Illinois River Basin NAWQA pilot study. These data are useful in comparing the results from the two analytical methods.

Sources of Data

The data used in this report came from two sources: the IEPA AWQMN and data collected during 1988–90 as part of the upper Illinois River Basin NAWQA pilot study. These data sets consist of data that are (1) collected by use of composited depth-integrating, multivertical sampling methods, (2) analyzed at two laboratories that cooperated in quality-assurance testing, such as analyzing duplicate, blank, and standard-reference samples, and (3) contained in a digital data base. Although the sampling sites are restricted to the Illinois part of the basin, these data provide a long-term temporal description and a detailed spatial description of water quality of the streams in the study area.

The IEPA currently operates 39 AWQMN sites in the study area (Illinois Environmental Protection Agency, 1996c) (table 1, fig. 3). These sites are currently (1999) sampled every 6 weeks on a fixed schedule. Of these 39 sites, 25 are collocated with USGS streamflow sites. The upper Illinois River Basin NAWQA pilot study included eight surface-water sites that were sampled monthly during 1987–90, with additional samples collected during high streamflows. Information on land use and location of wastewater-treatment plants relative to the IEPA sites is listed in table 2.

The period of data collection at IEPA sites varied. The year 1978 was selected as a common starting date for the analyses in this report because 1978 was the first year that IEPA and USGS worked cooperatively on the AWQMN, and the IEPA has used USGS data-collection methods since then. Therefore, no differences were expected between IEPA and USGS data because of differences in collection techniques.

Long-term water-quality monitoring data not used in this report include those collected by the MWRDGC. These data were excluded from the analyses because they are collected immediately upstream and downstream from MWRDGC wastewater-treatment plants (WWTP’s), and the purpose of this report is to characterize the water quality of the streams of the study area, not to assess the effects of WWTP’s on receiving streams.

Quality Assurance of Data

The IEPA has maintained a comprehensive surface-water monitoring network since 1970. The IEPA, in conjunction with the U.S. Environmental Protection Agency, has a comprehensive water-quality-monitoring strategy that outlines monitoring programs, quality-assurance activities, laboratory-support needs, and data-management procedures (Illinois Environmental Protection Agency, 1996, 1994). In addition, USGS and IEPA water-quality data were compared in a previous USGS study (Melching and Coupe, 1995); although some statistical differences were found between the data from the two laboratories, the differences were not unusually large with respect to available data on interlaboratory precision. In their study, Melching and Coupe (1995) recommend that data not be mixed for statistical analyses. Thus, only IEPA data are used in this report.

Comparisons of total-suspended-solids data collected by the IEPA with suspended-sediment data collected by USGS were made using data collected as sample splits at eight sites during the upper Illinois River Basin NAWQA pilot study. The reason for the comparison is that although the laboratory methods are similar for the two analyses, the methods are not identical. The methods are similar in that both use a filtra-

Table 1. Selected information for Illinois Environmental Protection Agency monitoring sites in the upper Illinois River Basin

Map reference number	IEPA station number	USGS station number	Station name	Drainage area (square miles)	Mean annual streamflow	Period of record[1]	
						Stream-flow	Water quality
			Kankakee River Basin				
1	F 02	05520500	Kankakee River at Momence, Ill.	2,294[2]	2,081	1914	1975
2	FL 04	05525000	Iroquois River at Iroquois, Ill.	686	589	1945	1972
3	FLI 02	05525500	Sugar Creek at Milford, Ill.	446	380	1948	1978
4	FL 02	05526000	Iroquois River near Chebanse, Ill.	2,091	1,741	1923	1959
5	F 01	05527500	Kankakee River near Wilmington, Ill.	5,150	4,709	1934	1959
			Des Plaines River Basin				
6	G 08	05527800	Des Plaines River at Russell, Ill.	123	97.9	1967	1964
7	G 07	05528000	Des Plaines River near Gurnee, Ill.	232	237	1977	1972
8	G 22	05529000	Des Plaines River near Des Plaines, Ill.	360	289	1941	1977
9	G 15	05530590	Des Plaines River at Schiller Park, Ill.	444	--	--	1967
10	GL 09	05531500	Salt Creek at Western Springs, Ill.	115	128	1946	1977
11	GLA 02	05532000	Addison Creek at Bellwood, Ill.	17.9	16.5	1950	1979
12	G 39	05532500	Des Plaines River at Riverside, Ill.	630	538	1944	1987
13	G 11	05534050	Des Plaines River at Lockport, Ill.	700	--	--	1966
14	HCCC 02	05534500	North Branch Chicago River at Deerfield, Ill.	19.7	16.3	1953	1964
15	HCC 07	05536000	North Branch Chicago River at Niles, Ill.	100	100	1951	1972
16	HB 42	05536195	Little Calumet River at Munster, Ind.	90	--	--	1977
17	HBD 04	05536275	Thorn Creek at Thornton, Ill.	104	106	1948	1979
18	H 01	05536700	Calumet-Sag Channel near Lemont, Ill.	389	--	--	1965
--	GI 01	05536995	Chicago Sanitary and Ship Canal at Romeoville, Ill.	739	3,493	1984	1987–91
19	GI 02	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill.	740	--	--	1964
20	G 23	05537980	Des Plaines River at Rte. 53 at Joliet, Ill.	--	--	--	1982
21	GG 02	05539000	Hickory Creek at Joliet, Ill.	107	88.9	1945	1979
22	GBK 09	05539900	West Branch Du Page River near West Chicago, Ill.	28.5	36.2	1961	1979
23	GBK 05	05540095	West Branch Du Page near Warrenville, Ill.	90.4	105	1969	1964

Table 1. Selected information for Illinois Environmental Protection Agency monitoring sites in the upper Illinois River Basin—Continued

Map reference number	IEPA station number	USGS station number	Station name	Drainage area (square miles)	Mean annual streamflow	Period of record[1]	
						Stream-flow	Water quality
			Des Plaines River Basin—Continued				
24	GBL 10	05540210	East Branch Du Page River at Route 34 bridge at Lisle, Ill.	57	--	--	1977
25	GB 10	05540290	Du Page River near Naperville, Ill.	220	--	--	1968
26	GB 11	05540500	Du Page River at Shorewood, Ill.	324	286	1941	1978
			Illinois River Basin				
27	DW 01	05541710	Aux Sable Creek near Morris, Ill.	172	--	--	1979
28	DV 04	05542000	Mazon River near Coal City, Ill.	455	355	1940–95	1978
29	D 23	05543500	Illinois River at Marseilles, Ill.	8,259[3]	10,820	1920	1975
			Fox River Basin				
30	DT 35	05546700	Fox River near Channel Lake, Ill.	1,256	--	--	1971
31	DTK 04	05548280	Nippersink Creek near Spring Grove, Ill.	192	152	1976	1976
32	DT 22	05549600	Fox River near Crystal Lake, Ill.	1,278	--	--	1979
33	DT 06	05550000	Fox River at Algonquin, Ill.	1,403	885	1916	1959
34	DTG 02	05550500	Poplar Creek at Elgin, Ill.	35.2	26.2	1951	1977
35	DT 09	05551000	Fox River at South Elgin, Ill.	1,556	1,290	1990	1969
36	DT 38	05551540	Fox River at Montgomery, Ill.	1,732	--	--	1971
37	DTD 02	05551700	Blackberry Creek near Yorkville, Ill.	70.2	54.2	1961	1977
38	DTB 01	05551995	Somonauk Creek near Sheridan, Ill.	83.3	--	--	1979
39	DT 46	05552500	Fox River at Dayton, Ill.	2,642	1,792	1915	1978

[1]Period of record begins with year shown and is ongoing at date of writing unless otherwise noted.

[2]Of this drainage area, two hundred one square miles is probably noncontributing.

[3]Does not include diversion from Lake Michigan through the Chicago Sanitary and Ship Canal, which has occurred since Jan. 17, 1900.

Table 2. Land use and number of wastewater-treatment plants upstream from Illinois Environmental Protection Agency water-quality monitoring sites in the upper Illinois River Basin

[Map reference numbers from figure 1; WWTP, wastewater-treatment plant]

Map reference number	USGS station number	Number of WWTP's upstream	Percentage of basin in indicated land use[1]					
			Urban	Agriculture	Forest	Water	Wetland	Barren
1	05520500	27	3.82	86.8	6.63	0.73	1.68	0.27
2	05525000	5	1.34	94.3	3.86	.11	0.20	.20
3	05525500	2	0.64	99.0	0.30	.02	0	.01
4	05526000	12	1.24	95.4	3.02	.13	.11	.13
5	05527500	44	3.12	90.8	4.63	.44	.79	.22
6	05527800	0	7.84	84.1	4.36	.84	1.86	1.04
7	05528000	4	12.2	78.7	4.58	1.69	2.06	.73
8	05529000	9	28.2	62.6	5.09	1.66	1.35	1.13
9	05530590	12	40.4	51.1	4.87	1.44	1.10	1.03
10	05531500	12	86.0	7.41	4.66	.91	0	.98
11	05532000	1	98.5	0.75	0	.31	0	.41
12	05532500	25	55.3	37.2	4.58	1.18	.76	.91
13	05534050	32	58.4	33.2	4.98	1.14	1.06	1.21
14	05534500	0	37.8	59.9	2.36	<0.01	0	0
15	05536000	1	75.0	22.0	1.98	.72	0	.24
16	05536195	2	49.6	39.8	7.96	.63	.70	1.36
17	05536275	1	53.2	36.9	5.78	.69	1.83	1.62
18	05536700	12	68.1	21.2	7.72	.69	.96	1.28
19	05537000	19	78.5	14.4	5.11	.54	.54	.87
20	05537980	56	66.7	25.1	5.37	.90	.83	1.12
21	05539000	8	31.8	58.9	6.49	.29	1.24	1.22
22	05539900	6	76.1	19.3	1.54	.88	0	2.18
23	05540095	8	67.0	26.3	3.35	.61	.01	2.77
24	05540210	2	90.4	5.60	3.16	.38	0	.43
25	05540290	14	72.7	21.7	2.78	.66	.03	2.08
26	05540500	16	55.9	38.8	1.98	.88	.02	2.44
27	05541710	0	.92	98.1	.80	.01	0	.13
28	05542000	3	1.91	94.6	.44	.21	0	2.82
29	05543500	144	17.5	75.6	4.65	.67	.72	.76
30	05546700	9	14.6	63.9	11.7	3.51	4.07	2.20
31	05548280	4	8.70	79.1	6.52	2.17	2.65	.87
32	05549600	20	15.4	63.4	10.8	4.21	3.98	2.13
33	05550000	25	17.6	61.5	10.9	4.10	3.83	2.11
34	05550500	0	43.5	48.6	2.57	1.48	.52	3.25
35	05551000	36	19.7	60.5	10.1	3.84	3.50	2.28
36	05551540	40	21.1	60.3	9.54	3.53	3.16	2.39
37	05551700	0	10.8	83.5	2.69	.29	.59	2.07
38	05551995	2	4.49	91.6	3.60	.03	0	.25
39	05552500	51	15.6	71.0	7.18	2.37	2.09	1.77

[1]Based on Anderson and others (1976) classification system; percentages estimated from digital land use/land cover data compiled from high-altitude photography (1978-81) onto 1:250,000-scale topographic map base and interpreted according to methods in Fegeas and others (1983). Urban land use was updated with reference to 1990 population data obtained from the U.S. Bureau of the Census according to methods in Hitt (1994).

tion/evaporation method; however, suspended-sediment concentration is determined by filtering the entire volume of water sample in a pint or quart bottle (Guy, 1969; Knott and others, 1993), whereas suspended-solids concentration is determined by filtering a 250-mL aliquot from a sample (Illinois Environmental Protection Agency, 1987). Scatterplots of the data indicated strong correlations between results from the two methods (fig. 6). Regression analyses of data from the eight sites indicated that differences between the two methods were statistically different except at the Chicago Sanitary and Ship Canal ($p<0.05$). The data show strong correlation at all the sites, however, with *r*-values ranging from 0.22 to 0.98 and average percent differences of less than 10 percent at five sites. The largest differences between results were at two sites in the agricultural Kankakee River Basin, where the USGS suspended-sediment method resulted in consistently higher concentrations. This result may be due to an undersampling of the heavier sands in the sediment load of these streams by the IEPA method. Overall, suspended-solids concentrations determined by the IEPA are related to suspended-sediment concentrations and thus can be used to represent suspended-sediment concentrations, keeping in mind the fact that suspended-solids concentrations may be lower than suspended-sediment concentrations at some sites.

METHODS OF DATA ANALYSIS

Loads were estimated by use of the ESTIMATOR computer program (Cohn and others, 1989), which calibrates a constituent-transport model on the basis of multiple-regression analyses for all but one site. ESTIMATOR implements the Minimum Variance Unbiased Estimator (MVUE); Cohn and others, 1989, and the Adjusted Maximum Likelihood Estimator (AMLE); Cohn, 1988, and Cohn and others, 1992. The AMLE allows ESTIMATOR to use data sets containing values reported as less than the analytical reporting limit. Each calibration procedure incorporated all of the available data for each site from water years 1978–97. These estimates were used to determine the average annual loads of nutrients and suspended solids at each site from 1978–97.

The constituent-transport models were based on the relations between constituent load and two variables: stream discharge (Q, in cubic feet per second) and time of year (T, in radians) (Cohn and others, 1989). The general form of the model was

$$\text{Log (Daily Load)} = a + b(\log Q) - c) + d(\log(Q) - c)^2 + e(\sin(T)) + f(\cos(T)). \quad (1)$$

Equation 1 was calibrated by use of multiple regression analyses between daily loads (estimated by multiplying daily average discharges by instantaneous concentrations) and daily average discharges, Q, and the time of year, T. The calibration coefficients (a, b, c, d, e, and f) are specific to the river and the constituent being modeled. All load estimates and export rates for nutrients and suspended sediments were estimated for the same period.

Loads were estimated for the Chicago Sanitary and Ship Canal (site 19) by multiplying nutrient concentrations in individual samples by discharge at time of sampling. This method was necessary because flow data were insufficient to use ESTIMATOR. However, because discharge is less variable at this site than a natural river system, this technique was considered adequate.

Trends were quantified by use of the program EStimate TREND (ESTREND) (Schertz and others, 1991). The statistical procedures used in ESTREND overcome common statistical problems encountered in the use of conventional statistical-trend techniques. These problems include data that are not normally distributed and seasonally varying, water-quality records with missing values, values less than reporting limits (censored values), and outliers. All of these problems can adversely affect the performance of conventional statistical techniques. In addition, concentrations of suspended sediment and various nutrients are commonly strongly related to streamflow. This relation to streamflow may mask trends if it is not removed from the data.

The ESTREND program uses instantaneous discharge to flow-adjust concentrations. The program does this by one of several options; in this study, the program automatically chose the best flow-adjustment model. Flow adjustments determined were seasonally fit, and one of two methods were used to compute trends depending on the level of censoring in the data. For uncensored data or data with a single reporting limit, the Seasonal Kendall trend test (a nonparametric test) was used to detect statistically significant monotonic trends (Crawford and others, 1983). The seasonal Kendall trend test is generally restricted to pairs of data that are 12 months (seasons) apart, thereby eliminating comparisons of data from different seasons (Smith and others, 1982). Other seasonal designations, such as four sea-

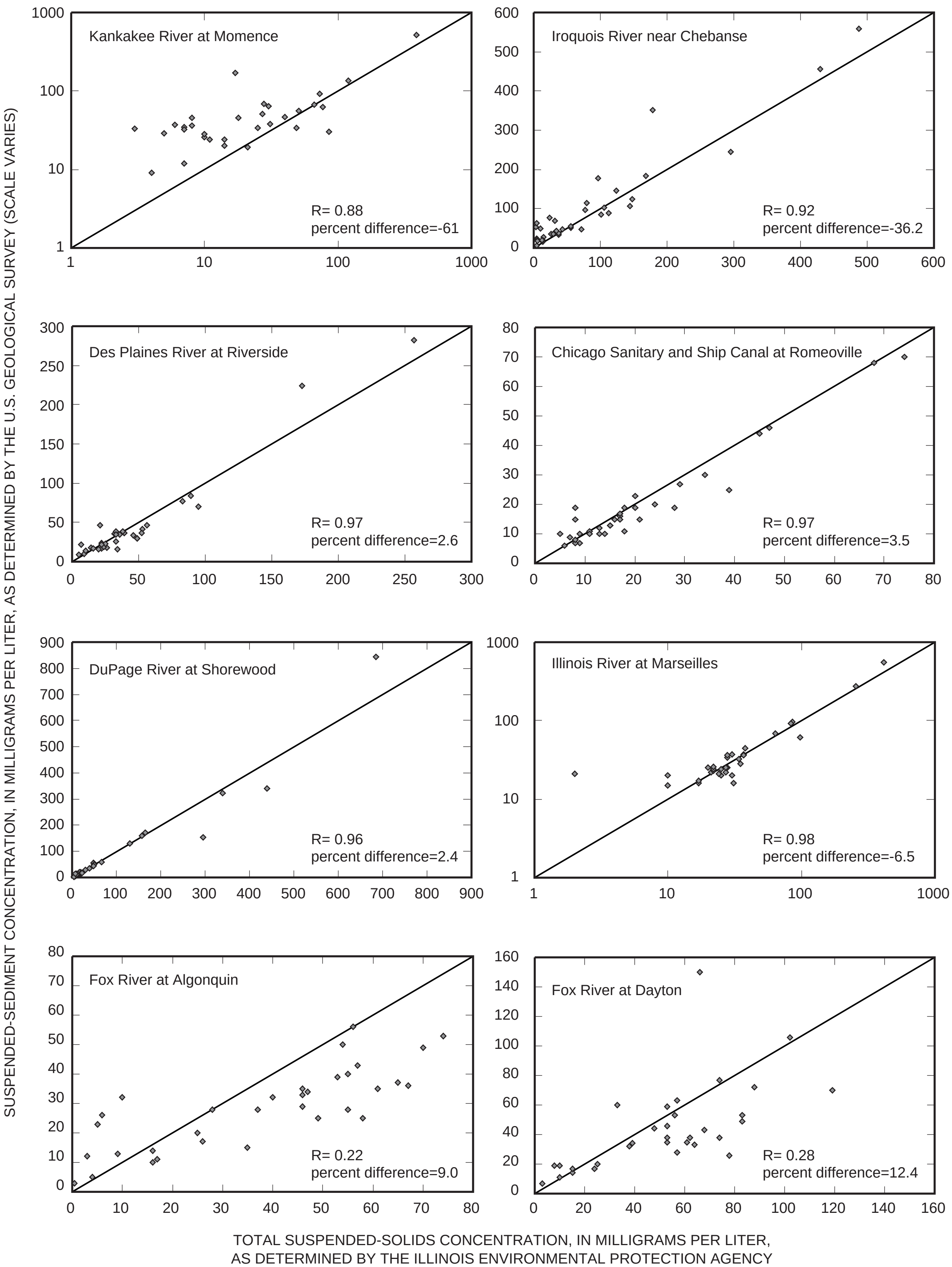


Figure 6. Suspended-sediment and total-suspended-solids concentrations in split samples of water from upper Illinois River Basin streams.

sons per year, also can be used. For this report, all data except those for total ammonia were analyzed for trends using the seasonal Kendall test.

For total ammonia data (which were censored at multiple levels), a censored regression technique, Tobit (Cohen, 1976; Cohn, 1988), was used to test for monotonic trends. Tobit uses a maximum likelihood estimation procedure (Cohn, 1988) to estimate the parameters of a regression model relating concentration and time.

NUTRIENTS AND SUSPENDED SOLIDS IN THE UPPER ILLINOIS RIVER BASIN, 1978–97

In this section, nutrient and suspended-solids data collected at sites in the upper Illinois River Basin during 1978–97 are used to describe the sources of nutrients and suspended solids in the upper Illinois River Basin and to determine the environmental factors influencing the spatial variability of these constituents. Data are also examined for temporal trends.

Sources of Nutrients and Suspended Solids in the Upper Illinois River Basin

The probable sources of nutrients to streams in the study area were described by Terrio (1995). This information is summarized, and in some cases updated, in table 3. Data compiled from the early 1980's indicated that about 54 percent of the total nutrient load in upper Illinois River Basin streams was attributed to nonpoint sources and about 46 percent from point sources (Gianessi, 1986).

Most domestic and industrial wastewaters have much higher concentrations of ammonia, nitrate, and phosphorus than streamwater does; thus, the approximately 196 wastewater-treatment plants in the study area (U.S. Environmental Protection Agency, 1997) are a major influence on study-area streams. Zogorski and others (1990) estimated that about 2,810 ft^3/s of effluent is discharged into streams in the upper Illinois River Basin by these facilities. Of this amount, about 75 percent (2,100 ft^3/s) comes from the three largest treatment plants—Northside, Stickney, and Calumet—which discharge to the North Shore Channel, the Chicago Sanitary and Ship Canal, and the Little Calumet River, respectively (fig. 4).

Urban nonpoint sources can cause elevated nutrient concentrations in urban-area streams. About 17 percent of the study area was urbanized as of 1990 (Arnold and others, 1999). According to estimates by Terrio (1995), total urban runoff contributes about 17 percent as much phosphorus to streams in the study area as agriculture, and only about 1.5 percent as much total nitrogen (table 3).

Atmospheric contributions are another source of nutrients to streams. Nutrient concentration data from National Atmospheric Deposition Program (NADP) sites in or near the study area were examined (table 3). The average volume-weighted concentrations of nitrate and ammonium in precipitation from 1980 to 1997 were 1.62 mg/L and 0.43 mg/L, respectively. If 36 in. is assumed to be the average annual precipitation for the study area, then precipitation would contribute about 46,000 tons of nitrate and 12,300 tons of ammonium to the study area each year; however, the proportion of this load transported to study-area streams is unknown. Precipitation represents a significant contribution of nutrients to the upper Illinois River Basin (table 3).

Ground water can contribute nutrients to streams either through water-supply-system withdrawals and returns or through direct input. Ground-water withdrawals have fluctuated in the study area. In 1995, an estimated 498 ft^3/s was withdrawn for public-supply purposes (Arnold and others, 1999). The nutrient contribution to study-area streams is included in the estimate for wastewater-treatment facilities (table 3). Direct input of ground-water flows to study-area streams is a minor contributor of nutrients (table 3).

Lake Michigan waters that are diverted directly to study-area streams are also a small contributor to nutrient loads (table 3). On the basis of water-quality data collected near Lake Michigan diversion locations, the 1,810 ft^3/s that is diverted from the lake directly to the study area through canals contributes 1,100 ton/yr total nitrogen and 180 ton/yr total phosphorus.

Plant material is another source of nutrients to streams. As plants decompose or are consumed by aquatic fauna and microbial organisms, nutrients are released. Some plant materials that may be important nutrient contributors are leaf litter, aquatic flora, and agricultural crop residue. Nitrogen fixation by certain bacteria and blue-green algae also can contribute to the nitrogen in streams. The contributions of nutrients to study-area streams from plant-material decomposition and nitrogen fixation are unknown, and amounts are likely to vary from year to year.

Most suspended solids in Illinois streams are from soil erosion and consist of silts, clays, and sand (Illinois

Table 3. Sources and estimated inputs of nutrients and sediment to streams in the upper Illinois River Basin

[From Terrio, 1995 unless otherwise noted; ton/yr, tons per year; --, undetermined, unknown, or not applicable]

Source	Estimated input to basin (ton/yr)				Estimated input to streams (ton/yr)				
	Total nitrogen	Total phosphorus	Ammonia	Nitrite plus nitrate	Total nitrogen	Total phosphorus	Ammonia	Nitrite plus nitrate	Sediment
Wasterwater-treatment-plant effluent[1]	26,000	5,410	--	--	26,000	5,410	--	--	--
Fertilizer applied to agricultural lands[2]	215,000[3]	87,000[4]	--	--	--	--	--	--	--
Urban runoff	--	--	--	--	855	1,250	--	--	--
Precipitation[5]	--	--	12,300	46,000	--	--	--	--	--
Ground-water flow into streams	--	--	--	--	--	20	408	102	--
Lake Michigan diversion[6]	1,100	180	--	--	1,100	180	--	--	--
Soil erosion	--	--	--	--	--	--	--	--	34,000,000
Plant decomposition	--	--	--	--	--	--	--	--	--

[1]Includes input from Lake Michigan and ground-water withdrawals.

[2]Data from 1988: assumes that all nutrients in fertilizers sold that year were applied to fields the same year.

[3]Agricultural runoff for the study area was estimated at 55,500 tons per year (Gianessi, 1986).

[4]Agricultural runoff for the study area was estimated at 7,340 tons per year (Gianessi, 1986).

[5]Loads for precipitation are for total load to basin land area; portion contributing to streams is unknown.

[6]Approximately 33 percent of the total streamflow at the Illinois River at Marseilles, Ill. is water diverted or withdrawn from Lake Michigan.

Environmental Protection Agency, 1996b). Other sources may include industrial and mine wastes, construction projects, and detrital remains of aquatic and terrestrial plants and animals. Concentrations of total suspended solids are generally affected by runoff and not necessarily stream discharge. During periods of low flow, a locally heavy rainfall can significantly increase the total suspended solids in a stream while only slightly increasing streamflow.

Nitrogen Concentrations

Nitrogen is present in water in anionic form as nitrite and nitrate (NO_2- and NO_3-), in cationic form as ammonium (NH_4+), and at intermediate oxidation states as a part of organic solutes (Hem, 1985). Nitrate (NO_3-) is generally far more abundant than nitrite (NO_2-) because nitrite is an intermediate oxidation state and readily oxidizes to nitrate in natural waters. Ammonium is strongly sorbed to particulate material, whereas nitrate generally remains dissolved and stable over a wide range of conditions. In most rivers, the nitrogen concentration is sufficient for plant growth.

Nitrogen is introduced into aquatic environments from agricultural fertilizers and manures, organic wastes in sewage and industrial effluent, atmospheric deposition, decomposition of organic material, biotic fixation, and ambient soils and rocks. Nitrogen generally is introduced as nitrate, ammonia, organic nitrogen, or molecular nitrogen, which can be rapidly transformed from one form to another by way of short-lived intermediate forms. The various forms of nitrogen are actively cycled in aquatic environments in what is commonly referred to as “the nitrogen cycle” (Stumm and Morgan, 1981; Wetzel, 1983). Molecular nitrogen is converted into ammonia by nitrogen fixation, which can then be assimilated into various forms of organic nitrogen or be nitrified into dissolved nitrate. Nitrogen fixation in aquatic environments is brought about only by cyanobacteria (blue-green algae) and other specific bacteria. Ammonia is also produced by the decomposition of organic nitrogen, in compounds such as amino acids and proteins. During nitrification, ammonia is oxidized into nitrate with nitrite as an intermediate transient. Nitrification occurs fairly rapidly in aerobic environments. Nitrates may be converted to molecular nitrogen in anaerobic environments through denitrification (again with nitrite as an intermediate form) or may be reduced to ammonia in an assimilatory pathway leading to the synthesis of amino acids.

The principal toxic form of ammonia has been demonstrated to be un-ionized ammonia (NH_3). Un-ionized ammonia was reported to be acutely toxic to 29 fish species at concentrations of 0.083 to 4.60 mg/L (U.S. Environmental Protection Agency, 1986). The proportion of ammonia in the un-ionized form depends on the concentration of ammonia, water temperature, and pH, and it is usually a minor component of ammonia at pH's that are common in streams.

Several forms of dissolved nitrogen are essential for algal and macrophyte growth but can be toxic to aquatic and terrestrial life. High concentrations of nitrite and nitrate can be harmful if consumed by warm-blooded animals. Nitrite reacts with hemoglobin to cause impairment of oxygen transport. Nitrate can be converted to nitrite within the gastrointestinal tract and therefore is potentially harmful. The maximum contaminant level (MCL) for nitrate in drinking water is 10 mg/L; concentrations above 10 mg/L can cause methemoglobinemia in small children. The MCL for nitrite in drinking water is 1 mg/L (U.S. Environmental Protection Agency, 1986).

Total Ammonia

Median ammonia concentrations for 1978–97 ranged from below the minimum reporting level (either 0.01 mg/L or 0.1 mg/L, depending on the site) at sites in all subbasins to a maximum of about 4 mg/L at the Calumet-Sag Channel near Lemont, Ill. (site 18) (fig. 7). The sites with the next-highest median ammonia concentrations were downstream from this site: the Chicago Sanitary and Ship Canal (site 19) and the Des Plaines River at Joliet, Ill. (site 20). Median ammonia concentrations at sites in the Fox and Kankakee River Basins were an order of magnitude or more lower, as were sites in the upper Des Plaines River Basin upstream from the most heavily urbanized areas of Chicago. Because ammonia-concentration data were censored at concentrations above the median at many sites, the sites with the lowest median concentrations could not be determined. Concentrations of ammonia nitrogen at the Illinois River at Marseilles (site 29) were significantly higher than those at 42 sites studied as part of a comprehensive study of the entire Mississippi River Basin (Goolsby and others, 1999).

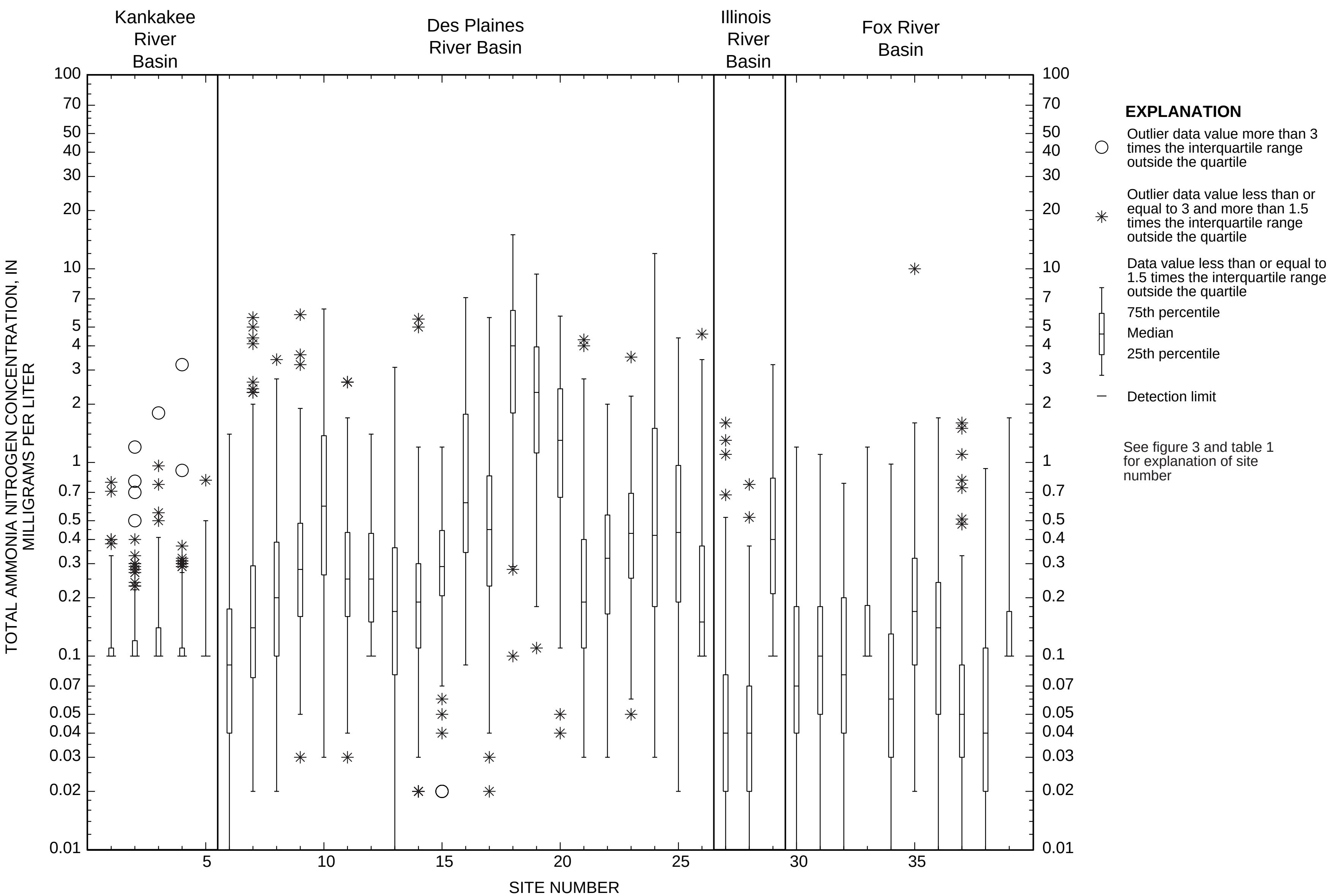


Figure 7. Total ammonia nitrogen concentrations in streams of the upper Illinois River Basin, 1978–97.

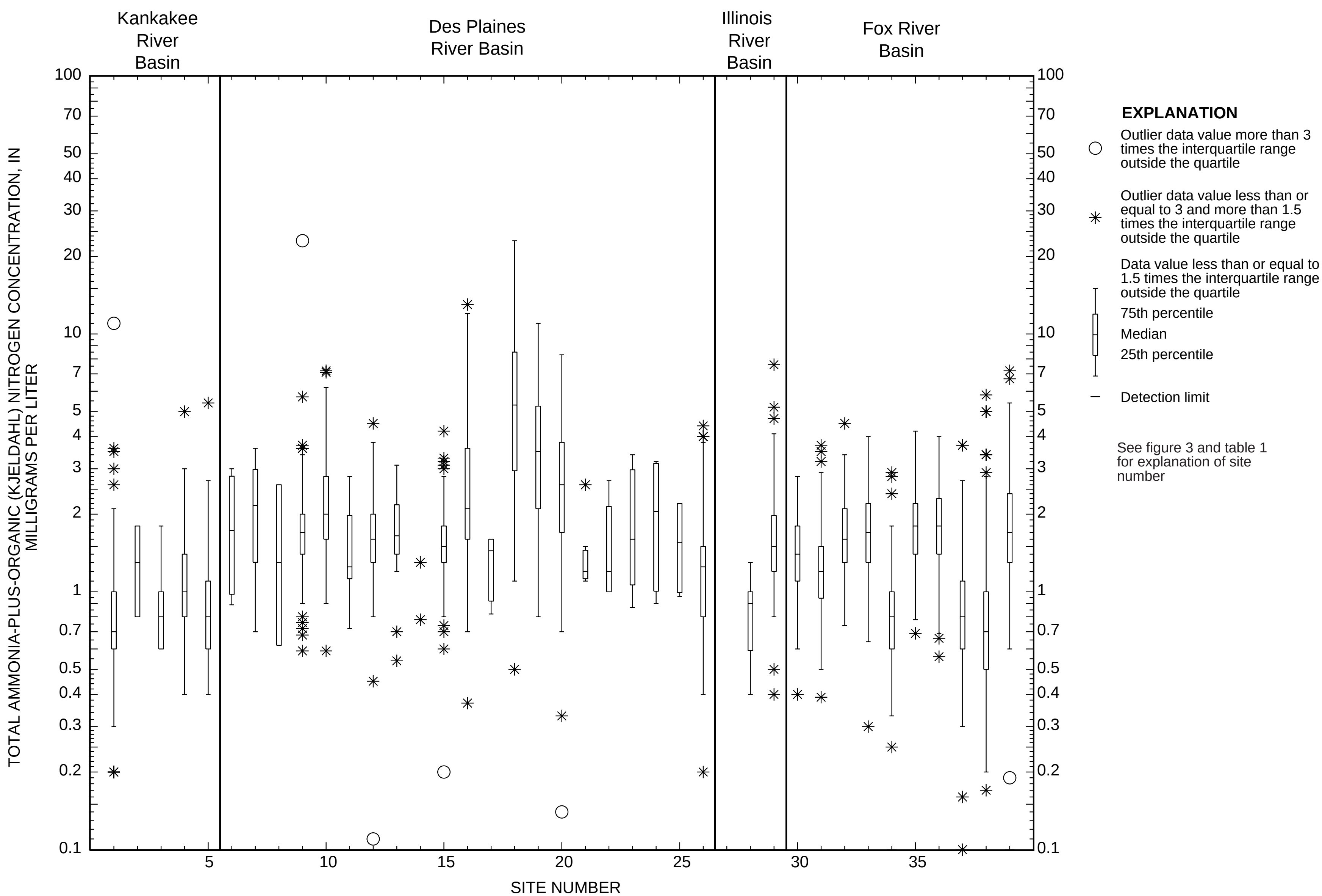


Figure 8. Total ammonia-plus-organic (Kjeldahl) nitrogen concentrations in streams of the upper Illinois River Basin, 1978–97.

Total Ammonia-Plus-Organic (Kjeldahl) Nitrogen

Median Kjeldahl nitrogen concentrations mirrored those of ammonia, and were highest at the same three sites (fig. 8). The lowest median Kjeldahl nitrogen concentrations were found at a Fox River tributary (site 38, Somonauk Creek) and the Kankakee River at Momence, Ill. (site 1).

Total Nitrite Plus Nitrate

The highest median nitrate concentration was at an Illinois River tributary, Aux Sable Creek (site 27), where the median nearly equaled the 10 mg/L drinking-water limit for nitrate (fig. 9). The median at a nearby stream, the Mazon River (site 28), was only slightly lower. Other streams with median nitrate concentrations between 5 and 10 mg/L were three Iroquois River sites (sites 2,3,4), two sites in the Des Plaines River Basin (sites 7 and 10) and all the sites in the Du Page River Basin (sites 22-26). Median nitrate concentrations were lowest (about 0.7 mg/L) at a Fox River main-stem site (site 33) and the upstream site on the North Branch Chicago River (site 14) (fig. 9). A Fox River tributary, Poplar Creek (site 34) was the only other site where median nitrate concentration was less than 1 mg/L (about 0.9 mg/L). Median nitrate concentrations were generally lowest at sites in the Fox River Basin.

Concentrations of nitrate were higher in tributaries of the Fox River than in the main stem. These tributary streams drain agricultural lands with clayey soils, in contrast to the coarser soils and suburbanizing land in the northern (upstream) parts of the Fox River Basin. Concentrations of nitrate were considerably higher at the Fox River at Dayton (site 39), the most downstream site on the Fox River, than at sites upstream on the main stem, a reflection of the input of the tributary streams in the southwestern part of the Fox River Basin.

Concentrations of nitrate at the Illinois River at Marseilles (site 29) were among the highest of those at 42 sites studied as part of a comprehensive study of the entire Mississippi River Basin (Goolsby and others, 1999). Most of the other basins with similar high concentrations of nitrate were in Illinois and Iowa. A correlation was found in that study between nitrate concentrations and the percentage of basin in row crops.

Phosphorus Concentrations

Phosphorus concentrations in rivers are generally much lower than those of nitrogen; consequently, phosphorus concentrations more often limit aquatic plant growth. Plants usually require less phosphorus than nitrogen, however, so plants may be nitrogen limited even though phosphorus concentrations are lower than those of nitrogen.

Phosphates, the most common forms of phosphorus found in natural waters, are not mobile in soil water because they tend to attach to soil and aquifer particles. Phosphates can have a significant effect on streams and lakes, however, because eroded soil can transport considerable amounts of attached phosphates by way of runoff. Orthophosphate, which typically constitutes the majority of dissolved phosphates, can be readily assimilated by aquatic plants and can promote eutrophication.

Sources of phosphorus to surface waters are similar to those of nitrogen and include synthetic fertilizers, soil and rock minerals, and wastewater. Domestic wastewater contains a higher proportion of orthophosphate than does runoff from agricultural and urban areas.

Total Phosphorus

Median total phosphorus concentrations were highest (about 2 mg/L) at Thorn Creek (site 17) (fig. 10), a stream that flows to the Calumet-Sag Channel, and at Salt Creek (site 10, about 1.6 mg/L). The median concentrations of most sites in the Des Plaines River Basin were significantly higher than those for sites in the other subbasins of the study area. The lowest observed total phosphorus concentrations were at Poplar Creek (site 34), a tributary to the Fox River. Total phosphorus concentrations at the Illinois River at Marseilles (site 29) were among the highest in the Mississippi River Basin (Goolsby and others, 1999).

Dissolved Phosphorus

The overall pattern of dissolved-phosphorus concentrations was similar to that for total phosphorus. Median dissolved-phosphorus concentrations, like total phosphorus, were highest at Thorn Creek (site 17) (fig. 11). The contrast between Des Plaines River sites and sites outside the Des Plaines River Basin, however, is greater for dissolved phosphorus. Median dissolved-phosphorus concentrations were an order of magnitude or more greater at most Des Plaines River sites than at

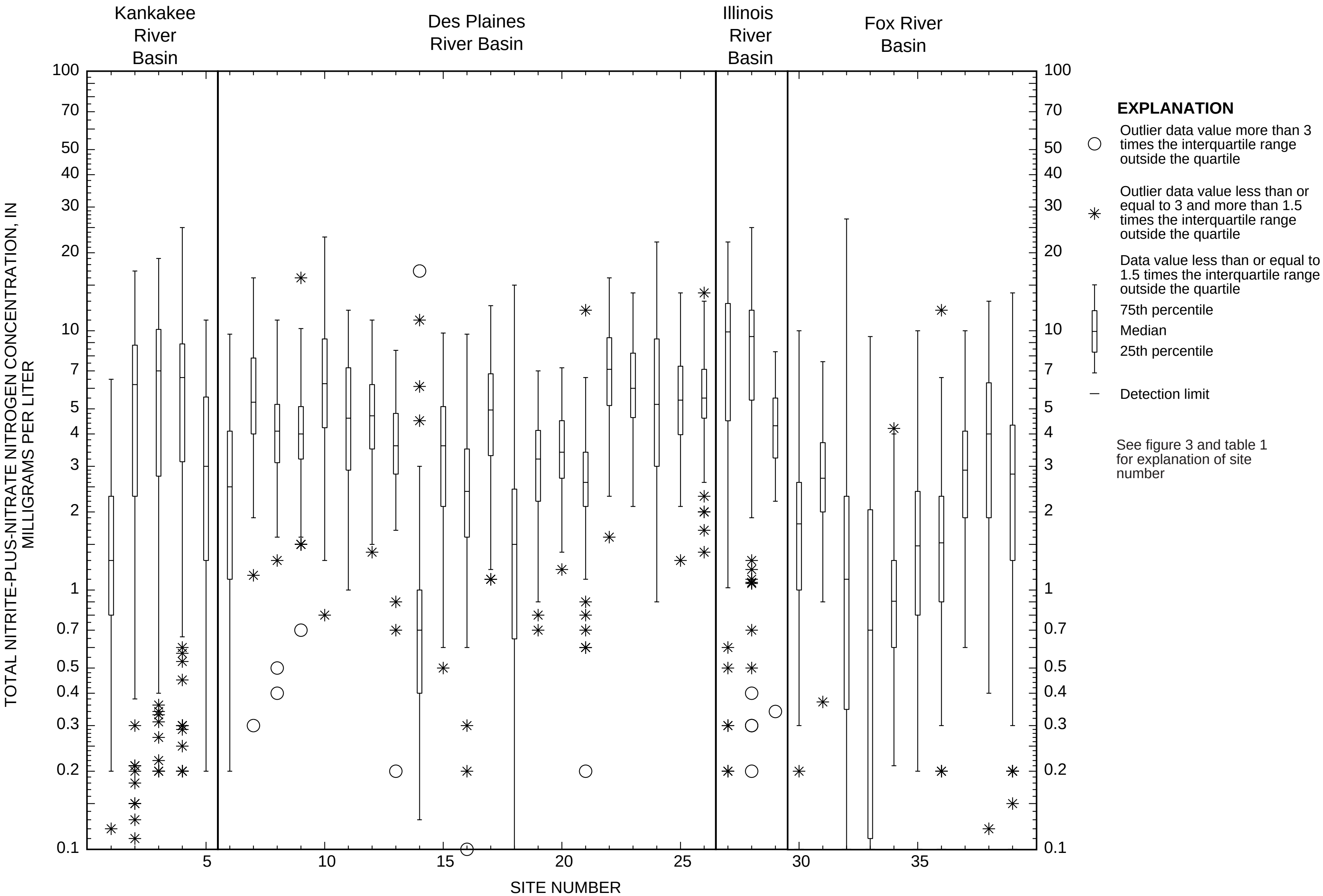


Figure 9. Total nitrite-plus-nitrate nitrogen concentrations in streams of the upper Illinois River Basin, 1978–97

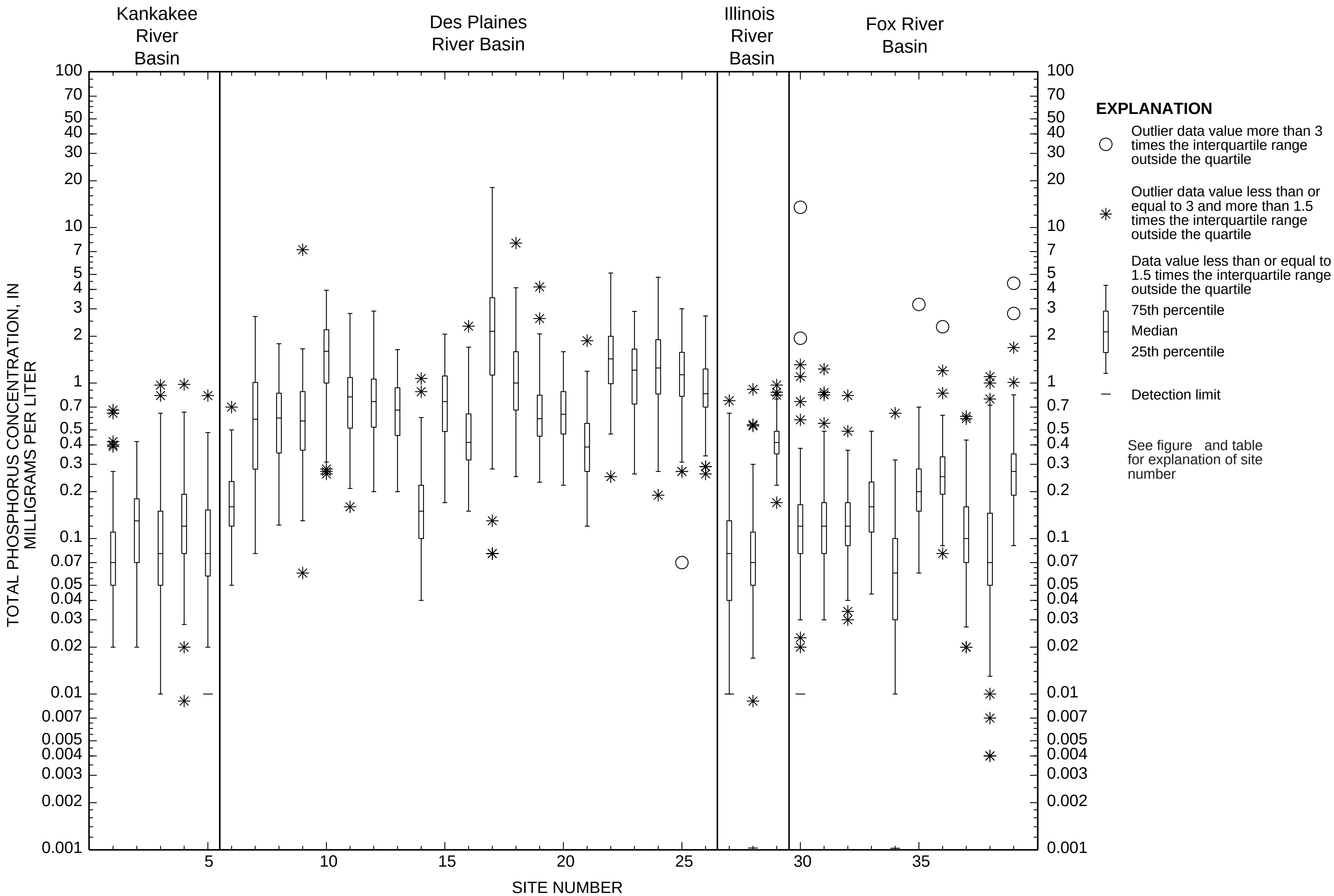


Figure 10. Total-phosphorus concentrations in streams of the upper Illinois River Basin, 1978–97.

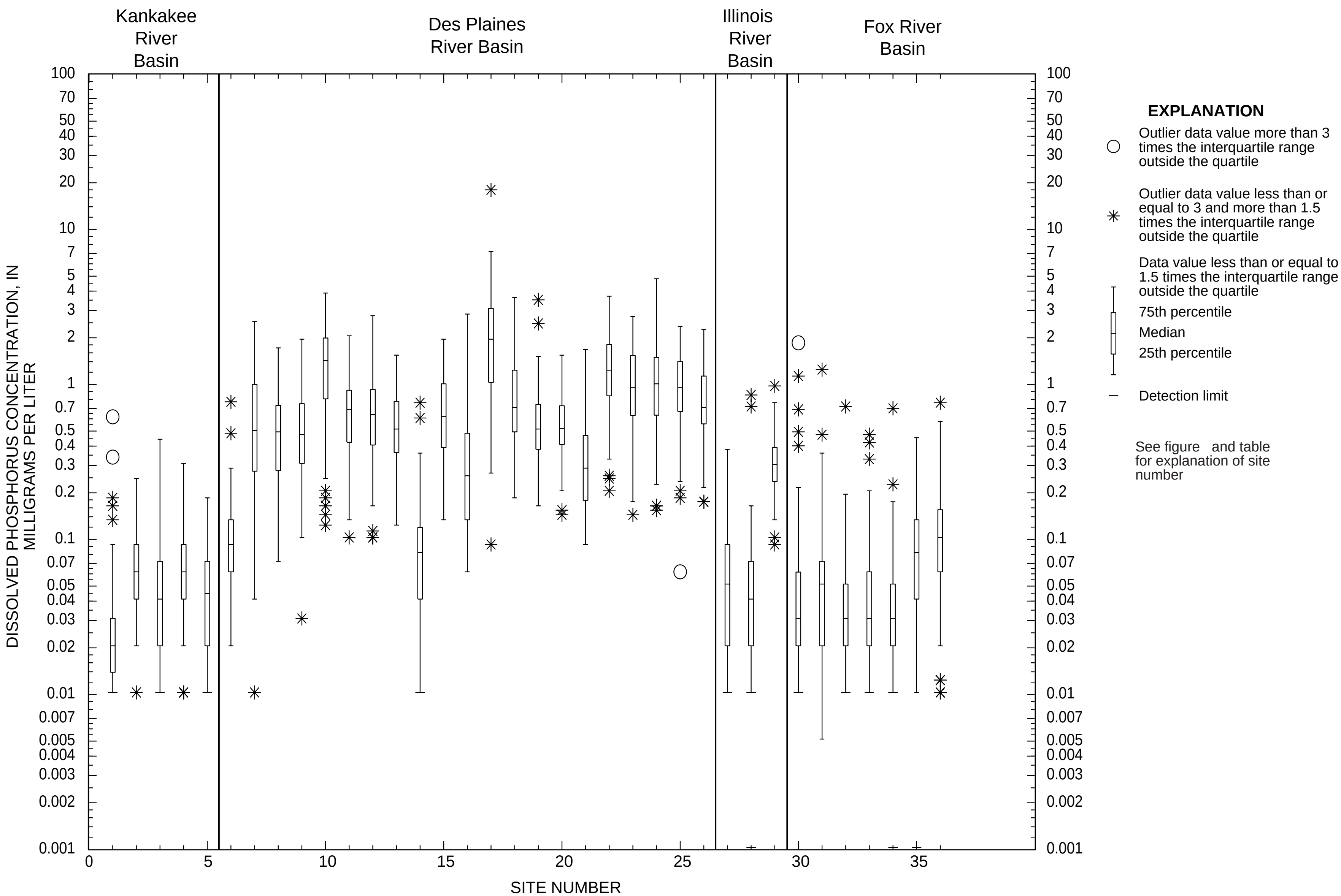


Figure 11. Dissolved-phosphorus concentrations in streams of the upper Illinois River Basin, 1978–97.

Table 4. Mean ratios of dissolved to total phosphorus for selected groups of sites in the upper Illinois River Basin, 1978–97

[Sites refer to figure 3 and table 1. The ratio of dissolved to total phosphorus was computed at each site for each date when values for both concentrations were available. These ratios were then averaged for the 1978–97 water years. Means for site groups representing different parts of the upper Illinois River basin are shown.]

Basin or group	Site numbers	Ratio of dissolved to total phosphorus
Kankakee-Iroquois	1,2,3,4,5	0.48
Des Plaines - upper Illinois	6,7,8,9,12,20,29	.70
Du Page	26,25,24,23,22	.85
Fox River mainstream	30,32,33,35,36,39	.36
Fox River tributaries	31,34,37,38	.49
Tributaries to the Des Plaines	10,11,13,14,15,16,17,18,19,21,27,28	.82

other sites in the study area. Comparison of orthophosphate concentrations at the Illinois River at Marseilles (site 29) to other sites in the Mississippi River Basin shows that, again, outflow from the upper Illinois River Basin contains concentrations as high or higher than all other sites for this main component of dissolved phosphorus (Goolsby and others, 1999).

The ratio of dissolved to total phosphorus can be useful for assessing how nutrients are released and transported in hydrologic systems, as well as for identifying possible sources of phosphorus. Decimal numbers representing the ratios of dissolved to total phosphorus for selected groups of sites are listed in table 4. Ratios in the Des Plaines-Illinois River Basins were considerably higher than those in the Kankakee-Iroquois and Fox River Basins. In addition, ratios tended to be higher at tributary sites than at the main-stem sites. The soluble (dissolved) fraction of phosphorus transported in many streams is typically in the range of 20 to 30 percent, even as small as 10 percent (Elder, 1985; Hickman, 1987); hence, the ratios observed in the study area, especially in the Illinois and Des Plaines River Basins, are remarkably large. These high ratios are due to the number of wastewater-treatment plants in the Des Plaines River Basin, most of which discharge to tributaries.

Patterns and Variability in Nutrient Concentrations

For 1978–97, in general, nutrient concentrations except for nitrate were highest at streams in the urban areas of the Des Plaines River Basin. Streams in the Kankakee and Fox River Basins generally had the lowest concentrations, although concentrations appeared to increase downstream in these basins.

These spatial patterns in nutrient concentrations correspond closely with land use. The elevated concentrations of ammonia and phosphorus in the urbanized Des Plaines River Basin with respect to other sites in the study area provide evidence that municipal- and industrial-waste discharges into streams of the basin increase concentrations of these nutrients in the receiving streams. For example, the median concentration of total phosphorus was highest at Thorn Creek (site 17), whereas the highest median total-ammonia concentration was at the Calumet-Sag Channel (site 18), both sites in the Des Plaines River Basin. Phosphorus and ammonia concentrations in Aux Sable Creek near Morris (site 26) and the Mazon River near Coal City (site 27) were among the lowest in the study area; however, median concentrations of nitrate in both of these tributaries were the highest, near 10 mg/L. Conditions in these latter two streams may exemplify land-use effects on different nutrients; these streams were in predominantly agricultural areas, and their relatively large ratios of nitrogen to phosphorus and nitrate to ammonia are characteristic of agricultural drainage.

The apparent, but nonuniform, correspondence of nutrient concentrations in streams to urban and agricultural land use in the upper Illinois River Basin was generally consistent with findings in other river basins. A study of data collected from the first 20 NAWQA study areas found that, in most cases, streams were enriched with nutrients in regions dominated by agricultural or urban land use (U.S. Geological Survey, 1999). Robertson and Saad (1996) found that total nitrogen concentrations in streams draining to western Lake Michigan mirrored the sum of inputs for various land-use categories. In a review of published literature on nutrient exports from various watershed types, Beaulac and Reckhow (1982) compiled substantial evidence that agricultural and urbanized watersheds produce larger nutrient outputs than do forested watersheds; however, the authors also pointed out that agriculture and urbanization lead to a great deal of variability in nutrient export relative to the more uniform output from undisturbed forested areas. Hence, in a basin such as the upper Illinois, an overall pattern relating nutrient concentrations to land use can be expected, but substantial deviations from that pattern are likely within certain reaches or subbasins. Such deviations interfere with unequivocal identification of links between specific sources and observed nutrient trends.

An example of the variability of nutrient concentrations in agricultural areas can be found in the Iroquois and Kankakee River Basins. Despite similar agricultural land use, nitrate and organic nitrogen concentrations (the latter estimated by subtracting ammonia nitrogen from Kjeldahl nitrogen) observed in the Iroquois River Basin were generally higher than those in the Kankakee River. This water-quality difference may reflect the differences in the quantity of sand and organic matter present in the soils in each river basin; soils in the Iroqouis River Basin have more organic matter and less sand than the soils in the Kankakee River Basin. This difference in surficial deposits results in greater direct runoff to surface waters in the Iroquois River Basin. By contrast, precipitation easily percolates through the sandy soils in the Kankakee River Basin, resulting in movement of nitrate to the ground water.

Nitrogen and phosphorus concentrations in surface waters tend to be subject to considerable seasonal variation (Stanley and Hobbie, 1981; Prairie and Kalff, 1988). Such variation can be attributed to natural factors and to human activity. One of the most frequently recognized causative factors is the effect of uptake and release of these nutrients by biota, especially aquatic plants (Goldman and Horne, 1983; Vincent and others, 1984). During spring, summer, and early fall, intense biological activity results in important metabolic processes that consume and release nutrients. Seasonal variations in nutrient concentrations may also be related to flow volume or discharge (Hill, 1986). Human activities that can produce seasonal variation in nutrient concentrations include industrial discharges, the operation of wastewater-treatment facilities, and the application of fertilizer.

Biological uptake of nitrate, ammonia, and dissolved phosphorus commonly produces a seasonal pattern that is characterized by high concentrations in the winter months, depletion during the spring and summer, and minimum levels in the late summer or early fall. This pattern was observed in some of the data from the upper Illinois River Basin. Monthly median concentrations of total ammonia were at minimum levels from July through October (fig. 12A). A similar seasonal pattern was observed for nitrate (fig. 12B) but not for total phosphorus concentrations (fig. 12C).

Background concentrations of nutrients were estimated as part of a recent study of data collected at 20 NAWQA study areas across the country (U.S. Geological Survey, 1999). Background concentrations are defined as concentrations that would be observed in streams that have been subject to little or no disturbance from human activities. Thus, the estimates of background concentrations were based on data collected from streams in areas minimally affected by agriculture, urbanization, and associated land uses. The estimated background concentrations of nitrate are about 0.6 mg/L; of ammonia, 0.1 mg/L; and of total phosphorus, 0.1 mg/L. At all the sites discussed in this report, median nitrate concentrations were greater than 0.6 mg/L. In general, nutrient concentrations in the upper Illinois River Basin reflect the point and nonpoint sources that have substantially increased nutrient concentrations beyond background levels. However, at some sites in the Kankakee and Fox River Basins and on tributaries to the mainstem Illinois River, median ammonia and total phosphorus concentrations were below the background concentrations.

The net result of nutrient inputs and transport through the river system were elevated nutrient concentrations at the Illinois River at Marseilles (site 29). Although concentrations were higher at numerous upstream tributaries, the concentrations at Marseilles were higher than at most of the tributary sites upstream from major urban areas. As stated earlier, the median concentration of nitrate, total phosphorus, and orthophosphate at site 29 was among the highest in the Mississippi River Basin and was the highest for ammonia (Goolsby and others, 1999).

Suspended-Solids Concentrations

Suspended solids are materials suspended in the water column, typically consisting of fragmental miner-

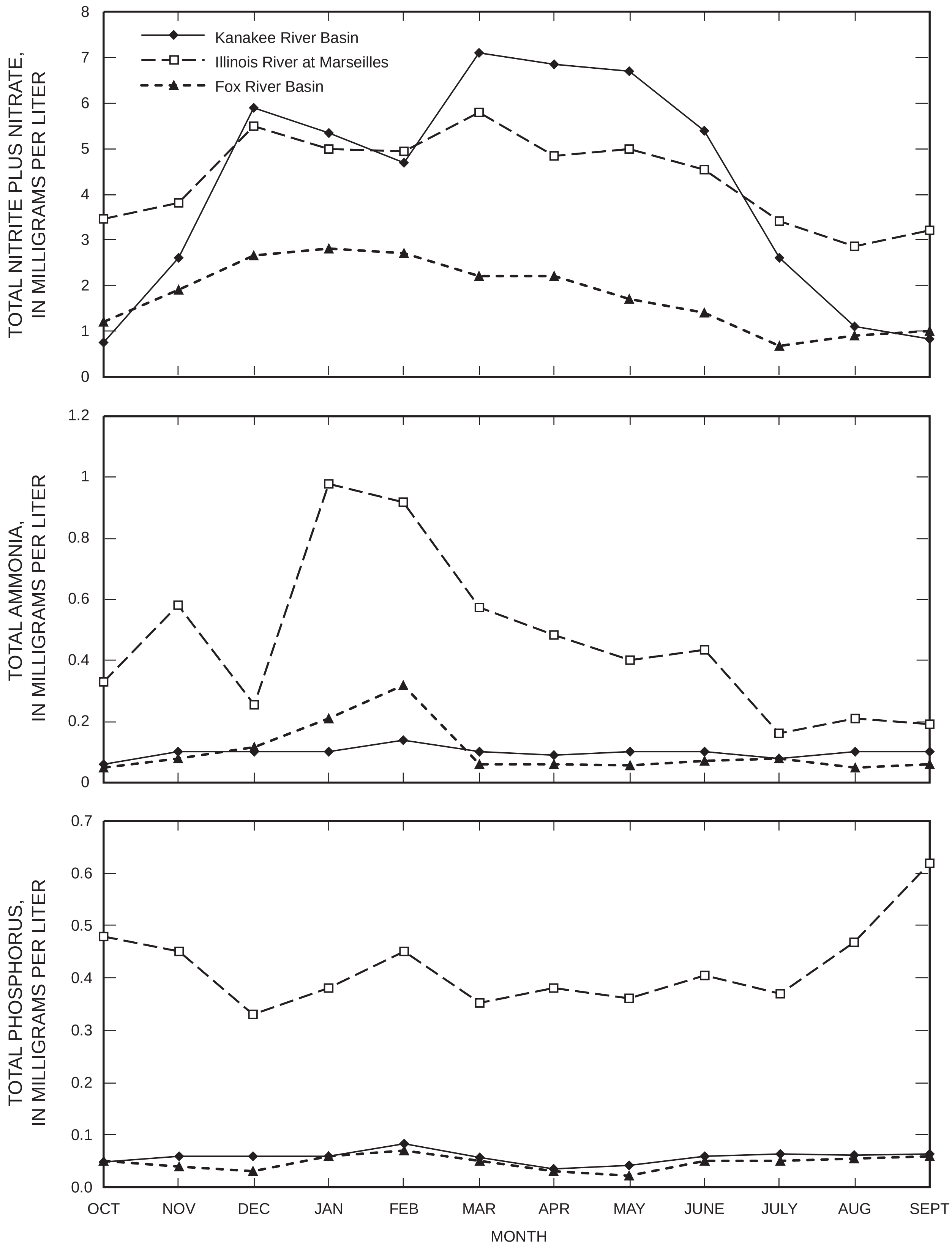


Figure 12. Median monthly concentrations of selected nutrients in the upper Illinois River Basin, 1978–97.

als, silt, sand, and organic matter. Particulate matter, in suspension or at the streambed, plays an important role in the chemistry of aquatic systems (Stumm and Morgan, 1981). Particulate matter commonly affects the degree and rate at which many aqueous chemical reactions proceed, in particular, ion-exchange reactions between sediment minerals and cations in solution.

Organic matter contributes to the suspended-solids concentration and to the sediment-related chemistry of a stream. Many of the large particles found in streams are primarily organic material. Particulates that fall out of suspension and are deposited in stream bottoms commonly reduce the dissolved-oxygen content of the water column because of oxygen-consuming reactions and organic-matter decomposition that takes place in the particulates (Kimmel, 1981). This oxygen demand of particulates has been a concern in the upper Illinois River Basin (Butts, 1974).

Sources of suspended solids in rivers include erosion of soils, streambeds and streambanks, input from point sources, and atmospheric deposition. The upper Illinois River Basin has historically had, and continues to have, problems with erosion of agricultural lands in the northern and eastern parts of the basin. Erosion is often cited as the primary nonpoint-source-contamination concern in Illinois (Hendrickson, 1987; Vonnahme, 1987). Each phase of the sediment cycle (erosion, transport, and deposition) can present environmental and water-quality concerns.

Suspended-solids concentrations at the 39 IEPA sites do not indicate any particularly strong spatial patterns among major river basins in the study area (fig. 13). Instead, individual sites with high suspended-solids concentrations are found within each subbasin and in all types of land use and hydrologic conditions.

Median suspended-solids concentrations ranged from less than 10 mg/L below a small (35.2 mi^2) drainage to the Fox River (Poplar Creek, site 34), to more than 50 mg/L at the downstream-most site on the Fox River (site 39). Other sites with high median concentrations included all three sites on the Iroquois River (sites 2, 3, and 4), an agricultural area of poorly permeable, easily eroded soils, and at three sites in urban areas: Salt Creek at Western Springs (site 10), Des Plaines River at Schiller Park (site 9), and Little Calumet River at Munster, Ind. (site 16).

Maximum suspended-solids concentrations observed across the basin were generally at the same sites with the highest median concentrations. Observed maximum concentrations were greater than 1,500 mg/L at Sugar Creek at Milford (site 3), a tributary to the Iroquois River; Hickory Creek at Joliet (site 21), a small, flashy tributary to the Des Plaines River; and the downstream-most site on the Fox River (site 39).

Seasonal variation of suspended solids was consistent at sites across the basin. In general, the concentrations were highest in the summer and lowest in the winter (fig. 14). The increase in suspended-solids concentrations during the summer can be attributed to concurrent higher streamflow and the associated increase in runoff and transport. In addition, increased phytoplankton growth in the summer months, as shown by the pattern of total volatile solids (fig. 14), is a contributor to higher concentrations of suspended solids in the summer.

TRANSPORT OF NUTRIENTS AND SUSPENDED SOLIDS IN THE UPPER ILLINOIS RIVER BASIN, 1978–97

Transport of nutrients and suspended solids within and out of the study area were documented by computation of mean annual loads and yields at 24 sites where streamflow data were available (tables 5–10). Basin-wide patterns are illustrated in figures 15–17.

The loads plots clearly show that the major contributor of ammonia nitrogen (fig. 15), total Kjeldahl nitrogen (fig. 15), and phosphorus (fig. 17) loads to the total study-area output was the Des Plaines River Basin, the Chicago Sanitary and Ship Canal in particular. The high concentrations in this area and the high volume of water result in the large load output. The high loads in the Ship Canal reflect the input from the three large MWRDGC treatment plants.

In contrast, nitrate loads were highest from the agricultural Kankakee River Basin (fig. 16). Total suspended-solids loads were also highest from agricultural areas, in particular the Iroquois River Basin and tributaries to the lower Fox River (fig. 18). These are areas of intensive row-crop agriculture and fine, easily erodable soils.

Among individual sites, ammonia nitrogen loads were highest at the Chicago Sanitary and Ship Canal (site 19). The loads at this site were an order of magnitude higher than at the site with the next-highest loads, the Kankakee River Basin outlet site (site 5). Yields were highest at two sites in the Des Plaines River Basin (10 and 12) that receive large amounts of wastewater. Yields were not computed for the Ship Canal because of the hydraulics of the system. In general, high yields of

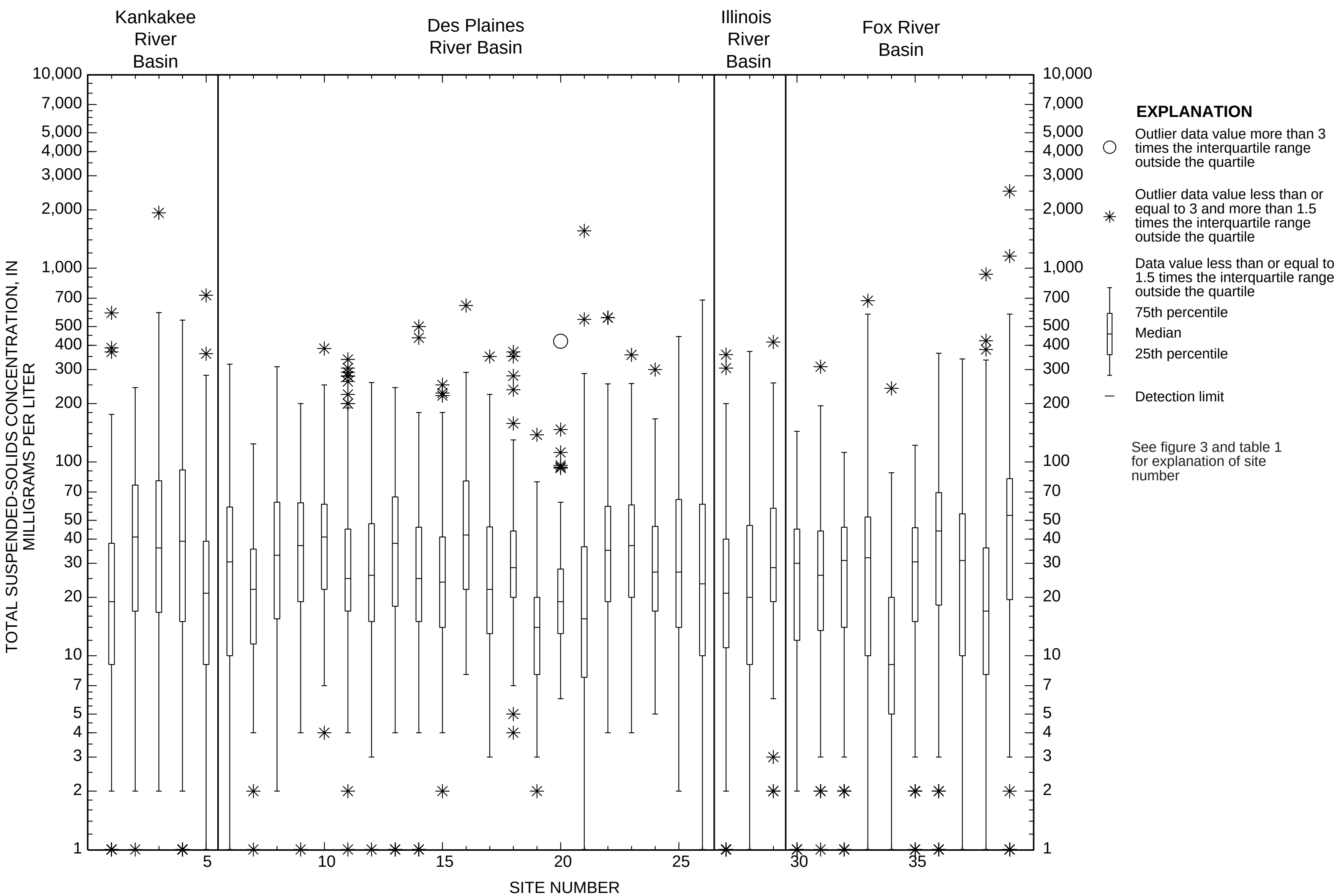


Figure 13. Total suspended-solids concentrations in streams of the upper Illinois River Basin, 1978–97.

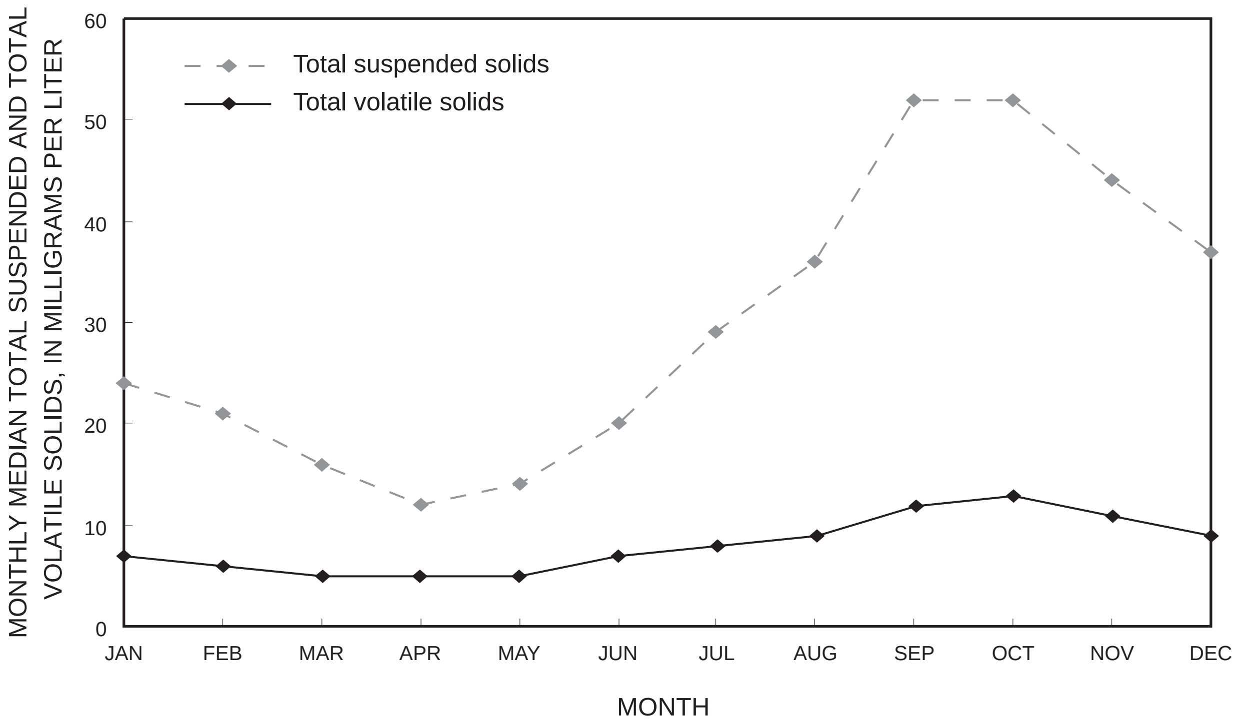


Figure 14. Median monthly concentrations of total suspended-solids and total volatile-solids concentrations in the upper Illinois River Basin, 1978–97.

ammonia nitrogen seem most closely related to urban land use and wastewater discharge.

Total nitrate loads were highest in the agricultural Kankakee River Basin, with the Fox and Des Plaines River Basins contributing roughly similar loads. Yields were about 2-1/2 times higher from sites in the Kankakee than most other sites in the Fox and Des Plaines River Basins.

The total nitrogen export from the upper Illinois River Basin for 1978–97 was 91,800 ton/yr. This amount corresponds well with estimates of loads from urban, agricultural, and other sources, and is about 30 percent of the estimated total nitrogen input to the basin of about 300,000 ton/yr. The total phosphorus export from the study area for 1978–97 was about 5,400 ton/yr, or about 6 percent of estimated phosphorus inputs of 94,000 ton/yr.

Suspended-solids loads were highest in the Kankakee River Basin, with an average annual load of about 470,000 ton/yr. The Iroquois River, with its high-clay-content surficial deposits and intensive row-crop agriculture, contributes more than 375,000 ton/yr to the total output from the Kankakee River Basin. The mean annual yield of 180 ton/mi^2 measured at site 4 on the Iroquois River was more than 4 times higher than the mean annual yield of 43 tons/mi^2 from a comparable drainage area on the main stem Kankakee River (site 1). The Fox River Basin contributed the next highest amount, much of that coming from agricultural lands in the southern parts of the basin.

The importance of surficial deposits on suspended-solids loads is illustrated in the following example. In the Iroquois River Basin, about 41,000 ton/yr was transported past site 2 on the Iroquois main stem. Furthermore, the load from the Sugar Creek site (site 3), which drains 446 mi^2 in the Illinois part of the Iroquois River Basin, was about 3 times the load at site 2 on the Iroquois River main stem, which drains 686 mi^2. Overall, of the approximate 375,000 ton/yr of suspended solids that was transported past the site on the Iroquois River near its mouth (site 4), about 89 percent came from the Illinois part of the basin, either by erosion from farm fields and streambanks or resuspended from the river channel in Illinois. In the Indiana part of the Iroquois River Basin, the soils are primarily loam, while in Illinois they are predominantly clays and silts, which are

Table 5. Estimated transport of total ammonia nitrogen at selected sites in the upper Illinois River Basin
[USGS, U.S. Geological Survey]

Map reference number	USGS station number	Station name	Period of record for load computations	Average annual load (tons)	Average annual yield (tons per mi^2)	Load model statistics			
						Number of samples	Standard deviation	Coefficient of determination (R^2)	Root-mean-square standard error
1	05520500	Kankakee River at Momence, Ill.	12/16/77–11/25/96	251	0.12	198	59.6	53.8	132
2	05525000	Iroquois River at Iroquois, Ill.	1/25/78–11/25/96	79.8	.12	162	32.9	78.5	56.3
2	05525500	Sugar Creek near Milford, Ill.	10/11/78–11/25/96	50.5	.11	161	24.2	74.2	46.9
4	05526000	Iroquois River near Chebanse, Ill.	10/19/78–11/25/96	261	.12	184	110	79.6	165
5	05527500	Kankakee River near Wilmington, Ill.	4/30/80–11/25/96	655	.13	165	269	69.8	495
6	05527800	Des Plaines River at Russell, Ill.	11/17/77–11/18/96	15.0	.12	186	0.5	76.7	0.7
7	05528000	Des Plaines River near Gurnee, Ill.	10/29/80–11/18/96	85.7	.37	150	58.9	43.9	77.4
8	05529000	Des Plaines River near Des Plaines, Ill.	12/19/77–12/4/96	115	.32	186	59.7	68.1	53.2
10	05531500	Salt Creek at Western Springs, Ill.	12/14/77–12/9/96	126	1.10	195	92.2	75.4	51.6
11	05532000	Addison Creek at Bellwood, Ill.	6/18/79–12/9/96	8.61	.48	174	2.25	63	4.6
12	05532500	Des Plaines River at Riverside, Ill.	7/7/87–12/9/96	495	.79	104	356	70.2	523
14	05534500	North Branch Chicago River at Deerfield, Ill.	12/19/77–12/4/96	4.43	.22	186	1.5	70.2	2.5
15	05536000	North Branch Chicago River at Niles, Ill.	9/13/78–12/4/96	39.4	.39	178	14.1	63.5	18.6
17	05536275	Thorn Creek at Thornton, Ill.	6/19/79–12/30/96	73.0	.68	167	32.2	50.1	42.2
19	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill.	11/16/77–9/13/79, 10/29/84–4/9/97	11,500	--	137	299	--	--
21	05539000	Hickory Creek at Joliet, Ill.	6/14/79–12/3/96	39.7	.37	163	5.0	75.3	6.7
22	05539900	West Branch Du Page River near West Chicago, Ill.	6/18/79–12/3/96	16.2	.57	165	5.3	70.2	7.0
23	05540095	West Branch Du Page River near Warrenville, Ill.	10/28/80–12/3/96	48.2	.53	148	11.9	68.7	22.1
26	05540500	Du Page River at Shorewood, Ill.	10/18/78–11/25/96	200	0.62	212	97.1	67.8	150
28	05542000	Mazon River near Coal City, Ill.	5/2/78–9/18/95	31.4	0.07	165	11.9	84.7	28.4
29	05543500	Illinois River at Marseilles, Ill.	4/29/80–12/17/96	10,500	1.27	165	8,596	65.8	7,230
31	05548280	Nippersink Creek near Spring Grove, Ill.	12/29/77–11/18/96	34.9	0.18	181	18.6	53.2	46.8
33	05550000	Fox River at Algonquin, Ill.	11/8/77–11/19/96	210	0.15	227	51.3	31.1	128
35	05551000	Fox River at South Elgin, Ill.	10/23/89–11/19/96	227	0.15	62	99.6	42.7	128
37	05551700	Blackberry Creek near Yorkville, Ill.	10/11/78–11/26/96	9.14	0.13	172	5.4	65.7	18.9
39	05552500	Fox River at Dayton, Ill.	10/4/78–11/26/96	376	0.14	190	141	48	261

Table 6. Estimated transport of total ammonia-plus-organic (Kjeldahl) nitrogen at selected sites in the upper Illinois River Basin
[USGS, U.S. Geological Survey]

Map reference number	USGS station number	Station name	Period of record for load computations	Average annual load (tons)	Average annual yield (tons per mi^2)	Load model statistics			
						Number of samples	Standard deviation	Coefficient of determination (R^2)	Root-mean-square standard error
1	05520500	Kankakee River at Momence, Ill.	9/18/79–11/25/96	2,580	1.2	175	628	75.7	747
2	05525000	Iroquois River at Iroquois, Ill.	--	--	--	--	--	--	--
2	05525500	Sugar Creek near Milford, Ill.	--	--	--	--	--	--	--
4	05526000	Iroquois River near Chebanse, Ill.	12/5/79–8/9/90	3,100	1.48	61	1,190	95.6	1,560
5	05527500	Kankakee River near Wilmington, Ill.	4/30/80–11/25/96	7,220	1.40	163	2,480	92.7	1,850
6	05527800	Des Plaines River at Russell, Ill.	--	--	--	--	--	--	--
7	05528000	Des Plaines River near Gurnee, Ill.	--	--	--	--	--	--	--
8	05529000	Des Plaines River near Des Plaines, Ill.	--	--	--	--	--	--	--
10	05531500	Salt Creek at Western Springs, Ill.	11/15/79–12/9/96	357	3.11	166	113	82.4	72.9
11	05532000	Addison Creek at Bellwood, Ill.	--	--	--	--	--	--	22.0
12	05532500	Des Plaines River at Riverside, Ill.	7/7/87–12/9/96	1,430	2.28	103	451	78.7	723
14	05534500	North Branch Chicago River at Deerfield, Ill.	--	--	--				--
15	05536000	North Branch Chicago River at Niles, Ill.	10/15/79–12/4/96	186	1.86	161	41.8	89	46.4
17	05536275	Thorn Creek at Thornton, Ill.	--	--	--	--	--	--	--
19	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill.	10/29/84–9/13/79, 10/29/84–4/9/97	18,600	--	110	21,100	--	--
21	05539000	Hickory Creek at Joliet, Ill.	--	--	--	--	--	--	--
22	05539900	West Branch Du Page River near West Chicago, Ill.	--	--	--	--	--	--	--
23	05540095	West Branch Du Page River near Warrenville, Ill.	--	--	--	--	--	--	
26	05540500	Du Page River at Shorewood, Ill.	8/13/81–9/12/90	680	2.10	54	213	80.9	373
28	05542000	Mazon River near Coal City, Ill.	--	--	--	--	--	--	--
29	05543500	Illinois River at Marseilles, Ill.	4/29/80–12/17/96	22,000	2.66	166	7,120	77.4	5,930
31	05548280	Nippersink Creek near Spring Grove, Ill.	3/14/79–11/18/96	204	1.06	169	76.8	82.6	48.5
33	05550000	Fox River at Algonquin, Ill.	3/13/79–11/19/96	1,790	1.28	183	471	83.1	316
35	05551000	Fox River at South Elgin, Ill.	10/23/89–11/19/96	2,000	1.29	62	628	93	215
37	05551700	Blackberry Creek near Yorkville, Ill.	2/6/79–11/26/96	77.1	1.10	166	40.0	89.8	31.0
39	05552500	Fox River at Dayton, Ill.	4/25/79–11/26/96	4,700	1.78	188	1,770	75.6	1,390

Table 7. Estimated transport of total nitrite-plus-nitrate nitrogen in the upper Illinois River Basin
[USGS, U.S. Geological Survey]

Map reference number	USGS station number	Station name	Period of record for load computations	Average annual load (tons)	Average annual yield (tons per mi^2)	Load model statistics			
						Number of samples	Standard deviation	Coefficient of determination (R^2)	Root-mean-square standard error
1	05520500	Kankakee River at Momence, Ill.	12/16/77–11/25/96	5,600	2.67	200	1,540	89.1	1,430
2	05525000	Iroquois River at Iroquois, Ill.	10/11/78–11/25/96	6,200	9.05	162	2,190	96.1	1,850
2	05525500	Sugar Creek near Milford, Ill.	10/11/78–11/25/96	4,250	9.52	166	1,550	95.1	1,570
4	05526000	Iroquois River near Chebanse, Ill.	10/19/78–11/25/96	18,900	9.06	185	6,320	95.6	5,521
5	05527500	Kankakee River near Wilmington, Ill.	4/30/80–11/25/96	32,800	6.37	170	12,300	90.8	11,300
6	05527800	Des Plaines River at Russell, Ill.	11/17/77–11/18/96	477	3.88	179	121	94.1	21.1
7	05528000	Des Plaines River near Gurnee, Ill.	10/29/80–11/18/96	987	4.26	150	257	70.6	289
8	05529000	Des Plaines River near Des Plaines, Ill.	12/19/77–12/4/96	1,310	3.64	186	285	80.9	249
10	05531500	Salt Creek at Western Springs, Ill.	12/14/77–12/9/96	776	6.74	195	166	65	144
11	05532000	Addison Creek at Bellwood, Ill.	6/18/79–12/9/96	81.7	4.56	176	19.2	71.1	27.3
12	05532500	Des Plaines River at Riverside, Ill.	7/7/87–12/9/96	2,560	4.07	104	297	76.7	333
14	05534500	North Branch Chicago River at Deerfield, Ill.	12/19/77–12/4/96	28.4	1.44	187	12.8	84.8	15.8
15	05536000	North Branch Chicago River at Niles, Ill.	9/13/78–12/4/96	341	3.41	180	66.4	64	92.4
17	05536275	Thorn Creek at Thornton, Ill.	6/19/79–12/30/96	391	3.62	167	47.9	71.4	84.1
19	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill.	11/17/77–9/13/79, 10/29/84–4/9/97	19,900	--	137	27,400	--	--
21	05539000	Hickory Creek at Joliet, Ill.	6/14/79–12/3/96	332	3.10	163	90.5	92.8	199
22	05539900	West Branch Du Page River near West Chicago, Ill.	6/18/79–12/3/96	222	7.79	165	30.8	70.2	33.1
23	05540095	West Branch Du Page River near Warrenville, Ill.	10/28/80–12/3/96	493	5.46	148	67.6	82	60.5
26	05540500	Du Page River at Shorewood, Ill.	10/18/78–11/25/96	1,890	5.85	212	414	85.8	328
28	05542000	Mazon River near Coal City, Ill.	5/2/78–9/18/95	5,070	11.14	165	1,790	96.4	1,930
29	05543500	Illinois River at Marseilles, Ill.	4/29/80–12/17/96	51,900	6.29	165	12,400	87.8	10,900
31	05548280	Nippersink Creek near Spring Grove, Ill.	12/29/77–11/18/96	560	2.92	186	256	90.7	142
33	05550000	Fox River at Algonquin, Ill.	11/8/77–11/19/96	2,560	1.83	224	1,130	82.3	1,290
35	05551000	Fox River at South Elgin, Ill.	10/23/89–11/19/96	2,860	1.84	62	1,020	77.4	991
37	05551700	Blackberry Creek near Yorkville, Ill.	12/14/77–11/26/96	241	3.43	186	90.5	92.1	65.2
39	05552500	Fox River at Dayton, Ill.	10/4/78–11/26/96	13,200	4.98	195	4,870	79.7	6,470

Table 8. Estimated transport of total phosphorus in the upper Illinois River Basin, 1978–97
[USGS, U.S. Geological Survey]

Map reference number	USGS station number	Station name	Period of record for load computations	Average annual load (tons)	Average annual yield (tons per mi^2)	Load model statistics			
						Number of samples	Standard deviation	Coefficient of determination (R^2)	Root-mean-square standard error
1	05520500	Kankakee River at Momence, Ill.	1/19/78–11/25/96	266	0.13	183	75.2	69.3	71.6
2	05525000	Iroquois River at Iroquois, Ill.	4/10/84–11/25/96	108	.16	113	38.6	90.9	52.1
2	05525500	Sugar Creek near Milford, Ill.	7/30/81–11/25/96	150	.34	113	84.2	93.2	157
4	05526000	Iroquois River near Chebanse, Ill.	10/19/78–11/25/96	545	.26	155	269	94	232
5	05527500	Kankakee River near Wilmington, Ill.	10/22/80–11/25/96	1,050	.20	168	462	84.1	490
6	05527800	Des Plaines River at Russell, Ill.	12/29/77–11/18/96	18.0	.15	133	4.8	92.7	4.4
7	05528000	Des Plaines River near Gurnee, Ill.	8/12/81–11/18/96	77.1	.33	126	26.8	30.6	31.8
8	05529000	Des Plaines River near Des Plaines, Ill.	1/18/78–12/4/96	150	.42	129	26.4	64.8	39.8
10	05531500	Salt Creek at Western Springs, Ill.	1/22/80–12/9/96	148	1.29	133	9.1	38	25.4
11	05532000	Addison Creek at Bellwood, Ill.	6/18/79–12/9/96	16.0	.89	141	3.0	74.7	5.6
12	05532500	Des Plaines River at Riverside, Ill.	7/7/87–12/9/96	419	.67	104	49.3	67.3	69.0
14	05534500	North Branch Chicago River at Deerfield, Ill.	3/15/78–12/4/96	3.3	.17	156	1.2	91.5	1.4
15	05536000	North Branch Chicago River at Niles, Ill.	9/13/78–12/4/96	71.1	.71	150	15.1	68.1	19.2
17	05536275	Thorn Creek at Thornton, Ill.	7/24/79–12/30/96	202	1.87	126	20.5	24.6	82.9
19	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill.	1/19/78–2/6/79, 10/29/84–4/9/97	4,300	--	119	3,350	--	--
21	05539000	Hickory Creek at Joliet, Ill.	6/14/79–12/3/96	37.8	.35	127	13.0	85.5	19.2
22	05539900	West Branch Du Page River near West Chicago, Ill.	6/18/79–12/3/96	48.3	1.70	128	6.6	62.3	8.6
23	05540095	West Branch Du Page River near Warrenville, Ill.	8/12/81–12/3/96	89.7	.99	124	7.5	63.3	10.4
26	05540500	Du Page River at Shorewood, Ill.	11/16/78–11/25/96	295	.91	169	53.5	71.2	67.7
28	05542000	Mazon River near Coal City, Ill.	6/20/78–9/18/95	119	.26	111	66.4	92.5	129
29	05543500	Illinois River at Marseilles, Ill.	4/29/80–12/17/96	4,680	.57	166	1,120	83.5	1,040
31	05548280	Nippersink Creek near Spring Grove, Ill.	12/29/77–11/18/96	34.5	.18	180	23.2	71.8	38.3
33	05550000	Fox River at Algonquin, Ill.	11/08/77–11/19/96	175	.12	222	48.6	72.1	42.0
35	05551000	Fox River at South Elgin, Ill.	10/23/89–11/19/96	252	.16	62	61.4	81.6	45.5
37	05551700	Blackberry Creek near Yorkville, Ill.	12/14/77–11/26/96	15.0	.21	186	15.9	87.4	28.6
39	05552500	Fox River at Dayton, Ill.	10/23/78–11/26/96	726	.27	195	262	77.3	215

Table 9. Estimated transport of dissolved phosphorus in the upper Illinois River Basin, 1978–97

[USGS, U.S. Geological Survey]

Map reference number	USGS station number	Station name	Period of record for load computations	Average annual load (tons)	Average annual yield (tons per mi^2)	Load model statistics			
						Number of samples	Standard deviation	Coefficient of determination (R^2)	Root-mean-square standard error
1	05520500	Kankakee River at Momence, Ill.	10/1/79–4/24/97	79.5	0.20	158	18.5	54.3	26.9
2	05525000	Iroquois River at Iroquois, Ill.	4/10/84–4/23/97	62.4	.52	116	24.2	89.5	52.1
2	05525500	Sugar Creek near Milford, Ill.	4/10/1984–4/23/97	58.5	.72	115	209	89.3	66.2
4	05526000	Iroquois River near Chebanse, Ill.	12/5/79–4/24/97	231	.60	132	106	91.2	110
5	05527500	Kankakee River near Wilmington, Ill.	11/19/81–4/4/97	461	.52	148	269	79.3	335
6	05527800	Des Plaines River at Russell, Ill.	8/12/81–4/30/97	10.9	.48	123	4.4	91.5	4.1
7	05528000	Des Plaines River near Gurnee, Ill.	8/12/81–4/30/97	76.4	1.85	126	11.8	8.3	32.3
8	05529000	Des Plaines River near Des Plaines, Ill.	8/12/81–12/4/96	105	1.65	116	16.0	45	26.0
10	05531500	Salt Creek at Western Springs, Ill.	1/22/80–4/7/97	148	7.28	136	9.0	37.2	24.8
11	05532000	Addison Creek at Bellwood, Ill.	8/13/81–12/9/96	11.1	3.50	116	1.3	69.8	2.5
12	05532500	Des Plaines River at Riverside, Ill.	7/7/87–12/9/96	423	3.78	104	157	44.9	784
14	05534500	North Branch Chicago River at Deerfield, Ill.	9/19/79–12/04/96	1.6	.44	113	0.5	85.9	0.8
15	05536000	North Branch Chicago River at Niles, Ill.	8/12/81–4/29/97	55.9	3.14	131	9.6	55.8	20.7
17	05536275	Thorn Creek at Thornton, Ill.	8/13/81–12/30/96	161	8.41	116	10.5	22	42.9
19	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill.	7/10/84–4/9/97	3,480	--	106	2,800	--	--
21	05539000	Hickory Creek at Joliet, Ill.	8/13/81–12/3/96	18.8	.97	117	4.5	77.9	6.8
22	05539900	West Branch Du Page River near West Chicago, Ill.	9/20/79–12/3/96	40.1	7.93	125	4.2	43.1	10.8
23	05540095	West Branch Du Page River near Warrenville, Ill.	8/12/81–5/5/97	72.8	4.55	128	4.8	57.3	7.9
26	05540500	Du Page River at Shorewood, Ill.	8/13/81–4/4/97	227	3.94	161	36.0	66.6	72.2
28	05542000	Mazon River near Coal City, Ill.	2/17/84–9/18/95	52.0	.64	94	36.0	89.5	43.4
29	05543500	Illinois River at Marseilles, Ill.	10/28/81–12/17/96	3,010	2.05	154	638	68.4	841
31	05548280	Nippersink Creek near Spring Grove, Ill.	11/19/79–11/18/96	14.0	.40	151	10.6	51.5	28.9
33	05550000	Fox River at Algonquin, Ill.	10/17/79–3/26/97	58.7	.24	189	18.3	37.9	34.2
35	05551000	Fox River at South Elgin, Ill.	10/23/89–3/26/97	88.8	.32	65	10.5	18.5	23.6
37	05551700	Blackberry Creek near Yorkville, Ill.	10/16/79–4/8/97	11.3	.89	150	21.6	77.5	73.7
39	05552500	Fox River at Dayton, Ill.	3/12/80–4/8/97	349	.76	173	148	60.6	232

Table 10. Estimated transport of total suspended solids at selected sites in the upper Illinois River Basin

[USGS, U.S. Geological Survey]

Map reference number	USGS station number	Station name	Period of record for load computations	Average annual load (tons)	Average annual yield (tons per mi^2)	Load model statistics			
						Number of samples	Standard deviation	Coefficient of determination (R^2)	Root-mean-square standard error
1	05520500	Kankakee River at Momence, Ill.	2/22/79–11/25/96	91,100	44	179	33,400	63.9	50,200
2	05525000	Iroquois River at Iroquois, Ill.	10/11/78–11/25/96	41,300	60	161	17,700	84.4	25,100
2	05525500	Sugar Creek near Milford, Ill.	1/19/78–11/25/96	125,000	281	174	75,200	84.2	196,000
4	05526000	Iroquois River near Chebanse, Ill.	2/22/79–11/25/96	376,000	180	174	230,000	88.6	285,000
5	05527500	Kankakee River near Wilmington, Ill.	4/30/80–11/25/96	469,000	91	167	227,000	77.7	367,000
6	05527800	Des Plaines River at Russell, Ill.	3/14/79–11/18/96	3,800	31	169	1,830	79.4	1,590
7	05528000	Des Plaines River near Gurnee, Ill.	10/29/80–11/18/96	5,910	26	149	2,120	74.2	2,635
8	05529000	Des Plaines River near Des Plaines, Ill.	3/27/79–12/4/96	17,800	49	170	7,320	82	8,380
10	05531500	Salt Creek at Western Springs, Ill.	3/5/79–12/9/96	12,800	111	178	5,150	86.1	5,330
11	05532000	Addison Creek at Bellwood, Ill.	6/18/79–12/9/96	2,240	125	176	1,210	83.1	2,910
12	05532500	Des Plaines River at Riverside, Ill.	7/7/87–12/9/96	52,700	84	95	27,000	85	38,400
14	05534500	North Branch Chicago River at Deerfield, Ill.	3/27/79–12/4/96	1,100	56	172	434	83.2	704
15	05536000	North Branch Chicago River at Niles, Ill.	10/13/78–12/4/96	8,660	87	176	3,310	85.4	4,750
17	05536275	Thorn Creek at Thornton, Ill.	6/19/79–12/30/96	14,000	130	167	8,170	88.1	9,680
19	05537000	Chicago Sanitary and Ship Canal at Lockport, Ill.	3/1/79–9/13/79, 10/29/84–4/9/97	132,000	--	119	119,000	--	--
21	05539000	Hickory Creek at Joliet, Ill.	6/14/79–12/3/96	53,000	495	162	93,700	88.4	106,000
22	05539900	West Branch Du Page River near West Chicago, Ill.	6/18/79–12/3/96	2,750	96	165	917	75.9	1,660
23	05540095	West Branch Du Page River near Warrenville, Ill.	10/28/80–12/3/96	24,800	275	147	32,700	84.1	111,000
26	05540500	Du Page River at Shorewood, Ill.	3/29/79–11/25/96	64,500	199	176	71,600	80.9	109,000
28	05542000	Mazon River near Coal City, Ill.	6/20/78–9/18/95	166,000	365	165	66,800	90.7	266,000
29	05543500	Illinois River at Marseilles, Ill.	4/29/80–12/17/96	957,000	116	182	446,000	85.8	513,000
31	05548280	Nippersink Creek near Spring Grove, Ill.	3/14/79–10/1/96	6,920	36	169	4,510	72.9	5,320
33	05550000	Fox River at Algonquin, Ill.	3/13/79–11/19/96	50,500	36	178	23,600	71.7	24,000
35	05551000	Fox River at South Elgin, Ill.	10/23/89–11/19/96	46,400	30	62	24,700	80.1	16,700
37	05551700	Blackberry Creek near Yorkville, Ill.	3/21/79–11/26/96	7,440	106	169	10,300	79.7	15,900
39	05552500	Fox River at Dayton, Ill.	10/4/78–11/26/96	331,000	125	186	257,000	77.4	306,000

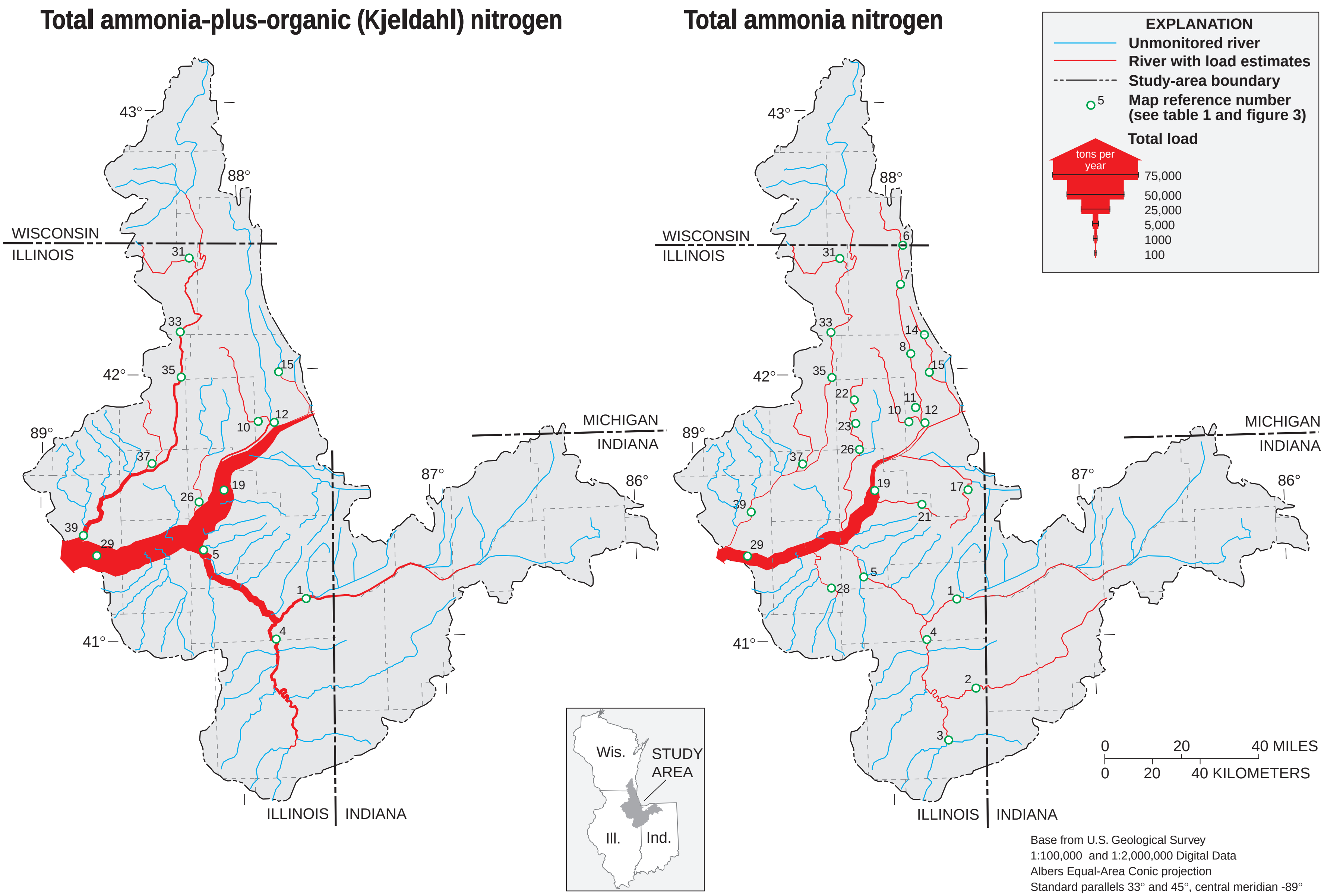


Figure 15. Estimated annual load of total ammonia-plus-organic (Kjeldahl) nitrogen (left) and estimated annual load of total ammonia nitrogen (right) in streams of the upper Illinois River Basin, 1978–97.

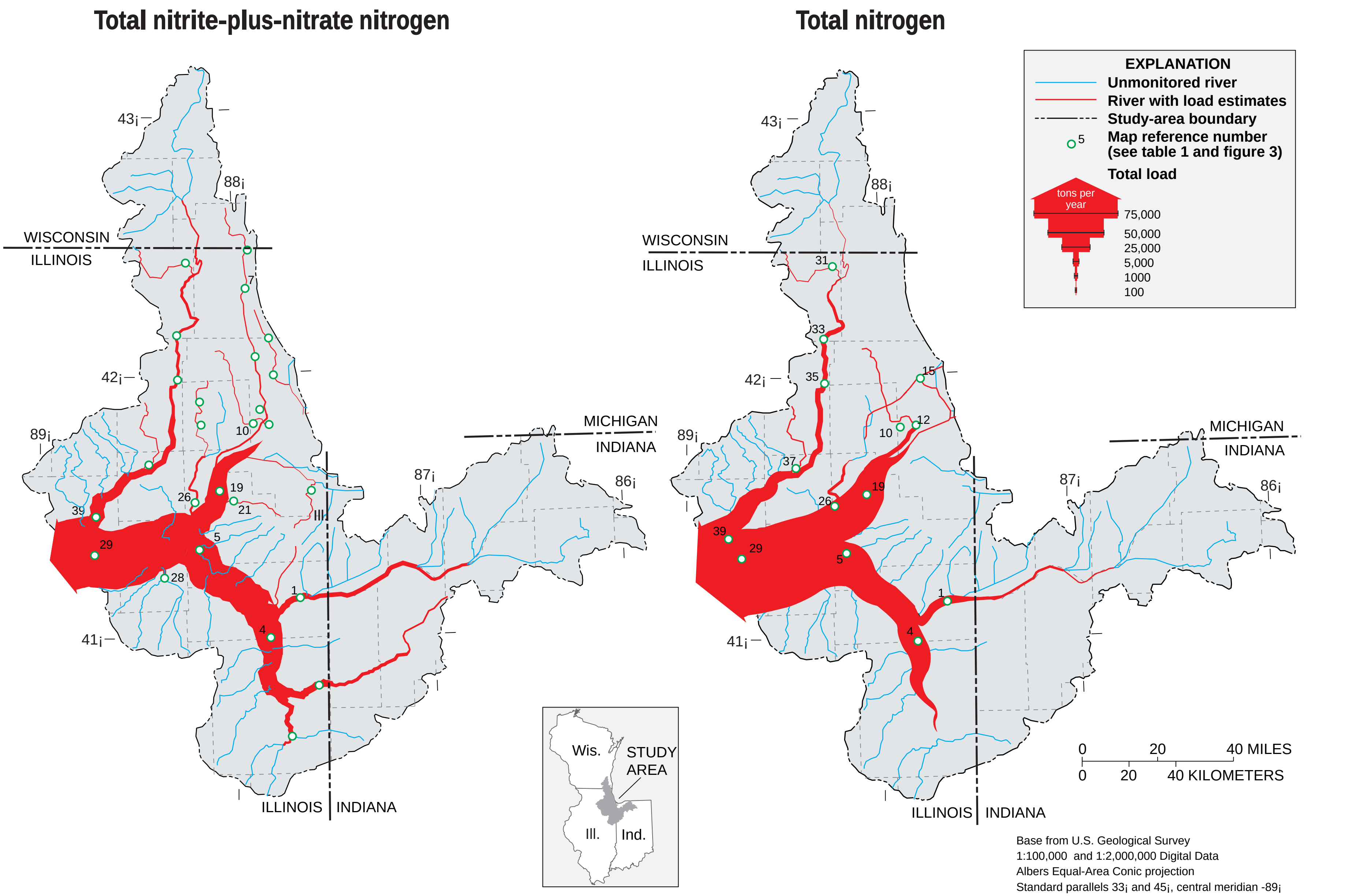


Figure 16. Estimated annual load of total nitrite-plus-nitrate nitrogen (left) and estimated load of total nitrogen (right) in streams of the upper Illinois River Basin, 1978–97.

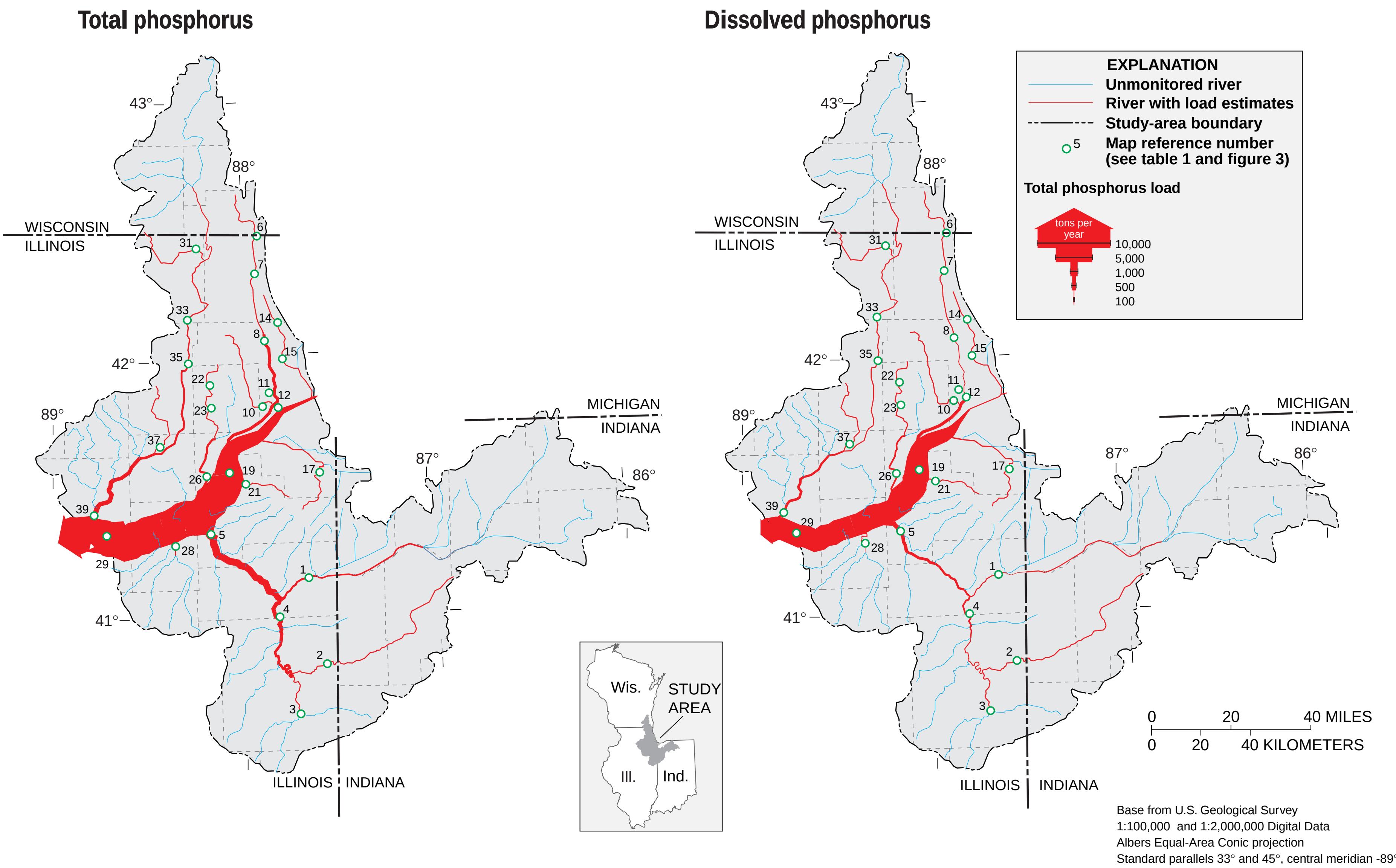


Figure 17. Estimated annual load of total phosphorus (left) and dissolved phosphorus (right) in streams of the upper Illinois River Basin, 1978–97.

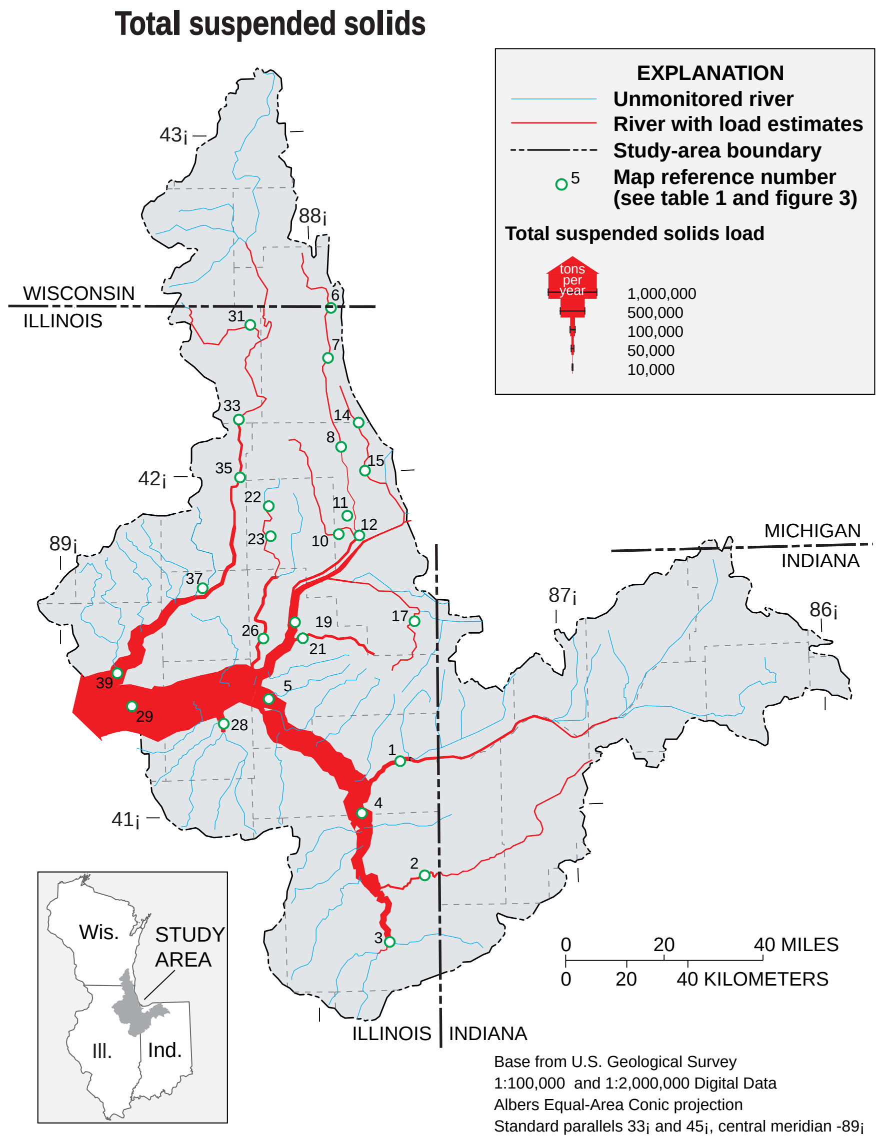


Figure 18. Estimated annual load of total suspended solids in streams of the upper Illinois River Basin, 1978–97.

more prone to erosion. These results are similar to results from a study of suspended-sediment loading in the Kankakee River Basin done during 1993–95, where 86 percent of the suspended-sediment load in the Iroquois River Basin was found to originate in the Illinois part of the basin (Holmes, 1997).

Yields of total suspended solids appear to be more strongly related to surficial deposits than to land use. Yields were highest at Hickory Creek (site 21) and Mazon River (28). Drainage above both sites is on poorly permeable surficial deposits, but site 21 is 32 percent urban land and site 28 is 95 percent agricultural. Other sites with high yields of total suspended solids (3, 4, 10, 11, 17, 23, 26, and 39) are also below drainages of poorly permeable soils or have significant input from streams draining poorly permeable soils, but with land use ranging from 99 percent agricultural (site 3) to 98.5 percent urban (site 11).

Loads and yields of nitrogen and phosphorus from the upper Illinois River Basin were compared to results from other NAWQA study areas in the upper Midwest (figs. 19–20). Yields from the upper Illinois River Basin are the highest of all the basins shown for nitrate, total nitrogen, and total phosphorus. Loads were greater for nitrate and total nitrogen from the upper Mississippi River Basin NAWQA study area, but the drainage area is about 4 times larger than that of the upper Illinois River Basin, whereas nitrate loads are not quite twice as great, and total nitrogen is slightly more than 2 times higher. These results correspond closely with recent work done by Goolsby and others (1999) indicating that yields at the Illinois River at Marseilles (site 29) are highest for nitrate, total nitrogen, total phosphorus, and orthophosphorus (the main component of dissolved phosphorus).

TRENDS IN WATER QUALITY, 1978–97

Results of the trend analyses are listed in table 11. Data were adequate for trend analyses at all sites for all constituents with the exception of total Kjeldahl nitrogen. For this constituent, data at 15 sites were insufficient for computing trends. The table lists only trend-analysis results that were significant at the 0.1 probability level.

The data listed in table 11 indicate significant downward trends of ammonia concentrations at 25 sites in the study area (fig. 21). The slopes of these trends were greater than 5 percent per year in many cases, and greater than 10 percent in a few cases. A significant upward trend was found at one site in the Fox River Basin (Blackberry Creek near Yorkville, site 37), although the magnitude is small.

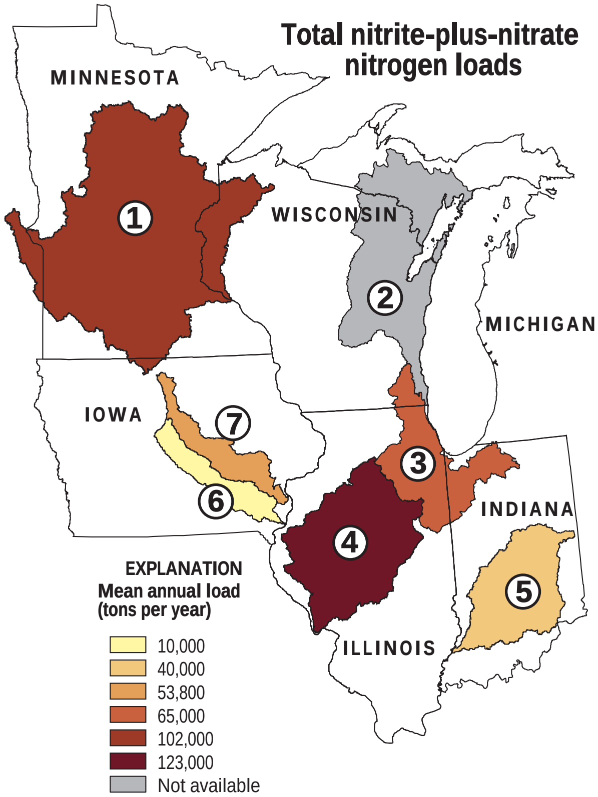
Analyses of Kjeldahl nitrogen data indicate significant downward trends at 10 sites (fig. 22), nine of which reflect the ammonia results described previously. Five of these sites are on the main stem of the Fox River, and four are in the Des Plaines River Basin. An upward trend was found at a tributary of the Fox River (Nippersink Creek, site 31).

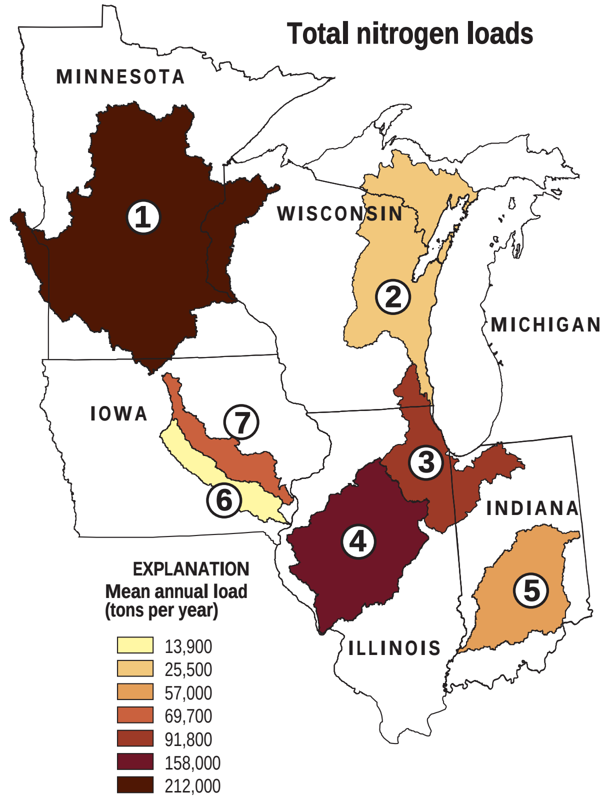
Analyses of nitrate data indicated a significant upward trend at 18 sites, mostly at urban sites within the Des Plaines River Basin (fig. 23). Downward trends were found at only three sites. No trends were detected at the most downstream sites of the Fox, Kankakee, Des Plaines, and Illinois Rivers.

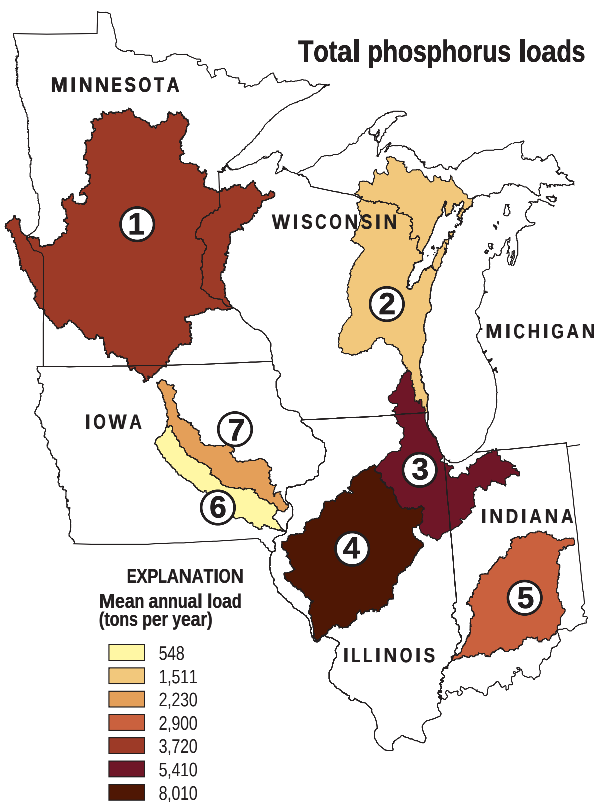
The nitrate trends results are consistent with findings of Smith and others (1987) showing a predominance of nitrate uptrends in the upper Midwest; however, however, more recent findings by Smith and others (1993) indicate fewer uptrends, although several sites in the upper Midwest continue to show upward trends in the later study.

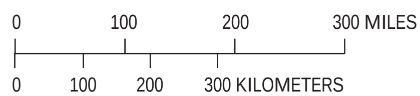
Comparison of trend results for nitrate and ammonia indicate a possible inverse relation between the two forms of nitrogen. Most ammonia trends were downward, whereas most nitrate trends were upward. At 14 sites, significant trends were observed in both constituents; at 12 of these, the trends were upward for nitrate and downward for ammonia. This apparent relation is consistent with nitrogen chemistry. Nitrate (the oxidized form) and ammonia (the reduced form) are interconvertible by way of oxidation-reduction reactions, including nitrification, denitrification, ammonification, and nitrogen fixation. Nitrogen gas may be an intermediate in these conversions. Such reactions are commonly facilitated by microorganisms, which gain energy as a result (Goldman and Horne, 1983, p.122). In the case of the upper Illinois River Basin, most of the sites with downward ammonia trends are downstream from urban areas and are in streams that receive treated wastewater effluent discharges. Wastewater-treatment plants commonly convert ammonia to nitrate during the treatment process. Treatment makes the discharge less toxic to fish, but does not reduce the overall nitrogen load to the stream.

Trends in total phosphorus and dissolved-phosphorus concentrations were similar and will be discussed together. The numbers of upward and downward trends were approximately equal (figs. 24 and 25). Sites with



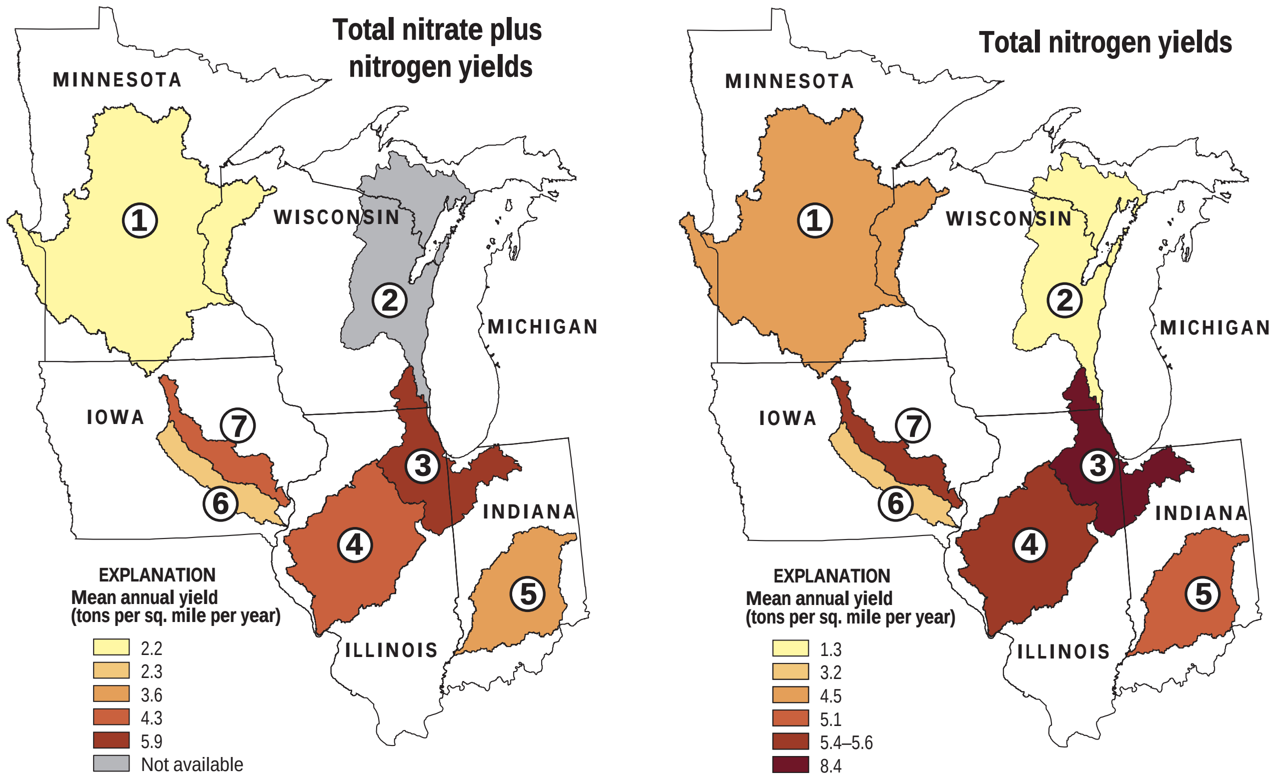


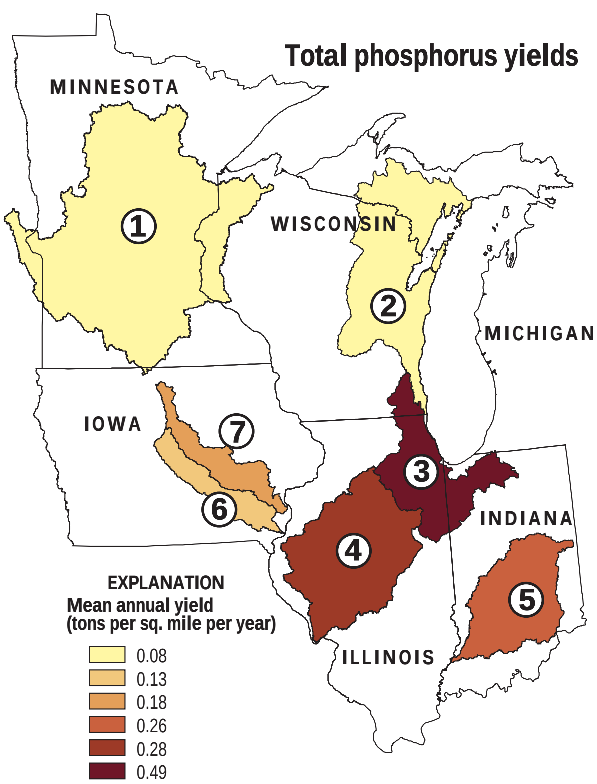


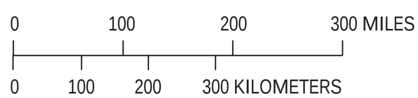


Map number	Basin name	Drainage area (square miles)	Period of record
1	Upper Mississippi River	47,300	1984–93
2	Western Lake Michigan Drainages	19,900	1971–90
3	Upper Illinois River	10,949	1978–97
4	Lower Illinois River	17,960	1978–97
5	White River	11,125	1981–90
6	Skunk River	4,303	1970–95
7	Iowa River	12,499	1970–95

Figure 19. Estimated nutrient loads from selected watersheds in the Mississippi River Basin.







Map number	Basin name	Drainage area (square miles)	Period of record
1	Upper Mississippi River	47,300	1984–93
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4	Lower Illinois River	17,960	1978–97
5	White River	11,125	1981–90
6	Skunk River	4,303	1970–95
7	Iowa River	12,499	1970–95

Figure 20. Estimated nutrient yields from selected watersheds in the Mississippi River Basin.

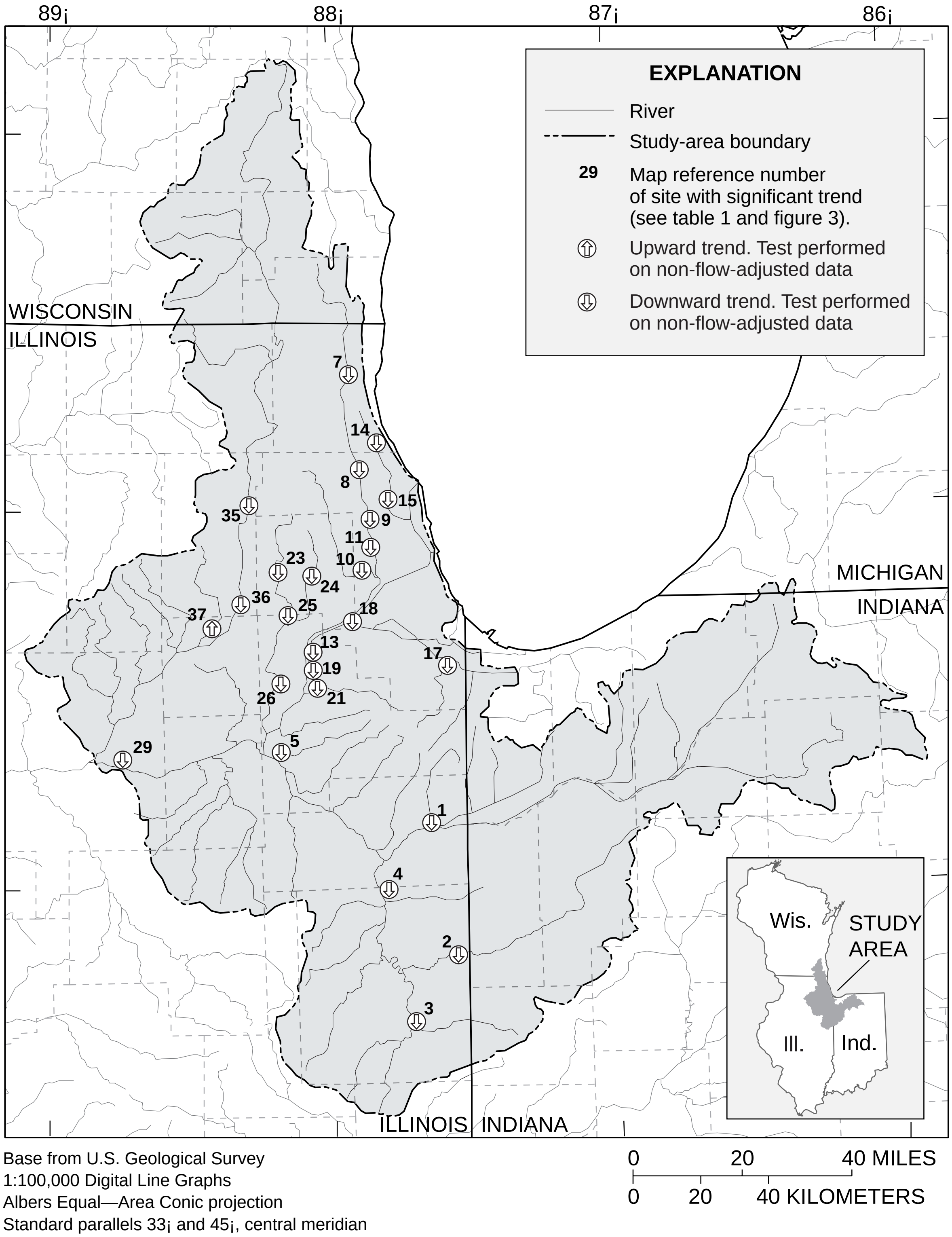


Figure 21. Trends in total ammonia nitrogen concentrations in streams of the upper Illinois River Basin, 1978–97. (Trend tests performed on non-flow-adjusted data.)

Table 11. Trend test results for selected nutrients and suspended solids at Illinois Environmental Protection Agency monitoring sites in the upper Illinois River Basin, 1978–97

[*, unable to compute flow-adjusted trends because of censoring of data; --, no trend detected; ***, insufficient flow data to compute flow-adjusted trends]

Map reference number	Station name	Direction of trend	Concentrations			Flow-adjusted concentrations		
			Probability level	Trend	Percent per year	Probability level	Trend	Percent per year
			Ammonia					
1	Kankakee River at Momence, Ill.	↓	0.004	-<0.005	-3.4	*	*	*
2	Iroquois River at Iroquois, Ill.	↓	<.0005	-.01	-5.8	*	*	*
3	Sugar Creek near Milford, Ill.	↓	<.0005	-.01	-5.8	*	*	*
4	Iroquois River near Chebanse, Ill.	↓	.087	-<.005	-2.0	*	*	*
5	Kankakee River near Wilmington, Ill.	↓	<.0005	-.01	-7.0	*	*	*
7	Des Plaines River near Gurnee, Ill.	↓	<.0005	-.04	-10.4	*	*	*
8	Des Plaines River near Des Plaines, Ill.	↓	<.0005	-.03	-7.9	*	*	*
9	Des Plaines River near Schiller Park, Ill.	↓	.001	-.02	-3.9	*	*	*
10	Salt Creek at Western Springs, Ill.	↓	<.0005	-.13	-14.0	*	*	*
11	Addison Creek at Bellwood, Ill.	↓	.040	-.01	-2.5	*	*	*
13	Des Plaines River at Lockport, Ill.	↓	<.0005	-.02	-5.6	*	*	*
14	North Branch Chicago River at Deerfield, Ill.	↓	.006	-.01	-3.4	*	*	*
15	North Branch Chicago River at Niles, Ill.	↓	<.0005	-.02	-4.8	*	*	*
17	Thorn Creek at Thonton, Ill.	↓	<.0005	-.06	-8.3	*	*	*
18	Calumet-Sag Channel near Lemont, Ill.	↓	<.0005	-.47	-11.0	*	*	*
19	Chicago Sanitary and Ship Canal at Lockport, Ill.	↓	<.0005	-.23	-8.4	*	*	*
21	Hickory Creek at Joliet, Ill.	↓	.006	-.02	-3.9	*	*	*
23	West Branch Du Page River near Warrenville, Ill.	↓	<.0005	-.03	-4.7	*	*	*
24	East Branch Du Page River at Route 34 bridge at Lisle, Ill.	↓	<.0005	-.27	-16.0	*	*	*
25	Du Page River near Naperville, Ill.	↓	<.0005	-.11	-12.5	*	*	*
26	Du Page River at Shorewood, Ill.	↓	.024	-.02	-4.3	*	*	*
29	Illinois River at Marseilles, Ill.	↓	<.0005	-.07	-12.6	*	*	*
32	Fox River near Crystal Lake, Ill.	↓	.081	-<.005	-2.7	*	*	*
35	Fox River at South Elgin, Ill.	↓	<.0005	-.02	-5.3	*	*	*
36	Fox River at Montgomery, Ill.	↓	.018	-.01	-3.5	*	*	*
37	Blackberry Creek near Yorkville, Ill.	↑	.060	+<.005	+2.7	*	*	*
			Total Kjeldahl nitrogen					
1	Kankakee River at Momence, Ill.	↓	--	--	--	.036	-<.005	-.49
10	Salt Creek at Western Springs, Ill.	↓	<.0005	-.08	-3.3	<.0005	-.08	-3.64
15	North Branch Chicago River at Niles, Ill.	↓	.013	-.02	-1.1	.009	-.02	-1.26
18	Calumet-Sag Channel near Lemont, Ill.	↓	<.0005	-.38	-6.6	***	***	***
19	Chicago Sanitary and Ship Canal at Lockport, Ill.	↓	<.0005	-.18	-4.9	***	***	***
31	Nippersink Creek near Spring Grove, Ill.	↑	.008	+.02	+1.3	.003	+.02	+1.33
32	Fox River near Crystal Lake, Ill	↓	.018	-.02	-1.4	***	***	***
33	Fox River at Algonquin, Ill.	↓	.013	-.02	-1.1	.003	-.02	-1.37
35	Fox River at South Elgin, Ill.	↓	.023	-.02	-1.2	***	***	***
36	Fox River at Montgomery, Ill.	↓	.095	-.01	-.8	***	***	***
39	Fox River at Dayton, Ill.	↓	.017	-.03	-1.5	.022	-.02	-1.28
			Total nitrite + nitrate nitrogen					
6	Des Plaines River at Russell, Ill.	↑	--	--	--	.019	+.06	+2.14
8	Des Plaines River near Des Plaines, Ill.	↑	.028	+.08	+1.9	.001	+.06	+1.33
9	Des Plaines River near Schiller Park, Ill.	↑	.055	+.05	+1.3	***	***	***
10	Salt Creek at Western Springs, Ill.	↑	<.0005	+.20	+2.9	<.0005	+.12	+1.82

Table 11. Trend test results for selected nutrients and suspended solids at Illinois Environmental Protection Agency monitoring sites in the upper Illinois River Basin, 1978–97—Continued

Map reference number	Station name	Direction of trend	Concentrations			Flow-adjusted concentrations		
			Probability level	Trend	Percent per year	Probability level	Trend	Percent per year
11	Addison Creek at Bellwood, Ill.	↑	.080	+.09	+1.7	.041	+.09	+1.69
14	North Branch Chicago River at Deerfield, Ill.	↓	.002	-.02	-1.9	.002	-.02	-2.11
15	North Branch Chicago River at Niles, Ill.	↑	.001	+.13	+3.4	<.0005	+.13	+3.24
17	Thorn Creek at Thonton, Ill.	↓	.065	-.07	-1.4	--	--	--
18	Calumet-Sag Channel near Lemont, Ill.	↑	<.0005	+.15	+7.9	***	***	***
19	Chicago Sanitary and Ship Canal at Lockport, Ill.	↑	<.0005	+.12	+3.5	***	***	***
21	Hickory Creek at Joliet, Ill.	↑	.022	+.03	+1.2	.085	+.02	+.85
22	West Branch Du Page River near West Chicago, Ill.	↑	--	--	--	.013	+.09	+1.17
24	East Branch Du Page River at Route 34 bridge at Lisle, Ill.	↑	<.0005	+.33	+5.1	***	***	***
25	Du Page River near Naperville, Ill.	↑	<.0005	+.20	+3.4	***	***	***
26	Du Page River at Shorewood, Ill.	↑	.002	+.10	+1.7	<.0005	+.12	+2.05
28	Mazon River near Coal City, Ill.	↑	--	--	--	.016	+.13	+1.40
30	Fox River near Channel Lake, Ill.	↑	.029	+.02	+1.1	***	***	***
31	Nippersink Creek near Spring Grove, Ill.	↑	--	--	--	.027	+.03	+1.15
33	Fox River at Algonquin, Ill.	↑	--	--	--	.006	+.02	+1.68
35	Fox River at South Elgin, Ill.	↑	<.0005	+.03	+2.0	***	***	***
38	Somonauk Creek near Sheridan, Ill.	↓	.021	-.08	-1.8	***	***	***
	Dissolved phosphorus							
2	Iroquois River at Iroquois, Ill.	↓	.065	<0.005	-2.6	*	*	*
15	North Branch Chicago River at Niles, Ill.	↑	.042	+.03	3.9	*	*	*
18	Calumet-Sag Channel near Lemont, Ill.	↑	<.0005	+.04	4.7	*	*	*
19	Chicago Sanitary and Ship Canal at Lockport, Ill.	↑	<.0005	+.02	4.0	*	*	*
20	Des Plaines River at Rte. 53 at Joliet, Ill.	↑	<.0005	+.02	3.3	*	*	*
28	Mazon River near Coal City, Ill.	↓	.082	<.005	-2.0	*	*	*
30	Fox River near Channel Lake, Ill.	↓	.007	<.005	-1.8	*	*	*
32	Fox River near Crystal Lake, Ill	↓	<.0005	<.005	-2.9	*	*	*
34	Poplar Creek at Elgin, Ill.	↓	<.0005	<.005	-3.8	*	*	*
	Total phosphorus							
14	North Branch Chicago River at Deerfield, Ill.	↓	.044	-<.005	-1.9	.026	-<.005	-1.65
15	North Branch Chicago River at Niles, Ill.	↑	.060	+.02	+2.6	<.0005	+.03	+3.08
18	Calumet-Sag Channel near Lemont, Ill.	↑	<.0005	+.03	+2.9	***	***	***
19	Chicago Sanitary and Ship Canal at Lockport, Ill.	↑	.002	+.01	+2.0	***	***	***
24	East Branch Du Page River at Route 34 bridge at Lisle, Ill.	↓	.001	-.06	-4.4	***	***	***
30	Fox River near Channel Lake, Ill.	↓	.011	-<.005	-1.4	***	***	***
32	Fox River near Crystal Lake, Ill	↓	.059	-<.005	-.9	***	***	***
37	Blackberry Creek near Yorkville, Ill.	↑	.074	+<.005	+1.2	.023	+<.005	+1.45
	Total suspended solids							
2	Iroquois River at Iroquois, Ill.	↓	.024	-.78	-1.6	.015	-.82	-1.66
4	Iroquois River near Chebanse, Ill.	↓	--	--	--	.005	-1.70	-2.52
6	Des Plaines River at Russell, Ill.	↓	--	--	--	.076	-.92	-2.16
13	Des Plaines River at Lockport, Ill.	↑	.007	+.80	+1.9	***	***	***
21	Hickory Creek at Joliet, Ill.	↑	.024	+.50	+1.4	--	--	--
25	Du Page River near Naperville, Ill.	↑	.059	+.60	+1.4	***	***	***
31	Nippersink Creek near Spring Grove, Ill.	↑	.011	+.67	+2.0	.005	+.76	+2.29

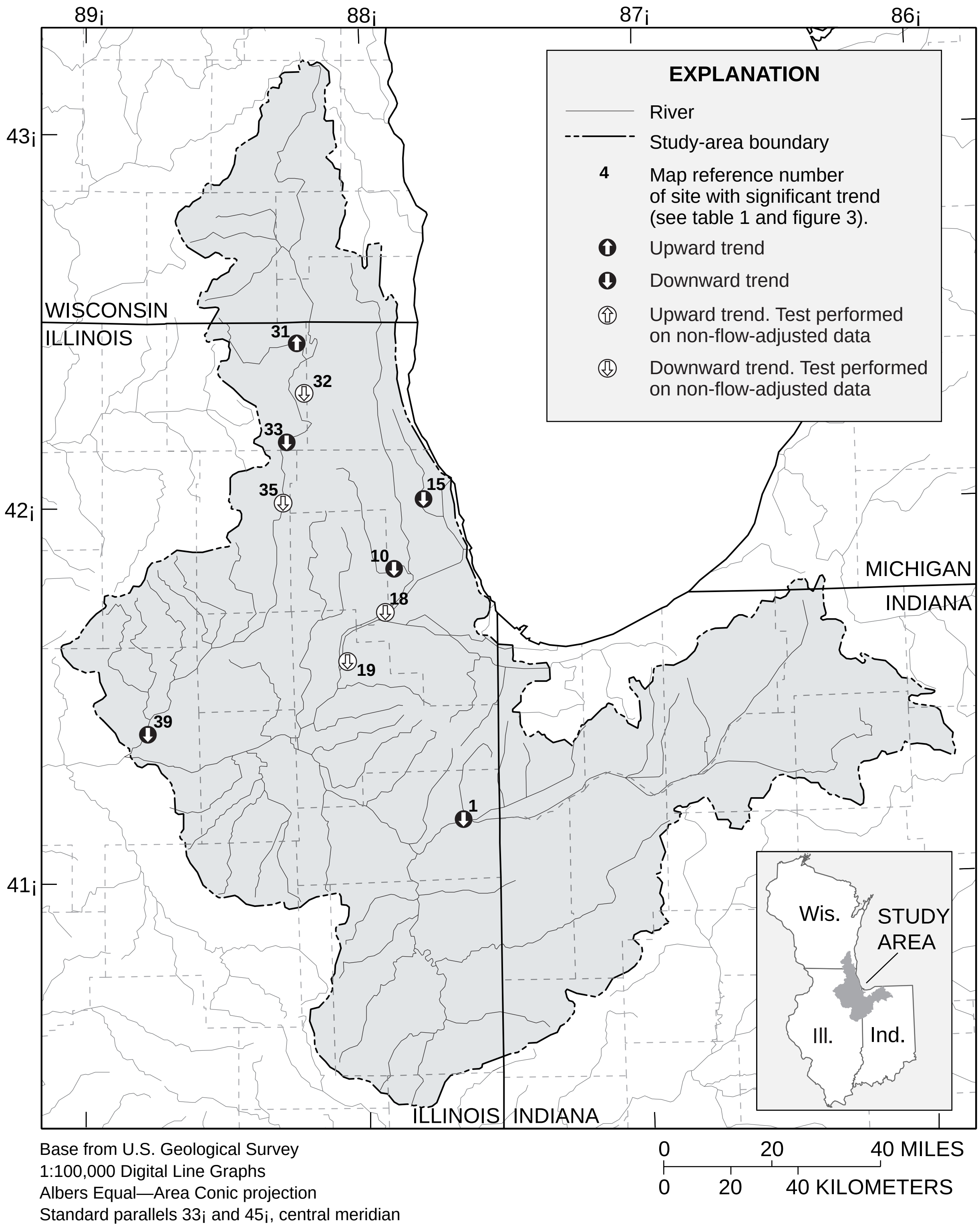
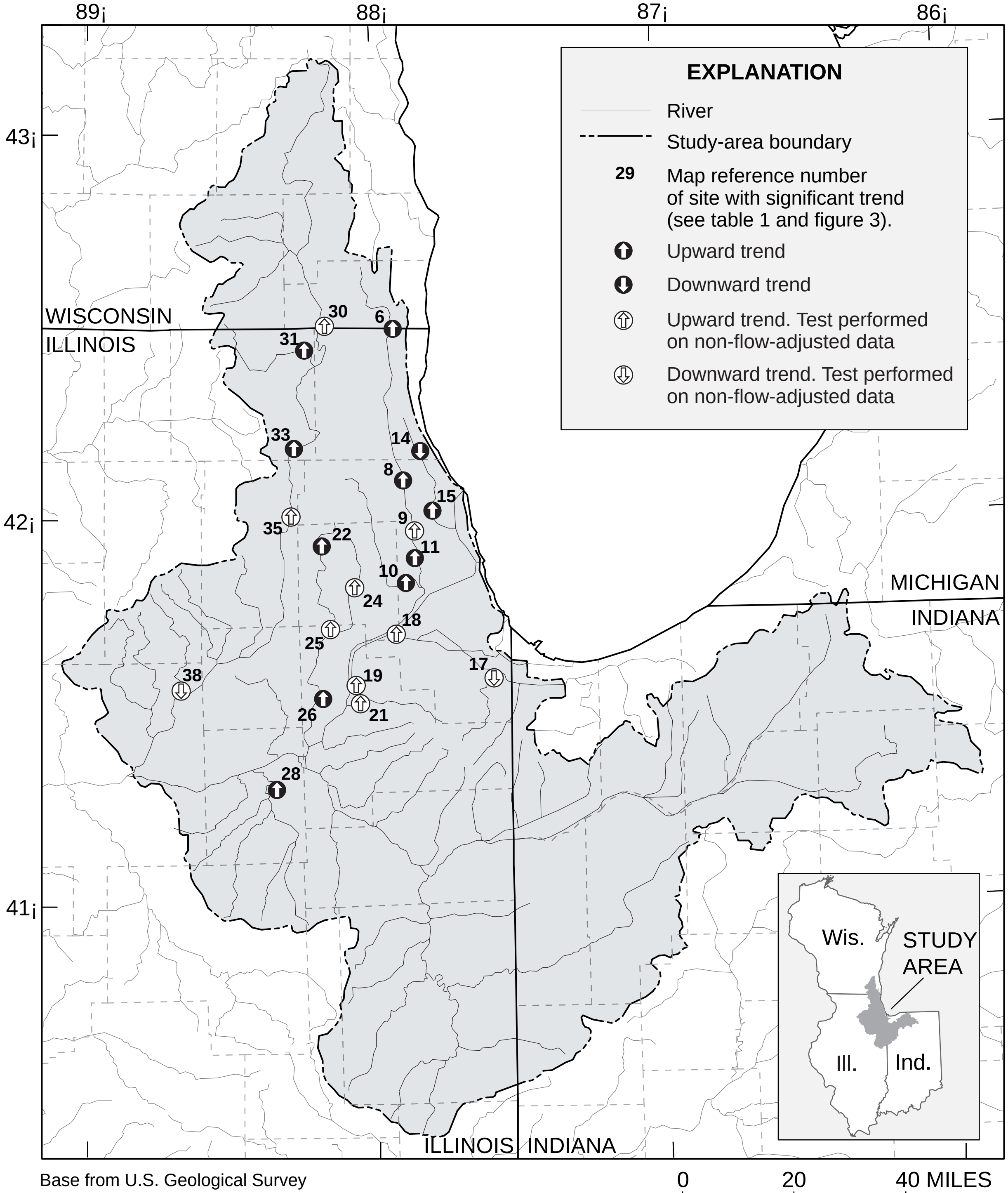


Figure 22. Trends in total ammonia-plus-organic (Kjeldahl) nitrogen in streams of the upper Illinois River Basin, 1978–97.



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

Figure 23. Trends in total nitrite-plus-nitrate nitrogen in streams of the upper Illinois River Basin, 1978–97.

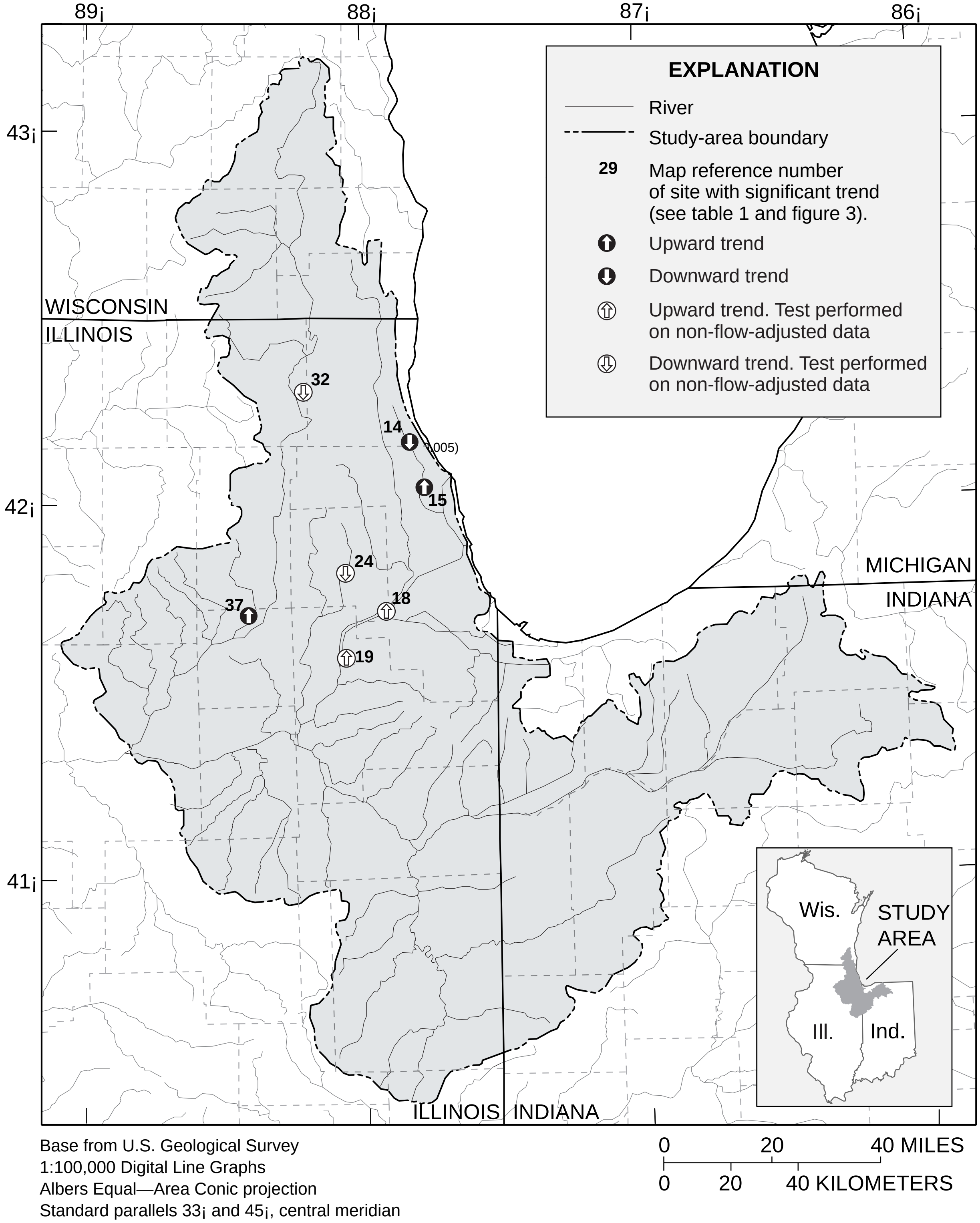


Figure 24. Trends in total phosphorus in streams of the upper Illinois River Basin, 1978–97.

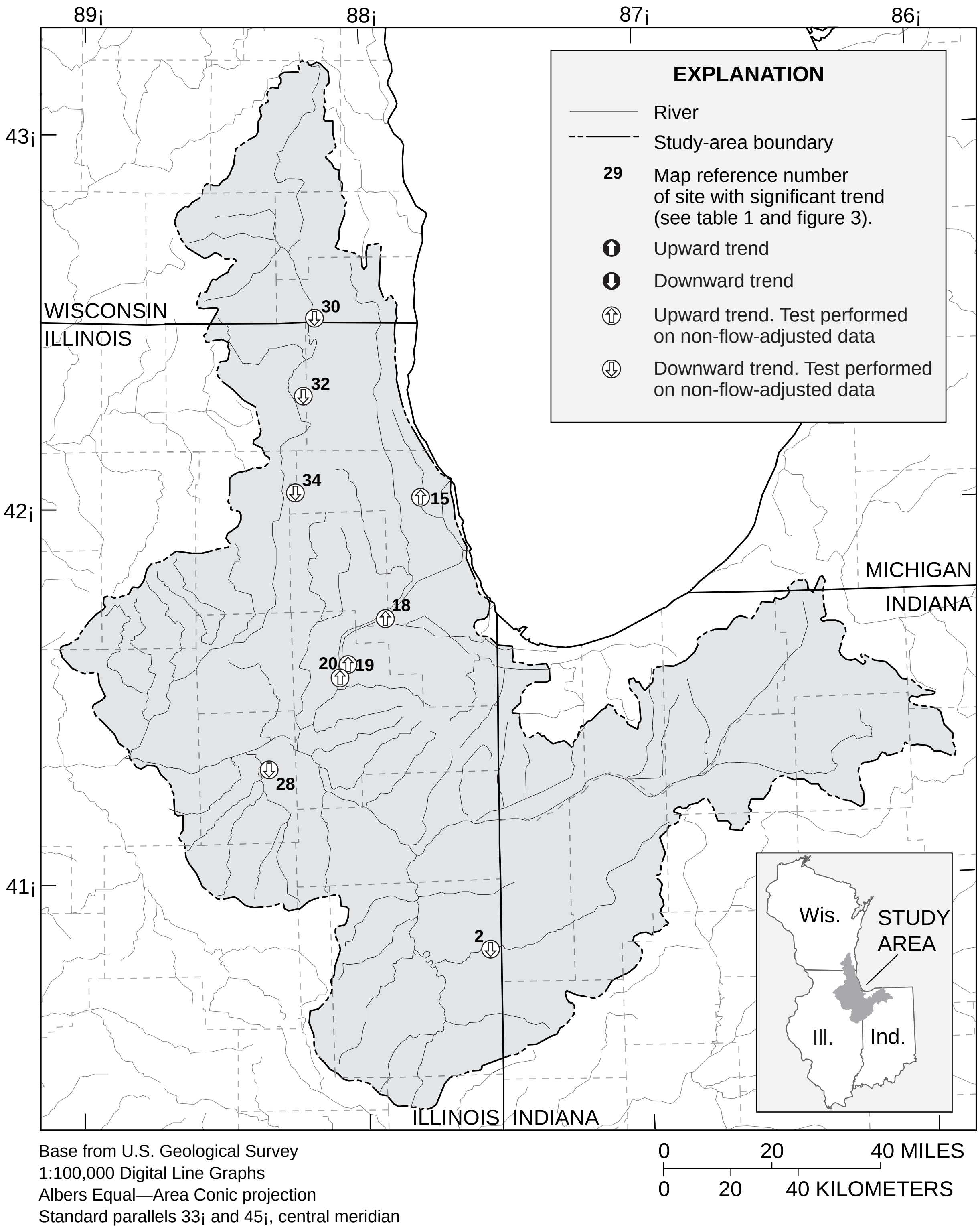


Figure 25. Trends in dissolved phosphorus in streams of the upper Illinois River Basin, 1978–97.

upward trends were all within the Des Plaines River Basin, whereas sites with downward trends were mostly in the Fox River Basin, although dissolved-phosphorus downtrends were also found at one site in the Iroquois River Basin and one site in the Illinois River. Because particulate (total) phosphorus is commonly associated with sediments (Goldman and Horne, 1983, p. 19), a decrease in suspended-solids loads could lead to a corresponding decrease in total phosphorus concentrations; however, no correspondence was found between sites with trends in total phosphorus and sites with trends in suspended solids. This lack of correspondence indicates that trends in phosphorus may have been influenced primarily by trends in the dissolved phase of phosphorus. In fact, the magnitude of trends is virtually the same for both phases of phosphorus, further evidence that changes in phosphorus concentrations are due to changes in the dissolved phase.

Trend-analysis results for suspended solids show downward trends at three sites draining agricultural areas: two in the Iroquois River Basin (sites 2 and 4) and one in the upper Des Plaines River Basin (site 6) (fig. 26). Upward trends were found at three sites in the Des Plaines River Basin (sites 13, 21, and 25) and at one site on a tributary to the Fox River (site 31). These trends seem to be localized, as evidenced by an absence of trends at the most downstream sites on all the major rivers in the study area, and by the fact that the percent change was less than 2 percent at all the sites.

In a nationwide study of water-quality trends in rivers during 1974–81, Smith and others (1987) found a general tendency for upward trends of nitrate in many areas of the country, especially east of the Mississippi River. Total phosphorus trends were nearly equally divided among increases and decreases; but within certain regions, one or the other tended to predominate. In a similar study on water-quality trends during 1982–89, Smith and others (1993) found nearly equal numbers of increases and decreases for nitrate, most areas showing no trends. During that period, total phosphorus decreased at most sites where trends were found, with a few increases mostly in the southeastern United States, whereas sites with no trends were scattered around the country.

SUMMARY AND CONCLUSIONS

The upper Illinois River Basin drains 10,949 mi^2 of Illinois, Indiana, and Wisconsin. Approximately 91 percent of the basin is drained by three principal rivers: the Kankakee (and its major tributary, the Iroquois), the Des Plaines, and the Fox. In 1990, agriculture, urban land, and forest accounted for about 75, 17, and 5 percent, respectively, of the land use in the basin.

Nutrients and siltation have been identified as the major causes of water-quality problems in Illinois. The major source of this pollution statewide is agriculture. However, the upper Illinois River Basin is unique in Illinois in that much of the greater Chicago area lies within its hydrologic boundaries. Chicago is the third-largest metropolitan area in the United States and the largest city within the Mississippi River drainage, the largest watershed in the Nation. Thus, urban sources of pollutants are also a major concern in the upper Illinois River Basin.

The hydrology of the study area has been greatly changed by human activity. Major changes include construction of navigable waterways linking Lake Michigan with the Mississippi River, and the reversal of flow of a stream, the Chicago River, that historically drained to Lake Michigan and now flows down the Illinois River. This flow reversal was done to improve the water quality of Lake Michigan, the main drinking-water supply for Chicago. The result has been an increase in flow in the Illinois River.

Long-term trends in streamflow were analyzed at seven stations that represent flow from major rivers in the study area. Results of regression analyses indicate that annual mean flows increased during the 1950–97 period at all seven stations, the annual 7-day low flow increased at five of seven stations analyzed, annual maximum flow increased at three of seven stations. Increases in flow reflect not only upward trends in precipitation but also upward trends in effluent return flows.

Among all the subareas of the upper Illinois River Basin, concentrations of nutrients were, in general, highest at streams in the urban areas of the Des Plaines River Basin during 1978–97. Streams in the Kankakee and Fox River Basins generally had lower concentrations, although there was evidence that concentrations increased downstream in these basins. Certain tributaries contained disproportionately large concentrations of certain nutrients, probably because of concentrated nutrient inputs within relatively small watersheds. Examples include nitrate in Aux Sable Creek and the Mazon River, ammonia in the Calumet-Sag Channel, and phosphorus in Thorn Creek.

These spatial patterns in nutrient concentrations correspond closely with land use in the respective

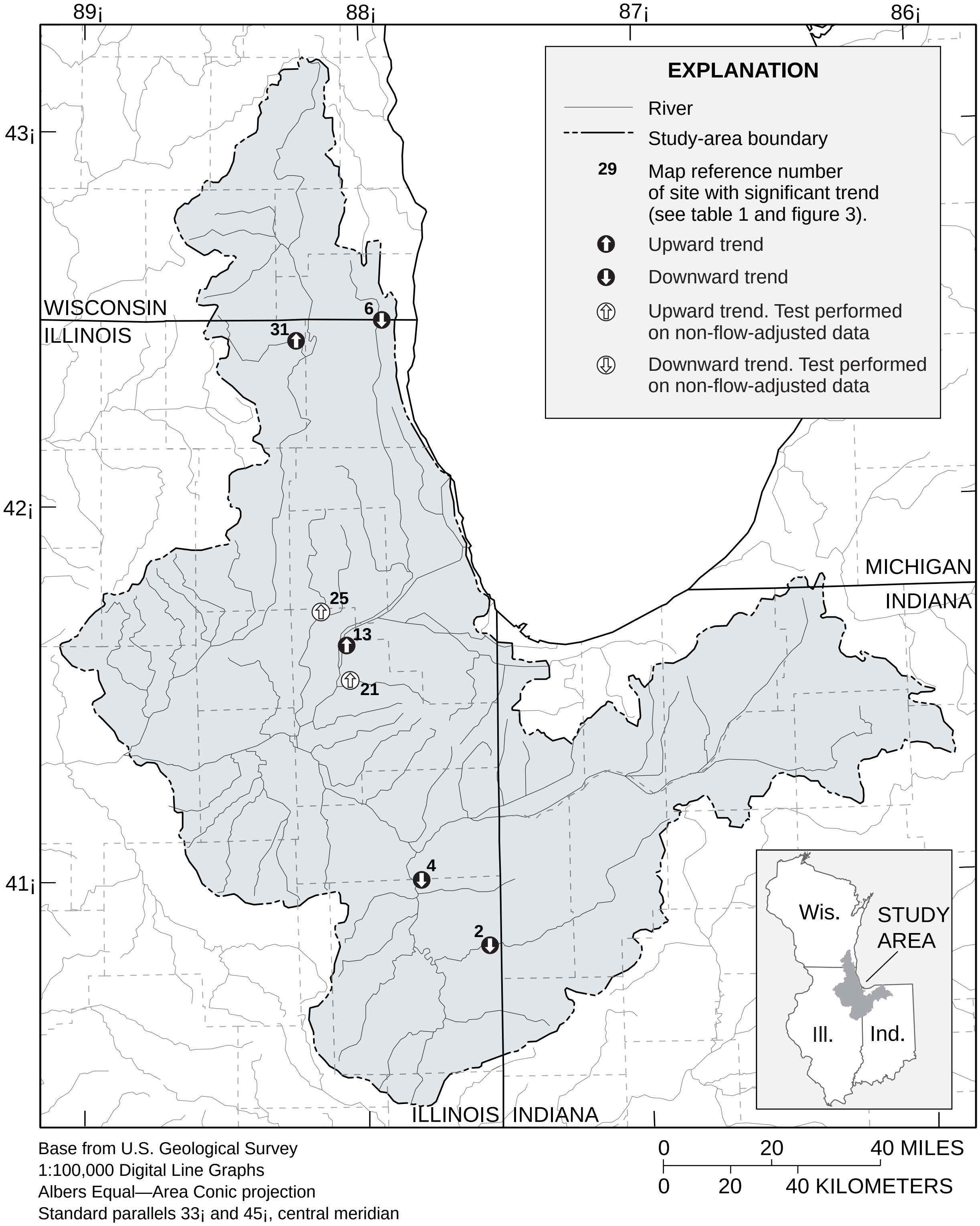


Figure 26. Trends in total suspended solids in streams of the upper Illinois River Basin, 1978–97.

basins. The elevated concentrations of ammonia and phosphorus in the urbanized Des Plaines River Basin with respect to other sites in the study area provide evidence that municipal- and industrial-waste discharges into streams of the basin increase concentrations of these nutrients in the receiving streams. In contrast, nitrate concentrations were highest in agricultural areas. Relatively large ratios of nitrogen to phosphorus and nitrate to ammonia are characteristic of agricultural drainage in comparison to urban-area drainage. The apparent, but nonuniform, correspondence of nutrient transport to urban and agricultural land use in the upper Illinois River Basin was generally consistent with findings in other river basins.

Monthly median concentrations of ammonia and nitrate were at minimum levels from July through October. Ammonia concentrations were characterized by high concentrations in the winter, depletion during the spring and summer, and minimum levels in the late summer or early fall. Nitrate concentrations were highest in the winter and early spring. Seasonal variation of phosphorus was not evident, probably because phosphorus was continually replenished as it was consumed.

The net result of nutrient inputs and transport through the river system were elevated nutrient concentrations at the most-downstream site in the study area on the Illinois River. At this site, the median concentrations of nitrate, total phosphorus, and orthophosphate were among the highest in the Mississippi River Basin, and the median concentration of ammonia was highest.

Suspended-solids concentrations do not indicate any particularly strong spatial patterns among major river basins in the study area. Instead, high suspended-solids concentrations are observed at sites draining areas of poorly permeable, easily eroded soils in both agricultural and urban areas. Seasonal variation of suspended solids were consistent at sites across the study area. In general, suspended-solids concentrations were highest in the summer and lowest in the winter. The increase during the summer can be attributed to higher streamflow and the associated increase in runoff and transport, as well as increased phytoplankton growth.

Because of the high nutrient concentrations in the upper Illinois River Basin, annual loads and yields were also large; however, yields of phosphorus from the Fox and Kankakee River Basins were not unusually high. The major contributor of total ammonia nitrogen, total Kjeldahl nitrogen, and phosphorus loads to the total study-area output was the Des Plaines River Basin, the Chicago Sanitary and Ship Canal in particular. The high concentrations in this waterway coupled with the high volume of streamflow contribute to the large load output. The high loads in the Ship Canal reflect the input from the three largest wastewater treatment plants in the study area. In contrast, nitrate loads were higher from the agricultural Kankakee River Basin. Total suspended-solids loads were also greatest from agricultural areas, in particular the Iroquois River Basin and tributaries to the lower Fox River. These are areas of intensive row-crop agriculture and fine, easily erodable soils.

The total nitrogen export from the upper Illinois River Basin for 1978–97 was 91,800 ton/yr. This figure corresponds closely with estimates of loads from urban, agricultural, and other sources, and is about 30 percent of the estimated total nitrogen input to the basin of about 300,000 ton/yr. The total phosphorus export from the study area during 1978–97 was about 5,400 ton/yr, or about 6 percent of estimated phosphorus inputs of 94,000 ton/yr. Loads and yields of nutrients from the upper Illinois River Basin are among the very highest in the entire Mississippi River drainage system.

Significant downward trends in total ammonia concentrations were observed at many sites during the period of analysis, along with correlative upward trends in nitrate. This opposite relation is consistent with the reversible capacity for transformation between the reduced form (ammonia) and the oxidized form (nitrate) and may be related to nitrification of wastewater effluents. Significant downward trends in total ammonia plus organic nitrogen were related to downward trends in ammonia concentrations. Few trends in phosphorus concentrations were observed; however, upward trends were observed at two sites downstream from major wastewater-treatment plants.

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