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Concentrations, Fluxes, and Yields of Nitrogen, Phosphorus, and Suspended Sediment in the Illinois River Basin, 1996-2000

Scientific Investigations Report 2006-5078

U.S. Department of the Interior
U.S. Geological Survey

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By Paul J. Terrio

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Front Cover: Illinois River at Naples, Illinois (photograph by Mitchell A. Harris)

FOREWORD

The U.S. Geological Survey (USGS) is committed to providing the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the quality of the Nation's water resources is critical to assuring the long-term availability of water that is safe for drinking and recreation and suitable for industry, irrigation, and habitat for fish and wildlife. Population growth and increasing demands for multiple water uses make water availability, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities.

From 1991-2001, the NAWQA Program completed interdisciplinary assessments in 51 of the Nation's major river basins and aquifer systems, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html). Baseline conditions were established for comparison to future assessments, and long-term monitoring was initiated in many of the basins. During the next decade, 42 of the 51 Study Units will be reassessed so that 10 years of comparable monitoring data will be available to determine trends at many of the Nation's streams and aquifers. The next 10 years of study also will fill in critical gaps in characterizing water-quality conditions, enhance understanding of factors that affect water quality, and establish links between sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems.

The USGS aims to disseminate credible, timely, and relevant science information to inform practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To Obtain
mile (mi.)	1.60	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per square mile per year ((ton/mi^2)/yr)	2.3496	megagram per square kilometer per year ((Mg/km^2)/yr)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton, short (2,000 lb)	0.9071	metric ton
gallon	3.785	liters (L)

Temperature, in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by use of the following equation: °C = (°F – 32) / 1.8.

ABBREVIATIONS AND ACRONYMS

C	Celsius
CSSC	Chicago Sanitary and Ship Canal
DP	dissolved phosphorus
IEPA	Illinois Environmental Protection Agency
IRB	Illinois River Basin
LIRB	Lower Illinois River Basin
mg/L	milligrams per liter
mm	millimeter
NAWQA	National Water-Quality Assessment
NH_3	ammonia
NH_3-N	ammonia nitrogen
NH_4^+	ammonium
NO_2^-	nitrite
NO_2^--N	nitrite nitrogen
NO_3^-	nitrate
NO_3^--N	nitrate nitrogen
no.	number
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
PO_4^{3-}-P	orthophosphate
QA/QC	Quality Assurance / Quality Control
TP	total phosphorus
UIRB	Upper Illinois River Basin
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey

Concentrations, Fluxes, and Yields of Nitrogen, Phosphorus, and Suspended Sediment in the Illinois River Basin, 1996-2000

By Paul J. Terrio

Abstract

Concentrations, spatial and temporal variations, and fluxes of nitrogen, phosphorus, and suspended sediment were determined for 16 streams in the Illinois River Basin, Illinois from October 1996 through September 2000. Water samples were collected through the National Water-Quality Assessment's Lower Illinois River Basin (LIRB) and Upper Illinois River Basin (UIRB) Study Units on a monthly to weekly frequency from watersheds representing predominantly agricultural and urban land, as well as areas of mixed land-use.

Streams in agricultural watersheds had high concentrations and fluxes of nitrate nitrogen, whereas streams in predominantly urban watersheds had high concentrations (above background levels) of ammonia nitrogen, organic nitrogen, and phosphorus. Median concentrations of nitrate nitrogen and total phosphorus were similar at the two Illinois River sampling stations (Illinois River at Ottawa, Ill. and Illinois River at Valley City, Ill.) that represented the downstream points of the UIRB and LIRB Study Units, respectively, and integrated multiple land-use areas.

Concentrations of nitrogen were typically highest in the spring and lowest in the fall in agricultural watersheds, but highest in the winter in urban watersheds. Phosphorus concentrations in urban watersheds were highest in the fall and winter, but there was minimal seasonal variation in phosphorus concentrations in agricultural watersheds. Concentrations of nitrate and total nitrogen were affected primarily by non-point sources and hydrologic factors such as streamflow, storm intensity, watershed configuration, and soil permeability, whereas concentrations of phosphorus were affected largely by point-source contributions that typically have little seasonal variation. Seasonal variation in hydrologic conditions was an important factor for seasonal variation in nutrient concentration.

Fluxes and yields of nitrogen and phosphorus forms varied substantially throughout the Illinois River Basin, and yields of specific nutrient forms were determined primarily by upstream land uses. Yields of nitrate nitrogen were highest in predominantly agricultural watersheds, whereas yields of phosphorus and ammonia nitrogen were highest in urban watersheds with wastewater effluent contributions. Yields of both total nitrogen and total phosphorus were similar at the two Illinois River stations representing the integrated UIRB and LIRB Study Units.

Concentrations of suspended sediment ranged from 1 to 3,110 milligrams per liter (mg/L), with median concentrations generally higher in the UIRB. Suspended-sediment concentrations were highest and most variable in the LaMoine River Basin. The median concentration of suspended sediment in the Illinois River at Valley City, Ill. (155 mg/L) was twice as high as that at Ottawa, Ill. (80 mg/L).

Fluxes of suspended sediment generally corresponded to watershed size and yields from agricultural watersheds were larger than yields from urban watersheds. The flux in the Illinois River at Valley City, Ill. (4,880,000 tons per year) was approximately four times the flux in the Illinois River at Ottawa, Ill. (1,060,000 tons per year).

Introduction

The Illinois River Basin (IRB) includes varying landscapes and land uses, ranging from large expanses of row-crop agriculture in central Illinois to densely populated and expanding urban areas in and around the greater Chicago metropolitan area. Most of this land was low-lying wetland, marsh, and prairie until the latter part of the 19th century. The past and continuing changes in land-use practices, population, and landscape modification continue to affect the quality of surface-water resources in the IRB and the suitability of these resources for natural and anthropogenic uses. Conversion of land in the IRB from its natural state to row-crop agriculture, pasture, and urban areas and the associated modifications to drainage have resulted in increased concentrations and transport of nutrients and sediment to streams, rivers, and lakes in the basin.

Nutrients (primarily nitrogen and phosphorus) and siltation are commonly cited as principal reasons why water bodies in the IRB do not fully support their designated uses (Illinois Environmental Protection Agency, 2003). Nitrogen and phosphorus are required nutrients for both terrestrial and aquatic plant and animal growth. Although these nutrients are necessary to maintain the viability of aquatic flora and fauna, excessive amounts can result in eutrophication and can limit the suitability of a water body for both natural biota and human uses. Sediment (soil and other particulate mater) is virtually always present in natural stream systems and contributes to bottom material composition, water-column turbidity, and chemical constituent transport. As with nutrients, excessive amounts of sediment can degrade water quality and can harm a stream system through physical, biological, and chemical processes.

In 1986, the U.S. Geological Survey (USGS) began a pilot study in the Upper Illinois River Basin (UIRB), as well as in several other basins across the country, to develop and test sampling techniques and assessment methods for a National Water Quality Assessment (NAWQA) Program (Schmidt and Blanchard, 1997). Incorporating the findings of the pilot studies, the USGS implemented the full-scale NAWQA Program in 1991 to assess the quality of the Nation's surface- and ground-water resources. The primary goals of the NAWQA Program are to (1) provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources, (2) define long-term 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, 1998). In 1994, the NAWQA Program began a study of surface- and ground-water quality in the Lower Illinois River Basin (LIRB). A similar study began in the UIRB in 1997. The LIRB and UIRB are 2 of more than 51 NAWQA Study Units distributed nationally to provide timely and relevant information regarding quality of the Nation's water resources. Together, the results from these two Study Units provide information on the quality of the water resources throughout the entire IRB.

Purpose and Scope

This report describes the occurrence, distribution and transport of nitrogen, phosphorus, and suspended sediment in streams and rivers of the IRB. The UIRB and LIRB were studied as separate NAWQA Study Units because of distinct differences in land-use practices, hydrology, soils, and other natural and anthropogenic factors. However, there is benefit in assessing concentrations, fluxes, and yields of these constituents using a basin-wide approach. This report provides information useful to managers of water resources in the IRB, the State of Illinois, and the Nation for addressing issues such as regulatory nutrient standards, hypoxia in the Gulf of Mexico, and water-quality best-management practices. Included in this report are data on concentrations and flux estimates for various forms of nitrogen and phosphorus, as well as suspended sediment. The data were collected primarily at 16 sites representing various watersheds and land-use areas of the IRB from 1996 to 2000.

Description of the Illinois River Basin

The Illinois River Basin emcompasses 28,949 mi^2 in central and northeast Illinois, southeast Wisconsin, northeastern Indiana, and southwestern Michigan (fig. 1). The IRB is composed of two hydrologic units: 0712 (the Upper Illinois River Basin) and 0713 (the Lower Illinois River Basin). Only a brief overview of the IRB is provided here and the reader is referred to Warner (1998) and Arnold and others (1999) for detailed descriptions of the environmental settings for the LIRB and UIRB, respectively.

The UIRB encompasses 11,000 mi^2 and extends from the headwaters in southeastern Wisconsin and southwestern Michigan to a point just below the mouth of the Fox River at Ottawa, Ill. Major subbasins in the UIRB are the Kankakee River Basin (5,165 mi^2), Fox River Basin (2,658 mi^2), Iroquois River Basin (2,137 mi^2), and Des Plaines River Basin (2,111 mi^2). A canal system routes diverted water from Lake Michigan, runoff from the Chicago area, and treated wastewater to the Illinois River from an area that had naturally and historically been part of the Lake Michigan drainage basin.

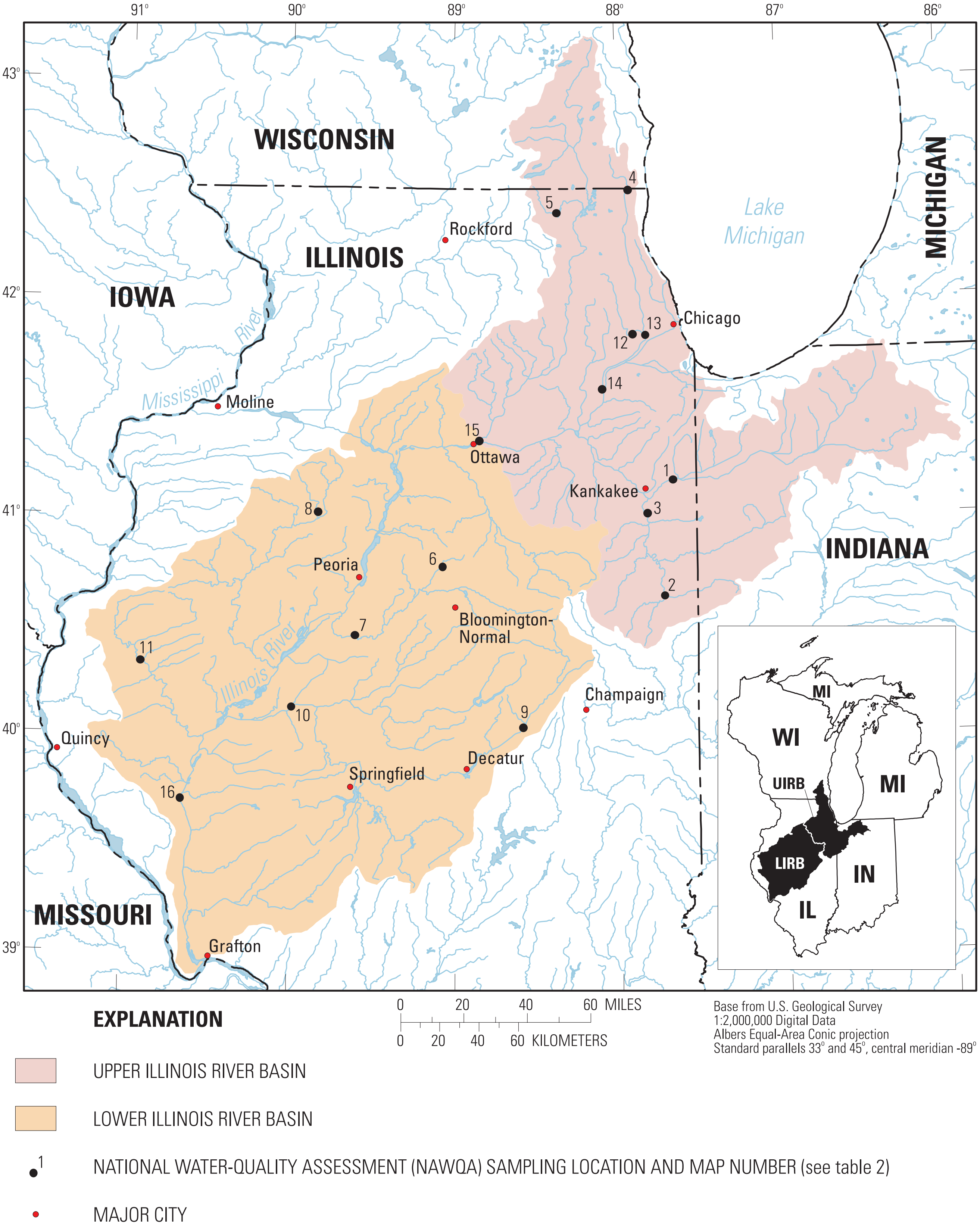


Figure 1. Location of the Illinois River Basin in Illinois, Indiana, Michigan, and Wisconsin.

The LIRB includes 18,000 mi^2 beginning just downstream of Ottawa, Ill. and extending downstream to the mouth of the Illinois River at Grafton, Ill. The major watersheds in the LIRB are the Sangamon River Basin (5,418 mi^2), Mackinaw River Basin (1,136 mi^2), LaMoine River Basin (1,350 mi^2), Spoon River Basin (1,855 mi^2), and Vermilion River Basin (1,331 mi^2). Mean annual streamflow values for the periods of record at streamgaging stations nearest the terminus of each sub-basin for the major watersheds of the IRB are presented in table 1.

The 1990 census population for the IRB was approximately 8.9 million (Arnold and others, 1999 and Warner, 1998). At that time, approximately 6 million people resided in the greater Chicago metropolitan area. Approximately 7.6 million people resided in the UIRB and 1.3 million people lived in the LIRB. The primary land uses in the IRB are agriculture (24,052 mi^2, or 83 percent of the area), urban (2,221 mi^2, or 8 percent of the area), forest (1,807 mi^2, or 6 percent of the area), and other miscellaneous uses such as wetlands, water, and barren land (868 mi^2, or 3 percent of the area).

The climate of the IRB is categorized as humid continental with cool, dry winters and warm, humid summers. The average temperature in the IRB through 2001 (the beginning year for the period of record differs among the various stations used in this analysis) ranged from 7.8°C in the north to 37.2°C in the south (National Oceanic and Atmospheric Administration, 2001). Average January temperatures were from -5.5 to -3.9°C and average July temperatures were from 22.8 to 24.4°C across the basin. Annual precipitation totals ranged from 35 to 38 inches basin wide, with marginally greater precipitation typically occurring in the southern parts of the basin. The period of record for precipitation data differs among the stations used in this analysis.

Streamflow conditions varied among the respective sampling periods of the UIRB and LIRB studies. The 1985-2002 mean annual streamflow for each NAWQA sampling station is shown in table 2. In general, streamflow in the LIRB in 1997 was less than the 1985-2002 (long-term) mean, but streamflow was greater than the long-term mean in 1998. For the UIRB, streamflows in 1999 were marginally less than the long-term mean in the Kankakee River Basin and approximately equal to the long-term mean in the Des Plaines River Basin. In 2000, streamflow in the UIRB typically amounted to less than 50 percent of the 1985-2002 mean in the Kankakee River Basin, near the 1985-2002 mean in the lower Des Plaines Basin, and slightly greater than the 1985-2002 mean in the upper Des Plaines Basin.

Most of the IRB lies within two physiographic sections, the Great Lakes Section and the Till Plains Section (fig. 2). Various soil types are present within the IRB, ranging from fine-grained, low-permeability soils with greater than 20 percent organic material in the Fox and Des Plaines River basins to highly permeable sandy soils in the Kankakee River Basin and along some reaches of the Illinois River. Most soils within the IRB have low to moderate permeability and subsurface tile drainage is present in much of the basin to facilitate row-crop agriculture.

Nutrients and Sediment in the Illinois River Basin

Nitrogen and phosphorus are required nutrients for both terrestrial and aquatic plant and animal

Table 1. Mean annual streamflow at gaging stations representing the major watersheds in the Illinois River Basin, 1985-2000.

Station Name	U.S. Geological Survey Station Number	Drainage Area (square miles)	Mean Annual Streamflow 1985-2000 (cubic feet per second)
Fox River at Dayton, Ill.	05552500	2,642	1,820
Des Plaines River at Riverside, Ill.	05532500	630	560
Kankakee River near Wilmington, Ill.	05527500	5,150	4,750
Iroquois River near Chebanse, Ill.	05526000	2,091	1,750
Chicago Sanitary and Ship Canal at Romeoville, Ill.	05536995	739	3,410
Vermilion River near Leonore, Ill.	05555300	1,251	1,070
LaMoine River at Colmar, Ill.	05584500	655	850
Sangamon River near Oakford, Ill.,	05583000	5,093	3,500
Spoon River at Seville, Ill.	05570000	1,636	1,110
Mackinaw River near Green Valley, Ill.	05568000	1,073	725

Table 2. National Water-Quality Assessment sampling stations in the Illinois River Basin, 1996-2000.

Station Name	Abbreviated Station Name	U.S. Geological Survey Station Number	Map Number (Fig. 2)	Drainage Area (square miles)	Mean Annual Streamflow, 1985-2000 (cubic feet per second)	Predominant Land Use
Upper Illinois River Basin Study Unit						
Kankakee River at Momence, Ill.	Kankakee River	05520500	1	2,294	2,080	Agriculture
Sugar Creek at Milford, Ill.	Sugar Creek	05525500	2	446	379	Agriculture
Iroquois River near Chebanse, Ill.	Iroquois River	05526000	3	2,091	1,740	Agriculture
Des Plaines River at Russell, Ill.	Des Plaines River at Russell	05527800	4	123	100	Agriculture
Salt Creek at Western Springs, Ill.	Salt Creek	05531500	12	115	131	Urban
Des Plaines River at Riverside, Ill.	Des Plaines River at Riverside	05532500	13	630	551	Urban
Chicago Sanitary and Ship Canal at Romeoville, Ill.	CSSC	05536995	14	739	3,490	Urban
Nippersink Creek above Wonder Lake, Ill.	Nippersink Creek	05548105	5	192	63	Agriculture
Lower Illinois River Basin Study Unit						
Illinois River at Ottawa, Ill.	Illinois River at Ottawa	05553500	15	10,949	12,600	Agriculture / Urban
Panther Creek near El Paso, Ill.	Panther Creek	05567000	6	94	57	Agriculture
Mackinaw River near Green Valley, Ill.	Mackinaw River	05568000	7	1,073	730	Agriculture
Indian Creek near Wyoming, Ill.	Indian Creek	05568800	8	63	50	Agriculture
Sangamon River at Monticello, Ill.	Sangamon River at Monticello	05572000	9	550	422	Agriculture
Sangamon River near Oakford, Ill.	Sangamon River at Oakford	05583000	10	5,093	3,490	Agriculture
LaMoine River at Colmar, Ill.	LaMoine River	05584500	11	655	460	Agriculture
Illinois River at Valley City, Ill.	Illinois River at Valley City	05586100	16	26,743	22,910	Agriculture/ Urban

growth. The amounts of these nutrients in water bodies can affect the suitability of the water for water supply (domestic and industrial), recreation, biological habitat, and for the sustenance of aquatic life. Excess amounts of nutrients in water bodies can result in eutrophication (excessive aquatic plant and algae growth) and can be harmful to an aquatic ecosystem. Eutrophication typically results in a subsequent die-off of algae and aquatic plants and an associated release of organic material and waste products. Decomposition of these materials and products creates a demand for oxygen that might result in adverse effects on and possibly the death of fish and other aquatic fauna that rely on oxygen in the water for survival. Nutrients are often cited as one of the most common causes of less than full support of designated uses in streams and lakes across the United States and in Illinois. In recent years, many surface- and ground-water supplies throughout Illinois have had nitrate concentrations exceeding the State's water-quality standard for drinking water and have needed to take corrective measures or find alternative supplies (*http://www.ipcb.state.il.us/SLR/IPCBandIEPAEnvironmental-Regulations-Title35.asp*). Concentrations of nitrogen and phosphorus in lakes, streams, and rivers throughout the Midwest, and particularly in the Mississippi River Basin, have received increased attention over the past 5-10 years because these nutrients have been identified as contributing to hypoxic conditions in the Gulf of Mexico (McIsaac and others, 2001, Goolsby and others, 1999, Rabalais and others, 1999). The IRB has been identified as one of the principal watersheds contributing nutrients to the Mississippi River (Goolsby and others, 1999), however, these processes and mechanisms contributing to the hypoxic conditions in the Gulf of Mexico continue to be studied. In 2002, the U.S. Environmental Protection Agency (USEPA) published draft nutrient water-quality criteria for the Nation's surface-water bodies, based upon inferred reference conditions within the Nation's major ecoregions (United States Environmental Protection Agency, 2000). Most States are currently developing state-specific nutrient standards based on cause-effect relations in preference to promulgation of the USEPA nutrient criteria.

Nitrogen is present in various forms in surface waters, with the most common forms being nitrate (NO_3^-), ammonium (NH_4^+), and organic nitrogen

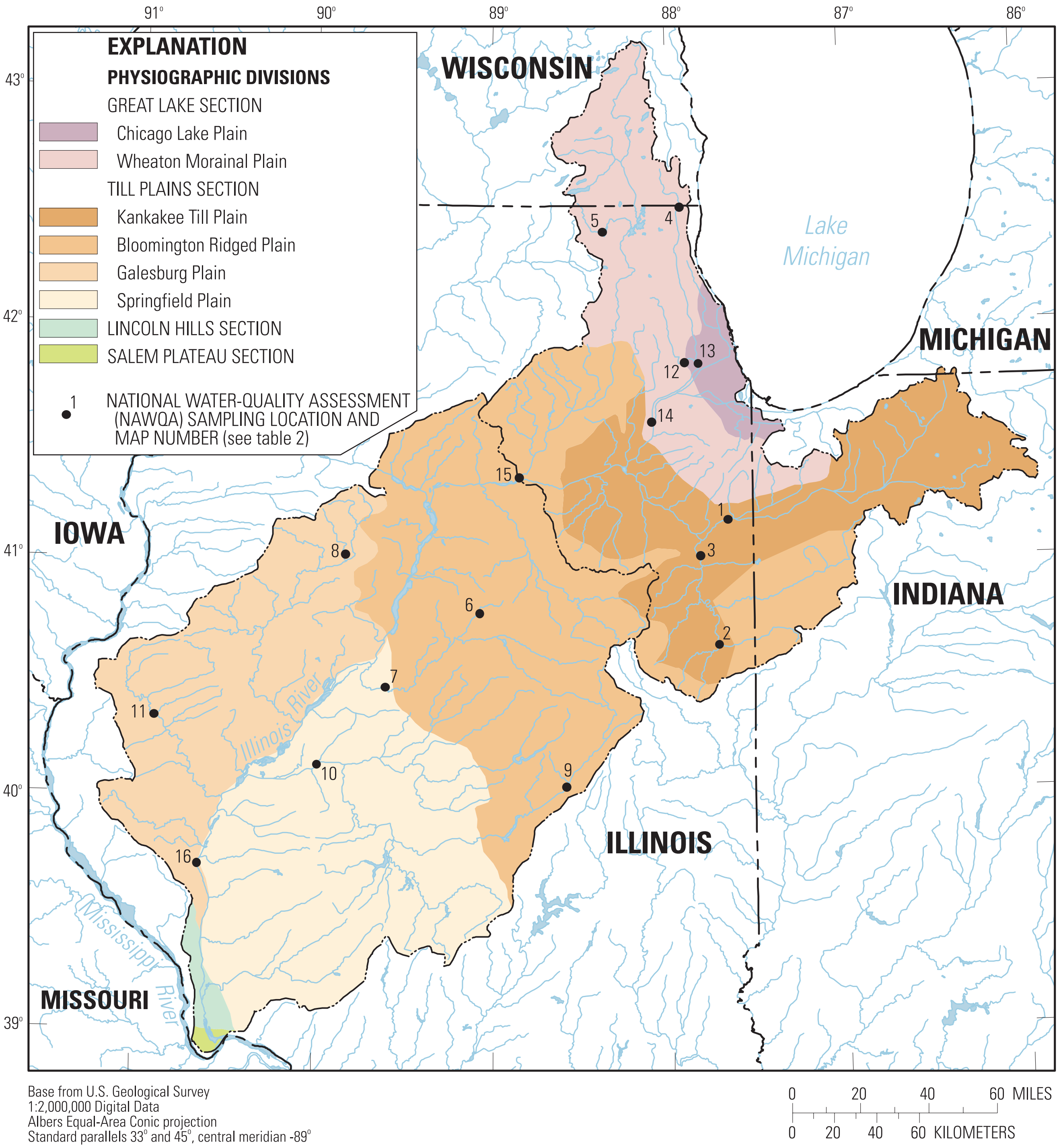


Figure 2. Physiographic divisions in the Illinois River Basin.

(nitrogen incorporated in organic matter such as plant tissue, urea, and proteins). Nitrite (NO_2^-) and un-ionized ammonia (NH_3) are generally present in low concentrations as transitional forms of nitrogen and typically indicate a source of organic material. Un-ionized NH_3-N is toxic to many aquatic organisms with an equilibrium concentration in natural water bodies that is dependent on temperature and pH. NO_3^- and NO_2^- are soluble forms of nitrogen available for biological uptake. NH_4^+ is also used readily by biological organisms, but is absorbed to particulate matter by cation exchange and is transported in association with fine sediments (Hem, 1985 and McNeely and others, 1979).

Phosphorus in surface waters is present in soluble and particulate forms (McNeely and others, 1979, American Public Health Association, 1998). Phosphorus is a necessary plant nutrient and is often thought to be the limiting nutrient for aquatic plant growth in most environments. Phosphorus is most readily available to biota in the orthophosphate form (PO_4^{3-}). Like nitrogen, phosphorus is frequently applied to agricultural land to promote crop production. Phosphorus is generally transported to surface-water bodies through overland runoff and in association with sediment particles, but can also be transported in the dissolved phase through shallow ground-water flow and artificial subsurface drainage systems. Phosphorus is also prevalent in domestic and industrial wastewater and in livestock wastes. When sufficient amounts of nitrogen are present, phosphorus concentrations in excess of 0.1 mg/L may promote eutrophication and increased growth of algae (McNeely and others, 1979).

In 2002, the Illinois Environmental Protection Agency (IEPA) listed nutrients as the most common cause for impairment of surface-water bodies in Illinois, including the impairment of 3,082 miles of assessed streams and 114,903 acres of assessed lakes (Illinois Environmental Protection Agency, 2003). Organic enrichment and low dissolved-oxygen concentrations (potential outcomes of excessive nutrient levels) were listed among the most frequent causes for stream impairment by the IEPA. Excessive algal growth was listed as causing impairment in approximately 80,000 acres of Illinois lakes.

The State of Illinois currently (2005) has numeric water-quality standards for NO_3^--N and NH_3-N. The standard for NO_3^--N is 10 mg/L and applies only to public and food processing water supplies. For NH_3-N, the standard for both general-use waters and public and food processing water supply is a maximum of 15 mg/L total NH_3-N. Illinois also has an acute and chronic standard for total NH_4^+-N that varies with temperature and season. The only current water-quality standard for phosphorus in Illinois general-use and public and food processing waters is for lakes or impoundments of 20 acres or more and at the point where a stream enters a lake or impoundment of this size. For these waters, the standard for total phosphorus concentration is 0.05 mg/L. In addition, Illinois has narrative standards that might be applicable to nutrient concentrations. These narrative standards state that "Waters of the State shall be free from…plant or algal growth, color or turbidity of other than natural origin" (35 Illinois Administrative Code, 1999).

Sediment is virtually always present in natural stream systems and can alter the substrate used by aquatic flora and fauna, can attenuate light penetration, and can contribute to changes in channel morphology. Excessive amounts of sediment can degrade water quality and harm an aquatic ecosystem through physical, biological, and chemical processes. Depending on hydrologic and land-use conditions, sediment can be scoured or deposited in various areas of a stream system. Sediment can also limit the recreational and industrial uses of a water body. Many elements and compounds, including some forms of nitrogen and phosphorus, absorb to sediment particles and are transported and deposited with the sediment. Over time, substantial quantities of these sediments and compounds can accumulate and can subsequently be re-suspended during high-flow events or through natural or anthropogenic disturbance. The IEPA listed siltation (accumulation of sediments) as one of the principal causes of use-impairment of Illinois streams, affecting 1,978 mi of assessed streams and 98,523 acres of lakes (Illinois Environmental Protection Agency, 2003).

Natural Sources

Natural sources of nitrogen and phosphorus include the atmosphere, soils, rocks, plants, and animals. Nitrogen is one of the most prevalent natural elements in the atmosphere and atmospheric deposition of nitrogen can be substantial. In addition, the combustion of fossil fuels contributes large amounts of nitrogen to the atmosphere (Hem, 1985, McNeely and others, 1979). More than 3.2 million tons of nitrogen are deposited from the atmosphere each year across the Nation (Puckett, 1994). Sullivan (2000) noted that atmospheric deposition of NO_3^--N and NH_4^+-N in the UIRB from 1980 to 1997 amounted to approximately 46,000 tons and 12,300 tons, respectively. Assuming similar atmospheric concentrations and average precipitation amounts for the entire IRB, approximately 121,623 ton/yr of NO_2^--N and 32,521 tons per year of NH_4^+-N are deposited over the IRB annually from the atmosphere. Determinations of the amounts of phosphorus in atmospheric deposition are not generally made as there is no natural atmospheric source of phosphorus. However, phosphorus can be present in the atmosphere associated with dust and particulate matter and atmospheric deposition of phosphorus might be substantial in some local areas (Harned, 1995). Meybeck (1982) estimated a world-wide average phosphorus deposition rate of 0.029 (ton/mi^2)/yr. This rate was similar to an estimate of 0.031 (ton/mi^2)/yr that McClurkin and others (1987) derived for northern Mississippi.

Biological contributions of nitrogen and phosphorus can be substantial in an aquatic ecosystem. Incorporation of nutrients into plant and animal tissues can represent a appreciable portion of the nitrogen and phosphorus present locally in the aquatic ecosystem. These nutrients are released upon death and decomposition of the aquatic organisms. Estimates of the inputs of nutrients into aquatic systems through leaf litter, woody plant debris, crop residue, and aquatic flora and fauna are substantial, but difficult to quantify.

In streams in which inflow from shallow ground water is a substantial part of the streamflow, and during base-flow periods, the contribution of nutrients from ground-water inflow may be important in the health of the aquatic ecosystem. However, contributions of nutrients to streams from ground-water inflows in the IRB are typically only a small percentage of the total nutrient input. Return flows from ground-water withdrawls can be substantial, but typically are routed to streams through wastewater-treatment plants so that contributions from return flows are accounted for as point-source inputs.

Suspended sediment analyses include natural and synthetic inorganic and organic material. However, most of the suspended sediment present in Illinois surface water bodies consists of natural soil particulate matter that has been eroded from the land surface, stream banks, and the stream bottom. Other sources or activities contributing suspended sediment may include industrial wastes, mining, and construction activities (Sullivan, 2000). Organic material from the riparian corridor and agricultural fields also can contribute substantially to the suspended-sediment concentration directly, as well as providing material that can be mineralized to form soil particles.

Anthropogenic Sources

The largest anthropogenic sources of nitrogen and phosphorus to aquatic systems are agricultural fertilizers and wastewater effluents. As mentioned earlier, the combustion of fossil fuels, including gasoline, coal, and oil, also contributes substantial amounts of nitrogen to the atmosphere and some of this nitrogen is eventually transported to surface waters. Anthropogenic sources in both agricultural areas and metropolitan areas contribute appreciable amounts of nutrients in the IRB.

Agriculture

Approximately 88 percent of the land area of the LIRB, 75 percent of the land in the UIRB, and 83 percent of land in the entire IRB is used for agricultural production, principally row-crop production of corn and soybeans (Groschen and others, 2000, Arnold and others, 1999). Typically, an annual rotation between corn and soybean production is used and nitrogen and phosphorus fertilizer is applied to the land prior to and sometimes during the years of corn production. Fertilizers are applied for soybean production much less frequently than for corn. In the IRB, fertilizer is often applied in the fall and sometimes applied with a nitrification inhibitor that prevents the conversion of NH_3^- to NO_3^-. Some of the nitrogen fertilizer is used by the crop, some is released to the atmosphere, some is incorporated into the soil, and some is transported to stream systems through overland runoff, subsurface drainage, or shallow (generally less than 100 feet) ground-water flow. Phosphorus fertilizer is generally applied as phosphate and readily absorbs to fine soil particulates. Because of this absorption, phosphorus is conveyed to streams primarily through soil erosion and overland runoff.

Records of fertilizer sales and crop production by county are typically used to estimate the amounts of fertilizer applied to agricultural land. Estimates of nitrogen and phosphorus inputs to the UIRB from agricultural fertilizer were made by Terrio (1995) and Sullivan (2000). Using these published estimates and extrapolating the application rates to the total area of agricultural land in the IRB, a gross approximation of the amounts of nitrogen and phosphorus applied annually in commercial fertilizers in the IRB would be 630,000 tons and 259,000 tons, respectively.

Nitrogen and phosphorus are also introduced into the IRB through livestock waste from pastures and feedlots and through land application of manure. In addition, the cycle of forage crop production, consumption by livestock, manure production, and subsequent local land application of manure can result in little net export of nutrients.

Wastewater

Wastewater-treatment plant effluents typically have concentrations of NH_3^-, phosphorus, and NO_2^- higher than stream water concentrations. Most of the wastewater effluent discharged to the IRB is from the Chicago metropolitan area. However, other large communities in the IRB such as Peoria, Springfield, Decatur, and Bloomington-Normal, as well as many smaller communities, also discharge substantial amounts of wastewater. Zogorski and others (1990) estimated that approximately 2,810 ft^3/s of effluent is discharged from more than 181 wastewater-treatment plants in the UIRB alone. These plants were estimated to discharge approximately 26,000 tons of nitrogen and 5,410 tons of phosphorus per year to UIRB streams (Terrio, 1995). Using these estimates to derive per capita figures and extrapolating to the population of the entire IRB, approximately 31,200 ton/yr of nitrogen and 65,000 ton/yr of phosphorus are discharged in wastewater-treatment plant effluents in the IRB.

Urban Runoff

Runoff from urbanized land and combined sewer systems also transport nutrients to stream water. Turf fertilizers and many cleaning compounds used in urban environments contain various forms of nitrogen and phosphorus. Terrio (1995) estimated that approximately 855 ton/yr of nitrogen and 1,250 ton/yr of phosphorus were conveyed to streams in the UIRB from urban runoff. No estimate of the amounts of nutrient inputs to streams from urban runoff was made for the entire IRB.

Study Methods

Data for this report were collected during the 2-year intensive monitoring periods of the LIRB and UIRB NAWQA Study Unit investigations. Eight surface-water stations were sampled in each of the Study Units (fig. 1 and table 2). Both the complete station names and the abbreviated station names as well as map numbers are listed in table 2. For brevity, the abbreviated station names will be used in subsequent text, and the map numbers will be used in figures and tables. Sampling stations were selected on the basis of various criteria, including watershed characteristics such as drainage area, soil type and land-use, availability of streamflow record, and other information pertinent to the interpretation of water-quality data. The sampling period for the LIRB Study Unit was from October 1996 through September 1998, while the sampling period for the UIRB Study Unit was from October 1998 through September 2000. The basic sampling frequency was monthly, but sampling frequency was increased at most stations during the growing season, operationally defined as March through September. Stations in the LIRB were sampled weekly from March through September, while stations in the UIRB were sampled bi-weekly during these months. These sampling frequencies provided information on short-term fluctuations and variability of constituents during periods when increases in concentrations and the effects of high concentrations on water chemistry and aquatic biota were expected to be most evident. Some additional samples were collected during high- and low-flow periods to quantify the water-quality conditions during these periods.

Sample Collection, Processing, and Chemical Analysis

Water samples were collected from boats, bridges, or by wading using documented depth- and width-integrating techniques and samplers (Shelton, 1994, Ward and Harr, 1990, U.S. Geological Survey, 2005). Samples were collected using DH-81, D-77, and D-95 isokinetic samplers, except where low stream velocities or shallow stream depths necessitated the use of an open-bottle sampler. Water was generally collected from at least 10 equally-spaced locations across the stream and subsequently composited into a single non-contaminating container. Samples collected during periods of ice cover were collected at locations and by methods determined by field personnel to be the most appropriate with due consideration given to both sample integrity and personal safety. The resulting composite sample of approximately 5–12 L was subsequently split into subsamples of various volumes using a Teflon® cone splitter (Shelton, 1994, U.S. Geological Survey, 2005). Samples for dissolved inorganic constituent analysis, including nutrients, were filtered through a 0.45 micron cellulose acetate filter, chilled to 4^0C, and shipped to the U.S. Geological Survey's National Water-Quality Laboratory (NWQL) in Arvada, Colo. by way of overnight mail. Samples for analysis of suspended-sediment concentration were stored in cool, dark locations until shipment to U.S. Geological Survey's Kentucky or Missouri Science Center sediment laboratories.

Water samples were analyzed for nitrogen and phosphorus using documented USGS laboratory methods (Fishman and Friedman, 1989). Forms of nitrogen and phosphorus analyzed included dissolved NH_3-N, dissolved NH_3-N+organic-N, total NH_3^-+organic-N, dissolved NO_2^--N, dissolved NO_2^- +NO_3^--N, dissolved phosphorus, total phosphorus, and dissolved PO_4^{3-}-P. Nitrogen and phosphorus samples were analyzed using colorimetry (Fishman, 1993, Patton and Truitt, 2000). Suspended-sediment samples were analyzed using methodology documented in Guy (1969). Chemical constituents and associated analytical methodologies used for data collected and analyzed during this study are listed in table 3.

Streamflow records were obtained from gaging stations operated by the USGS. All NAWQA water-quality sampling stations were co-located with streamflow-gaging stations, with the exception of Illinois River at Ottawa, Ill. Streamflow volumes for this site were calculated as the summation of streamflows at Illinois River at Marseilles, Ill. and Fox River at Dayton, Ill. gaging stations.

Quality Assurance and Quality Control

Mueller and others (1997) provide a detailed description of the quality-assurance and quality-control practices implemented by the NAWQA Program. Quality-control samples and procedures include sample collection, processing, and analysis techniques designed to identify the presence, degree, and persistence of bias and variability in both the field and laboratory aspects of the sampling program. Blanks are a type of quality-control sample that identify bias in sample-collection or treatment procedures. Blanks are designed to indicate the addition of a contaminant through some aspect of the sample collection, processing, or shipment process. Blanks can be collected at various steps of the sampling processes to provide information indicative of which step might be introducing the contamination. Replicate samples are used to indicate the variability in sample collection and analysis. As with blank samples, replicate samples can be designed to indicate whether differences among replicate samples are the result of natural environmental variability, sample collection and processing methods, or laboratory analysis techniques.

Twenty-four equipment blank samples were collected and analyzed for nitrogen and phosphorus concentrations from 1996 to 2000. The percentage of blank samples with concentrations higher than the method reporting limit varied among constituents (table 4). Multiple reporting levels were used for some constituents in samples analyzed from 1996 to 2000. Detectable concentrations were not found in any samples analyzed for total phosphorus. Between 4 and 17 percent of the blank samples analyzed for other forms of nutrients were found to have concentrations at or above the respective minimum reporting levels. These percentages represent only 1 to 4 samples because there were only 24 blank samples in total. More importantly, the levels at which the nutrients were present in the blank samples do not represent environmentally significant concentrations and are not seen as presenting a significant bias in the dataset.

Twenty-seven replicate samples were collected during the 1996-2000 period. These samples consisted of distinct sample analyses performed on either 1) a single water sample that was subsequently been split into two separate samples for analysis or 2) two samples collected concurrently by the same individual(s) and using the same equipment. For all nutrient forms, the median relative percent differences between the replicate samples were all less than 10 percent. The highest median relative percent difference was for dissolved NH_3 + organic-N (fig. 3). The smallest variability in relative percent difference was found for NO_2^-+NO_3^--N and the largest variability in relative percent difference was found for NH_3-N.

Table 3. Analytical methods used for the analyses of nitrogen and phosphorus in samples collected in the Illinois River Basin, 1996-2000.

[Some constituents have two minimum reporting levels because of changes in method accuracy or because of in instrument calibration capabilities;mg/L, milligram per liter]

Constituent	Parameter code	Method	Minimum reporting level (mg/L)
Ammonia-N, dissolved	00608	Colorimetry, salicylate-hypochlorite	0.015 and 0.020
Ammonia + organic-N, dissolved	00623	Colorimetry, microkjeldahl Digestion	0.100 and 0.200
Ammonia plus organic-N, total	00625	Colorimetry, microkjeldahl digestion	0.100 and 0.200
Nitrite-N, dissolved	00613	Colorimetry	0.010
Nitrite plus nitrate-N, dissolved	00631	Colorimetry, cadmium reduction - diazotization	0.050
Phosphorus, dissolved	00666	Semi-automated Colorimetry	0.004 and 0.008
Ortho-phosphate, dissolved	00671	Colorimetry, phosphomolybdate	0.010
Phosphorus, total	00665	Semi-automated colorimetry	0.004 and 0.006

Table 4. Results of blank samples collected and analyzed for nitrogen and phosphorus in the Illinois River Basin, 1996-2000.

[Some constituents have two minimum reporting levels because of changes in method accuracy or because of in instrument calibration capabilities; mg/L, milligram per liter; --, no data]

Constituent	Percentage of blank samples with detections	Range of detected concentrations (mg/L)	Method reporting level (mg/L)
Ammonia-N, dissolved	12	0.020-0.030	0.015 and 0.02
Nitrite-N, dissolved	8	.010-.028	0.010
Ammonia plus organic-N, total	4	.100-.190	0.10 and 0.20
Nitrite plus nitrate-N, dissolved	17	.050-.060	0.050
Phosphorus, dissolved	12	.010-.020	0.004 and 0.008
Phosphorus, total	0	--	0.004 and 0.006
Orthophosphate, dissolved	17	.010-.020	0.010

All inorganic samples were analyzed at the NWQL. The NWQL follows internal quality-assurance and quality-control (QA/QC) procedures and participates in external quality-assurance reviews and certification and accreditation programs. Information regarding the QA/QC practices and activities of the NWQL can be found in Maloney, 2005.

Results of analytical determinations made at the NWQL are entered into the USGS National Water Information System (NWIS). Results from NWQL analyses are transmitted electronically to the Illinois Water Science Center where they are reviewed for accuracy by project personnel following procedures documented in the Illinois District Quality-Assurance Plan for Water-Quality Activities (internal USGS document) prior to permanent storage in the local NWIS data base and subsequent deposition into the national NWIS data base.

Data Analysis and Computation

Data were examined using a variety of graphical, tabular, statistical, and correlative techniques. Measures of central tendency, variability, extreme values, and correlations among various parameters

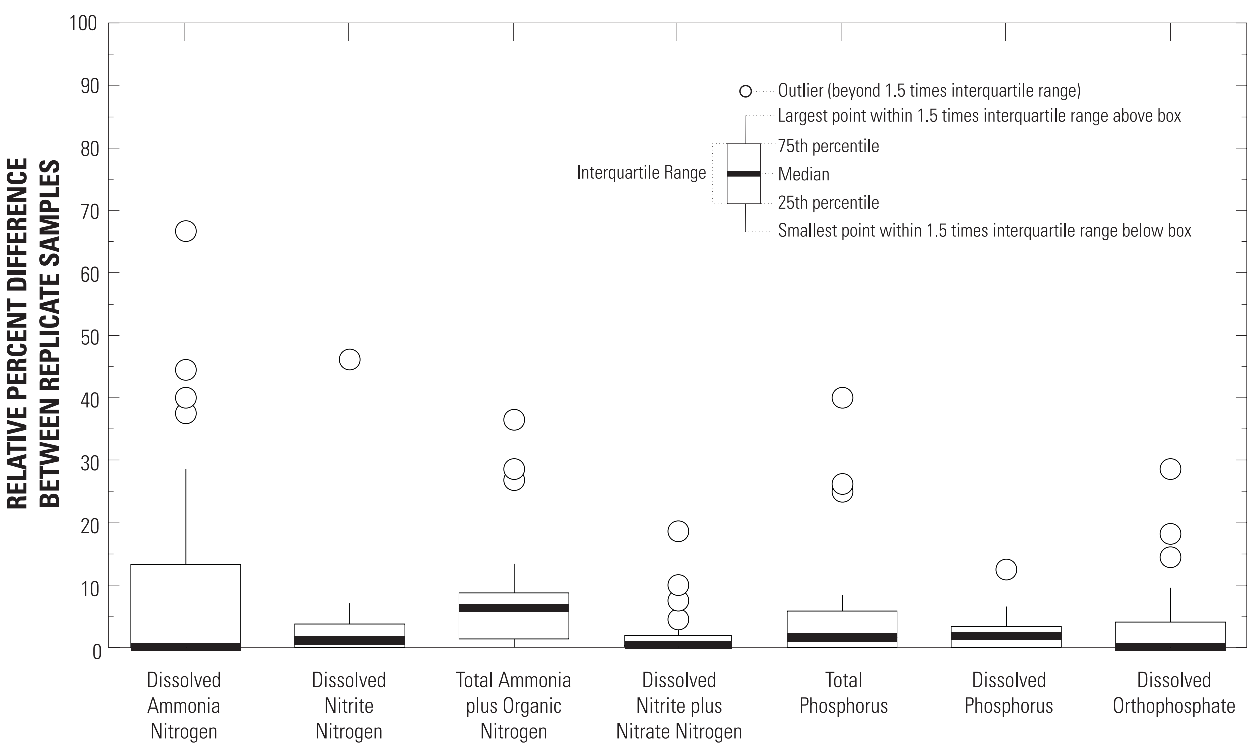


Figure 3. Relative percent difference between replicate samples at sampling stations in the Illinois River Basin, 1996-2000.

were assessed using commercial software (Velleman, 1988). Boxplots were used for graphical depictions of data set distribution characteristics (Helsel and Hirsch, 1992).

Spearman's Rank Correlation test was used to determine relations among various forms of nitrogen, phosphorus, and suspended-sediment concentrations. Spearman's Rank Correlation test is a nonparametric test that determines correlations between the ranks of two variables and does not require the variables to be linearly related. Spearman's correlation coefficient, rho, ranges between –1 and 1, with values close to these endpoints representing the strongest correlative relations (either negative or positive, respectively) and values near zero representing poor correlative relations.

Data analyses also were performed on the basis of climatic season. Four seasons were operationally defined to represent periods of the year with typically different hydrologic, climatic, and land-use attributes. The four seasons were defined as: spring (March – May), summer (June – August), fall (September – November), and winter (December – February). These seasons represent different conditions that affect nutrient concentrations in streams. The spring season represents a period of potentially wet weather, high runoff and subsurface-drain flow, fertilizer and pesticide application, and the beginning of the growing season. The summer months represent most of the growing season in the IRB and might include both dry periods and intense thunder storms that can produce substantial runoff. The fall months include the transition period from the growing to fallow seasons, the typical season for fertilizer application, and usually a period of reduced precipitation and streamflow. Winter is the core of the fallow season when common conditions include frozen soils, dormant vegetation, and variable streamflow.

The mass of any given constituent that passes a point along the course of a stream during a specified time period is commonly referred to as the flux of that constituent. Flux is computed as the product of the concentration of a constituent and volume of water over a specified time period. Fluxes are expressed as a quantity per unit of time, such as tons per year or tons per day. Fluxes also may be expressed on a per-unit basis, termed "yield". Common expressions of yield are tons per year per square mile or pounds per day per acre. For this report, flux estimates were calculated by using the program ESTIMATOR (Cohn and others, 1989, and Cohn, 2002). ESTIMATOR uses multivariate regression and the Minimum Variance Unbiased Estimator procedure to account for log-transformation bias. This program calculates monthly and annual flux estimates using daily mean streamflow and periodic constituent concentration data. The following equation was used to estimate fluxes of nitrogen, phosphorus, and suspended sediment.

$$\ln(CQ) = B_0 + B_1(\ln Q) + B_2\sin(2\pi T) + B_3\cos(2\pi T), \quad (1)$$

where

ln = natural logarithm,
C = constituent concentration,
Q = daily mean streamflow,
B_0, B_1, B_2 B_3 = regression coefficients,
π = 3.1416, and
T = time .

The ESTIMATOR program reports a standard error of the predictor variable that can be used in combination with an appropriate t-statistic to obtain a 95-percent confidence interval for the calculated annual flux (Helsel and Hirsch, 1992).

Concentrations of Nutrients and Suspended Sediment

In-stream concentrations of nitrogen and phosphorus are affected temporally and spatially by variations in climate, by plant and algae growth, land-use practices, and hydrology. Reduced forms of nitrogen and phosphorus readily absorb to particulate material. Consequently, these forms are transported and,depending upon hydrologic conditions, sequestered with sediments and particulate organic matter. NO_3^- and PO_4^{3-} are the fully oxidized and readily soluble forms of nitrogen and phosphorus. Consequently, these forms are typically found dissolved in the water column.

Suspended sediment is common in Illinois surface waters and high concentrations can promote undesirable conditions, including siltation of lakes and low-velocity stream segments, loss of habitat for aquatic organisms, increased turbidity, and decreased aesthetic appeal. Within the watersheds of the IRB, many combinations of parent materials, topographic settings, hydrologic conditions, and land-use practices result in wide differences of in-stream suspended-sediment concentrations and fluxes.

Nutrients

In-stream concentrations of nitrogen and phosphorus varied throughout the IRB. Land use was determined have a substantial effect on in-stream nutrient concentrations. Streams in primarily urban watersheds had higher concentrations of NH_3-N, NH_3+organic-N and phosphorus, whereas stations in agricultural basins generally had higher concentrations of NO_2^-+NO_3^--N.

Concentrations

Concentrations of total nitrogen (TN) (computed as the summation of NO_2^-+NO_3^--N and NH_3+organic-N) ranged from 0.29 to 21 mg/L and were highest in the most intensive agricultural watersheds (fig. 4 and table 5). The highest median concentration of TN (13 mg/L) was in Panther Creek (map no. 6), and median TN concentrations were equal to or greater than 9.0 mg/L in the Sangamon River at Monticello (map no. 9), the Iroquois River (map no. 3), Sugar Creek (map no. 2), and Indian Creek (map no. 8). The lowest TN median concentrations were found in the Kankakee River (map no. 1)(2.7 mg/L) and the Des Plaines River at Russell (map no. 4)(2.8 mg/L). The variability in TN concentration was substantially larger in agricultural watersheds than in urban watersheds. The median TN concentrations at the two Illinois River stations, representing the outlets of the UIRB and LIRB, were virtually the same (5.9 mg/L at Ottawa (map no. 15) and 5.7 mg/L at Valley City (map no. 16), respectively).

NH_3-N concentrations ranged from less than the reporting level of 0.02 mg/L, found at many stations, to 1.95 mg/L in the Chicago Sanitary and Ship Canal (CSSC)(map no. 14). The median concentrations at most stations were typically between 0.02 and 0.04 mg/L, with the higher median concentrations (0.08–0.39 mg/L) at stations in predominantly urban watersheds. The median NH_3-N concentration in the CSSC was 0.39 mg/L. In contrast to TN, NH_3-N concentrations were most variable in urban watersheds, particularly in the CSSC, and least variable in agricultural watersheds (fig. 5).

Concentrations of total NH_3+organic-N ranged from about 0.20 mg/L, found at five stations in agricultural watersheds, to a maximum of about 4.5 mg/L in the Illinois River at Ottawa and in the lower Sangamon River and LaMoine River (map no. 11). Median concentrations higher than 1.0 mg/L were determined for the three streams in urban watersheds and for streams in mixed land-use watersheds including the Illinois River. Similar to the pattern for NH_3-N, the highest median concentration of NH_3+organic-N (1.4 mg/L) was in the CSSC (fig. 6). There were not large differences in the variability of NH_3+organic-N concentrations among the watersheds, with the exception of greater variability in the CSSC. The concentrations and variation in concentrations of NH_3+organic-N at the two Illinois River locations were similar.

Concentrations of NO_2^-+NO_3^--N ranged 0.050 mg/L (found for six watersheds) to 19.1 mg/L in Sugar Creek. The highest NO_2^-+NO_3^--N median concentration (12 mg/L) was in Panther Creek, a small agricultural watershed. The lowest median concentrations were found in the Kankakee River (1.7 mg/L) and in the Des Plaines River at Russell (2.0 mg/L). Concentrations of NO_2^-+NO_3^--N were typically high in intensive agricultural watersheds, although the lowest concentrations were also in agricultural watersheds (fig. 7). Correspondingly, the greatest variability in NO_2^-+NO_3^--N concentrations was in agricultural watersheds and is likely due to the seasonality of agricultural land-use practices. NO_2^-+NO_3^--N concentrations at the two Illinois River stations were similar, were low in comparison concentrations at other stations, and had less variability than concentrations at many of the other stations. Concentrations of NO_2^-+NO_3^--N were less variable in urban watersheds than in agricultural watersheds, but concentrations in the urban watersheds also never reached low levels found in some other watersheds. Concentrations were never less than 3.00 mg/L in the CSSC. Concentrations of NO_2^-+NO_3^--N higher than the NO_3^--N drinking water maximum contaminant level of 10 mg/L were found at 9 of the 16 stations sampled.

Concentrations of NO_2^-+NO_3^--N were substantially lower in the Kankakee River and in the Des Plaines River at Russell than at other stations. Much of the Kankakee River Basin is composed of sandy soils. Consequently, infiltration is much greater in this watershed and the practice of subsurface tile drainage, which provides an efficient transport mechanism for soluble NO_3^--N to receiving streams, is not prevalent as in most other areas of the IRB. The watershed of the Des Plaines River above Russell includes marsh and wetland areas that provide natural attenuation of NO_2^-+NO_3^--N and might not contribute nitrogen to the stream system to the extent of most other intensive agricultural watersheds.

Total phosphorus (TP) concentrations ranged from a minimum of 0.01 mg/L (found in three watersheds) to a maximum of 3.74 mg/L in Salt Creek (map no. 12). Salt Creek also had the highest median TP concentration of 1.48 mg/L. All three urban watershed stations had median TP concentrations greater than 0.700 mg/L. All other stations had median concentrations less than 0.500 mg/L TP and the median TP concentrations at most stations were less than 0.200 mg/L. Concentrations of TP were more variable in the urban watersheds

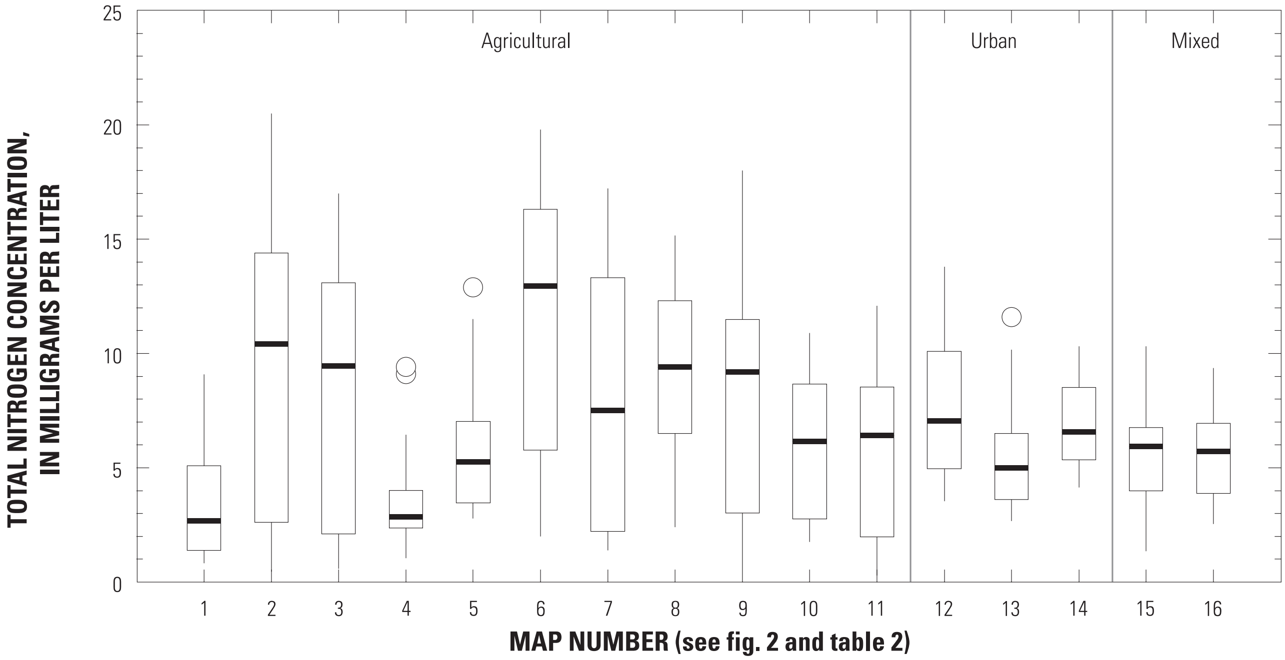


Figure 4. Distributions of total nitrogen concentrations at sampling stations in the Illinois River Basin, 1996-2000.

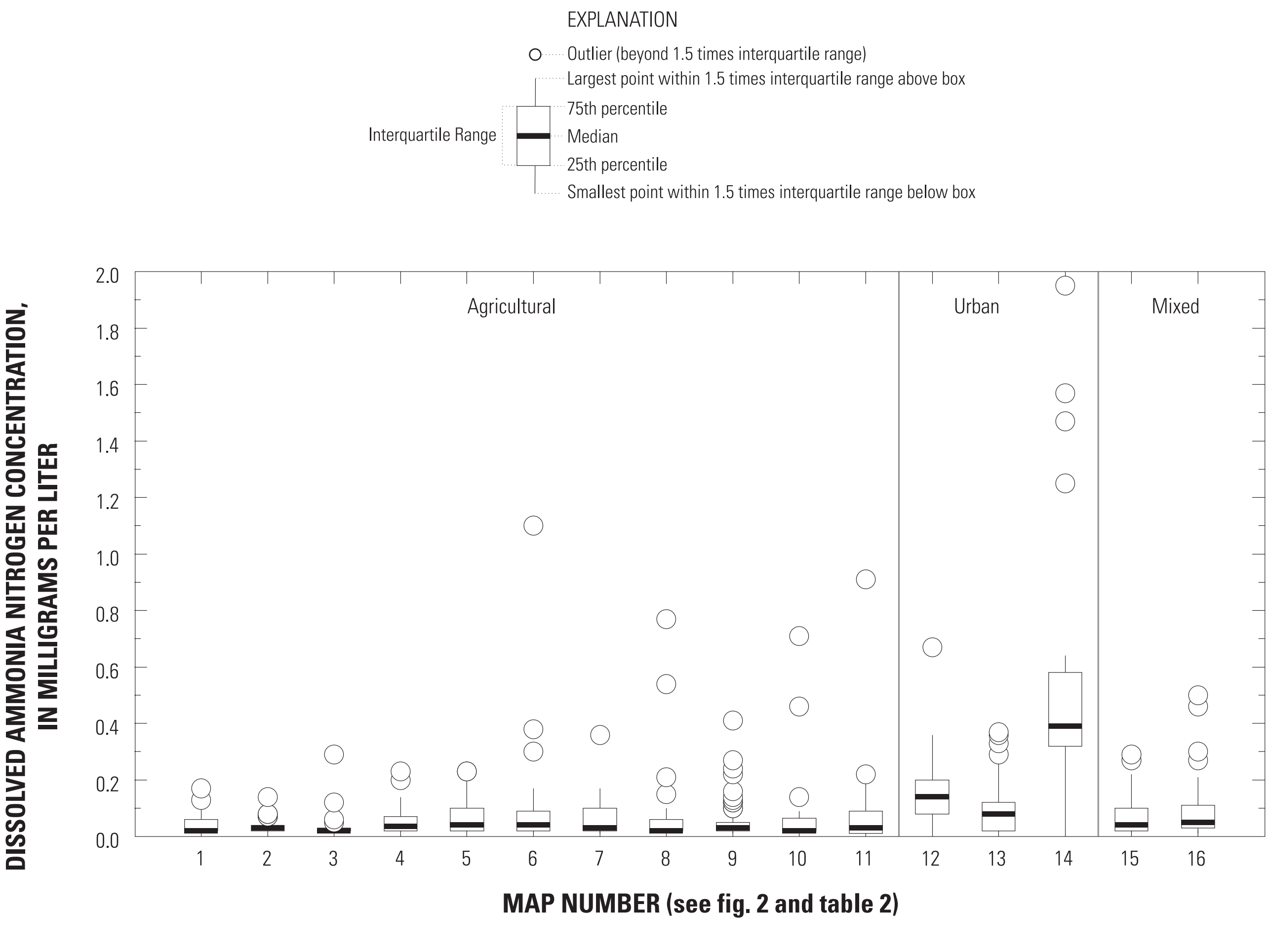


Figure 5. Distributions of dissolved ammonia nitrogen concentrations at sampling stations in the Illinois River Basin, 1996-2000.

Table 5. Statistical summaries of nitrogen, phosphorus, and suspended-sediment concentrations in the Illinois River Basin, 1996-2000.

[Map no. in parentheses following station name, see figure 2 and table 2; concentrations are in milligrams per liter.]

AGRICULTURAL STATIONS							
		Concentration in milligrams per liter					
Constituent	Number of samples	Mean	Median	Minimum	Maximum	10th Percentile	90th Percentile
Kankakee River (1)							
Total nitrogen	24	3.2	2.7	0.82	9.1	1.1	6.4
Ammonia-N, dissolved	24	.05	.02	.02	.17	.02	.12
Nitrite-N, dissolved	24	.026	.019	.010	.062	.010	.059
Ammonia plus organic-N, total	24	.88	.71	.36	2.1	.42	1.6
Nitrite plus nitrate-N, dissolved	24	2.4	1.7	.46	7.5	.58	4.6
Phosphorus, total	24	.14	.09	.02	.66	.05	.31
Phosphorus, dissolved	24	.03	.02	.01	.1	.01	.06
Orthophosphate, dissolved	24	.02	.01	.01	.08	.01	.05
Suspended sediment	24	123	95	44	447	73	198
Sugar Creek (2)							
Total nitrogen	35	9.1	10	0.45	21	0.97	16
Ammonia-N, dissolved	35	.04	.03	.02	.14	.02	.07
Nitrite-N, dissolved	35	.042	.035	.010	.106	.010	.085
Ammonia plus organic-N, total	35	.82	.69	.31	2.1	.45	1.4
Nitrite plus nitrate-N, dissolved	35	8.3	9.6	.05	19	.46	15
Phosphorus, total	35	.13	.10	.02	.59	.04	.21
Phosphorus, dissolved	35	.04	.04	.03	.19	.01	.08
Orthophosphate, dissolved	35	.04	.03	.01	.17	.01	.07
Suspended sediment	35	173	146	89	500	99	264
Iroquois River (3)							
Total nitrogen	27	8.2	9.4	0.59	17	0.98	15
Ammonia-N, dissolved	27	.04	.02	.02	.29	.02	.06
Nitrite-N, dissolved	27	.033	.025	.010	.104	.010	.065
Ammonia plus organic-N, total	27	.94	.86	.38	2.2	.46	1.6
Nitrite plus nitrate-N, dissolved	27	7.2	8.4	.05	16	.12	13
Phosphorus, total	27	.16	.13	.03	.47	.06	.30
Phosphorus, dissolved	27	.07	.06	.01	.19	.017	.14
Orthophosphate, dissolved	27	.05	.04	.01	.16	.01	.12
Suspended sediment	27	148	113	73	375	75	274
Des Plaines River at Russell (4)							
Total nitrogen	25	3.5	2.8	1.0	9.4	1.2	6.4
Ammonia-N, dissolved	25	.06	.04	.02	.23	.02	.14
Nitrite-N, dissolved	25	.033	.026	.010	.144	.010	.078
Ammonia plus organic-N, total	25	.97	1.0	.50	1.5	.56	1.3
Nitrite plus nitrate-N, dissolved	25	2.5	2.0	.05	8.1	.05	5.1
Phosphorus, total	25	.18	.18	.06	.36	.08	.30
Phosphorus, dissolved	25	.09	.08	.02	.23	.04	.17
Orthophosphate, dissolved	25	.07	.06	.01	.18	.02	.14
Suspended sediment	25	139	129	69	218	93	211

Table 5. Statistical summaries of nitrogen, phosphorus, and suspended-sediment concentrations in the Illinois River Basin, 1996-2000—continued.

[Map no. in parentheses following station name, see figure 2 and table 2; concentrations are in milligrams per liter.]

AGRICULTURAL STATIONS (continued)								
		Concentration in milligrams per liter						
Constituent	Number of samples	Mean	Median	Minimum	Maximum	10th Percentile	90th Percentile
Nippersink Creek (5)							
Total nitrogen	25	5.9	5.3	2.8	13	3.2	11
Ammonia-N, dissolved	25	.08	.04	.02	.23	.02	.21
Nitrite-N, dissolved	25	.032	.024	.010	.067	.013	.064
Ammonia plus organic-N, total	25	1.3	.77	.31	4.2	.38	3.4
Nitrite plus nitrate-N, dissolved	25	4.6	3.9	2.3	9.0	2.4	7.8
Phosphorus, total	25	.27	.10	.03	1.2	.04	.80
Phosphorus, dissolved	25	.07	.04	.01	.19	.01	.17
Orthophosphate, dissolved	25	.05	.04	.01	.15	.01	.14
Suspended sediment	25	239	184	60	688	125	546
Panther Creek (6)							
Total nitrogen	29	11	13	2	20	2.5	19
Ammonia-N, dissolved	29	.11	.04	.01	1.1	.01	.25
Nitrite-N, dissolved	29	.067	.056	.013	.155	.024	.137
Ammonia plus organic-N, total	29	.87	.69	.25	2.6	.37	1.5
Nitrite plus nitrate-N, dissolved	29	10	12	.33	18	1.4	18
Phosphorus, total	29	.17	.13	.01	.91	.02	.34
Phosphorus, dissolved	29	.10	.08	.01	.68	.01	.17
Orthophosphate, dissolved	29	.10	.07	.01	.59	.02	.16
Suspended sediment	29	66	55	7	178	9	155
Mackinaw River (7)							
Total nitrogen	29	8.0	7.5	1.4	17	1.6	15
Ammonia-N, dissolved	29	.06	.03	.01	.36	.01	.16
Nitrite-N, dissolved	29	.042	.031	.010	.145	.017	.073
Ammonia plus organic-N, total	29	.80	.66	.2	3.4	.3	1.4
Nitrite plus nitrate-N, dissolved	29	7.2	6.8	.26	16	1.0	14
Phosphorus, total	29	.16	.10	.01	1.2	.04	.30
Phosphorus, dissolved	29	.05	.03	.01	.24	.01	.16
Orthophosphate, dissolved	29	.05	.03	.01	.23	.01	.16
Suspended sediment	29	207	79	3	1,940	13	236
Indian Creek (8)							
Total nitrogen	29	9.2	9.4	2.4	15	3.4	14
Ammonia-N, dissolved	29	.09	.02	.01	.77	.01	.19
Nitrite-N, dissolved	29	.052	.043	.014	.170	.019	.089
Ammonia plus organic-N, total	29	.64	.48	.21	2.3	.22	1.5
Nitrite plus nitrate-N, dissolved	29	8.5	8.2	1.8	15	2.8	13
Phosphorus, total	29	.15	.10	.03	.59	.04	.44
Phosphorus, dissolved	29	.08	.06	.01	.43	.02	.15
Orthophosphate, dissolved	29	.08	.06	.01	.42	.03	.13
Suspended sediment	29	120	97	3	344	8	295

Table 5. Statistical summaries of nitrogen, phosphorus, and suspended-sediment concentrations in the Illinois River Basin, 1996-2000—continued.

[Map no. in parentheses following station name, see figure 2 and table 2; concentrations are in milligrams per liter.]

AGRICULTURAL STATIONS (continued)							
		Concentration in milligrams per liter					
Constituent	Number of samples	Mean	Median	Minimum	Maximum	10th Percentile	90th Percentile
Sangamon River at Monticello (9)							
Total nitrogen	78	7.8	9.2	0.55	18	0.83	12
Ammonia-N, dissolved	78	.05	.03	.01	.41	.01	.12
Nitrite-N, dissolved	78	.044	.040	.010	.122	.010	.084
Ammonia plus organic-N, total	78	.75	.69	.19	2.5	.30	1.3
Nitrite plus nitrate-N, dissolved	78	7.0	8.3	.05	17	.12	12
Phosphorus, total	78	.16	.14	.01	.67	.04	.27
Phosphorus, dissolved	78	.06	.05	.01	.26	.02	.12
Orthophosphate, dissolved	78	.06	.05	.01	.23	.02	.10
Suspended sediment	78	110	89	1	688	27	200
Sangamon River near Oakford (10)							
Total nitrogen	28	5.9	6.2	1.8	11	2.1	10
Ammonia-N, dissolved	28	.08	.02	.01	.71	.01	.12
Nitrite-N, dissolved	28	.039	.038	.010	.084	.016	.060
Ammonia plus organic-N, total	39	1.2	1.1	.43	2.4	.56	1.8
Nitrite plus nitrate-N, dissolved	28	4.9	5.1	.06	10	1.4	8.8
Phosphorus, total	39	.50	.40	.16	2	.22	.77
Phosphorus, dissolved	38	.35	.22	.01	1.9	.11	.69
Orthophosphate, dissolved	28	.25	.18	.02	.61	.11	.50
Suspended sediment	30	145	127	3	480	6	372
LaMoine River (11)							
Total nitrogen	72	5.8	6.4	0.29	12	0.94	10
Ammonia-N, dissolved	72	.66	.03	.01	.91	.01	.13
Nitrite-N, dissolved	72	.043	.039	.010	.120	.010	.072
Ammonia plus organic-N, total	72	1.0	.72	.20	4.4	.39	2.2
Nitrite plus nitrate-N, dissolved	72	4.8	5.1	.05	1.7	.07	.61
Phosphorus, total	72	.28	.18	.03	1.7	.07	.61
Phosphorus, dissolved	72	.07	.06	.01	.36	.02	.14
Orthophosphate, dissolved	72	.07	.06	.01	.33	.02	.11
Suspended sediment	72	337	127	6	3,110	25	781

Table 5. Statistical summaries of nitrogen, phosphorus, and suspended-sediment concentrations in the Illinois River Basin, 1996-2000—continued.

[Map no. in parentheses following station name, see figure 2 and table 2; concentrations are in milligrams per liter.]

URBAN STATIONS

Constituent	Number of samples	Concentration in milligrams per liter: Mean	Median	Minimum	Maximum	10th Percentile	90th Percentile
Salt Creek (12)							
Total nitrogen	42	7.5	7.1	3.5	14	4.3	12
Ammonia-N, dissolved	42	.15	.14	.02	.67	.04	.25
Nitrite-N, dissolved	42	.074	.068	.010	.251	.036	.112
Ammonia plus organic-N, total	42	1.2	1.2	.57	2.8	.94	1.6
Nitrite plus nitrate-N, dissolved	42	6.3	5.2	1.5	13	2.8	11
Phosphorus, total	42	1.6	1.5	.14	3.7	.70	3.0
Phosphorus, dissolved	42	1.50	1.3	.22	3.7	.57	2.8
Orthophosphate, dissolved	42	1.4	1.1	.19	3.5	.49	2.6
Suspended sediment	42	142	136	69	471	90	182
Des Plaines River at Riverside (13)							
Total nitrogen	23	5.5	5.0	2.7	12	3.4	9.1
Ammonia-N, dissolved	23	.12	.08	.02	.37	.02	.34
Nitrite-N, dissolved	23	.059	.050	.022	.222	.024	.095
Ammonia plus organic-N, total	23	1.2	1.1	.58	2.2	.86	1.9
Nitrite plus nitrate-N, dissolved	23	4.3	3.6	1.8	10	2.0	8.1
Phosphorus, total	23	.91	.70	.29	2.1	.35	1.7
Phosphorus, dissolved	23	.74	.60	.20	2.0	.24	1.6
Orthophosphate, dissolved	23	.66	.51	.17	1.7	.20	1.4
Suspended sediment	23	143	134	81	277	103	198
Chicago Sanitary and Ship Canal (14)							
Total nitrogen	21	7.0	6.6	4.1	10	4.9	9.7
Ammonia-N, dissolved	21	.58	.39	.02	1.95	.13	1.5
Nitrite-N, dissolved	21	.183	.162	.080	.355	.105	.314
Ammonia plus organic-N, total	21	1.6	1.4	.94	3.1	.98	2.6
Nitrite plus nitrate-N, dissolved	21	5.4	5.0	3.2	7.9	3.8	7.4
Phosphorus, total	21	1.3	1.2	.13	2.7	.68	2.2
Phosphorus, dissolved	21	1.2	1.0	.09	2.3	.58	2.0
Orthophosphate, dissolved	21	1.1	1.0	.52	1.9	.57	1.8
Suspended sediment	21	99	77	47	257	57	166

Table 5. Statistical summaries of nitrogen, phosphorus, and suspended-sediment concentrations in the Illinois River Basin, 1996-2000—continued.

[Map no. in parentheses following station name, see figure 2 and table 2; concentrations are in milligrams per liter.]

MIXED LAND USE STATIONS

Constituent	Number of samples	Concentration in milligrams per liter					
		Mean	Median	Minimum	Maximum	10th Percentile	90th Percentile
Illinois River at Ottawa (15)							
Total nitrogen	56	5.8	5.9	1.4	10	3.7	8.1
Ammonia-N, dissolved	56	.06	.04	.01	.29	.01	.15
Nitrite-N, dissolved	56	.063	.058	.010	.126	.037	.101
Ammonia plus organic-N, total	56	1.2	1.1	.74	4.5	.83	1.6
Nitrite plus nitrate-N, dissolved	56	4.5	4.6	.05	8.7	2.4	7.1
Phosphorus, total	56	.52	.50	.19	1.1	.31	.83
Phosphorus, dissolved	56	.36	.30	.05	1	.15	.67
Orthophosphate, dissolved	56	.33	.25	.01	.91	.13	.63
Suspended sediment	56	94	80	10	308	24	191
Illinois River at Valley City (16)							
Total nitrogen	68	5.4	5.7	2.6	9.4	2.9	7.8
Ammonia-N, dissolved	68	.08	.05	.01	.5	.02	.19
Nitrite-N, dissolved	68	.075	.062	.015	.210	.033	.131
Ammonia plus organic-N, total	68	1.1	1.0	.50	3.0	.70	1.5
Nitrite plus nitrate-N, dissolved	68	4.3	4.4	1.6	7.9	1.9	6.6
Phosphorus, total	68	.43	.43	.11	1.4	.24	.65
Phosphorus, dissolved	68	.22	.19	.07	.67	.12	.37
Orthophosphate, dissolved	68	.20	.18	.07	.60	.11	.32
Suspended sediment	68	204	154	44	1,010	65	349

(fig. 8). Median TP concentrations at Illinois River at Ottawa and Illinois River at Valley City were similar (0.50 mg/L and 0.43 mg/L, respectively), as was the variability in TP concentrations at these two stations.

Concentrations of PO_4^{3-}-P ranged from the minimum reporting level of 0.010 mg/L, found at virtually all stations except the urban stations, to a maximum of 3.49 mg/L in Salt Creek. As with TP, the highest median PO_4^{3-}-P concentrations and the largest variability in concentrations were found in the three urban watersheds (fig. 9). In these urban watersheds, most of the phosphorus was present as PO_4^{3-}-P. In agricultural watersheds, the proportion of phosphorus present in various forms varied with climatic season and streamflow conditions, but median TP concentrations were substantially higher than median dissolved PO_4^{3-}-P concentrations. Most of the in-stream phosphorus in urban watersheds was present as PO_4^{3-}-P, whereas PO_4^{3-}-P composed a much smaller portion of the in-stream phosphorus in agricultural watersheds.

The ratio of PO_4^{3-}-P to TP provides a simple way to evaluate the potential availability of phosphorus to biota in a particular stream system. Dissolved PO_4^{3-}-P is the form of phosphorus most easily used by aquatic biological organisms (Hem, 1985) and this form of phosphorus us often referred to as “bioavailable phosphorus”. In many Illinois streams, the majority of phosphorus is present as PO_4^{3-}-P. PO_4^{3-}-P consistently composed a large portion of the phosphorus in the streams in urban watersheds that receive effluent from wastewater-treatment plants (fig. 10). The Minnesota Pollution Control Agency concluded that phosphorus in wastewater effluent is “largely in a chemical form readily useable by plants (ca. 97 percent available)”, meaning the phosphate form (Minnesota Pollution Control Agency, 2004). Ratios of PO_4^{3-}-P to TP were also high for mixed land-use watersheds (Illinois River at Ottawa and Sangamon River near Oakford)(map no. 10), as well as for Panther Creek, which receives effluent from some small wastewater-treatment plants. The Panther Creek watershed

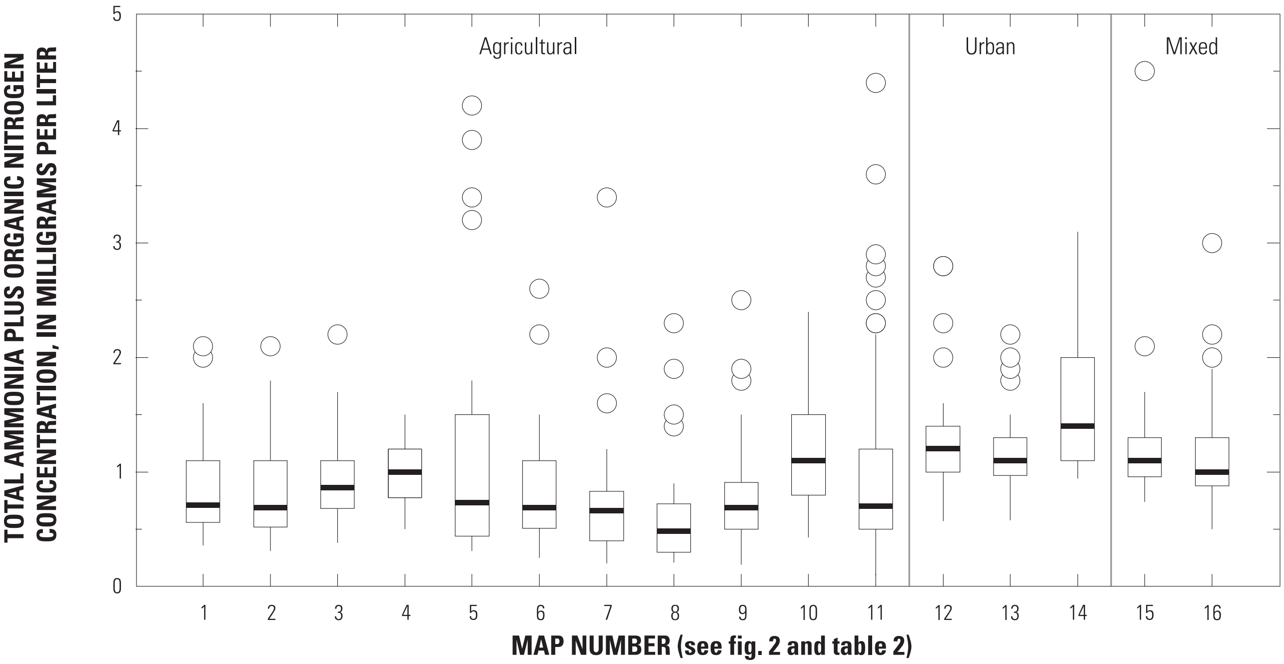
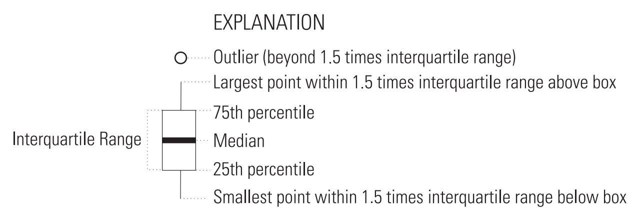


Figure 6. Distributions of total ammonia plus organic nitrogen concentrations at sampling stations in the Illinois River Basin, 1996-2000.



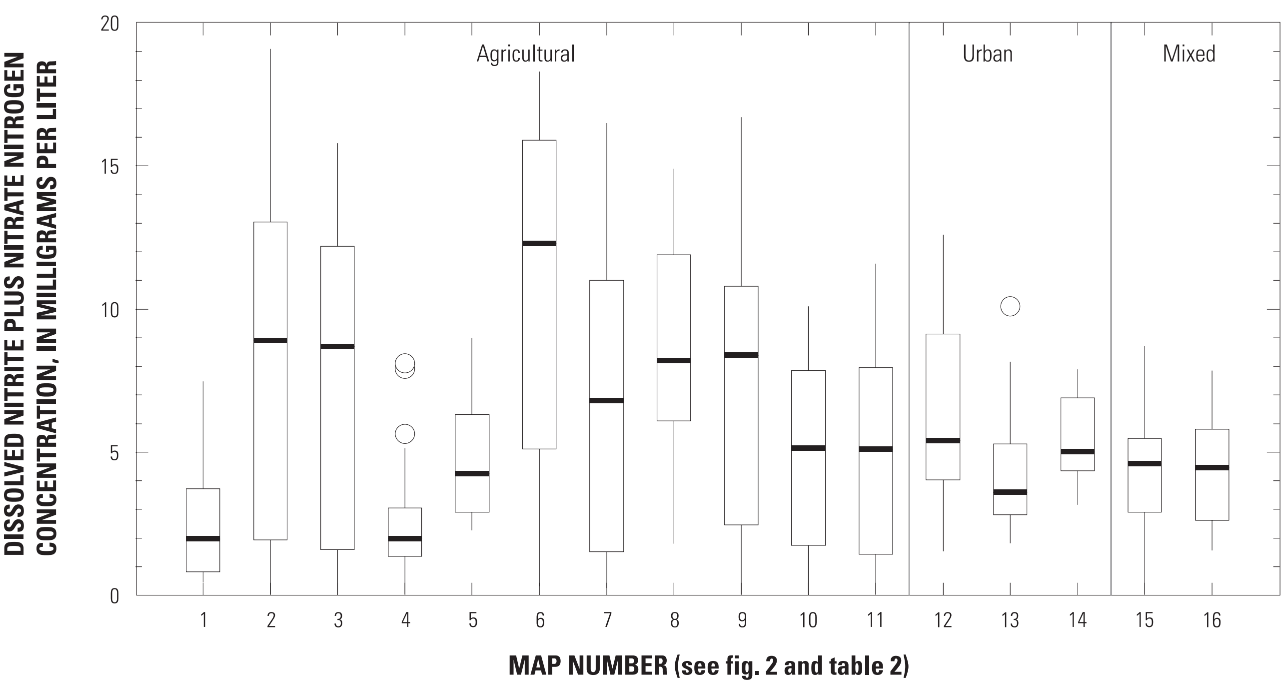


Figure 7. Distributions of dissolved nitrite plus nitrate nitrogen concentrations at sampling stations in the Illinois River Basin, 1996-2000.

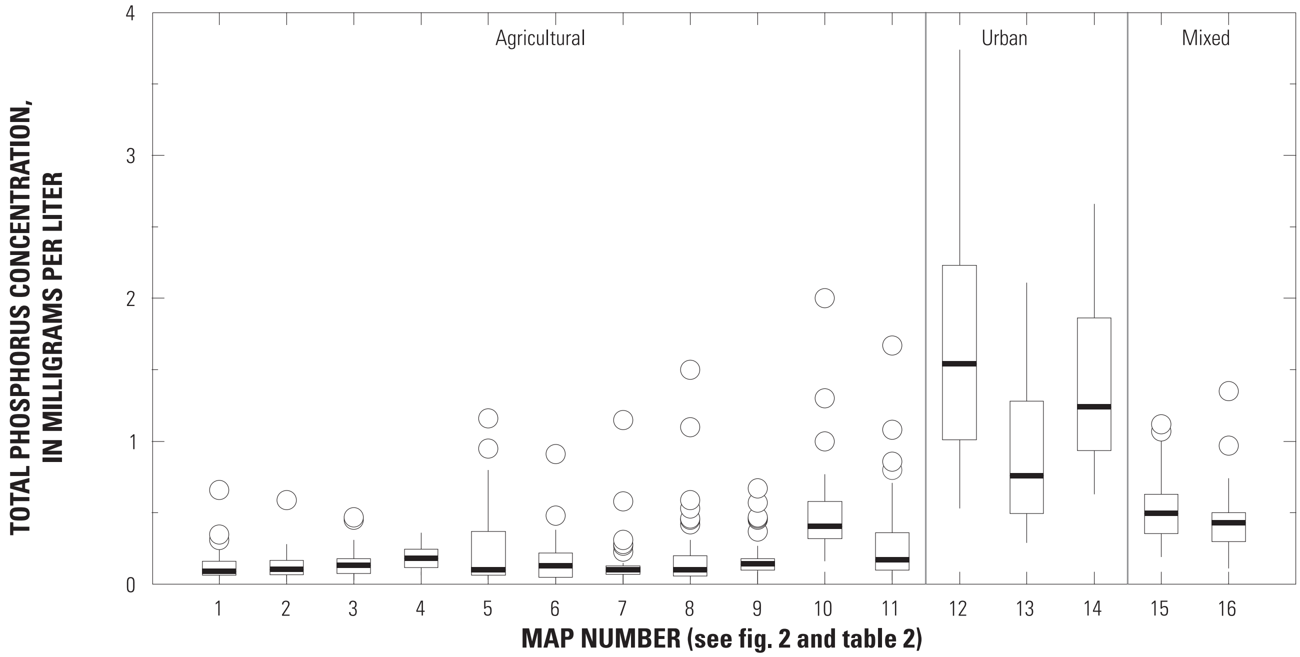
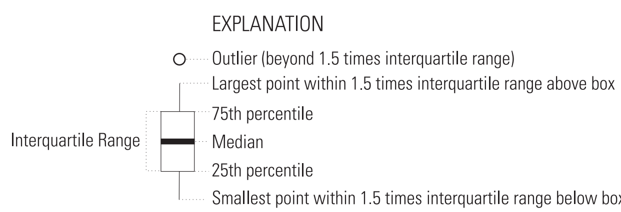


Figure 8. Distributions of total phosphorus concentrations at sampling stations in the Illinois River Basin, 1996-2000.



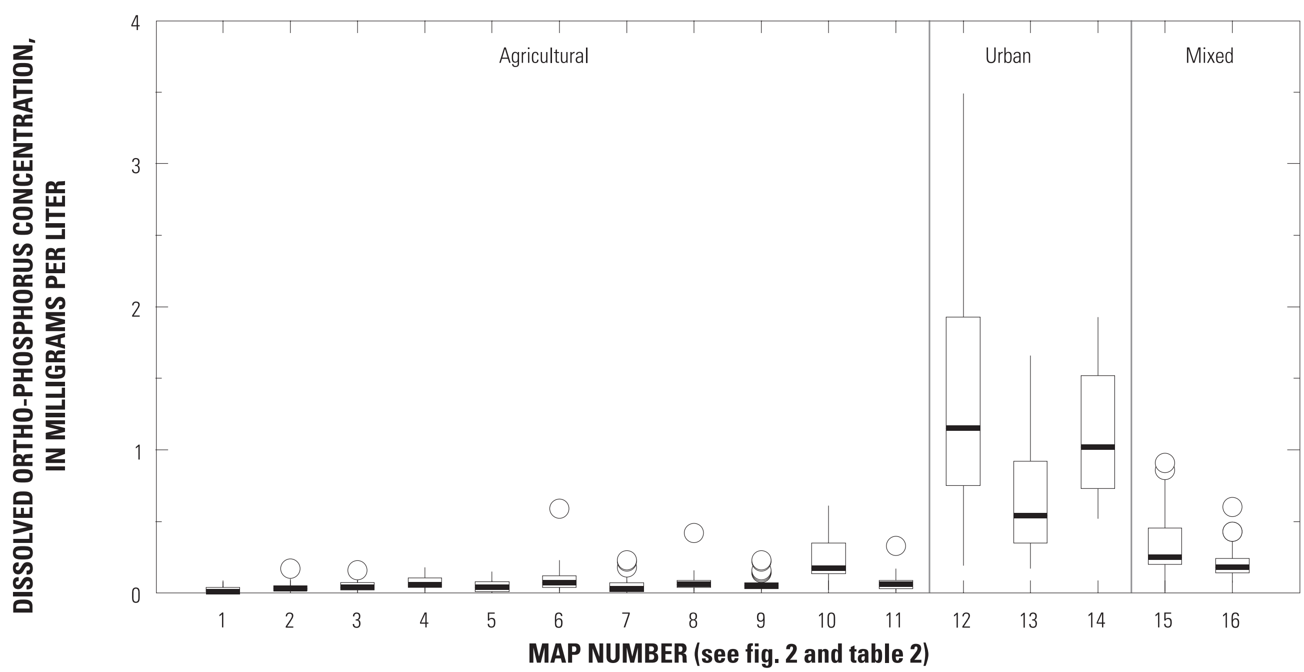


Figure 9. Distributions of dissolved orthophosphate concentrations at sampling stations in the Illinois River Basin, 1996-2000.

also includes some hog farms that contribute phosphorus to the watershed. The reason for the high ratio for Indian Creek is not known. The smallest ratios were found for Kankakee River, Nippersink Creek (map no. 5), and LaMoine River. The low ratios for the Kankakee River and Nippersink Creek might be attributed to permeable sandy soils and wetland areas, respectively. The reason for the relatively low ratio for the LaMoine River is not known, but might result from much of the phosphorus absorbing to fine particulate matter in the stream system.

Temporal Distributions

Water temperature, precipitation, land-use practices, point-source inputs, and aquatic vegetative growth can affect in-stream concentrations of nitrogen and phosphorus. Temporal variations in in-stream nutrient concentrations can occur on a short-term (diurnal) to long-term (decadal) basis, and seasonal variations are common. Diurnal changes in concentrations are typically driven by biological processing of nutrients in the stream or by anthropogenic inputs such as wastewater effluents. Seasonal changes in nutrient concentrations are generally caused by changes in source loading (such as agricultural fertilization), changes in biological processes due to increases or decreases in temperature and sunlight, and variations in precipitation and streamflow. Long-term temporal changes, or trends, in concentrations can result from changes in land use, climate, nutrient sources, degradation or maturation of flora and fauna communities, and anthropogenic activities in the watershed.

Evaluation of diurnal variance requires more intensive short-term data collection than is typically accomplished through the NAWQA Program. Assessment of long-term changes in nutrient concentrations requires data collected over an extended period, either routinely or periodically. Over time, the cyclical design of the NAWQA Program should provide data useful for the determination of long-term changes and trends in concentrations. Four of the UIRB NAWQA stations (Kankakee River at Momence, Iroquois River near Chebanse, Des

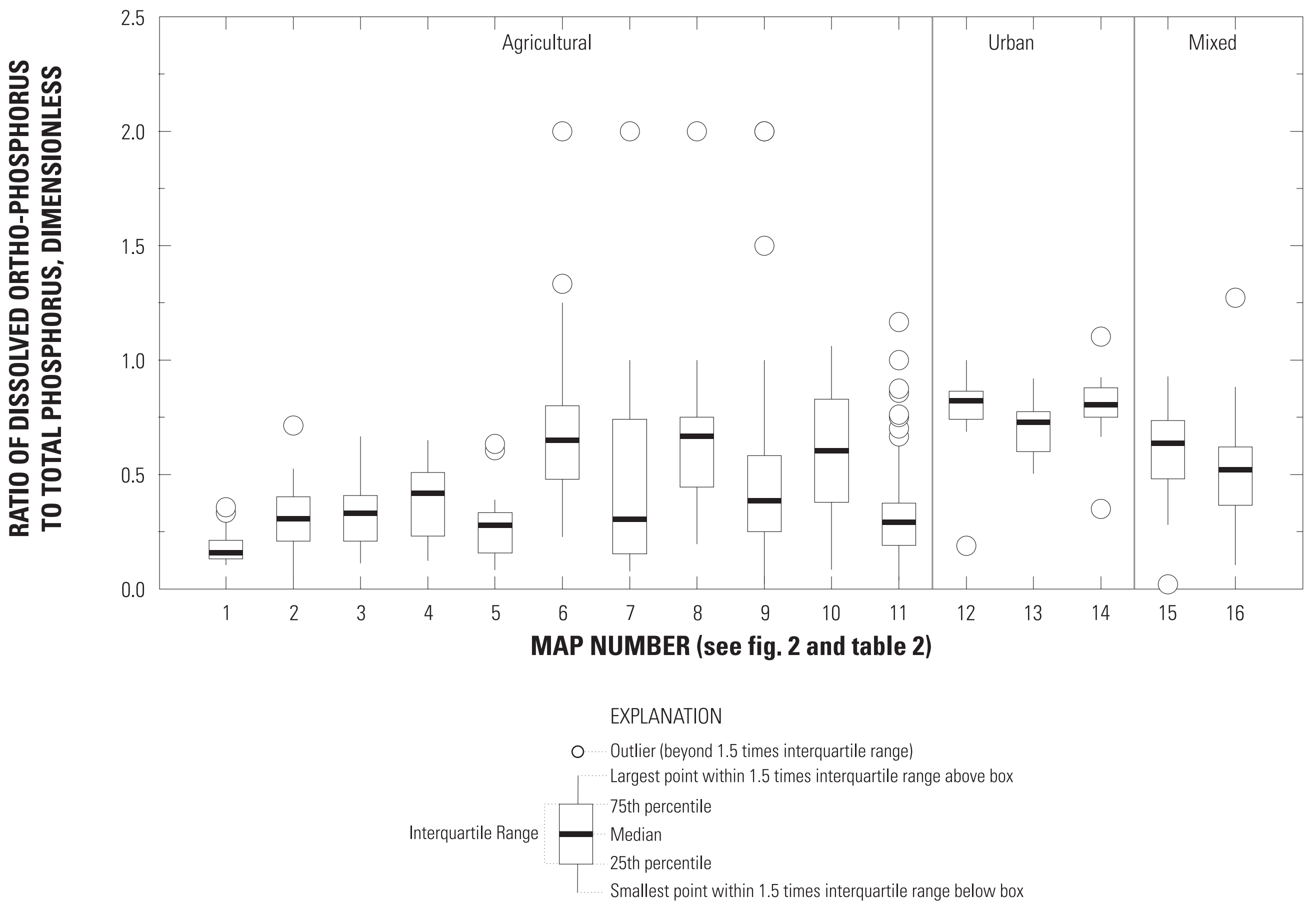


Figure 10. Distributions of the ratio of dissolved orthophosphate to total phosphorus at sampling stations in the Illinois River Basin, 1996-2000.

Plaines River at Riverside (map no. 13), and CSSC at Romeoville) were sampled during the UIRB pilot study from 1986 to 1990 and again during the recent NAWQA cycle from 1999 to 2000. However, laboratory analyses for the pilot study were performed by the IEPA and laboratory analyses for the subsequent sampling effort were performed by the USGS NWQL. A statistical comparison of IEPA and USGS NWQL data (Melching and Coupe, 1995) indicated various statistically significant differences in analytical data provided by the two laboratories, although there were no systematic biases in either data set. Specifically, differences were noted in NH_3-N and TP concentrations. Melching and Coupe (1995) concluded that because of statistically significant differences between the data sets, the data from the two agencies should not be combined for statistical analyses. Consequently, the data from the 1986-90 pilot study of the UIRB and data from the 1999-2000 UIRB study can not be combined for the purposes of evaluating long-term trends in nutrient concentrations.

The USGS (Sullivan, 2000) and the IEPA (Short, 1999) performed trend analyses using long-term IEPA ambient water-quality monitoring data. Sullivan (2000) examined data from 39 IEPA monitoring stations in the UIRB from 1978-1997. Short (1999) examined data from eight IEPA monitoring stations in the UIRB from 1981 to 1995. Trends in water quality identified by the two agencies were similar; although Sullivan identified a some trends not identified by Short. In no case did the trends identified by the two studies conflict.

Seasonal concentrations of total nitrogen and NO_2^-+NO_3^--N at six stations are shown in figures 11 and 12. These six stations were selected to represent urban, agricultural, and mixed land-use watersheds in the IRB. Total nitrogen concentrations were typically highest during the spring and lowest during the fall at stations in predominantly agricultural and mixed land-use watersheds because of the seasonal application of nitrogen fertilizer. Conversely, concentrations of total nitrogen in urban land use watersheds were highest in the winter because of the relatively constant input of wastewater effluents. Streamflow in the Illinois River at Ottawa is composed of approximately 60 percent agricultural runoff, 10 percent urban runoff, and 20 percent flow from the CSSC. The effect of the contributions from agricultural watersheds at this station can be seen in the similarities between the distributions of the data for this station and the data distributions for the stations in agricultural watersheds. The set of boxplots depicting seasonality at the Illinois River at Valley City (fig. 11) shows seasonality that is virtually identical to the boxplots for agricultural basins. Seasonality of NO_2^-+NO_3^--N is practically identical to the seasonality of TN at all of these stations because most of the nitrogen in IRB streams is present as NO_3^--N.

Seasonal concentrations of TP for the same six stations described above are shown in figure 13. The magnitude of the seasonal variability in TP concentrations is much less than for TN concentrations and most of the seasonal differences depicted in the boxplots are not statistically significant for stations in agricultural watersheds. The greatest variability is seen for the urban Salt Creek and Des Plaines River watersheds, where concentrations are generally lowest in the spring and highest in the fall and winter. The seasonal variability depicted for TP at Illinois River at Ottawa, although smaller in magnitude, mirrors that seen at the urban stations. Although the seasonal variability of TP concentrations in the Illinois River at Valley City is minimal, the pattern is similar to the seasonal pattern of TP concentrations in urban watersheds.

Various contrasting observations can be made between seasonal distributions of TN and TP. The seasonality of TN in the IRB and in the Illinois River itself, whether at the upstream station at Ottawa or at the downstream station at Valley City, is consistent to and dominated by agricultural nitrogen inputs. Conversely, the seasonality of TP in the Illinois River, especially at Ottawa, is dominated by urban sources of phosphorus and the seasonality of phosphorus concentrations in the Illinois River is a result of urban phosphorus sources.

Factors Contributing to Observed Nutrient Concentrations

Stream water quality is typically determined by the inputs to the stream from the contributing watershed(s) and the in-stream processing of these inputs. Direct interactions with the atmosphere can be an important factor affecting some water-quality constituents, including dissolved oxygen. Streamflow, land-use practices, point-source inputs, stream morphology, aquatic biology, and climate are major factors affecting water quality for most streams. Some of these factors and constituents, such as dissolved oxygen, can have substantial effects on the nitrogen and phosphorus concentrations in streams of the IRB.

Streamflow

In this study, in-stream concentrations of many nutrient forms were correlated with streamflow. Spearman Rank correlation analyses were done to determine relations between streamflow and nitro-

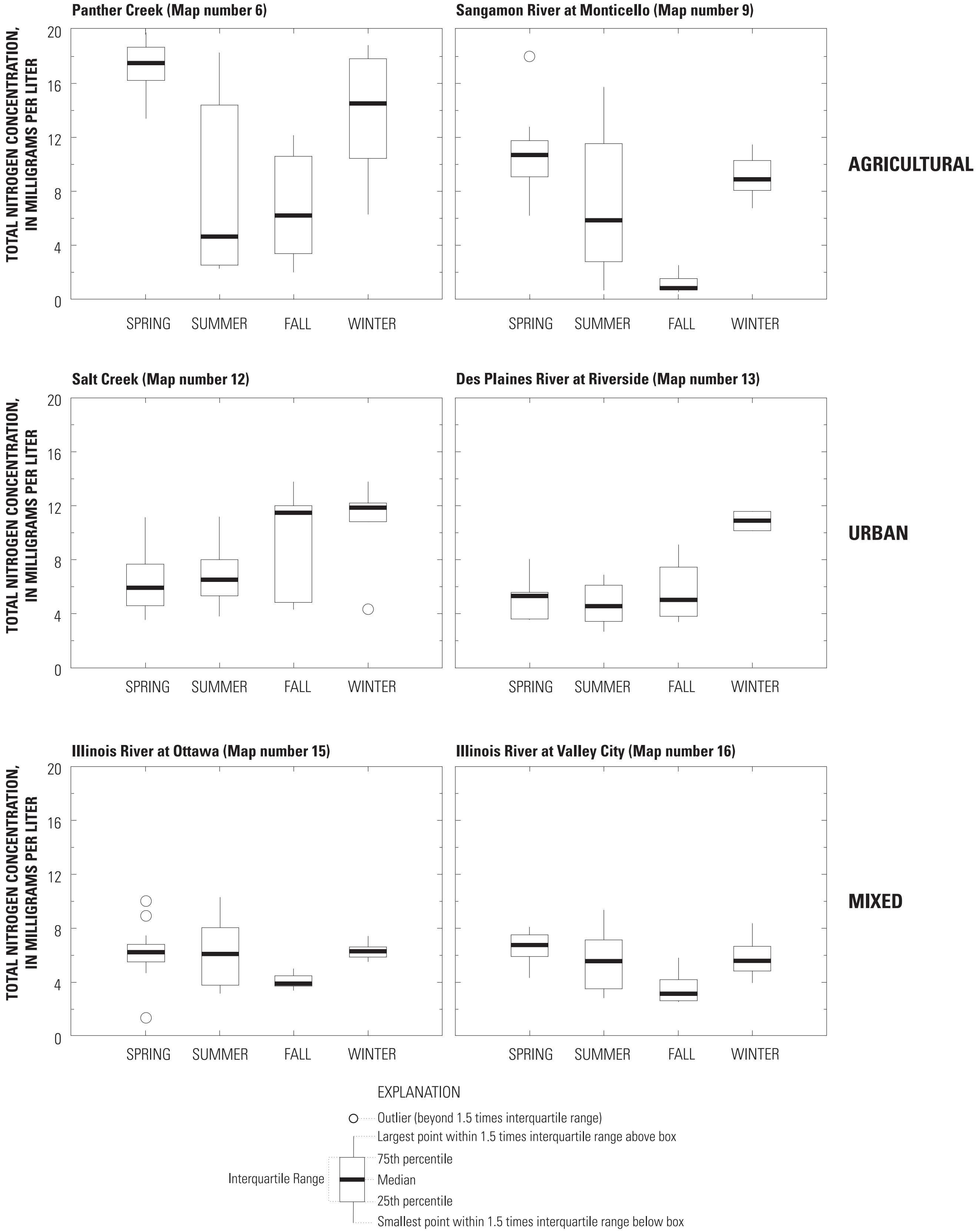


Figure 11. Distribution of total nitrogen concentrations, by season, at six sampling stations in the Illinois River Basin, 1996-2000.

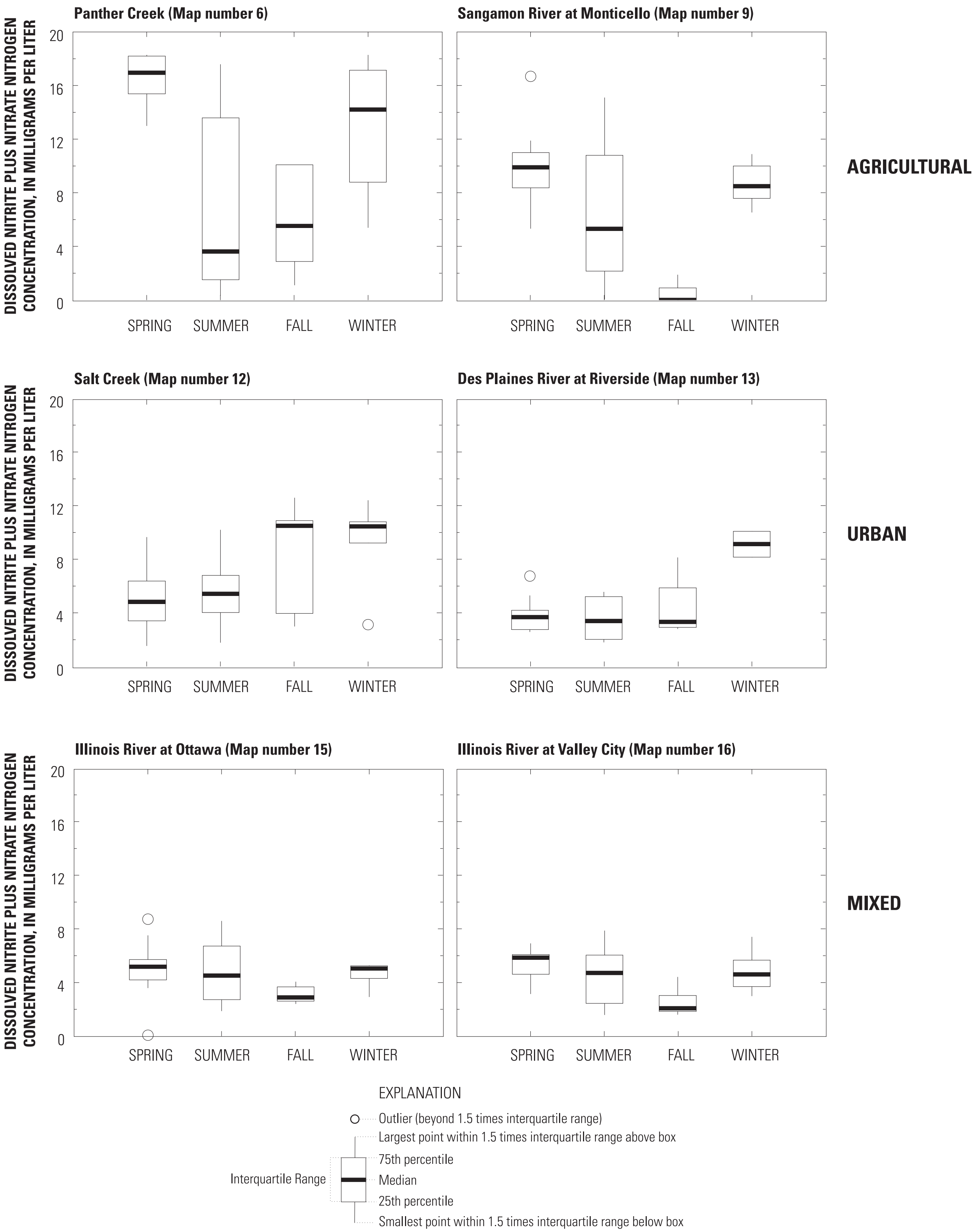


Figure 12. Distribution of dissolved nitrite plus nitrate nitrogen concentrations, by season, at six sampling stations in the Illinois River Basin, 1996-2000.

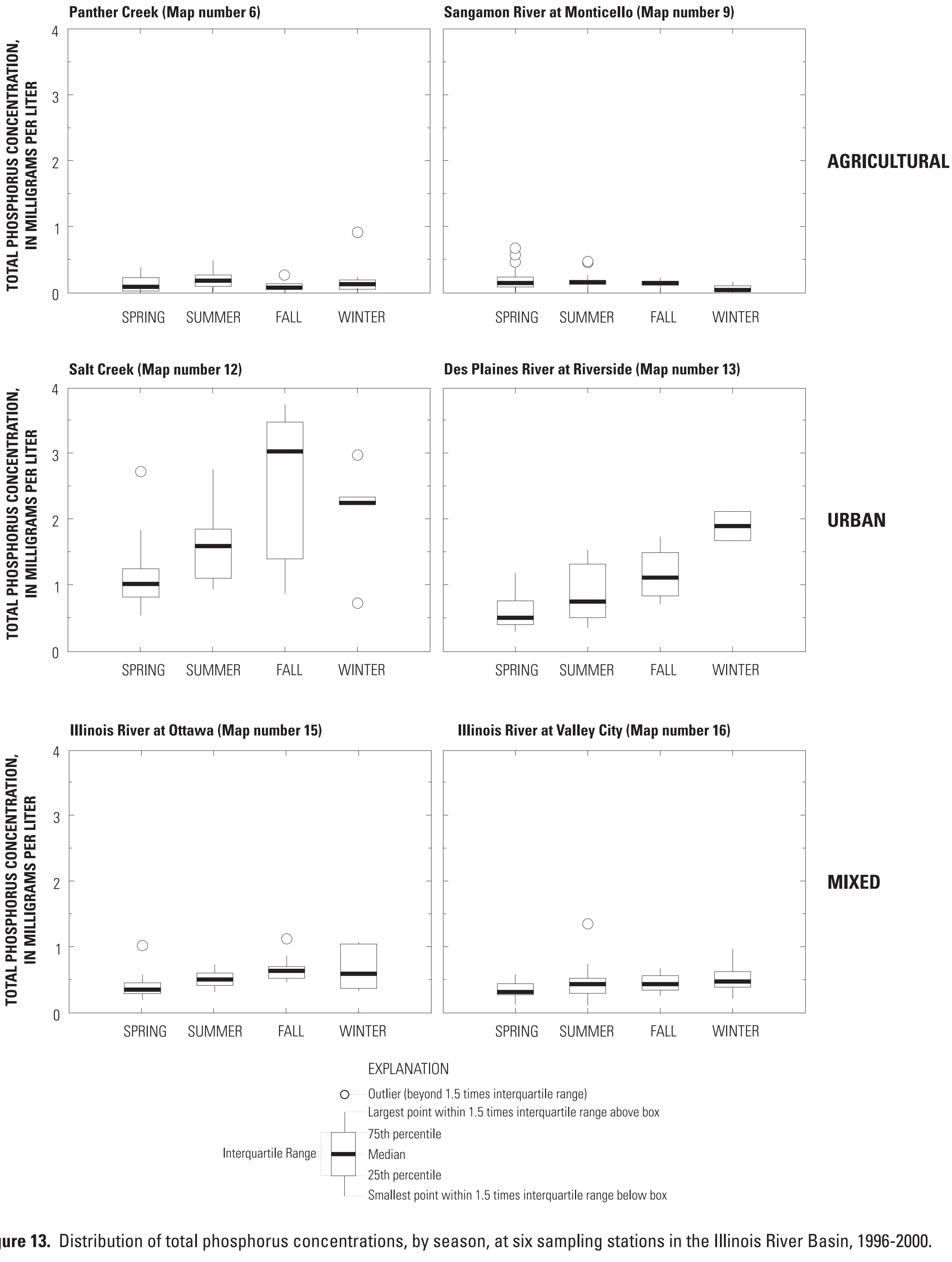


Figure 13. Distribution of total phosphorus concentrations, by season, at six sampling stations in the Illinois River Basin, 1996-2000.

gen and phosphorus concentrations for streams in the IRB. Results of these analyses are given in table 6. Correlations with a Spearman's Rho value equal to or greater than 0.5 (indicating at least a moderately-strong correlation) are noted in bold type. Some of the correlations between NO_2^-+NO_3^--N, TP and streamflow at the six representative stations are shown in figures 14 and 15. In these figures, Salt Creek and Des Plaines River at Riverside were selected to represent urban watersheds and Sangamon River at Monticello and Panther Creek were selected to represent streams in predominantly agricultural watersheds. As previously mentioned, the Illinois River stations integrate multiple land-use areas.

In streams for which nutrient inputs are predominantly from non-point agricultural sources, concentrations of NO_2^-+NO_3^--N were virtually always positively correlated with streamflow. In contrast, negative correlations between NO_2^-+NO_3^--N concentrations and streamflow (dilutions) were found for streams in predominantly urban watersheds (Salt Creek, the Des Plaines River at Riverside, and the CSSC) where most of the nitrogen input comes from relatively constant point-sources and increases in streamflow result in dilution of these sources.

The relation between NO_2^-+NO_3^--N and streamflow is closest during the initial increases in streamflow and concentrations, whether increased (non-point sources) or decreased (point sources), tend to remain relatively constant through further increases in streamflow (fig. 15). However, for many of the streams in agricultural watersheds (Sugar Creek, Iroquois River, Des Plaines River at Russell, Indian Creek, Panther Creek, Mackinaw River (map no. 7), Sangamon River near Oakford, and the La Moine River) concentrations increase with streamflow only to a certain point. At streamflows greater than this point, concentrations decreased. It is presumed that the readily available sources of NO_2^-+NO_3^--N were flushed during increasing streamflows in these watersheds and further increases or high streamflow conditions resulted in lower concentrations because of dilution effects. This finding was also noted for other streams in the Mississippi River basin (Coupe, 2002, Schnoebelen and others, 1999, Becher and others, 2001).

The strongest positive correlations for NO_2^-+NO_3^--N were found for agricultural watersheds in the LIRB. Subsurface tile-drainage is extensive in these watersheds and tile-drain water often has high concentrations of dissolved nitrogen and is an important component of nitrogen transport (Gentry and others, 1998, Baker and others, 2003, McIsaac and Xuetao, 2003). Similarly strong negative correlations between NO_2^-+NO_3^--N concentrations and streamflow were determined for the urban watershed stations where dilution of nitrogen point source inputs occurs. The Illinois River stations represent mixed land-use watersheds and data from both of the Illinois River stations showed positive correlations between NO_2^-+NO_3^--N concentrations and streamflow. These results incicate that non-point sources and agricultural areas of the watershed were predominant sources of NO_2^-+NO_3^--N.

The relations between streamflow and other nitrogen forms were similar to those for NO_2^-+NO_3^--N with regards to whether they were positive or negative correlations at sites representing agricultural and urban land watersheds. However, correlations of other nitrogen forms were typically not as strong (as indicated by the Spearman Rank Correlation coefficient) as correlations for NO_2^-+NO_3^--N at most stations. NO_2^-+NO_3^--N was the only nitrogen form found to have a Spearman Rank Correlation coefficient greater than 0.5 at every station in the LIRB and at all but one station in the UIRB. Borah and others (2003) suggest that correlations between streamflow and NO_3^--N vary with climate, season, and land-use practices and that analyses using short time periods (days, weeks, or seasons) rather than year-round data sets might indicate varying strengths and directions in these correlations.

Phosphorus concentrations were not always correlated to streamflow in the IRB. Correlations among phosphorus concentrations and streamflow were not as common as correlations between nitrogen forms and streamflow and were typically negative (table 6). Correlation coefficients were largest in the intensive urban watersheds of Salt Creek and Des Plaines River at Riverside. All three forms of phosphorus were negatively correlated with streamflow at these stations because of dilution of point-source phosphorus sources. Similar negative correlations were identified for the mixed land-use watersheds represented by the Illinois River and the Sangamon River near Oakford stations, indicating the effects of urban phosphorus sources. Graphs of TP and streamflow are shown for six stations in figure 14. These graphs show that the relations between TP and streamflow differ even among those stations having similar Spearman Rank correlations. In Salt Creek and at Des Plaines River at Riverside, there is a dramatic decrease in TP concentration with the initial increases in streamflow. However, this initial reduction levels off after point-source inputs are diluted and little further reduction in TP concentration is observed with further increases in streamflow (fig. 14). A similar pattern is seen for Illinois River at Ottawa, indicating the effect of urban point sources of phosphorus. The graphs for

Table 6. Spearman rank sum correlation results between streamflow and nitrogen, phosphorus, and suspended-sediment concentrations in the Illinois River Basin, 1996-2000.

[Correlation coefficients greater than 0.50 or less than -0.50 shown in bold; map no. in parentheses following station name, see figure 2 and table 2]

	Spearman Rank Correlation Coefficient with Streamflow															
	Agricultural											Urban			Mixed	
Constituent	Kankakee River (1)	Sugar Creek (2)	Iroquois River (3)	Des Plaines River at Russell (4)	Nippersink Creek (5)	Panther Creek (6)	Mackinaw River (7)	Indian Creek (8)	Sangamon River at Monticello (9)	Sangamon River at Oakford (10)	LaMoine River (11)	Salt Creek (12)	Des Plaines River at Riverside (13)	Chicago Sanitary and Ship Canal (14)	Illinois River at Ottawa (15)	Illinois River at Valley City (16)
Ammonia-N, dissolved	**0.51**	0.35	**0.73**	0.31	**0.70**	0.26	-0.08	0.08	0.47	0.21	**0.54**	0.15	0.08	**-0.52**	0.39	-0.10
Nitrite-N, dissolved	**.86**	**.64**	**.66**	.36	**.51**	.43	.30	-.16	**.64**	.44	**.62**	-.15	-.20	-.40	-.02	.08
Ammonia plus organic-N, total	**.76**	**.78**	**.51**	-.01	**.85**	-.05	.34	-.05	.40	.29	**.51**	.11	-.04	-.29	.24	.02
Nitrite plus nitrate-N, dissolved	**.85**	**.85**	**.77**	**.54**	.38	**.87**	.90	**.90**	**.76**	**.86**	**.60**	**-.89**	**-.78**	**-.52**	**.65**	**.74**
Phosphorus, total	**.68**	.47	.45	-.02	**.84**	-.04	.44	-.14	.40	-.43	**.59**	**-.82**	**-.72**	-.14	-.40	-.33
Phosphorus, dissolved	**.51**	.20	**.57**	.19	**.74**	-.06	.33	-.34	.18	**-.59**	**.71**	**-.86**	**-.81**	-.17	**-.60**	**-.80**
Orthophosphate, dissolved	**.73**	.34	**.62**	.20	**.83**	-.04	.36	-.35	.15	**-.67**	**.72**	**-.86**	**-.80**	-.33	**-.61**	**-.80**
Suspended sediment	**.50**	**.78**	.49	**-.63**	**.56**	.28	**.71**	**.63**	.43	**.71**	**.77**	.39	.37	-.24	.36	.24

Panther Creek and Sangamon River at Monticello show TP concentrations that continue to increase with increasing streamflow for the range over which samples were collected in these agricultural watersheds. This relation was seen for all agricultural watersheds.

No correlations among any forms of phosphorus and streamflow were found for the CSSC, even though the CSSC receives substantial phosphorus loading from multiple large wastewater-treatment plants. Streamflow in the CSSC is composed primarily of water diverted from Lake Michigan, which has low phosphorus concentration, and wastewater effluent, which has relatively high phosphorus concentrations. Because increases in streamflow in the CSSC typically result from increased output from wastewater-treatment plants or combined sewage and stormwater overflows (the typical sources of phosphorus to the stream), the phosphorus concentration does not change substantially with increases in streamflow. A year-round data set was used for this correlation analysis and the relation between streamflow and phosphorus in the CSSC might be different at various times or the year or in response to particular storm events.

Dissolved phosphorus and PO_4^{3-}-P concentrations were negatively correlated with streamflow in virtually all of the urban and mixed land-use watersheds, except for the CSSC. These correlations indicate the effect of point-source phosphorus inputs even in mixed land-use watersheds with predominantly agricultural areas. Positive correlations between streamflow and dissolved phosphorus forms

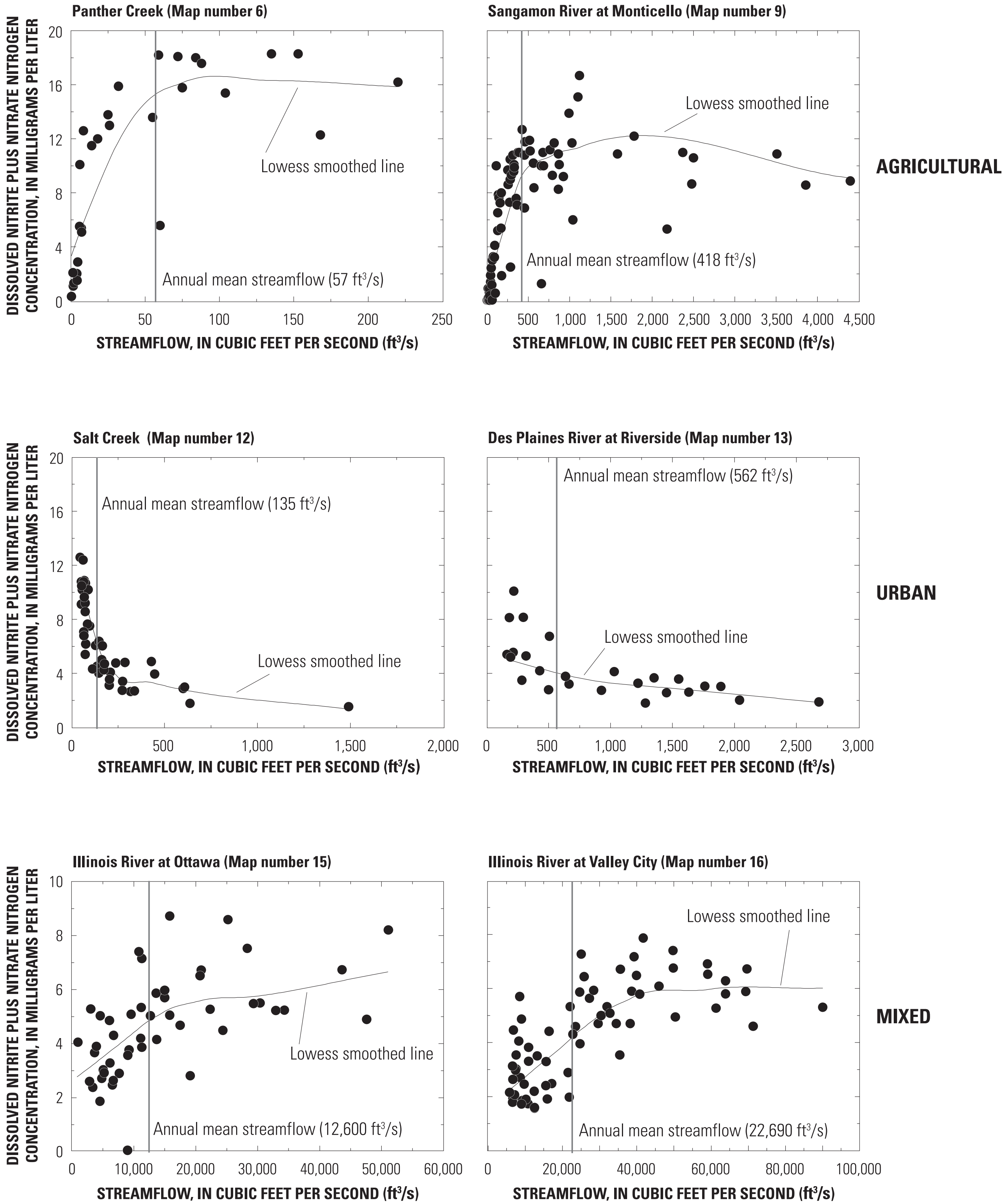


Figure 14. Relations between nitrite plus nitrate nitrogen concentrations and streamflow at six sampling stations in the Illinois River Basin, 1996-2000. A Lowess smoothing factor of 0.80 was used for all graphs.

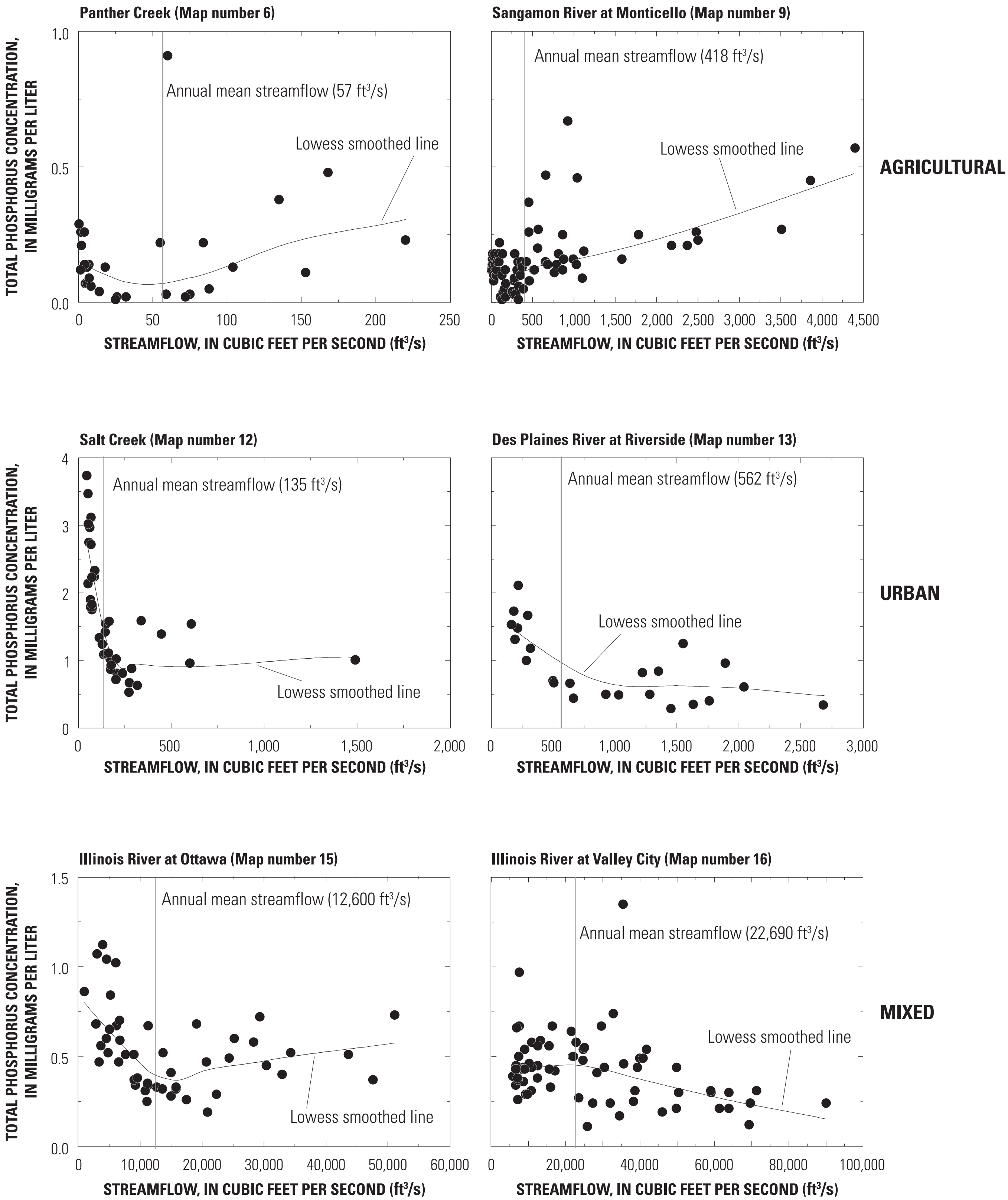


Figure 15. Relations between total phosphorus concentrations and streamflow at six sampling stations in the Illinois River Basin, 1996-2000. A Lowess smoothing factor of 0.80 was used for all graphs.

were indicated for three of the agricultural watersheds in the UIRB, but for only one agricultural watershed (LaMoine River) in the LIRB.

Land Use

In general, agricultural land use was the primary factor affecting in-stream nitrogen concentrations (dissolved NO_2^-+NO_3^--N in particular), whereas phosphorus concentrations were affected primarily by urban land uses. There are a wide variety of land-use activities and practices in the IRB. The UIRB Study Unit included five agricultural and three urban stations (table 2) and the LIRB Study Unit included five agricultural and three mixed land-use stations.

Nitrogen was present principally in the fully oxidized NO_3^- form at all stations; however, transitional forms were found at high concentrations at stations in urban watersheds (table 5 and figs. 4–7). NO_2^-+NO_3^--N concentrations were typically higher and more variable in streams draining agricultural watersheds, but phosphorus concentrations were higher and more variable in urban watersheds.

The seasonality of in-stream nutrient concentrations also was affected by land-use practices. Nitrogen concentrations in agricultural basins were typically highest in the spring because of fall and spring fertilizer application, whereas concentrations in urban watersheds were typically highest in the winter and were attributed to the constant point-source inputs. The characteristics of nitrogen and phosphorus concentrations at the two Illinois River stations, which represent cumulative affects from multiple landuses, reinforce the importance of non-point sources on nitrogen concentrations and the influence of point-sources on phosphorus concentrations.

As mentioned earlier, streamflow conditions varied among the respective sampling periods for the UIRB and LIRB Study Unit investigations (table 2). Wilcoxon signed rank analyses were run for some stations comparing daily streamflow values for the 1997-98 water years[1] (LIRB intensive study period) to daily streamflow values for the 1999-2000 water years (UIRB intensive study period). These analyses identified statistically-significant differences in streamflow conditions between the two periods. The statistical tests were also run using streamflow data for single years (1997, 1998, 1999 and 2000) and these tests also indicated statistically significant differences in streamflow among all four of the years.

[1] A water year is the period from October 1 of the previous year to September 30 of the year designated.

Differences in streamflow conditions among the four years and even among different parts of watersheds in any given year contribute to the uncertainty of defining differences in concentrations and loads of nutrients because of land-use practices. These differences need to be recognized and considered when evaluating the results of the land-use comparisons. However, the consistency of the differences in nutrient characteristics between agricultural and urban land-use watersheds indicates that streamflow conditions were not the primary factor effecting nutrient concentration and flux characteristics, but that land-use effects were more important.

Suspended Sediment

Median concentrations of suspended sediment at the stations ranged from 55 to 184 mg/L, with individual sample concentrations as low as 1 mg/L and as high as 3,110 mg/L (table 5 and fig. 16). Concentrations were generally higher at the UIRB sites than at the LIRB stations, with the exceptions of the Kankakee River and the CSSC. The lowest and least variable concentrations were found in the Illinois River at Ottawa, Panther Creek, Kankakee River, and the CSSC. The low concentrations at these stations are attributed to various factors. There are dams on both the Illinois and Fox Rivers approximately five miles upstream from the Illinois River at Ottawa station. These dams may function as sediment traps. Water in the CSSC is composed primarily of water diverted from Lake Michigan and wastewater effluent; both of which typically have low suspended-sediment concentrations. The Kankakee River watershed has sandy soils and coarse sediment particles that settle out of the water column relatively quickly (within hours) in stream reaches where the velocity is not great enough to keep the sediment particles in suspension. Median suspended-sediment concentrations were lowest in Panther Creek, where the channel bottom is composed primarily of sand and gravel and there is substantial grass and forbs riparian cover upstream (Sorenson and others, 1999). The highest concentration and the greatest variability in suspended-sediment concentration was found in the La Moine River. The stream bottom at this station is composed principally of silt and clay (Adolphson and others, 2001). Suspended-sediment concentration and streamflow were strongly correlated (correlation coefficient = 0.77) at this station (table 6), although similar correlations were determined for three other stations in the LIRB. Unlike nutrient concentrations, which were similar at the two Illinois River stations, the median suspended-sediment concentration in the Illinois River at Valley City was twice the median concentration at Illinois River at Ottawa. Suspended-sediment concentrations were generally more variable, although not necessarily higher, in agricultural watersheds than in urban watersheds.

Analyses of the percentage of suspended sediment finer than 0.062 mm, a differentiation commonly referred to as the sand/fine break, indicated that suspended sediment in UIRB watersheds is composed primarily of fine material (all median values were greater than 90 percent fine material at the UIRB stations), whereas only the La Moine River and the Illinois River at Valley City had similarly high percentages of fine-sized particles in the LIRB.

Suspended-sediment concentrations were found to be fairly consistent among seasons and only marginally greater during summer months in the Kankakee River watershed and at most of the stations in the LIRB. These differences could be due to the increased presence of algae and other organic material in the water column during the warmer months. Variability in suspended-sediment concentrations was greatest during the spring and summer seasons, presumably because of variations in streamflow resulting from thunderstorm precipitation, as well as biological production. There was little variation in suspended-sediment concentrations at the station on the Illinois River.

Fluxes and Yields of Nutrients and Suspended Sediment

Fluxes of nutrients and suspended sediment were calculated using data from the 1997-98 and 1999-2000 sampling periods for the LIRB and UIRB Study Units, respectively. Comparisons of the resulting flux estimates among stations in the LIRB and UIRB are representative of general flux magnitudes and relations among these stations.

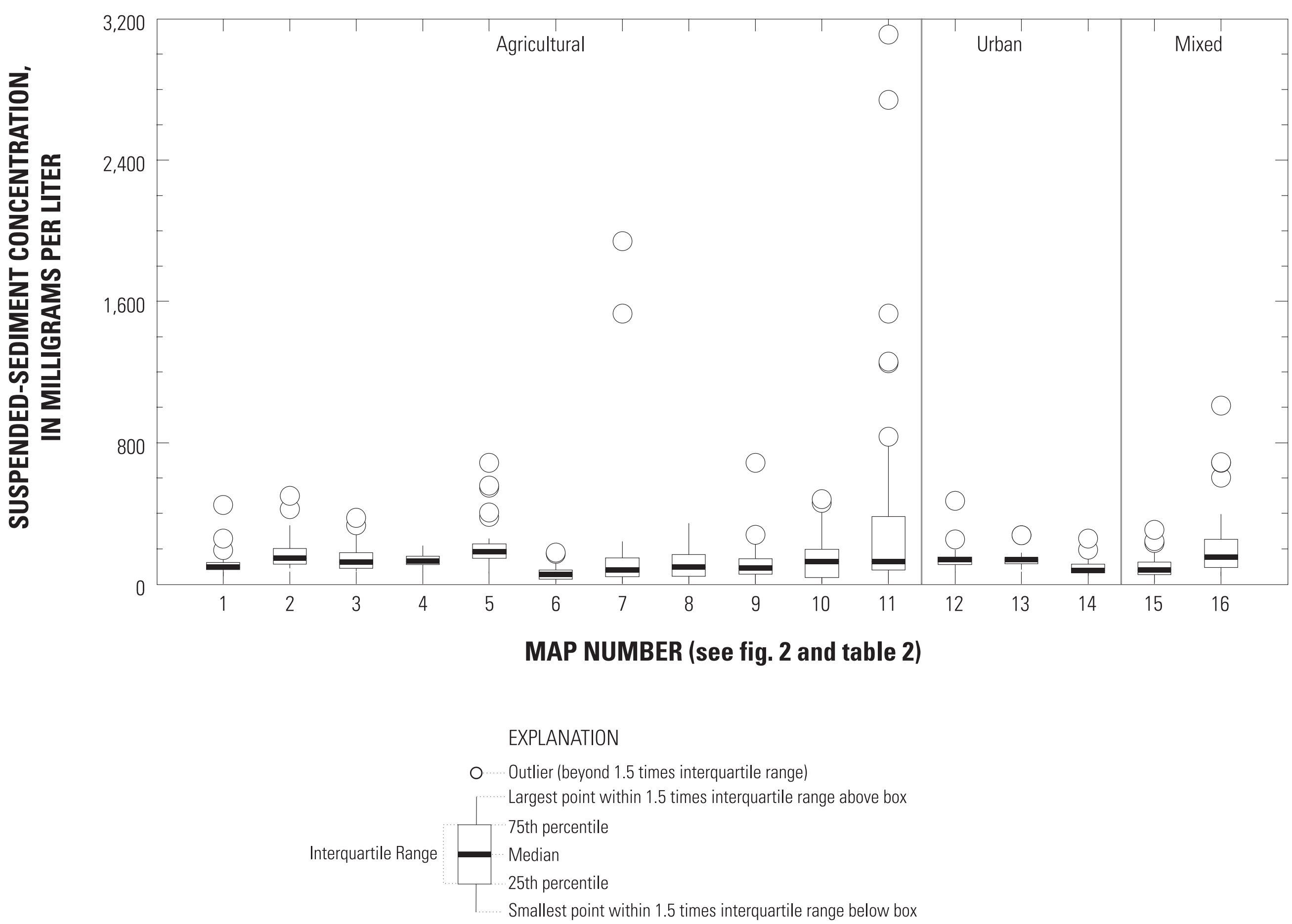


Figure 16. Distributions of suspended-sediment concentrations at sampling stations in the Illinois River Basin, 1996-2000.

However, climatic and hydrologic conditions varied during the different periods of sample collection. Streamflows at sampling stations in the LIRB were typically less than the long-term (1985-2002) averages in 1997, but were greater than the long-term averages in 1998 (table7). In the UIRB, streamflows in 1999 and 2000 were generally lower than the long-term average in the Kankakee River Basin and greater than the long-term average in the Des Plaines River Basin.

Mean fluxes of nutrients and suspended sediment calculated from the respective 2-year NAWQA sampling periods are presented in table 7. Fluxes and yields of nitrogen and phosphorus forms varied substantially throughout the IRB. Yields of specific nitrogen and phosphorus forms were influenced primarily by upstream land-use practices. Fluxes and yields of NH_3-N and NO_2^--N, nutrient forms generally associated with wastewater sources, were higher in predominantly urban watersheds, as well as at stations in mixed land-use watersheds. Yields of nitrate plus NO_2^-+ NO_3^--N were highest at stations in predominantly agricultural watersheds.

Nitrogen

Dissolved NH_3-N fluxes were largest in the Illinois River, simply because of the direct relation with streamflow. However, the mean NH_3-N flux in the Chicago Sanitary and Ship Canal (1,400 ton/yr) constituted virtually all (94 percent) of the NH_3-N flux in the Illinois River at Ottawa (1,500 ton/yr) and approximately 62 percent of the total NH_3-N flux in the Illinois River at Valley City (2,400 ton/yr). Yields of NH_3-N were highest in Salt Creek (0.28 (ton/mi^2)/yr), at Des Plaines River at Riverside (0.17 (ton/ mi^2)/yr), and in Panther Creek (0.17 (ton/mi^2)/yr). Salt Creek and Des Plaines River at Riverside are intensive urban watersheds. Panther Creek is a small stream (drainage area = 94 mi^2) in an intensive agricultural watershed, however, two wastewater-treatment plants and various hog farms are also present in the Panther Creek watershed and contribute to the nutrient load of the stream. Transport of NH_3-N in these streams is increased during March and April, corresponding to seasonal high streamflow conditions. There were many more high-flow events for Panther Creek in 1998 than there were in 1997. The NH_3-N flux in Panther Creek was likely resultant of local application of anhydrous NH_3-N fertilizer and runoff from pasture areas, whereas wastewater is the likely source of NH_3-N in the urban watersheds.

Fluxes of NO_2^--N were proportionally similar to the distribution of NH_3-N fluxes (table 7). NO_2^--N is a transitional form of nitrogen present during nitrification of reduced nitrogen forms and the decomposition of organic materials. The mean dissolved NO_2^--N flux in the CSSC (500 ton/yr) was just over one half of the mean flux in the Illinois River at Ottawa (860 ton/yr) and was an order of magnitude larger than at any other station, with the exception of Sangamon River near Oakford (190 ton/yr). In contrast to NH_3-N, the flux of NO_2^--N in the CSSC was only 27 percent of the flux in the Illinois River near Valley City. Similar to NH_3-N, the highest yields of NO_2^--N were in urban watersheds, mixed basins with urban inputs, and in Panther Creek. The high yield of NO_2^--N in Panther Creek indicates the presence of livestock and possibly the associated application of manure as fertilizer in the watershed.

Flux of total NH_3+organic-N was highest in the Illinois River and the flux in the Illinois River at Ottawa (16,000 ton/yr) was approximately 57 percent of the flux in the Illinois River at Valley City (28,000 ton/yr). The magnitude of the fluxes generally corresponded to streamflow. In general, NH_3-N contributed less than 5 percent of the NH_3+organic-N flux, indicating a large amount of organic nitrogen in IRB streams. Exceptions to this general result were the CSSC and Panther Creek, where dissolved NH_3-N constituted slightly over 10 percent of the NH_3+organic-N flux. The highest yield of NH_3+organic-N was for Salt Creek (2.1 (tons/mi^2)/yr), whereas the second highest yield was for Illinois River at Ottawa (1.4 (tons/mi^2)/yr). The CSSC contributes substantially to the dissolved NH_3+organic-N flux in the Illinois River at Ottawa. High yields were derived for two stations in agricultural watersheds; Des Plaines River at Russell and the LaMoine River. Both of these stations also had relatively high NH_3-N yields as compared to other streams.

Like many nitrogen forms, fluxes of NO_2^-+NO_3^--N were highest in the largest rivers because of streamflow. The flux of NO_2^-+NO_3^--N at Illinois River at Ottawa (69,100 ton/yr) was approximately one-half (48 percent) of the flux at Illinois River at Valley City (145,000 ton/yr). In noted contrast to previously discussed forms of nitrogen, fluxes of NO_2^-+NO_3^--N were lowest at stations in urban watersheds. The NO_2^-+NO_3^--N flux for the Kankakee River was notably smaller than might be expected based on the volume of streamflow and the predominant agricultural land use at this station. The highly permeable sandy soils and lower use of subsurface drainage in this watershed, as compared to other watersheds, allow soluble NO_3^--N to infiltrate into the ground and, consequently, less NO_3^--N is transported to surface-water bodies.

Table 7. Flux and yield estimates for nitrogen, phosphorus, and suspended sediment in the Illinois River Basin, 1996-2000.

[mi^2, square miles; ft^3/s, cubic foot per second; $(ft^3/s)/mi^2$, cubic foot per second per square mile; NAWQA, National Water-Quality Assessment; NA, not applicable; ton/yr, tons per year; $(ton/yr)/mi^2$, tons per year per square mile]

Station name and map number (fig. 2 and table 2)	Drainage area (mi^2)	Mean streamflow 1985-2002 (ft^3/s)	Mean streamflow during 2-Year NAWQA sampling (ft^3/s)	Mean streamflow yield during 2-year NAWQA sampling ($(ft^3/s)/mi^2$)
Kankakee River at Momence, Ill. (1)	2,294	2,081	1,721	0.75
Sugar Creek at Milford, Ill. (2)	446	379	199	.45
Iroquois River near Chebanse, Ill. (3)	2,091	1,740	1,119	.54
Des Plaines River at Russell, Ill. (4)	123	100	127	1.0
Nippersink Creek above Wonder Lake, Ill. (5)	192	63	81	.42
Panther Creek near El Paso, Ill. (6)	94	57	62	.66
Mackinaw River near Green Valley, Ill. (7)	1,073	730	780	.73
Indian Creek near Wyoming, Ill. (8)	63	50	63	1.0
Sangamon River at Monticello, Ill. (9)	550	422	526	.96
Sangamon River near Oakford, Ill. (10)	5,093	3,488	3,968	.78
LaMoine River at Colmar, Ill. (11)	655	460	569	.87
Salt Creek near Western Springs, Ill. (12)	115	131	194	1.7
Des Plaines River at Riverside, Ill. (13)	630	551	789	1.2
Chicago Sanitary and Ship Canal at Romeoville, Ill. (14)	NA	3,488	2,672	NA
Illinois River at Ottawa, Ill. (15)	10,949	12,636	14,037	1.3
Illinois River at Valley City, Ill. (16)	26,743	22,910	26,342	.98

Station name and map number (fig. 2 and table 2)	Ammonia Nitrogen, Dissolved		Nitrite Nitrogen, Dissolved	
	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling ($ton/mi^2/yr$)	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling ($ton/mi^2/yr$)
Kankakee River at Momence, Ill. (1)	78	0.03	39	0.02
Sugar Creek at Milford, Ill. (2)	7.8	.02	13	.03
Iroquois River near Chebanse, Ill. (3)	92	.04	41	.02
Des Plaines River at Russell, Ill. (4)	9.0	.07	6	.05
Nippersink Creek above Wonder Lake, Ill. (5)	4.7	.02	1	.01
Panther Creek near El Paso, Ill. (6)	16	.17	6	.06
Mackinaw River near Green Valley, Ill. (7)	49	.04	25	.02
Indian Creek near Wyoming, Ill. (8)	3.7	.06	3	.04
Sangamon River at Monticello, Ill. (9)	34	.06	32	.06
Sangamon River near Oakford, Ill. (10)	260	.05	190	.04
LaMoine River at Colmar, Ill. (11)	74	.11	33	.05
Salt Creek near Western Springs, Ill. (12)	32	.28	13	.11
Des Plaines River at Riverside, Ill. (13)	100	.17	43	.07
Chicago Sanitary and Ship Canal at Romeoville, Ill. (14)	1,500	NA	500	NA
Illinois River at Ottawa, Ill. (15)	1,600	.15	860	.08
Illinois River at Valley City, Ill. (16)	2,400	.09	1,830	.07

Table 7. Flux and yield estimates for nitrogen, phosphorus, and suspended sediment in the Illinois River Basin, 1996-2000—continued.

[mi^2, square miles; ft^3/s, cubic foot per second; (ft^3/s)/mi^2, cubic foot per second per square mile; NAWQA, National Water-Quality Assessment; NA, not applicable; ton/yr, tons per year; (ton/yr)/mi^2, tons per year per square mile]

	Total Ammonia plus Organic Nitrogen		Nitrite plus Nitrite Nitrogen, Dissolved	
Station name	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling (ton/mi²/yr)	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling (ton/mi²/yr)
Kankakee River at Momence, Ill. (1)	1,400	0.60	3,900	1.7
Sugar Creek at Milford, Ill. (2)	90	.20	2,700	6.1
Iroquois River near Chebanse, Ill. (3)	1,200	.56	16,000	7.7
Des Plaines River at Russell, Ill. (4)	130	1.1	890	7.2
Nippersink Creek above Wonder Lake, Ill. (5)	110	.56	420	2.2
Panther Creek near El Paso, Ill. (6)	41	.43	5,600	60
Mackinaw River near Green Valley, Ill. (7)	730	.68	15,600	14
Indian Creek near Wyoming, Ill. (8)	35	.56	1,100	18
Sangamon River at Monticello, Ill. (9)	430	.78	12,500	23
Sangamon River near Oakford, Ill. (10)	4,800	.94	41,100	8.1
LaMoine River at Colmar, Ill. (11)	700	1.1	6,900	11
Salt Creek near Western Springs, Ill. (12)	240	2.1	2,800	25
Des Plaines River at Riverside, Ill. (13)	580	.91	14,800	23
Chicago Sanitary and Ship Canal at Romeoville, Ill. (14)	4,400	NA	630	NA
Illinois River at Ottawa, Ill. (15)	16,000	1.4	69,100	6.3
Illinois River at Valley City, Ill. (16)	28,000	1	145,000	5.4

	Total Nitrogen		Total Phosphorus	
Station name	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling (ton/mi²/yr)	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling (ton/mi²/yr)
Kankakee River at Momence, Ill. (1)	5,300	2.3	190	0.08
Sugar Creek at Milford, Ill. (2)	2,800	6.3	190	.43
Iroquois River near Chebanse, Ill. (3)	17,000	8.1	250	.12
Des Plaines River at Russell, Ill. (4)	1,000	8.1	21	.17
Nippersink Creek above Wonder Lake, Ill. (5)	520	2.7	17	.09
Panther Creek near El Paso, Ill. (6)	5,600	60	6	.07
Mackinaw River near Green Valley, Ill. (7)	16,000	15	180	.18
Indian Creek near Wyoming, Ill. (8)	1,100	18	15	.24
Sangamon River at Monticello, Ill. (9)	13,000	24	110	.20
Sangamon River near Oakford, Ill. (10)	46,000	9	1,500	.30
LaMoine River at Colmar, Ill. (11)	7,600	12	230	.35
Salt Creek near Western Springs, Ill. (12)	3,100	27	1,500	13
Des Plaines River at Riverside, Ill. (13)	15,000	24	1,600	2.6
Chicago Sanitary and Ship Canal at Romeoville, Ill. (14)	5,100	NA	3,600	NA
Illinois River at Ottawa, Ill. (15)	85,000	7.8	5,700	.52
Illinois River at Valley City, Ill. (16)	170,000	6.4	9,700	.36

Table 7. Flux and yield estimates for nitrogen, phosphorus, and suspended sediment in the Illinois River Basin, 1996-2000—continued.

[mi², square miles; ft³/s, cubic foot per second; (ft³/s)/mi², cubic foot per second per square mile; NAWQA, National Water-Quality Assessment; NA, not applicable; ton/yr, tons per year; (ton/yr)/mi², tons per year per square mile]

	Phosphorus, Dissolved		Orthophosphate, Dissolved	
Station name	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling (ton/mi²/yr)	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling (ton/mi²/yr)
Kankakee River at Momence, Ill. (1)	51	0.02	35	0.02
Sugar Creek at Milford, Ill. (2)	57	.13	47	.11
Iroquois River near Chebanse, Ill. (3)	89	.04	120	.06
Des Plaines River at Russell, Ill. (4)	10	.08	9	.07
Nippersink Creek above Wonder Lake, Ill. (5)	3	.02	4	.02
Panther Creek near El Paso, Ill. (6)	3	.03	4	.04
Mackinaw River near Green Valley, Ill. (7)	61	.06	230	.21
Indian Creek near Wyoming, Ill. (8)	6	.09	4	.06
Sangamon River at Monticello, Ill. (9)	47	.09	43	.08
Sangamon River near Oakford, Ill. (10)	900	.18	76	.02
LaMoine River at Colmar, Ill. (11)	73	.11	64	.10
Salt Creek near Western Springs, Ill. (12)	210	1.8	190	1.6
Des Plaines River at Riverside, Ill. (13)	440	.70	390	.62
Chicago Sanitary and Ship Canal at Romeoville, Ill. (14)	3,500	NA	9	NA
Illinois River at Ottawa, Ill. (15)	3,600	.32	3,400	.31
Illinois River at Valley City, Ill. (16)	4,500	.17	4,200	.16

	Suspended Sediment	
Station name	Mean flux during 2-Year NAWQA sampling (ton/yr)	Mean yield during 2-year NAWQA sampling (ton/mi²/yr)
Kankakee River at Momence, Ill. (1)	170,000	74
Sugar Creek at Milford, Ill. (2)	124,000	280
Iroquois River near Chebanse, Ill. (3)	169,000	81
Des Plaines River at Russell, Ill. (4)	25,300	210
Nippersink Creek above Wonder Lake, Ill. (5)	16,800	88
Panther Creek near El Paso, Ill. (6)	9,089	69
Mackinaw River near Green Valley, Ill. (7)	342,000	320
Indian Creek near Wyoming, Ill. (8)	20,600	330
Sangamon River at Monticello, Ill. (9)	64,300	120
Sangamon River near Oakford, Ill. (10)	1,260,000	250
LaMoine River at Colmar, Ill. (11)	450,000	690
Salt Creek near Western Springs, Ill. (12)	31,200	270
Des Plaines River at Riverside, Ill. (13)	171,000	270
Chicago Sanitary and Ship Canal at Romeoville, Ill. (14)	283,000	NA
Illinois River at Ottawa, Ill. (15)	1,060,000	97
Illinois River at Valley City, Ill. (16)	4,880,000	180

Yields of NO_2^-+NO_3^--N were substantially higher than other forms of nitrogen in both agricultural and urban watersheds. The yield for Panther Creek (60 (tons/mi^2)/yr) was the highest yield at any station and was over twice the next highest yield (25 (tons/mi^2)/yr for Salt Creek). The dissolved NO_2^-+NO_3^--N yield for Illinois River at Ottawa (the outlet for the UIRB) and the yield for Illinois River at Valley City (the outlet for the LIRB) were similar and were among the lowest yields for all stations. The lowest yields were found for the Kankakee River and Nippersink Creek watersheds. Dissolved NO_2^-+NO_3^--N fluxes and yields in the Iroquois River were approximately four times larger than in the Kankakee River, although the drainage areas for the two stations are comparable. The differences in yields are likely due to differences in soil types and corresponding infiltration characteristics.

The cumulative sum of the NO_2^-+NO_3^--N fluxes at Illinois River at Ottawa and the tributary watersheds in LIRB was approximately 92 percent of the NO_2^-+NO_3^--N flux at Illinois River at Valley City, indicating the conservation of NO_2^-+NO_3^--N in the stream system. The cumulative flux of NO_2^-+NO_3^--N for the watersheds upstream of Illinois River at Ottawa constituted only about 50 percent of the total flux at Ottawa. However, the Fox River (not sampled during the UIRB study period) likely contributes a substantial amount of NO_2^-+NO_3^--N to the Illinois River upstream of Ottawa.

Phosphorus

The contribution of phosphorus from urban areas of the IRB was pronounced. The largest fluxes of TP, DP, and PO_4^{3-}-P were for the Illinois River at Valley City (9,700 ton/yr TP), Illinois River at Ottawa (5,700 ton/yr TP), and the CSSC (3,600 ton/yr TP). Unlike soluble NO_3^--N, loads of TP were similar in the Kankakee River and Iroquois River watersheds. Yields of TP were distinctly higher in urban watersheds. The highest TP yield (13 (tons/mi^2)/yr) was calculated for Salt Creek and the second highest yield was for Des Plaines River at Riverside. Total phosphorus yields were also high for the Illinois River (mixed land uses) and in the Sugar Creek and LaMoine River watersheds (agricultural watersheds with a high percentage of fine-grained sediments).

Dissolved phosphorus flux generally accounted for between 20 and 60 percent of the TP flux. The relative magnitudes of DP fluxes and yields among the stations were similar to those for TP. However, the DP flux for CSSC was similar to the flux for Illinois River at Ottawa, indicating a minimal contribution of DP from the Fox River basin. The flux at Illinois River at Valley City was approximately equal to the cumulative sum of the fluxes from the upstream stations. The average flux of DP constituted only 13–27 percent of the TP flux in urban watersheds, with the exception of the CSSC where it constituted 96 percent of the TP flux. In contrast, the DP flux generally constituted between 30 and 50 percent of the TP flux in agricultural watersheds. Yields of DP were generally 30–50 percent of the TP yields in most watersheds, but only 13 percent of the TP yield in Salt Creek, a highly urbanized watershed.

Suspended Sediment

Fluxes of suspended sediment generally corresponded to watershed size. However, fluxes and yields of suspended sediment in agricultural watersheds of the LIRB were comparatively higher than in the urban watersheds of the UIRB. The suspended-sediment flux at Illinois River at Valley City (4,880,000 ton/yr) was approximately four times the flux at Illinois River at Ottawa (1,060,000 ton/yr). The suspended sediment flux in the Sangamon River at Oakford was itself larger than the flux at Illinois River at Ottawa. Climatic variation had a substantial effect on suspended-sediment fluxes and, in some instances, fluxes computed for the LIRB stations for 1998 were substantially larger than those computed for 1997. The suspended-sediment flux at Sangamon River at Oakford for 1998 was almost five times the flux in 1997.

Suspended sediment yields generally ranged from about 200 to 300 (tons/mi^2)/yr for stations in the both the UIRB and LIRB and in both urban and agricultural watersheds. The yield at Valley City (180 (tons/mi^2)/yr) was approximately double the yield at Ottawa (97 (tons/mi^2)/yr). Surprisingly, yields of suspended-sediment for four agricultural watersheds (Kankakee River, Iroquois River, Panther Creek, and Nippersink Creek) were lower than the yields for the two urban watersheds (Salt Creek and Des Plaines River at Riverside). Streams in watersheds with predominantly agricultural land use typically have higher amounts of suspended sediment because of the erosion of sediment from fields and stream channels. The suspended sediment yield for the La Moine River (690 (tons/mi^2)/yr) was over twice the yield estimated for any other station.

Seasonality

In-stream flux of nutrients varied by climatic season, principally because of seasonal streamflow fluctuations. Plots of NO_2^-+NO_3^--N and TP over time at selected stations in the IRB are shown in figures 17–22. A general increase in flux magnitude typically begins in the late winter or early spring and commonly continues through June. In addition to snowmelt during this time, thawing of soils releases some nutrients and they are subsequently transported to the streams through overland runoff and shallow ground-water flow.

The seasonal variation in nutrient flux in the urban Salt Creek and Des Plaines River watersheds is not as great as in many other watersheds. Seasonality of flux in these watersheds is minimized because of the consistency of point-source nutrient sources. It should be noted that although concentrations can be diluted during high streamflow events, the flux of a nutrient can be either unchanged or increased during these times if there is a predominant point source.

Seasonal variation in suspended-sediment fluxes closely resembled seasonal streamflow patterns. Time-series graphs of suspended-sediment flux and streamflow for three watersheds in the IRB are shown in figure 23. Suspended-sediment flux in the Illinois River was substantially higher from January through July and lowest during the fall and early winter months. A similar pattern is seen for Sangamon River at Monticello, however, flux remained relatively high at this station through August. In Salt Creek, seasonal variation in suspended-sediment flux was less evident with only slightly larger flux from January through July 1999. Both streamflow and suspended-sediment flux at this station have short-term temporal variability throughout the year and less seasonal variation than the other stations. These variations are characteristic of urban watersheds and result from both the year-round inputs from treatment plants and return flows as well as the hydrologic characteristics of urban watersheds with a high percentage of impervious land cover. The general correspondence between suspended-sediment flux and streamflow is expected in most watersheds and particularly in those with agricultural areas where sediment is transported through overland runoff, bank erosion, and the re-suspension of benthic sediments during periods of precipitation and increased stream velocity.

Comparison of Flux Estimates with Previous Studies

Short (1999) calculated nutrient fluxes based on data collected through the IEPA ambient monitoring program from 1981 to 1996. Sullivan (2000) also calculated fluxes based on data from the IEPA ambient monitoring program using data from 1978 to 1997. These references provide flux calculations based on long-term data sets of at least 15 years in duration. Analyses of these long-term data sets provide approximations of the average long-term fluxes and minimize sensitivity to short-term temporal conditions, whereas flux estimates calculated for this report were based on 2-year intensive data collection periods and resulted in values which were more strongly affected by the short-term climatic, hydrologic, and land-use conditions present at the time of sample collection. A comparison of the flux values presented by these three sources provides information regarding both the long-term average fluxes and the temporal variability in fluxes of nutrients at these stations.

Nitrogen

Sullivan (2000) reported fluxes of various nitrogen forms, but did not report estimates for total nitrogen or inorganic nitrogen. Short (1999) reported flux estimates for inorganic nitrogen and total nitrogen. For purposes of this comparison, estimates of inorganic nitrogen fluxes were calculated from Sullivan's reported data as the summation of the reported NO_2^-+NO_3^--N and NH_3-N fluxes. The resulting estimates of inorganic nitrogen fluxes reported by Short and flux estimates from Sullivan's data were in general agreement. This result was not unexpected because the estimates were based on similar and overlapping IEPA data sets.

Inorganic nitrogen fluxes from the NAWQA data were calculated as the summation of NH_3-N and NO_2^-+NO_3^--N fluxes. Comparisons among inorganic nitrogen fluxes using NAWQA data and the long-term flux estimates derived by Short and Sullivan are shown in table 8. Inorganic-nitrogen flux estimates using NAWQA data were similar to the Short (1999) and Sullivan (2000) estimates at those stations for which the streamflow during the 2-year NAWQA sampling period was similar to the long-term average streamflow (Kankakee River, Sugar Creek and Illinois River at Ottawa). Mean annual streamflows were less than the 1985-2000 average in the Kankakee River Basin in 1999 and 2000 and the flux estimates based on the NAWQA data for this watershed were consequently lower than the estimates by Short and Sullivan. Similarly, mean annual streamflows in most of the LIRB in 1998 was substantially higher than the long-term average and the NAWQA flux estimates of inorganic nitro-

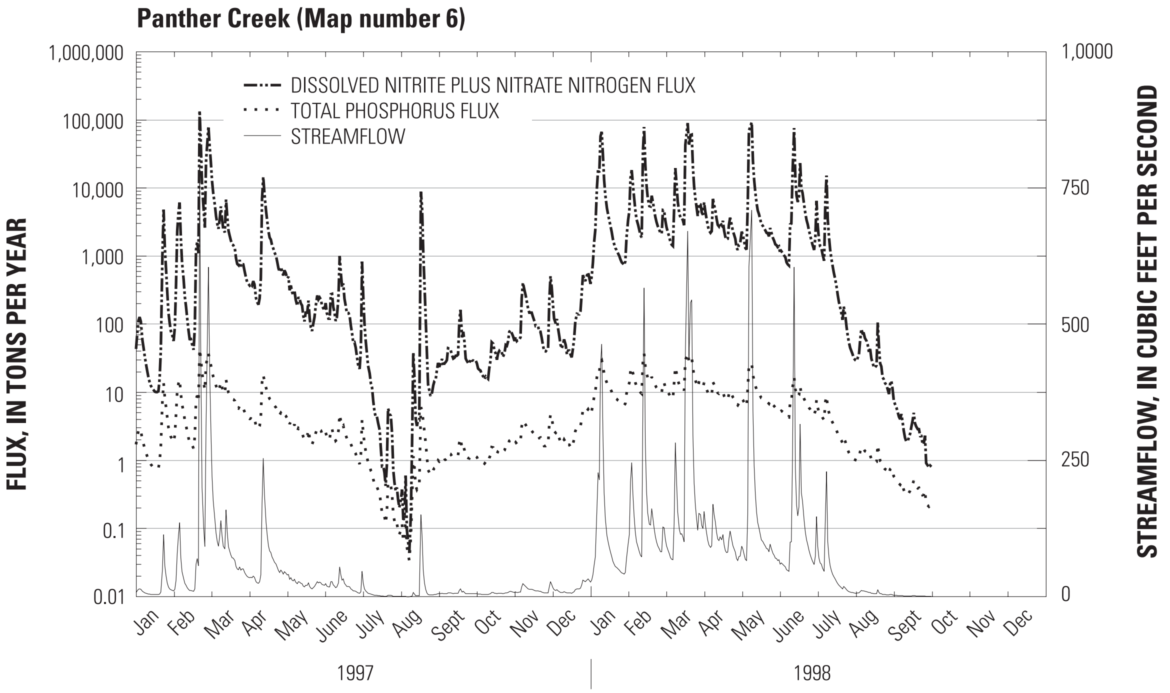


Figure 17. Flux of dissolved nitrite plus nitrate nitrogen and total phosphorus, and streamflow in Panther Creek near El Paso Illinois, 1997-98.

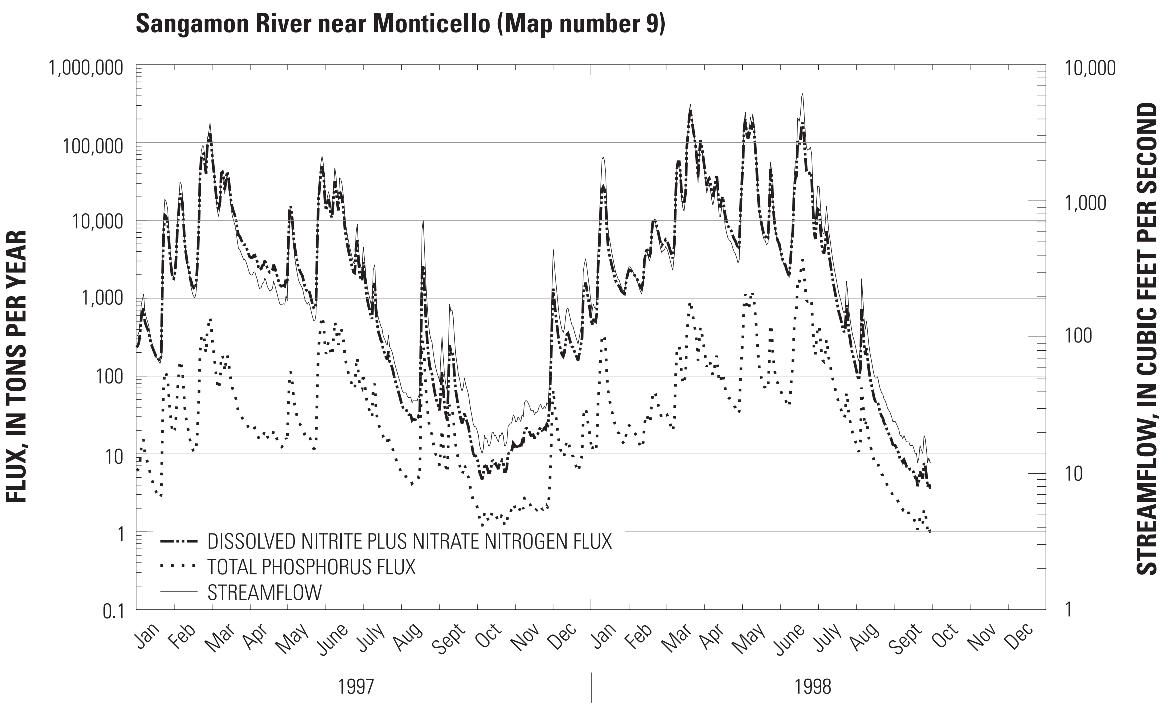


Figure 18. Flux of dissolved nitrite plus nitrate nitrogen and total phosphorus, and streamflow in Sangamon River at Monticello, Illinois, 1997-98.

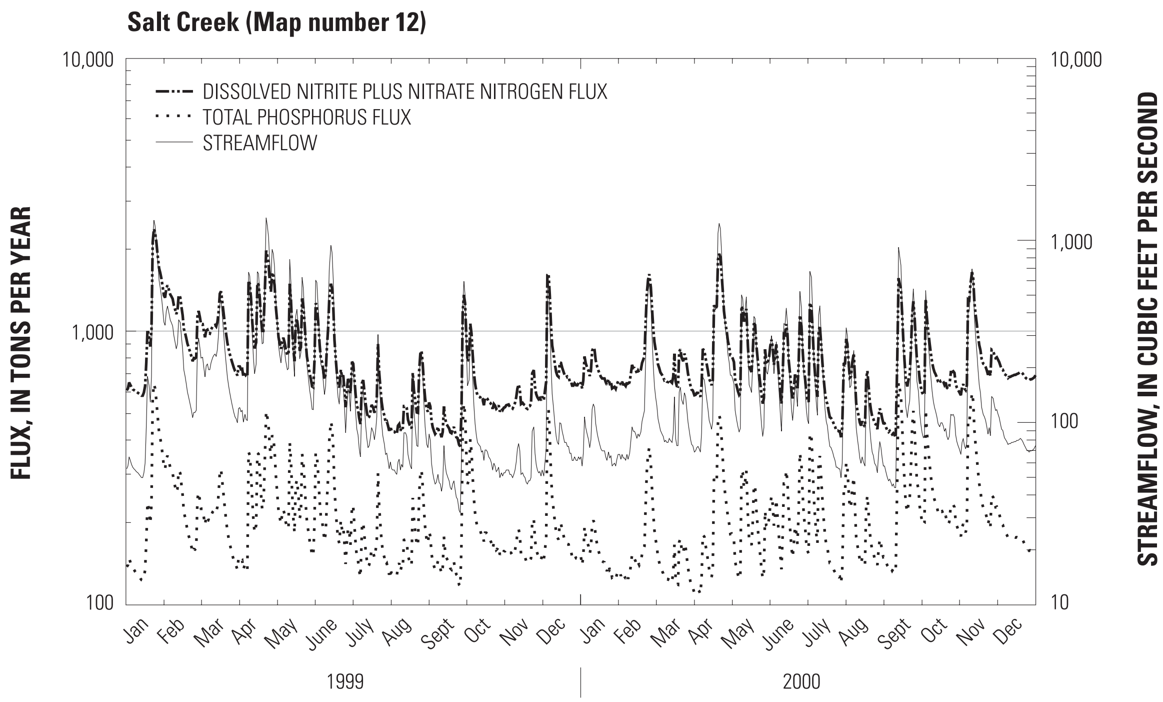


Figure 19. Flux of dissolved nitrite plus nitrate nitrogen and total phosphorus, and streamflow in Salt Creek near Western Springs, Illinois, 1999-2000.

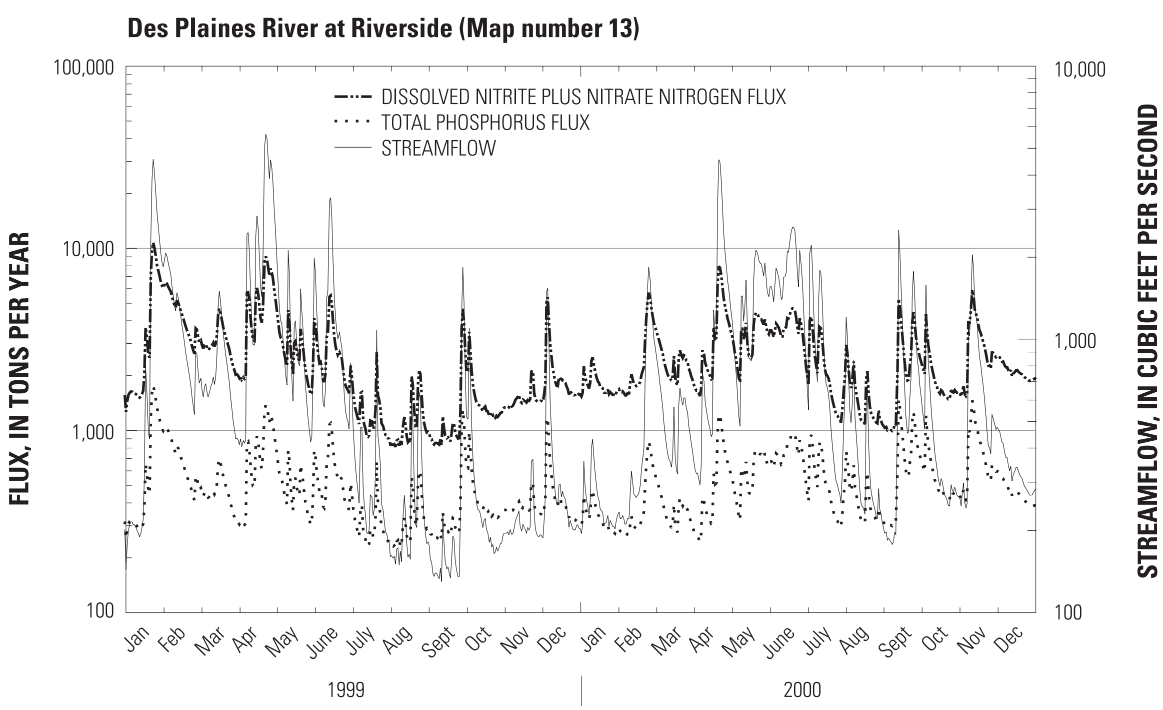


Figure 20. Flux of dissolved nitrite plus nitrate nitrogen and total phosphorus, and streamflow in Des Plaines River near Riverside Illinois, 1999-2000.

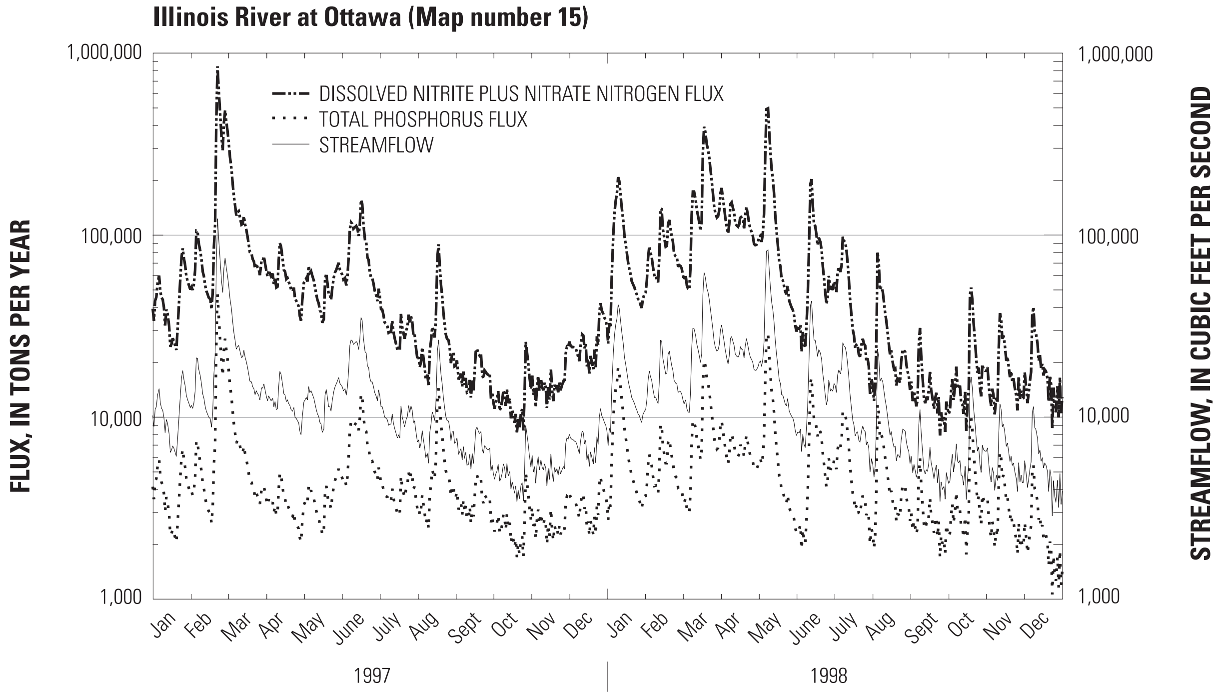


Figure 21. Flux of dissolved nitrite plus nitrate nitrogen and total phosphorus, and streamflow in Illinois River at Ottawa, Illinois, 1997-98.

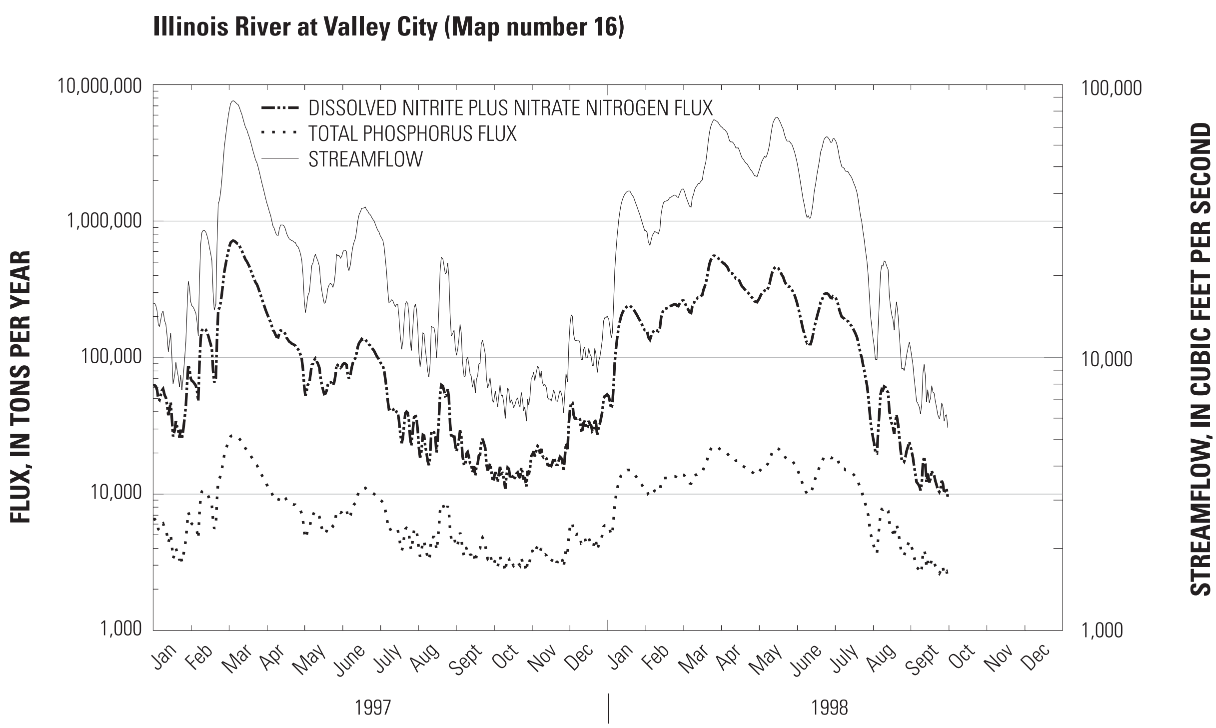


Figure 22. Flux of dissolved nitrite plus nitrate nitrogen and total phosphorus, and streamflow in Illinois River at Valley City, Illinois, 1997-98.

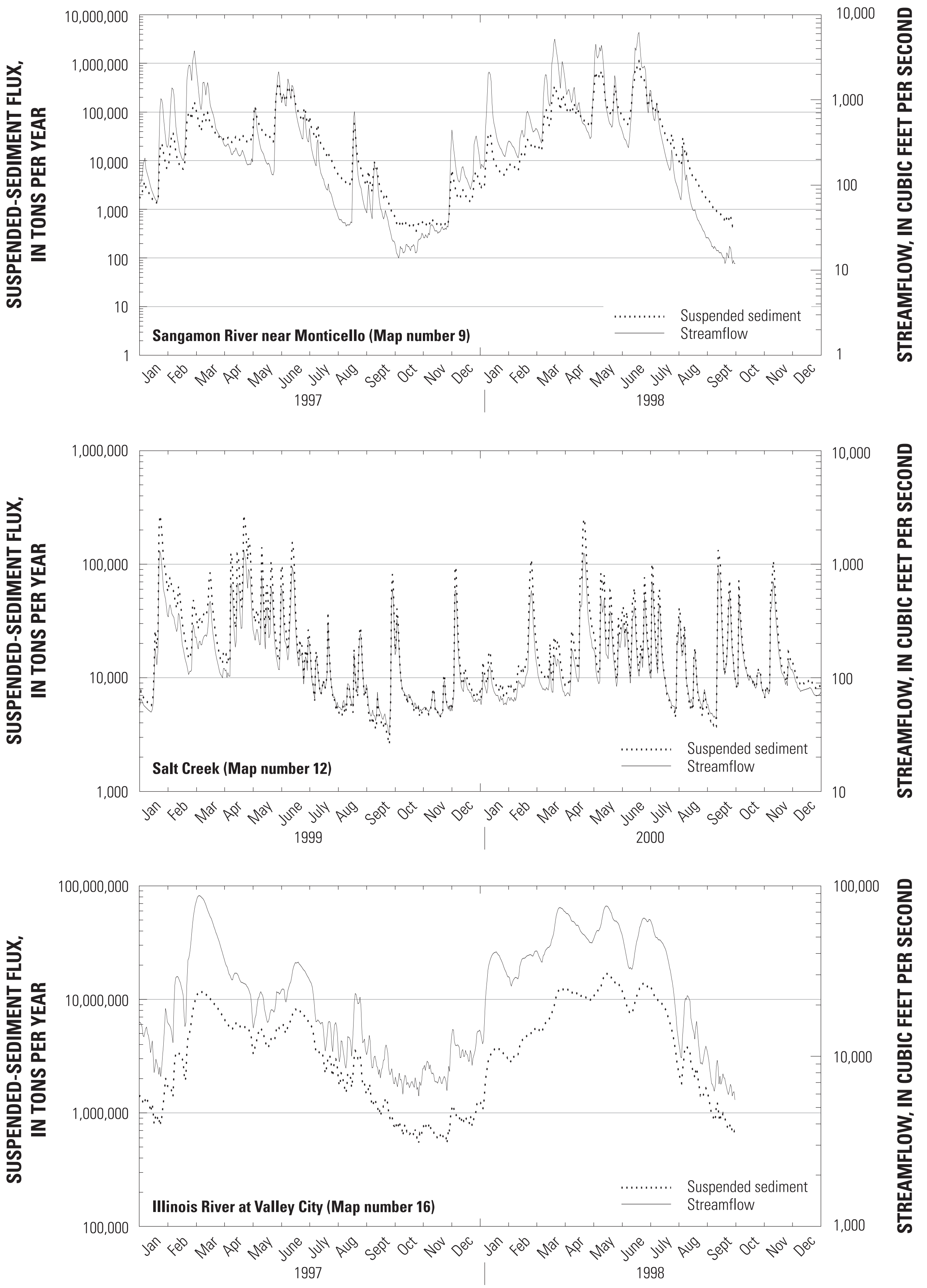


Figure 23. Flux of suspended sediment at three stations in the Illinois River Basin, 1997-2000.

gen at most stations in the LIRB were consequently higher than those estimated by Short.

Phosphorus

Fluxes of total phosphorus computed from the NAWQA data were generally not substantially different than fluxes computed by Short (1999) and Sullivan (2000). Exceptions to this generality were smaller fluxes computed using the NAWQA data for Iroquois River, Mackinaw River, and LaMoine River. For the Illinois River, flux estimates derived using the NAWQA data constituted approximately 125 percent and 120 percent of the estimated long-term fluxes at Ottawa and Valley City, respectively. Differences among streamflow conditions present during the 2-year NAWQA sampling periods and during the long-term data periods did not appear to affect fluxes of total phosphorus to the extent that they affected inorganic nitrogen.

Suspended Sediment and Suspended Solids

An attempt was made to compare fluxes of NAWQA suspended-sediment with total suspended solids fluxes estimated by Short (1999) and Sullivan (2000). These two analyses are similar, yet different, and the comparison resulted in widely differing flux values between suspended sediment and total suspended solids. Gray and others (2000) states that "In natural waters, suspended sediment and total suspended solids are not comparable. The analysis for total suspended solids was originally designed for wastewater samples and has been shown to be unreliable for natural water samples". It was determined that this comparison was indeed inaccurate and, consequently, no comparison of suspended-sediment and suspended solids fluxes are presented in this report.

Table 8. Flux estimates of total inorganic nitrogen and total phosphorus from previous studies in the Illinois River Basin in Illinois, Indiana, Michigan, and Wisconsin.

[Complete station names are listed in table 2; NAWQA, National Water-Quality Assessment; ton/yr, ton per year; --, no data]

	Total inorganic nitrogen flux (ton/yr)			Total phosphorus flux (ton/yr)		
Station and map no. (fig. 2 and table 2)	1996-2000 NAWQA	Short (1999)[1,3]	Sullivan (2000)[2,4]	1996-2000 NAWQA	Short (1999)[1,3]	Sullivan (2000)[2,4]
Kankakee River (1)	3,640	5,198	5,308	176	250	241
Sugar Creek (2)	2,460	3,640	3,901	172	119	136
Iroquois River (3)	14,700	17,260	17,383	226	542	494
Des Plaines River at Russell (4)	580	331	446	19	17	16
Nippersink Creek (5)	382	479	--	15	22	--
Panther Creek (6)	5,090	--	--	5	--	--
Mackinaw River (7)	14,200	8,230	--	166	369	--
Indian Creek (8)	1,110	490	--	14	15	--
Sangamon River at Monticello (9)	11,400	4,767	--	102	151	--
Sangamon River near Oakford (10)	37,500	27,370	--	1,370	1,403	--
LaMoine River (11)	6,360	2,410	--	209	553	--
Salt Creek (12)	834	823	818	216	163	134
Des Plaines River at Riverside (13)	2,740	2,604	2,771	522	416	380
Chicago Sanitary and Ship Canal[5] (14)	14,800	16,682	28,486	3,770	1,703	3,901
Illinois River at Ottawa[6] (15)	64,200	58,786	68,924	5,200	4,190	--
Illinois River at Valley City (16)	134,000	126,444	--	8,830	7,367	--

[1] Short, M.B., 1999.

[2] Sullivan, D.J., 2000.

[3] Data from Short (1999) converted from kilograms per day to metric tons per year.

[4] Data from Sullivan (2000) converted from tons per year to metric tons per year.

[5] Short (1999) and Sullivan (2000) estimates based on data collected at Chicago Sanitary and Ship Canal at Lockport, Illinois.

[6] Illinois River at Ottawa estimates computed as the summation of flux values from Fox River at Dayton and Illinois River at Marseilles.

Summary

As part of its National Water-Quality Assessment Program, the U.S. Geological Survey sampled 16 stations in the Illinois River Basin (IRB) during a Lower Illinois River Basin (LIRB) study from 1996 to 1998 and during an Upper Illinois River Basin (UIRB) study from 1999 to 2000. The IRB encompasses 28,949 mi^2 in Illinois, Indiana, Michigan, and Wisconsin. Major land uses in the basin which influence water quality conditions are agriculture (83 percent of the area) and urban (8 percent of the area). Nutrients and siltation are routinely cited by the Illinois Environmental Protection Agency as two of the most common causes for waters not attaining full support of designated uses in streams and lakes in Illinois.

Samples were collected monthly to weekly for a period of 2 years from watersheds of various sizes and land uses from 1996 to 2000. Analyses were performed to evaluate the occurrence, distribution, and transport of nitrogen, phosphorus, and suspended sediment in these watersheds.

In-stream concentrations of nitrogen and phosphorus varied throughout the IRB, principally because of land-use characteristics. Streams in primarily urban watersheds typically had higher concentrations of NH_3-N, NH_3+organic-N and phosphorus, whereas stations in agricultural watersheds generally had higher concentrations of NO_2^-+NO_3^--N.

Concentrations of total nitrogen (TN) ranged from 0.29 mg/L to 21 mg/L and were highest in intensive agricultural watersheds. The highest median concentration of TN (13 mg/L) was in Panther Creek, and median TN concentrations were equal to or greater than 9.0 mg/L at Sangamon River at Monticello and in Iroquois River, Sugar Creek and Indian Creek. The lowest median concentrations of TN were found in the Kankakee River (2.7 mg/L) and at Des Plaines River at Russell (2.8 mg/L). TN concentrations at the two Illinois River stations, representing the outlets of the UIRB and the LIRB, were virtually the same and were 5.9 mg/L at Ottawa and 5.7 mg/L at Valley City. The variability in TN concentration was typically larger in agricultural watersheds than in urban watersheds. Concentrations of NO_2^-+NO_3^--N constituted the majority of the nitrogen found in streams in the IRB and, correspondingly, NO_2^-+NO_3^--N concentrations were highest and most variable in agricultural watersheds. In contrast, NH_3-N concentrations were higher and more variable in urban watersheds.

Total phosphorus (TP) concentrations ranged from at or near the reporting level of 0.01 mg/L (found at 10 stations) to a maximum of 3.74 mg/L in Salt Creek. Salt Creek also had the highest median TP concentration of 1.48 mg/L. All three urban watershed stations had median TP concentrations over 0.70 mg/L. All other stations had median concentrations less than 0.50 mg/L TP and the median TP concentrations at most stations were less than 0.20 mg/L. Concentrations of TP were more variable in the urban watersheds than in agricultural or mixed watersheds. Median TP concentrations at Illinois River at Ottawa and Illinois River at Valley City were similar (0.50 mg/L and 0.43 mg/L, respectively), as was the variability in TP concentrations at these two stations.

Total nitrogen concentrations were typically highest during the spring and lowest during the fall at stations in agricultural and mixed land-use watersheds. Conversely, concentrations of TN in urban land-use watersheds were highest in the winter due to the constant, non-seasonal input of wastewater effluent. Seasonality of NO_2^-+NO_3^--N is practically identical to the seasonality of TN at all of these stations. The magnitude of seasonal variability in TP concentrations is much lower than for TN concentrations, and most seasonal differences in TP concentrations are not statistically significant for stations in agricultural watersheds. The greatest variability in TP is seen for the urban Salt Creek and Des Plaines River watersheds, where concentrations are generally lowest in the spring and highest in the fall and winter. The seasonal variability of TP at Illinois River stations is similar to the seasonal variability of TP concentrations in urban watersheds.

The presence and seasonality of nutrients in the IRB is dominated by land-use practices. The seasonality of TN in the Illinois River, whether at the upstream station at Ottawa or at the downstream station at Valley City, is similar to and dictated by agricultural nitrogen inputs. Conversely, the concentrations and seasonality of TP in the Illinois River, especially at Ottawa, is driven primarily by urban sources of phosphorus and the seasonality of phosphorus concentrations in the Illinois River reflects the effect of urban phosphorus sources.

In streams for which nutrient inputs are predominantly from non-point agricultural sources, concentrations of NO_2^-+NO_3^--N were virtually always positively correlated with streamflow. In contrast, negative correlations between NO_2^-+NO_3^--N concentrations and streamflow were found for streams in predominantly point-source affected urban watersheds. Correlations among phosphorus concentrations and streamflow were not as strong as correlations between nitrogen forms and streamflow and were typically negative. All forms of phosphorus were negatively correlated with streamflow

at Salt Creek and Des Plaines River at Riverside because of dilution of point-source phosphorus sources.

Median concentrations of suspended sediment ranged from 55 to 184 mg/L, with individual concentrations as low as 1 mg/L and as high as 3,110 mg/L. Concentrations were generally higher at the UIRB stations than at LIRB stations. The lowest and least variable concentrations were found in the Illinois River at Ottawa, Panther Creek, Kankakee River, and the Chicago Sanitary and Ship Canal (CSSC). The highest concentrations and the greatest variability in suspended-sediment concentrations were found in the La Moine River. The median suspended-sediment concentration in the Illinois River at Valley City (155 mg/L) was twice the median concentration at Illinois River at Ottawa (80 mg/L). Suspended-sediment concentrations were generally more variable, although not necessarily higher, in agricultural watersheds than in urban watersheds. Suspended-sediment concentrations were found to be fairly consistent among seasons and only marginally higher during summer months in the Kankakee River watershed and in most of the LIRB watersheds.

Fluxes and yields of nitrogen and phosphorus forms varied substantially throughout the IRB. Yields of specific nitrogen and phosphorus forms were determined primarily by upstream land-use practices. Fluxes and yields of NH_3-N and NO_2^--N, nutrient forms generally associated with wastewater sources, were higher in predominantly urban watersheds, as well as at stations in mixed land-use watersheds.

Fluxes of $NO_2^-+NO_3^-$-N were highest in the Illinois River because of streamflow. The flux of $NO_2^-+NO_3^-$-N at Illinois River at Ottawa (69,100 ton/yr) was approximately one-half (48 percent) of the flux at Illinois River at Valley City (145,000 ton/yr). Fluxes of $NO_2^-+NO_3^-$-N were lowest at stations in urban watersheds. Yields of $NO_2^-+NO_3^-$-N were substantially higher than other forms of nitrogen in both agricultural and urban watersheds and yields of $NO_2^-+NO_3^-$-N were highest at stations in predominantly agricultural watersheds.. The $NO_2^-+NO_3^-$-N yield for Illinois River at Ottawa (the outlet for the UIRB) and the yield for Illinois River at Valley City (the outlet for the LIRB) were similar and were among the lowest yields for all stations.

The highest fluxes of TP, DP, and PO_4^{3-}-P were for the Illinois River at Valley City (9,700 ton/yr TP), Illinois River at Ottawa (5,700 ton/yr TP), and the CSSC (3,600 ton/yr TP). Yields of TP were distinctly higher in urban watersheds than in agricultural or mixed land uses watersheds. Dissolved phosphorus flux generally accounted for between 20 and 60 percent of the TP flux. Dissolved phosphorus constituted the majority (typically greater than 60 percent) of the TP flux at stations in urban and mixed land-use watersheds. Conversely, DP fluxes in agricultural watersheds typically amounted to between 30 and 50 percent of the TP flux. The contribution of phosphorus from wastewater in urban areas and in association with sediment in agricultural areas is evident in these comparisons.

Fluxes of suspended sediment generally corresponded to watershed size. However, fluxes and yields of suspended sediment in agricultural watersheds of the LIRB were comparatively higher than in the urban watersheds of the UIRB. The suspended-sediment flux at Illinois River at Valley City (4,880,000 ton/yr) was approximately four times the flux at Illinois River at Ottawa (1,060,000 ton/yr) and the yield at Valley City (180 (tons/mi^2)/yr) was approximately two times the yield at Ottawa (97 (tons/mi^2)/yr). Climatic variation had a substantial effect on suspended-sediment fluxes calculated from the NAWQA data and some fluxes computed for the LIRB sites for 1998 were substantially higher than those computed for 1997; the suspended-sediment flux at Sangamon River at Oakford for 1998 was almost five times greater than the flux in 1997. Suspended-sediment yields in four agricultural watersheds (Kankakee River, Iroquois River, Panther Creek, and Nippersink Creek) were unexpectedly lower than the yields from the urban watersheds (Salt Creek and Des Plaines River at Riverside).

Fluxes of nutrients varied by climatic season, principally because of seasonal streamflow differences. A general increase in flux typically begins in the late winter or early spring of each year and often continues through June. The seasonal variations in nutrient fluxes in the urban Salt Creek and Des Plaines River watersheds is not as great as in many other watersheds. Seasonality of flux in these watersheds is minimized because of both the consistency of point-source nutrient sources and the negative correlations between nutrient concentrations and streamflow.

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Science Center Director
USGS Illinois Water Science Center
1201 W. University Ave., Suite 100
Urbana, IL 61801

http://il.water.usgs.gov

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