NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Nitrogen and Phosphorus in Streams of the Great Miami River Basin, Ohio, 1998-2000

Water-Resources Investigations Report 02-4297

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

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By David C. Reutter

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2003

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. 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. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program 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 Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
kilometer (km)	0.6214	mile
mile (mi)	1.609	kilometer
acre	0.4047	square hectometer
square kilometer (km^2)	0.3861	square mile
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
kilogram (kg)	2.205	pound
kilogram per square kilometer (kg/km^2)	5.711	pound per square mile
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Abbreviated water-quality units used in this report: Chemical concentration is given in milligrams per liter (mg/L), a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value is approximately the same as for concentrations in parts per million. Nutrient loads are given in kilograms (kg), whereas nutrient yields are given in kilograms per square kilometer (kg/km^2).

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Abstract

Sources and loads of nitrogen and phosphorus in streams of the Great Miami River Basin were evaluated as part of the National Water-Quality Assessment program. Water samples were collected by the U.S. Geological Survey from October 1998 through September 2000 (water years 1999 and 2000) at five locations in Ohio on a routine schedule and additionally during selected high streamflows. Stillwater River near Union, Great Miami River near Vandalia, and Mad River near Eagle City were selected to represent predominantly agricultural areas upstream from the Dayton metropolitan area. Holes Creek near Kettering is in the Dayton metropolitan area and was selected to represent an urban area in the Great Miami River Basin. Great Miami River at Hamilton is downstream from the Dayton and Hamilton-Middletown metropolitan areas and was selected to represent mixed agricultural and urban land uses of the Great Miami River Basin.

Inputs of nitrogen and phosphorus to streams from point and nonpoint sources were estimated for the three agricultural basins and for the Great Miami River Basin as a whole. Nutrient inputs from point sources were computed from the facilities that discharge one-half million gallons or more per day into streams of the Great Miami River Basin. Nonpoint-source inputs estimated in this report are atmospheric deposition and commercial-fertilizer and manure applications.

Loads of ammonia, nitrate, total nitrogen, orthophosphate, and total phosphorus from the five sites were computed with the ESTIMATOR program. The computations show nitrate to be the primary component of instream nitrogen loads, and particulate phosphorus to be the primary component of instream phosphorus loads.

The Mad River contributed the smallest loads of total nitrogen and total phosphorus to the study area upstream from Dayton, whereas the Upper Great Miami River (upstream from Vandalia) contributed the largest loads of total nitrogen and total phosphorus to the Great Miami River Basin upstream from Dayton. An evaluation of monthly mean loads shows that nutrient loads were highest during winter 1999 and lowest during the drought of summer and autumn 1999. During the 1999 drought, point sources were the primary contributors of nitrogen and phosphorus loads to most of the study area. Nonpoint sources, however, were the primary contributors of nitrogen and phosphorus loads during months of high streamflow. Nonpoint sources were also the primary contributors of nitrogen loads to the Mad River during the 1999 drought, owing to unusually large amounts of groundwater discharge to the stream.

The Stillwater River Basin had the highest nutrient yields in the study area during months of high streamflow; however, the Mad River Basin had the highest yields of all nutrients except ammonia during the months of the 1999 drought. The high wet-weather yields in the Stillwater River Basin were caused by agricultural runoff, whereas high yields in the Mad

River Basin during drought resulted from the large, sustained contribution of ground water to streamflow throughout the year.

In the basins upstream from Dayton, an estimated 19 to 25 percent of the nonpoint source of nitrogen and 4 to 5 percent of the nonpoint source of phosphorus that was deposited or applied to the land was transported into streams.

Introduction

Living organisms require chemical nutrients to sustain their growth and development. If one of these nutrients is in short supply, it controls the population density of certain organisms and is said to be the "limiting" nutrient. In most aquatic ecosystems, the limiting nutrient is thought to be either nitrogen or phosphorus. When the amount of nutrients entering a stream or lake is not controlled and concentrations of nitrogen and phosphorus become sufficiently large, then water quality can be adversely affected, as reflected by algal blooms, toxicity to aquatic life, and (or) toxicity to warmblooded animals that drink the water (Litke, 1999; Thomann and Mueller, 1987; Hem, 1989). Moreover, algal blooms can cause large diurnal variations in dissolved-oxygen concentrations, which consequently can eliminate susceptible fish species in streams and lakes.

Nutrient concentrations in the Nation's streams and lakes increased substantially during the past century. This increase was mainly due to increases in municipal and industrial discharges, fertilizer use, and atmospheric inputs (Puckett, 1995). In the 1970s, however, this trend began to change. The Federal Government enacted the Federal Water Pollution Control Act of 1972, in part to begin lowering concentrations of nutrients in many streams and lakes of the Nation. This act (also known as the Clean Water Act) helped fund the upgrading of wastewater-treatment facilities to remove nutrients and other contaminants from effluent. By the 1990s, wastewater-treatment facilities had become more efficient in removing nutrients from effluent (Litke, 1999). For example, the Ohio Environmental Protection Agency (Ohio EPA) did studies of the biological integrity of the Great Miami River in 1980, 1989, and 1995 and observed a trend of improvement. The agency concluded that part of the improvement was caused by a decrease in ammonia being introduced into streams from wastewater-treatment facilities, a direct result of the Clean Water Act (Rankin and others, 1997). Some state and local governments have also banned household use of phosphate detergents in order to limit phosphorus inputs to the environment. Currently (2002) the only counties in the Great Miami River Basin (fig. 1) with a ban on phosphate detergents are Auglaize and Shelby, and only because parts of these counties drain into Lake Erie.

Despite the noted improvements, algal blooms were observed in the Great Miami River between Dayton and Hamilton during the latest biological and water-quality assessment of the Lower Great Miami River by the Ohio EPA in 1995 (Ohio Environmental Protection Agency, 1997). The amount of nutrients found in waters of the Great Miami River Basin is not only a local concern but also a concern for aquatic life in the Gulf of Mexico. A study by Goolsby and others (1999) on the flux and sources of nutrients in the Mississippi-Atchafalaya River Basin found that the Great Miami River Basin has some of the highest yields of nitrogen and phosphorus in the Mississippi River Basin. Only a few basins in Iowa and Illinois are thought to produce higher yields. High loads of nutrients in spring runoff to the Gulf of Mexico from the Mississippi River Basin were found to be responsible for increased algal growth in the Gulf of Mexico, which has led to seasonal oxygen depletion (hypoxia) (Goolsby and others, 1999).

Purpose and Scope

This report describes and quantifies major sources of nutrients (nitrogen and phosphorus) in the Great Miami River Basin, describes spatial and temporal variations in nutrient concentrations at selected monitoring sites, lists estimated loads and yields of nutrients from five stream sites monitored, and relates observed loads and yields to selected environmental factors and land use. Nutrient sources are evaluated by quantifying, where possible, contributions of point and nonpoint sources. Instream concentrations of nutrients are based on analyses of water samples collected from three tributaries of the Great Miami River and from two main-stem sites. Nutrient loads were computed from analyses of samples collected during October 1998 through September 2000 (water years 1999–2000). These loads are compared with load estimates derived from nutrient data collected by the U.S. Environmental Protection Agency (USEPA) and the USGS National Stream Quality Accounting Network (NASQAN). Daily mean streamflows were determined from gaging-station records maintained by the USGS and Miami Conservancy District (MCD).

Acknowledgments

The author acknowledges the significant contributions of the U.S. Environmental Protection Agency; the Water Quality Unit of Ohio EPA, Southwest District Office; the Miami Conservancy District; and the Ohio Department of Agriculture in providing information and data vital to this report. The author thanks the numerous publicly owned wastewater-treatment facilities that provided monthly operating reports detailing quantity and quality of waters being discharged into streams.

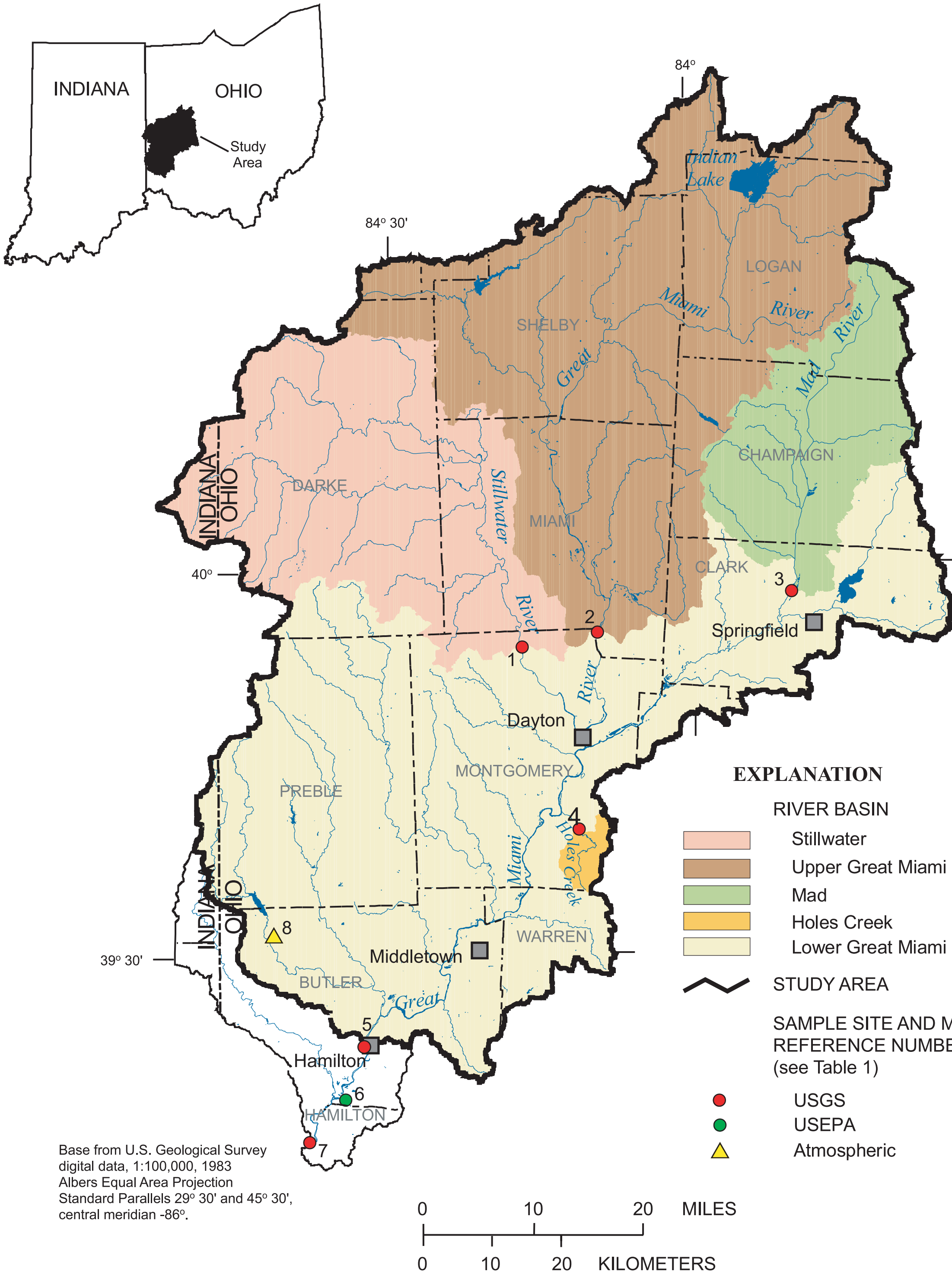

Figure 1. Location of U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (USEPA) water-sampling sites and the atmospheric-depostition sampling site for the Great Miami River Basin.

Description of Study Area

The Great Miami River drainage area is 5,330 mi^2 where the Great Miami joins the Ohio River at the Ohio-Indiana State line. The Great Miami River originates within the drainage basin of Indian Lake in Hardin, Auglaize, and Logan Counties. The Stillwater and Mad Rivers merge with the Great Miami River within a 2-mi reach near downtown Dayton to make up the lower reach of the Great Miami River (fig. 1). Long-term (1971–2000) mean daily streamflow for Mad River near Eagle City (03267900) is 310 ft^3/s; however, the long-term mean daily streamflow for Mad River near Dayton (03270000), 6 mi upstream from the confluence with the Great Miami River, increases to 683 ft^3/s. Long-term mean daily streamflows for Great Miami River at Taylorsville (03263000) and Stillwater River at Englewood (03266000) are 1,020 ft^3/s and 589 ft^3/s, respectively. At Great Miami River at Hamilton (03274000), 45 mi downstream from the merger of these two rivers, long-term mean streamflow is 3,340 ft^3/s. In comparison, long-term mean streamflow for the mouth of the Ohio River (Grand Chain, Ill. (03612500)) is 296,000 ft^3/s. Great Miami River streamflow, therefore, constitutes slightly more than 1 percent of the entire Ohio River streamflow on average.

Physiography and geology

The study area is entirely within the Till Plains section of the Central Lowland Physiographic Province (Fenneman, 1938). All of the study area was affected by Pleistocene glaciation in which advance and retreat of ice sheets produced a flat to gently rolling land surface.

The geology of the study area is dominated by Quaternary glacial deposits that overlie a sequence of Ordovician, Silurian, and Devonian sedimentary rocks. Glacial deposits found in the study area consist of till, outwash, and lacustrine deposits. The till is an unsorted mixture of clay, silt, sand, and gravel that was deposited by advancing glaciers or by melting stagnant ice. The outwash consists of well-sorted sand and gravel that was deposited when ice sheets melted and large volumes of meltwater flowed through stream valleys; the Mad River Interlobate Area, in particular, is characterized by extensive outwash deposits that are high-yielding aquifers (Brockman, 1998).The lacustrine sediments consist of layered silt and clay that formed in basins or valleys dammed by glacial ice (Debrewer and others, 2000).

Climate

The study area has a temperate continental climate characterized by four distinct seasons and moderate extremes in annual temperature variations. Mean annual precipitation for Dayton is 38 in. (National Oceanic and Atmospheric Administration, 2001; Miami Conservancy District, 2001). Spring and summer tend to receive greatest monthly precipitation amounts, which are usually associated with thunderstorms. The precipitation pattern that developed during part of the study period, however, was not normal. During most of spring, summer, and autumn 1999, monthly precipitation was below the mean monthly precipitation for 1971 through 2000 (fig. 2).

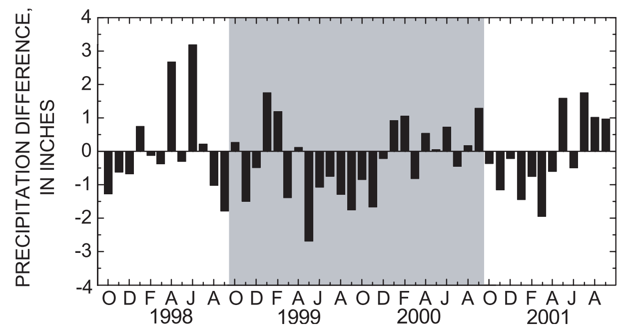

Figure 2. Difference in monthly precipitation recorded for the study area for water years 1998 through 2001 as compared to the mean monthly precipitation for 1971 through 2000. (Shaded timespan represents the sampling period for report. Data from National Oceanic and Atmospheric Administration, 2002.)

Land Use

Approximately 81 percent of the study area is used for agriculture (fig. 3), and most of this agricultural land is in corn, soybean, and wheat production. Approximately 30 percent of the land in the three basins upstream from Dayton is planted in soybeans and 25 percent in corn. Generally less than 10 percent of the land is in wheat (Ohio Agricultural Statistics, 1999a, 1999b, and 1999c). Corn and soybeans are planted in spring and early summer and harvested in autumn whereas winter wheat is planted in autumn and harvested in summer (Debrewer and others, 2000).

Livestock production is also common in the study area, particularly in the Stillwater River Basin. On the basis of 1997 data, an estimated 145,000 cattle, 350,000 hogs and pigs, and 8,300,000 fowl were raised in the study area. Of this, approximately 8,000,000 fowl and 150,000 hogs were raised in the Stillwater River Basin. In comparison, approximately 3,000 fowl and 50,000 hogs were raised in the Mad River Basin and approximately 140,000 fowl and 90,000 hogs in the Upper Great Miami River Basin. (U.S. Department of Agriculture, 1999).

Figure 3. Land use in the Great and Little Miami River Basins.

Most of the Dayton-Springfield Metropolitan area (Clark, Miami, Greene, and Montgomery Counties) is in the Great Miami River Basin, although some communities east of Dayton lie outside the study area (fig. 3).This metropolitan area has a population of 950,000. South of Dayton is the Hamilton-Middletown metropolitan area (Butler County), with a population of 330,000 (U.S. Census Bureau, 2001a). Total population of the study area has increased little in recent decades, from an estimated 1.3 million in 1970 to an estimated 1.4 million in 2000 (U.S. Census Bureau, 1995; U.S. Census Bureau, 2001a).

For purposes of this study, the farthest downstream site selected for nutrient load computations is Great Miami River at Hamilton, Ohio. Selection of this site permits the study to focus on the part of the Great Miami River Basin that includes the Dayton-Springfield and Hamilton-Middletown metropolitan areas but excludes western reaches of the Cincinnati metropolitan area and contributions from the Whitewater River Basin in southeastern Indiana. For the remainder of this report, "Great Miami River Basin" refers to only the drainage area of the Great Miami River upstream from Hamilton.

Sampling Sites

Water samples were collected for nutrient analysis at five USGS sampling sites (table 1). Three of the sites are upstream from Dayton and have drainage areas that are not affected by the Dayton metropolitan area (fig. 1). These sites are Stillwater River near Union, Great Miami River near Vandalia, and Mad River near Eagle City. The basins for these sites consist of agricultural lands mixed with low-density residential areas. The Mad River site is just upstream from the city of Springfield. The Holes Creek site is in the Dayton metropolitan area and is in a predominantly urban setting that consists of residential and commercial land uses. The Holes Creek basin has no industrial or municipal point sources and has a drainage area of only 20 mi^2; this site is especially important to the study because urban fertilizer application and atmospheric deposition would be the main sources of the nutrient loads and yields for this basin. The Great Miami River at Hamilton site is downstream from the Dayton-Springfield Metropolitan area, and the cities of Hamilton, Middletown, Miamisburg are also within its drainage area. An unexpected problem arose when the bridge at the Hamilton site underwent reconstruction during spring and summer of 2000; samples could not be collected at the site during most of that time.

Although the three basins upstream from Dayton are in predominantly agricultural lands, urban areas are present in each. The Mad River Basin includes Urbana (population 11,613). The Upper Great Miami River Basin includes Bellfontaine (population 13,069), Piqua (population 20,738), Sidney (population 20,211), and Troy (population 21,999). The Stillwater River Basin includes Greenville (population 13,294), Union (population 5,574) and Covington (population 2,559) (U.S. Census Bureau, 2001b). These municipalities have publicly owned wastewater-treatment facilities that individually discharge 0.5 Mgal/d or more of effluent into streams of the Great Miami River Basin.

Sampling and Analytical Methods

From October 1998 through September 2000 (water years 1999 and 2000), USGS personnel collected water samples to be analyzed for nutrients at the five sites. Samples were collected on a routine schedule and additionally during selected high streamflows. Sample collection continued during water year 2001 at the Mad River, Holes Creek, and Great Miami River at Hamilton sites; however, because samples were not collected at all sites for water year 2001, the samples collected in 2001 were used only for calibrating the model used to estimate instream nutrient loads.

Sampling Frequency

The sampling schedule differed from site to site and from season to season (fig. 4). Mad River near Eagle City, Holes Creek near Kettering, and the Great Miami River at Hamilton were sampled more frequently than Stillwater River near Union and Great Miami River near Vandalia.

Samples were collected at Stillwater River near Union and Great Miami River near Vandalia during 31 visits and 30 visits, respectively. Routine samples were collected monthly at both sites throughout the monitoring period. During the first 18 months of the monitoring period, daily mean streamflows were usually below the 30-year daily median streamflows (that is, the median of the daily mean streamflows for each calendar day; fig. 4). At both sites, the lowest recorded streamflow for the monitoring period was during autumn 1999. The 30-year daily median streamflow during October through December is 140 ft^3/s for Stillwater River near Union and 330 ft^3/s for Great Miami River near Vandalia. From October through December of 1999, however, mean streamflow was 65 ft^3/s for Stillwater River near Union and 120 ft^3/s for Great Miami River near Vandalia. Not until March 2000 did daily mean streamflows reach levels similar to the 30-year daily median streamflows.

Nutrient samples were collected during 51 visits to Mad River near Eagle City for water years 1999 and 2000. Routine samples were collected at this site monthly during autumn and winter and weekly or twice a month during spring and summer. Streamflow at this site was below the 30-year daily median streamflow during most of the sampling period; however, streamflow of the Mad River was not as affected by droughts as the other sites in the study area because of the large amount of ground water that

Table 1. Description of the water-quality, streamflow, and atmospheric stations used in the study

[Population density data from 1990 U.S. Census; land-use data from Earth Resource Observations Systems Data Center, 1992 (U.S. Geological Survey, 2002); mi^2, square mile; NA, not applicable]

Reference Number	Station number	Station name	Station purpose	Latitude	Longitude	Drainage area (mi^2)	Population density of drainage basin (people per mi^2)	Percentage of basin area in indicated land use		
								Agriculture	Urban	Forest
1	395355084173600	Stillwater River near Union, Ohio[1]	Water quality	39°53’55”	84°17’36”	646	124	92	2	6
2	395457084095100	Great Miami River near Vandalia, Ohio[2]	Water quality	39°54’57”	84°09’51”	1,142	150	87	3	9
3	03267900	Mad River at St. Paris Pike near Eagle City, Ohio	Water quality and streamflow	39°57’51”	83°49’54”	310	133	82	3	15
4	393944084120700	Holes Creek at Huffman Park near Kettering, Ohio	Water quality and streamflow	39°39’44”	84°12’07”	20	1,297	28	62	9
5	03274000	Great Miami River at Hamilton, Ohio	Water quality and streamflow	39°23’28”	84°34’20”	3,630	319	80	8	10
6	03274060	Great Miami River at Fairfield, Ohio[3]	Water quality	39°19’03”	84°36’23”	3,670	343	80	8	11
7	03274600	Great Miami River at New Baltimore, Ohio[4]	Water quality	39°15’50”	84°40’00”	3,814	342	80	8	11
8	OH09	Oxford, Ohio	Atmospheric	39°31’53”	84°43’27”	NA	NA	NA	NA	NA

[1]Streamflow measured at station 03266000, Stillwater River at Englewood, Ohio, latitude 39°52’10”, longitude 84°16’57”; 2.8 river miles downstream from sampling station.
[2]Streamflow measured at station 03263000, Great Miami River at Taylorsville, Ohio, latitude 39°52’27”, longitude 84°09’45”; 3.2 river miles downstream from sampling station.
[3]Water-quality samples collected by the U.S. Environmental Protection Agency, December 1999–December 2000.
[4]Water-quality samples collected by the U.S. Geological Survey as part of the National Stream Quality Accounting Network (NASQAN), 1975–93.

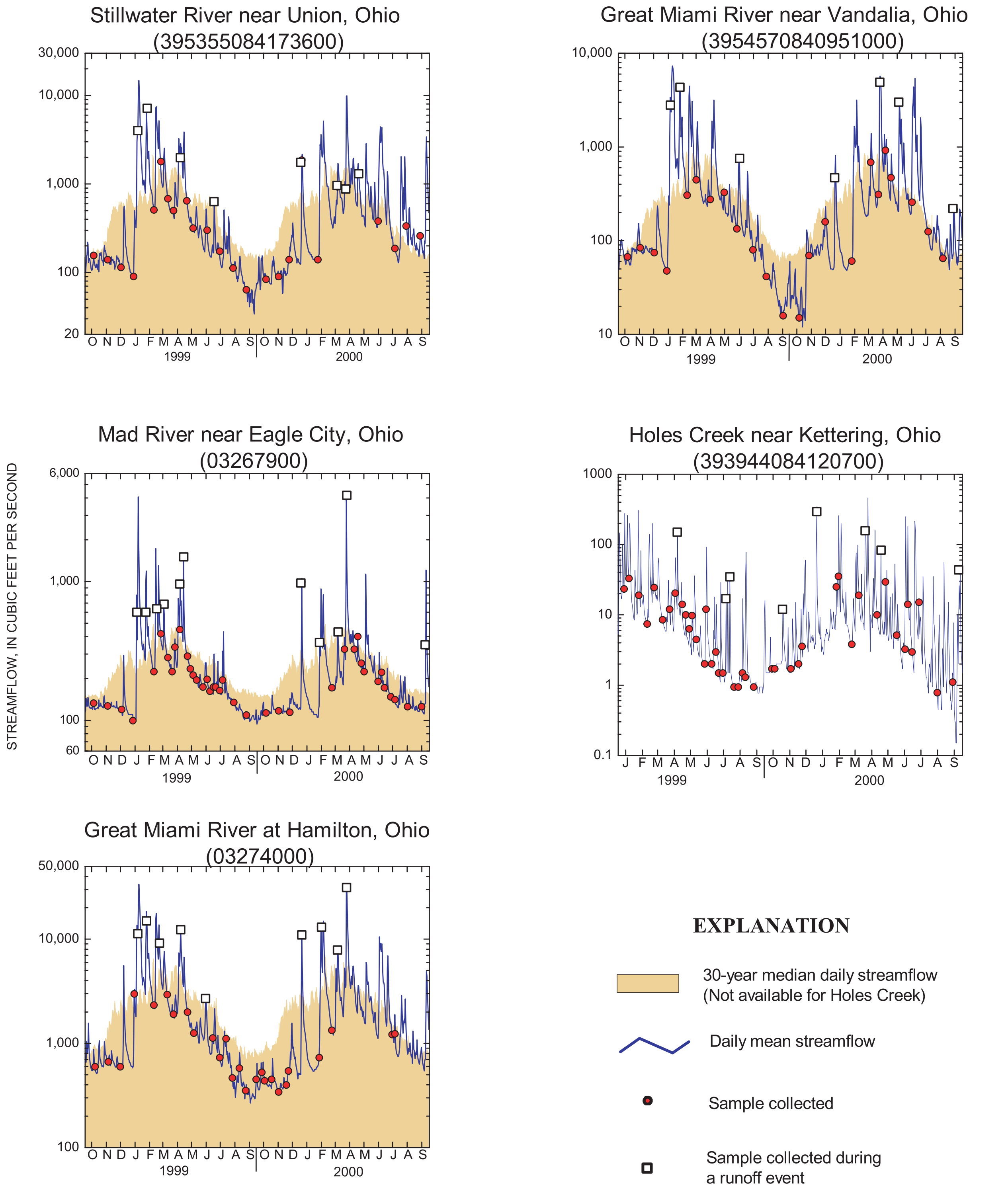

Figure 4. Daily mean streamflow, 30-year median daily streamflow, and sample collections for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

discharges to the stream (Koltun, 1995). This difference can be seen in daily-streamflow hydrographs for the 1999 drought (fig. 4).

Samples were collected at Holes Creek near Kettering during 53 visits from January 1999 through September 2000. Samples were collected twice a month during winter 1999, four times a month during spring and summer 1999, then twice a month from October 1999 through September 2000. Streamflow record for the Holes Creek site were unavailable until January 1999 because of problems with data storage at the site. Samples collected in October, November, and December 1998 could not be included in load computations because of missing streamflow data for those months.

Samples were collected during 35 visits to Great Miami River at Hamilton during water years 1999 and 2000. As observed at the other sites in the study area, the 1999 drought had an effect on streamflow at Hamilton: the 30-year mean streamflow during October through December is 1,500 ft^3/s, but mean streamflow was 500 ft^3/s from October through December 1999.

Sample Collection and Laboratory Methods

USGS personnel used National Water-Quality Assessment (NAWQA) sampling protocols (Shelton, 1994) to collect and process samples. These protocols require samples to be collected by means of the equal-width increment (EWI) method, in which depth-integrated samples are collected at equal distances across the entire stream width and composited.

Samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, using methods described by Fishman (1993). The NWQL determined the long-term method detection level (LT-MDL) for each nutrient species. At LT-MDL concentration, 99 percent of reported detections are true detections of the chemical of interest; however, at LT-MDL concentration, there is a 50 percent chance of the target chemical's not being detected—a false-negative detection (Childress and others, 1999). To avoid a high number of false-negative detections, the NWQL has established the laboratory reporting level (LRL) for a chemical at twice the LT-MDL. Concentrations measured between the LRL and the LT-MDL are reported as estimated concentrations (Childress and others, 1999). Nutrients that were measured at the NWQL, along with the LRL established by the NWQL, for the individual nutrient species are listed in table 2.

Quality-Control Sampling

Quality-control samples were collected to estimate bias and variability of the environmental data. For this study, quality-control samples consisted of field blanks and replicates collected periodically throughout the sampling period. Field blanks consisted of deionized water, certified to be free of inorganic compounds, that was passed through all equipment used in the field for sample collection and processing. Replicate samples were splits of the environmental-water sample that were processed through the same sampling equipment. Field blanks were used to test for bias from contamination at any stage of sample collection and analysis. Replicates were used to estimate variability from sampling and analysis processes (Mark Sandstrom, USGS, written commun., 1996). These quality-control samples were collected periodically during the sampling period and accounted for about 12 percent of the samples collected for this study. Results of the quality-control sampling effort are given in Appendix A. Field blanks indicated no consistent contamination problems with any of the nutrient species.

Table 2. Nutrients determined by the National Water Quality Laboratory

[mg/L, milligrams per liter; N, nitrogen; P, phosphorus]

Constituent	Laboratory reporting level
Ammonia nitrogen, dissolved	0.02 mg/L as N
Nitrite nitrogen, dissolved	0.01 mg/L as N
Organic nitrogen and ammonia, dissolved	0.1 mg/L as N
Organic nitrogen plus ammonia, total	0.1 mg/L as N
Nitrite plus nitrate, dissolved	0.1 mg/L as N
Phosphorus, total	0.008 mg/L as P
Phosphorus, dissolved	0.006 mg/L as P
Orthophosphate, dissolved	0.01 mg/L as P

Computation of Instream Loads

Loads and yields of dissolved ammonia, dissolved nitrate, dissolved ammonia plus organic nitrogen, total nitrogen, dissolved orthophosphate, and total phosphorus were estimated for the five sites selected in the study area. Nutrient loads during October 1998 through September 2000 (water years 1999 and 2000) were computed by use of the ESTIMATOR program.

The ESTIMATOR program developed in 1988 by the USGS was initially used to estimate nutrient loads entering Chesapeake Bay through its major tributaries (T.A.Cohn, U.S. Geological Survey, written commum., 1995). This program performs multivariate regression computations that include streamflow, time, and seasonal indicators as explanatory variables. Two methods are used for load estimates: For uncensored data (no less-than values in the data set), ESTIMATOR implements the Minimum Variance Unbiased Estimator procedure. For censored data (some concentrations less than the LT-MDL), ESTIMATOR implements the Adjusted Maximum Likelihood Estimator procedure (Cohn and others, 1992; Cohn and others, 1989).

The ESTIMATOR program allows the user to select a model best suited for the particular study. Results from previous studies (Cohn and others, 1992; Goolsby and others, 1999; Trench, 2000) have found that a seven-parameter model commonly is sufficient for accurate load estimates. The following equation form was chosen for this study:

$$\ln[C] = B_o + B_1\ln[Q] + B_2\ln^2[Q] + B_3T + B_4T^2 + B_5\sin[2\pi T] + B_6\cos[2\pi T] + e,$$

where ln denotes the natural logarithm function,

C is constituent concentration (milligrams per liter),

Q is daily average discharge (cubic feet per second),

T is time (decimal years),

B_0 through B_6 are coefficients estimated from the data, and e is an independent random error.

The sine and cosine terms in the equation adjust the model for seasonal variability. Time (T) and natural log of streamflow ($\ln[Q]$) are centered values, which are usually very close to the mean value. Coefficients B_0 through B_6 used in the ESTIMATOR concentration models are listed in Appendix B.

There was one exception to the use of the seven-parameter model in the study. Samples collected at Great Miami River near Vandalia had many ammonia concentrations below the LT-MDL. Because of the low number of detectable concentrations, a three-parameter model had to be used for this constituent at this site. The following equation form was chosen:

$$\ln[C] = B_o + B_1\ln[Q] + B_2\ln^2[Q].$$

This model was not able to account for annual or seasonal variability not already reflected in the streamflow record.

Loads were computed by ESTIMATOR (in kilograms) for each of the months and water years of interest, along with the corresponding 95-percent confidence intervals. In general, the accuracy of estimates derived from ESTIMATOR models increases with the amount of data available for model calibration.

Sources of Nitrogen and Phosphorus

Nutrients introduced into the Great Miami River Basin come from point and nonpoint sources. Nutrients from point sources come from a discrete location, such as a pipe or drainage ditch. All nutrients from point sources that this report covers are assumed to enter the streams. Nutrients from nonpoint sources, on the other hand, are deposited onto basins over broad areas, such as by fertilizer application, animal-waste excretion, or atmospheric deposition. Only some of the available nonpoint-source nutrients are transported to streams.

Nonpoint Sources

Nonpoint sources of nutrients to the study area include commercial-fertilizer and manure application to cropland, nitrogen fixation from soybeans, and atmospheric deposition of nutrients from sources that can extend beyond the study area.

Because of the small amount of data available on nutrients from urban runoff, household use of fertilizers, combined sewer overflows, and failing septic systems, these potential sources were not included as part of the nonpoint-source computations in this report.

Commercial Fertilizer and Manure. Commercial fertilizer applied to agricultural lands has become a primary nonpoint source of nitrogen and phosphorus in the United States. Application of nitrogen in commercial fertilizer in the Nation increased from 0.5 million to more than 10 million metric tons between 1945 and 1993. Application of phosphorus in commercial fertilizer also increased during this time, from 0.5 million to 1.8 million metric tons (Puckett, 1995). Application of manure to agricultural lands is also a common source of nitrogen and phosphorus in the Nation.

Soybeans, corn, and, to a lesser extent, wheat, make up the majority of crops planted in the Great Miami River Basin. In 1999, approximately 650,000 acres of the study area were planted in soybeans, 540,000 acres in corn, and 105,000 acres in wheat (Ohio Agricultural Statistics Service, 1999a, 1999b, and 1999c). Most of the commercial nitrogen fertilizer used in the study area, however, is for corn. In Ohio, nitrogen fertilizer is applied to 100 percent of the corn acreage, 98 percent of the wheat acreage, and 21 percent of the soybean acreage. Phosphorus fertilizer is applied to 97 percent of the corn acreage, 93 percent of the wheat acreage, and 35 percent of the soybean acreage (Ohio Agricultural Statistics Service, 2000). Nitrogen and phosphorus fertilizers generally are applied in spring during corn planting. Nitrogen fertilizer is then reapplied to corn fields 6 to 10 weeks after planting. Phosphate fertilizer generally is applied to corn and soybean fields at planting. For wheat, nitrogen and phosphate fertilizers are applied in late summer through early autumn.

Manure is applied to the land not only to supply nutrients but also to improve the water-holding capacity of soil, improve aeration of soil, and promote beneficial microorganisms (Ohio State University Extension, 1992). It is generally applied in autumn and winter. An estimated 17 percent of the corn acreage, 8 percent of the soybean acreage, and 5 percent of the wheat acreage in Ohio receive applications of manure (Ohio State University Extension, 1995a).

Nutrient inputs from commercial fertilizer applied to agricultural lands in the study area were estimated on a county level from information on commercial-fertilizer sales collected by the Census of Agriculture in 1997 (U.S. Department of Agriculture, 1999). Nutrient inputs from manure were estimated on a county level from a census of livestock, also collected by the Census of Agriculture in 1997 (U.S. Department of Agriculture, 1999). Manure estimates are based on average manure production rates per type of animal, developed by Goolsby and others (1999). Estimates of manure and commercial-fertilizer applications for the basins are based on these county estimates. Where needed, application amounts were adjusted to reflect the percentage area of the county in the basin (table 3).

Nitrogen Fixation by Soybeans . Residing in root nodules of plants in the legume family (such as the soybean) are symbiotic bacteria that are able to convert atmospheric nitrogen (N_2) into ammonia (NH_3), the biologically useful form of nitrogen. Almost all of the nitrogen converted to ammonia is then used by the plant; only a small proportion of the fixed nitrogen is transferred to soil (Lindemann and Glover, 1990). Although an important source of nitrogen in the Great Miami River Basin—owing to the large acreage of soybeans in the study area—fixation of nitrogen from crops is not used in computations of nonpoint-source inputs of nitrogen to the study area because little of this nitrogen is available to enter streams. The amount of nitrogen produced by crop fixation in the basins (table 3) is based on the area of soybeans planted in the basins and an annual nitrogen fixation rate of 75 kilograms per hectare, as estimated by Burkart and James (1999) for soybeans in the Midwest.

Atmospheric Deposition. Atmospheric deposition of nitrogen has been measured at a site near Oxford, Ohio (approximately 30 mi southwest of Dayton), since 1989. Data are collected for two USEPA-funded programs. Nitrate (NO_3) and ammonia (NH_3) nitrogen concentrations in wet deposition (rain or snow) were obtained from the National Atmospheric Deposition Program (NADP) (National Atmospheric Deposition Program, 2001). Nitric acid (HNO_3) vapor, particulate nitrate (NO_3), and particulate ammonia (NH_3) nitrogen fluxes in dry deposition were obtained from the Clean Air Status and Trends Network (CASTNET) (U.S. Environmental Protection Agency, 2001). Atmospheric deposition of phosphorus is not monitored by either NADP or CASTNET but is believed to be an insignificant source (National Atmospheric Deposition Program, 2001; U.S. Environmental Protection Agency, 2001).

Atmospheric loads of inorganic nitrogen for 1998, 1999, 2000, as well as the 10-year mean load for 1991–

Table 3. Estimated 1997 amounts of nitrogen and phosphorus from manure and commercial-fertilizer applications and nitrogen from nitrogen fixation

[in million kilograms per year]

	Manure		Commercial fertilizer		Nitrogen fixation	Total	
Basin	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Nitrogen	Phosphorus
Mad River	0.7	0.2	4.1	0.8	1.7	6.5	1.0
Upper Great Miami River	3.3	1.0	13.8	2.5	6.0	23.1	3.5
Stillwater River	5.7	2.0	9.7	1.8	3.9	19.3	3.8
Great Miami River (study area)	13.7	4.5	44.0	8.1	17.8	75.5	12.6

2000, were computed from the NADP/CASTNET data from the Oxford station (table 4). The source of nitrate and ammonium nitrogen is mainly wet deposition, whereas nitrogen from dry deposition is mainly in the form of nitric acid vapor. The contribution of nitrogen from dry deposition is relatively constant from year to year, whereas the contribution of nitrogen from wet deposition depends on the amount of precipitation for that year. Wet-deposition inputs for 1999 were lower than the 10-year mean, reflecting the below-average precipitation for that year. Wet-deposition loads for 1998 and 2000, however, were higher than the 10-year mean, reflecting the above-average precipitation for those years (table 4).

Atmospheric deposition of inorganic nitrogen for individual basins and the study area on the whole is based on measurements from CASTNET and the NADP at the Oxford, Ohio, site (table 5). The 10-year mean of inorganic nitrogen deposited from the atmosphere onto the study area is estimated to be 8.6 million kg/yr.

Manure and nitrogen fertilization of croplands are believed to be the main sources of ammonia in the atmosphere (Vitousek and others, 1997). A USEPA report (1998a) estimated that the agricultural sector contributes approximately 85 percent of the ammonia emissions to the Nation's atmosphere. Ammonia emitted to the atmosphere is in a highly water-soluble form that is easily removed from the atmosphere by precipitation (Goolsby and others, 1999). Fossil-fuel combustion is a major source of nitrogen monoxide (NO) and nitrogen dioxide (NO_2) to the atmosphere. Nitric acid vapor and particulate NO_3 are then formed in the atmosphere by oxidation of NO and NO_2. Particulate NO_3 can be transported for hundreds of miles from its source because of its low deposition velocity. Nitric acid vapor typically reacts with other pollutants to form particles that also have low deposition velocities (Lawrence and others, 1999).

Nonpoint-Source Distribution of Nutrients in the Study Area. Using the most recent data available, nonpoint-source inputs of nutrients were computed for each basin. Of the sources evaluated, application of commercial fertilizer to agricultural lands was the greatest nonpoint-source contributor of nitrogen and phosphorus in the study area (figs. 5 and 6). Commercial-fertilizer applications account for between 70 and 80 percent of the input of nitrogen and phosphorus to the Mad River and Upper Great Miami River Basins; however, commercial-fertilizer applications contributed only 57 percent of the nitrogen inputs and 46 percent of the phosphorus inputs to the Stillwater River Basin. For the Great Miami River Basin, commercial-fertilizer applications contributed 67 percent of the nitrogen inputs and 64 percent of the phosphorus inputs.

Manure is a potentially large nonpoint source of nitrogen and phosphorus in the Stillwater River Basin. Because of the high concentration of livestock in this basin, manure contributed 54 percent of the phosphorus input and 34 percent of the nitrogen input. Farms in this basin do not apply all available manure to cropland within the basin, however, and much of the manure is transported for application outside of the basin. For example, approximately 40 percent of the poultry manure generated in Darke County

Table 4. Atmospheric deposition of inorganic nitrogen and precipitation measured at Oxford, Ohio

[Sources: Dry-deposition data, Clean Air Status and Trends Network (2001); Wet-deposition and precipitation data, National Atmospheric Deposition Program (2001)]

Year	Deposition of nitrogen, in kilograms per square kilometer per year			Annual precipitation
	Dry	Wet	Total	(inches)
1998	346	777	1,123	44.1
1999	376	410	786	29.4
2000	321	607	928	44.5
1991–2000, mean	352	570	922	39.0

Table 5. Estimated atmospheric deposition of inorganic nitrogen to the basins and study area

[in million kilograms of nitrogen per year]

Basin	1998	1999	2000	1991–2000, mean
Mad River	0.9	0.6	0.7	0.7
Upper Great Miami River	3.3	2.3	2.8	2.7
Stillwater River	1.9	1.3	1.6	1.5
Great Miami River (study area)	10.6	7.4	8.7	8.6

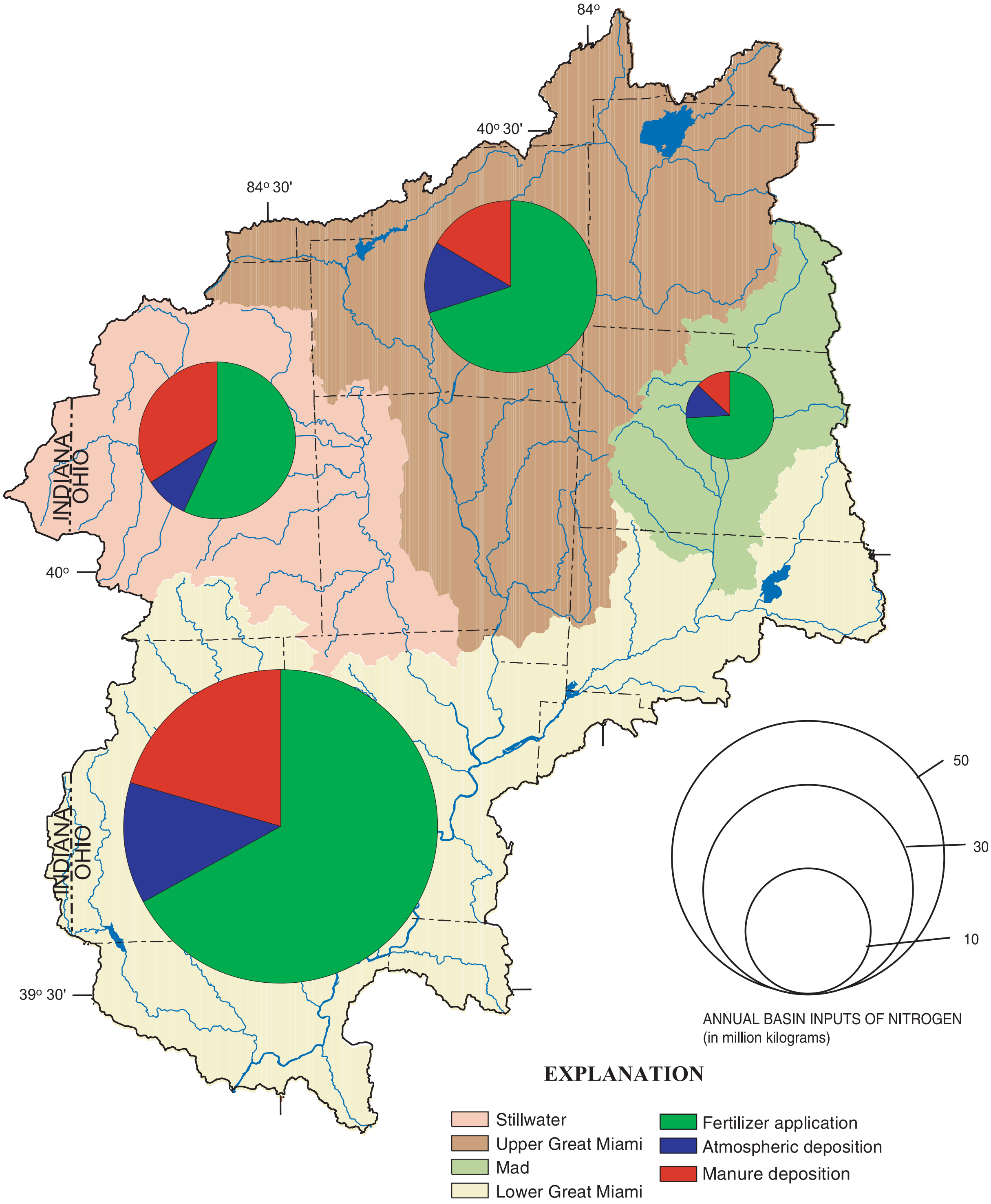

Figure 5. Estimated nonpoint-source inputs of nitrogen to the Stillwater River, Upper Great Miami River, Mad River, and Lower Great Miami River Basins.

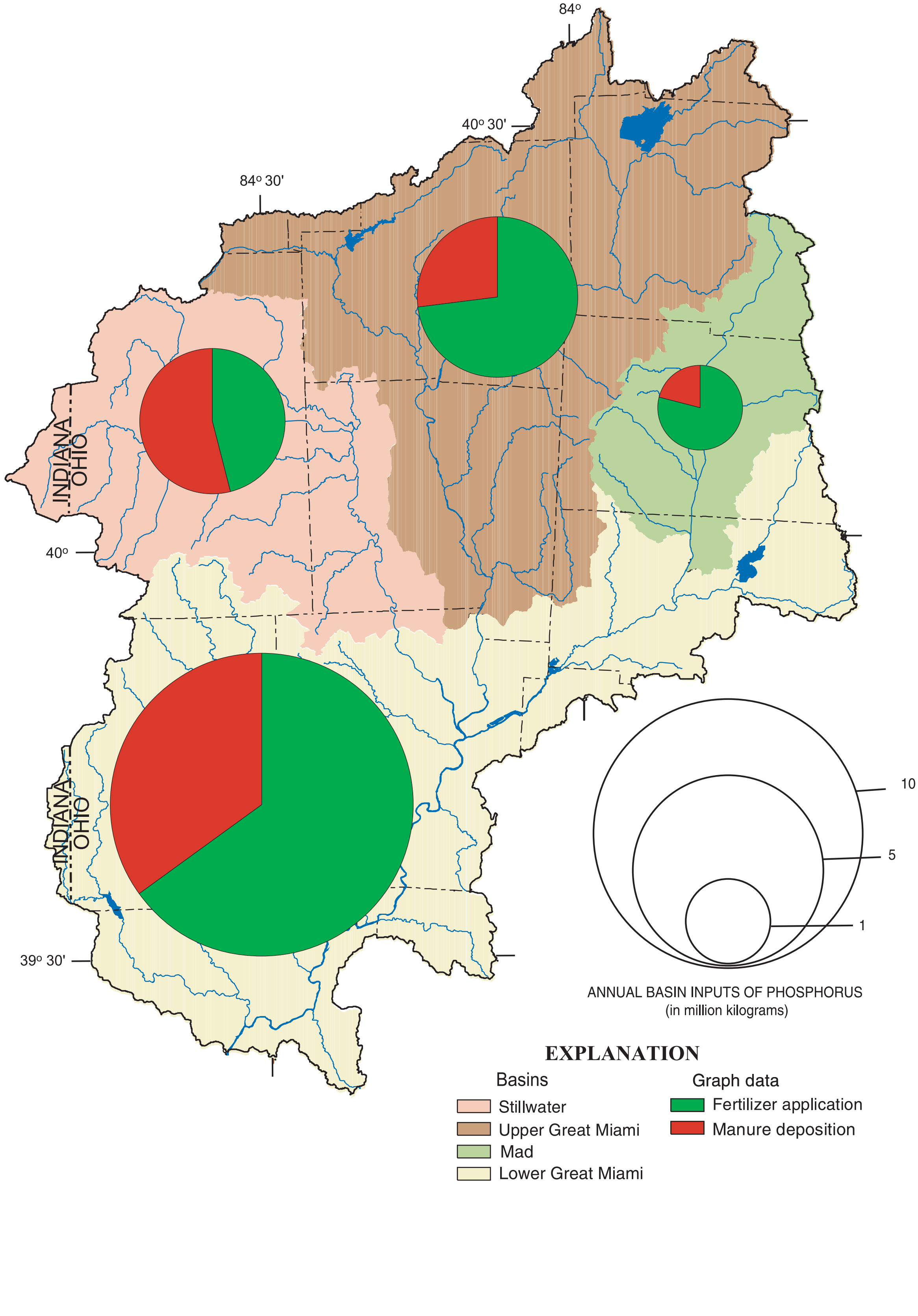

Figure 6. Estimated nonpoint-source inputs of phosphorus to the Stillwater River, Upper Great Miami River, Mad River, and Lower Great Miami River Basins.

within the Stillwater River Basin is exported to other counties within and outside of the Stillwater River Basin (Nikki Reese, Darke County Soil and Water Conservation Service, oral commun., 2002). The contribution of manure to this basin is, therefore, an overestimation. Contributions of manure to the Mad River and Upper Great Miami River Basins constituted approximately 15 percent of the nitrogen inputs and approximately 25 percent of the phosphorus inputs. Manure contributed 20 percent of the nitrogen inputs and 36 percent of the phosphorus inputs to the overall study area.

Atmospheric deposition was also an important contributor of nitrogen throughout the study area, contributing an estimated 9 to 14 percent of the nonpoint source of nitrogen to the basins (fig. 5).

Nonpoint-source inputs for the Holes Creek Basin could not be estimated for this report because of the lack of available data on commercial-fertilizer and manure applications to urban lands; however, most of the nutrients found in this stream can be attributed to commercial-fertilizer application and atmospheric deposition.

Point Sources

Nutrient inputs to the Great Miami River Basin from point sources were computed for each month of the study period. The nutrient inputs are based on information compiled from monthly operating reports (MORs) that dischargers must provide to the Ohio EPA. In most cases, the MORs provide mean daily conduit flows and ammonia concentrations measured from the effluent. Many of the dischargers must also submit concentration data for nitrite plus nitrate and total phosphorus measured in the effluent. Ammonia concentrations are measured daily, whereas nitrite plus nitrate and total phosphorus are usually measured less frequently. For this study, only facilities that discharge 0.5 Mgal/d or more into the basin were available for input computations (table 6). This cutoff rate, unfortunately, excludes many minor dischargers in the study area, which, if totaled, could be a significant source of nutrients into the basin. Discharges of industrial cooling water also were excluded from this study. For months in which the MOR was unavailable from a discharger, median concentration and discharge, computed from available months, were used. In cases where dischargers were not required to submit total phosphorus or nitrate measurements as part of their MOR, median concentrations measured from previous Ohio EPA studies were used. Locations of the dischargers used to compute point sources contributing nutrients to the study area are shown in figure 7.

Nitrogen and Phosphorus in Streams

The species distribution patterns of nitrogen and phosphorus found in streams of the Great Miami River Basin were determined from analyses of samples collected during water years 1999 and 2000 (Appendix C). Variations in concentrations associated with changes in seasons or changes in streamflow conditions were also examined during this 2-year sampling period.

Forms of Nitrogen and Phosphorus

Estimates of total nitrogen concentrations were computed by adding concentrations of total organic nitrogen plus ammonia to concentrations of dissolved nitrite plus nitrate. Because nitrite and nitrate are highly soluble in water, the particulate fraction of the nitrite plus nitrate concentration is considered negligible. Nitrate concentrations were obtained by subtracting nitrite concentrations from nitrite plus nitrate concentrations. Dissolved organic nitrogen concentrations were computed by subtracting ammonia concentrations from dissolved ammonia plus organic nitrogen concentrations. Concentrations of the particulate forms of phosphorus were computed by subtracting dissolved phosphorus concentrations from total phosphorus concentrations. Concentrations of dissolved phosphorus not in the form of orthophosphate were computed by subtracting orthophosphate concentrations from dissolved phosphorus concentrations.

Mean concentrations of dissolved ammonia, organic nitrogen, nitrite, nitrate and particulate forms of organic nitrogen and ammonia were computed from samples collected at the five sites (fig. 8). Mean concentrations of dissolved orthophosphate phosphorus, other forms of dissolved phosphorus, and particulate forms of phosphorus also were computed for each of the streams sampled.

The dominant form of nitrogen in the streams is dissolved nitrate. Mean concentrations of dissolved nitrate ranged from 0.93 mg/L (56 percent of the total nitrogen concentration) for Holes Creek near Kettering to 4.05 mg/L (84 percent of the total nitrogen concentration) for Mad River near Eagle City. Mean concentrations of dissolved organic nitrogen ranged from 0.24 mg/L (5 percent of the total nitrogen concentration) for Mad River near Eagle City to 0.46 mg/L (20 percent of the total nitrogen concentration) for Great Miami River at Hamilton. Mean concentrations of dissolved ammonia and dissolved nitrite add up to 0.1 mg/L or less (5 percent or less of the total nitrogen concentration) at all sites. In many samples, ammonia concentrations were below the LT-MDL. Ammonia was less than the LT-MDL in 23 percent of samples from Stillwater River near Union to 56 percent of the samples from Great Miami River near Vandalia. Mean concentrations of total nitrogen were between 4 and 5 mg/L for all sampling sites with the

Table 6. Description of dischargers used in point-source input calculations
[Mgal/d, million gallons per day; WWTP, wastewater treatment plant]

Reference number (fig. 7)	Facility name	County	Receiving stream	Current population receiving collection[1]	Existing flow (Mgal/d)[2]	Current design flow (mgal/d)[1]
			Publicly owned wastewater-treatment facilities			
1	Indian Lake WWTP	Logan	Great Miami River	10,200	1.8	4.6
2	Bellfontaine WWTP	Logan	Blue Jacket Creek	17,000	2.8	3.5
3	Sidney WWTP	Shelby	Great Miami River	18,600	4.1	4.5
4	Arcanum WWTP	Darke	Painter Creek	5,600	0.5	0.40
5	Greenville WWTP	Darke	Greenville Creek	15,100	2.5	3.5
6	Piqua WWTP	Miami	Great Miami River	20,400	3.4	4.5
7	Troy WWTP	Miami	Great Miami River	23,800	5.7	6.0
8	Covington WWTP	Miami	Stillwater River	2,600	0.5	0.75
9	Urbana WWTP	Champaign	Mad River	12,100	1.8	3.0
10	Clark Southwestern Regional	Clark	Mad River	3,200	1.1	1.0
11	Springfield WWTP	Clark	Mad River	72,600	14.2	25.0
12	New Carlisle WWTP	Clark	Honey Creek	7,200	0.6	1.0
13	Fairborn WWTP	Greene	Mad River	34,300	3.7	5.5
14	Brookville WWTP	Montgomery	Wolf Creek	4,900	0.8	0.65
15	TriCity North Regional WWTP	Montgomery	Great Miami River	58,200	7.7	11.3
16	Dayton WWTP	Montgomery	Great Miami River	147,900	52.5	72.0
17	Englewood WWTP	Montgomery	Stillwater River	9,200	1.3	1.75
18	Union WWTP	Montgomery	Stillwater River	5,500	0.6	1.0
19	New Lebanon WWTP	Montgomery	Bear Creek	5,600	0.8	0.80
20	Miamisburg WWTP	Montgomery	Great Miami River	17,800	2.4	3.0
21	West Carrolton WWTP	Montgomery	Great Miami River	12,000	1.5	1.4
22	Western Regional WWTP	Montgomery	Great Miami River	61,400	12.7	20.0
23	Eaton WWTP	Preble	Seven Mile Creek	6,800	1.5	1.4
24	Lesourdsville Regional WWTP	Butler	Great Miami River	8,600	5.6	4.0
25	Middletown WWTP	Butler	Great Miami River	47,200	17.6	26.0
26	Oxford WWTP	Butler	Four Mile Creek	21,200	2.5	4.2
27	Springboro WWTP	Warren	Clear Creek	5,300	2.1	2.0
28	Franklin WWTP / U. S. Filter	Warren	Great Miami River	22,000	2.9	4.5

Table 6. Description of dischargers used in point-source input calculations—Continued

[Mgal/d, million gallons per day; WWTP, wastewater treatment plant]

Reference number (fig. 7)	Facility name	County	Receiving stream	Current population receiving collection[1]	Existing flow (Mgal/d)[2]	Current design flow (mgal/d)[1]
			Privately-owned dischargers			
29	Appleton Papers	Montgomery	Great Miami River	---	7.2	6.5
30	Fraser Paper	Montgomery	Owl Creek	---	3.4	5.0
31	AK Steel (outfalls 2, 3, 4, 11, and 15)	Butler	North Branch Dick's Creek, Dick's Creek, Great Miami River	---	14.0	13.2
32	Bay West Paper	Butler	Great Miami River	---	3.6	3.7
33	Crystal Paper Co.[3]	Butler	Great Miami River	---	2.6	3.0
34	Miller Brewing Co.	Butler	Great Miami River	---	2.3	6.1
TOTAL				676,300	188.3	254.8

[1] Source, U.S. Environmental Protection Agency, 1996.

[2] Existing flow averaged from monthly operating reports for study period.

[3] Crystal Paper Co. began diverting wastewater to the Middletown WWTP in November 1999.

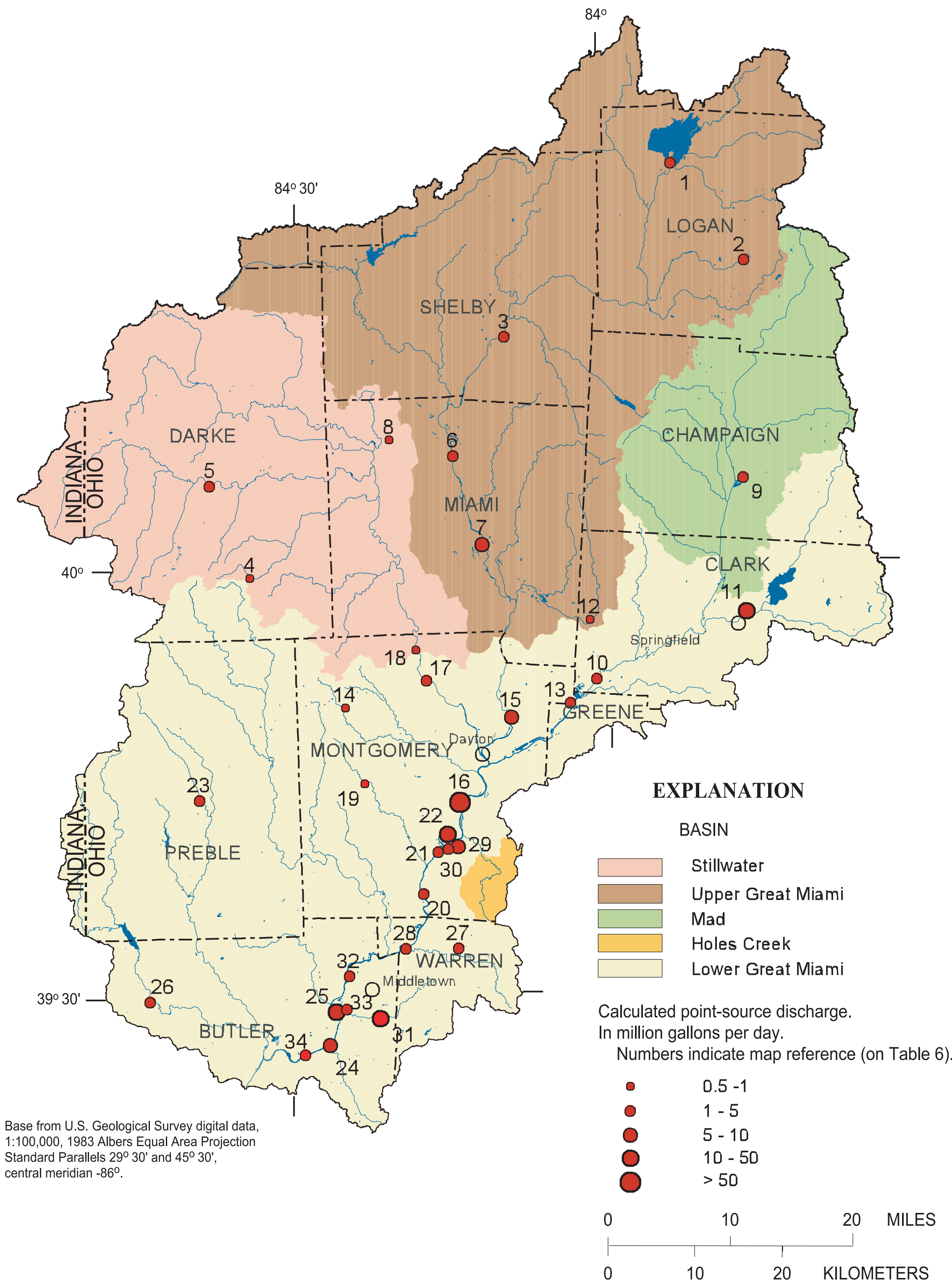

Figure 7. Location of dischargers used in estimating the point-sources inputs to the study area.

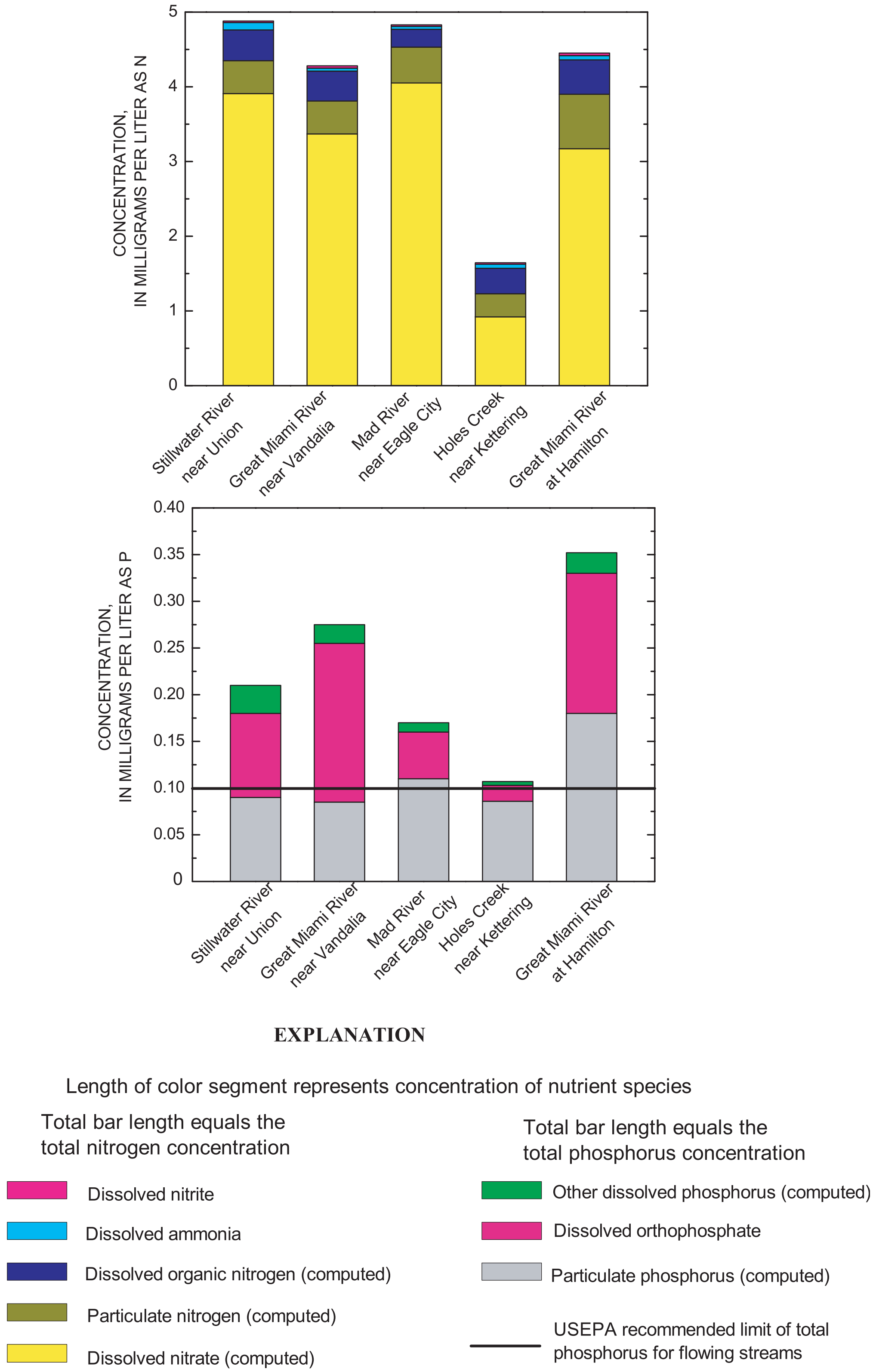

Figure 8. Mean concentration distribution of nitrogen and phosphorus species computed from samples collected at Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

exception of Holes Creek near Kettering. The mean concentration of total nitrogen for Holes Creek near Kettering was 1.7 mg/L (fig. 8).

Mean concentrations of dissolved orthophosphate ranged from 0.02 mg/L (18 percent of the total phosphorus concentration) at Holes Creek near Kettering to 0.17 mg/L (63 percent of the total phosphorus concentration) at Great Miami River near Vandalia. Mean concentrations of particulate phosphorus ranged from 0.08 mg/L (30 percent of the total phosphorus concentration) at Great Miami River near Vandalia to 0.18 mg/L (50 percent of the total phosphorus concentration) at Great Miami River at Hamilton. Mean concentration of particulate phosphorus at the Holes Creek site was 0.09 mg/L, amounting to 80 percent of the total phosphorus concentration. All sites had mean concentrations of total phosphorus greater than 0.1 mg/L, the U.S. Environmental Protection Agency's (1986) recommended limit for flowing streams (fig. 8).

Relation of Nitrogen and Phosphorus Concentrations to Season

Concentrations of nutrient species commonly vary seasonally. Nitrate concentrations, for instance, tend to be highest during late autumn through spring and lowest during summer and early autumn (fig. 9). During October through March, plants in the study area are dormant and not using much of the available nutrients; therefore, nutrients build up in the soil. Rains are then able to flush soluble nutrients, such as nitrate, from surrounding soils into streams. In late spring and early summer, nitrogen fertilizers are applied to corn and wheat fields. These fertilizer applications extend the availability of nutrients through early summer. During late summer and early autumn, rains become less frequent, terrestrial and aquatic plants use much of the available nutrients, and nitrate concentrations in streams decline.

Nitrate and total nitrogen concentrations were grouped by season and compared by means of Tukey's test. This test confirmed that mean nitrate concentrations were statistically different ($p<0.05$) between winter and autumn and between winter and summer at all sites. Mean total nitrogen concentrations were statistically different between winter and autumn at all sites and between winter and summer at all sites, with the exception of the Holes Creek site.

Orthophosphate concentrations typically are high during autumn and low during spring (fig.10). Orthophosphate is readily consumed by terrestrial and aquatic plants during the spring and summer growing period; however, an increase in orthophosphate in summer was observed at Great Miami River near Vandalia and Great Miami River at Hamilton. These sites have a number of wastewater-treatment facilities in their drainage areas. During summer, streamflow was low, and effluent from these facilities was a major contributor to streamflow. Seasonal variation in total phosphorus concentration was minimal in the study area. Because total phosphorus is transported to the streams mainly by runoff, high concentrations are more associated with runoff events than with seasonal variation. Most of the high total phosphorus concentrations in the study area were from samples collected during runoff events.

Tukey's test shows that mean orthophosphate and total phosphorus concentrations were not statistically different between any of the seasons for Stillwater River near Union and Holes Creek near Kettering; however, mean orthophosphate concentrations were statistically different between spring and autumn for Great Miami River near Vandalia, Mad River near Eagle City, and Great Miami River at Hamilton. Mean total phosphorus concentrations were statistically different only between spring and summer for Great Miami River near Vandalia.

Relation of Nitrogen and Phosphorus Concentrations to Land Use

The sites sampled in the Great Miami River Basin represent drainage areas in predominantly agricultural areas, predominantly urban areas, or a mixture of both. Forested areas represent only a small part of the study area. In general, the urban site—Holes Creek near Kettering—had the lowest nitrogen and phosphorus concentrations of the sites sampled (fig. 8). The sites representing predominantly agricultural basins had nitrogen concentrations similar to Great Miami River at Hamilton, the mixed-land-use site. Great Miami River at Hamilton had the highest phosphorus concentrations for the study area (fig. 8), probably because of the many point-source dischargers in the Great Miami River Basin between Dayton and Hamilton.

The role of agriculture—specifically, cropland—on nitrogen concentrations was investigated by plotting median concentrations of total nitrogen and total phosphorus against percentage of drainage area in row crops (fig. 11). This comparison included surface-water sites with 10 or more nutrient samples in the Great Miami and Little Miami River Basins NAWQA study area, along with the two adjacent NAWQA study areas—the White River Basin NAWQA in Indiana and the Lake Erie-Lake Saint Clair Drainages NAWQA in Michigan, Ohio, Indiana, New York, and Pennsylvania. As in the Great Miami River Basin, corn and soybeans are the principal crops produced in these adjacent study areas. As figure 11 shows, higher median nitrogen concentrations typically are associated with a higher percentage of drainage area in row crops. Median phosphorus concentrations, however, did not necessarily increase with an increase in drainage area dedicated to row crops.

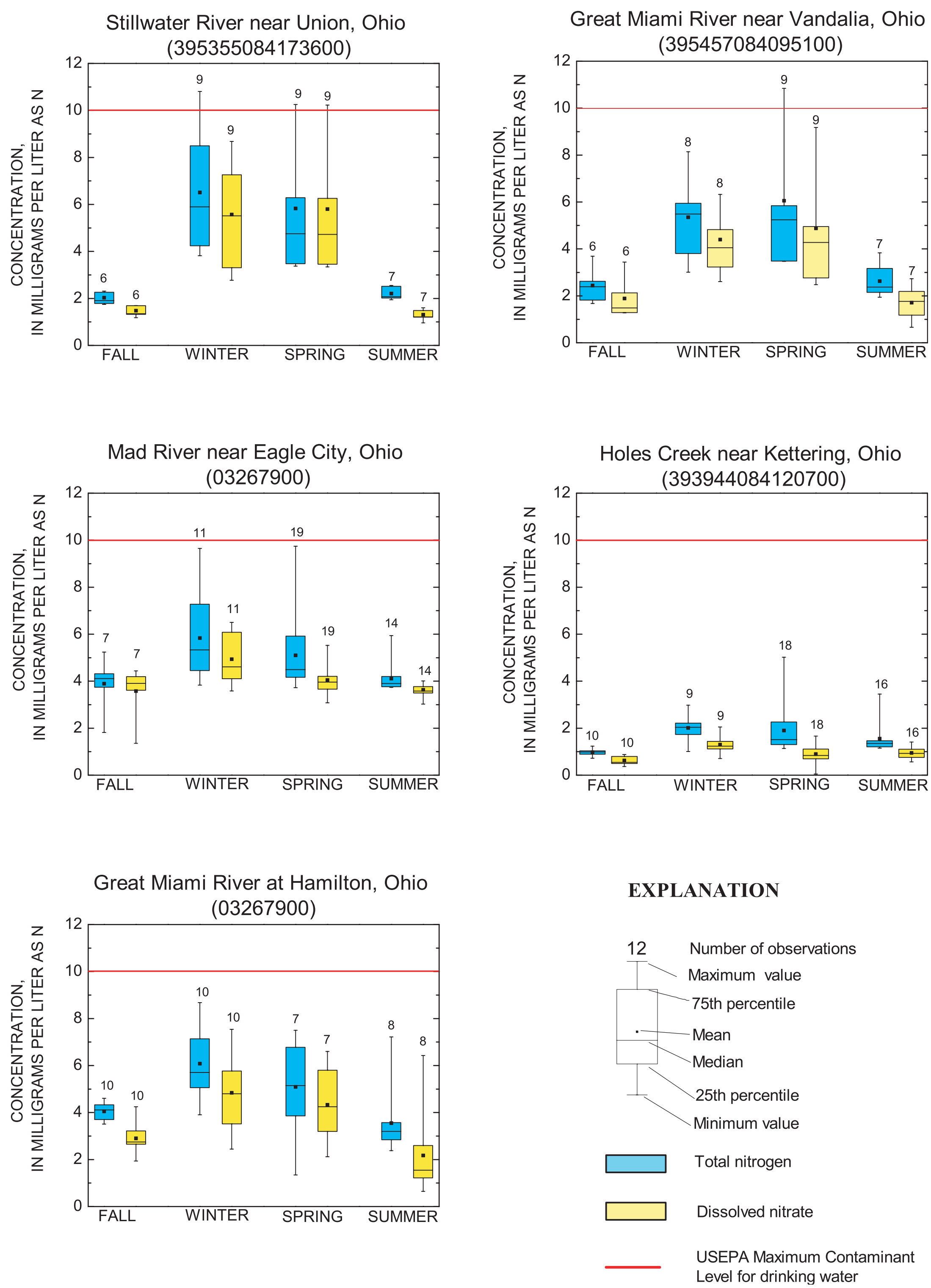

Figure 9. Seasonal distribution of total nitrogen and dissolved nitrate concentrations for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

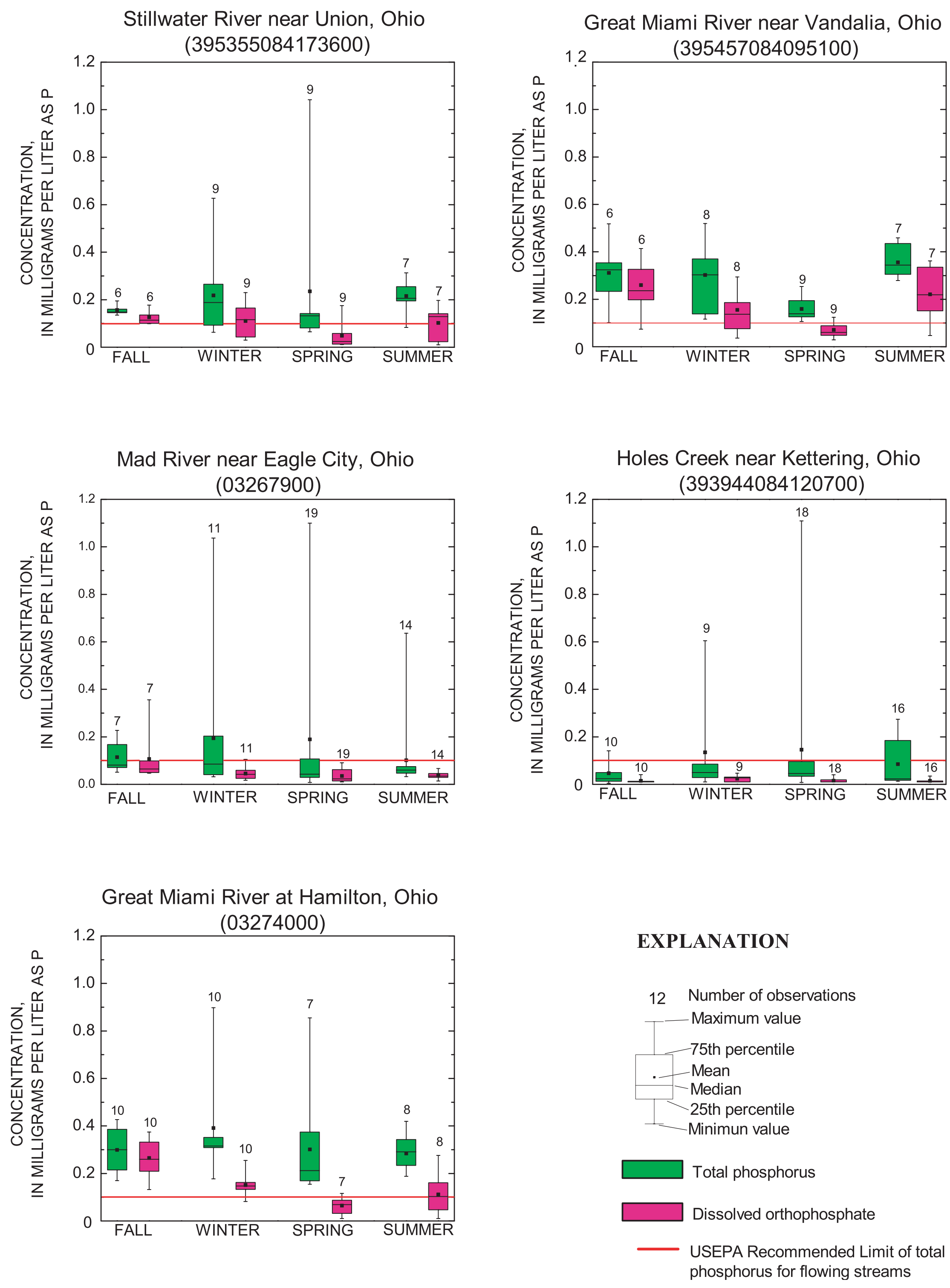

Figure 10. Seasonal distribution of total phosphorus and dissolved orthophosphate concentrations for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

Estimated Nitrogen and Phosphorus Loads

Transport of nutrients within and out of the study area was determined by instream-load computations. Loads determined for this study are computed as constituent concentration multiplied by streamflow and a units-conversion factor, which in turn is multiplied by an applicable time period. The loads are then summed to determine the total load for the period of interest.

Proportions of the individual nitrogen and phosphorus species that contribute to the total nitrogen and phosphorus loads are similar to what was observed for total nitrogen and phosphorus concentrations (figs. 8, 12, and 13). For instance, most of the nitrogen load for Great Miami River at Hamilton was in the form of nitrate. Nitrate contributed 74 percent of the nitrogen load to Great Miami River at Hamilton, whereas ammonia and nitrite together contributed only 2 percent of the nitrogen load (table 7).

Of the three streams upstream from Dayton, the Upper Great Miami River was the largest contributor of total nitrogen to the study area with a mean daily load of 12,600 kg, followed by the Stillwater River with a mean daily load of 9,100 kg and the Mad River with a mean daily load of 2,900 kg during water years 1999 and 2000. Great Miami River at Hamilton had a mean daily total nitrogen load of 30,800 kg. The combined daily load of total nitrogen from the three streams upstream from Dayton was 24,600 kg, or 83 percent of the nitrogen load computed for Great Miami River at Hamilton (fig. 12). Point sources used in the computations (discharges of 0.5 Mgal/d or more) contributed 5 percent of the nitrogen load computed for the three sites upstream from Dayton during the 2-year monitoring period. Nonpoint sources of nitrogen (commercial fertilizer, manure, and atmospheric deposition) and minor point sources (discharges less than 0.5 Mgal/d), therefore, contributed 95 percent of the nitrogen load computed for the three sites upstream from Dayton.

Particulate phosphorus represented the largest proportion of the total phosphorus load to the sampling sites upstream from Dayton and to Great Miami River at Hamilton during the study period (fig. 13 and table 8). Of the three streams upstream from Dayton, the Upper Great Miami River contributed the largest daily load of total phosphorus with 560 kg, followed by the Stillwater River with 430 kg and the Mad River with 160 kg. The daily load of total phosphorus increases to 2,400 kg at Great Miami River at Hamilton. The combined daily load of total phosphorus for the three streams upstream from Dayton is 1,150 kg or 47 percent of the total phosphorus load computed for Great Miami River at Hamilton (fig.13).

Nitrogen and phosphorus loads of Holes Creek, however, differ from those of the other streams. Nitrate represents a much smaller proportion of the total nitrogen load, whereas ammonia and organic nitrogen represent larger proportions. In addition, particulate phosphorus represents an appreciably greater proportion of the total phosphorus load of Holes Creek (table 8).

Monthly Loads. Monthly loads of nitrate, total nitrogen, orthophosphate, and total phosphorus were computed for each site sampled by means of the ESTIMATOR program. The degree of confidence in these load estimates varies by nutrient species, site, and streamflow condition for the month (Appendix D). In general, monthly loads of nitrate and total nitrogen had the smallest confidence limits, typically ranging from 25 to 80 percent of the estimated loads.

Table 7. Percentage contribution to mean total nitrogen and total phosphorus loads by species, October 1998–September 2000

Nutrient	Stillwater River near Union	Great Miami River near Vandalia	Mad River near Eagle City	Holes Creek near Kettering	Great Miami River at Hamilton
Nitrogen					
Dissolved ammonia	1.2	1.0	1.2	5.6	1.4
Dissolved nitrite	0.4	0.4	0.4	1.0	0.6
Dissolved nitrate	81.6	80.0	80.5	45.6	73.9
Dissolved organic nitrogen	7.1	8.1	5.2	17.5	8.6
Particulate nitrogen	9.6	10.5	12.7	30.3	15.5
Phosphorus					
Dissolved orthophosphate	33.4	45.4	18.9	8.6	32.3
Other dissolved phosphorus	9.4	4.6	4.5	2.2	5.3
Particulate phosphorus	57.2	50.0	76.6	89.2	62.4

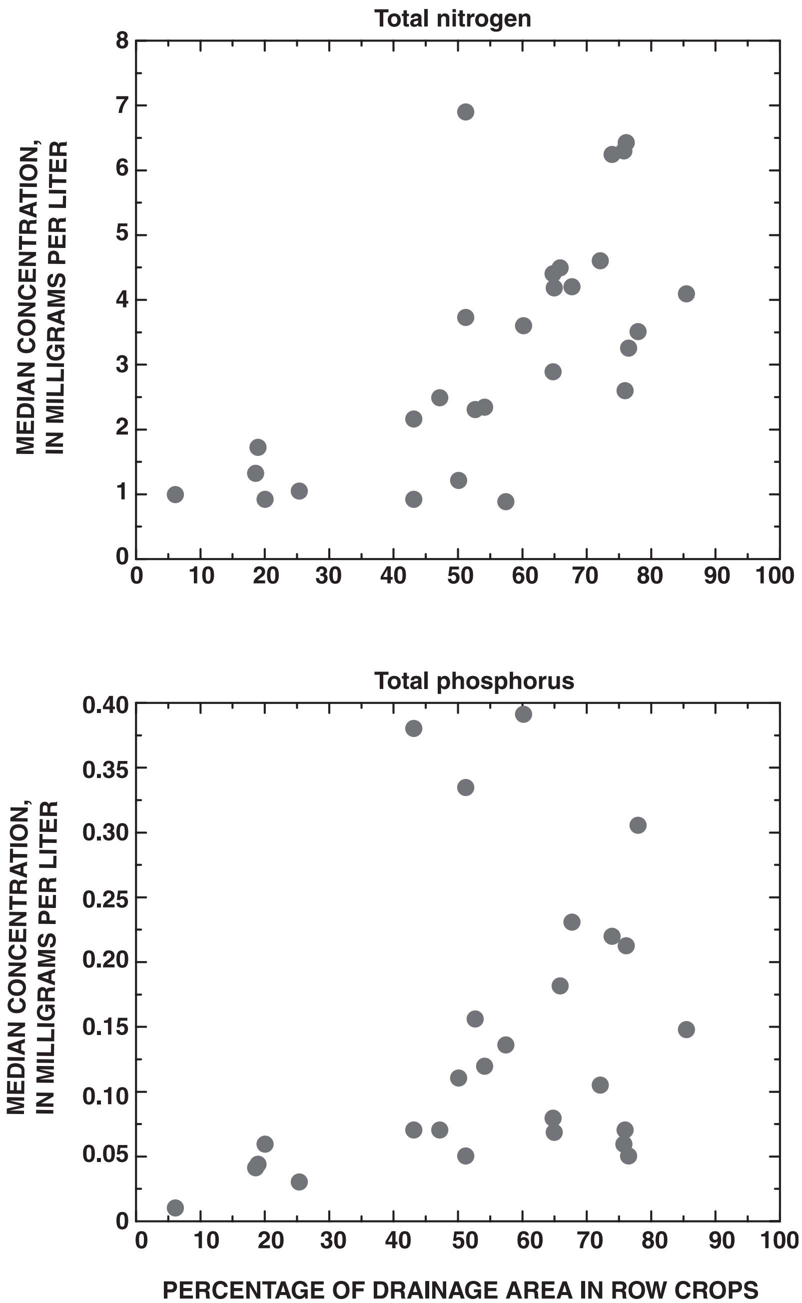

Figure 11. Relation between the percentage of drainage basin in row crops and the median concentrations of total nitrogen and total phosphorus for sites in the Great Miami and Little Miami Basins, Lake Erie-Lake Saint Clair Drainages, and White River Basin study units.

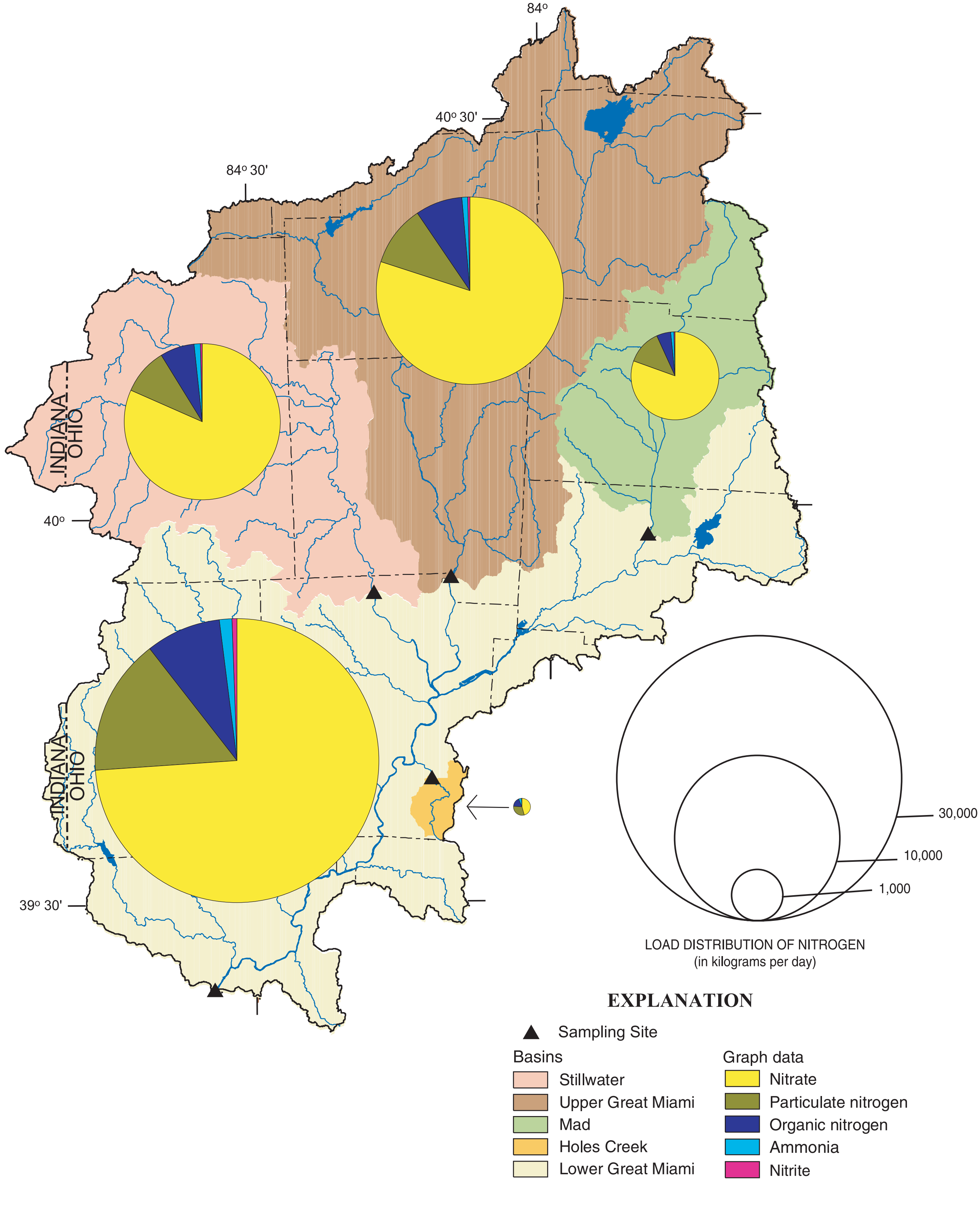

Figure 12. Load distribution of nitrogen species based on ESTIMATOR means for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

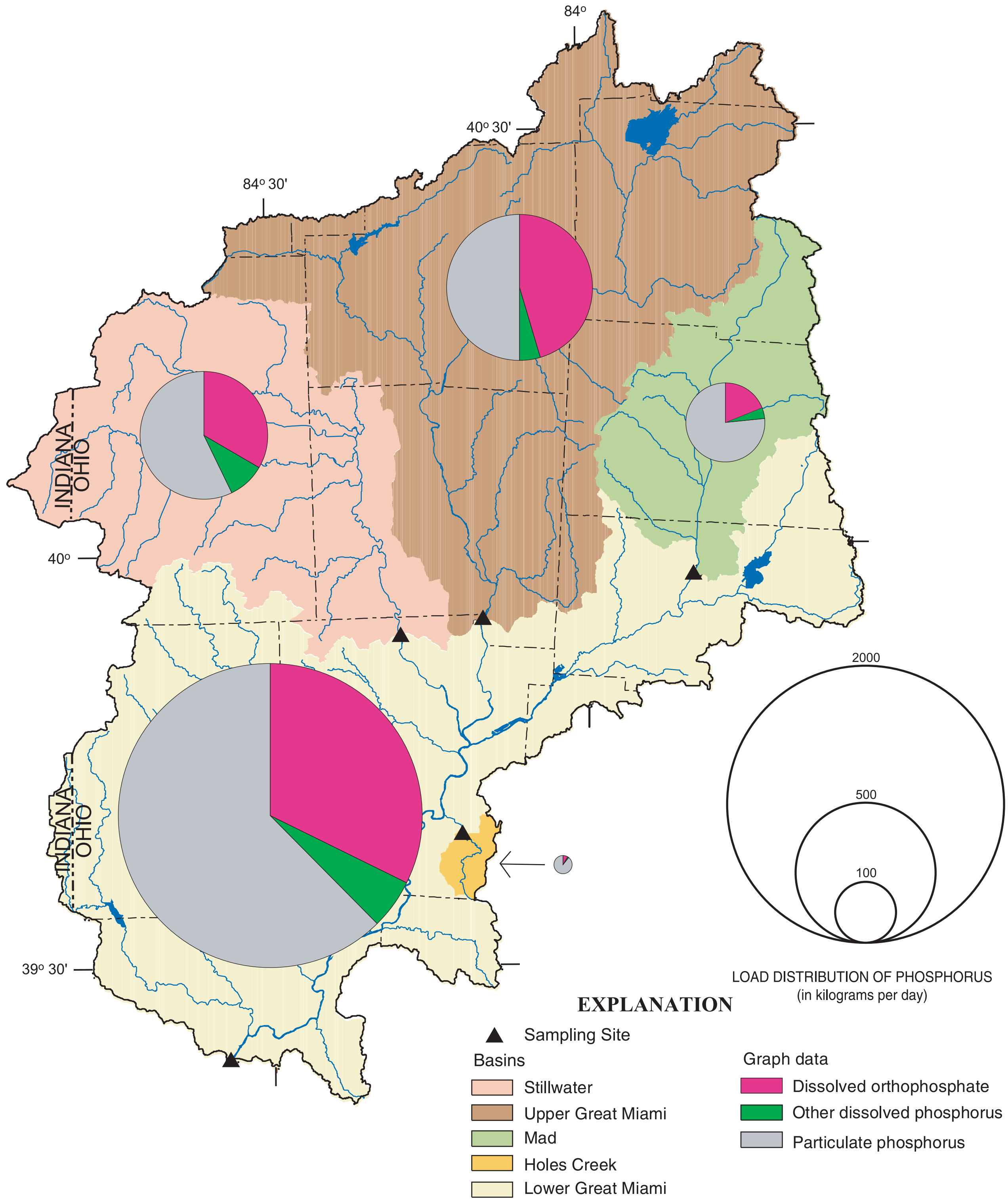

Figure 13. Load distribution of phosphorous species based on ESTIMATOR means for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

Monthly loads of ammonia also were computed; however, because confidence limits of the ammonia load estimates were consistently 100 to 300 percent of the estimated loads at all sites, monthly loads of ammonia are not addressed in this report.

Seasonal patterns in nutrient loads were observed at all sampling sites. Monthly loads of nitrate and total phosphorus, as displayed in figures 14 and 15, are typical of the pattern in the study area. Seasonal patterns in nutrient loads (figs. 14 and 15) are similar to monthly streamflow patterns in the study area (fig. 4) and thus demonstrate the importance of streamflow to load computations. Dramatic increases in streamflow and nutrient loads during winter and early spring were followed by reduced streamflow and nutrient loads during late spring and summer. Streamflow and nutrient loads were lowest during summer and autumn 1999. The number and intensity of runoff events were below normal in the study area for much of summer and autumn 1999 (fig. 2), resulting in low flows at most streams. Nitrate loads were highest during winter and spring 1999 and lowest during summer and autumn 1999. Nitrate loads were also relatively high throughout spring 2000 (fig. 14).

Differences between estimated maximum monthly loads and minimum monthly loads for the study period are large at all sites with the exception of Mad River near Eagle City (table 8). Minimum monthly loads of nitrate and total nitrogen estimated at the Mad River site were about 15 percent and 10 percent, respectively, of corresponding maximum monthly loads; at the other sites, however, minimums ranged from about 0.2 percent to 2 percent of the corresponding maximums (table 8). A possible explanation for this difference is that the more permeable soils in the Mad River Basin allow for infiltration of fertilizer-derived nitrogen to shallow ground water, leaving less nitrogen at land surface for transport to streams during runoff events. Nitrate-bearing shallow ground water, however, will discharge into streams year round as base flow. Nitrate concentrations of ground-water samples collected from 11 shallow wells (well depths between 11 and 53 feet) within the Mad River Basin were higher than the mean concentration of samples collected from the Mad River (5.5 mg/L as compared to 4.05 mg/L). The continuous ground-water discharge provides a stable input of nitrate to the Mad River and its tributary streams. By contrast, the differences between the minimum monthly loads and the maximum monthly loads of orthophosphate and total phosphorus at the Mad River site are more similar to those at some of the other sites.

Monthly inputs from point sources into the basins of the sampling sites also were included in figures 14 and 15 to illustrate the importance of point sources to instream loads during low-flow months. Point sources were the primary contributor of nitrate loads in all of the rivers during summer and autumn, with the exception of the Mad River and Holes Creek (fig.14), and actually contribute more nitrogen than is reflected in the computed instream loads for Stillwater River near Union, Great Miami River near Vandalia, and Great Miami River at Hamilton during some months in summer and autumn 1999.

Total phosphorus loads were highest during winter and spring 1999 and lowest during summer and autumn 1999. Phosphorus loads were also elevated during winter and spring 2000 (fig. 15). As with the nitrogen loads, the highest total phosphorus loads occurred in January 1999. Point sources were the major contributors of total phosphorus to the Great Miami River and Mad River during summer and autumn 1999, whereas point sources were the major contributors of total phosphorus to the Stillwater River only from August through October 1999.

The anomaly of point-source inputs being higher than computed instream discharges of nitrate and total phosphorus in many months is examined for Great Miami River at Hamilton in figure 16. In this example, the percentage of instream loads from point-source inputs was nearly 400 percent for total nitrogen and 300 percent for total phosphorus during summer 1999. Although errors in the load estimates could account for some of the high percentages, nutrients are likely being used by algae and other aquatic plants in the streams, because much of the growth and development of aquatic plants occurs during summer and early autumn. Porter (2000) found that concentrations of dissolved nitrate plus nitrite nitrogen and orthophosphate decreased significantly with increases in algal productivity in Upper Midwest river systems.

Estimated monthly loads contributed by the three streams upstream from Dayton are compared to the estimated monthly load at Great Miami River at Hamilton in figure 17. Contributions of total nitrogen and total phosphorus upstream from Dayton varied from stream to stream as a function of streamflow. The Mad River contributed 20 percent or less of the total nitrogen load of Great Miami River at Hamilton during most of the study period; but during the drought, total nitrogen contributions from the Mad River rose to more than 25 percent of the load of Great Miami River at Hamilton. The higher contribution from the Mad River during the drought was most likely due to the high ground-water discharge to the river. During spring 2000, total contributions of total nitrogen from the three streams upstream from Dayton exceeded the estimated load for Great Miami River at Hamilton by as much as 23 percent. This discrepancy may be caused by errors in the load estimates for Great Miami River at Hamilton. (No samples were collected at Great Miami River at Hamilton during these months because of bridge construction.)

Loads Computed from U.S. Environmental Protection Agency Data. Monthly loads based on analyses of samples collected by the USEPA also were computed by use of ESTIMATOR. The water samples were collected from

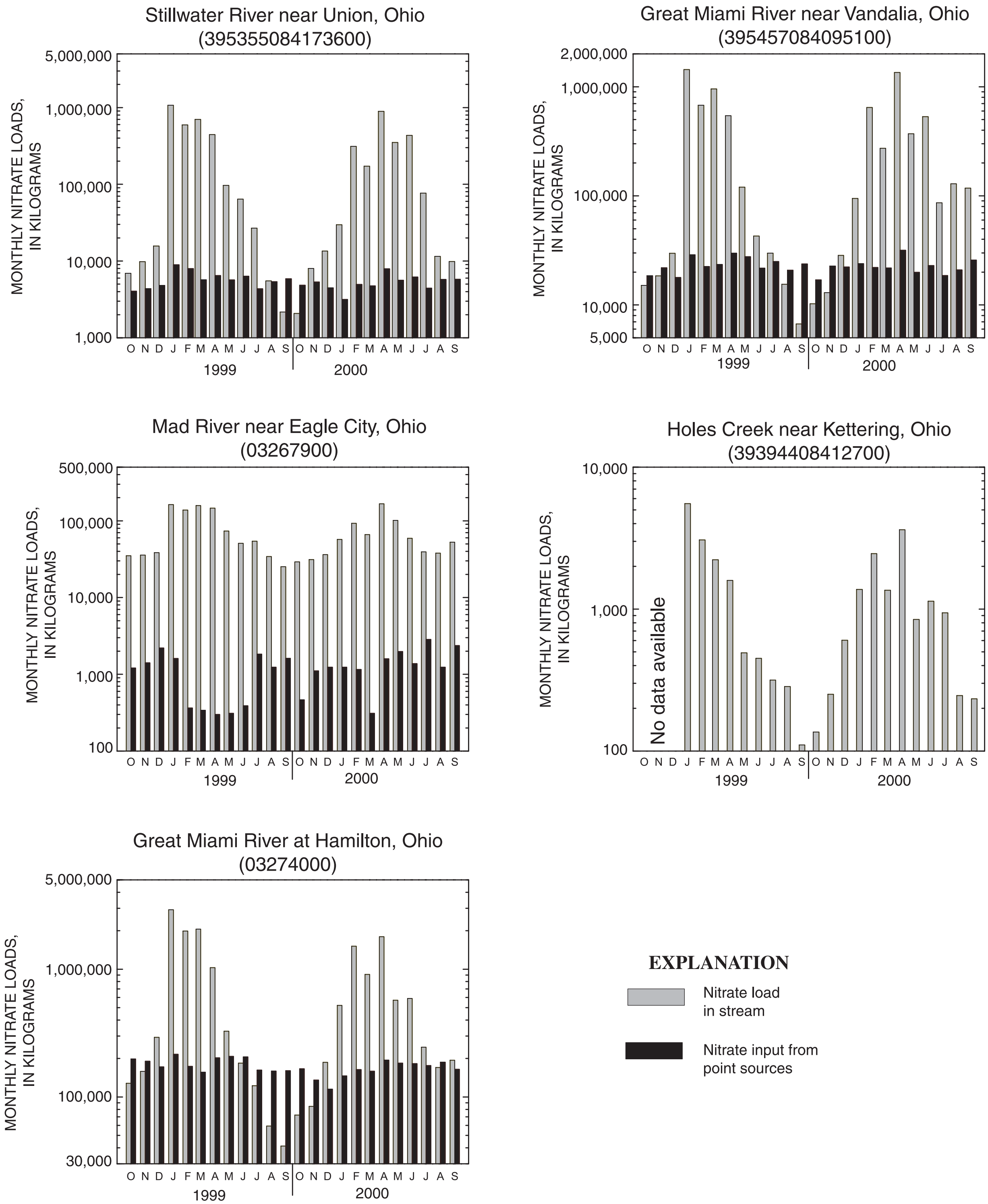

Figure 14. Instream loads and point-source inputs of nitrate for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

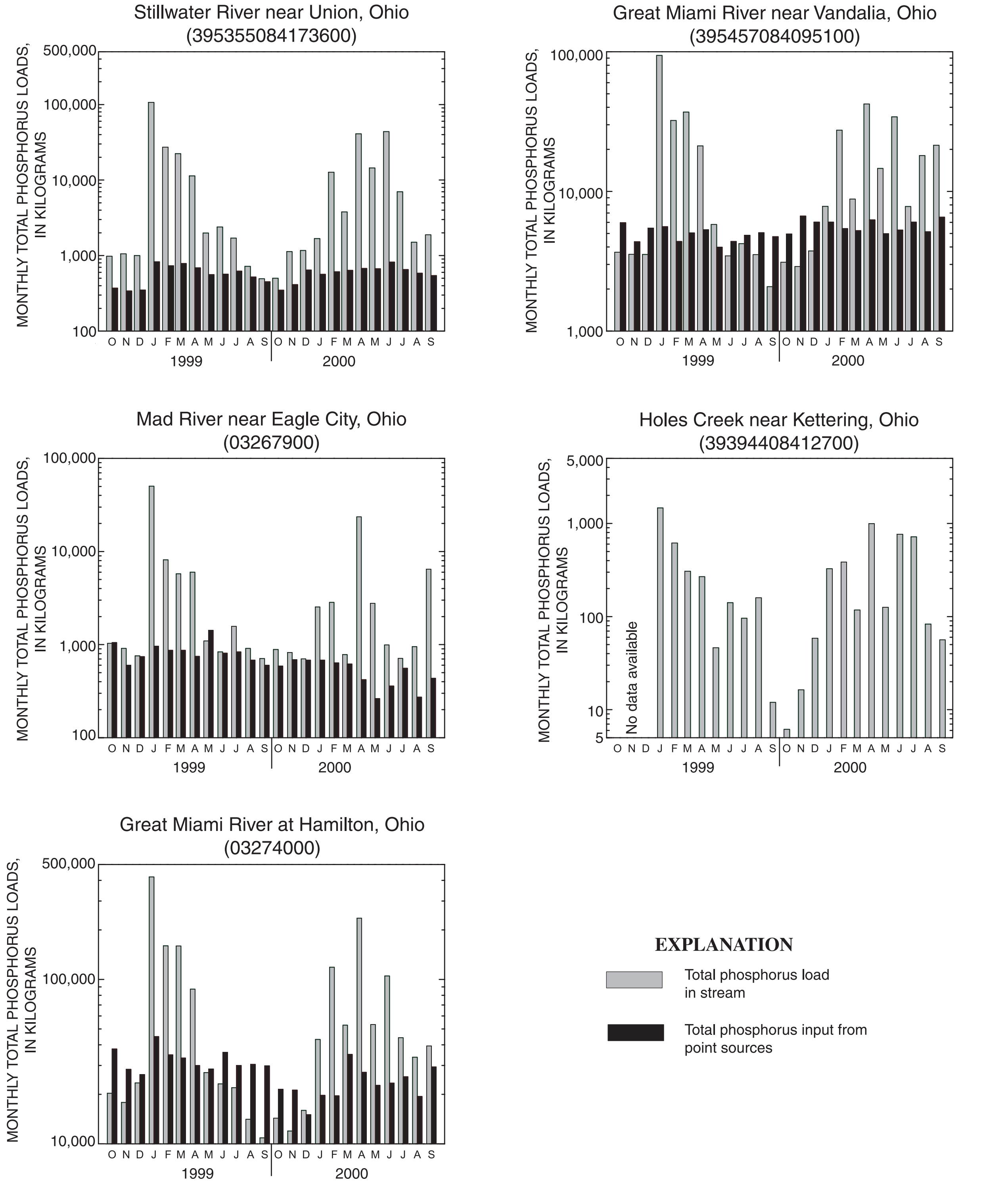

Figure 15. Instream loads and point-source inputs of total phosphorus for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

Table 8. Statistical summary of the monthly nutrient loads for sites in the Great Miami River Basin, October 1998–September 2000
[All loads in kilograms]

Nutrient	Maximum load	Mean load	Median load	Minimum load
Stillwater River near Union, Ohio				
Nitrate	1,100,000	220,000	47,000	2,100
Total nitrogen	1,300,000	270,000	62,000	3,400
Orthophosphate	46,000	4,300	1,100	180
Total phosphorus	110,000	13,000	1,900	500
Great Miami River near Vandalia, Ohio				
Nitrate	1,400,000	310,000	110,000	6,700
Total nitrogen	1,700,000	380,000	140,000	9,800
Orthophosphate	43,000	7,700	3,800	1,600
Total phosphorus	94,000	17,000	7,800	2,100
Mad River near Eagle City, Ohio				
Nitrate	160,000	72,000	53,000	25,000
Total nitrogen	250,000	88,000	65,000	28,000
Orthophosphate	4,900	960	630	410
Total phosphorus	50,000	5,100	1,000	700
Holes Creek near Kettering, Ohio				
Nitrate	5,500	1,300	850	110
Total nitrogen	14,000	3,000	1,800	180
Orthophosphate	180	28	15	2.2
Total phosphorus	1,500	320	140	6.2
Great Miami River at Hamilton, Ohio				
Nitrate	2,900,000	670,000	270,000	41,000
Total nitrogen	3,800,000	930,000	410,000	79,000
Orthophosphate	140,000	24,000	12,000	3,400
Total phosphorus	420,000	73,000	37,000	11,000

December 1999 through December 2000 by the USEPA at a Great Miami River sampling station in the Greater Cincinnati Water Works' Bolton well field near Fairfield, Ohio, 6.7 mi downstream from Great Miami River at Hamilton (fig 1). USEPA samples were collected from a single intake point at the left bank of the river. An automatic sampler was activated each hour to pump water from the intake point. Daily composites of these subsamples were stored in a holding facility that was refrigerated to 4°C. A linear regression analysis of data for USEPA and USGS samples collected on the same day show that concentrations of nitrate, total nitrogen, and total phosphorus were similar, with p-values less than 0.0001 for the three comparisons (fig. 18). Any discrepancies found between sample sets are probably the result of different sample-collection methods and use of different laboratories for the sample analyses. For most months, loads of nitrate, total nitrogen, and total phosphorus from both data sources produced comparable seasonal patterns (fig. 19).

Both data sources show the highest monthly loads in April 2000 and the lowest monthly loads during August and September 2000. However, more than half of the nitrate and total nitrogen loads computed from USEPA data were outside the 95-percent confidence interval of the loads computed from USGS data; loads computed from USEPA data were higher than loads computed from USGS data for all months but September 2000. In contrast, total phosphorus loads were more comparable; loads computed from USEPA data were inside of the 95-percent confidence intervals of loads computed from USGS data for all months.

Historical Trends of Nitrogen and Phosphorus Loads for the Great Miami River. Historical loads of nitrogen and phosphorus were computed for the Great Miami River by means of the ESTIMATOR program calibrated with nutrient data collected by the NASQAN program at Great Miami River near New Baltimore from 1974 through 1993 (Appendix E). Great Miami River at New Baltimore is 13 mi downstream from Great Miami River at Hamilton and

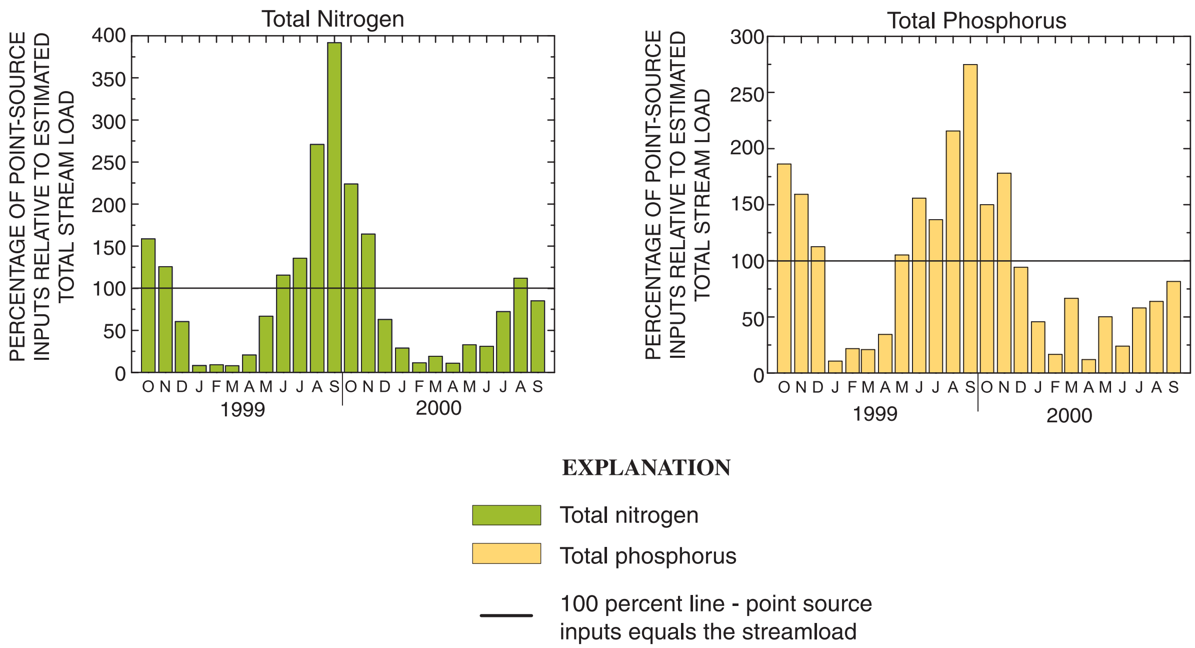

Figure 16. Percentage of stream load from point-source contributions for total nitrogen and total phosphorus at Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

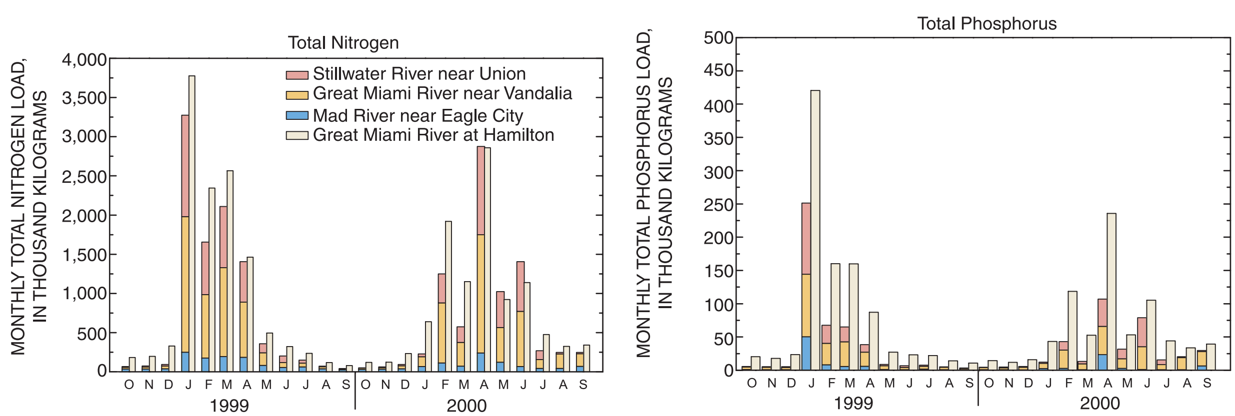

Figure 17. Monthly loads of total nitrogen and total phosphorus for the three sites above Dayton, Ohio, and Great Miami River at Hamilton, Ohio, water years 1999 and 2000.

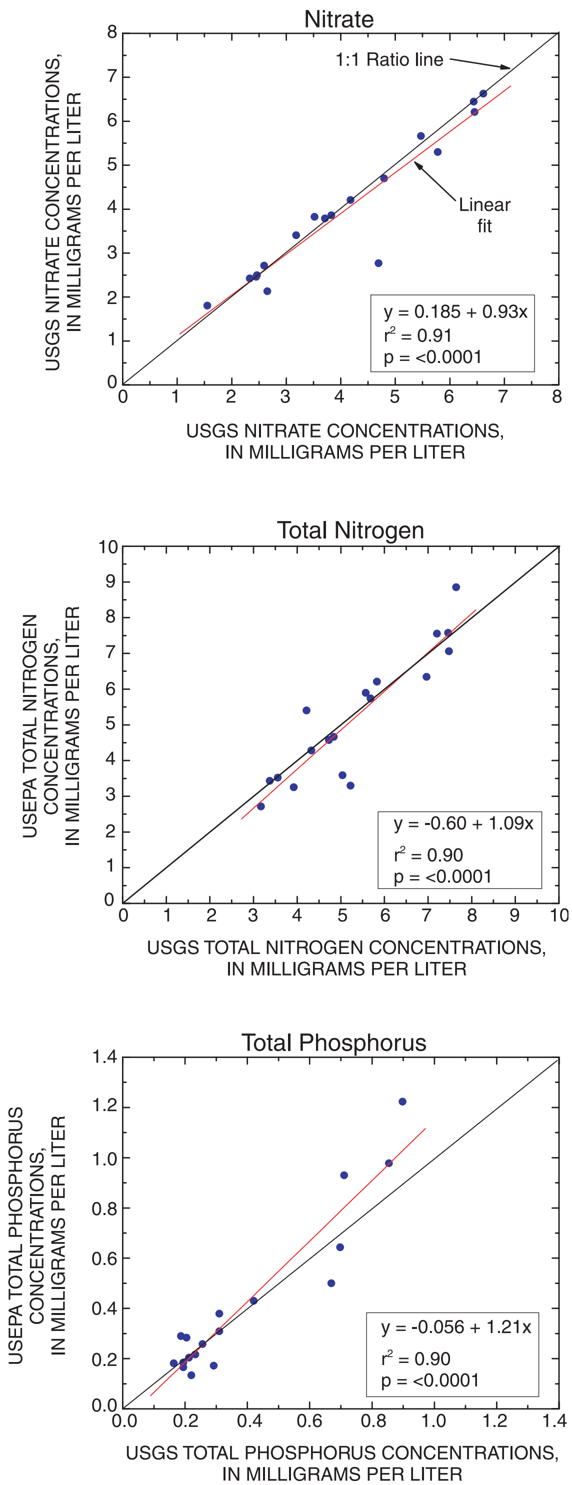

Figure 18. Comparison of nitrate, total nitrogen, and total phosphorus concentrations from samples collected on the same day by the U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey (USGS).

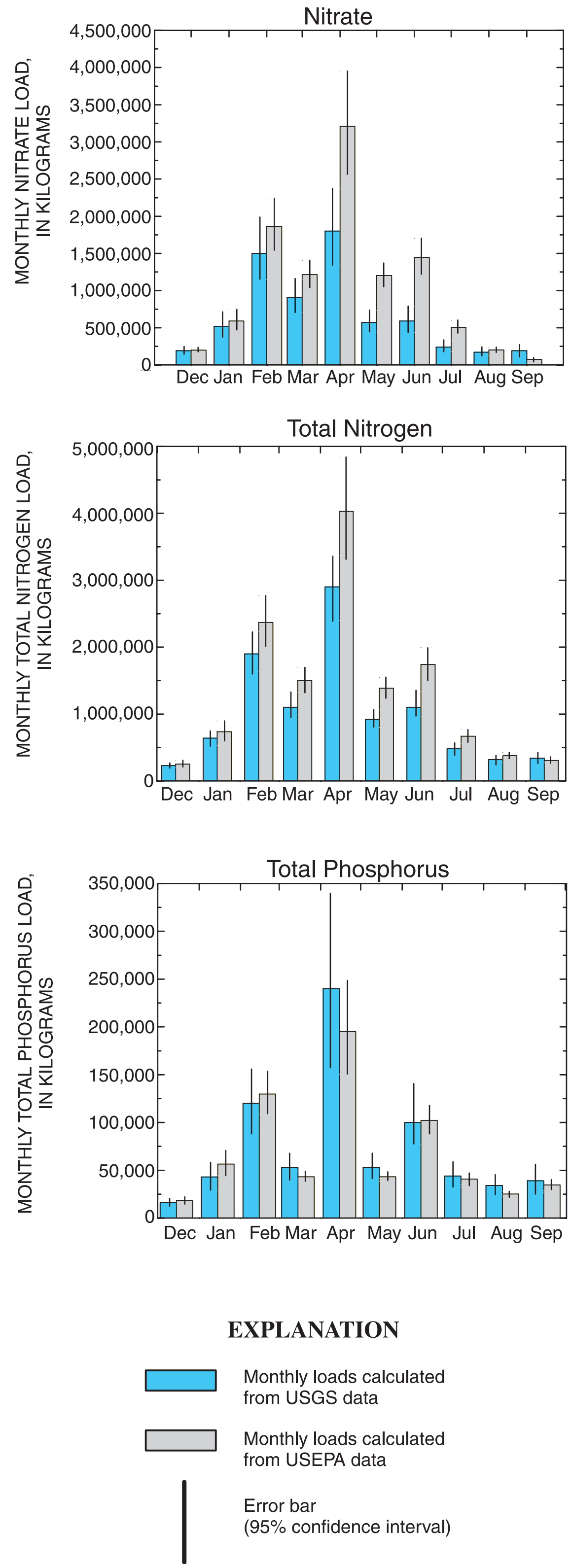

Figure 19. Monthly loads of nitrate, total nitrogen, and total phosphorus computed from U.S. Environmental Protection Agency (USEPA) and U.S. Geological Survey (USGS) data, December 1999 through September 2000.

is influenced by two additional major point sources that contribute an estimated 26 Mgal/d (40 ft^3/s) of effluent to the Great Miami River. Streamflow measured at Great Miami River at Hamilton, however, was used in load computations for Great Miami River at New Baltimore.

Annual nutrient loads were computed for water years 1974 through 2000 for Great Miami River at Hamilton using the NASQAN and NAWQA data sets. (Nutrient data were not available for water years 1994 through 1998.) The highest total nitrogen and total phosphorus loads occurred during the 1970s and early 1980s (fig. 20). The 1999 and 2000 annual loads computed from this study were comparatively low, but annual mean streamflows for these years also were low (fig. 20). In order to determine whether a downtrend in nutrient loads actually occurred from 1974 through 2000, linear regression analyses adjusted for flow were done on total nitrogen and total phosphorus annual loads. These analyses found trends of lower total nitrogen and total phosphorus to be statistically significant ($p<0.001$). The decrease in nutrient loads for this period of record was probably due to improvements in wastewater-treatment plants. Most of the major wastewater-treatment plants in the study area have upgraded their treatment process at least once since 1974 (Ohio Environmental Protection Agency 1996, 1997, and 2001).

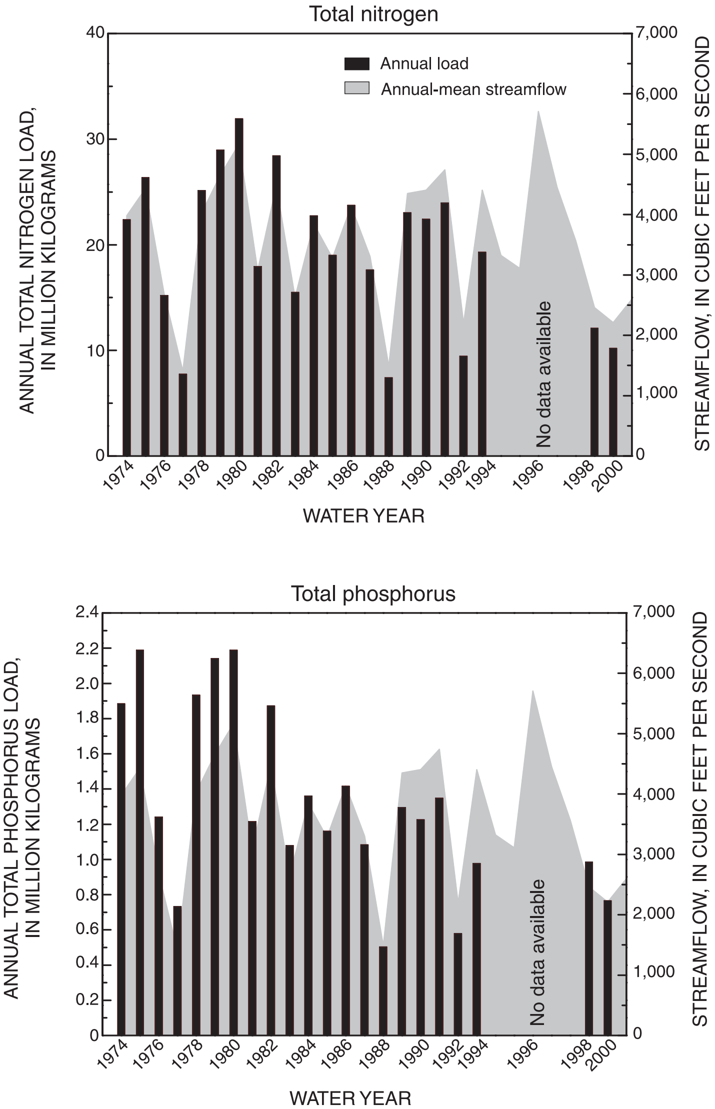

Figure 20. Annual loads of total nitrogen and total phosphorus for the Great Miami River at Hamilton, Ohio, water years 1974 through 2000.

Nitrogen and Phosphorus Yields

The size of a drainage area often overshadows the effects that land use and physiography have on loads because large basins contribute large loads. The importance of land use and physiography to drainage basins is better observed when yields rather than loads of nutrients are compared. Yields are computed by dividing load by basin area. Maximum, mean, median, and minimum monthly yields were computed for each site (table 9).

Nutrient yields commonly are related to land-use practices in the drainage basin. For example, previous NAWQA studies have shown that streams in agricultural and urban areas typically had the highest nutrient concentrations, whereas streams in undeveloped, forested areas typically had the lowest nutrient concentrations (U.S. Geological Survey, 1999). Nutrient sources in urban basins include fertilizers applied to lawns and golf courses, auto mobile emissions, and effluent from wastewater-treatment facilities. Agricultural basins with numerous animal feeding operations or a high proportion of land dedicated to row crops can be major sources of nutrients (U.S. Geological Survey, 1999).

Physiography of a drainage basin can also influence nutrient yields. Unconsolidated glacial sediment was deposited throughout the study area during three episodes of Pleistocene glaciation. Most of the study area is dominated by glacial till—an unsorted mixture of clay, silt, sand, and gravel. The Mad River Basin, however, is dominated by glacial outwash—sediment consisting of well-sorted sand and gravel, which forms a productive aquifer that discharges high volumes of ground water to the Mad River (Debrewer and others, 2000; Koltun, 1995).

Mean nutrient yields were computed for the drainage areas of the five sites sampled by the USGS (fig. 21). Mean yield was also computed for Great Miami River at Hamilton on the basis of NASQAN samples collected at Great Miami River near New Baltimore during 1975–93. A comparison of mean yields for water years 1999 and 2000 shows that

Table 9. Statistical summary of the monthly nutrient yields for sites in the Great Miami River Basin, October 1998– September 2000

[All yields in kilograms per square kilometer]

Nutrient	Maximum yield	Mean yield	Median yield	Minimum yield
Stillwater River near Union, Ohio				
Nitrate	640	130	28	1.2
Total nitrogen	770	170	38	2.1
Orthophosphate	27	2.6	0.67	0.11
Total Phosphorus	64	7.7	1.2	0.30
Great Miami River near Vandalia, Ohio				
Nitrate	480	110	36	2.3
Total nitrogen	580	130	48	3.3
Orthophosphate	15	2.6	1.3	0.53
Total Phosphorus	32	5.7	2.6	0.70
Mad River near Eagle City, Ohio				
Nitrate	210	89	67	31
Total nitrogen	310	110	81	34
Orthophosphate	6.1	1.2	0.79	0.47
Total phosphorus	63	6.3	1.3	0.88
Holes Creek near Kettering, Ohio				
Nitrate	106	25	16	2.1
Total nitrogen	260	58	34	3.5
Orthophosphate	3.5	0.55	0.28	0.04
Total phosphorus	28	6.2	2.7	0.12
Great Miami River at Hamilton, Ohio				
Nitrate	310	72	29	4.4
Total nitrogen	400	99	44	8.4
Orthophosphate	16	2.5	1.3	0.37
Total phosphorus	45	8.0	4.0	1.2

mean nitrogen yields for the Stillwater River were the highest in the study area. The Stillwater River and the Upper Great Miami River had the highest mean orthophosphate yields (85 g/km^2/d); however, the highest mean total phosphorus yields were for Great Miami River at Hamilton (257 g/km^2/d). For comparisons of yields, the analysis period was shortened at all sites to include only the months that streamflow data were available for Holes Creek (January 1999 through September 2000). The Holes Creek site had the lowest yields in the study area for all nutrient species examined; this site differs substantially from the other study sites in that it has a drainage area largely absent of point sources and dominated by residential and commercial land use. Principal sources of nutrients for Holes Creek are limited to atmospheric deposition, septic systems, and residential fertilizer applications.

Estimated historical daily yields of total nitrogen and total phosphorus for Great Miami River at Hamilton were higher than those computed from the samples collected in water years 1999 and 2000. Total nitrogen and total phosphorus daily yields computed from the historical data were 5.8 kg/km^2 and 0.39 kg/km^2, respectively, whereas total nitrogen and total phosphorus mean daily yields computed for water years 1999 and 2000 at Great Miami River at Hamilton were 3.3 kg/km^2 and 0.26 kg/km^2, respectively. Lower than normal streamflows during the study period for the Great Miami River Basin are most likely the reason for this difference. Mean streamflow for Great Miami River at Hamilton was 2,350 ft^3/s for water years 1999 and 2000, compared to 3,570 ft^3/s for water years 1975–93.

An examination of monthly nutrient yields (Appendix D) reveals other variations between basins. For the study period, the Stillwater River had some of the smallest

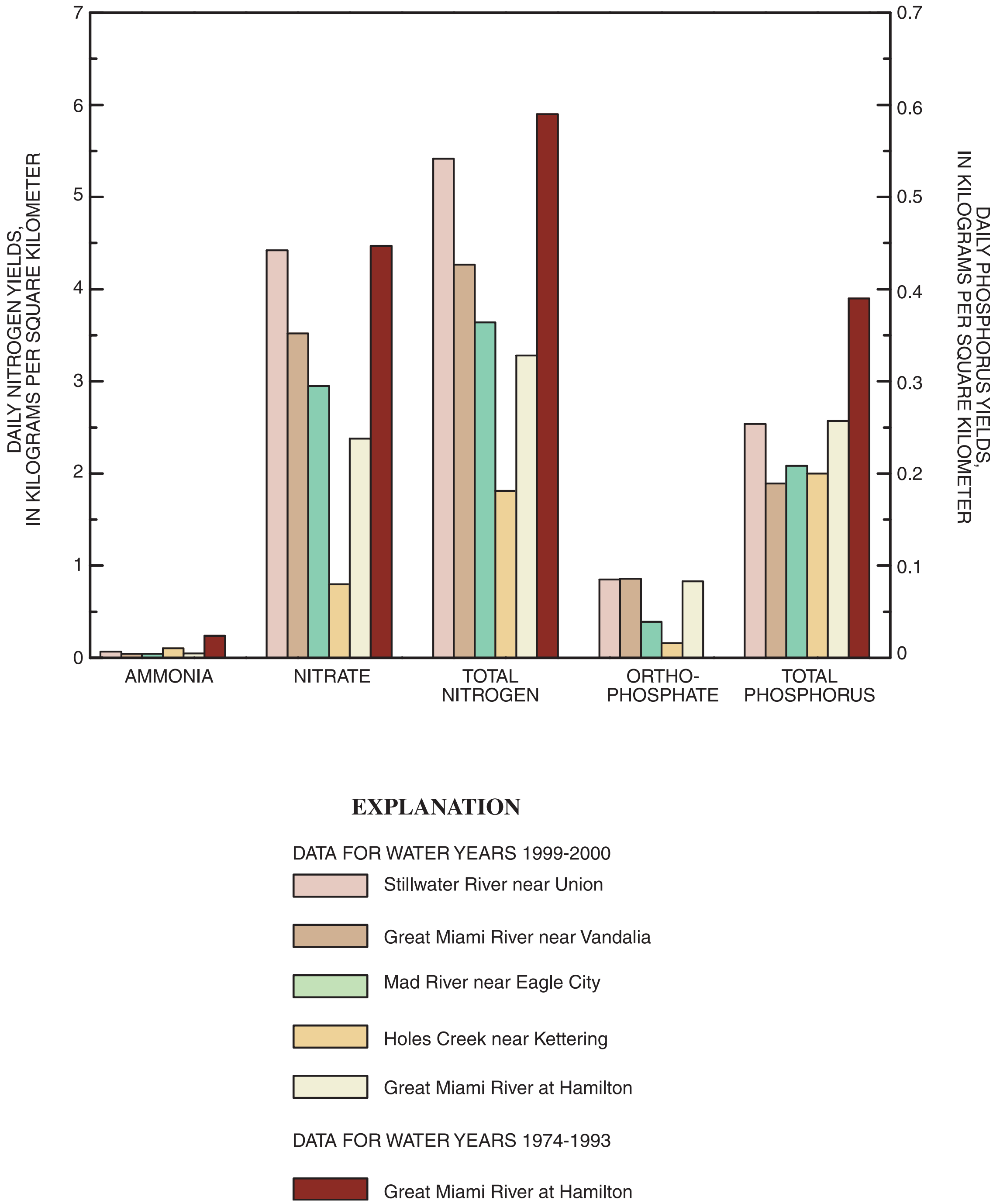

Figure 21. Daily mean yields of ammonia, nitrate, total nitrogen, orthophosphate, and total phosphorus for Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, and Holes Creek near Kettering, Ohio, water years 1999–2000, and Great Miami River at Hamilton, Ohio, water years 1974–1993 and 1999–2000.

Table 10. Estimated daily point- and nonpoint-source inputs of total nitrogen and total phosphorus to the three sites upstream from Dayton, Ohio, and to the Great Miami River at Hamilton, Ohio, water years 1999 and 2000
[kg, kilograms]

	Total nitrogen				Total phosphorus			
	Stillwater River near Union	Great Miami River near Vandalia	Mad River near Eagle City	Great Miami River at Hamilton	Stillwater River near Union	Great Miami River near Vandalia	Mad River near Eagle City	Great Miami River at Hamilton
Estimated mean daily instream load (kg)	9,000	12,600	2,900	30,800	420	560	170	2,400
Estimated mean daily point-source input (kg)[1]	160	880	58	6,800	20	180	22	1,100
Point-source load as percentage of instream load[2]	2	7	2	22	5	31	13	45
Nonpoint-source load as percentage of instream load[3]	98	93	98	78	95	69	87	55
Computed nonpoint-source load in streams (kg)[4]	8,800	11,700	2,800	24,000	400	380	150	1,300

[1]Total nitrogen loads computed for point sources include only ammonia, nitrite, and nitrate.
[2]Estimated point-source input/estimated stream load x 100.
[3]100 percent minus the percent point-source load.
[4]Estimated stream load minus the mean daily point-source input.

yields of total nitrogen and total phosphorus during months of low streamflow. During months of high streamflow, however, the Stillwater River has some of the highest yields of total nitrogen and total phosphorus (Appendix D). This pattern may reflect the combined effects of intense row-crop production and high density of animal feeding operations; the feeding operations produce large amounts of manure, some of which is applied locally to fertilize corn and winter wheat fields. During months of high streamflow, the Mad River Basin usually has some of the lowest nutrient yields for the study area. However, during summer and autumn 1999, the Mad River had the highest nutrient yields for the Great Miami River Basin—particularly nitrate.

Comparison of Nitrogen and Phosphorus Inputs and Instream Loads

Instream loads and point-source inputs computed for this report indicate that nonpoint sources contribute most of the instream nutrient loads to the Stillwater, Upper Great Miami, and Mad Rivers upstream from Dayton (table 10). Although point sources in the Dayton Metropolitan area contribute a significant proportion of nutrient load as compared to that at Great Miami River at Hamilton, nonpoint sources of nutrients from the streams upstream from Dayton were still the major contributor of nutrients to the study area. The percentage contributions of point- and nonpoint-source loads of total nitrogen and total phosphorus to the sites upstream from Dayton and Great Miami River at Hamilton are listed in table 10. Total nitrogen loads computed in this comparison are the sum of the ammonia, nitrite, and nitrate loads. This total nitrogen load does not include organic nitrogen because most point-source dischargers do not include organic nitrogen data as part of their monthly operating reports.

Total nitrogen loads from nonpoint sources were greater than 90 percent of the load measured at the sites upstream from Dayton but decreased to 78 percent of the load measured at Great Miami River at Hamilton. This decrease is mainly due to the many point sources in and downstream from the Dayton metropolitan area. A similar pattern is observed with total phosphorus. Total phosphorus loads from nonpoint sources were from 69 to 95 percent of the loads measured at the sites upstream from Dayton but decreased to 55 percent of the load measured at Hamilton.

The estimated annual inputs of nutrients to each basin from nonpoint sources were much higher than the amount that actually enters into the streams. The intention of commercial-fertilizer and manure applications is, to provide nutrients to crops—not to the aquatic system. Removal of nitrogen and phosphorus by crop harvesting was estimated for the study area. The estimates were computed from nitrogen and phosphorus removal rates used by Goolsby and others (1999) for harvested soybeans, wheat, corn for grain, and corn for silage and from 1997 county estimates of harvested crops (U.S. Department of Agricul-

Table 11. Daily nonpoint-source inputs of total nitrogen and total phosphorus and estimated percentage of nonpoint inputs deposited onto the basins that enter the stream, water years 1999 and 2000

[kg, kilograms]

	Total nitrogen				Total phosphorus			
	Stillwater River near Union	Great Miami River near Vandalia	Mad River near Eagle City	Great Miami River at Hamilton	Stillwater River near Union	Great Miami River near Vandalia	Mad River near Eagle City	Great Miami River at Hamilton
Computed nonpoint-source load in streams (kg)[1]	8,900	11,700	2,800	24,000	400	380	150	1,300
Nonpoint-source loads deposited onto the basin (kg)[2]	46,200	54,200	15,200	181,000	10,500	9,500	2,600	34,500
Percentage of the nonpoint-source load that enters a stream	19	25	18	13	3.8	4.0	5.8	3.8

[1]Computations from table 10.

[2]Nitrogen loads computed from 1997 manure and commercial-fertilizer application rates from table 4 and the 1991–2000 averaged annual atmospheric deposition rates from table 6; phosphorus loads computed from 1997 manure and commercial-fertilizer application rates from table 4.

ture, 1999). These estimates show that 70 million kilograms of nitrogen and 10 million kilograms of phosphorus were removed from the study area by crop harvesting. These amounts equal to 93 percent of the estimated nonpoint-source nitrogen inputs (commercial-fertilizer and manure applications, atmospheric deposition, and nitrogen fixation) and 79 percent of the estimated nonpoint-source phosphorus inputs (commercial-fertilizer and manure applications).

Computations show that a higher percentage of total nitrogen from nonpoint-source inputs has been transported to streams than total phosphorus from nonpoint-source inputs (table 11). Because nitrate is highly soluble and is not readily sorbed to soil or organic matter, much of it is available for transport. In contrast, phosphorus is relatively insoluble and tends to bind strongly to soil and organic matter. Most phosphorus, therefore, was transported to streams during runoff events that are of sufficient magnitude to mobilize and transport sediment from surrounding land to streams (Becher and others, 2001; U.S. Geological Survey, 1999).

The data show that, although point sources above Great Miami River at Hamilton were major contributors to nutrient loads, agricultural nonpoint sources from the streams upstream from Dayton contributed most of the instream nitrogen loads and almost half of the instream phosphorus loads at Hamilton. Monthly nutrient loads show that only during periods of low streamflow were point sources likely contributing most of the nutrient loads. During periods of low streamflow, however, nutrient loads were much lower than during periods of high streamflow.

The USEPA states that runoff from agricultural nonpoint sources is now the leading source of pollution to rivers and lakes in the United States (U.S. Environmental Protection Agency, 2002). In an assessment of 42 interior basins of the Mississippi River Basin, Goolsby and others (1999) estimate that the Great Miami River Basin had one of the highest total nitrogen and total phosphorus yields. Within the Great Miami River Basin, the highest nutrient yields were from the Stillwater River Basin. These high yields were most likely the result of predominantly agricultural land use. The USEPA has encouraged the use of best management practices (BMPs) to manage agricultural runoff through economic incentives, technical assistance, and cost-share programs. Common BMPs in Ohio include conservation tillage and installation of buffers and filter strips on fields that border waterways (Ohio State University Extension, 1995b). Implementation of more BMPs in the study area would likely help to reduce nutrient loads and yields. For example, if BMPs were able to reduce nonpoint-source loads 10 percent below current levels, the monthly load of total nitrogen at Great Miami River at Hamilton would decrease to 850,000 kg, and the monthly yield would decrease to 90 kg/km^2. The monthly load of total phosphorus would decrease to 68,000 kg and the monthly yield to 7.2 kg/km^2. Comparatively, these reduced yields are still high—estimated monthly total nitrogen and total phosphorus yields for the Mississippi-Atchafalaya River Basin, in contrast, are 41 kg/km^2 and 3.5 kg/km^2, respectively (Goolsby and others, 1999). Although any decrease in nutrient loads and yields would be beneficial, the Great Miami River Basin would still have one of the higher nutrient yields within the Mississippi River Basin, even with a 10-percent decrease in nonpoint-source loads.

Suggestions for Further Work

A program to continue sampling for nutrients in these basins would be beneficial for many reasons. A larger sample set could result in improved load estimates by expanding coverage of the range of streamflow conditions and providing more values with which to calibrate load models. A continuation of sampling would facilitate analysis of any trends that might develop or continue over an extended period. For example, an examination of nutrients in the Great Miami River since the 1970s has shown a decrease in total nitrogen concentrations and, to a lesser extent, total phosphorus concentrations. Continuation of the sampling program would facilitate monitoring and verification of such trends, which may accelerate as more BMPs are introduced to agricultural lands in the Great Miami River Basin.

Summary and Conclusions

Sources and loads of nitrogen and phosphorus in streams are described for five sites in the Great Miami River Basin monitored from October 1998 through September 2000 by the U.S. Geological Survey: Stillwater River near Union, Great Miami River near Vandalia, Mad River near Eagle City, Holes Creek near Kettering, and Great Miami River at Hamilton. The relation of land use and physiography to estimated nutrients loads and yields also are examined for the Great Miami River Basin.

Two distinct land uses have developed within the Great Miami River Basin. The northern, upper part of the basin consists primarily of agricultural land, where soybeans and corn are the chief products. The southern, downstream part of the basin, however, is dominated by urban land in and around the cities of Springfield, Dayton, Middletown, and Hamilton. Both land-use types introduce nutrients into streams of the Great Miami River Basin. Commercial-fertilizer and manure application onto corn and soybean fields is the principal source of nutrients in agricultural areas. Some of the nutrients from agricultural nonpoint sources are eventually transported to streams by surface runoff, sediment erosion, or ground-water discharge. Sources of nutrients in urban areas, in contrast, are mainly discharges from wastewater-treatment facilities and fertilizer applications onto lawns.

An examination of monthly mean loads during water years 1999 and 2000 shows that nonpoint sources were the main contributor of nutrients to instream loads during months of high streamflow, whereas point sources were the main contributor of nutrients to instream loads during months of low streamflow. Because larger loads are contributed to streams during high streamflows, nonpoint sources are considered to be the main overall contributors of nutrients to the Great Miami River.

Physiographic regions in the study area also have an influence on nutrient loads in the Great Miami River. Most of the study area consists of till plains that are absent of high-yielding aquifers. The Mad River Basin, however, lies within an interlobate area that consists of glacial outwash with an associated high-yielding aquifer; this high-yielding aquifer supplies an unusually large proportion of groundwater discharge to total Mad River streamflow, which results in a relatively large nitrogen load during low-flow periods. An examination of the three streams upstream from Dayton indicates that nitrate and total nitrogen loads were highest at Mad River near Eagle City during the drought months of summer and autumn 1999.

An estimate of annual loads of total nitrogen and total phosphorus for Great Miami River at Hamilton since the mid-1970s indicates that nutrient loads could be decreasing for the study area. Although population in the Great Miami River Basin increased slightly (about 8 percent) between 1970 and 2000, with accompanying increases in wastewater discharges, improvements in many of the wastewater-treatment facilities may have decreased the amounts of nitrogen and phosphorus being discharged into streams.

Mean nutrient yields computed for each basin also demonstrate the importance of land use in relation to nutrient loads in the study area. The three agricultural basins upstream from Dayton had the highest nitrate and total nitrogen yields, whereas the urban Holes Creek Basin had the lowest nitrate and total nitrogen yields. Great Miami River at Hamilton, whose drainage area is a mixture of agricultural and urban areas, had nitrate and total nitrogen yields slightly lower than those of the agricultural basins. Nutrient inputs to the three agricultural basins are primarily from application of commercial fertilizers and manure onto corn and soybean fields, whereas nutrient inputs to the Holes Creek Basin are primarily from application of commercial fertilizer to residential lawns and from automobile emissions. Little variation was observed in phosphorus yields between agricultural, urban, and mixed-land-use basins.

The percentages of nonpoint-source nutrients that are transported from the applied land surface to the stream vary with nutrient type and basin. Between 13 and 22 percent of the nonpoint-source nitrogen is able to reach a stream, whereas only 4 to 6 percent of the nonpoint-source phosphorus is able to reach a stream.

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Glossary

Ammonia - A compound of nitrogen and hydrogen (NH_3) that is a common byproduct of animal waste. Ammonia readily converts to nitrate in soils and streams

Atmospheric deposition - The transfer of substances from the air to the surface of the Earth, either in wet form (rain, fog, snow, dew, frost, hail) or in dry form (gases, aerosols, particles).

Best management practice (BMP) - A management practice that has been determined to be an effective, practical means of preventing or reducing nonpoint-source pollution.

Concentration - The amount or mass of a substance present in a given volume or mass of sample. Commonly expressed as milligram per liter in water samples.

Confluence - The flowing together of two or more streams; the place where a tributary joins the main stream.

Cubic foot per second (ft^3/s) - Rate of water discharge (streamflow) representing a volume of 1 cubic foot passing a given point during 1 second, equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.02832 cubic meter per second.

Environmental sample - A water sample collected from an aquifer or stream for the purpose of chemical, physical, or biological characterization of the sampled resource.

Eutrophication - The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Hypoxia - Seasonal depletion of dissolved oxygen (to less than 2.0 milligrams per liter) within a water body, related to eutrophication of the water body. Most aquatic species cannot survive at such low oxygen levels.

Load - General term that refers to a material or constituent in solution, in suspension, or in transport; usually expressed in terms of mass or volume.

Maximum contaminant level (MCL) - Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

Method detection limit - The minimum concentration of a substance that can be accurately identified and measured with present laboratory technologies.

Milligrams per liter (mg/L) - A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million.

Nitrate - An ion consisting of nitrogen and oxygen (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

Nonpoint source - A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint-source pollution.

Nutrient - Element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Orthophosphate - An ion consisting of phosphorus and oxygen (PO_4^{-3}). This is the only inorganic form of phosphate that can be used by plants as a nutrient.

Phosphorus - A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Physiography - A description of the surface features of the Earth, with an emphasis on the origin of landforms.

Point source - A pollution source at a discrete location such as a discharge pipe, drainage ditch, tunnel, well, or concentrated livestock operation.

Quality assurance - Evaluation of quality-control data to allow quantitative determination of the quality of chemical data collected during a study. Techniques used to collect, process, and analyze water samples are evaluated.

Season - one of the four natural divisions of the year (spring, summer, fall, and winter) indicated by the passage of the sun through an equinox or solstice.

Water year - The continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with the surface-water supply. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1999, is referred to as “water year 1999.”

Yield - The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

Appendixes

Appendix A. Quality-Control Data

Data from the quality-control sampling effort are listed in table A1. Field blanks indicate no consistent contamination problem with any of the nutrient species. Median concentrations of all nutrient species in the field blanks were less than the respective laboratory reporting limits. Ammonia and orthophosphate, however, were detected in at least one field blank at a concentration above the laboratory reporting limit. The relative percent difference (RPD) is a nonparametric method used to compare replicate samples to environmental samples. The RPD was computed by means of the following equation:

$$RPD = |Sample_1 - Sample_2| / (Sample_1 + Sample_2 / 2) \times 100.$$

The median relative percent difference for all nutrient species was less than 10 percent, although total ammonia plus organic nitrogen approached this level with a median of 9.7 percent (for eight sample sets, the RPD was higher than 10 percent). For ammonia, five sample sets had an RPD higher than 10 percent, although the median RPD was zero. This disparity is probably explained by the large number of less-than values associated with this nutrient. In most of the sample sets, there were nondetections for both replicate samples, resulting in an RPD of zero.

Table A1. Summary of quality-control data for nitrogen and phosphorus in the Great Miami River Basin, October 1998–September 2000

[LRL, laboratory reporting level; mg/L, milligrams per liter; RPD, relative percent difference; N, nitrogen; P, phosphorus; <, less than; E, estimate]

Constituent	LRL	Number of blank samples	Maximum concentration (mg/L)	Median concentration (mg/L)	Number of blank samples with concentrations greater than LRL	Number of replicate samples	Median RPD	Number of replicate samples with RPD greater than 10 percent
Ammonia (as N), dissolved	0.02	10	0.04	<0.02	1	16[1]	0	5
Ammonia plus organic nitrogen (as N), total	0.1	10	E0.06	<0.1	0	16	9.7	8
Ammonia plus organic nitrogen (as N), dissolved	0.1	10	<0.1	<0.1	0	16	3.3	3
Nitrite (as N), dissolved	0.01	10	<0.01	<0.01	0	16	0	0
Nitrite plus nitrate (as N), dissolved	0.05	10	<0.1	<0.05	0	16	0.6	1
Phosphorus (as P), total	0.01	10	<0.01	<0.01	0	16	2	2
Orthophosphate (as P), dissolved	0.01	10	0.02	<0.01	1	16	6.5	3
Phosphorus (as P), dissolved	0.01	10	E 0.003	<0.01	0	16	2	1

[1]Two of the ammonia replicate sets produced a detectable concentration with a nondetectable concentration. In these cases, the minimum reporting limit was used in the computations as the nondetectable concentration.

Appendix B. Coefficients B_0 through B_6 used in the ESTIMATOR concentration models

Nutrient	B_0	B_1	B_2	B_3	B_4	B_5	B_6
Stillwater River near Union							
Dissolved ammonia	-3.4927	-0.2291	0.1513	0.3175	0.4448	0.5041	1.2469
Dissolved nitrate	1.0263	0.1742	0.0351	-0.0773	0.0120	0.7172	-0.0493
Total nitrogen	1.3101	0.1579	0.0487	-0.0191	-0.0190	0.5834	-0.1147
Dissolved orthophosphate	-3.2419	0.0501	0.1484	0.3203	0.7486	-0.4012	0.7608
Total phosphorus	-1.8692	0.2956	0.1264	0.1009	-0.1038	-0.5084	0.0061
Great Miami River near Vandalia							
Dissolved ammonia	-4.4116	0.3017	0.3148	--	--	--	--
Dissolved nitrate	0.7665	0.1107	0.0905	0.2857	0.4293	0.5917	0.0536
Total nitrogen	1.2542	0.1886	0.0574	0.1948	0.1066	0.3489	-0.0223
Dissolved orthophosphate	-2.5413	-0.1902	0.1875	0.2453	0.6444	-0.3740	0.1291
Total phosphorus	-1.4666	0.1064	0.0948	0.1305	0.0274	-0.4837	0.0277
Mad River near Eagle City							
Dissolved ammonia	-3.5252	0.9407	-0.0472	-0.4395	0.1319	-0.1239	0.2166
Dissolved nitrate	1.4848	0.1013	-0.0831	-0.0125	0.0081	0.0012	0.0542
Total nitrogen	1.7474	0.3012	-0.0600	-0.0289	-0.0376	-0.0682	0.0411
Dissolved orthophosphate	-3.1686	0.3881	0.1266	-0.1798	0.0880	-0.6210	0.2028
Total phosphorus	-1.7278	1.2774	0.0588	-0.1947	-0.1548	0.0943	-0.8334
Holes Creek near Kettering							
Dissolved ammonia	-4.2263	0.6336	-0.0142	-1.1910	-0.0055	-0.5768	-0.4142
Dissolved nitrate	-0.3850	-0.1258	0.0528	-0.0739	0.0411	0.2727	0.1654
Total nitrogen	0.2548	0.1069	0.0393	-0.1784	0.0423	0.0843	-0.0851
Dissolved orthophosphate	-4.6059	0.2884	-0.0317	-0.6419	0.0459	-0.4340	-0.1162
Total phosphorus	-3.0243	0.6291	0.0219	-0.2657	0.0800	-0.4968	-0.4880
Great Miami River at Hamilton							
Dissolved ammonia	-3.0719	0.8079	0.0036	-1.4136	-1.2482	-1.1848	0.3361
Dissolved nitrate	1.0607	0.0732	-0.0118	0.1075	0.0773	0.2716	0.4463
Total nitrogen	1.5022	0.1186	0.0166	0.0404	-0.0329	0.1179	0.2038
Dissolved orthophosphate	-2.4990	-0.0578	0.0362	-0.0548	0.1705	-0.3384	0.8695
Total phosphorus	-1.1827	0.2750	0.1199	-0.0680	-0.0875	-0.4031	0.0296
Great Miami River at New Baltimore							
Total nitrogen	1.6964	0.0908	0.0221	-0.0138	-0.0020	0.0465	0.0089
Total phosphorus	-1.0289	-0.1980	0.1754	-0.0400	-0.0015	-0.0801	-0.0445
Great Miami River near Fairfield							
Dissolved nitrate	0.8238	0.1958	-0.0490	-1.1641	8.0460	0.7075	-0.5173
Total nitrogen	1.7068	0.1816	-0.0082	-0.7589	-0.6336	0.1050	-0.0714
Total phosphorus	-1.6550	0.3073	0.1296	-0.2366	4.2113	0.0667	0.2567

Appendix C. Statistical summary of nitrogen and phosphorus concentrations in the Great Miami River Basin, October 1998–September 2000

[MCL, maximun contamination limit; RAL, recommended action level; N, nitrogen; P, phosphorus; na, not applicable; <, less than]

Constituent	Number of samples	Number of detections	Number of detections greater than MCL or RAL	Concentrations, in milligrams per liter					
				Minimum	25th percentile	Median	Mean	75th percentile	Maximum
Stillwater River near Union, Ohio									
Ammonia (as N), dissolved	31	24	na	<0.02	0.03	0.06	0.06	0.10	0.51
Ammonia plus organic nitrogen (as N), total	31	31	na	0.36	0.61	0.80	0.95	1.0	3.4
Ammonia plus organic nitrogen (as N), dissolved	31	31	na	0.31	0.38	0.41	0.51	0.57	1.3
Nitrite (as N), dissolved	31	27	na	<0.01	0.02	0.02	0.04	0.03	0.41
Nitrite plus nitrate (as N), dissolved	30	30	na	1.2	1.6	3.4	4.1	6.3	10.3
Nitrate (as N), dissolved[1]	30	30	1	0.96	1.5	3.3	4.1	6.3	10.2
Phosphorus (as P), dissolved	31	31	na	0.01	0.05	0.12	0.12	0.17	0.23
Orthophosphate (as P), dissolved	31	30	na	<0.01	0.04	0.10	0.09	0.14	0.23
Phosphorus (as P), total	31	31	23	0.06	0.11	0.16	0.21	0.24	1.0
Great Miami River near Vandalia, Ohio									
Ammonia (as N), dissolved	30	13	na	<0.02	<0.02	<0.02	0.04	0.05	0.19
Ammonia plus organic nitrogen (as N), total	30	30	na	0.22	0.55	0.76	0.88	1.1	2.3
Ammonia plus organic nitrogen (as N), dissolved	30	30	na	0.11	0.34	0.41	0.44	0.45	0.99
Nitrite (as N), dissolved	30	29	na	<0.01	0.02	0.03	0.03	0.04	0.06
Nitrite plus nitrate (as N), dissolved	30	30	na	0.69	1.9	3.0	3.4	4.6	9.2
Nitrate (as N), dissolved[1]	30	30	0	0.66	1.8	3.0	3.4	4.6	9.2
Phosphorus (as P), dissolved	30	30	na	0.05	0.09	0.17	0.19	0.26	0.47
Orthophosphate (as P), dissolved	30	30	na	0.03	0.07	0.14	0.17	0.25	0.41
Phosphorus (as P), total	30	30	30	0.10	0.14	0.29	0.27	0.35	0.52
Mad River near Eagle City, Ohio									
Ammonia (as N), dissolved	51	26	na	<0.02	<0.02	<0.02	0.04	0.04	0.32
Ammonia plus organic nitrogen (as N), total	51	51	na	0.13	0.21	0.29	0.76	0.52	6.1
Ammonia plus organic nitrogen (as N), dissolved	51	50	na	<0.1	0.16	0.22	0.28	0.29	0.99

Appendix C. Statistical summary of nitrogen and phosphorus concentrations in the Great Miami River Basin, October 1998–September 2000—Continued

[MCL, maximun contamination limit; RAL, recommended action level; N, nitrogen; P, phosphorus; na, not applicable; <, less than]

Constituent	Number of samples	Number of detections	Number of detections greater than MCL or RAL	Concentrations, in milligrams per liter					
				Minimum	25th percentile	Median	Mean	75th percentile	Maximum
Mad River near Eagle City, Ohio - continued									
Nitrite (as N), dissolved	51	48	na	<0.01	0.01	0.02	0.02	0.03	0.06
Nitrite plus nitrate (as N), dissolved	51	51	na	1.4	3.7	3.9	4.1	4.2	6.5
Nitrate (as N), dissolved[1]	51	51	0	1.3	3.6	3.9	4.1	4.2	6.5
Phosphorus (as P), dissolved	51	51	na	0.01	0.03	0.04	0.06	0.07	0.40
Orthophosphate (as P), dissolved	51	49	na	<0.01	0.02	0.04	0.05	0.06	0.36
Phosphorus (as P), total	51	50	13	<0.01	0.04	0.07	0.17	0.1	1.7
Holes Creek at Huffman Park near Kettering, Ohio									
Ammonia (as N), dissolved	54	28	na	<0.02	<0.02	0.02	0.06	0.04	0.38
Ammonia plus organic nitrogen (as N), total	54	54	na	0.15	0.31	0.46	0.71	0.79	4.4
Ammonia plus organic nitrogen (as N), dissolved	54	54	na	0.05	0.24	0.33	0.40	0.48	1.4
Nitrite (as N), dissolved	54	30	na	<0.01	<0.01	0.01	0.02	0.02	0.12
Nitrite plus nitrate (as N), dissolved	54	53	na	<0.05	0.70	0.91	0.94	1.1	2.1
Nitrate (as N), dissolved[1]	54	53	0	<0.04	0.68	0.90	0.93	1.1	2.0
Phosphorus (as P), dissolved	54	52	na	<0.004	0.009	0.01	0.02	0.03	0.10
Orthophosphate (as P), dissolved	54	29	na	<0.01	<0.01	0.01	0.02	0.02	0.05
Phosphorus (as P), total	54	51	14	<0.008	0.02	0.04	0.11	0.09	1.1
Great Miami River at Hamilton, Ohio									
Ammonia (as N), dissolved	35	34	na	<0.02	0.02	0.03	0.06	0.09	0.19
Ammonia plus organic nitrogen (as N), total	35	35	na	0.51	0.91	1.2	1.3	1.6	2.6
Ammonia plus organic nitrogen (as N), dissolved	35	35	na	0.31	0.41	0.50	0.52	0.60	0.85
Nitrite (as N), dissolved	35	34	na	<0.01	0.02	0.03	0.03	0.04	0.08
Nitrite plus nitrate (as N), dissolved	35	34	na	<0.05	2.1	3.1	3.2	4.4	7.6
Nitrate (as N), dissolved[1]	35	34	0	<0.04	2.0	3.1	3.2	4.4	7.5
Phosphorus (as P), dissolved	35	35	na	0.02	0.11	0.16	0.18	0.22	0.43
Orthophosphate (as P), dissolved	35	34	na	<0.01	0.08	0.13	0.15	0.20	0.37
Phosphorus (as P), total	35	35	35	0.1	0.27	0.33	0.36	0.43	0.90

[1]Dissolved nitrite plus nitrate minus dissolved nitrite.

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load[1]
Stillwater River near Union, Ohio—Nitrate					
October 1998	6,900	4.1	5,000	9,300	62
November 1998	9,800	5.9	7,400	12,700	54
December 1998	16,000	9.4	12,200	20,000	49
January 1999	1,100,000	640	706,000	1,570,000	78
February 1999	590,000	360	440,000	789,000	59
March 1999	700,000	420	535,000	903,000	53
April 1999	440,000	270	338,000	574,000	55
May 1999	97,000	58	76,000	122,000	47
June 1999	64,000	38	48,000	84,000	56
July 1999	27,000	16	19,400	36,400	63
August 1999	5,500	3.3	4,100	7,300	56
September 1999	2,200	1.3	1,600	2,900	59
October 1999	2,100	1.2	1,600	2,700	57
November 1999	8,000	4.8	5,900	10,600	60
December 1999	13,000	8.1	10,100	17,700	58
January 2000	30,000	18	21,800	39,500	60
February 2000	310,000	190	234,000	410,000	58
March 2000	170,000	100	136,000	216,000	47
April 2000	890,000	530	622,000	1,240,000	70
May 2000	350,000	210	268,000	450,000	51
June 2000	430,000	260	299,000	609,000	72
July 2000	77,000	46	54,300	105,000	66
August 2000	12,000	6.9	8,800	14,700	49
September 2000	9,900	5.9	7,200	13,200	61
Mean	220,000	130	161,000	303,000	65
Median	47,000	28	34,800	61,900	57

[1]Calculated by taking the difference between the upper and lower confidence limit and dividing by monthly load.

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Stillwater River near Union, Ohio—Total Nitrogen					
October 1998	9,800	5.9	7,700	12,300	48
November 1998	13,000	8.0	10,500	15,900	42
December 1998	19,000	12	15,800	23,200	38
January 1999	1,300,000	770	935,000	1,750,000	62
February 1999	670,000	440	530,000	838,000	46
March 1999	780,000	470	634,000	953,000	41
April 1999	520,000	320	418,000	630,000	40
May 1999	120,000	70	97,700	140,000	35
June 1999	85,000	52	68,300	104,000	42
July 1999	38,000	23	30,400	48,100	47
August 1999	8,900	5.3	7,200	10,700	39
September 1999	3,700	2.3	3,000	4,500	41
October 1999	3,400	2.1	2,800	4,200	41
November 1999	12,000	7.1	9,200	14,400	43
December 1999	18,000	11	14,500	22,200	43
January 2000	37,000	22	29,200	46,200	46
February 2000	370,000	240	295,000	455,000	43
March 2000	200,000	120	167,000	239,000	36
April 2000	1,100,000	700	849,000	1,460,000	54
May 2000	460,000	270	374,000	559,000	41
June 2000	630,000	391	475,000	830,000	57
July 2000	110,000	68	87,200	145,000	53
August 2000	18,000	11	15,000	22,200	40
September 2000	16,000	9.8	12,400	19,800	46
Mean	270,000	170	212,000	348,000	50
Median	62,000	38	49,300	76,100	44

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Stillwater River near Union, Ohio—Orthophosphate					
October 1998	770	0.46	380	1,390	130
November 1998	1,000	0.60	550	1,720	120
December 1998	1,100	0.64	610	1,740	100
January 1999	46,000	27	17,300	99,100	178
February 1999	11,000	6.8	5,300	21,600	145
March 1999	7,400	4.4	3,600	13,600	133
April 1999	2,200	1.3	1,100	3,800	118
May 1999	390	0.23	230	620	100
June 1999	340	0.20	180	580	115
July 1999	250	0.15	130	440	124
August 1999	180	0.11	100	300	105
September 1999	210	0.12	110	360	114
October 1999	320	0.19	170	540	115
November 1999	720	0.43	370	1,260	123
December 1999	910	0.55	490	1,560	120
January 2000	1,200	0.70	600	2,100	125
February 2000	5,500	3.3	2,800	10,000	130
March 2000	1,600	0.96	940	2,600	100
April 2000	9,500	5.7	3,800	19,900	168
May 2000	2,800	1.7	1,500	5,000	125
June 2000	6,600	4.0	2,700	13,900	167
July 2000	1,400	0.86	680	2,700	143
August 2000	680	0.40	380	1,100	109
September 2000	1,300	0.78	650	2,400	131
Mean	4,300	2.6	1,900	8,700	158
Median	1,100	0.67	600	1,900	118

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Stillwater River near Union, Ohio—Total Phosphorus					
October 1998	980	0.59	630	1,500	85
November 1998	1,100	0.63	720	1,500	72
December 1998	1,100	0.60	700	1,400	62
January 1999	110,000	64	57,300	183,000	118
February 1999	27,000	16	16,600	42,300	96
March 1999	22,000	13	14,200	33,500	86
April 1999	11,000	6.8	7,400	16,700	85
May 1999	2,000	1.2	1,400	2,700	65
June 1999	2,400	1.4	1,600	3,500	79
July 1999	1,700	1.0	1,100	2,500	82
August 1999	720	0.43	500	1,000	69
September 1999	500	0.30	340	700	74
October 1999	500	0.30	340	710	74
November 1999	1,100	0.68	740	1,600	82
December 1999	1,200	0.70	780	1,700	75
January 2000	1,700	1.0	1,000	2,600	88
February 2000	13,000	7.6	8,100	19,100	85
March 2000	3,800	2.3	2,700	5,200	66
April 2000	41,000	24	22,700	68,300	112
May 2000	14,000	8.6	9,400	21,200	86
June 2000	44,000	26	23,900	73,700	114
July 2000	7,000	4.2	4,100	11,100	100
August 2000	1,500	0.90	1,000	2,100	67
September 2000	1,900	1.1	1,200	2,800	84
Mean	13,000	7.7	7,400	20,800	100
Median	1,900	1.2	1,300	2,800	79

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River near Vandalia, Ohio—Nitrate					
October 1998	15,000	5.1	9,400	23,000	93
November 1998	18,000	6.2	12,200	26,800	78
December 1998	30,000	10	20,200	42,300	73
January 1999	1,400,000	480	636,000	2,810,000	151
February 1999	680,000	230	420,000	1,040,000	91
March 1999	960,000	320	626,000	1,400,000	80
April 1999	540,000	180	380,000	753,000	68
May 1999	120,000	40	87,100	161,000	62
June 1999	43,000	14	30,800	58,100	63
July 1999	30,000	10	20,800	41,400	70
August 1999	15,000	5.2	10,700	21,700	73
September 1999	6,700	2.3	4,200	10,200	90
October 1999	10,000	3.5	7,100	14,400	74
November 1999	13,000	4.4	8,900	18,300	72
December 1999	28,000	9.6	18,800	41,300	79
January 2000	95,000	32	58,600	145,000	92
February 2000	650,000	220	419,000	953,000	82
March 2000	270,000	92	192,000	378,000	70
April 2000	1,400,000	460	654,000	2,480,000	135
May 2000	370,000	130	258,000	518,000	70
June 2000	530,000	180	320,000	838,000	98
July 2000	86,000	29	57,600	124,000	78
August 2000	130,000	44	79,200	200,000	92
September 2000	120,000	40	61,900	204,000	117
Mean	310,000	110	183,000	512,000	106
Median	110,000	36	60,300	153,000	73

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River near Vandalia, Ohio—Total Nitrogen					
October 1998	20,000	6.8	14,600	27,200	65
November 1998	24,000	8.0	17,800	30,800	54
December 1998	36,000	12	27,500	46,400	52
January 1999	1,700,000	580	994,000	2,810,000	104
February 1999	810,000	270	587,000	1,090,000	62
March 1999	1,100,000	380	853,000	1,480,000	56
April 1999	700,000	240	551,000	885,000	47
May 1999	160,000	54	129,000	197,000	42
June 1999	62,000	21	49,100	76,300	44
July 1999	49,000	16	38,000	61,400	47
August 1999	26,000	8.7	20,000	32,900	50
September 1999	9,800	3.3	7,100	13,200	62
October 1999	16,000	5.3	12,200	20,000	50
November 1999	18,000	6.1	14,000	23,000	50
December 1999	37,000	13	28,200	48,900	57
January 2000	130,000	42	88,900	171,000	64
February 2000	770,000	260	572,000	1,010,000	57
March 2000	300,000	100	238,000	380,000	47
April 2000	1,500,000	510	923,000	2,330,000	93
May 2000	440,000	150	343,000	559,000	50
June 2000	700,000	240	495,000	974,000	68
July 2000	110,000	38	85,600	147,000	55
August 2000	190,000	63	133,000	253,000	63
September 2000	160,000	55	104,000	243,000	87
Mean	380,000	130	264,000	538,000	71
Median	140,000	48	96,600	184,000	54

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River near Vandalia, Ohio—Orthophosphate					
October 1998	3,400	1.1	2,000	5,500	103
November 1998	3,100	1.0	1,900	4,700	90
December 1998	2,800	0.95	1,800	4,100	82
January 1999	43,000	15	16,600	92,700	176
February 1999	13,000	4.4	7,600	21,000	103
March 1999	14,000	4.7	8,500	21,900	96
April 1999	7,000	2.4	4,700	10,100	79
May 1999	2,200	0.76	1,600	3,100	68
June 1999	1,600	0.53	1,100	2,200	68
July 1999	1,900	0.63	1,300	2,700	74
August 1999	1,900	0.65	1,300	2,800	79
September 1999	1,900	0.65	1,100	3,200	105
October 1999	2,300	0.77	1,500	3,300	82
November 1999	2,200	0.75	1,400	3,300	82
December 1999	2,400	0.81	1,500	3,600	88
January 2000	3,500	1.2	2,100	5,600	97
February 2000	11,000	3.6	6,500	16,300	93
March 2000	4,000	1.3	2,700	5,700	75
April 2000	18,000	5.9	7,600	35,000	157
May 2000	6,200	2..1	4,100	9,000	79
June 2000	14,000	4.6	7,600	22,700	107
July 2000	4,500	1.5	2,900	6,700	84
August 2000	9,200	3.1	5,400	14,700	101
September 2000	13,000	4.3	6,400	22,800	126
Mean	7,700	2.6	4,100	13,400	120
Median	3,800	1.3	2,400	5,600	92

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River near Vandalia, Ohio—Total Phosphorus					
October 1998	3,700	1.2	2,300	5,600	89
November 1998	3,600	1.2	2,300	5,100	78
December 1998	3,500	1.2	2,400	5,000	74
January 1999	94,000	32	41,700	184,000	151
February 1999	32,000	11	20,100	49,000	91
March 1999	37,000	13	24,100	54,500	82
April 1999	21,000	7.2	14,800	29,400	69
May 1999	5,800	1.9	4,200	7,700	60
June 1999	3,500	1.2	2,500	4,700	63
July 1999	4,200	1.4	3,000	5,900	69
August 1999	3,500	1.2	2,500	4,900	71
September 1999	2,100	0.70	1,300	3,200	90
October 1999	3,100	1.1	2,100	4,400	71
November 1999	2,900	1.0	2,000	4,100	72
December 1999	3,700	1.3	2,500	5,400	80
January 2000	7,800	2.6	4,700	12,200	95
February 2000	27,000	9.3	17,800	40,400	84
March 2000	8,800	3.0	6,200	12,200	67
April 2000	42,000	14	20,600	77,500	135
May 2000	15,000	4.9	10,100	20,400	69
June 2000	34,000	11.6	20,400	54,000	99
July 2000	7,800	2.6	5,300	11,200	76
August 2000	18,000	6.1	11,200	27,600	92
September 2000	21,000	7.2	11,300	37,100	122
Mean	17,000	5.7	9,800	27,800	105
Median	7,800	2.6	5,000	11,700	76

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Mad River near Eagle City, Ohio—Nitrate					
October 1998	35,000	44	29,600	41,300	34
November 1998	36,000	44	30,600	41,500	30
December 1998	38,000	48	33,200	44,300	29
January 1999	160,000	200	134,000	196,000	38
February 1999	140,000	170	120,000	157,000	26
March 1999	160,000	200	140,000	177,000	23
April 1999	150,000	180	130,000	164,000	23
May 1999	74,000	92	66,400	81,600	21
June 1999	51,000	64	45,900	56,600	21
July 1999	54,000	68	48,500	60,700	23
August 1999	34,000	43	30,400	38,300	23
September 1999	25,000	31	22,100	28,600	26
October 1999	29,000	36	25,600	33,200	26
November 1999	31,000	39	27,300	35,600	27
December 1999	36,000	45	31,500	41,500	27
January 2000	57,000	71	49,400	65,900	29
February 2000	93,000	120	81,100	106,000	26
March 2000	66,000	83	58,400	74,900	25
April 2000	170,000	210	144,000	192,000	29
May 2000	100,000	130	90,400	113,000	22
June 2000	59,000	74	53,100	65,600	21
July 2000	39,000	49	35,300	44,000	22
August 2000	38,000	47	33,800	42,400	23
September 2000	53,000	66	44,600	61,500	32
Mean	72,000	89	62,800	81,700	26
Median	53,000	67	47,200	61,100	23

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Mad River near Eagle City, Ohio—Total Nitogen					
October 1998	37,000	46	31,800	42,400	29
November 1998	37,000	46	32,300	42,100	26
December 1998	39,000	49	34,500	44,300	25
January 1999	250,000	310	205,000	301,000	38
February 1999	180,000	220	154,000	197,000	25
March 1999	190,000	240	175,000	215,000	21
April 1999	180,000	230	167,000	206,000	21
May 1999	81,000	100	74,300	88,800	18
June 1999	56,000	70	51,000	61,200	18
July 1999	63,000	78	56,900	69,300	20
August 1999	38,000	47	34,400	42,000	20
September 1999	28,000	34	24,600	30,800	22
October 1999	32,000	40	28,700	35,900	22
November 1999	34,000	42	30,200	38,000	23
December 1999	39,000	48	34,200	43,300	23
January 2000	67,000	83	58,500	76,600	27
February 2000	110,000	140	99,600	126,000	24
March 2000	71,000	89	64,100	79,500	22
April 2000	240,000	300	205,000	282,000	32
May 2000	120,000	150	111,000	136,000	20
June 2000	67,000	83	60,800	73,000	18
July 2000	43,400	54	39,400	47,700	19
August 2000	43,000	53	38,500	46,800	19
September 2000	69,000	85	58,400	80,200	32
Mean	88,000	110	77,900	100,000	25
Median	65,000	81	57,600	71,100	21

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Mad River near Eagle City, Ohio—Orthophosphate					
October 1998	990	1.2	580	1,600	99
November 1998	890	1.1	550	1,400	90
December 1998	730	0.9	470	1,100	86
January 1999	4,900	6.1	1,900	10,500	174
February 1999	1,700	2.2	1,100	2,700	95
March 1999	1,500	1.8	980	2,100	75
April 1999	1,200	1.5	810	1,800	81
May 1999	500	0.63	370	680	64
June 1999	430	0.54	310	580	65
July 1999	630	0.78	430	880	70
August 1999	540	0.68	380	760	70
September 1999	520	0.65	350	750	77
October 1999	630	0.78	420	900	76
November 1999	600	0.74	390	870	80
December 1999	520	0.65	340	780	86
January 2000	680	0.85	400	1,100	104
February 2000	740	0.92	470	1,100	88
March 2000	370	0.47	250	550	81
April 2000	1,900	2.3	740	3,900	163
May 2000	630	0.79	430	900	75
June 2000	410	0.51	300	550	61
July 2000	380	0.47	270	510	63
August 2000	500	0.62	360	680	66
September 2000	1,100	1.3	560	1,800	115
Mean	960	1.2	550	1,600	109
Median	630	0.79	430	900	76

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Mad River near Eagle City, Ohio—Total Phosphorus					
October 1998	1,000	1.3	560	1,700	118
November 1998	910	1.1	520	1,500	104
December 1998	760	0.94	440	1,200	103
January 1999	50,000	63	12,000	140,000	258
February 1999	8,200	10	3,700	15,800	148
March 1999	5,800	7.2	3,200	9,700	112
April 1999	6,000	7.5	3,100	10,600	126
May 1999	1,100	1.4	740	1,600	75
June 1999	840	1.0	570	1,200	74
July 1999	1,600	2.0	960	2,400	91
August 1999	910	1.1	600	1,300	79
September 1999	710	0.88	450	1,100	87
October 1999	890	1.1	560	1,300	88
November 1999	820	1.0	510	1,300	91
December 1999	700	0.88	430	1,100	94
January 2000	2,500	3.2	870	5,800	199
February 2000	2,800	3.6	1,500	5,000	124
March 2000	780	1.0	480	1,200	94
April 2000	24,000	29	5,200	69,200	267
May 2000	2,800	3.5	1,400	5,000	129
June 2000	1,000	1.2	680	1,400	74
July 2000	710	0.89	480	1,000	75
August 2000	950	1.2	640	1,400	78
September 2000	6,500	8.0	1,900	16,400	225
Mean	5,100	6.3	1,700	12,500	212
Median	1,000	1.3	660	1,500	86

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Holes Creek near Kettering, Ohio—Nitrate					
January 1999	5,500	106	3,200	8,900	104
February 1999	3,100	59	1,700	5,100	107
March 1999	2,200	43	1,400	3,300	87
April 1999	1,600	30	1,100	2,300	76
May 1999	490	9.4	360	660	61
June 1999	450	8.6	280	690	91
July 1999	320	6.0	210	450	75
August 1999	280	5.4	170	460	104
September 1999	110	2.1	76	160	74
October 1999	140	2.6	98	180	61
November 1999	250	4.8	170	350	72
December 1999	600	12	400	880	80
January 2000	1,400	26	670	2,500	131
February 2000	2,500	47	1,400	4,000	101
March 2000	1,400	26	920	1,900	73
April 2000	3,600	69	1,900	6,300	121
May 2000	850	16	580	1,200	73
June 2000	1,100	22	600	2,000	124
July 2000	940	18	520	1,600	114
August 2000	250	4.7	160	370	84
September 2000	230	4.5	150	350	83
Mean	1,300	25	730	2,000	100
Median	850	16	460	1,100	80

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Holes Creek near Kettering, Ohio—Total Nitrogen					
January 1999	14,000	260	9,700	18,700	64
February 1999	7,000	130	4,800	9,900	73
March 1999	4,600	88	3,400	6,100	59
April 1999	3,600	68	2,700	4,600	53
May 1999	930	18	760	1,100	41
June 1999	1,200	22	810	1,600	68
July 1999	810	16	620	1,000	52
August 1999	820	16	560	1,200	74
September 1999	180	3.5	140	240	54
October 1999	190	3.6	150	220	38
November 1999	370	7.1	290	460	46
December 1999	990	19	750	1,300	53
January 2000	2,900	56	1,800	4,600	98
February 2000	5,000	95	3,500	6,900	70
March 2000	2,400	46	1,800	3,000	49
April 2000	9,400	180	6,100	13,800	82
May 2000	1,800	34	1,400	2,300	48
June 2000	3,700	71	2,400	5,500	84
July 2000	3,200	61	2,100	4,600	77
August 2000	590	11	430	800	63
September 2000	500	9.6	370	660	58
Mean	3,000	58	2,100	4,200	70
Median	1,800	34	1,400	2,300	48

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Holes Creek near Kettering, Ohio—Orthophosphate					
January 1999	180	3.5	67	400	183
February 1999	72	1.4	25	170	194
March 1999	45	0.87	19	92	162
April 1999	34	0.66	15	67	153
May 1999	9.1	0.17	4.5	16	131
June 1999	14	0.27	4.2	34	214
July 1999	12	0.24	4.7	27	183
August 1999	15	0.29	4.0	41	247
September 1999	2.7	0.05	0.9	6.5	207
October 1999	2.2	0.04	1.1	3.8	123
November 1999	5.0	0.10	2.2	9.9	156
December 1999	12	0.23	4.7	26	175
January 2000	24	0.46	5.3	70	266
February 2000	31	0.60	11	72	196
March 2000	15	0.28	6.3	29	153
April 2000	44	0.84	14	105	205
May 2000	12	0.23	5.4	23	150
June 2000	26	0.50	7.3	68	234
July 2000	27	0.52	8.3	67	214
August 2000	6.9	0.13	2.2	16	202
September 2000	6.3	0.12	2.2	14	190
Mean	28	0.55	9.4	62	186
Median	15	0.28	5.0	38	220

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Holes Creek near Kettering, Ohio—Total Phosphorus					
January 1999	1,500	28	470	3,500	202
February 1999	620	12	140	1,800	261
March 1999	310	5.8	82	811	235
April 1999	270	5.1	78	680	222
May 1999	46	0.88	18	98	174
June 1999	140	2.7	28	440	293
July 1999	96	1.8	33	220	195
August 1999	160	3.0	34	480	275
September 1999	12	0.23	3.2	32	233
October 1999	6.2	0.12	3.1	11	126
November 1999	16	0.31	6.8	34	169
December 1999	59	1.1	19	140	203
January 2000	330	6.2	49	1,100	333
February 2000	380	7.4	98	1,000	250
March 2000	120	2.2	44	260	175
April 2000	1,000	19	210	3,000	277
May 2000	130	2.4	48	270	169
June 2000	770	15	160	2,300	280
July 2000	720	14	160	2,100	266
August 2000	83	1.6	21	230	253
September 2000	56	1.1	17	140	214
Mean	320	6.2	79	870	253
Median	140	2.7	46	460	278

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River at Hamilton, Ohio—Nitrate					
October 1998	130,000	14	93,700	171,000	60
November 1998	160,000	17	120,000	206,000	54
December 1998	290,000	31	219,000	383,000	56
January 1999	2,900,000	310	2,040,000	4,060,000	69
February 1999	2,000,000	210	1,540,000	2,520,000	49
March 1999	2,100,000	220	1,620,000	2,570,000	46
April 1999	1,000,000	110	813,000	1,280,000	46
May 1999	330,000	35	256,000	413,000	48
June 1999	180,000	20	144,000	231,000	48
July 1999	120,000	13	96,200	154,000	47
August 1999	59,000	6.3	47,400	73,100	43
September 1999	41,000	4.4	31,900	52,700	51
October 1999	72,000	7.7	58,000	88,600	42
November 1999	84,000	9.0	66,800	105,000	46
December 1999	190,000	20	146,000	235,000	48
January 2000	520,000	55	374,000	706,000	63
February 2000	1,500,000	160	1,150,000	1,970,000	54
March 2000	910,000	97	706,000	1,150,000	49
April 2000	1,800,000	190	1,340,000	2,370,000	57
May 2000	570,000	61	440,000	728,000	50
June 2000	590,000	63	434,000	782,000	59
July 2000	240,000	26	180,000	327,000	60
August 2000	170,000	18	123,000	229,000	62
September 2000	190,000	21	130,000	279,000	77
Mean	670,000	72	507,000	879,000	55
Median	270,000	29	199,000	355,000	57

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River at Hamilton, Ohio—Total Nitrogen					
October 1998	180,000	19	153,000	215,000	34
November 1998	200,000	21	169,000	229,000	30
December 1998	330,000	35	280,000	383,000	31
January 1999	3,800,000	400	3,080,000	4,590,000	40
February 1999	2,300,000	250	2,030,000	2,690,000	28
March 1999	2,600,000	270	2,250,000	2,910,000	26
April 1999	1,500,000	160	1,280,000	1,660,000	26
May 1999	500,000	53	432,000	564,000	27
June 1999	320,000	34	282,000	367,000	26
July 1999	240,000	25	206,000	267,000	26
August 1999	120,000	12	104,000	132,000	24
September 1999	79,000	8.4	68,300	90,500	28
October 1999	120,000	13	106,000	135,000	24
November 1999	120,000	13	107,000	138,000	25
December 1999	230,000	25	203,000	265,000	26
January 2000	640,000	68	530,000	765,000	37
February 2000	1,900,000	200	1,640,000	2,230,00	30
March 2000	1,100,000	120	1,000,000	1,320,000	27
April 2000	2,900,000	300	2,400,000	3,370,000	34
May 2000	920,000	98	800,000	1,060,000	28
June 2000	1,100,000	120	960,000	1,340,000	33
July 2000	480,000	51	401,000	562,000	34
August 2000	320,000	35	272,000	385,000	35
September 2000	340,000	36	274,000	421,000	43
Mean	930,000	99	793,000	1,090,000	31
Median	410,000	44	341,000	491,000	34

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads		
			Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River at Hamilton, Ohio—Orthophosphate					
October 1998	16,000	1.7	8,300	27,600	121
November 1998	20,000	2.1	11,100	33,200	110
December 1998	27,000	2.9	15,200	44,700	109
January 1999	140,000	16	69,300	270,000	138
February 1999	75,000	7.9	43,300	120,000	102
March 1999	56,000	5.9	33,200	87,500	97
April 1999	20,000	2.2	12,500	31,300	94
May 1999	6,800	0.72	4,100	10,600	96
June 1999	4,500	0.48	2,700	7,000	94
July 1999	4,200	0.45	2,600	6,400	91
August 1999	3,400	0.37	2,200	5,200	90
September 1999	3,800	0.40	2,200	6,100	103
October 1999	7,400	0.79	4,700	11,200	88
November 1999	9,000	0.95	5,500	13,900	93
December 1999	14,000	1.5	8,600	22,600	99
January 2000	25,000	2.7	12,800	44,600	127
February 2000	40,000	4.3	22,600	67,100	111
March 2000	18,000	1.9	10,700	28,900	100
April 2000	28,000	3.0	14,800	47,600	117
May 2000	8,700	0.93	5,200	13,900	100
June 2000	10,000	1.1	5,500	17,500	119
July 2000	5,900	0.63	3,200	9,900	113
August 2000	6,400	0.68	3,400	11,100	119
September 2000	11,000	1.1	4,700	20,200	147
Mean	24,000	2.5	12,900	39,900	112
Median	12,000	1.3	6,900	21,400	118

Appendix D. Monthly loads, yields, and confidence intervals for nitrate, total nitrogen, orthophosphate, and total phosphorus—Continued.

[kg, kilograms; kg/km^2, kilograms per square kilometer]

Month	Monthly Load (kg)	Monthly Yield (kg/km^2)	95-percent confidence range of monthly loads: Lower (kg)	Upper (kg)	Percent of monthly load
Great Miami River at Hamilton, Ohio—Total phosphorus					
October 1998	20,000	2.2	14,900	27,000	60
November 1998	18,000	1.9	13,600	23,100	53
December 1998	23,000	2.5	17,400	30,900	59
January 1999	420,000	45	275,000	615,000	81
February 1999	160,000	17	120,000	210,000	56
March 1999	160,000	17	124,000	204,000	50
April 1999	87,000	9.3	68,300	110,000	48
May 1999	27,000	2.9	21,400	33,900	46
June 1999	23,000	2.5	18,400	28,800	45
July 1999	22,000	2.3	17,500	27,100	44
August 1999	14,000	1.5	11,400	17,300	42
September 1999	11,000	1.2	8,400	13,800	49
October 1999	14,000	1.5	11,600	17,600	43
November 1999	12,000	1.3	9,500	14,800	44
December 1999	16,000	1.7	12,600	20,000	47
January 2000	43,000	4.6	29,100	61,800	76
February 2000	120,000	13	88,000	156,000	57
March 2000	53,000	5.6	40,800	67,000	50
April 2000	240,000	25	157,000	339,000	77
May 2000	53,000	5.7	41,400	67,300	49
June 2000	100,000	11	76,900	140,000	63
July 2000	44,000	4.7	32,400	58,900	60
August 2000	34,000	3.6	24,700	44,800	60
September 2000	39,000	4.2	26,400	56,600	77
Mean	73,000	8.0	52,600	99,400	64
Median	37,000	4.0	25,500	50,700	62

Appendix E. Annual loads and confidence intervals for total nitrogen and total phosphorus

Water year	Annual load (million kilograms)	95-percent confidence interval of loads		
		Lower (million kilograms)	Upper (million kilograms)	Percent of annual load
Great Miami River at New Baltimore, Ohio—Total nitrogen				
1974	22.4	18.4	26.9	37.9
1975	26.4	21.9	31.4	36.0
1976	15.2	13.2	17.4	27.3
1977	7.8	6.8	8.8	25.0
1978	25.1	21.5	29.3	31.1
1979	29.0	24.9	33.5	29.7
1980	31.9	27.8	36.4	26.9
1981	18.0	16.0	20.1	23.1
1982	28.4	24.0	33.4	33.1
1983	15.5	13.3	17.9	29.7
1984	22.8	19.9	26.0	26.9
1985	19.0	16.5	21.9	28.4
1986	23.7	20.5	27.4	29.1
1987	17.6	15.5	20.0	25.9
1988	7.4	6.5	8.4	25.4
1989	23.0	19.7	26.7	30.5
1990	22.4	19.1	26.1	31.3
1991	24.0	19.8	28.8	37.6
1992	9.5	7.8	11.3	36.0
1993	19.3	15.7	23.5	40.1
Great Miami River at New Baltimore, Ohio—Total phosphorus				
1974	1.9	1.6	2.2	31.6
1975	2.2	1.9	2.6	32.5
1976	1.2	1.1	1.4	21.8
1977	0.73	0.66	0.80	18.9
1978	1.9	1.7	2.2	26.8
1979	2.1	1.9	2.4	25.7
1980	2.2	2.0	2.5	23.3
1981	1.2	1.1	1.3	18.0
1982	1.9	1.6	2.2	29.0
1983	1.1	0.95	1.2	25.7
1984	1.4	1.2	1.5	21.4
1985	1.2	1.0	1.3	23.0
1986	1.4	1.2	1.6	24.7
1987	1.1	0.97	1.2	22.2
1988	0.50	0.46	0.55	19.6
1989	1.3	1.1	1.5	26.8
1990	1.2	1.1	1.4	26.8
1991	1.4	1.1	1.6	34.4
1992	0.58	0.50	0.67	28.9
1993	0.98	0.82	1.2	33.6
Great Miami River at Hamilton, Ohio—Total nitrogen				
1999	12.1	10.8	13.2	19.8
2000	10.2	9.2	11.3	20.6
Great Miami River at Hamilton, Ohio—Total phosphorus				
1999	0.99	0.77	1.2	43.4
2000	0.77	0.63	0.93	39.0

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