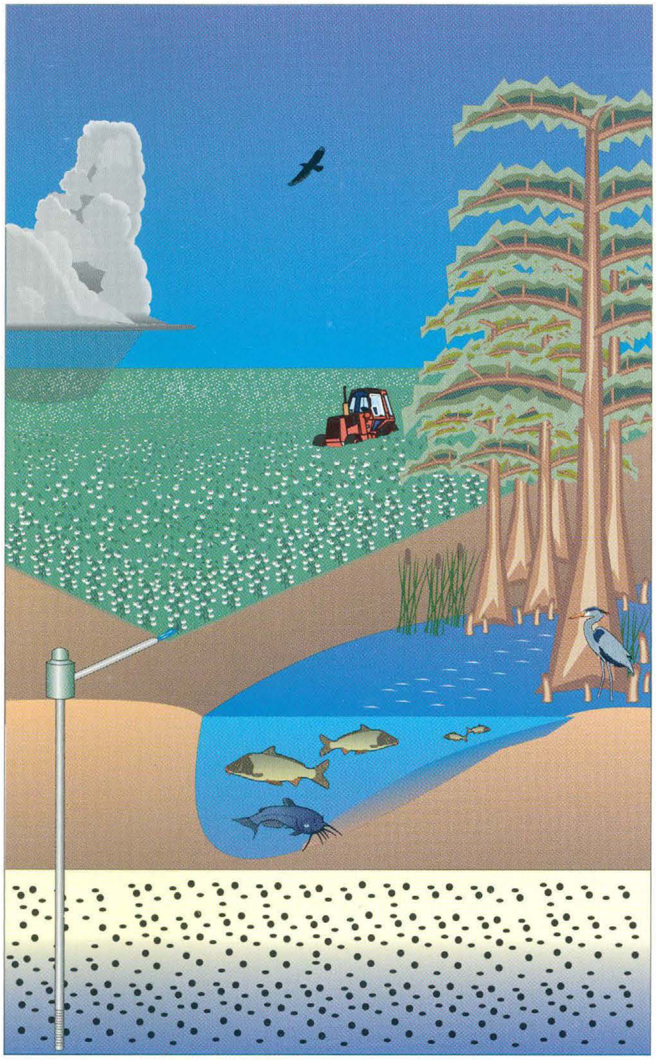
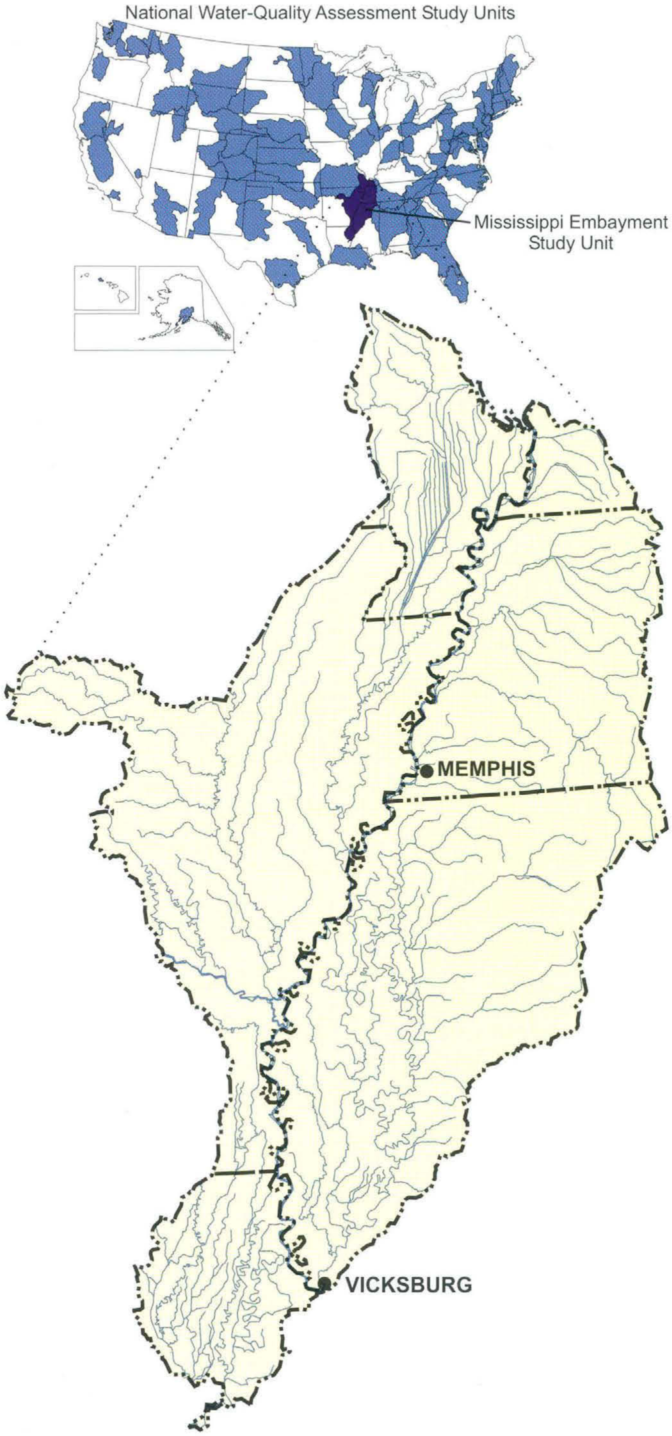
NITROGEN AND PHOSPHORUS CONCENTRATIONS AND FLUXES OF STREAMS IN THE MISSISSIPPI EMBAYMENT STUDY UNIT, 1996–98

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 01–4024





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National Water-Quality Assessment Program

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by R.H. Coupe

U.S. Geological Survey
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National Water-Quality Assessment Program

Pearl, Mississippi
2002

U.S. DEPARTMENT OF THE INTERIOR
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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

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
	Length	
inch(in.)	25.4	millimeter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Mass	
ton	907.1847	kilograms
tons per square mile	350.26	kilograms per square kilometer
	Rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Abbreviations and Acronyms

ft/mi	feet per mile
L	liter
mg/L	milligram per liter
µm	micrometer
MCL	Maximum contaminant level
MISE	Mississippi Embayment
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water-Quality Assessment
RPD	relative percent difference
USACOE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Nitrogen and Phosphorus Concentrations and Fluxes of Streams in the Mississippi Embayment Study Unit, 1996–98

by R.H. Coupe

ABSTRACT

The occurrence, spatial and temporal distribution, and yields of nitrogen and phosphorus were determined for streams of the Mississippi Embayment National Water-Quality Assessment Study Unit from February 1996 through January 1998. More than 400 samples were collected and analyzed during the 2-year study. Nine sites on eight streams were sampled on a monthly to weekly basis and included streams with small, primarily agricultural watersheds, streams with small watersheds with mixed agriculture and forest land use, one stream with a small urban watershed, and two large streams with mixed land use: row crop agriculture, pasture, forest, and urban. An additional 30 sites on 27 streams were sampled three times during the 1997 growing season to determine the spatial variability of nutrient concentrations in streams of the Study Unit.

All samples collected during this study had concentrations of nitrate and ammonia that were less than the drinking water Maximum Contaminant Level of 10 milligrams per liter and the aquatic life criteria, respectively. The median concentration of phosphorus exceeded the U.S. Environmental Protection Agency's recommendation of 0.1 milligram per liter of phosphorus for flowing waters in seven of the nine streams sampled from February 1996 through January 1998. The 0.1 milligram per liter goal was exceeded in every sample collected from Fletcher Creek and the Tensas and Yazoo Rivers.

Annual yields of nitrogen and phosphorus from streams in the Study Unit for 1996 and 1997 were compared to the average annual yields from 42 streams for 1980-96 in the Mississippi River Basin. The nitrogen yields from the Study Unit were higher than yields from the drier western parts and the colder northern parts of the Mississippi River Basin, but lower than those from the agriculturally intensive Midwest. Yields of phosphorus in the Mississippi River Basin are highest in the Mississippi Embayment Study Unit, although the use of phosphorus as a fertilizer is less in the Study Unit than in the Midwest and there are few significant point sources. The large amount of rainfall, extensive surface drainage, and poorly drained soils all contribute to the large phosphorus yields in the Study Unit.

INTRODUCTION

Nitrogen and phosphorus are essential nutrients for a healthy aquatic ecosystem because they regulate the productivity of organisms in freshwater systems. However, excessive amounts of nitrogen and phosphorus can adversely affect surface-water quality through eutrophication (excessive aquatic-plant growth) and toxicity to aquatic life.

In 1994, the U.S. Geological Survey (USGS), through its National Water-Quality Assessment (NAWQA) Program, began an assessment of water quality in the Mississippi Embayment (MISE) Study Unit (fig. 1). The goal of the NAWQA Program is to assess the status and trends in the quality of the

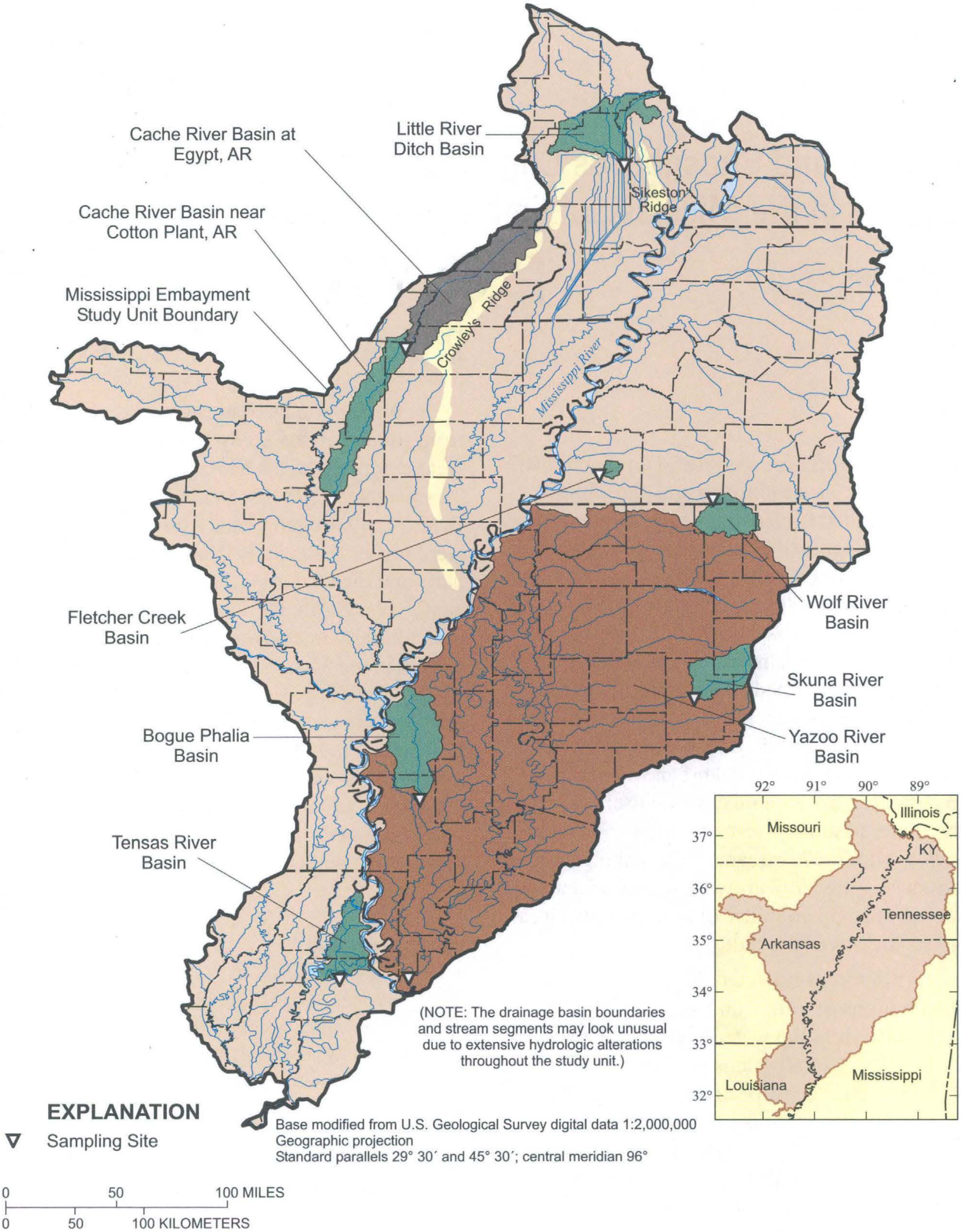

Figure 1. Mississippi Embayment Study Unit and location of sampling sites.

Nation's ground- and surface-water resources and to link the status and trends with an understanding of the natural and human factors that affect the quality of water (Gilliom and others, 1995). The MISE NAWQA is one of more than 50 Study Units distributed nationally and contributes to the goals of the NAWQA Program by providing water-quality information on a local scale that can be used in combination with data from other NAWQA Study Units to assess the water quality of the Nation's rivers and aquifers on regional or national scales.

This report (1) summarizes nitrogen and phosphorus concentration data collected from streams in the MISE Study Unit, (2) presents the results of flux calculations for nitrogen and phosphorus, (3) and compares the results of these flux calculations within the Study Unit to historical data from within the Mississippi River Basin. More than 300 samples were collected from eight streams in the MISE Study Unit from February 1996 through January 1998. The sampling frequency was at least monthly for all streams and up to weekly during the growing season for selected streams. Thirty additional sites on 27 streams, primarily in the Mississippi River Alluvial Plain, were sampled during May, July, and September 1997, to further define the spatial distribution of nitrogen and phosphorus concentrations in surface waters of the Study Unit.

The following people contributed significantly to the data collection efforts from February 1996 through January 1998: Michael A. Manning, Charles H. Lee, and Desmond J. Funchess from the USGS office in Pearl, Mississippi; Robert L. Joseph, Larry M. Remsing, A. Dwight Lasker, and Phillip L. Stephens from the USGS office in Little Rock, Arkansas; and Robert E. Whitaker, Howard C. French, Brett D. Gidens, and Kelly R. Brady from the USGS office in Rolla, Missouri.

Description of Study Unit

The MISE Study Unit is situated in the northern part of the Mississippi Embayment, a geologic structural trough. The axis of the Embayment roughly follows the course of the Mississippi River and gently slopes to the south-southwest. The Study Unit covers an area of approximately 48,500 square miles (mi^2) and includes parts of six States: Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee (fig. 1). The Mississippi River flows approximately north to south and bifurcates the Study Unit.

Much of the Study Unit was forested wetlands until relatively recently, and some of the most important bottomland hardwood stands remaining in the United States are in the Study Unit. Most of the original forests were cleared for timber and for agricultural use of the land during the 19th and early 20th centuries. Colorful descriptions of the richness of these immense wetlands exist. In October 1907, President Theodore Roosevelt hunted bear on the Tensas Bayou (part of the Tensas River) not far from the site where samples were collected for this study and wrote about his experiences "In the Louisiana Canebrakes" (Roosevelt, 1908). Roosevelt describes a virtual wilderness, with old growth forest and wetlands dominating the landscape with a few farms hacked out of the forest. He further describes canebrakes 20 feet (ft) tall extending for miles and the bayous teaming with alligator, garfish, and "monstrous snapping turtles, fearsome brutes of the slime." In 1863, following the battle of Chalk Bluff, a Confederate colonel wrote the following after crossing the swampy area around the Cache River.

> Day after day, in mud and water, with artillery, baggage, and ammunition wagons mired down, and horses and mules floundering in exhaustion, did my men and animals toil and struggle, when after three days of untold trials and hardships, the entire command emerged from this wilderness of mud and disease-generating miasma more like an army of denizens of a semi-amphibious subterranean world than one of men and animals (Anonymous, 1999).

Climate

The climate of the MISE Study Unit is subtropical with hot, humid summers and moderate winters. Normal annual precipitation is 51 inches, varying from north to south with less in the northern part of the Study Unit and more in the southern part; most rainfall occurs from December to April, and the least rainfall occurs in September and October. However, rainfall that produces locally intense runoff can occur at any time of the year. The average snowfall is about 7 inches in southeastern Missouri and decreases to practically zero inches on an annual basis in the southern part of the Study Unit. The typical length of the frost-free growing season is slightly longer than 7 months.

Physiography

The MISE Study Unit is located in the Coastal Plain Physiographic Province. The Study Unit is located mostly in the Mississippi River Alluvial Plain and the East Gulf Coastal Plain physiographic sections, but, also includes some small areas in the Ouachita Mountains in Arkansas and the Ozark Plateaus in Missouri and Arkansas.

More than half of the region is in the low, relatively flat alluvial valley of the Mississippi River, a slightly undulating area of little topographic relief with an average gulf ward slope of about 0.5 foot per mile (ft /mi). The width of the alluvial plain ranges from about 40 to 110 mi and is greatest in the middle third of the Study Unit. A major topographic feature in the alluvial plain is Crowley's Ridge, a narrow, segmented ridge about 200 mi long, extending northward from near the Mississippi River in east-central Arkansas into southeastern Missouri. The ridge, an erosional remnant, is as much as 250 ft higher than the surrounding alluvial plain. Most of the Study Unit west of the Mississippi River and the western part of the Yazoo River Basin is located in the Mississippi River Alluvial Plain.

The East Gulf Coastal Plain topography is gently rolling to hilly and abuts the eastern edge of the alluvial plain and extends most of the length of the Study Unit east of the Mississippi River. The wind-blown material rises several hundred feet above the plain. Most of the Study Unit located in Kentucky and Tennessee, as well as the eastern part of the Yazoo River Basin, is located in the East Gulf Coastal Plain, referred to hereafter in this report as the uplands.

Land Use

The land use in the Study Unit is about two-thirds agriculture (approximately 21 million acres), and the only major metropolitan area within the Study Unit is Memphis, Tennessee. Agricultural land use within the Study Unit is described in table 1. These data are from a survey of farmers conducted by the U.S. Department of Agriculture and represent the agricultural land use in 1993 (Stuart and others, 1996). Agricultural land use in the Study Unit is almost 80 percent row crop agriculture with another 15 percent in pasture and the Conservation Reserve Program (table 1). The major crops in 1993 were soybean and cotton, with smaller amounts of rice, corn, wheat, and a few miscellaneous crops. Only 6.3 percent of the land was in the category other, which includes fallow fields, set-aside, building sites, wetlands, wooded areas, and aquaculture.

Cotton is an economically important crop in the Mississippi Embayment Study Unit.

Table 1. Agricultural land-use characteristics of the Mississippi Embayment Study Unit in 1993

[CRP, Conservation Reserve Program; from Stuart and others, 1996]

Land use	Percent
soybean	34.9
cotton	21.8
rice	6.8
wheat	5.4
corn	5.2
other crops	4.5
Total crop	**78.7**
pasture	10.1
other	6.3
CRP	4.9

Surface-Water Hydrology

Annual precipitation for 1996 ranged from about 48 inches in southeastern Missouri to 53 inches in parts of Louisiana and Mississippi (National Atmospheric Deposition Program, 2000). The exception in 1996 was in the northern part of Mississippi and western Tennessee, where rainfall averaged between 56 and 59 inches. Precipitation for 1997 was higher throughout the Study Unit and ranged from 49 inches in southeastern Missouri to almost 66 inches in southern Arkansas, Louisiana, and Mississippi. Average or below average streamflow conditions existed throughout the Study Unit for 1996 (table 2), and streamflow was higher than average for 1997 throughout most of the Study Unit.

Description of Sampling Sites

In order to describe stream-water quality in the Study Unit, it was subdivided into major drainage basins that are either wholly or partially contained within the Study Unit (fig. 2, table 2) and might be considered to have similar water quality. These major drainage basins are the St. Francis, the White, the Tensas, the Yazoo, and in northern Mississippi, Tennessee, and Kentucky, the Northern Independent Streams, a set of relatively small streams that drain directly into the Mississippi River. Streams were selected for study based on several factors: land use that was representative of the Study Unit (table 2), spatial representativeness, local interest, historical data collection at that site, and the cost of sampling.

Nine sampling sites on eight streams (fig. 1) were sampled for 2 years to determine the spatial and temporal distribution of nitrogen and phosphorus in surface waters of the Study Unit. Seven of the sites were chosen to represent a single dominant land use—either row crop agriculture (four sites), forest/pasture/small farms (two sites), or urban (one site). Two sites were on large streams that integrated the effects of several land uses. These sampling sites are referred to as fixed sites within this report, and summary statistics of these data are shown in appendix I. During the growing season of 1997, an additional 30 sites located on 27 streams in the Mississippi River Alluvial Plain were sampled three times to further describe the spatial and temporal distribution of nitrogen and phosphorus in surface waters of this physiographic province (fig. 2). These data are shown in appendix II.

St. Francis River Basin, Arkansas and Missouri

The headwaters of the St. Francis River are in southeastern Missouri in the Ozarks Plateau outside of the Mississippi Embayment Study Unit. Lead mining began in the early 18^{th} century, and copper, nickel, and cobalt mining continued into the early 1980's; some of the soils and streambed sediment in this area are contaminated by heavy metals (Missouri Department of Natural Resources, 1996). The St. Francis River enters the Study Unit after flowing through a large reservoir and continues southward through northeastern Arkansas and joins the Mississippi River below Memphis, Tennessee. The St. Francis River and most of its tributaries flow in a north to south direction. The exceptions are the Whitewater and Castor Rivers in the extreme northernmost part of the Study Unit. The Headwater Diversion Canal that flows west to east connects these two streams to the Mississippi River. The Headwater Diversion Canal diverts water from about 1,130 mi^2 of a wooded and hilly terrain part of the Ozarks Plateau, which before construction of the canal would have had to flow southward several hundred miles before reaching the Mississippi River. Crowley's Ridge (fig. 1), the largest feature in the area, is as much as 250 ft higher than the surrounding area.

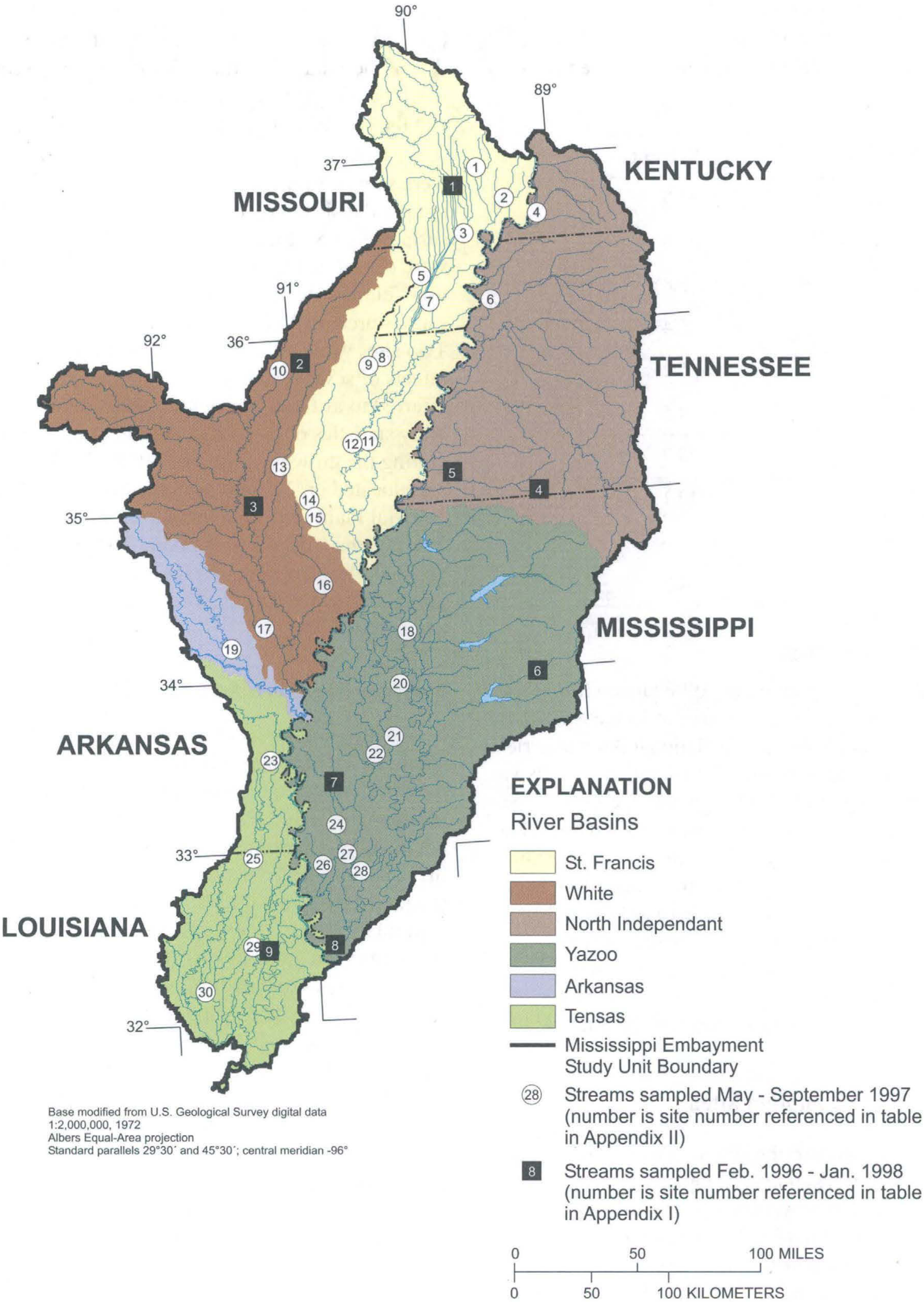

Figure 2. Major drainage basins in the Mississippi Embayment Study Unit and locations of sampling sites.

Table 2. —Streamflow at nine sampling sites in the Mississippi Embayment Study Unit
[mi^2, square mile; ft^3/s, cubic feet per second; --, not applicable]

Sampling Site	Basin size at sampling site (mi^2)	Predominate type of land use	Period of record	Flow (ft^3/s) Period of record mean annual	1996 annual mean	1997 annual mean
		St. Francis River Basin				
Little River Ditch No. 1 near Morehouse, MO	450	Row crop Agriculture	1945-91, 1995-98	547	415	667
		White River Basin				
Cache River at Egypt, AR	701	Row crop Agriculture	1964-98	863	755	832
Cache River near Cotton Plant, AR	1,172	Mixed-row crop/ bottomland hardwood wetlands	1987-98	1,464	1,117	1,532
		North Independent River Basin – Wolf River Basin				
Wolf River near LaGrange, TN	210	Forest/pasture /small farms	1995-98	323	276	370
Fletcher Creek at Memphis, TN	30.5	Urban	April 1996-98	126	--	129
		Yazoo River Basin				
Skuna River at Bruce, MS	254	Forest/pasture /small farms	1947-98	371	381	671
Bogue Phalia near Leland, MS	484	Row crop Agriculture	1996-98	629	443	866
Yazoo River below Steele Bayou, MS	13,355	Mixed-row crop/urban/ forest/pasture/small farms	1996-98	18,510	14,240	24,590
		Tensas River Basin				
Tensas River at Tendal, LA	309	Row crop Agriculture	1935-98	354	218	474

Little River Ditch 1 near Morehouse, MO—The sampling site is located in Stoddard County near the town of Morehouse, Missouri (fig. 3), in the Morehouse Lowlands, between Sikeston and Crowley's Ridges. This is in the northernmost extent of the Mississippi Embayment and consists of mostly lowlands, with some hills and ridges that are erosional remnants of a plain that once evolved in the area. The drainage basin upstream of the sampling site is 450 mi^2 and includes parts of Cape Girardeau, Scott, and Stoddard Counties. The bulk of the drainage basin is in Stoddard County. The channel slope is 0.77 ft/mi, and the main channel length above the sampling site is 64.9 mi (G.L. Wilson, USGS, Rolla, Missouri, written commun., 1999). The mean annual flow for the period of record at this site (1945-91, 1995-98) is 547 ft^3/s. The annual mean flow for 1996 and 1997 was 415 and 667 ft^3/s, respectively. Current land use in the basin above the Little River Ditch 1 sampling site is more than 84 percent agriculture and 13 percent forest (Vogelmann and others, 1998).

Agriculture is important economically in southeastern Missouri. Most of the cotton and rice, as well as 20 percent of the Missouri soybean production in 1996, was grown in southern Missouri (Hamer and Schlegel, 1997). The six Missouri counties that are in the Study Unit are the top six counties in cash receipts for crops in Missouri.

White River Basin, Arkansas

The White River Basin is mostly located in northwestern Arkansas and southwestern Missouri, and the majority of the basin is not included in the Study Unit. The part of the White River Basin included in the Study Unit begins where the White River reaches the Mississippi River Alluvial Plain near Newport, Arkansas, and includes the Bayou DeView and Cache River Basins north of the White River and LaGrue Bayou south of the White River.

The Cache River Basin is located in northeastern Arkansas in the Western Lowlands part of the Mississippi River Alluvial Plain (fig. 4). The Cache River is an underfit stream, flowing in an old channel of the present-day Black and St. Francis Rivers. From its headwaters on the western slope of Crowley's Ridge just north of the Arkansas State boundary, the Cache River flows southwesterly until it joins the White River near Clarendon, Arkansas. The watershed is about 140 mi long, with a maximum width of about 18 mi and an area of about 2,020 mi^2. The main channel and tributaries in the upper part of the Cache River Basin were dredged and channelized during the 1920's and 1930's to drain the land for agricultural use. Downstream of Grubbs, Arkansas, the Cache River flows in a meandering natural channel (Smith, 1996).

The Cache River Basin is mainly rural, with agriculture being the dominant land use. The major crops are soybean, rice, cotton, and wheat with soybean being the major crop by area; combined, these crops account for up to 90 percent of the crop area in the Cache River Basin. Arkansas is the leading producer of rice in the United States, and the counties in which the Cache River is located are some of the most productive for rice in the State (Arkansas Agricultural Statistics Service, 1996). Rice production has been shown to have changed the hydrology of the Cache River Basin by increasing the frequency of extreme low flows and increasing the average monthly flows for August and September (Wilber and others, 1996). This is due to the extensive use of the alluvial aquifer for rice irrigation, followed by the draining of the rice fields prior to harvest in August and September.

Cache River at Egypt, AR—The sampling site is located in Craighead County, Arkansas, and has a drainage area of 701 mi^2 (fig. 4). This site is located in the dredged and channelized part of the Cache River. The mean annual flow (1964-98) is 863 ft^3/s. The annual mean flow was 755 and 832 ft^3/s in 1996 and 1997, respectively. The Cache River had several days of zero flow during October 1996.

Cache River near Cotton Plant, AR—The sampling site is located in Woodruff County, Arkansas, and the drainage area upstream from the sampling site is 1,172 mi^2 (fig. 4). The mean annual flow (1987-98) is 1,464 ft^3/s, and the annual mean flow was 1,117 and 1,532 ft^3/s in 1996 and 1997, respectively. Although the drainage area upstream of the sampling site is primarily agricultural, the sampling site is located downstream of a small, but relatively contiguous tract of bottomland hardwood forest known as the Black Swamp, which is part of the Cache River National Wildlife Refuge. The effects of the Black Swamp on the Cache River have been intensively studied (Wilcox, 1996) and included flood attenuation and storage, higher nitrate reduction, and increased sediment retention compared to the Cache River upstream from the Black Swamp.

The land use upstream from the two Cache River sampling sites is fairly similar: for example, each basin has more than 80 percent of the land use in agriculture,

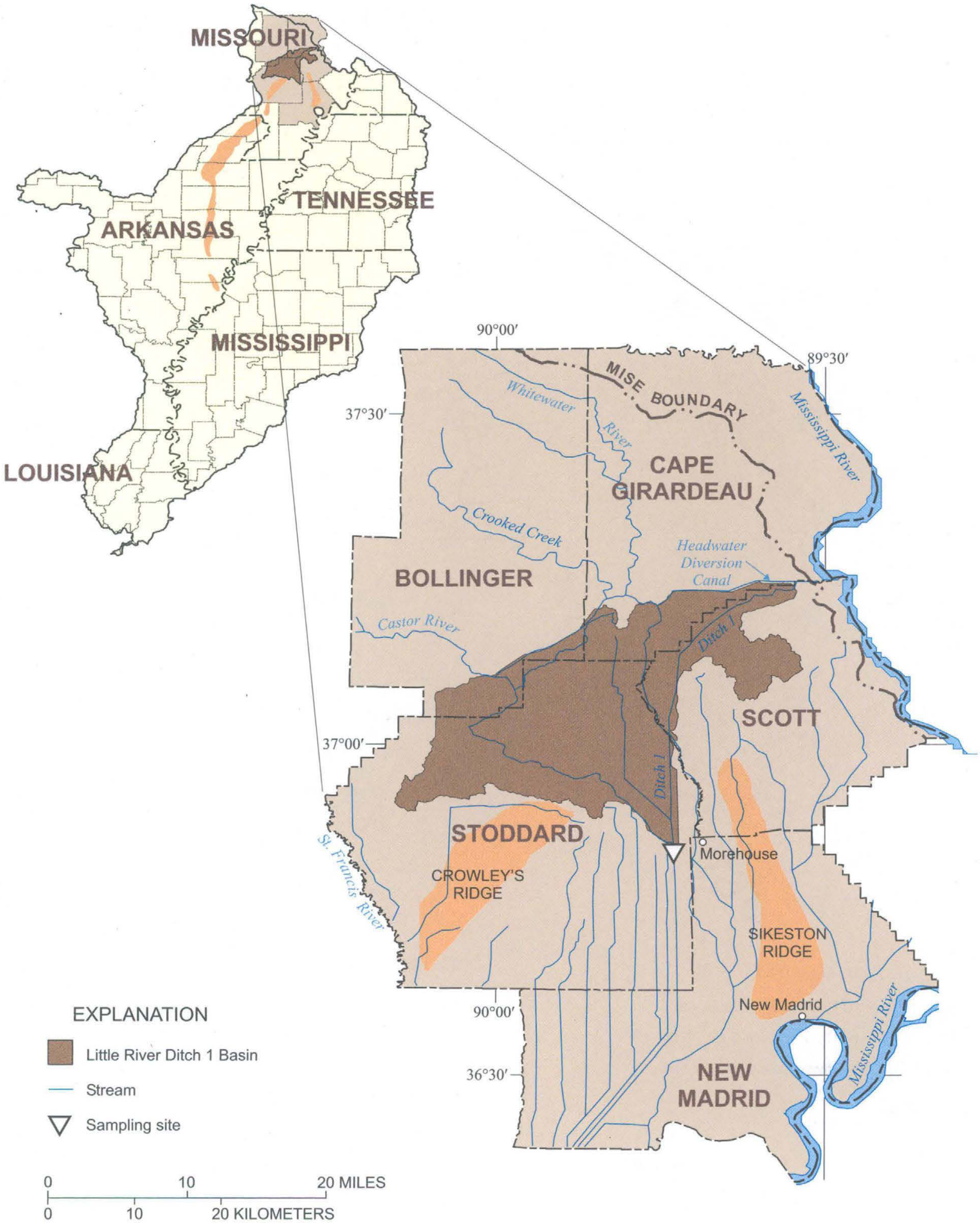

Figure 3. Little River Ditch 1 Basin and location of sampling site.

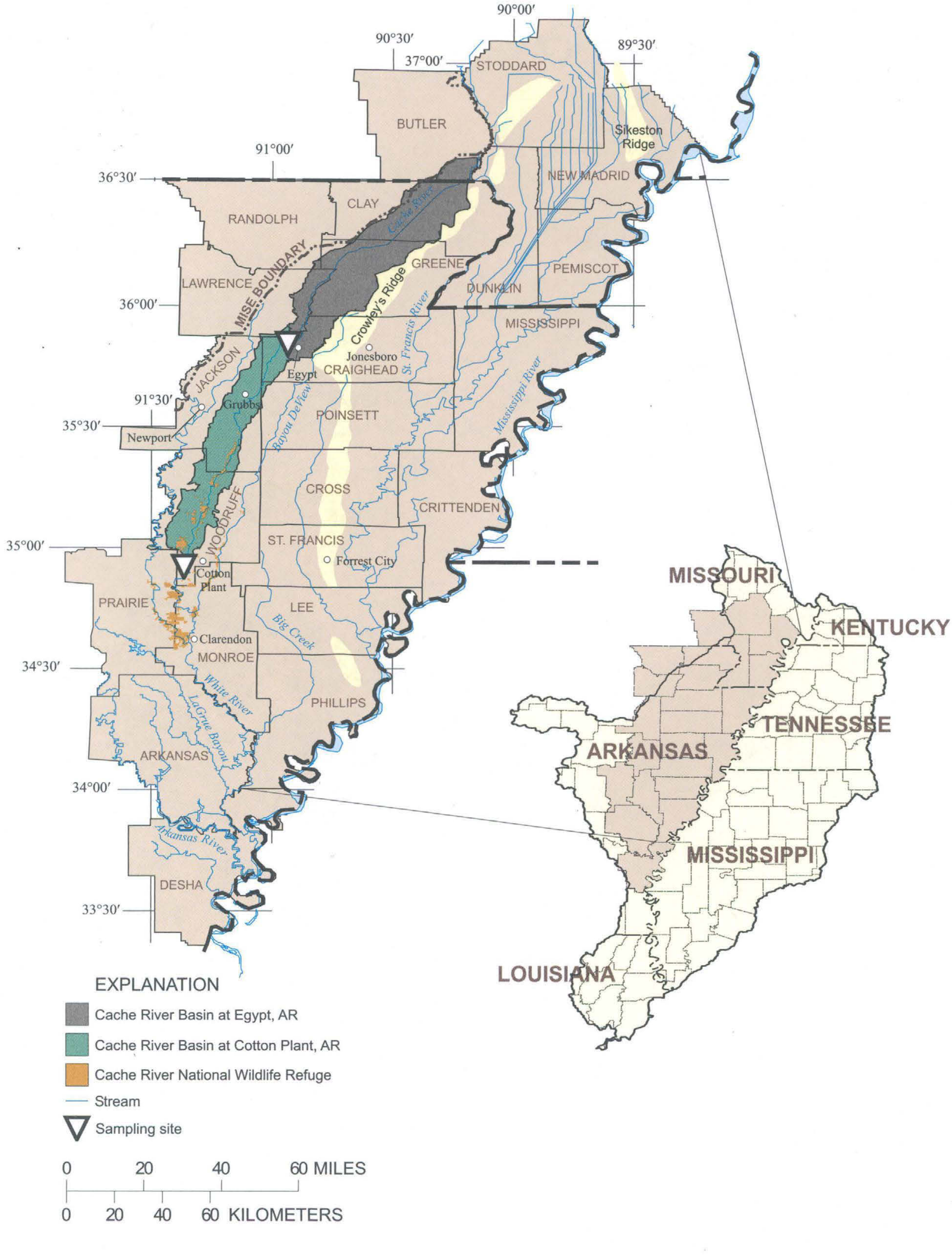

Figure 4. Cache River Basin and location of sampling sites.

The highly armored and rip rapped Fletcher Creek at Memphis, Tennessee.

and 16 and 10 percent in forest above Egypt and Cotton Plant, respectively. The major difference in land use upstream of each sampling site is that an additional 6 percent of the land above Cotton Plant but below Egypt is classified as wetlands, whereas less than 1 percent is classified as wetlands above Egypt. Thus, most of the wetlands are in the drainage between the Egypt and Cotton Plant sampling sites.

Wolf River Basin, Mississippi and Tennessee

The Wolf River originates about 15 mi south of the Mississippi State boundary in Tippah County, Mississippi. After crossing into Tennessee, the Wolf River flows in a northwesterly direction for about 80 mi across Fayette and Shelby Counties, through the northern part of Memphis to the river's confluence with the Mississippi River (fig. 5).

Wolf River near LaGrange, TN—The sampling site is located in Fayette County, Tennessee, but most of the 210-mi^2 drainage basin is located in the uplands of Benton County, Mississippi (fig. 5). The gage at this site was installed in September 1995, and the annual mean flow for 1996 and 1997 was 276 and 370 ft^3/s, respectively. The land use is primarily forest (57 percent), with less than 32 percent of the land in agriculture (Vogelmann and others, 1998).

Fletcher Creek at Memphis, TN— Fletcher Creek is tributary to the Wolf River and is located slightly northeast of the Memphis metropolitan area (fig. 5). Historically, the land use in this basin has been agriculture, but recently the basin has undergone urbanization. The drainage area for the basin upstream of the sampling site is 30.5 mi^2, and the land use is 50 percent developed, 23 percent forested, and 25 percent agricultural (Vogelmann and others, 1998). Development continued in the drainage basin during the study and is predominantly residential mixed with some commercial development. The topography in the basin is characterized by gently rolling to steep hills. The stream has been heavily armored with riprap, and rectangular concrete channels have been installed at road crossings to increase the stream carrying capacity for flood control. Streambed slopes in this area range from about 18 to 70 ft/mi (Neely, 1984). The gaging station at this site was installed in April 1996. The annual mean flow for 1997 was 129 ft^3/s (table 2).

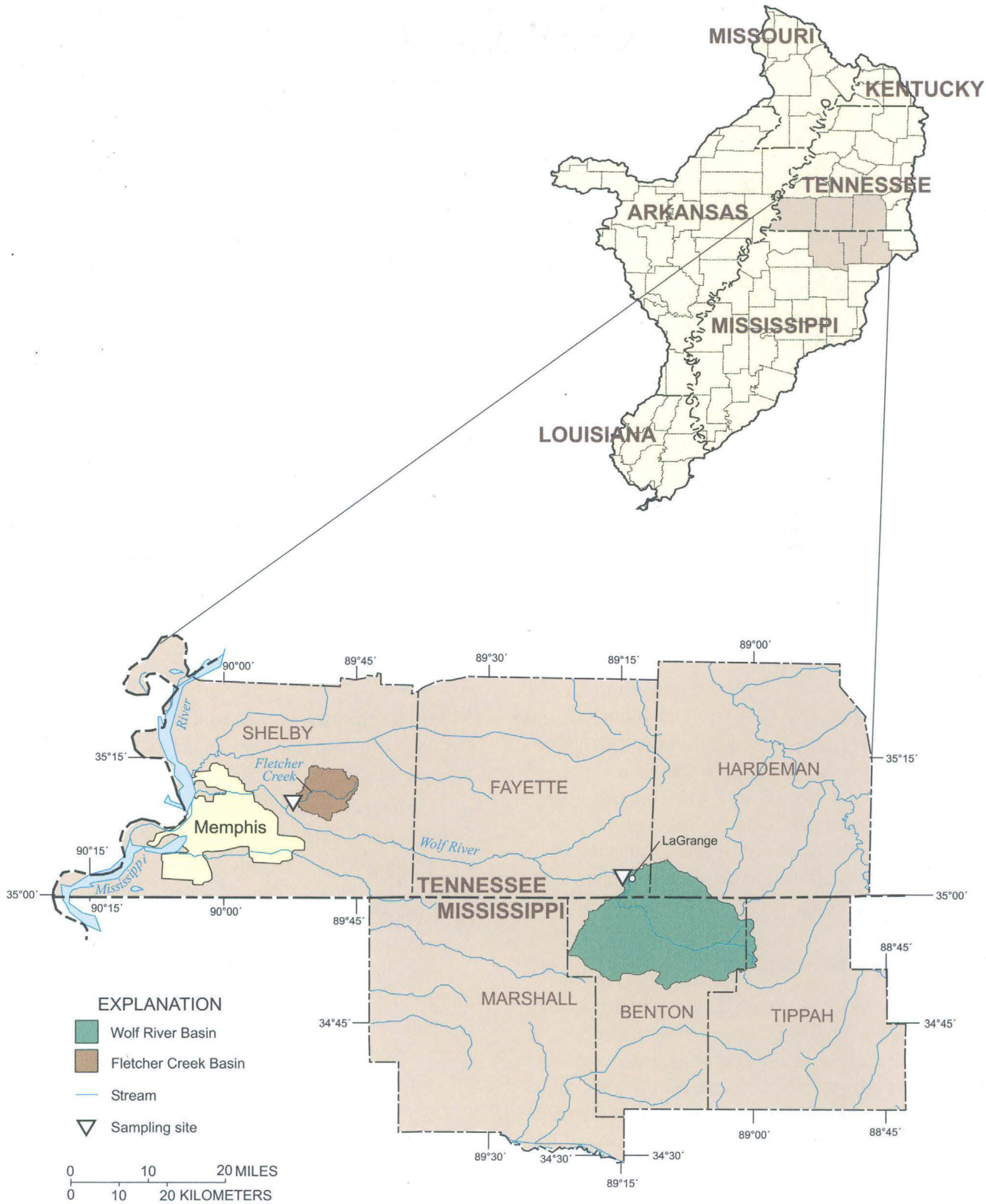

Figure 5. Wolf River Basin and location of sampling sites.

Yazoo River Basin, Mississippi

The Yazoo River Basin (fig. 6) consists of more than 13,000 mi^2 in northwestern Mississippi. The basin is divided almost equally between lowlands in the Mississippi River Alluvial Plain (commonly referred to as the Delta), an intensive agricultural area of mostly cotton, rice, and soybean production, and the uplands, which generally consist of forest, pastures, and small farms. The Yazoo River Basin is sparsely populated with no major metropolitan areas, although there are a number of communities with populations less than 50,000. Land use in the Yazoo River Basin is predominantly agriculture: 37 percent is in row crop production, and 14 percent in pasture or hay. The Yazoo River Basin also has approximately 29 percent of its land use in forest, and approximately 10.5 percent is classified as wetlands (Vogelman and others, 1998).

Skuna River near Bruce, MS—The Skuna River flows southwestward through the uplands in Calhoun and Chickasaw Counties, Mississippi, with a drainage area of 254 mi^2 upstream of the sampling site at Bruce (fig. 6). The length of the main channel upstream of the sampling site is 31 mi, and the average slope of the channel is about 3.6 ft/mi (Wilson and Turnipseed, 1994). The Skuna River flows into Grenada Lake about 34 mi downstream from the sampling site. The mean annual flow (1947-98) of the Skuna River at Bruce is 371 ft^3/s. The annual mean flow for 1996 and 1997 was 381 and 671 ft^3/s, respectively.

The Skuna River has undergone extensive modifications during the 20th century to improve runoff for agriculture. Much of the old run of the Skuna River was abandoned and replaced with a canal. Estimates are that the channel length upstream of the sampling site was shortened from 36 to 31 mi, and the channel slope was increased from 2.9 to 3.6 ft/mi by these modifications (Wilson and Turnipseed, 1994). Land use in the Skuna River Basin is divided almost equally between forest and agriculture: 46 and 51 percent, respectively. Most of the agricultural land, approximately 60 percent, is in pasture or hay production.

Bogue Phalia near Leland, MS—The Bogue Phalia flows in a north to south direction from its headwaters near the Mississippi River levee in Bolivar County to its confluence with the Big Sunflower River in Washington County. The Bogue Phalia sampling site is located in west-central Mississippi near the town of Leland. The drainage basin above the sampling site is approximately 484 mi^2 and is located mostly in Bolivar County (fig. 6). Land use in the Bogue Phalia drainage is predominately agriculture with 71 percent of the land used for row crops and 15 percent in small grains such as wheat or rice. Bolivar County is the top rice-producing county in Mississippi. Less than 2 percent of the land is forested, but approximately 10.5 percent of the land is classified as wetlands. The channel slope is approximately 0.8 ft/mi, and the channel length above the sampling site is approximately 58.2 mi (K.V. Wilson, Jr., USGS, Pearl, Mississippi, written commun., 1998). The gaging station at the sampling site has been in operation for many years by the U.S. Army Corps of Engineers (USACOE), but as a stage-only gage. Streamflow at the site has been measured since October 1995, and the annual mean flow for 1996 and 1997 calendar years was 443 and 866 ft^3/s, respectively.

Yazoo River below Steele Bayou, MS—The Yazoo River drains the entire Mississippi River Alluvial Plain in Mississippi and is formed by the confluence of the Tallahatchie and Yalobusha Rivers at Greenwood (fig. 6). The sampling site is located below the Steele Bayou control structure and about 9.5 mi upstream from the confluence of Steele Bayou and the Mississippi River. The Yazoo River flows southward from Greenwood along the eastern edge of the alluvial valley until reaching the Mississippi River at Vicksburg. Four flood-control reservoirs (Arkubutla, Sardis, Enid, and Grenada Lakes) were built between 1940 and 1950 and are located in the uplands of the northeastern part of the basin. These reservoirs control the streamflow from more than 4,400 mi^2 of drainage area within the Yazoo River Basin, and combined, the reservoirs provide 3.8 million acre-ft of storage at flood pool (U.S. Army Corps of Engineers, 1968).

Tributary inflow from the alluvial plain below Yazoo City to the Yazoo River is diverted by a levee along the right bank of the stream channel from Yazoo City to the split of the old channel and the Yazoo River Diversion Channel. In the mid 1960's, the USACOE constructed a diversion canal that connected Steele Bayou, Deer Creek, Little Sunflower, and Big Sunflower drainage basins. Only two flood-control structures, Steele Bayou and Little Sunflower, control runoff from the four basins. The floodgates at Steele Bayou and Little Sunflower are closed when tailwater elevations (Yazoo River stage) nearly equal the pool elevations at each structure. This prevents extensive alluvial flooding by backwater from the Mississippi River. When the stage in the Yazoo River drops below

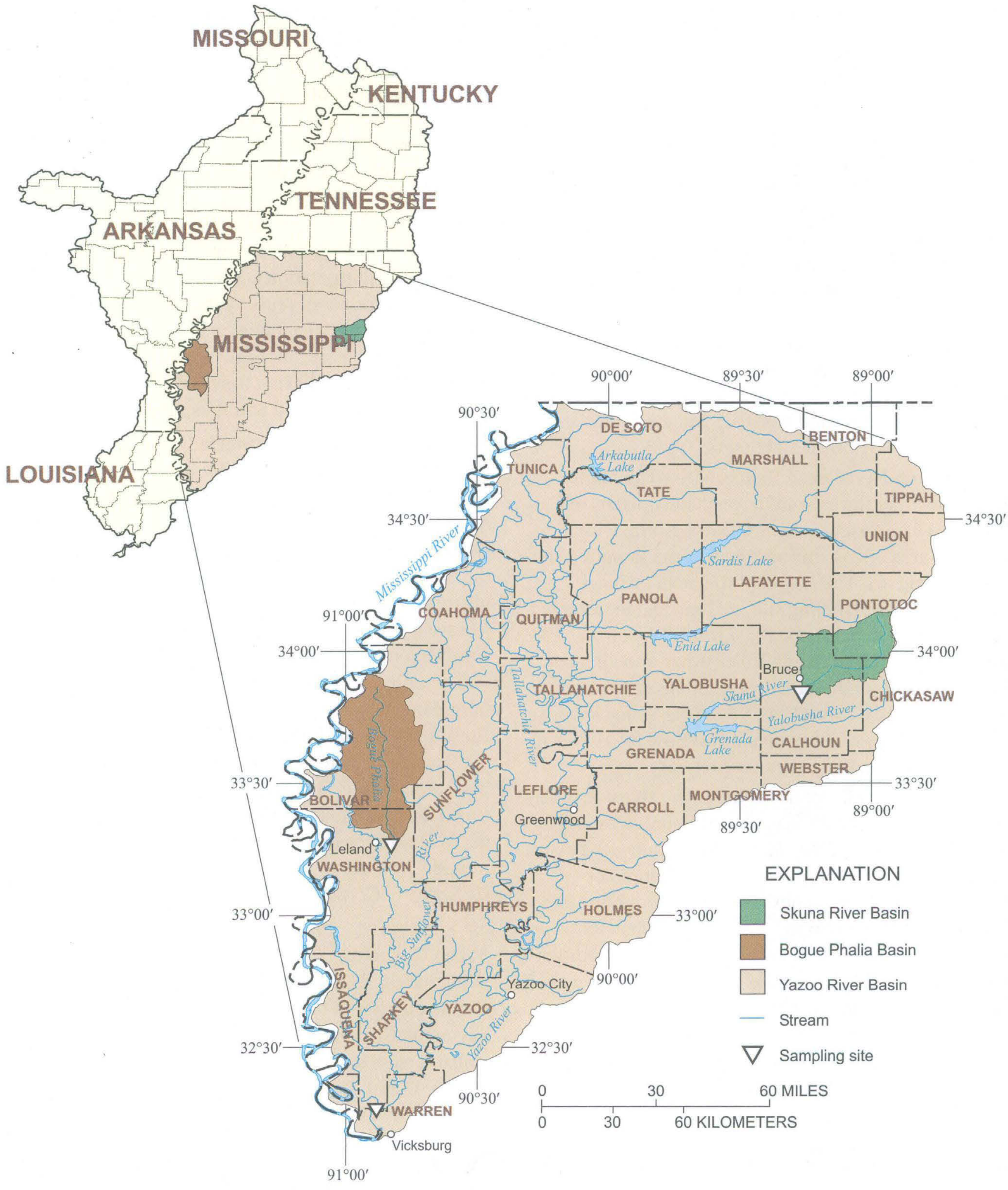

Figure 6. Bogue Phalia, Skuna, and the Yazoo River Basins and location of sampling sites.

the pool elevation, the flood-control structures are opened allowing the tributaries to flow into the Yazoo River.

The complex hydrology associated with the Yazoo River has made the measurement of streamflow difficult and, historically, there has not been a continuous record of streamflow from the mouth of the Yazoo River. The USACOE has maintained a gaging station on the Yazoo River upstream at Greenwood, but streamflow at this site does not include the contribution from the alluvial plain part of the Yazoo River Basin. With the development of new technology, a continuous record of flow from the Yazoo River began in October 1995 (Manning, 1997). The annual mean flow for 1996 and 1997 was 14,240 and 24,590 ft^3/s, respectively.

Measuring discharge on the Yazoo River using a boat-mounted acoustic Doppler.

Tensas River Basin, Arkansas and Louisiana

The Tensas River, located in northeastern Louisiana, flows 165 mi from Lake Providence, an oxbow lake separated from the Mississippi River by a levee, to Jonesville, where the Tensas River joins the Ouachita and Little Rivers to form the Black River. The Tensas River drains about 2,517 mi^2 and is believed to be an abandoned course of the Mississippi River due to its meandering pattern (USACOE, 1974). Some of the largest remaining tracts of forested wetlands in the Mississippi Valley are located in the basin and are of prime interest to many (Gosselink and others, 1990).

The Tensas River at Tendal, LA—The sampling site is located in Madison Parish near the town of Tendal; however, most of the basin upstream of the sampling site is located in East Carroll Parish (fig. 7). The Tensas River at Tendal drains approximately 309 mi^2, the channel length from Lake Providence to the sampling site is 44.4 mi, and the channel slope is 1.10 ft/mi. The mean annual flow (1935-98) for the Tensas River at this site is 354 ft^3/s. The annual mean flow for 1996 was 218 ft^3/s, and for 1997 it was 474 ft^3/s. Currently, land use in the basin is mostly agricultural (greater than 87 percent) with about 6.5 percent classified as forested wetland (Vogelmann and others, 1998).

Mississippi River Alluvial Plain Sampling Sites

Agriculture is the dominant land use in the Mississippi River Alluvial Plain, but the type of crops grown varies throughout the Study Unit; hence, the influence of agriculture on water quality varies. Soybean production occurs on about 20 to 50 percent of the crop acreage in each drainage basin. Because of this, the influence of soybean production on water quality is considered to be uniform throughout the Study Unit. But the amounts of corn, cotton, and rice grown in the Study Unit vary considerably within the Study Unit, in both a north to south and an east to west direction. To further define the spatial distribution of nitrogen and phosphorus in the surface waters of the Mississippi River Alluvial Plain, 30 additional sites were sampled 3 times during the growing season in 1997 (fig. 2). These sites were selected to represent various configurations of crop types and acreage.

Figure 7. Tensas River Basin and location of sampling site.

Methods

Sampling Frequency, Collection, Processing, and Laboratory Procedures

Water samples were collected from bridges, boats, or by wading using established velocity-weighted, depth- and width-integrating techniques (Shelton, 1994). Sample collection began in February 1996 and continued through January 1998 (table 3). Approximately 6 to 9 L of water was collected for each sample. Immediately after collection, the samples were subsampled by using a cone splitter (Shelton, 1994). Filtered samples for dissolved nutrients were passed through a 0.45-μm filter, chilled and sent with the whole water samples to the USGS National Water Quality Laboratory in Arvada, Colorado, for analysis by standard procedures (Fishman and Friedman, 1989).

The water samples were analyzed for total ammonia, nitrite, nitrite plus nitrate, dissolved ammonia and organic nitrogen, total ammonia and organic nitrogen, and total phosphorus, dissolved phosphorus, and orthophosphate. Total nitrogen as used in this report is the sum of total ammonia plus organic nitrogen and nitrite plus nitrate. Total nitrogen and total phosphorus in this report will be referred to as nitrogen and phosphorus, respectively. Hereafter, nitrite plus nitrate will be referred to as nitrate.

The sampling frequency varied annually, seasonally, and between sites, depending upon the sampling objectives of each site, the expected variability of the site, and the resources available at the time (table 3). During the 1997 growing season, 30 sites on 27 streams were sampled 3 times: once each during the months of May, July, and September. All 30 of the sampling sites and the 9 fixed sites were sampled during a 1-week period to reduce the variability due to changing climatic conditions.

Table 3.—Sample collection frequencies at nine sites in the Mississippi Embayment Study Unit, February 1996-January 1998

Sampling Station	Time Period			
	Feb – Sept 1996	Oct 1996 – Feb 1997	Mar – Aug 1997	Sept 1997 – Jan 1998
Little River Ditch 1, near Morehouse, MO	Biweekly	Biweekly	Weekly	Biweekly
Cache River at Egypt, AR	Monthly	Monthly	Monthly	Monthly
Cache River near Cotton Plant, AR	Monthly	Monthly, 7 samples Feb 5-21	Monthly, 5 samples July 28 – Aug 12	Monthly, 5 samples Oct 17-30
Fletcher Creek at Memphis, TN	Monthly – Started April	Biweekly	Weekly	Monthly
Wolf River near LaGrange, TN	Monthly	Monthly	Monthly	Monthly
Skuna River near Bruce, MS	Monthly	Monthly	Monthly	Monthly
Bogue Phalia near Leland, MS	Biweekly	Biweekly	Weekly	Biweekly
Yazoo River below Steele Bayou, MS	Biweekly	Biweekly	Biweekly	Biweekly
Tensas River at Tendal, LA	Monthly	Biweekly	Biweekly	Biweekly

Water samples were filtered and processed in a mobile laboratory immediately after sample collection.

These data were not meant to be a statistical representation of commonly occurring conditions in the surface water of the Study Unit. A major component of the site selection process was to target specific watersheds that are influenced primarily by a single dominant land use (agriculture or urban) and to investigate the occurrence and distribution of nutrients in surface water in these basins. Additionally, because most of the nitrogen and phosphorus used for agricultural purposes is applied seasonally and because high concentrations of nutrients in streams may be related to rainfall runoff events, more sampling was done during these periods. Therefore, the statistics shown in appendix I may not represent ambient conditions in streams of the Study Unit, but show nutrient concentrations that reflect impacts of the targeted land uses.

Data-Analysis Procedures

Statistical and graphical methods were used to analyze the nitrogen and phosphorus data by sampling site and by basin. The data were displayed graphically by using Tukey's "schematic plot," commonly referred to as boxplots (Helsel and Hirsch, 1992, p. 26). These types of plots allow for the side-by-side comparisons of the distribution of data from each site or basin. In addition, Tukey's multiple comparison test (Helsel and Hirsch, 1992, p. 196) on rank transformed data was used to test if the medians of the data were significantly different.

Plotting a smoothed curve through the center of the data shows the general relation between streamflow and nutrient concentration. The method used to generate the smoothed data is the LOWESS method (Helsel and Hirsch, 1992). This method shows the general shape of the relation between streamflow and nutrient concentration for each sampling site. For ease of visual interpretation, concentrations reported to be less than the reporting limit were plotted as zero.

Quality-Control Data

About 15 percent of the samples were quality-control samples, which included field equipment blanks to measure contamination and replicate samples to measure precision. Eighteen field equipment blanks were collected and analyzed. The results indicated that there was low-level contamination of some blanks for ammonia, nitrate, phosphorus, dissolved phosphorus, orthophosphate, and especially nitrite (table 4). The concentration and the frequency of detection were not of environmental significance for most constituents; however, the nitrite results reported in appendix I and II should be used with caution.

Precision data were obtained from 16 sets of replicates and the relative percent differences (RPD) are shown graphically in figure 8. These replicates represent a mix of concurrent replicates, samples collected at the same time but by different field crews, and split replicates (one sample collected then split into two samples). The median RPDs are less than 10 percent for ammonia, dissolved ammonia plus organic nitrogen, total ammonia plus organic nitrogen, nitrite, nitrite plus nitrate, and orthophosphate; the median RPDs are less than 20 percent for total phosphorus and dissolved phosphorus. Most of the extreme values shown in figure 8 are associated with one replicate sample collected from Little River Ditch on May 21, 1997. There is no explanation for the large discrepancies in replicate values from this sample. Analysis of other replicate samples from Little River Ditch indicates that the variances should not affect the assessments of data from this site and that the May 21 replicate was an aberration.

Table 4.—Results of 18 field equipment blanks, 1996-98
[mg/L, milligrams per liter]

Constituent	Percent detections	Range of detections (mg/L)	Method reporting level (mg/L)
Nitrogen ammonia	17	0.020-0.040	0.015 and 0.020
Dissolved ammonia plus organic nitrogen	0	--	0.20
Total ammonia plus organic nitrogen	0	--	0.20
Nitrite	33	0.010-0.020	0.010
Nitrite plus nitrate	11	0.070-0.077	0.050
Phosphorus	28	0.020-0.14	0.010
Dissolved phosphorus	17	0.014-0.027	0.010
Orthophosphate	28	0.010-0.033	0.010

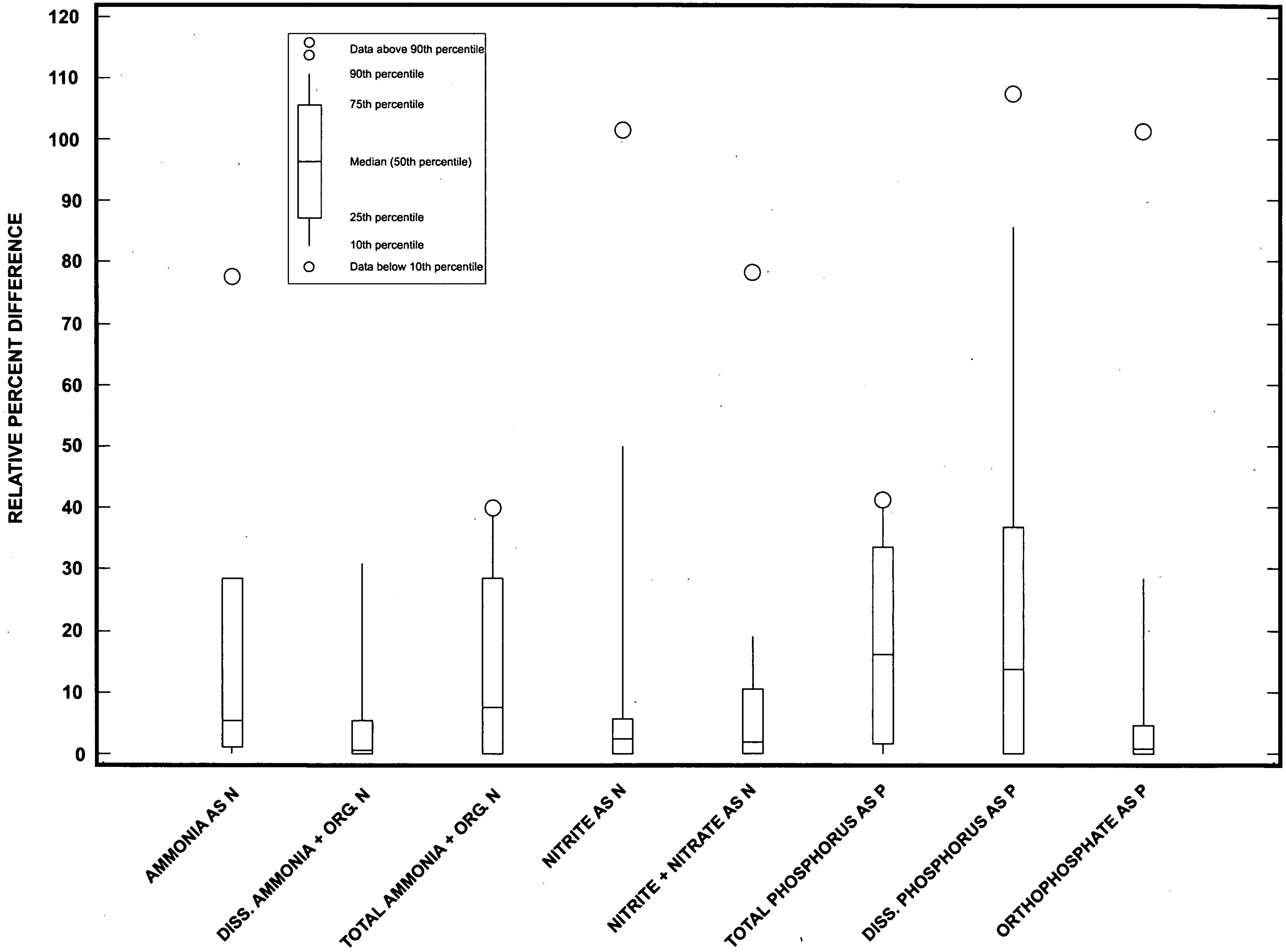

Figure 8. Relative percent difference between replicate samples for selected constituents, 1996-98.

Flux Calculations

Annual loads for 1996 and 1997 were calculated by using multivariate regression using the ESTIMATOR program (Cohn and others, 1992). ESTIMATOR, written in Fortran, uses multivariate regression and the Minimum Variance Unbiased Estimator procedure to correct for log-transformation bias (Cohn and others, 1989). The ESTIMATOR program does the multivariate regression for daily loads using streamflow, time, and seasonal indicators expressed as sine and cosine transformations of time as explanatory variables. Multiple explanatory variables are used in situations where one explanatory variable is not sufficient for accurate model prediction. The concentrations of most constituents in surface water are related to streamflow. However, in agricultural areas, the application of nitrogen and phosphorus as fertilizer occurs seasonally. Therefore, concentrations of nitrogen and phosphorus in waters draining these areas are expected to have an annual cyclical variation; hence, the inclusion of the sine and cosine variables.

A common set of explanatory variables was chosen for each constituent included in the analysis. Not all explanatory variables were statistically significant for every constituent. Statistically non-significant explanatory variables should not change the flux estimates appreciably (Goolsby and others, 1999). The regression equation for each constituent has the form

$$\ln(CQ) = B_0 + B_1 \ln(Q) + B_2T + B_3\sin(2\pi T) + B_4\cos(2\pi T) \qquad (1)$$

where

C = concentration,
B_0 = intercept,
B_1, B_2, B_3, B_4 = regression coefficients,
Q = daily mean streamflow,
T = time, and
π = 3.1416.

One advantage of using the multivariate method is that an error estimate was obtained that allowed for some level of certainty in the load estimate. The ESTIMATOR program generated the standard error of the predictor, which when used with the appropriate t-statistic, gave a 95 percent confidence interval for the calculated annual load (Helsel and Hirsch, 1992).

For the Fletcher Creek site, which did not have 2 complete years of streamflow data, and for the Skuna River site that had a standard error of the load estimate greater than 30 percent of the load, the results from the estimator program were not used. In these cases, the annual load was estimated by multiplying the annual flow-weighted mean concentration by the total annual flow.

SOURCES OF NITROGEN AND PHOSPHORUS IN SURFACE WATERS

Nitrogen and phosphorus are natural and important elements in a healthy aquatic environment. However, excessive inputs of nutrients can lead to eutrophication: the abundant growth of algae and aquatic plants. Eutrophication can lead to a reduction in the designated uses of a lake or stream because of the increased growth of algae and weeds that interfere with the use of the water for fisheries, recreation, industry, agriculture, and drinking-water supplies.

The primary forms of nitrogen found in the waters of natural streams are ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-), and as a part of organic solutes (Hem, 1985). The total phosphorus concentration of surface water is primarily made up of phosphorus in organisms, phosphorus adsorbed onto inorganic complexes such as clays, carbonates, and ferric hydroxides, and phosphorus adsorbed onto dead particulate organic matter. However, the most important form of phosphorus to aquatic systems is orthophosphate (PO_4^{3-}) because this is the phosphorus that is readily available for use by aquatic organisms and is usually only a small percentage of the total phosphorus (Hem, 1985).

The U.S. Environmental Protection Agency (USEPA) has established a maximum contaminant level in drinking water for nitrate of 10 mg/L (U.S. Environmental Protection Agency, 1990). The USEPA has also established criteria for maximum ammonia concentrations in surface water based on chronic and acute exposure of aquatic organisms to un-ionized ammonia. These criteria are variable and are dependent on pH and temperature that control the toxicity of un-ionized ammonia and the equilibrium between un-ionized ammonia and the ammonium ion. Within the ranges of pH (6.5-9.0) and temperature (0-30 °C) for most natural surface waters, total ammonia (NH_3 plus NH_4^+) concentrations greater than about 2.1 mg/L (as N) exceed the chronic criteria (Mueller and others, 1995). The USEPA (1986) makes the following recommendations for phosphorus concentrations in streams to control eutrophication:

- Total phosphorus should not exceed 0.05 mg/L (as P) in a stream at a point where it enters a lake or reservoir.
- Total phosphorus should not exceed 0.1 mg/L (as P) in flowing waters that do not discharge directly into lakes or impoundments.

The nitrogen and phosphorus present in the surface waters of the Study Unit originated from both anthropogenic and naturally occurring sources, but these can be broadly categorized as point and non-point sources.

Point Sources

Point sources of nitrogen and phosphorus, generally anthropogenic in nature, consist primarily of a variety of industries and wastewater-treatment plants. They discharge directly into a receiving stream at a discrete point (Puckett, 1994). Point sources such as discharges from wastewater-treatment plants tend to be continuous with little variability over time. The Study Unit (with the exception of the Memphis, Tennessee area) is rural, and the land use is mostly agricultural with few point sources of nitrogen and phosphorus (fig. 9 a and b). The point-source data shown in figure 9a and b are from a study conducted by the USEPA and represent an estimate of the 1996 nitrogen and phosphorus discharged to streams by regulated point sources (Goolsby and others, 1999). These data include only that from permitted discharges from facilities contained in the National Pollutant Discharge Elimination System and do not include dumping or other illegal discharges. These data are compiled and shown by 8-digit hydrologic unit code.

Non-Point Sources

Non-point sources of nitrogen and phosphorus originate at numerous and widespread locations rather than from a discrete point. Non-point sources can be continuous, but more often are intermittent and linked to seasonal agricultural activity or irregular events, such as heavy precipitation or construction (Carpenter and others, 1998). Non-point sources of nitrogen and phosphorus in surface waters can be natural or anthropogenic.

Biological fixation of atmospheric nitrogen can be a substantial input of nitrogen to a watershed and, thus, into a stream. Biological fixation occurs in naturally occurring plants, but the vast majority of nitrogen fixation occurs with cultivated crops.

Atmospheric deposition can also be a significant source of nitrogen for a watershed. The estimates of atmospheric deposition of nitrogen are fairly uniform across the Study Unit at about 1.5 tons per square mile per year (tons/mi^2)/yr (Puckett, 1994); however, estimates for several counties in southeastern Arkansas are greater than 1.8 (tons/mi^2)/yr. Atmospheric deposition contributes about the same amount of nitrogen to the Study Unit as point sources (fig. 9). Estimates of the atmospheric deposition of phosphorus are not commonly reported in published literature. A study conducted in 1977-78 in the northeastern part of the Yazoo River Basin gave an estimate of the annual phosphorus deposition of 0.031 (tons/mi^2)/yr (McClurkin and others, 1987), which is close to the worldwide average of 0.029 (tons/mi^2)/yr given by Meybeck (1982). There is no natural source of phosphorus in the atmosphere, and the phosphorus found in the atmosphere usually is attached to dust particles. In an agricultural area such as the MISE Study Unit where phosphorus is applied to the land surface as a fertilizer, the deposition of phosphorus by rainfall and dry fallout probably is balanced by wind erosion of phosphorus attached to dust particles so that there is no net gain in phosphorus to the land surface from atmospheric deposition.

An important input of nitrogen and phosphorus to an agricultural or urban watershed is in application of these elements as fertilizer (fig. 9c and d). The data shown in figure 9c and d are estimates of nitrogen and phosphorus application as fertilizer, by county, in the MISE Study Unit for July 1, 1990 to June 30, 1991 (Battaglin and Goolsby, 1995). The input of nitrogen and phosphorus to a watershed in the Study Unit from the application of both as fertilizer is much larger than the input from point sources. However, how this affects nitrogen and phosphorus concentrations in surface water is not clear because point sources generally are discharged directly into a stream, whereas the application of nitrogen and phosphorus as fertilizer occurs in small amounts over large areas and requires force (wind or water) to move offsite into a water body.

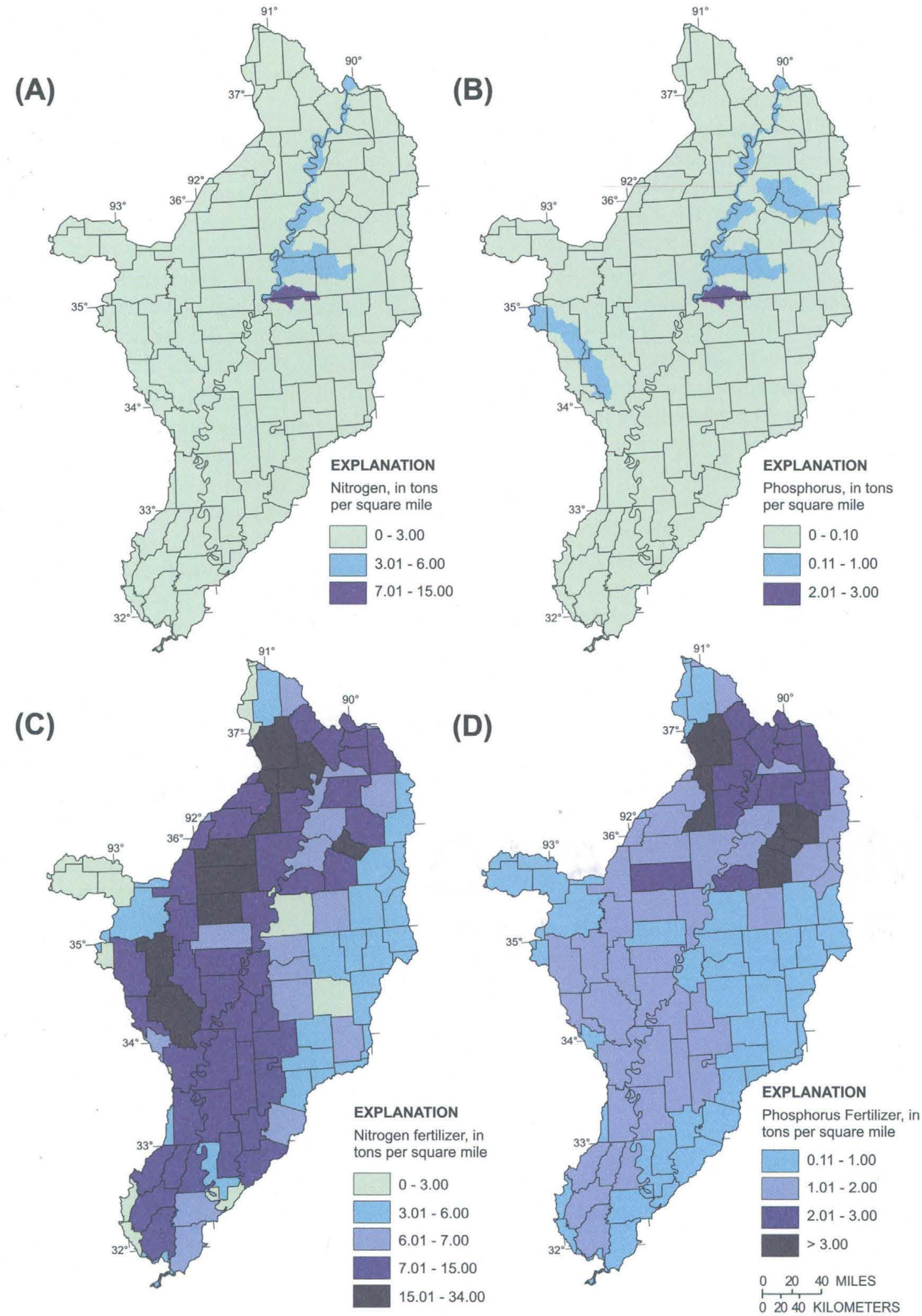

Figure 9. Estimated 1996 municipal and industrial point source inputs of nitrogen (A) and phosphorus (B), by 8-digit hydrologic unit code, and 1991 estimated amounts of nitrogen (C) and phosphorus (D) applied as fertilizer to agricultural fields, by county, in the Mississippi Embayment Study Unit.

CONCENTRATIONS OF NITROGEN AND PHOSPHORUS

Statistical descriptions of the distributions of nitrogen and phosphorus concentrations for the fixed sites are listed by sampling site in appendix I. The forms of dissolved nitrogen measured included nitrite, nitrite plus nitrate, ammonia, and ammonia plus organic nitrogen. Total ammonia plus organic nitrogen concentration was combined with the nitrite plus nitrate nitrogen concentrations to calculate the total nitrogen concentration. Three forms of phosphorus were measured for this study: dissolved phosphorus, orthophosphate, and total phosphorus. Dissolved phosphorus includes the orthophosphate form and other forms of dissolved phosphorus. However, it is clear from the data in appendix I and II that nearly all of the dissolved phosphorus (in some cases the median concentration of orthophosphate is slightly higher than the median concentration of dissolved phosphorus) is in the orthophosphate form; henceforth, only total phosphorus, referred to as phosphorus, and orthophosphate will be included in the discussion.

Nitrogen

Total nitrogen concentrations were significantly different among streams (fig. 10), and the streams can generally be divided into three tiers based on concentration and land use. The first tier of streams (multiple comparison groups A and AB)--with the highest median concentrations--included the Bogue Phalia, Fletcher Creek, the Tensas River, and the Cache River at Egypt. The land use for the Bogue Phalia, the Tensas, and the Cache Rivers is almost exclusively agricultural, but Fletcher Creek is an urban stream. The second tier of streams (multiple comparison groups BC and C)—with intermediate median nitrogen concentrations—included the two streams that have drainage basins with mixed land uses, the Yazoo River and the Cache River at Cotton Plant. The third tier (multiple comparison groups DE, and E)—with the lowest median nitrogen concentrations—included the Skuna and Wolf Rivers, the two streams that were located in the uplands of the Study Unit. It is noteworthy that the Little River Ditch 1, (multiple comparison group CD) which also drains an agricultural catchment, does not fit into the above tiers with a median nitrogen concentration less than that of the large river sites and just above that of the two upland sites. The Little River Ditch 1 median nitrogen concentration was significantly lower than that in the other agricultural streams. The reasons for this difference are not immediately clear.

The two highest nitrogen concentrations measured during this study were from the Tensas River and the Bogue Phalia, 10 and 6.7 mg/L, respectively. Both of these samples were collected in spring 1997. The majority of the nitrogen was in the nitrate form, 4.4 and 8.3 mg/L, respectively. The sample collected from the Tensas River had the highest nitrate concentration measured during this study. No surface-water sample collected for this study exceeded the drinking-water MCL of 10 mg/L of nitrate as N.

In most aquatic systems nitrite is unstable, so the nitrite plus nitrate is virtually all nitrate. This can be seen in the data from appendix I as the median nitrite concentration is less than 10 percent of the median nitrite plus nitrate concentration. Median nitrite as N concentrations were below the reporting level of 0.01 mg/L for the Wolf, Cache, and Skuna Rivers and were less than 0.03 mg/L for the other streams. The highest maximum concentrations were in the Tensas River and the Bogue Phalia.

The nitrate concentrations are not easily classed by land use. The three streams with the highest median nitrate concentrations include one of the agricultural streams, the Bogue Phalia; the urban stream, Fletcher Creek; and one large stream, the Yazoo River. With the exception of the Skuna River, median nitrate concentrations for most of the other steams were not significantly different from each other. Nitrate concentrations were significantly lower in the Skuna River than in any other stream sampled in this study.

Median ammonia as N concentrations ranged from less than the reporting level of 0.020 to 0.07 mg/L (data not shown). Ammonia concentrations varied with land use, with the highest median concentration in the urban stream, Fletcher Creek, followed by the agricultural streams: the Tensas, Bogue Phalia, Little River Ditch 1, and the Cache River at Egypt. The lowest median ammonia concentration was in the Wolf River, which drains a primarily forested basin. The maximum concentration of ammonia at all sites did not exceed 0.6 mg/L, which is well below the USEPA aquatic life criteria based on the pH of these streams.

There is a general pattern of increasing nitrogen concentrations with increasing streamflow, although for most sites the relation is not well defined. For example, at the urban stream, Fletcher Creek, the concentra-

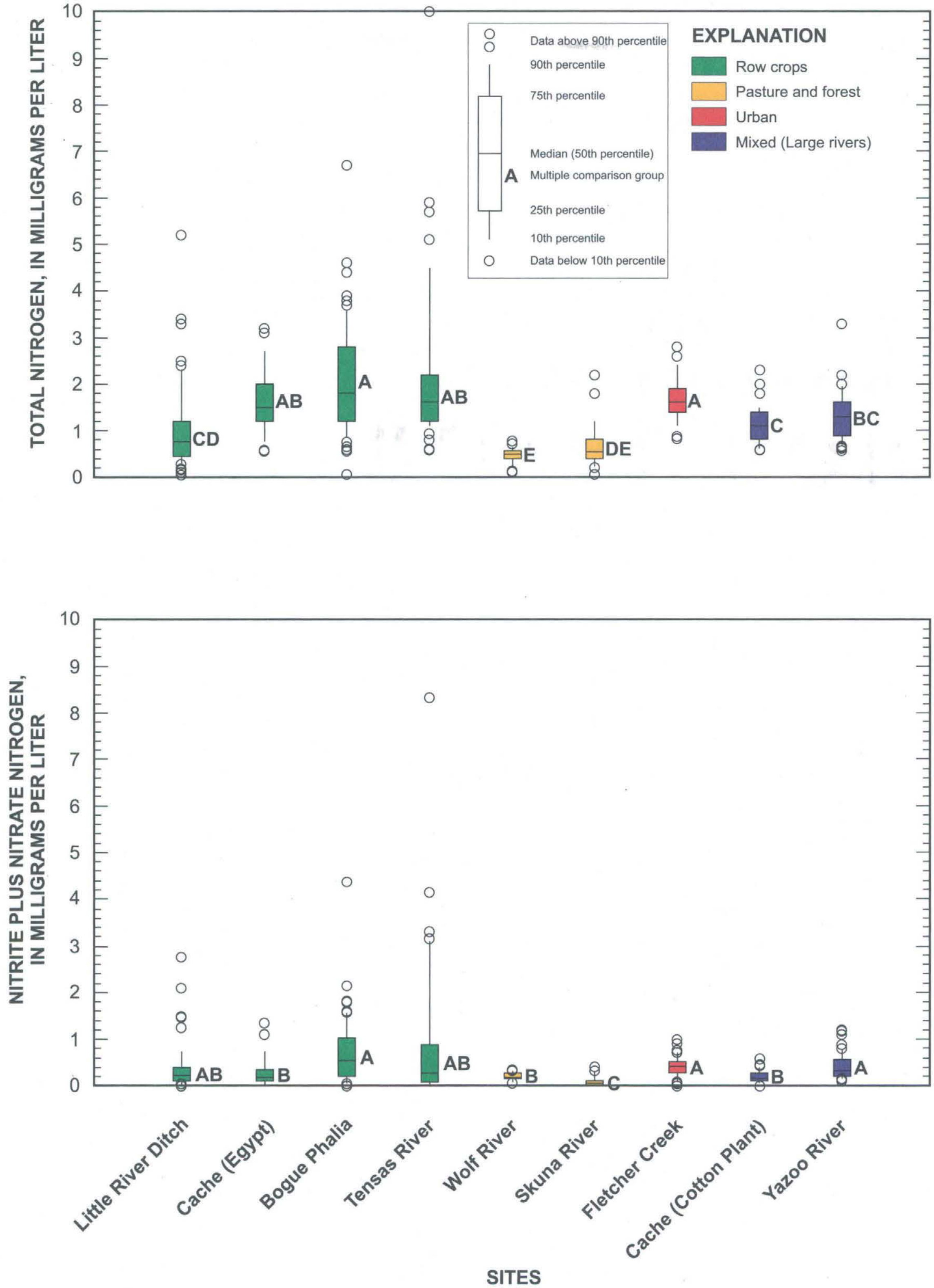

Figure 10. Distribution of total nitrogen and nitrite plus nitrate concentrations at nine sampling sites in the Mississippi Embayment Study Unit.

tion of nitrogen is usually about 1.5 mg/L although streamflow can change by several orders of magnitude (11a). For the streams that drain agricultural areas such as the Bogue Phalia (11b), there is a slight increase in nitrogen as streamflow increases. The exception is the Little River Ditch where there is a marked increase in nitrogen with increasing streamflow (11c). The distribution of nitrogen versus streamflow at Little River Ditch resembles a step function in that the concentrations are very low (about 0.02 mg/L) when the streamflow is less than about 100 ft^3/s, but as soon as the streamflow increases, the concentration of nitrogen rises to about 1.0 mg/L. This is a likely indication that the stream is receiving runoff from agricultural fields.

The relation between nitrate (a component of total nitrogen) concentrations and streamflow is much more complex than the relation for nitrogen and streamflow. The general relation of increasing nitrate concentrations with increasing streamflow only exists for a few streams in the Study Unit. At some streams there is an inverse relation between nitrate concentrations and streamflow, and at others there is a hybrid relation where nitrate concentration increases with increasing streamflow until the readily available nitrate is depleted, and then nitrate concentrations decrease as streamflow continues to increase. Of particular interest are the relations between nitrate concentrations and streamflow for the four streams draining agricultural land—the Bogue Phalia, the Cache River at Egypt, the Little River Ditch, and the Tensas River. The relation of nitrate concentration with streamflow shown for the Little River Ditch (fig. 12a) is an illustration of how dissolved nutrient concentrations typically change with streamflow (Muller, 1995). Nitrate is flushed from the soils, and the concentration increases as the streamflow increases. For the Bogue Phalia, the Cache River at Egypt, and the Tensas River, the relation between nitrate concentrations and streamflow is either an inverse one, as in the Cache River (fig. 12b), or one that shows an increase in nitrate concentrations with streamflow, but then changes to an inverse relation—as the streamflow continues to increase, nitrate concentrations decrease (figs. 12c & d). This can be attributed to dilution as the source of nitrate is depleted after the readily available nitrate is flushed from the soils.

The highest median monthly nitrogen and nitrate concentrations were in the streams with predominantly agricultural land use and occurred during the spring and early summer (fig. 13a and c). This corresponds with the planting season and application of fertilizers to agricultural fields. The streams with the most distinct seasonality in the nitrogen and nitrate concentrations were the Tensas River and the Bogue Phalia. These two streams and Fletcher Creek had the highest median concentrations of nitrogen. The urban stream and the two upland streams (Fletcher Creek and the Wolf and Skuna Rivers) showed very little seasonality in mean monthly nitrogen or nitrate concentrations (fig. 13b and d). The two streams that drain mixed land use (the Yazoo River and the Cache River at Cotton Plant) showed a moderate amount of seasonality, but the range of concentrations was smaller than for the agricultural sites (fig. 13b and d).

Phosphorus

The majority of the total phosphorus concentration (suspended plus dissolved) is composed of suspended phosphorus (appendix I). Suspended phosphorus includes phosphorus that is sorbed to suspended sediment and phosphorus that is incorporated into algal cells and other organic matter. The highly turbid nature of the streams in the Study Unit limits light penetration and the associated algal growth; therefore, most of the suspended phosphorus is probably associated with the sediment (Anonymous, 1987).

Median phosphorus concentrations were significantly different among sites (fig. 14), and the streams can generally be divided into the same three tiers as they were for nitrogen, based on median concentration and land use. However, demarcations for median phosphorus concentrations are not as clear as with median nitrogen concentrations. The first tier streams with the highest median phosphorus concentrations (multiple comparison groups A, AB, ABC, and BCD) were the urban stream, Fletcher Creek, and three streams draining agricultural land, the Tensas River, the Bogue Phalia, and the Cache River at Egypt. The phosphorus concentration from Fletcher Creek was significantly higher than the concentrations in all other streams except for the Tensas River and the Bogue Phalia. Phosphorus concentrations at the two large river sites with mixed land use, the Cache River at Cotton Plant and the Yazoo River, were in the middle tier with intermediate median phosphorus concentrations (multiple comparison groups CD and DE). Median phosphorus concentration was significantly lower in the Little River Ditch (multiple comparison group EF) than in any other agricultural stream and lower than any other stream except for the Skuna and Wolf Rivers. The third

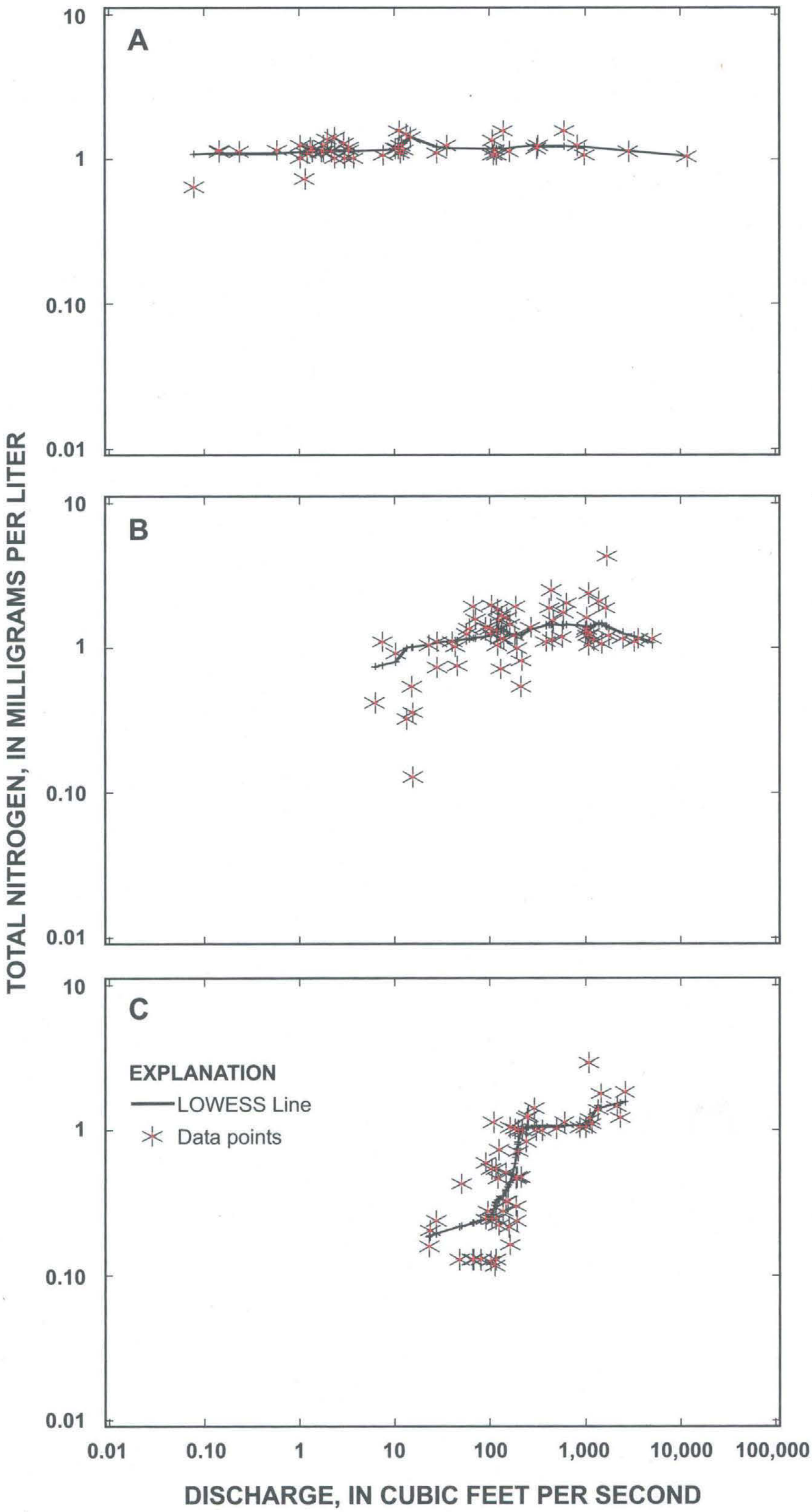

Figure 11. Relation between total nitrogen concentration and streamflow from (A) Fletcher Creek, (B) Bogue Phalia, and (C) Little River Ditch.

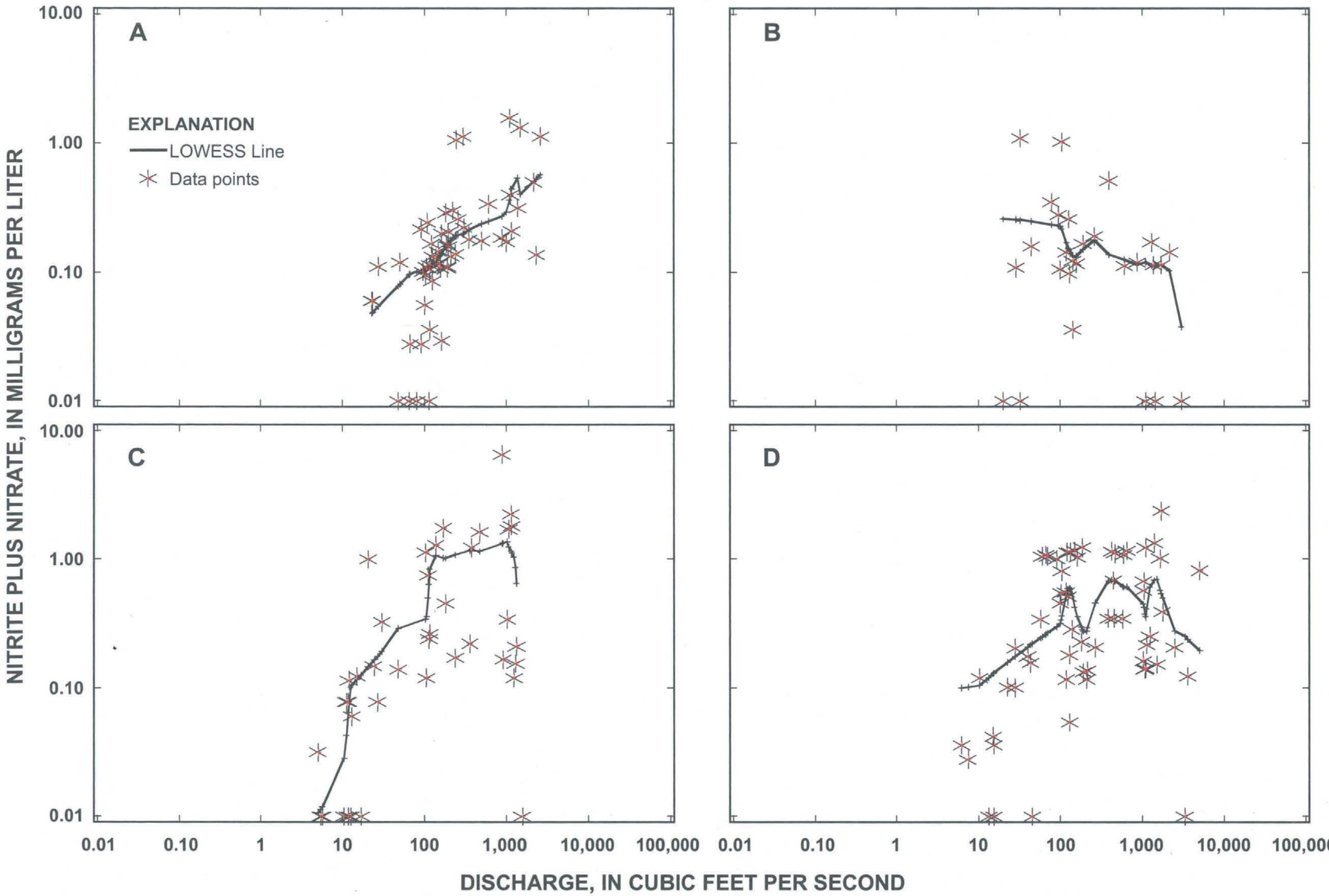

Figure 12. Relation between nitrite plus nitrate concentrations and streamflow from (A) Little River Ditch, (B) Cache River at Egypt, (C) Tensas River, and (D) Bogue Phalia.

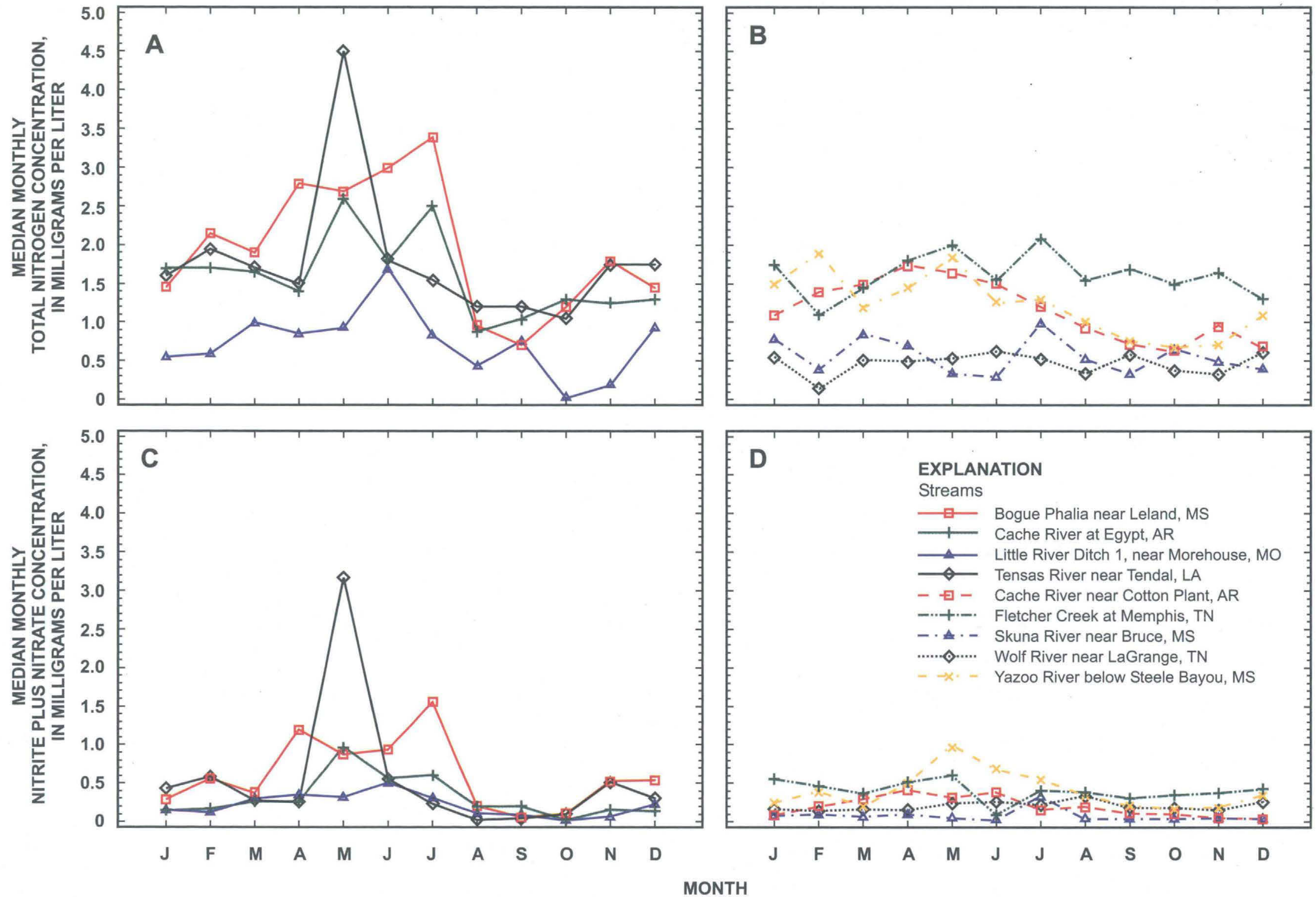

Figure 13. Median monthly total nitrogen and nitrite plus nitrate concentrations from streams draining predominantly agricultural land use (A and C) and streams draining urban or mixed land use (B and D).

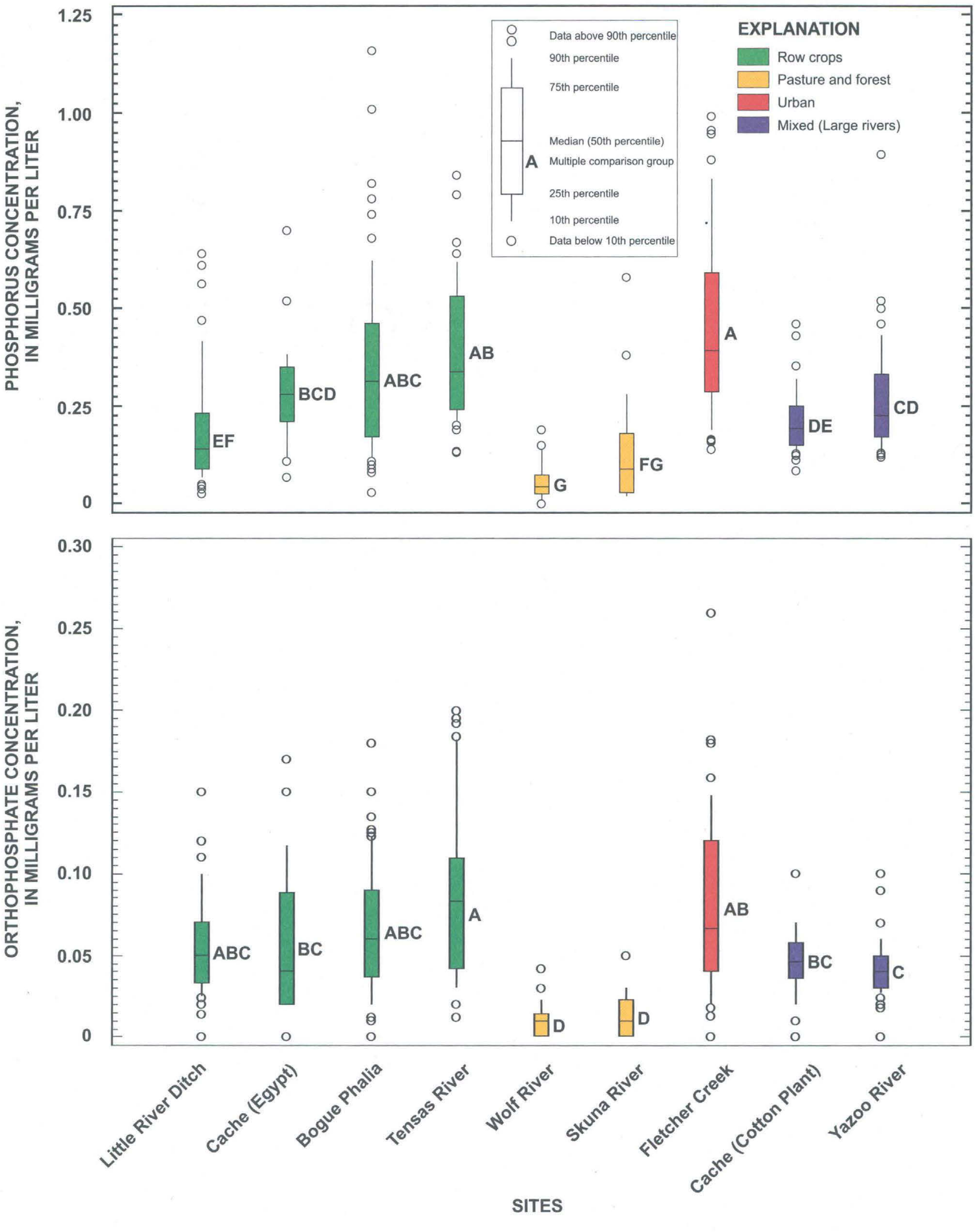

Figure 14. Distribution of total phosphorus and orthophosphate concentrations at nine sampling sites in the Mississippi Embayment Study Unit.

tier with the lowest phosphorus concentrations were the Skuna and Wolf Rivers (multiple comparison groups FG and G); phosphorus concentrations were significantly lower in the Wolf River than in all other streams except the Skuna River.

Median phosphorus concentrations ranged from 0.050 to 0.390 mg/L and exceeded the 0.1-mg/L USEPA maximum recommended goal for flowing waters at every site except for the Skuna and the Wolf Rivers. The minimum concentrations for Fletcher Creek, the Tensas, and the Yazoo Rivers exceeded 0.1 mg/L.

Orthophosphate concentrations ranged from the reporting level of 0.01 to 0.26 mg/L in a sample collected from Fletcher Creek. Median orthophosphate concentrations were significantly different among sites. The Tensas River had the highest median orthophosphate concentration, but it was not significantly different than the concentrations for the Bogue Phalia, Little River Ditch, or Fletcher Creek. The median orthophosphate concentration of 0.01 mg/L for the Skuna and Wolf Rivers was significantly lower than the median concentration in any of the other streams (fig. 14). The median orthophosphate concentrations at the other seven sampling sites ranged from 0.040 mg/L for the Yazoo River and the Cache River at Egypt to 0.080 mg/L for the Tensas River.

Phosphorus concentrations in Fletcher Creek, the urban stream, did not vary much with streamflow (fig. 15a). Most of the other streams had a general increase in phosphorus concentrations with streamflow similar to that at the Bogue Phalia (fig. 15b). This is expected as most of the phosphorus in the surface waters of the Study Unit is associated with sediment. The two upland streams, the Skuna and Wolf Rivers, had the most pronounced phosphorus concentration increases with streamflow (fig. 15c and d), probably because the median concentrations in the Skuna and Wolf Rivers generally were low compared to concentrations in the other streams.

There is a slight increase in the median monthly phosphorus concentration during the spring for the agricultural streams, but it is not nearly as distinct as the nitrogen increase, nor does the highest median monthly phosphorus concentration occur in the spring for every site (fig. 16a). The median monthly phosphorus concentration is near the highest or is the highest for the agricultural sites during the winter months when the rainfall and subsequent runoff is at maximum and after the crop has been harvested. This would imply that the movement of sediment and not the application of phosphorus as fertilizer might be more important in controlling the concentration of phosphorus in surface waters. The median monthly phosphorus and orthophosphate concentrations in the Skuna and Wolf Rivers varied little seasonally (fig. 16b and d). Median monthly orthophosphate concentrations increased in the spring in most of the streams in the MISE Study Unit, except for the Skuna and the Wolf Rivers (fig. 16c and d). Additionally, median monthly phosphorus and orthophosphate concentrations in most streams gradually increased throughout the summer and early fall. This increase during the summer months probably reflects the release of orthophosphate from the sediments and the cycling of orthophosphate through biota (Wetzel, 1983).

Spatial Variability

Nitrogen and phosphorus concentrations from the four agricultural streams (the Bogue Phalia, the Cache River at Egypt, Little River Ditch, and the Tensas River) can be used to evaluate the temporal variability in nitrogen and phosphorus concentrations in those streams at the sampling sites. However, characterizing the spatial variability of nitrogen and phosphorus concentrations in all the streams that drain agricultural areas in the Study Unit based on only these four sites is somewhat questionable. The fixed sites were carefully chosen to represent general agricultural land-use characteristics in the Study Unit, but there is no certainty that these fixed sites are representative of the surface-water quality conditions throughout the Study Unit.

Therefore, to better assess spatial variability, water samples were collected from an additional 30 sampling sites in the spring and summer of 1997 and were used to evaluate the spatial variability of nitrogen and phosphorus concentrations in streams draining agricultural areas. These streams were all located in the Mississippi River Alluvial Plain. Statistical analyses of the data indicated that there were differences in nitrogen and phosphorus concentrations among these streams. The land use in the Mississippi River Alluvial Plain is dominated by agriculture, and the type of agriculture changes from east to west and from north to south. Therefore, it is reasonable to subdivide the data into a more homogenous grouping to further evaluate

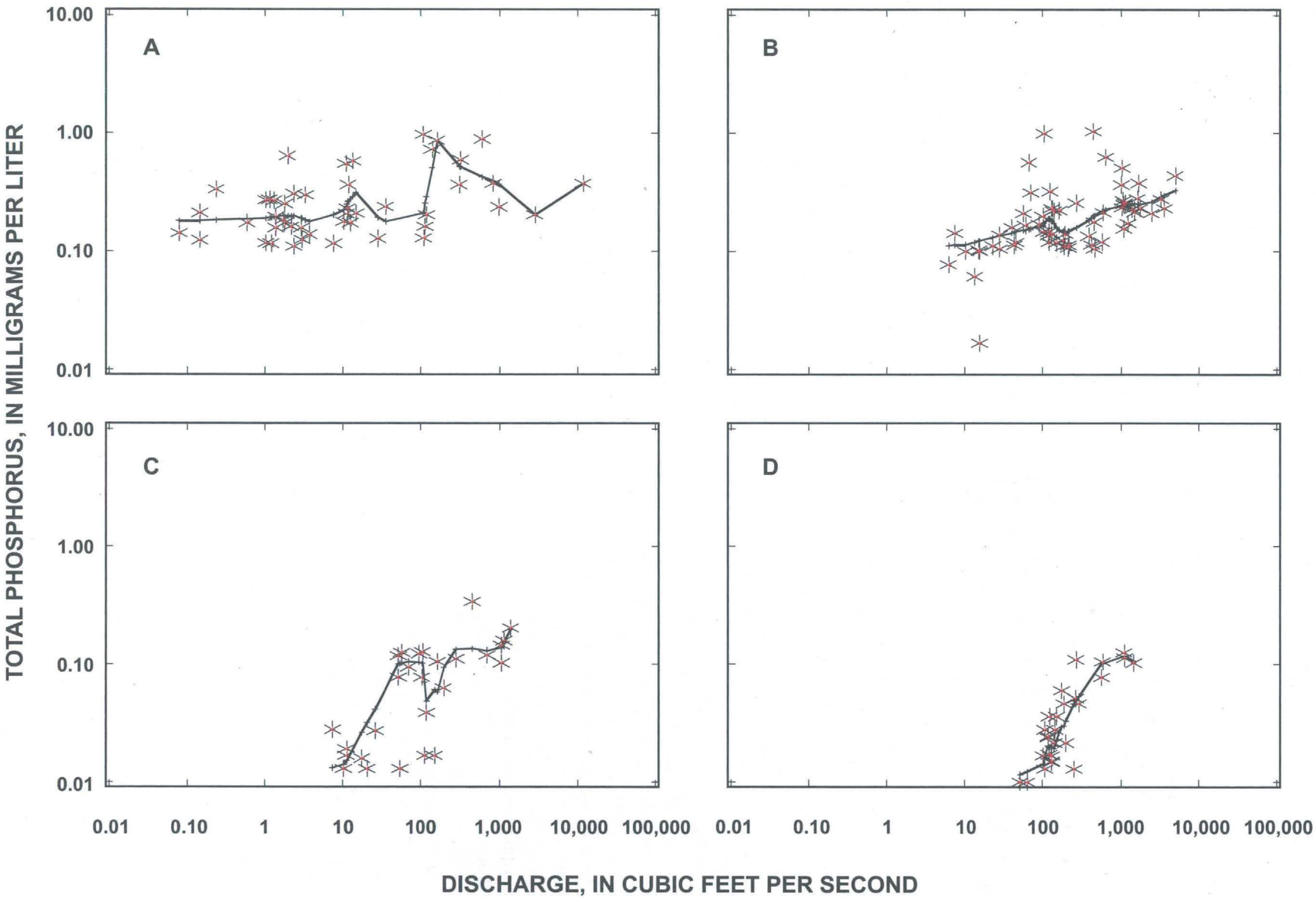

Figure 15. Relation between total phosphorus concentration and streamflow at (A) Fletcher Creek, (B) Bogue Phalia, (C) Skuna River, and (D) Wolf River.

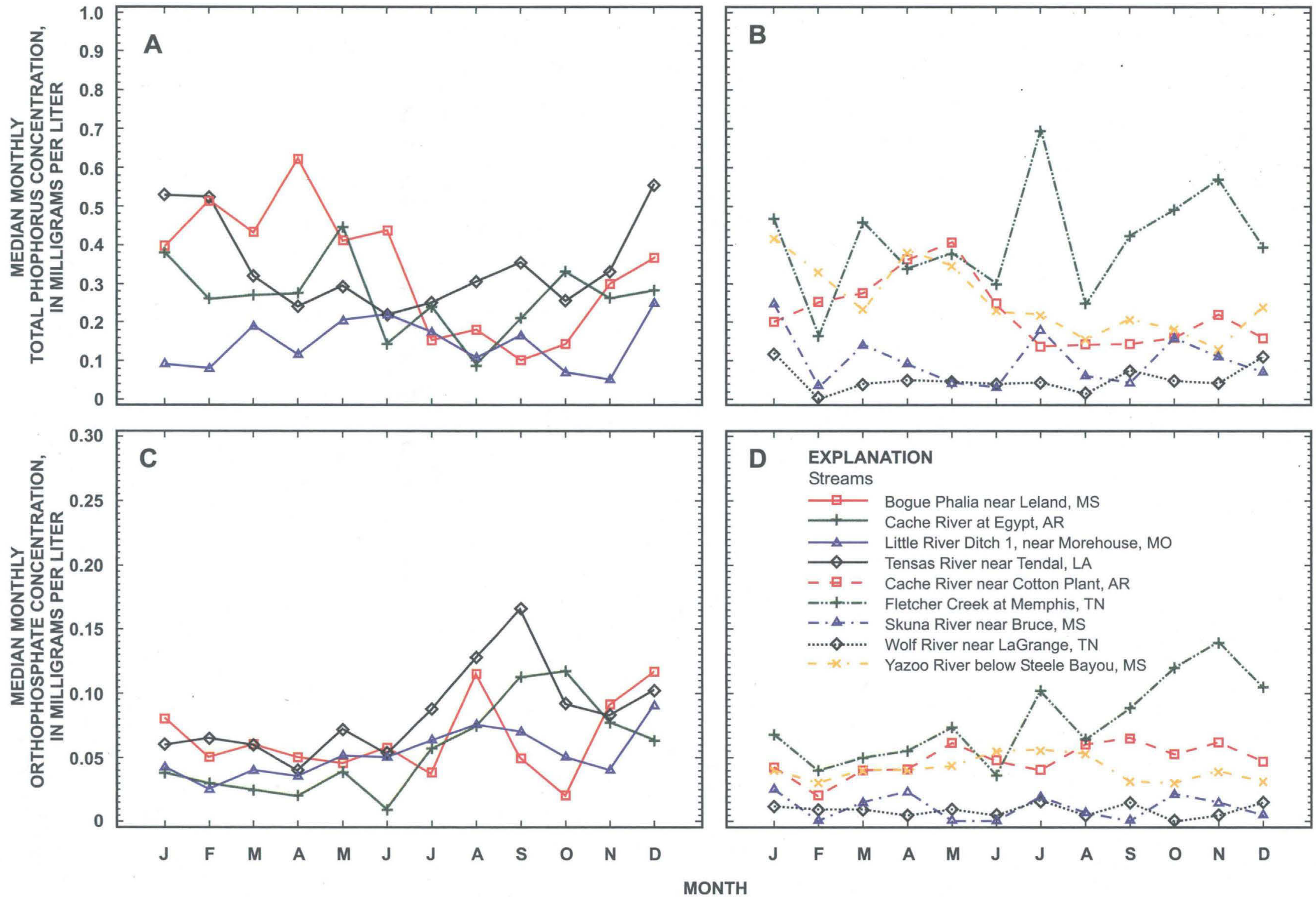

Figure 16. Median monthly total phosphorus and orthophosphate concentrations from streams draining predominantly agricultural land use (A and C) and streams draining urban or mixed land use (B and D).

spatial differences in surface-water quality. A natural division is to group the data according to major drainage basin: the St. Francis, Tensas, White, and Yazoo (fig. 2). Each basin had one fixed site on an agricultural stream that was sampled throughout the entire study (February 1996 – January 1998). Analyzing the data by major basin gives an indication of how well these fixed sites represent water quality from that basin. For this analysis, only the data collected during May-September 1997 were used. The following paragraphs present an analysis in the differences in nitrogen and phosphorus concentrations between major drainage basins, and are followed by an analysis of the differences in nitrogen and phosphorus concentration within each major drainage basin.

Nitrogen and phosphorus concentrations among basins fall into two distinct groupings: the Yazoo and the Tensas River Basins in one group and the St. Francis and the White River Basins in the other. Nitrogen and phosphorus median concentrations in the Yazoo and Tensas River Basins are not significantly different from each other, but are significantly higher than the median concentrations in the St. Francis and White River Basins (fig. 17) and have a much larger range of concentrations. Nitrogen and phosphorus concentration from the St. Francis and White River Basins are not significantly different from each other.

There are no significant differences in nitrogen concentration among streams within the Tensas, White, or Yazoo River Basins. The nitrogen concentrations for the Tensas River, the Cache River, and the Bogue Phalia in the Tensas, White, and Yazoo River Basins, respectively, are not significantly different from nitrogen concentrations from any other stream within their respective basin. However, in the St. Francis River Basin there were some statistically significant differences between the streams with the highest nitrogen concentrations and the streams with the lowest nitrogen concentrations. Nitrogen concentrations in the Little River Ditch in the St. Francis River Basin was the second highest in the basin and significantly higher than the nitrogen concentrations from the two streams in the basin with the lowest nitrogen concentrations.

There are no significant differences in phosphorus concentrations among streams within the St. Francis, Tensas, White, or Yazoo River Basins. The median phosphorus concentrations for the steams with data collected during the entire study are near the highest within their respective basins, except for the Yazoo River Basin, where the median phosphorus concentration in the Bogue Phalia is the lowest. Given that there are few significant differences in the median concentration of nitrogen or phosphorus within basins, this would indicate that the streams where data were collected for the entire study are good representative sites for characterizing the spatial variability in nitrogen and phosphorus concentrations in surface water within their respective basins.

It is not immediately clear why there are differences in median nitrogen and phosphorus concentrations in streams of the White and St. Francis River Basins, compared to streams in the Tensas and Yazoo River Basin. Climate may play a role, as there is more rainfall in the southern part of the Study Unit where the Tensas and Yazoo River Basins are located, than in the northern part of the Study Unit. Cultural practices, such as what crops are planted, change within the Study Unit, and it may be that other practices, such as irrigation and the use of Best Management Practices, may also change throughout the Study Unit. Additionally, geology may be important in explaining differences in water quality throughout the Study Unit. Kleiss and others (2001) showed that there were larger ammonia concentrations in streams, larger DDT concentrations in fish tissue, and a greater number of herbicides reported above the detection level for streams located in Holocene alluvium than for streams located in Pleistocene valley trains. The streams in the Tensas and Yazoo River Basins are mostly located in the Holocene alluvium, and streams in the White and St. Francis River Basins are mostly located in the Pleistocene valley trains.

FLUXES OF NITROGEN AND PHOSPHORUS

The annual flux varied considerably between 1996 and 1997, with the 1997 flux being higher at all sampling sites (table 5), especially in the Yazoo River Basin. This corresponds to 1997 being a wetter year than 1996. To normalize these data in order to compare between streams, the annual fluxes were divided by their respective drainage area to compute yields in tons per square mile per year (table 5).

The urban river, Fletcher Creek, had only one complete calendar year (1997) of data. The flux of nitrogen for 1997 was 169 tons, and the flux of phosphorus was 5.54 tons. The nitrogen and phosphorus yields from Fletcher Creek (table 5) were the highest from any site in the Study Unit. The phosphorus yield was more than twice the yield from any other stream.

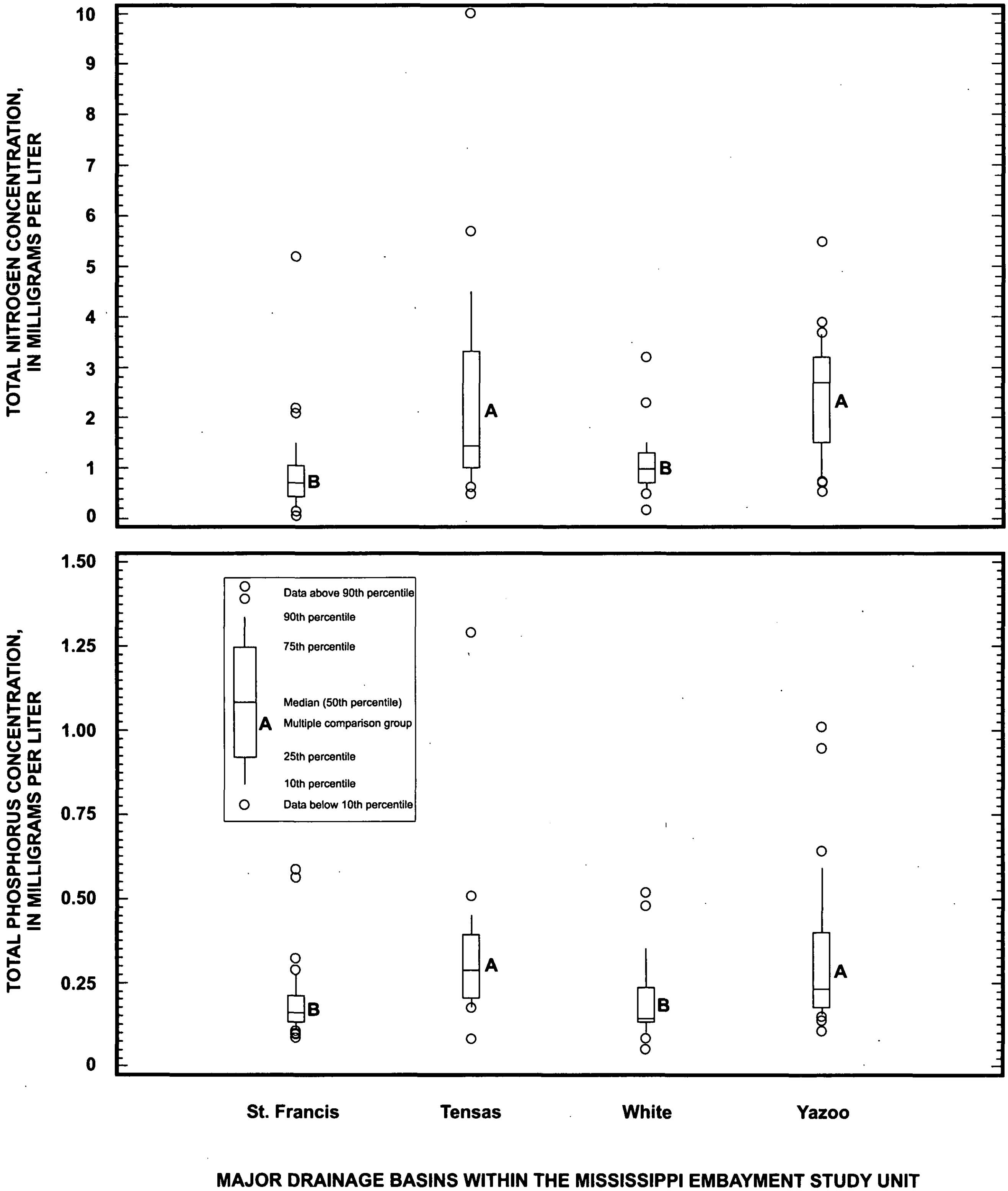

Figure 17. Distribution of total nitrogen and total phosphorus concentrations in four major drainage basins of the Mississippi Embayment Study Unit.

Table 5. Annual fluxes and yields of nitrogen and phosphorus at nine sites in the Mississippi Embayment Study Unit for 1996 and 1997 calendar years

[tons/yr, tons per year; tons/mi^2, tons per square mile; --, not applicable]

Sampling site	Year	Nitrogen flux (tons/yr)	Nitrogen 95 confidence interval	Nitrogen yield (tons/mi^2)	Phosphorus flux (tons/yr)	Phosphorus 95 confidence interval	Phosphorus yield (tons/mi^2)
St. Francis River Basin							
Little River Ditch 1	1996	829	250	1.84	134	38.4	0.297
near Morehouse, MO	1997	1,100	302	2.44	211	62.6	.468
White River Basin							
Cache River at	1996	1,110	250	1.58	258	72.0	.368
Egypt, AR	1997	1,550	395	2.21	286	85.8	.407
Cache River near	1996	1,240	89.8	1.06	253	31.0	.215
Cotton Plant, AR	1997	1,910	133	1.63	359	41.4	.307
North Independent River Basins - Wolf River Basin							
Wolf River near	1996	132	19.0	.628	17.5	7.59	.083
LaGrange, TN	1997	200	26.2	.954	29.9	12.3	.142
Fletcher[1] Creek at Memphis, TN	1997	169	--	5.54	80.5	--	2.64
Yazoo River Basin							
Bogue Phalia near	1996	1,000	196	2.08	225	53.6	.465
Leland, MS	1997	2,120	377	4.39	450	102	.930
Skuna[1] River near	1996	392	--	1.54	101	--	.396
Bruce, MS	1997	693	--	2.73	161	--	.635
Yazoo River below	1996	20,100	2,940	1.49	3,790	666	.283
Steele Bayou, MS	1997	35,800	4,760	2.67	8,000	1,270	.597
Tensas River Basin							
Tensas River near	1996	680	149	2.20	96.0	16.8	.311
Tendal, LA	1997	1,210	218	3.93	253	44.2	.819

[1] Loads were estimated by multiplying the flow-weighted mean concentration by the total annual flow.

The large flux of nitrogen and phosphorus from Fletcher Creek is due, in part, to the tremendous amount of runoff from the basin, as well as the high nitrogen and phosphorus concentrations relative to those at other sampling sites. In 1997, estimated runoff from the Fletcher Creek Basin was more than 57 inches (Flohr and others, 1999), very near to the estimated total amount of rainfall for the basin. The steep slopes of the area, the channelization of Fletcher Creek, and the large amount of impervious surface from urban development account for the large amount of runoff.

Of the four sites representing agricultural land use in the Mississippi River Alluvial Plain (Little River Ditch, Cache River at Egypt, Bogue Phalia, and Tensas River), the Bogue Phalia had the highest nitrogen and phosphorus yields, followed closely by the Tensas River. The Little River Ditch and Cache River at Egypt streams had considerably lower yields than the other agricultural streams. This was especially true during 1997, the wetter year, when the yields in the Bogue Phalia and Tensas River were much higher than during 1996. The Skuna and Wolf Rivers, two streams in the uplands of the Gulf Coast Province, had very dissimilar yields, with the Skuna River having more than twice the yield of nitrogen and more than four times the yield of phosphorus as the Wolf River. This is somewhat surprising as the median nitrogen and phosphorus concentrations at these two sites were the lowest in the Study Unit and not significantly different from each other. This difference is probably due to the fact that the Wolf River has not been channelized as extensively as the Skuna River, resulting in much more runoff in the Skuna River Basin (35.85 inches for 1997) compared to the Wolf River Basin (23.95 inches for 1997).

The Tensas River at Tendal, Louisiana, sampling site was part of the USGS National Stream Quality Accounting Network (NASQAN) from 1975 to 1993, and many researchers have used these data. Smith and others (1982) indicated that the mean daily load of phosphorus was 0.52 ton/d and that there was no significant trend in concentration or transport for the period 1975 to 1979. The 0.52 ton/d calculated by Smith and others (1982) is very close to the 0.48 ton/d average of the 1996 and 1997 data from this study. Gilbert (1993) analyzed the NASQAN data for the period 1980-89 and indicated that there was no significant trend in nitrate concentrations in the Tensas River. The Louisiana Department of Environmental Quality has also collected water samples from the Tensas River at Tendal. Creasman and others (1993) analyzed these data and indicated that for the period 1978-92 there was no significant trend for phosphorus concentrations, but there was a significant decreasing trend for total ammonia and organic nitrogen concentrations.

Measuring the Yazoo River at high flow.

Goolsby and others (1999), using similar methods as were used in this report and using NASQAN data collected during 1980-96, reported the average annual yield of nitrogen and phosphorus from the Yazoo River as 1.72 and 0.34 tons/mi^2, respectively. The average annual yield of nitrogen and phosphorus for data collected from the MISE NAWQA in 1996 and 1997 was 2.08 and 0.44 tons/mi^2, respectively. The results from the MISE NAWQA are close to those from the NASQAN, but slightly higher. These higher results may be a result of the climatic differences between the two time periods, or the fact that Goolsby did not have continuous streamflow data available for the calculations, or that the NASQAN data were collected upstream from the MISE NAWQA sampling site and excluded about 10 percent of the flow from the Delta part of the Yazoo River Basin.

The yield of material (for example, sediment, nitrogen, phosphorus) has been shown to be dependent upon many different aspects of a basin including size, geometry of the basin, population density, geology, and land use. The suspended sediment concentration in a stream has been shown to be directly proportional to the percentage of cultivated land in the basin (Ahl, 1988) and the yield of suspended sediment was shown to decrease more than sevenfold as the basin size increased from 10 mi^2 or less to greater than 1,000 mi^2 (Gottschalk, 1964). Because much of the nitrogen and phosphorus in surface water is attached to suspended particles, it might be expected that the yields of nitrogen and phosphorus for the smaller basins shown in table 5 might be higher than those for the larger basins.

The Yazoo River Basin, which includes the Bogue Phalia and the Skuna River, had a smaller estimated nitrogen and phosphorus yield than either the Bogue Phalia or the Skuna River (table 5). The lower yield estimates for the Yazoo River Basin are due, in part, to the factors discussed in the preceding paragraph and also probably reflect the larger variety of land uses in the Yazoo River Basin as opposed to the homogenous land use of the Bogue Phalia Basin (86 percent agriculture) or the almost equally mixed land use of the Skuna River Basin (46 percent forest and 51 percent agriculture). The Skuna River flows directly into Grenada Lake downstream of the sampling site before flowing into the Yazoo River. The slow velocities in the almost flat Delta and Grenada Lake probably allow some suspended material to settle to the streambed.

Nitrogen and phosphorus yields were lower at the downstream sampling site on the Cache River at Cotton Plant than at the upstream site at Egypt (table 5). The Cache River has been intensively studied because one of the last remaining tracts of bottomland hardwoods in the Alluvial Plain is in the Cache River Basin and because there is a need to study the functions of wetlands in a riverine system. Nutrient data collected from several sites on the Cache River during the 1970's and 1980's were statistically analyzed and tested for changes in concentrations over time (Petersen, 1988, 1990, 1992). These data were inadequate to determine changes in the quality of the Cache River along the stream length. However, these data did indicate that the highest median and mean concentrations of phosphorus and ammonia occurred at the farthermost upstream sites; whereas, the median and mean concentrations of nitrate appeared to increase slightly in a downstream direction. Data from the MISE study showed that there was a significant difference in nitrogen concentrations at the two Cache River sampling sites, with the upstream site (Egypt) having higher concentrations. However, there was not a significant difference for nitrate, phosphorus, or orthophosphorus. In a study sponsored by the USACOE, the bottomland hardwood forested wetland (the Black Swamp) located just upstream of the Cotton Plant sampling site, was shown to remove 21.4 percent of the nitrogen and 3 percent of the phosphorus carried by the Cache River (Dortch, 1996). The mechanisms involved included denitrification and burial. The MISE data are not adequate to determine if the forested wetland is affecting water quality or whether the reduction in yield is due to other factors.

In order to put into perspective the yields calculated from the Study Unit, they can be compared to yields of nitrogen and phosphorus for other drainage basins within the Mississippi River Basin. Goolsby and others (1999), using NASQAN data collected from 1980 through 1996, calculated the yields of nitrogen and phosphorus from 42 basins within the Mississippi River Basin. These 42 basins do not represent a statistical sampling of the Mississippi River Basin; however, they cover the full range of land uses and population density in the Mississippi River Basin and provide a good spatial representation of the entire basin. The aggregate drainage areas of these 42 basins account for about 70 percent of the entire Mississippi River Basin. These 42 basins include two basins within the MISE Study Unit, the St. Francis River Basin and the Yazoo River Basin.

Although the yield data for the 42 NASQAN basins represent an average annual yield of up to 17 years of data (1980-96) and the MISE data are annual yields for 1996 and 1997, it is still instructive to compare the data. The annual yields of nitrogen from basins in the MISE Study Unit generally occupy the middle third of the distribution of average annual yields over the entire Mississippi River Basin (fig. 18). Basins in the Ohio and Middle Mississippi River Basins have the highest yields. These basins are located in Iowa, Illinois, Indiana, and Ohio, an area known as the "Corn Belt," and have large percentages of land use in corn and soybean. The lowest nitrogen yields are in the drier western part of the Missouri River Basin and the colder Upper Mississippi River Basin.

The yields of phosphorus from the MISE Study Unit are among the highest in the Mississippi River Basin (fig. 19). This was unexpected as the amount of phosphorus contributed from point sources is low and there is much less phosphate used as fertilizer in the MISE Study Unit compared to that used in the Midwest (Battaglin and Goolsby, 1995). Goolsby and others (1999) described similar results from data collected from 1980 through 1996 for several sites located in the MISE Study Unit. Ambient soil phosphorus concentrations do not appear to be elevated in the Study Unit in comparison to concentrations in the Midwest (Shacklette and Boerngen, 1984; Sharpley and others, 1994). The mean phosphorus concentrations from rivers in the Midwest (based on NASQAN data) are about the same or a little higher than concentrations from streams in the MISE Study Unit. The increased yields are probably due to several factors, including increased precipitation and corresponding runoff in the Study Unit, and the process of enrichment, whereby the concentration of phosphorus on the eroded material, due to its high clay and organic matter content, is higher than the concentration of phosphorus in the source soil (Sharpley and others, 1994). In a 6-year study on an approximately 50-acre field planted in continuous cotton, the phosphorus yield was more than 5.5 tons/mi^2, although no phosphorus fertilizer had been applied to this field during the study (McDowell and others, 1989). The phosphorus enrichment ratio (phosphorus on sediment/phosphorus in soil) was 1.4.

Improved drainage of agricultural fields is needed and has been a principal land-management practice for growing most crops in the MISE Study Unit (Bengston and others, 1995), for the entire southeastern United States (Thomas and others, 1995), and for much of the fertile soils in Iowa, Illinois, and Indiana (Skaggs and others, 1994). Most of the counties in the Study Unit and in the Midwest have more than 40 percent of their land artificially drained (U.S. Department of Commerce, 1981). In the southeastern United States the need for improved drainage is due to the large amount of rainfall, along with low soil permeability and the flat topography that results in poor natural drainage conditions. These factors lead to an additional hypothesis that may explain why there are larger total phosphorus yields but lower nitrogen yields in the Study Unit than in the Midwest. The yields may be related to the ratio of surface to subsurface drainage in the Study Unit compared to the Midwest. While there is a significant amount of artificial drainage in both the MISE Study Unit and in the Midwest, there is virtually no subsurface drainage in the Study Unit or in the southeastern United States (Bengston and others, 1995; Thomas and others, 1995). Much of the drainage in the Midwest is subsurface drainage.

Artificial drainage has been shown to affect water quality in several ways depending upon the type of drainage: surface or subsurface. Increasing the intensity of surface drainage of agricultural fields has been shown to increase edge-of-field peak runoff rates and, consequently, to increase the amount of phosphorus, sediment, and organic nitrogen moved from agricultural fields. Conversely, increasing the intensity of subsurface drainage decreases peak runoff rates and, subsequently, the amount of sediment and phosphorus moved from agricultural fields, but also increases the amount of nitrate nitrogen moving off of agricultural fields (Skaggs and others, 1994). This increase in the amount of nitrate moved from agricultural fields has been attributed to an increase in the nitrification rate as the water moves through the oxygenated soil profile to the subsurface drainage, and also to a decrease in the denitrification rate because of greater water table depths due to drainage (Skaggs and others, 1994). Because phosphorus generally is associated with sediment particles, the reduction in the amount of overland runoff through the use of subsurface drainage would naturally reduce the amount of phosphorus that is moved from an agricultural field.

More study is needed to determine which of these factors (ambient soil concentrations, increased precipitation, enrichment, or surface drainage) has the most important role in the high phosphorus yields from the Study Unit, or if there are other factors which have not been enumerated here.

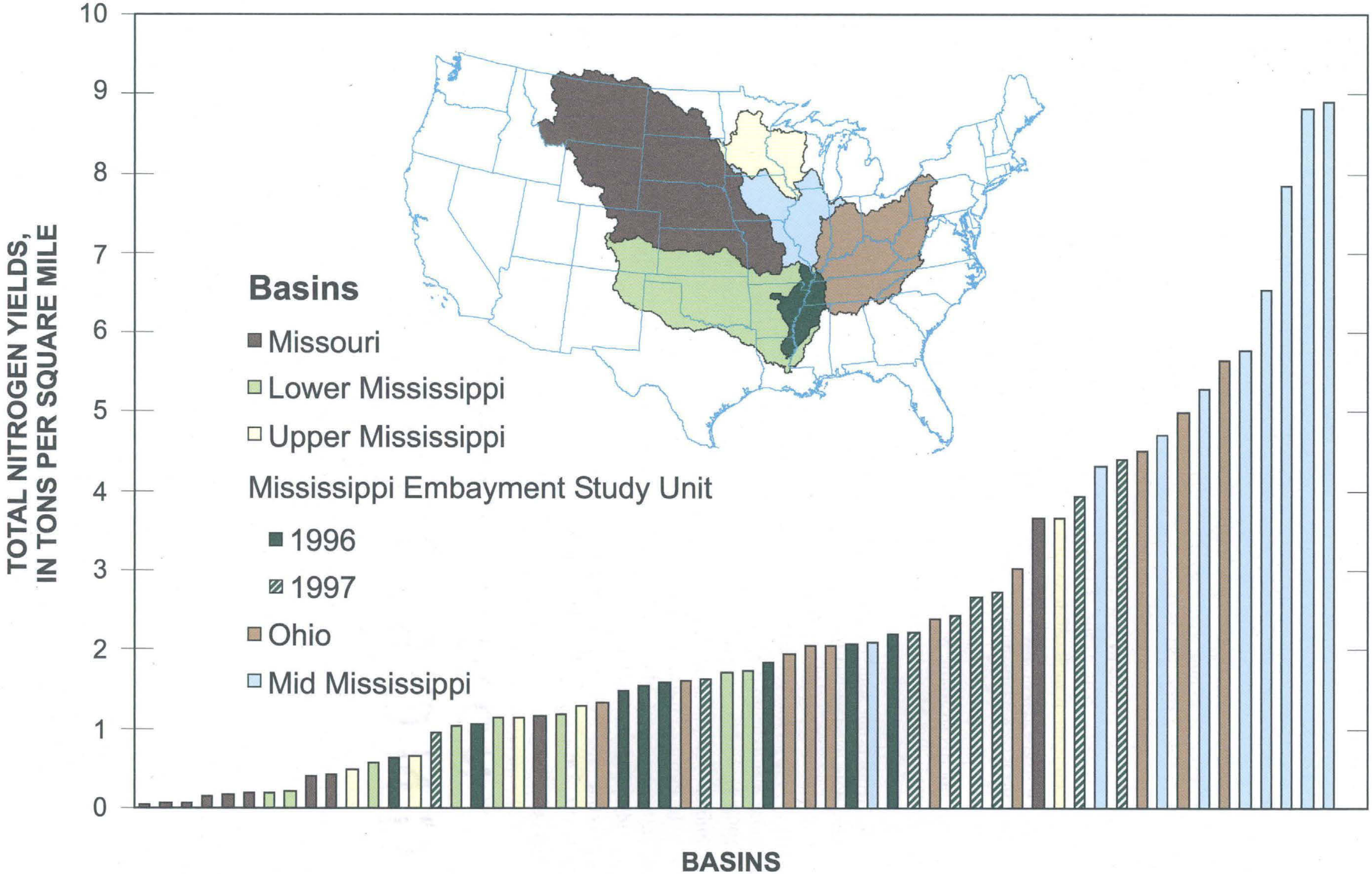

Figure 18. Average annual total nitrogen yields during 1980-96 for 42 NASQAN basins within the Mississippi River Basin and the annual average total nitrogen yields for 8 basins in the Mississippi Embayment Study Unit for 1996 and 1997.

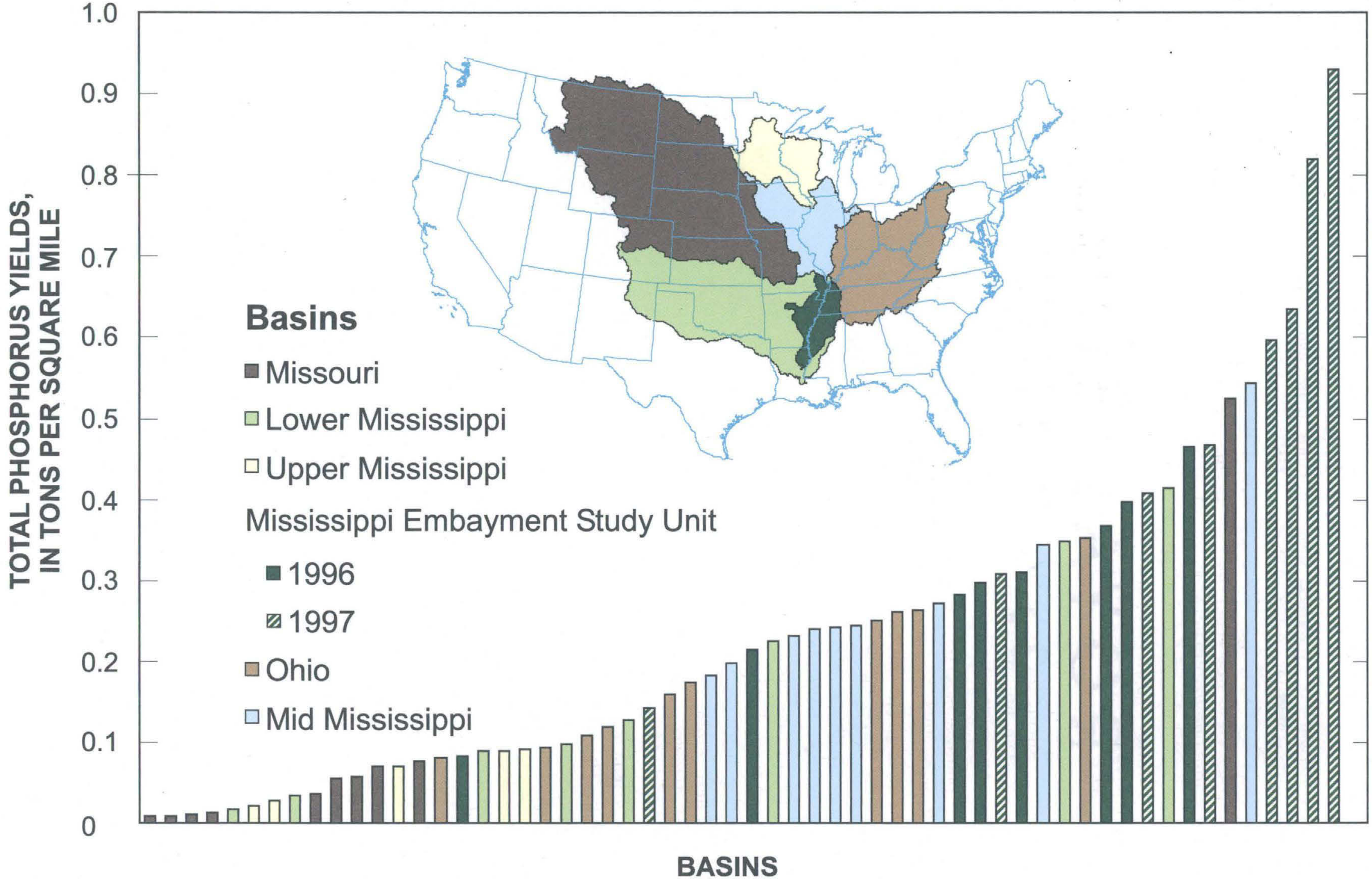

Figure 19. Average annual total phophorus yields during 1980-96 for 42 NASQAN basins within the Mississippi River Basin and the annual average total phophorus yields for 8 basins in the Mississippi Embayment Study Unit for 1996 and 1997.

SUMMARY

In 1994, the U.S. Geological Survey, through its National Water-Quality Assessment Program, began an assessment of water quality in the Mississippi Embayment Study Unit. The Study Unit is an area rich in agricultural resources with a warm, humid climate, and a long growing season, and is one of the most agriculturally productive areas in the world. The major crops grown in the Study Unit are corn, cotton, rice, and soybean. Excessive amounts of nitrogen and phosphorus can adversely affect surface-water quality through eutrophication and toxicity to aquatic life. As part of the overall assessment of water quality, more than 400 water samples were collected from 35 streams and analyzed for nitrogen and phosphorus concentrations from February 1996 through January 1998.

Nine sampling sites on eight streams were sampled, from monthly to weekly, and included four streams draining primarily agricultural watersheds, two streams with small watersheds with mixed agriculture and forest land use, one stream with a small urban watershed, and two large rivers with mixed land use: row crop agriculture, pasture, forest, and urban. Those rivers draining primarily agricultural watersheds were the Cache River at Egypt, Arkansas; the Little River Ditch 1 located in southeastern Missouri; the Tensas River in northeastern Louisiana; and the Bogue Phalia in west-central Mississippi. The urban stream was Fletcher Creek, located in a rapidly developing area of Memphis, Tennessee. The large streams were the Yazoo River that drains the relatively flat and heavily agricultural Mississippi Delta and the uplands area of mostly small farms, forest, and pasture and the Cache River downstream of the Black Swamp. An additional 30 sampling sites on 27 streams were sampled three times during the 1997 growing season to determine the spatial variability of nutrient concentrations in streams of the Study Unit.

The highest median nitrogen concentrations were from three of the four streams draining agricultural lands (the Bogue Phalia and the Cache and Tensas Rivers) and the stream draining the urban watershed (Fletcher Creek) in Memphis, Tennessee. The median nitrogen concentration from the fourth agricultural river, Little River Ditch, located in the northernmost part of the Study Unit, was significantly lower than the other agricultural rivers. The lowest median nitrogen concentrations were from two streams located in the uplands in the eastern part of the Study Unit (the Skuna and Wolf Rivers). The land use for these two streams is forest, pasture, and small farms. No sample collected during this study from any streams had a concentration for nitrate or ammonia that exceeded the USEPA drinking water MCL of 10 mg/L or the aquatic life criteria, respectively.

The distribution of median phosphorus concentrations was similar to the distribution of nitrogen concentrations, with the highest concentration from the urban stream and the same three agricultural streams. The lowest median concentrations were from the two streams in the uplands part of the Study Unit. The median concentration of phosphorus exceeded the USEPA recommended goal of 0.1 mg/L of phosphorus for flowing waters at seven of the nine sampling sites. The 0.1 mg/L goal was exceeded in every sample collected from three streams; Fletcher Creek, and the Tensas and Yazoo Rivers.

Data collected from an additional 27 streams during the growing season in 1997 were analyzed by major basin to determine if concentrations differed among basins. The four major basins were the St. Francis, Tensas, White, and Yazoo. Results indicated that nitrogen and phosphorus concentrations were higher in the Tensas and Yazoo River Basins.

Annual yields of nitrogen and phosphorus for 1996 and 1997 from streams in the Study Unit were compared to the average annual yields for 1980-96 from 42 streams in the Mississippi River Basin. The nitrogen yields from the Study Unit were higher than those from the drier western parts of the Mississippi River Basin and the colder northern parts, but less than those from the agriculturally intensive Midwest. Yields of phosphorus in the Mississippi River Basin were highest in the MISE Study Unit, although the use of phosphorus as a fertilizer is much less in the Study Unit and there are few significant point sources. The high phosphorus yields in the MISE Study Unit were attributed to the large amount of rainfall received in the Study Unit and to the soil texture of the Study Unit. Additionally, it was suggested that the large amount of surface drainage in the Study Unit could be contributing to the high phosphorus yields.

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APPENDIX I

Summary statistics of nutrient data collected during February 1996 through January 1998 from nine surface-water sites in the Mississippi Embayment Study Unit

Streams sampled from February 1996 through January 1998. Site numbers refer to figure 2.

Site number	Site Name
1.	Little River Ditch No. 1 near Morehouse, Missouri
2.	Cache River at Egypt, Arkansas
3.	Cache River near Cotton Plant, Arkansas
4.	Wolf River at LaGrange, Tennessee
5.	Fletcher Creek at Memphis, Tennessee
6.	Skuna River near Bruce, Mississippi
7.	Bogue Phalia near Leland, Mississippi
8.	Yazoo River below Steele Bayou, Mississippi
9.	Tensas River at Tendal, Louisiana

APPENDIX I – SUMMARY STATISTICS –continued

Little River Ditch No. 1 near Morehouse, Missouri--February 1996 to January 1998

[site 1, figure 2; <, less than]

Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	Percent of samples in which values were less than or equal to those shown: 95	75	50	25	5
Total nitrogen as N*	55	5.2	<0.05	0.50	0.70	0.60	0.50	0.40	0.10
Dissolved ammonia as N	56	0.47	<0.015	0.06**	0.28	0.06	0.03	<0.015	<0.015
Dissolved ammonia and organic as N	56	1.1	<0.10	0.30**	0.80	0.40	0.20	<0.20	<0.20
Ammonia and organic as N	56	2.5	<0.20	0.70**	1.8	0.80	0.50	0.30	<0.20
Nitrite as N	56	0.100	<0.010	0.020**	0.100	0.020	0.020	0.010	<0.010
Nitrite plus Nitrate as N	55	2.80	<0.050	0.640**	2.10	0.410	0.230	0.120	<0.050
Dissolved phosphorus	56	0.160	0.010	0.050	0.110	0.070	0.050	0.040	0.020
Total phosphorus as P	56	0.640	0.030	0.190	0.570	0.230	0.140	0.090	0.050
Orthophosphate as P	56	0.150	0.010	0.060	0.110	0.070	0.050	0.030	0.020

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

Cache River at Egypt, Arkansas--February 1996 to January 1998

[site 2, figure 2; <, less than]

Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	Percent of samples in which values were less than or equal to those shown: 95	75	50	25	5
Total nitrogen as N*	27	3.2	0.60	1.6	3.1	2.0	1.5	1.2	0.60
Dissolved ammonia as N	27	0.27	<0.015	0.07**	0.21	0.12	0.03	<0.02	<0.015
Dissolved ammonia and organic as N	27	1.0	0.30	0.50	1.0	0.60	0.50	0.40	0.30
Ammonia and organic as N	27	2.9	0.50	1.3	2.5	1.5	1.3	1.0	0.50
Nitrite as N	27	0.14	<0.010	0.02**	0.110	0.020	0.010	<0.010	<0.010
Nitrite plus Nitrate as N	27	1.40	<0.050	0.300**	1.10	0.350	0.170	0.100	<0.050
Dissolved phosphorus as P	27	0.160	<0.010	0.060**	0.130	0.070	0.050	0.020	<0.010
Total phosphorus as P	27	0.700	0.070	0.280	0.630	0.350	0.280	0.210	0.090
Orthophosphate as P	27	0.170	<0.010	0.060**	0.150	0.090	0.040	0.020	<0.010

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

APPENDIX I – SUMMARY STATISTICS –continued

Cache River near Cotton Plant, Arkansas--February 1996 to January 1998

[site 3, figure 2; <, less than]

Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	Percent of samples in which values were less than or equal to those shown				
					95	75	50	25	5
Total nitrogen as N*	42	2.3	0.60	1.1	1.8	1.4	1.1	0.8	0.60
Dissolved ammonia as N	42	0.18	<0.015	0.03**	0.09	0.04	0.02	<0.02	<0.015
Dissolved ammonia and organic as N	42	0.6	0.20	0.40	0.60	0.40	0.40	0.30	0.20
Ammonia and organic as N	42	1.7	0.50	0.90	1.6	1.1	0.90	0.70	0.50
Nitrite as N	42	0.06	<0.010	0.010**	0.040	0.020	<0.010	<0.010	<0.010
Nitrite plus Nitrate as N	42	0.590	<0.050	0.200**	0.450	0.280	0.160	0.100	<0.050
Dissolved phosphorus as P	39	0.150	<0.010	0.050**	0.110	0.060	0.050	0.040	<0.010
Total phosphorus as P	42	0.460	0.090	0.210	0.420	0.250	0.190	0.150	0.120
Orthophosphate as P	42	0.100	0.010	0.050**	0.100	0.060	0.050	0.030	0.010

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

Wolf River at LaGrange, Tennessee--February 1996 to January 1998

[site 4, figure 2; <, less than]

Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	Percent of samples in which values were less than or equal to those shown				
					95	75	50	25	5
Total nitrogen as N*	29	0.80	0.10	0.50	0.70	0.60	0.50	0.40	0.10
Dissolved ammonia as N	29	0.06	<0.015	0.02**	0.05	0.03	<0.02	<0.015	<0.015
Dissolved ammonia and organic as N	29	0.40	<0.10	0.10**	0.30	<0.20	<0.20	<0.20	<0.10
Ammonia and organic as N	29	0.60	<0.20	0.30**	0.60	0.40	0.30	0.15	<0.20
Nitrite as N	29	0.020	<0.010	0.010**	0.020	<0.010	<0.010	<0.010	<0.010
Nitrite plus Nitrate as N	29	0.350	0.060	0.200	0.340	0.280	0.180	0.140	0.060
Dissolved phosphorus	29	0.050	<0.010	0.010**	0.030	0.010	<0.010	<0.010	<0.010
Total phosphorus as P	29	0.190	<0.010	0.060**	0.150	0.070	0.050	0.030	<0.010
Orthophosphate as P	29	0.040	<0.010	0.010**	0.030	0.010	0.010	<0.010	<0.010

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

APPENDIX I – SUMMARY STATISTICS –continued

Fletcher Creek at Memphis, Tennessee--April 1996 to January 1998

[site 5, figure 2; <, less than]

Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	Percent of samples in which values were less than or equal to those shown: 95	75	50	25	5
Total nitrogen as N*	48	2.8	0.80	1.7	2.8	1.9	1.6	1.4	1.1
Dissolved ammonia as N	48	0.48	<0.015	0.11**	0.31	0.16	0.74	0.03	<0.015
Dissolved ammonia and organic as N	48	1.0	0.20	0.60	1.0	0.70	0.50	0.40	0.20
Ammonia and organic as N	48	2.2	0.60	1.3	2.0	1.4	1.3	1.0	0.6
Nitrite as N	48	0.090	<0.010	0.030**	0.060	0.040	0.030	0.015	<0.010
Nitrite plus Nitrate as N	48	1.00	0.050	0.410	0.850	0.530	0.420	0.270	0.060
Dissolved phosphorus	48	0.250	<0.010	0.080**	0.190	0.120	0.070	0.040	<0.010
Total phosphorus as P	48	0.990	0.140	0.450	0.950	0.600	0.390	0.280	0.160
Orthophosphate as P	48	0.260	0.010	0.080	0.180	0.120	0.070	0.040	0.010

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

Skuna River near Bruce, Mississippi--February 1996 to January 1998

[site 6, figure 2; <, less than]

					Percent of samples in which values were less than or equal to those shown				
Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	95	75	50	25	5
Total nitrogen as N*	27	2.2	<0.05	0.70	1.8	0.80	0.5	0.30	0.06
Dissolved ammonia as N	27	0.13	<0.015	0.03**	0.12	0.04	0.02	<0.015	<0.015
Dissolved ammonia and organic as N	27	0.60	<0.20	0.30**	0.60	0.30	0.30	<0.20	<0.20
Ammonia and organic as N	27	1.8	<0.20	0.60**	1.6	0.70	0.50	0.30	<0.20
Nitrite as N	27	0.020	<0.010	0.010**	0.020	<0.010	<0.010	<0.010	<0.010
Nitrite plus Nitrate as N	27	0.420	<0.050	0.090**	0.340	0.100	0.060	<0.050	<0.050
Dissolved phosphorus as P	27	0.080	<0.010	0.020**	0.040	0.030	0.010	<0.010	<0.010
Total phosphorus as P	27	0.580	0.020	0.130	0.500	0.180	0.090	0.030	0.020
Orthophosphate as P	27	0.050	<0.010	0.020**	0.030	0.020	0.010	<0.010	<0.010

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

APPENDIX I - SUMMARY STATISTICS –continued

Bogue Phalia near Leland, Mississippi--February 1996 to January 1998

[site 7, figure 2; <, less than]

					Percent of samples in which values were less than or equal to those shown				
Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	95	75	50	25	5
Total nitrogen as N*	62	6.7	0.06	2.10	3.9	2.8	1.8	1.2	0.60
Dissolved ammonia as N	62	0.57	<0.015	0.11**	0.27	0.14	0.06	0.03	<0.015
Dissolved ammonia and organic as N	62	1.5	0.20	0.60	1.3	0.70	0.50	0.40	0.20
Ammonia and organic as N	62	3.8	0.20	1.4	2.6	1.7	1.3	0.90	0.60
Nitrite as N	62	0.590	<0.010	0.070**	0.350	0.060	0.020	0.010	<0.010
Nitrite plus Nitrate as N	62	4.40	<0.050	0.720**	1.80	1.00	0.510	0.210	<0.050
Dissolved phosphorus as P	62	0.290	0.010	0.070	0.130	0.090	0.060	0.040	0.020
Total phosphorus as P	62	1.20	0.030	0.350	0.810	0.460	0.310	0.170	0.090
Orthophosphate as P	62	0.180	0.010	0.070	0.130	0.090	0.060	0.040	0.010

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

Yazoo River below Steele Bayou, Mississippi--February 1996 to January 1998

[site 8, figure 2; <, less than]

					Percent of samples in which values were less than or equal to those shown				
Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	95	75	50	25	5
Total nitrogen as N*	50	3.3	0.60	1.3	2.2	1.6	1.3	0.90	0.70
Dissolved ammonia as N	49	0.15	<0.015	0.05**	0.11	0.08	0.04	0.02	<0.015
Dissolved ammonia and organic as N	49	1.1	<0.20	0.40**	0.90	0.50	0.30	0.30	<0.20
Ammonia and organic as N	49	2.1	0.41	0.90	1.7	1.2	0.80	0.60	0.50
Nitrite as N	49	0.100	<0.010	0.020**	0.030	0.020	0.020	<0.010	<0.010
Nitrite plus Nitrate as N	50	1.20	0.120	0.420**	1.10	0.590	0.330	0.210	0.160
Dissolved phosphorus as P	49	0.180	0.010	0.050	0.110	0.070	0.040	0.030	0.020
Total phosphorus as P	49	0.890	0.120	0.270	0.510	0.340	0.220	0.170	0.120
Orthophosphate as P	49	0.100	0.010	0.040	0.090	0.050	0.040	0.030	0.020

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

APPENDIX I – SUMMARY STATISTICS –continued

Tensas River at Tendal, Louisiana--February 1996 to January 1998

[site 9, figure 2; <, less than]

Compound (milligrams per liter)	Number	Maximum	Minimum	Mean	Percent of samples in which values were less than or equal to those shown: 95	75	50	25	5
Total nitrogen as N*	43	10	0.60	2.2	5.7	2.2	1.6	1.2	0.8
Dissolved ammonia as N	43	0.6	<0.015	0.12**	0.33	0.18	0.07	0.02	<0.015
Dissolved ammonia and organic as N	43	1.6	0.20	0.60	1.2	0.70	0.50	0.40	0.20
Ammonia and organic as N	43	2.8	0.20	1.3	2.1	1.6	1.3	1.1	0.60
Nitrite as N	43	0.320	<0.010	0.040**	0.170	0.050	0.020	<0.010	<0.010
Nitrite plus Nitrate as N	43	8.30	<0.050	0.900**	3.30	0.890	0.270	0.080	<0.050
Dissolved phosphorus as P	43	0.230	0.030	0.090	0.210	0.110	0.080	0.050	0.030
Total phosphorus as P	43	0.840	0.130	0.380	0.770	0.530	0.340	0.240	0.150
Orthophosphate as P	43	0.200	0.010	0.090	0.190	0.110	0.080	0.040	0.020

* Total nitrogen is the sum of nitrite plus nitrate and ammonia and organic nitrogen. If one of these species making up total nitrogen was below the reporting level, total nitrogen was set to the other value. If both species were below the reporting level, total nitrogen was set to the method reporting level for nitrite plus nitrate of <0.05 milligrams per liter.

**Value is estimated by using a log-probability regression to predict the values of data below the detection limit

APPENDIX II

Nutrient concentrations data from 30 surface-water sites in the Mississippi Embayment Study Unit sampled during May–September 1997

Site Number	Site Name
1.	St. John's Ditch near Sikeston, Missouri
2.	Spillway Ditch at Hwy 102 near East Prairie, Missouri
3.	Little River Ditch 251 near Lilbourn, Missouri
4.	Obion Creek near Hickman, Kentucky
5.	Main Ditch at Hwy 153 near White Oak, Missouri
6.	Running Reelfoot Bayou at Hwy 103, Tennessee
7.	Elk Chute near Gobler, Missouri
8.	Cockle Burr Slough Ditch near Monette, Arkansas
9.	St. Francis River at Lake City, Arkansas
10.	Village Creek near Swifton, Arkansas
11.	Tyronza River near Twist, Arkansas
12.	St. Francis River at Coldwater, Arkansas
13.	Bayou Deview at Morton, Arkansas
14.	Second Creek near Palestine, Arkansas
15.	L`Anguille River at Palestine, Arkansas
16.	Big Creek at Poplar Grove, Arkansas
17.	La Grue Bayou near Dewitt, Arkansas
18.	Coldwater River at Marks, Mississippi
19.	Bayou Meto near Bayou Meto, Arkansas
20.	Cassidy Bayou at Webb, Mississippi
21.	Quiver River near Doddsville, Mississippi
22.	Big Sunflower River at Sunflower, Mississippi
23.	Bayou Macon near Halley, Arkansas
24.	Deer Creek near Hollandale, Mississippi
25.	Boeuf River near Arkansas-Louisiana state line
26.	Big Sunflower River near Anguilla, Mississippi
27.	Steele Bayou East Prong Near Rolling Fork, Mississippi
28.	Silver Creek near Bayland, Mississippi
29.	Bayou Macon near Delhi, Louisiana
30.	Big Creek near Sligo, Louisiana

St. John's Ditch near Sikeston, Missouri

[site 1, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970514	19970715	19970916
Total nitrogen as N	.50	.60	.40
Dissolved ammonia as N	.050	.040	.060
Nitrite as N	.020	.020	<.010
Dissolved ammonia and organic as N	<.20	<.20	<.20
Ammonia and organic as N	.30	.40	.30
Nitrite and nitrate as N	.210	.230	.110
Total phosphorus as P	.140	.240	.270
Dissolved phosphorus as P	.110	.090	.150
Orthophosphate as P	.110	.100	.150

Spillway Ditch at HWY 102 near East Prairie, Missouri

[site 2, figure 2;-- no data; <less than]

Compound (milligrams per liter)	Sampling Dates 19970514	19970716	19970915
Total nitrogen as N	.50	.90	--
Dissolved ammonia as N	<.015	.130	<.015
Nitrite as N	<.010	.050	<.010
Dissolved ammonia and organic as N	<.20	.40	<.20
Ammonia and organic as N	.50	.70	<.20
Nitrite and nitrate as N	<.050	.250	<.050
Total phosphorus as P	.250	.290	.190
Dissolved phosphorus as P	.090	.190	.130
Orthophosphate as P	.090	.180	.140

Little River Ditch 251 near Lilbourn, Missouri

[site 3, figure 2; -- no data; <less than]

Compound (milligrams per liter)	Sampling Dates 19970515	19970715	19970916
Total nitrogen as N	.30	.20	--
Dissolved ammonia as N	<.015	<.015	.020
Nitrite as N	<.010	<.010	<.010
Dissolved ammonia and organic as N	<.20	<.20	<.20
Ammonia and organic as N	.30	.20	<.20
Nitrite and nitrate as N	<.050	<.050	<.050
Total phosphorus as P	.170	.120	.130
Dissolved phosphorus as P	.040	.050	.070
Orthophosphate as P	.050	.070	.080

Obion Creek near Hickman, Kentucky
[site 4, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970514	19970716	19970915
Total nitrogen as N	1.8	2.7	.70
Dissolved ammonia as N	.130	.120	.050
Nitrite as N	.060	.030	<.010
Dissolved ammonia and organic as N	.70	.70	<.20
Ammonia and organic as N	.90	1.3	.50
Nitrite and nitrate as N	.910	1.50	.240
Total phosphorus as P	.200	.400	.190
Dissolved phosphorus as P	.020	.030	.020
Orthophosphate as P	<.010	.020	.030

Main Ditch at HWY 153 near White Oak, Missouri
[site 5, figure 2;-- no data; <less than]

Compound (milligrams per liter)	Sampling Dates 19970515	19970715	19970916
Total nitrogen as N	--	.16	.07
Dissolved ammonia as N	<.015	<.015	.020
Nitrite as N	.010	.010	<.010
Dissolved ammonia and organic as N	<.20	<.20	<.20
Ammonia and organic as N	<.20	<.20	<.20
Nitrite and nitrate as N	<.050	.160	.070
Total phosphorus as P	.120	.150	.140
Dissolved phosphorus as P	.070	.090	.080
Orthophosphate as P	.050	.100	.100

Running Reelfoot Bayou at HWY 103, Tennessee
[site 6, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970514	19970716	19970915
Total nitrogen as N	.70	1.0	.70
Dissolved ammonia as N	.040	.130	.160
Nitrite as N	<.010	.030	.015
Dissolved ammonia and organic as N	.40	.40	<.20
Ammonia and organic as N	.70	.80	.60
Nitrite and nitrate as N	<.050	.160	.090
Total phosphorus as P	.180	.170	.130
Dissolved phosphorus as P	<.010	.020	<.010
Orthophosphate as P	<.010	.020	<.010

Elk Chute near Gobler, Missouri

[site 7, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970515	19970715	19970916
Total nitrogen as N	.50	2.2	.80
Dissolved ammonia as N	<.015	.170	<.015
Nitrite as N	<.010	.050	<.010
Dissolved ammonia and organic as N	<.20	.80	<.20
Ammonia and organic as N	.50	1.4	.80
Nitrite and nitrate as N	<.050	.740	<.050
Total phosphorus as P	.132	.194	.155
Dissolved phosphorus as P	<.010	.040	<.010
Orthophosphate as P	.010	.040	.020

Cockle Burr Slough Ditch near Monette, Arkansas

[site 8, figure 2; -- no data; <less than]

Compound (milligrams per liter)	Sampling Dates 19970508	19970709	19970909
Total nitrogen as N	--	.07	.60
Dissolved ammonia as N	<.015	<.015	<.015
Nitrite as N	<.010	<.010	<.010
Dissolved ammonia and organic as N	<.20	<.20	<.20
Ammonia and organic as N	<.20	<.20	.58
Nitrite and nitrate as N	<.050	.070	<.050
Total phosphorus as P	.160	.160	.130
Dissolved phosphorus as P	.070	.110	.070
Orthophosphate as P	.080	.100	.080

St. Francis River at Lake City, Arkansas

[site 9, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970508	19970709	19970909
Total nitrogen as N	.70	.60	.60
Dissolved ammonia as N	.060	.030	.050
Nitrite as N	<.010	<.010	.010
Dissolved ammonia and organic as N	.20	.30	.30
Ammonia and organic as N	.60	.50	.40
Nitrite and nitrate as N	.170	.110	.150
Total phosphorus as P	.150	.160	.100
Dissolved phosphorus as P	.050	.060	.050
Orthophosphate as P	.040	.060	.050

Village Creek near Swifton, Arkansas

[site 10, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970508	19970710	19970910
Total nitrogen as N	1.0	1.1	.80
Dissolved ammonia as N	.110	.170	.050
Nitrite as N	<.010	.020	.010
Dissolved ammonia and organic as N	.40	.60	.40
Ammonia and organic as N	1.0	1.0	.60
Nitrite and nitrate as N	<.050	.130	.150
Total phosphorus as P	.480	.142	.133
Dissolved phosphorus as P	.070	.050	.070
Orthophosphate as P	.090	.050	.070

Tyronza River near Twist, Arkansas

[site 11, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970507	19970708	19970909
Total nitrogen as N	.70	1.3	.40
Dissolved ammonia as N	<.015	<.015	<.015
Nitrite as N	.020	.030	<.010
Dissolved ammonia and organic as N	<.20	.40	.30
Ammonia and organic as N	.30	.80	.40
Nitrite and nitrate as N	.420	.510	<.050
Total phosphorus as P	.170	.240	.160
Dissolved phosphorus as P	.050	.060	.120
Orthophosphate as P	.060	.060	.130

St. Francis River at Coldwater, Arkansas

[site 12, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970507	19970708	19970909
Total nitrogen as N	2.1	.70	.70
Dissolved ammonia as N	<.015	<.015	<.015
Nitrite as N	.040	.010	<.010
Dissolved ammonia and organic as N	.30	.20	<.20
Ammonia and organic as N	1.3	.50	.70
Nitrite and nitrate as N	.790	.180	<.050
Total phosphorus as P	.590	.180	.190
Dissolved phosphorus as P	.080	.120	.090
Orthophosphate as P	.080	.100	.100

Bayou Deview at Morton, Arkansas

[site 13, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970506	19970708	19970731	19970909
Total nitrogen as N	1.5	1.5	1.3	.20
Dissolved ammonia as N	.100	.070	.050	.030
Nitrite as N	.020	.050	.030	.010
Dissolved ammonia and organic as N	.60	.70	.50	.40
Ammonia and organic as N	1.2	1.1	1.2	<.20
Nitrite and nitrate as N	.280	.340	.100	.180
Total phosphorus as P	.340	.170	.170	.090
Dissolved phosphorus as P	.050	.090	.040	.070
Orthophosphate as P	.060	.030	.040	.070

Second Creek near Palestine, Arkansas

[site 14, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970506	19970708	19970908
Total nitrogen as N	1.2	.80	.30
Dissolved ammonia as N	<.015	.070	<.015
Nitrite as N	<.010	<.010	<.010
Dissolved ammonia and organic as N	.40	.70	.30
Ammonia and organic as N	1.0	.80	.30
Nitrite and nitrate as N	.230	.060	<.050
Total phosphorus as P	.290	.110	.090
Dissolved phosphorus as P	.060	.050	.080
Orthophosphate as P	.070	.050	.080

L'Anguille River at Palestine, Arkansas

[site 15, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970506	19970708	19970908
Total nitrogen as N	1.3	1.1	.80
Dissolved ammonia as N	.030	.060	.020
Nitrite as N	.010	.010	<.010
Dissolved ammonia and organic as N	.40	.60	.40
Ammonia and organic as N	1.0	.90	.60
Nitrite and nitrate as N	.360	.240	.150
Total phosphorus as P	.320	.160	.140
Dissolved phosphorus as P	.060	.030	.060
Orthophosphate as P	.060	.030	.070

Big Creek at Poplar Grove, Arkansas
[site 16, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970505	19970707	19970908
Total nitrogen as N	1.3	.90	.70
Dissolved ammonia as N	.040	.040	.040
Nitrite as N	<.010	.010	<.010
Dissolved ammonia and organic as N	.30	.40	.40
Ammonia and organic as N	.90	.80	.60
Nitrite and nitrate as N	.370	.160	.090
Total phosphorus as P	.340	.240	.180
Dissolved phosphorus as P	.070	.040	.070
Orthophosphate as P	.060	.040	.080

La Grue Bayou near Dewitt, Arkansas
[site 17, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970505	19970707	19970908
Total nitrogen as N	.80	1.00	.50
Dissolved ammonia as N	<.015	.040	<.015
Nitrite as N	<.010	.010	<.010
Dissolved ammonia and organic as N	.30	.50	.40
Ammonia and organic as N	.59	.75	.43
Nitrite and nitrate as N	.170	.230	.060
Total phosphorus as P	.100	.140	.050
Dissolved phosphorus as P	.020	.020	.030
Orthophosphate as P	.030	.030	.040

Coldwater River at Marks, Mississippi
[site 18, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970513	19970714	19970910
Total nitrogen as N	1.2	1.2	1.1
Dissolved ammonia as N	.020	.100	.020
Nitrite as N	<.010	.030	<.010
Dissolved ammonia and organic as N	.30	.50	.40
Ammonia and organic as N	.70	1.0	.90
Nitrite and nitrate as N	.430	.210	.180
Total phosphorus as P	.310	.400	.300
Dissolved phosphorus as P	.030	.030	.050
Orthophosphate as P	.040	.040	.060

Bayou Meto near Bayou Meto, Arkansas
[site 19, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970505	19970707	19970908
Total nitrogen as N	1.1	1.6	.80
Dissolved ammonia as N	.050	.060	<.015
Nitrite as N	.010	.030	<.010
Dissolved ammonia and organic as N	.40	.60	.40
Ammonia and organic as N	.80	1.1	.80
Nitrite and nitrate as N	.350	.490	<.050
Total phosphorus as P	.350	.290	.130
Dissolved phosphorus as P	.090	.050	.030
Orthophosphate as P	.100	.050	.040

Cassidy Bayou at Webb, Mississippi
[site 20, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970513	19970714	19970910
Total nitrogen as N	5.5	2.5	1.5
Dissolved ammonia as N	.020	.400	<.015
Nitrite as N	.160	.020	<.010
Dissolved ammonia and organic as N	.40	1.3	.40
Ammonia and organic as N	2.6	2.3	1.5
Nitrite and nitrate as N	2.90	.180	<.050
Total phosphorus as P	.950	.540	.260
Dissolved phosphorus as P	.040	.060	.040
Orthophosphate as P	.040	.060	.040

Quiver River near Doddsville, Mississippi
[site 21, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970508	19970711	19970910
Total nitrogen as N	2.9	2.9	.80
Dissolved ammonia as N	.160	.480	.050
Nitrite as N	.080	.170	<.010
Dissolved ammonia and organic as N	.60	1.8	.30
Ammonia and organic as N	1.2	2.0	.80
Nitrite and nitrate as N	1.70	.900	<.050
Total phosphorus as P	.320	.230	.190
Dissolved phosphorus as P	.050	.060	.060
Orthophosphate as P	.060	.060	.070

Big Sunflower River at Sunflower, Mississippi
[site 22, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970508	19970711	19970910
Total nitrogen as N	3.0	2.8	.60
Dissolved ammonia as N	.160	.310	.080
Nitrite as N	.130	.160	.020
Dissolved ammonia and organic as N	.70	1.6	.50
Ammonia and organic as N	1.1	1.9	.50
Nitrite and nitrate as N	1.90	.900	.070
Total phosphorus as P	.340	.230	.170
Dissolved phosphorus as P	.080	.090	.190
Orthophosphate as P	.080	.090	.190

Bayou Macon near Halley, Arkansas
[site 23, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970507	19970709	19970916
Total nitrogen as N	1.4	1.0	.50
Dissolved ammonia as N	.030	<.015	<.015
Nitrite as N	.030	.010	<.010
Dissolved ammonia and organic as N	.40	.50	.30
Ammonia and organic as N	.90	1.0	.50
Nitrite and nitrate as N	.460	.100	<.050
Total phosphorus as P	.450	.090	.220
Dissolved phosphorus as P	.190	.040	.080
Orthophosphate as P	.190	.040	.070

Deer Creek near Hollandale, Mississippi
[site 24, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970506	19970711	19970909
Total nitrogen as N	3.5	1.7	1.9
Dissolved ammonia as N	.170	.160	.500
Nitrite as N	.100	.050	.080
Dissolved ammonia and organic as N	.60	.60	1.0
Ammonia and organic as N	1.0	1.1	1.5
Nitrite and nitrate as N	2.50	.570	.380
Total phosphorus as P	.310	.240	.190
Dissolved phosphorus as P	.150	.080	.090
Orthophosphate as P	.130	.080	.070

Boeuf River near Arkansas-Louisiana state line
[site 25, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970507	19970709	19970916
Total nitrogen as N	1.5	2.5	.70
Dissolved ammonia as N	.140	<.015	<.015
Nitrite as N	.020	.050	<.010
Dissolved ammonia and organic as N	.50	.40	.30
Ammonia and organic as N	1.1	2.1	.60
Nitrite and nitrate as N	.470	.410	<.050
Total phosphorus as P	.390	.200	.180
Dissolved phosphorus as P	.110	<.010	.100
Orthophosphate as P	.110	.010	.100

Big Sunflower River near Anguilla, Mississippi
[site 26, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970506	19970714	19970909
Total nitrogen as N	3.0	3.5	1.1
Dissolved ammonia as N	.190	.300	.080
Nitrite as N	.060	.750	.020
Dissolved ammonia and organic as N	.50	1.2	.50
Ammonia and organic as N	1.3	1.5	1.0
Nitrite and nitrate as N	1.70	2.00	.090
Total phosphorus as P	.400	.190	.190
Dissolved phosphorus as P	.100	.050	.100
Orthophosphate as P	.090	.060	.080

Steele Bayou East Prong Near Rolling Fork, Mississippi
[site 27, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970506	19970714	19970909
Total nitrogen as N	2.1	2.9	1.0
Dissolved ammonia as N	.240	.510	<.015
Nitrite as N	.070	.180	<.010
Dissolved ammonia and organic as N	.70	1.6	.40
Ammonia and organic as N	1.1	2.2	1.0
Nitrite and nitrate as N	1.00	.730	<.050
Total phosphorus as P	.320	.190	.180
Dissolved phosphorus as P	.110	.030	.060
Orthophosphate as P	.100	.050	.050

Silver Creek near Bayland, Mississippi

[site 28, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970506	19970711	19970910
Total nitrogen as N	.70	2.2	2.6
Dissolved ammonia as N	<.015	<.015	.260
Nitrite as N	<.010	<.010	.050
Dissolved ammonia and organic as N	.50	1.0	1.4
Ammonia and organic as N	.70	2.2	2.4
Nitrite and nitrate as N	<.050	<.050	.190
Total phosphorus as P	.170	.640	.440
Dissolved phosphorus as P	.060	.160	.110
Orthophosphate as P	.050	.100	.100

Bayou Macon near Delhi, Louisiana

[site 29, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970505	19970707	19970908
Total nitrogen as N	3.7	1.8	.80
Dissolved ammonia as N	.140	<.015	<.015
Nitrite as N	.060	.140	<.010
Dissolved ammonia and organic as N	.50	.60	.30
Ammonia and organic as N	2.7	1.3	.80
Nitrite and nitrate as N	1.00	.470	<.050
Total phosphorus as P	1.30	.210	.180
Dissolved phosphorus as P	.110	.060	.090
Orthophosphate as P	.130	.040	.090

Big Creek near Sligo, Louisiana

[site 30, figure 2; <less than]

Compound (milligrams per liter)	Sampling Dates 19970505	19970707	19970908
Total nitrogen as N	1.3	1.1	.70
Dissolved ammonia as N	.150	.020	<.015
Nitrite as N	.030	<.010	<.010
Dissolved ammonia and organic as N	.60	.50	.20
Ammonia and organic as N	1.1	.90	.70
Nitrite and nitrate as N	.220	.180	<.050
Total phosphorus as P	.280	.300	.230
Dissolved phosphorus as P	.110	.110	.070
Orthophosphate as P	.120	.100	.070