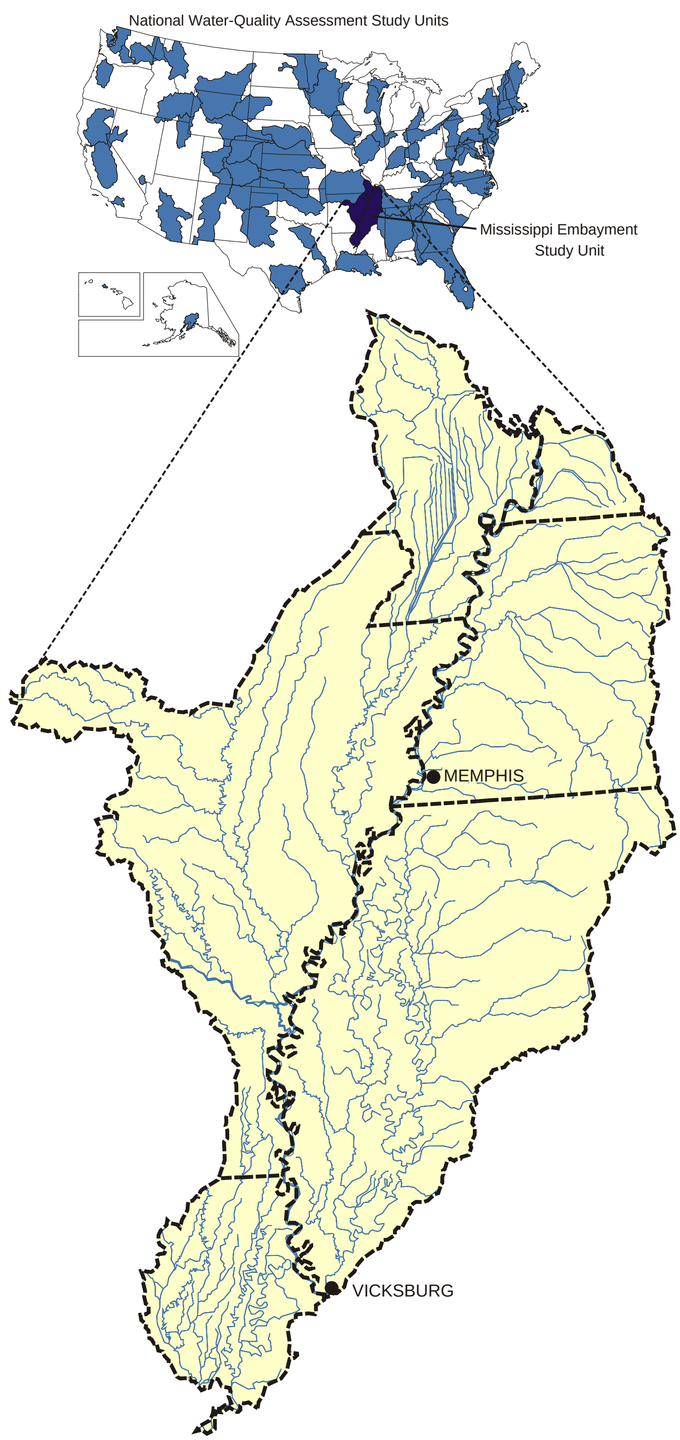
# CONCENTRATIONS AND LOADS OF NITROGEN AND PHOSPHORUS IN THE YAZOO RIVER, NORTHWESTERN MISSISSIPPI, 1996-97

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 98- 4219

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*By* **R.H.Coupe**

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U.S. Geological Survey

Water-Resources Investigations Report 98-4219

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# FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydro-geologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregations of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain difference and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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# CONVERSION FACTORS, ABBREVIATIONS, AND ACRONYMS

| Multiply | By | To obtain |
|---|---|---|
| meter (m) | 3.281 | foot |
| hectare (ha) | 2.471 | acre |
| kilometer (km) | 0.6214 | mile |
| square kilometer ($km^2$) | 0.3861 | square mile |
| kilogram (kg) | 2.205 | pound, avoirdupois |
| metric ton | 2205 | pound, avoirdupois |
| cubic meter per second ($m^3/s$) | 35.31 | cubic foot per second |
| kilogram per square kilometer (kg/ $km^2$) | 0.008924 | pounds per acre |
| kilograms per square kilometer per year (kg/ $km^2$/yr) | 0.008924 | pounds per acre per year |

**Abbreviations:**

L, liter

mg/L, milligrams per liter

µm, micron

**Acronyms**:

ADCP, Acoustic doppler current profiler

MVUE, Minimum variance unbiased estimator

NASQAN, National Stream Quality Accounting Network

NAWQA, National Water-Quality Assessment

USGS, U.S. Geological Survey

# CONCENTRATIONS AND LOADS OF NITROGEN AND PHOSPHORUS IN THE YAZOO RIVER, NORTHWESTERN MISSISSIPPI, 1996-97

*By* R.H. Coupe

## Abstract

Increased nutrient loading to the Gulf of Mexico from off-continent flux has been identified as contributing to the increase in the areal extent of the low dissolved-oxygen zone that develops annually off the coast of Louisiana and Texas. The proximity of the Yazoo River Basin in northwestern Mississippi to the Gulf of Mexico, and the intensive agriculture in the basin have lead to speculation that the Yazoo River Basin contributes a disproportionate amount of nitrogen and phosphorus to the Mississippi River and ultimately the Gulf of Mexico. Water samples from the Yazoo River were collected during 1996 and 1997 and were analyzed for total nitrogen, nitrate as nitrogen, total phosphorus, and orthophosphorus as part of the U.S. Geological Survey's National Water-Quality Assessment Program. These data were used to compute annual loads of nitrogen and phosphorus discharged from the Yazoo River for 1996 and 1997.

Annual loads of nitrogen and phosphorus were calculated by two methods. The first used multivariate regression and the second multiplied the mean annual concentration by the total annual flow. Load estimates based on the product of the mean annual concentration and the total annual flow were within the 95 percent confidence interval for the load calculated by multivariate regression in all cases. The Yazoo River loads, compared to long-term annual loads in the Mississippi River, indicated that the Yazoo River was contributing 2.3 percent or less of the total nitrogen load, 5.7 percent or less of the total phosphorus load, and 1 percent or less of the nitrate load in 1996 and 1997. The total nitrogen load from the Yazoo River Basin into the Mississippi River and ultimately the Gulf of Mexico was proportional to its discharge, the nitrate load was less than expected, whereas the total phosphorus load was slightly higher than expected based on discharge.

## INTRODUCTION

The annual reoccurrence of a zone of low dissolved oxygen concentration in the Gulf of Mexico (hypoxia) off of the coast of Louisiana and Texas has been documented, and a summary of available historical information is in Rabalais and others (1997). This hypoxic zone (dissolved oxygen concentration less than 2 mg/L), depending on its severity and duration, may cause a disruption of the fishing industry as mobile fauna move away from the zone or may also cause mortality to fauna unable to move to an area of sufficient oxygen. The hypoxic zone occurs each year during the late spring and summer following seasonal high inflows of freshwater and nutrients to the Gulf of Mexico. During the period 1985-92, estimates of the size of the hypoxic zone averaged about 10,000 $km^2$. Following the 1993 flood of the Missouri and upper Mississippi Rivers, the hypoxic zone covered nearly 17,000 $km^2$; during the period 1994-96, the hypoxic zone was reported to be as large or larger than that following the 1993 flood (Rabalais and others, 1997).

Changes in the quality of water discharging to the Gulf of Mexico have been implicated in contributing to the increase in the size of the hypoxic zone (Justic and others, 1993; Rabalais and others, 1996; Turner and Rabalais, 1991). Specifically, since World War II, the increased amounts of nitrogen and phosphorus fertilizer used for agriculture have been implicated in these changes. Because the outflow of the Mississippi River represents about 80 percent of the estimated freshwater discharged to the Gulf of Mexico (Dunn, 1996), research has focused on determining the source areas for nitrogen and phosphorus in the Mississippi River.

An area of particular interest is the Yazoo River Basin (fig. 1) in northwestern Mississippi. The Yazoo River Basin has some of the most intensively farmed land in the Mississippi River Basin and is relatively close to the mouth of the

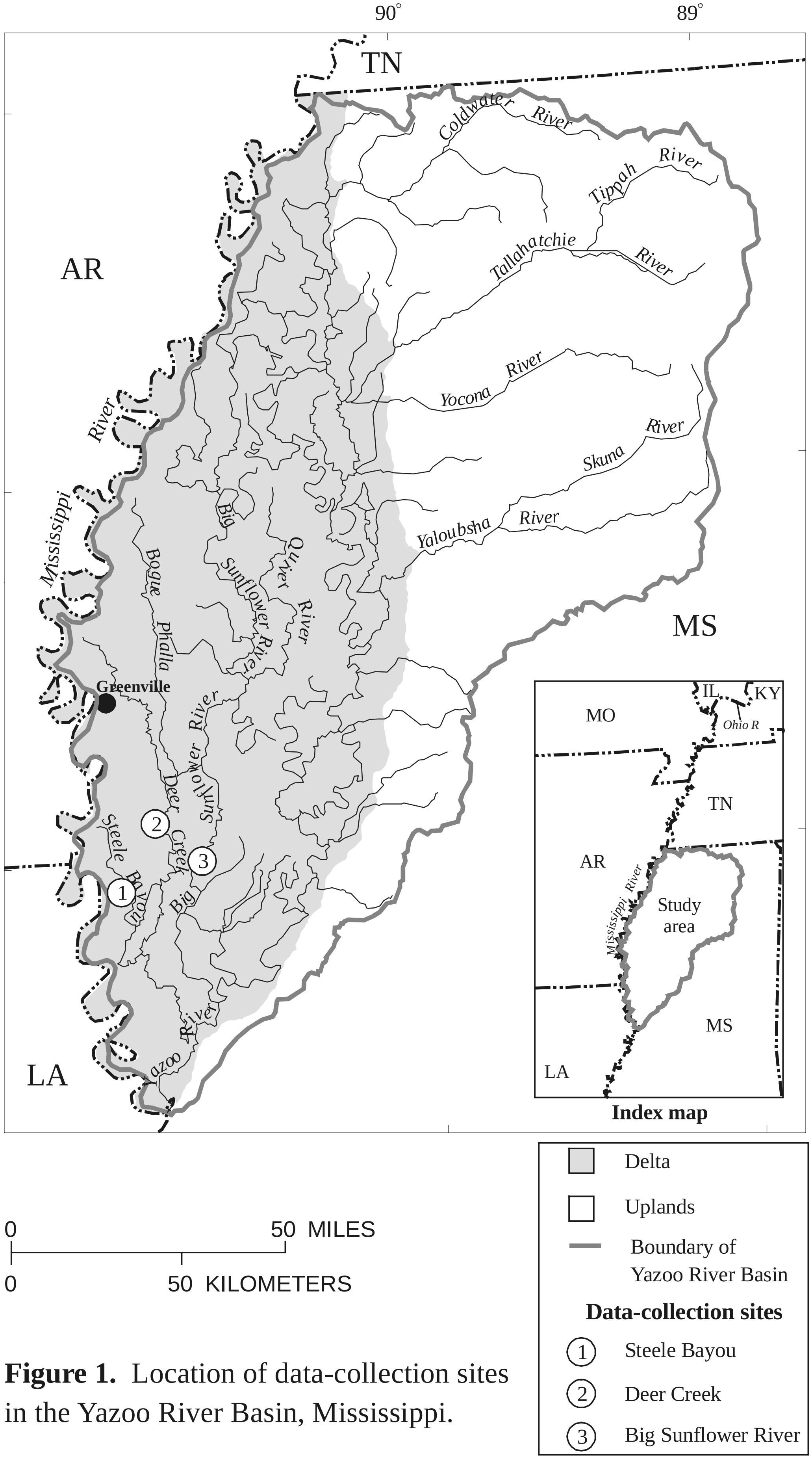


**Figure 1.** Location of data-collection sites in the Yazoo River Basin, Mississippi.

Mississippi River. Alexander and others (1997), using a modeling approach, identified the area below the confluence of the Ohio and Mississippi Rivers, including the Yazoo River Basin, as a significant source of nitrogen to the Gulf of Mexico, though other researchers have not reached this conclusion (Goolsby and Battaglin, 1993). The U.S. Environmental Protection Agency has questioned if on a per unit area basis there may be more nitrogen contributed from farmland in the Yazoo River Basin than from other parts of the Mississippi River Basin (Kopfler, 1998). The lack of historical streamflow data for the lower Yazoo River has precluded accurate calculation of loads from the Yazoo River Basin.

In 1996, as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program, surface-water data collection began in the Yazoo River. The surface water quality and quantity data that were collected are sufficient to calculate loads of nitrogen and phosphorus discharged from the Yazoo River to the Mississippi River.

## Purpose and Scope

This report describes concentrations and loads of nitrogen and phosphorus in the Yazoo River and compares data collected from the Yazoo River with historical data collected from the Yazoo and Mississippi River Basins. The water-quality data are based on water samples from the Yazoo River that were collected biweekly from February 1996 through December 1997. Annual loads of nitrogen and phosphorous were computed with ESTIMATOR software that uses multivariate regression.

## Description of the study area

The Yazoo River Basin, the largest river basin in Mississippi, encompasses about 34,700 $km^2$ (fig. 1). The basin is divided almost equally between lowlands in the Mississippi Alluvial Plain (commonly referred to as the Delta), an intensive agricultural area of mostly soybean, cotton, rice, corn, and grain sorghum production, and the uplands that generally consist of forests, pastures, and small farms. The Yazoo River Basin is sparsely populated, with no major metropolitan areas; approximately 60 percent of the land use in the basin is agricultural (U.S. Geological Survey, 1990). The major crops grown in the Yazoo River Basin are soybeans, cotton, rice, grain sorghum, and corn.

The Yazoo River is formed by the confluence of the Tallahatchie and Yalobusha Rivers and drains the entire Mississippi Alluvial Plain in Mississippi. The Yazoo River flows south from Greenwood along the eastern edge of the alluvial valley until it reaches the Mississippi River at Vicksburg. Four flood-control reservoirs (Arkabutla, Sardis, Enid, and Grenada Lakes) were built between 1940 and 1950 and are located in the northeastern part of the Yazoo River Basin. These reservoirs control the discharge from more than 11,400 $km^2$ of drainage in the uplands within the Yazoo River Basin.

Two flood-control structures control runoff from the Delta part of the Yazoo River Basin (fig. 1). The floodgates at the mouths of the Steele Bayou and Little Sunflower River are operated by the U.S. Army Corps of Engineers to help prevent extensive flooding in the lower reaches of the Yazoo River Basin by backwater from the Mississippi River. In 1996 and 1997, the gates of both structures were closed continuously for more than one month during March-June, and for shorter periods throughout the spring and summer (Plunkett and others, 1997; Plunkett and others, 1998).

Except during periods of extremely low flow in the Mississippi River, the stage and discharge of the lower Yazoo River are affected by backwater from the Mississippi River. During medium to high stage on the Mississippi River, the lower Yazoo River is greatly affected by a wedge of backwater that is forced into the Yazoo River channel. During periods when the Mississippi River is rising, water may flow in the upstream direction in all or part of the Yazoo River channel below Steele Bayou. This bidirectional flow makes it difficult to measure streamflow in the lower Yazoo River with conventional techniques. With the development of acoustic doppler current profiler (ADCP) technology, accurate streamflow measurements in large rivers with complex flow conditions are possible (Manning, 1997).

## Methods of analysis

Weekly discharge measurements were made at the Yazoo River below Steele Bayou site using ADCP technology beginning in January 1996 and continuing through December 1997. The ADCP uses the doppler principle by bouncing an ultrasonic sound pulse off small particles that are present in the water column and records the shift in frequency which is used to calculate velocity. The ADCP divides the stream cross section into subunit areas and measures the velocity in each subunit. Using subunit area and velocity, discharge is calculated for each subunit and is summed for total discharge. Bi-directional flow can be measured quickly and accurately (R.D. Instruments, 1989). A stage recorder was operated throughout the study, and an acoustic velocity meter was installed in October 1997 to measure instantaneous velocity. Prior to the installation of the velocity meter and during periods when it was not operational, daily mean discharges were computed by linear interpolation between weekly discharge measurements. Otherwise, daily mean discharge was computed according to the procedures outlined by Turnipseed and others (1998). Daily mean discharges for the Yazoo River for January 1996 through September 1997 were published by Plunkett and others (1998). The daily mean discharges for October, November, and December 1997 were obtained from the Mississippi District Office of the USGS (D. Phil Turnipseed, U.S. Geological Survey, Pearl, Mississippi, written commun., 1998).

The Yazoo River below Steele Bayou sampling site is located approximately 2.5 km downstream from the Steele Bayou control structure and approximately 8 km from the Mississippi River (fig. 1). Samples from the Yazoo River were collected from a boat using established velocity-weighted, depth- and width-integrating techniques (Shelton, 1994). Sample collection began in February 1996 and continued on a biweekly schedule through December 1997. Approximately 9 L of water was collected for each sample. Immediately after collection the samples were subsampled using a cone splitter (Shelton, 1994). Filtered samples were passed through a 0.45 µm filter, chilled and sent to the USGS National Water Quality Laboratory in Arvada, Colorado, for analysis by standard procedures (Fishman and Friedman, 1989).

Annual loads for 1996 and 1997 were calculated by two methods. The first uses multivariate regression and the second, a simple check of the multivariate results, multiplies the mean annual concentration by the total annual flow and appropriate conversion factors.

The multivariate regression calculations were made using the ESTIMATOR program (Cohn and others, 1992). ESTIMATOR, written in Fortran, uses multivariate regression and the Minimum Variance Unbiased Estimator (MVUE) 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 do not impair the accuracy of the model (Dunn, 1996). The regression equation for each constituent has the form

$$\ln(CQ) = B_0 + B_1 \ln(Q) + B_2 T + B_3 \sin(2\pi T) + B_4 \cos(2\pi T)$$

where

| | | |
|---|---|---|
| $C$ | = | concentration, |
| $B_0$ | = | intercept, |
| $B_1, B_2, B_3, B_4$ | = | regression coefficients, |
| $Q$ | = | daily mean streamflow, |
| $T$ | = | time, and |
| $\pi$ | = | 3.1416. |

A second method of determining annual loads is to multiply the total annual volume of water discharged out of the Yazoo River Basin by the mean annual concentration of the constituent of interest and the appropriate conversion factors. The result is an estimate of the annual loads to compare with the loads computed using the ESTIMATOR program.

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 used with the appropriate t-statistic, gave a 95 percent confidence interval for the calculated annual load (Helsel and Hirsch, 1992).

## CONCENTRATIONS OF NITROGEN AND PHOSPHORUS

The concentrations of total nitrogen in water samples from the Yazoo River below Steele Bayou collected during February 1996 through December 1997 ranged from 0.57 to 3.3 mg/L with a mean concentration of 1.3 mg/L (table 1). The lowest concentrations were measured during the low flow periods August through December 1996 and 1997 (figs. 2-4). The total nitrogen concentrations increased as discharge increased (fig. 2). The nitrate as nitrogen (throughout this report referred to as nitrate) concentrations in samples collected from the Yazoo River below Steele Bayou ranged from 0.12 to 1.2 mg/L, with a mean concentration of 0.42 mg/L. Nitrate was not well correlated with discharge (fig. 2), but there is a seasonal component as the highest nitrate concentrations occurred during the spring (fig. 3), corresponding to fertilizer application.

Total phosphorus concentrations in samples collected from the Yazoo River below Steele Bayou from February 1996 through December 1997 ranged from 0.12 to 0.89 mg/L, with a mean concentration of 0.27 mg/L (table 1). The lowest concentrations were measured during the extended low-flow period in late summer and early fall (fig. 3). Discharge was correlated with total phosphorus, as higher total phosphorus concentrations corresponded to higher discharge (fig. 2). The orthophosphorus concentrations in water samples collected from the Yazoo River below Steele Bayou ranged from 0.01 to 0.10 mg/L (table 1), with a mean concentration of 0.042 mg/L. The lowest orthophophorus concentrations occurred in the late fall and early winter October through January (fig. 3).

The concentrations of total nitrogen, nitrate, total phosphorus, and orthophosphorus collected from the Yazoo River below Steele Bayou as part of this study were compared with the most recent 10 years of data (1984-93) collected as part of the USGS National Stream Quality Accounting Network (NASQAN) program (table 1) (Alexander and others, 1996). The NASQAN samples were collected from the Yazoo River at Redwood, and from the Mississippi River at Vicksburg. The Yazoo River at Redwood sampling site is upstream from the present sampling site (fig. 1), above the confluence with the Steele Bayou. A summary of the NASQAN data from 1984-93 and the NAWQA data from 1996-97 is shown in table 1. The mean and median concentrations for total nitrogen and nitrate for both of the Yazoo River sites are less than the corresponding mean and median concentrations in the Mississippi River by about 1 mg/L. Mean and median total phosphorus concentrations were higher in the Yazoo River. Mean and median orthophosphorus concentrations were similar in the Yazoo and the Mississippi Rivers.

Mueller and others (1995) examined historical water-quality data from small undeveloped basins in 20 NAWQA study areas in the conterminous United States and reported that concentrations of nitrate less than 0.6 mg/L could be considered a general baseline for indicating the absence of significant anthropogenic effects. Seventy-five percent of the nitrate concentrations collected from the Yazoo River for this study were less than 0.68 mg/L. However, Mueller and others (1995) also indicated that concentrations of total phosphorus below 0.1 mg/L could also be considered a general baseline for indicating the absence of significant anthropogenic effects. The minimum concentration of total phosphorus measured in samples from the Yazoo River below Steele Bayou during 1996-97 was 0.12 mg/L.

The dichotomy here is probably related to the warm, humid climate of the Southeast that promotes biological activity leading to denitrification or uptake and incorporation of nitrate to organic forms of nitrogen. Indeed, nitrate is about 68 percent of the total nitrogen in the

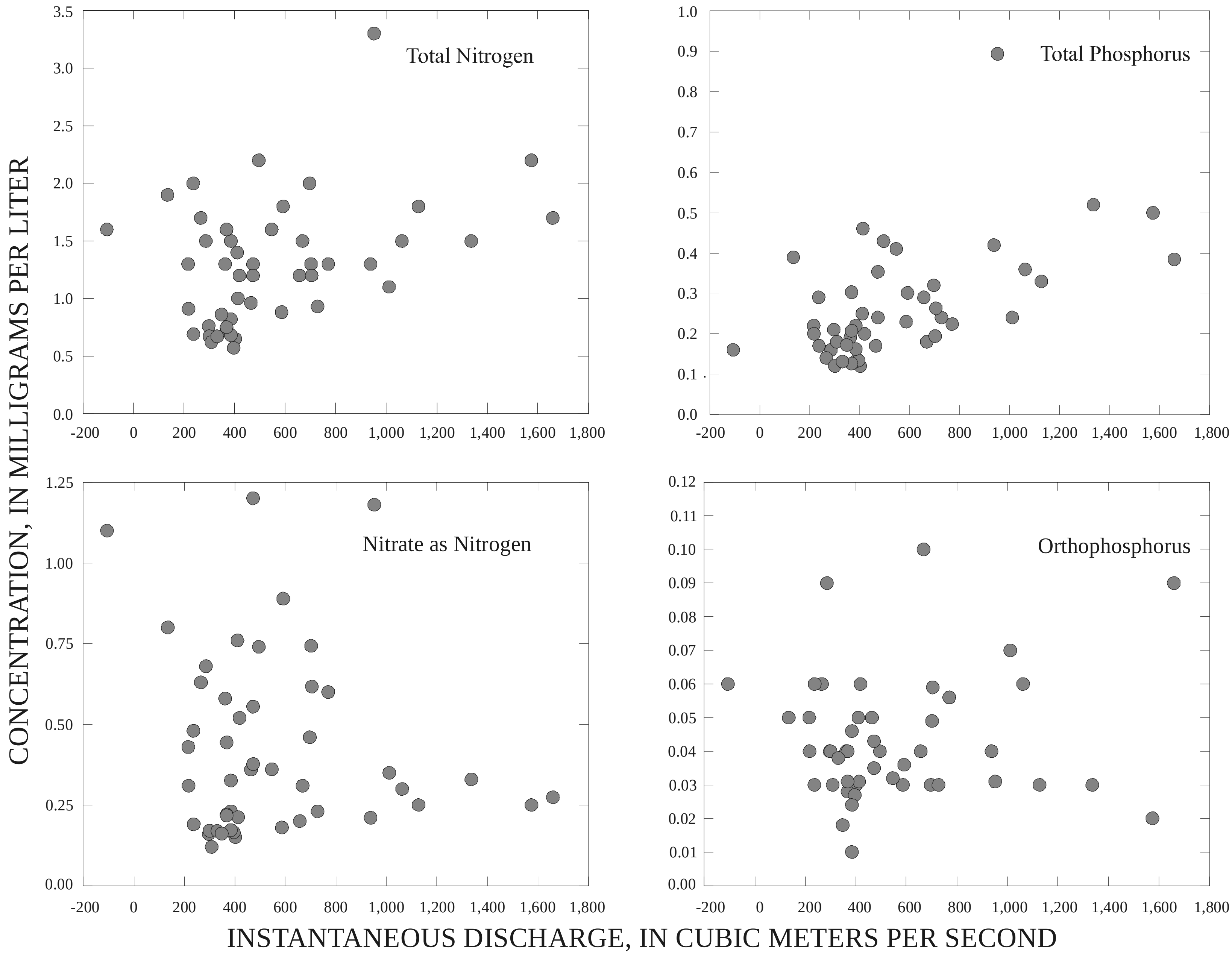


**Figure 2.** Concentrations of total nitrogen, total phosphorus, nitrate as nitrogen, and orthophosphorus, with discharge in water samples from the Yazoo River below Steele Bayou, February 1996 through December 1997.

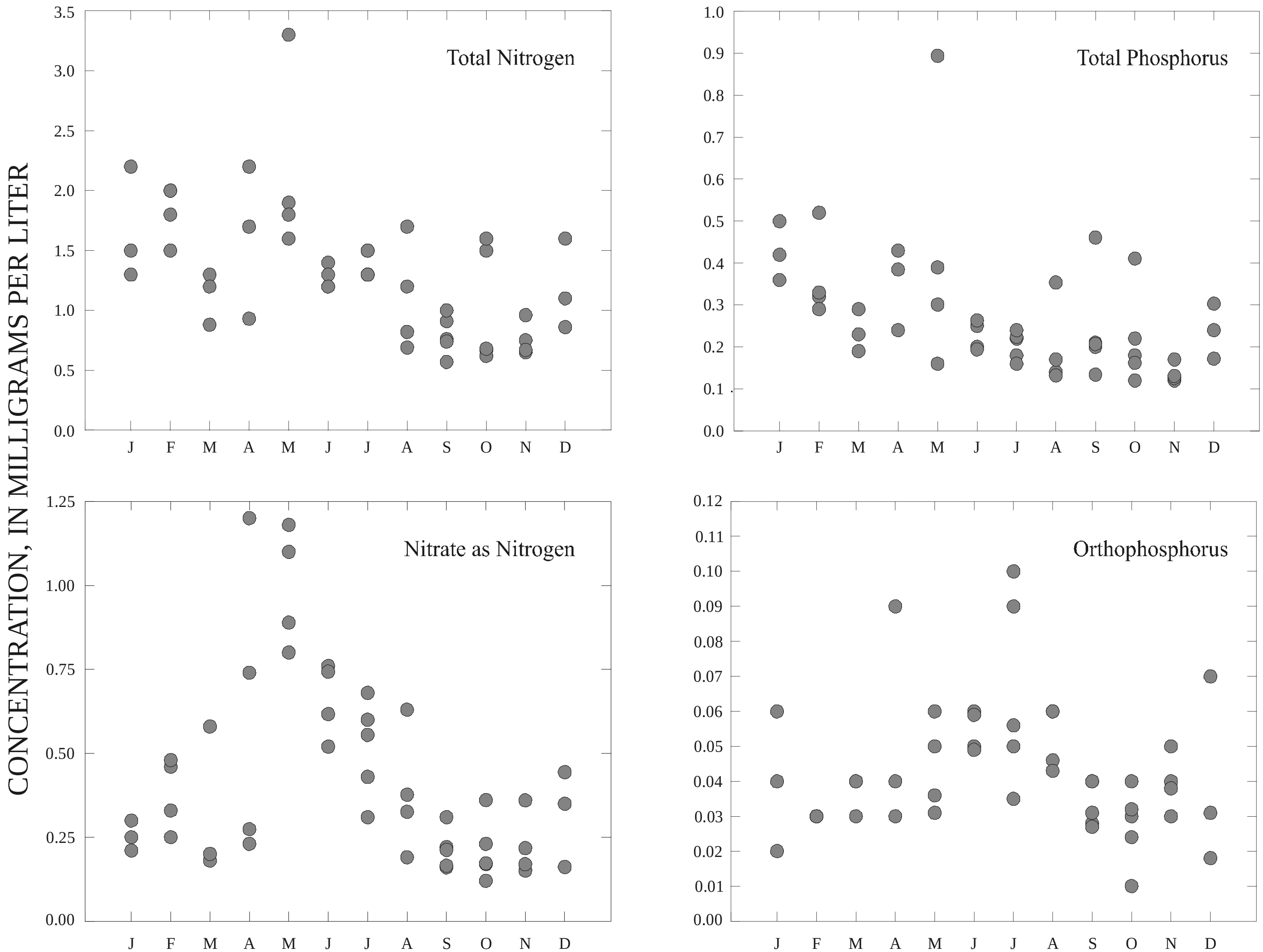


**Figure 3.** Concentrations of total nitrogen, total phosphorus, nitrate as nitrogen, and orthophosphorus, by month in water samples from the Yazoo River below Steele Bayou, February 1996 through December 1997.

**Table 1**. Concentrations of total nitrogen, nitrate as nitrogen, total phosphorus and orthophosphorus from water samples collected at three sites in the study area

[No., number of samples; max, maximum; min, minimum; all values in milligrams per liter; <, less than]

| Constituent | Site | No. | Year (19--) | Max | Min | Mean | Percentile 75th | Percentile 50th | Percentile 25th |
|---|---|---|---|---|---|---|---|---|---|
| Total nitrogen | Yazoo River below Steele Bayou | 21 | 96 | 2.2 | 0.62 | 1.3 | 1.7 | 1.3 | 0.84 |
| | Yazoo River below Steele Bayou | 26 | 97 | 3.3 | 0.57 | 1.3 | 1.6 | 1.3 | 0.85 |
| | Yazoo River at Redwood[1] | 54 | 84-93 | 5.0 | 0.49 | 1.3 | 1.5 | 1.1 | 0.91 |
| | Mississippi River at Vicksburg[1] | 38 | 84-93 | 3.8 | 1.1 | 2.3 | 2.6 | 2.2 | 1.9 |
| Nitrate | Yazoo River below Steele Bayou | 22 | 96 | 1.2 | 0.12 | 0.49 | 0.70 | 0.45 | 0.22 |
| | Yazoo River below Steele Bayou | 26 | 97 | 1.2 | 0.16 | 0.37 | 0.47 | 0.26 | 0.21 |
| | Yazoo River at Redwood[1] | 56 | 84-93 | 1.1 | 0.05 | 0.34 | 0.48 | 0.26 | 0.20 |
| | Mississippi River at Vicksburg[1] | 38 | 84-93 | 2.7 | 0.70 | 1.5 | 1.7 | 1.5 | 1.1 |
| Total phosphorus | Yazoo River below Steele Bayou | 21 | 96 | 0.43 | 0.12 | 0.22 | 0.25 | 0.20 | 0.17 |
| | Yazoo River below Steele Bayou | 26 | 97 | 0.89 | 0.13 | 0.31 | 0.39 | 0.28 | 0.19 |
| | Yazoo River at Redwood[1] | 56 | 84-93 | 0.83 | 0.01 | 0.20 | 0.23 | 0.17 | 0.13 |
| | Mississippi River at Vicksburg[1] | 38 | 84-93 | 0.38 | 0.04 | 0.16 | 0.21 | 0.16 | 0.11 |
| Ortho-phosphorus | Yazoo River below Steele Bayou | 21 | 96 | 0.100 | 0.010 | 0.049 | 0.060 | 0.050 | 0.035 |
| | Yazoo River below Steele Bayou | 26 | 97 | 0.090 | 0.018 | 0.038 | 0.044 | 0.034 | 0.030 |
| | Yazoo River at Redwood[1] | 56 | 84-93 | 0.080 | <.010 | 0.032 | 0.040 | 0.030 | 0.020 |
| | Mississippi River at Vicksburg[1] | 38 | 84-93 | 0.130 | 0.020 | 0.058 | 0.070 | 0.050 | 0.040 |

[1] These data were collected as part of the U.S. Geological Survey National Stream Quality Accounting Network program (Alexander and others, 1996).

Mississippi River at Vicksburg, whereas in the Yazoo River it is about 27 percent based on the median concentrations presented in table 1. The dominant form of nitrogen was organic in the Yazoo River, whereas in the Mississippi River it was nitrate.

Total phosphorus concentrations are related to sediment concentration. The Yazoo River carries a heavy load of sediment, a large percentage of which is fine material (<0.63 um), to which phosphorus can adsorb. During a 6-year study of surface runoff from an 18.7-ha watershed in the Delta, planted to continuous cotton, over 77 percent of the water samples contained concentrations of total phosphorus exceeding 0.1 mg/L (McDowell and others, 1989). No phosphorus fertilizer was applied to this watershed during the study.

## LOADS OF NITROGEN AND PHOSPHORUS

The flow regime was quite different in 1996 than in 1997 (fig. 4, table 2). However, without long-term historical record on the Yazoo River it is difficult to know how well these 2 years represent long-term conditions. The USGS operates gaging stations within the Yazoo River Basin, some of them have been in operation for more than 50 years. Comparing the annual runoff for 1996 and 1997 with the long-term record indicates that 1996 was a slightly drier than

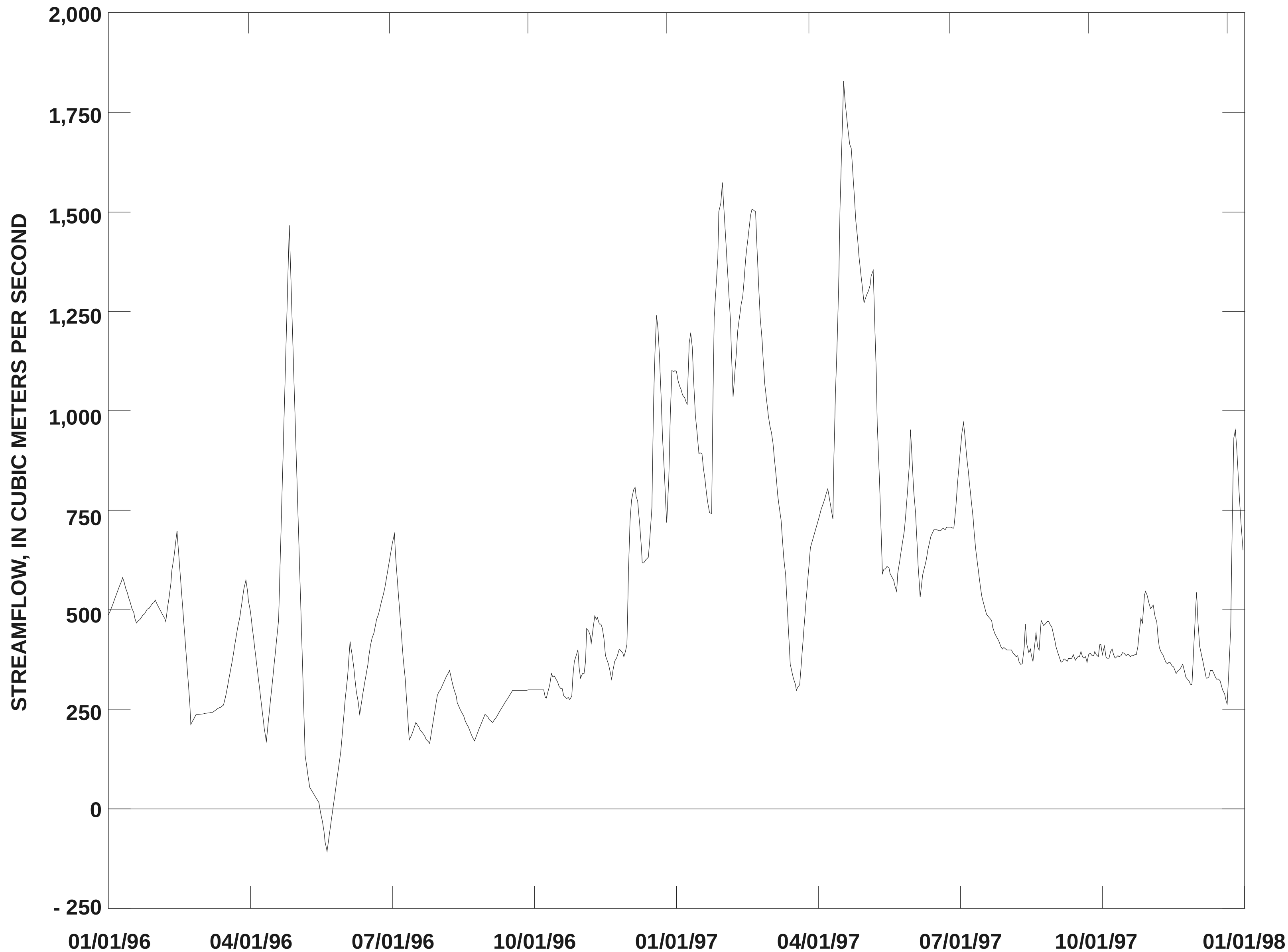


**Figure 4**. Daily mean streamflow in the Yazoo River below Steele Bayou, January 1996 through December 1997.

**Table 2**. Summary statistics for daily mean streamflow for the Yazoo River below Steele Bayou, 1996-97
[No., number of days in the year; max, maximum daily flow; min, minimum daily flow; $m^3/s$, cubic meters per second; $m^3/yr$, cubic meters per year]

| Calendar year | No. days | Sum ($m^3/yr$) | Max ($m^3/s$) | Mean ($m^3/s$) | Min ($m^3/s$) | percentile ($m^3/s$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 75th | 50th | 25th |
| 1996 | 366 | $1.27 * 10^{10}$ | 1,470 | 402 | -106[1] | 504 | 338 | 248 |
| 1997 | 365 | $2.19 * 10^{10}$ | 1,830 | 694 | 263 | 892 | 583 | 388 |

[1]Negative flow, May 1996.

**Table 3**. Coefficient estimates and goodness of fit parameters for nitrogen and phosphorus load models
[model: $\ln(\text{load}) = B_0 + B_1 \ln(Q) + B_2 T + B_3 \sin(2\pi T) + B_4 \cos(2\pi T)$ where load is estimated daily total load in kilograms per day; Q is daily mean streamflow in cubic meters per second; T is decimal time; p-value is the attained significance level in **bold** if statistically significant at the 0.05 level; $r^2$ is the coefficient of determination (variability explained by the model); s is the standard error of the regression (a measure of the dispersion of the data around the regression line in log units]

| Constituent | $B_0$ (p-value) | $B_1$ (p-value) | $B_2$ (p-value) | $B_3$ (p-value) | $B_4$ (p-value) | $r^2$ | s |
|---|---|---|---|---|---|---|---|
| Total nitrogen | 10.94 (**0.000**) | 1.1978 (**0.000**) | -0.1420 (0.125) | 0.2503 (**0.002**) | -0.0807 (0.204) | 86.2 | 0.31 |
| Nitrate as nitrogen | 9.67 (**0.000**) | 0.9643 (**0.000**) | -0.0719 (-.5798) | 0.3854 (**0.001**) | -0.400 (**0.000**) | 72.8 | 0.45 |
| Total phosphorus | 9.35 (**0.000**) | 1.2939 (**0.000**) | 0.011 (0.9196) | 0.2210 (**0.021**) | -0.0065 (0.931) | 83.9 | 0.37 |
| Orthophosphorus | 7.50 (**0.000**) | 1.2141 (**0.000**) | -0.1848 (0.1039) | -0.0403 (0.674) | -0.2710 (**0.000**) | 74.4 | 0.38 |

normal year, and 1997 was wetter than normal in the Yazoo River Basin (Plunkett and others, 1998).

The long-term annual mean streamflow (1932-96) for the Mississippi River at Vicksburg, which includes the outflow from the Yazoo River, is 16,990 $m^3/s$ (Plunkett and others, 1998). Discharge from the Yazoo River for 1996 and 1997 represents, respectively, 2.4 and 4.1 percent of the long term annual mean flow of the Mississippi River at Vicksburg for 1996 and 1997.

Note that during May 1996 (fig. 4, table 2) the flow in the Yazoo River was reversed for a short time. The ESTIMATOR load model cannot use negative flows in its calculations, therefore these values were replaced with very small positive values. This should not affect the overall load calculation as there were only 8 days of reverse flow, and the total summation of those days was –440 $m^3/s$, a little more than the daily mean flow for 1996.

The coefficient estimates and goodness of fit parameters for the nitrogen and phosphorus load models are listed in table 3. The total nitrogen and total phosphorus models fit better than the nitrate and orthophosphorus models as indicated by a higher percentage of the variability explained by the model and smaller standard errors. The better fit for total nitrogen and total phosphorus is probably related to the components of total nitrogen and total phosphorus that are suspended. Suspended material is generally better related to streamflow than are dissolved constituents such as nitrate and orthophosphorus. Using 0.05 as the level of significance, time is not a significant variable in any model. This is not surprising as the data were collected during a 2-year time period, a relatively short time period in which to distinguish changes in concentration over time from background variability. Either the sine or cosine parameters, or both were significant for every constituent, indicating some level of seasonality.

Loads of total nitrogen, nitrate, total phosphorus and orthophosphorus calculated by both methods are shown in table 4. Output from the ESTIMATOR program includes a 95 percent confidence interval (CI) and is also shown in table 4. The load plus or minus the confidence interval gives the 95 percent confidence interval for the load estimate.

The annual loads calculated by ESTIMATOR agreed well with the loads calculated by multiplying the annual mean concentration by the total annual flow. Except for the 1996 nitrate and orthophosphorus loads, the results fell within the 95 percent confidence interval calculated by ESTIMATOR.

Load calculations for the Yazoo River Basin can be compared with estimates of the average annual load for the Mississippi River. Lurry and Dunn (1997) calculated loads of total nitrogen and total phosphorus in the Mississippi River at Vicksburg for the period 1974-93. This site is just below the confluence of the Mississippi and Yazoo Rivers. Average annual loads of total nitrogen and total phosphorus were 1,397,000 and 127,000 metric tons, respectively. The loads of total nitrogen from the Yazoo River during 1996 and 1997 represent 1.3 and 2.3 percent, respectively, of the long-term average total nitrogen load in the Mississippi River. The loads of total phosphorus from the Yazoo River Basin represent 2.7 and 5.7 percent of the long-term annual load in the Mississippi River for 1996 and 1997, respectively. The Yazoo River Basin represents about 1.17 percent of the drainage area of the Mississippi River above Vicksburg; the flow of the Yazoo River contributed 2.4 and 4.1 percent of the long-term annual mean flow in the Mississippi River for 1996 and 1997, respectively. Therefore, based on these load estimates, the total nitrogen load from the Yazoo River Basin to the Mississippi River, was proportional to its discharge, whereas the total phosphorus load was slightly higher than expected, based on discharge.

**Table 4**. Results of load calculations for the Yazoo River below Steele Bayou in metric tons per year, 1996-97

[numbers in parenthesis are yields in kilograms per square kilometer per year; C • Q, annual mean concentration multiplied by total annual flow, in **bold** if within the 95 percent confidence interval of the load estimate calculated by multivariate regression; CI, 95 percent confidence interval of the load estimate]

| Constituent | Method of calculation | | | | | |
|---|---|---|---|---|---|---|
| | Multivariate regression | | | | C • Q | |
| | 1996 | CI | 1997 | CI | 1996 | 1997 |
| Total nitrogen | 18,200 (520) | ±2,700 | 32,500 (940) | 4,300 | **16,500** | **28,500** |
| Nitrate as nitrogen | 5,200 (150) | ±1,060 | 9,300 (270) | 1,800 | **6,220** | **8,100** |
| total phosphorus | 3,400 (99) | ±620 | 7,300 (210) | 1,200 | **2,790** | **6,790** |
| orthophosphorus | 580 (16.6) | ±101 | 960 (27.6) | 154 | **622** | **832** |

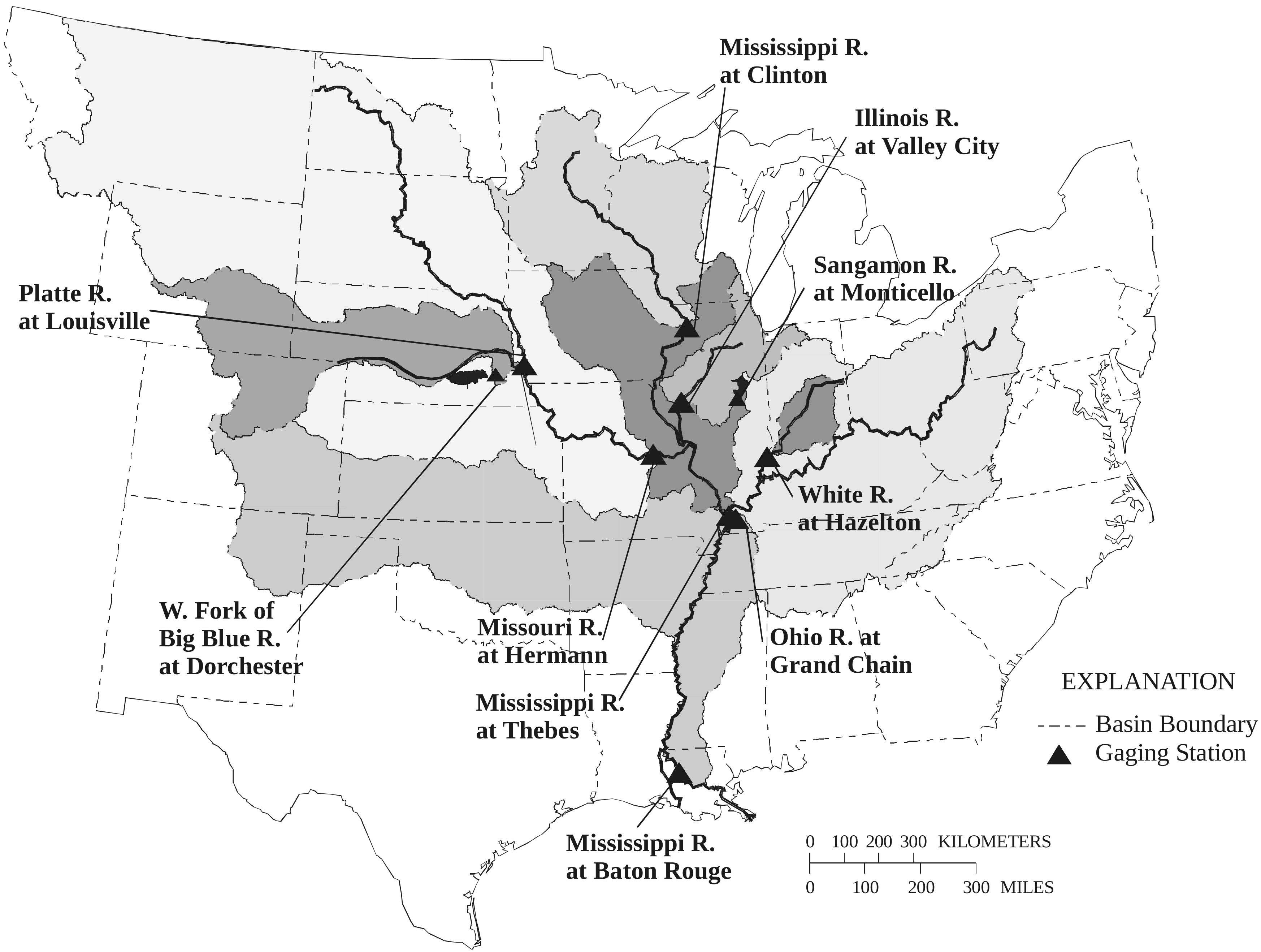


**Figure 5.** Data collection sites and associated drainage basins in Midwest study, April 1991 through March 1992 (Coupe and others,1995).

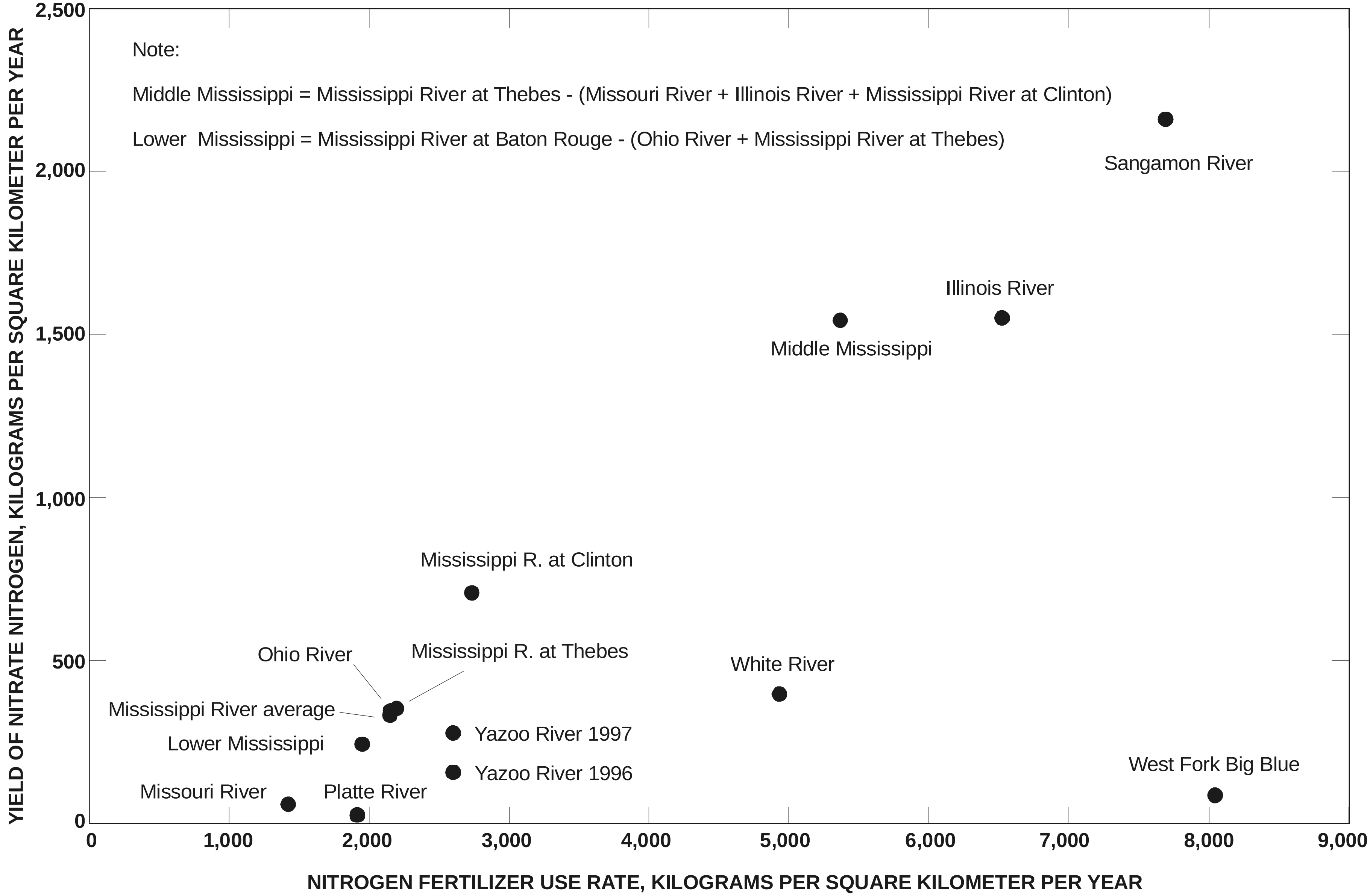


**Figure 6.** Comparison of nitrate yield to nitrogen fertilizer use for selected sub basins in the Mississippi River Basin, April 1991 through March 1992, and the Yazoo River Basin, January 1996 through December 1997 (Coupe and others, 1995).

Nitrate is an important component of total nitrogen, and some researchers believe it is the most important form of nitrogen from a biological perspective because it is readily mobile and in the form that is easily used by aquatic fauna. Long-term estimates of the annual load of nitrate discharged into the Gulf of Mexico by the Mississippi River are not available from Dunn (1996) or Lurry and Dunn (1997). However, Goolsby and others (1997) published a graph of the annual loads of nitrate to the Gulf of Mexico. The graph indicated that prior to 1972 annual loads of nitrate were less than 300,000 metric tons, but in the 1980's and 1990's the annual loads were often more than 800,000 metric tons. Battaglin and others (1994) reported that 967,000 metric tons of nitrate discharged into the Gulf of Mexico from the Mississippi River for the year beginning April 1, 1991. Using 900,000 metric tons as the estimate of the mean annual load of nitrate since 1978, the load of nitrate from the Yazoo River Basin represented 0.6 and 1.0 percent of the estimated nitrate discharged to Mississippi River and ultimately the Gulf of Mexico for 1996 and 1997, respectively. The nitrate load from the Yazoo River Basin to the Mississippi River was less than that expected based on discharge.

During 1991 and 1992, Coupe and others (1995) sampled rivers in the Midwest and the Mississippi River (fig. 5) for agricultural chemicals including nitrate. Battaglin and others (1994) calculated an annual load of nitrate from these data for each site and showed that the annual load of nitrate was linearly related to the total nitrogen used as fertilizer in the drainage basin. These data were normalized for drainage area by calculating the yield (the transport of nitrogen out of the basin by surface water) in kilograms per square kilometer per year [(kg/ $km^2$/year)], and plotted against fertilizer use rate (fig. 6). The subbasins in the Mississippi River Basin range in size from 1,430 $km^2$ to almost 3 million $km^2$ for the entire Mississippi Basin. The smaller subbasins with the more homogeneous agricultural land use (the Sangamon and the West Fork Big Blue River Basins) have the highest per unit area fertilizer use rates, but they differ in the yield of nitrate transported out of the basin, indicating a significant difference in the processes that deliver nitrate to surface water. The highest yield rates are in the central part of the Mississippi River Basin in the area known for its very high corn and soybean productivity.

The yields of nitrate from the Yazoo River Basin are less than the yields for the subbasins with comparable nitrogen use. Additionally, some basins in the Midwestern corn belt that are intensively farmed (the Sangamon and Illinois River Basins) have yields 10 to 20 times higher than yields of nitrate in the Yazoo River Basin. The nitrate yield for the Lower Mississippi River Basin falls between the nitrate yield for 1996 and 1997 for the Yazoo River Basin. The Lower Mississippi River Basin includes the Yazoo River Basin. The fertilizer use rate is less for the Lower Mississippi River Basin than for the Yazoo River Basin because the Lower Mississippi River Basin includes large areas that are less agricultural and more arid.

Agricultural lands in small areas of the Yazoo River Basin have been shown to have large nitrogen and phosphorus yields. McDowell and others (1989) measured the runoff from an 18.7-ha field that was planted to continuous cotton for 6 years. They analyzed the runoff for total nitrogen and total phosphorus and reported yields of 4,230 and 2,120 (kg/$km^2$)/yr, respectively. The nitrogen loss represented nearly 25 percent of the nitrogen applied as fertilizer. The phosphorus yields were higher than expected, as there was no phosphorus applied as fertilizer to these fields. In a study of nitrogen and phosphorus losses from soybeans in the loess hills of northern Mississippi the yield rates for total nitrogen and total phosphorus were 4,640 and 1,700 (kg/$km^2$)/yr, respectively (McDowell and others, 1978). These large yields were from small single cropped watersheds and were much higher than the yields from the Yazoo River Basin for 1996 and 1997 as a whole. This is probably because of differences of scale. These small watersheds had almost 100 percent of their basins in agriculture, whereas only about 60 percent of the land in the Yazoo River Basin is used for agriculture.

## SUMMARY

Increased nutrient loading to the Gulf of Mexico from off-continent flux has been identi fied as contributing to the increase in the areal extent of the low dissolved oxygen zone that develops annually off the coast of Louisiana and Texas. The proximity of the Yazoo River Basin in northwestern Mississippi to the Gulf of Mexico and the intensive agriculture in the basin have lead to speculation that the Yazoo River Basin contributes a disproportionate amount of nitrogen and phosphorus to the Mississippi River and ultimately the Gulf of Mexico.

The concentrations of nitrogen and phosphorus in the Yazoo River during this study (1996-97) were similar to those in the Yazoo River during an earlier study (1984-93). The mean and median concentrations of total nitrogen and nitrate in water samples from the Yazoo River are about 1 mg/L less than those for the Mississippi River at Vicksburg. Mean and median total phosphorus concentrations were higher in the Yazoo River than in the Mississippi River; orthophosphorus concentrations are nearly equal for the two rivers.

The streamflow from the Yazoo River for 1996 and 1997 represented, respectively, about 2.4 and 4.1 percent of the long-term annual mean flow in the Mississippi River at Vicksburg. In the Yazoo River Basin, 1996 was a drier than normal year, and 1997 was wetter than normal.

Annual loads of total nitrogen, nitrate, total phosphorus, and orthophosphorus from the Yazoo River Basin for 1996 and 1997 were calculated using two methods: a multivariate regression and a simple product of the mean concentration by the total annual flow and appropriate conversion factors. Results from the simple product were within the 95 percent confidence interval of the load calculated by the multivariate regression method in all cases.

Annual loads from the Yazoo River were compared to the long-term historical loads in the Mississippi River at Vicksburg, and it was demonstrated that the annual contribution of total nitrogen, nitrate, and total phosphorus from the Yazoo River Basin was 2.3, 1.0, and 5.7 percent or less, respectively for 1996 and 1997. Therefore, the total nitrogen load from the Yazoo River Basin into the Mississippi River and ultimately the Gulf of Mexico was proportional to its discharge, the nitrate load was less than expected based on discharge, whereas the total phosphorus load was slightly higher than expected based on discharge.

The yield of nitrate from the Yazoo River Basin for 1996 and 1997 was less than the yields of nitrate from subbasins in the Mississippi River Basin during April 1991 – March 1992, with comparable nitrogen fertilizer use rates. The yield for the Yazoo River Basin was much less than the yield for some intensively agricultural subasins in the corn belt of the Midwest.

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