Table of Contents

# STREAMFLOW AND NITROGEN AND PHOSPHORUS CONCENTRATIONS AND LOADS FOR THE YAZOO RIVER BELOW STEELE BAYOU NEAR LONG LAKE, MISSISSIPPI, 1996-2000

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## INTRODUCTION

The annual recurrence of a zone of low dissolved-oxygen concentration (hypoxia) in the Gulf of Mexico off the coast of Louisiana and Texas has been documented, and a summary of available historical information is provided in Rabalais, Turner, and Wiseman (1997). The hypoxic zone (dissolved-oxygen concentration less than 2 mg/L) may cause a disruption of the fishing industry as mobile fauna move away from the zone or die because of low dissolved- oxygen concentrations in the water. The hypoxic zone occurs each year during late spring and summer following seasonal high inflows of freshwater and nutrients to the Gulf of Mexico. During the period 1985-92, the size of the hypoxic zone was estimated to be about 3,860 $mi^2$. Following the 1993 flood on the Missouri and upper Mississippi Rivers, the hypoxic zone covered about 16,560 $mi^2$; during the period 1994-96, the hypoxic zone was reported to be equal to or greater than the zone's size following the 1993 flood (Rabalais, Turner, and Wiseman 1997).

Since World War II, the increased amounts of nitrogen and phosphorus fertilizer used for agriculture have been implicated in the increase in the size of the hypoxic zone (Justic et al. 1993; Rabalais et al. 1996; Turner and Rabalais 1991). 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 as a source of nitrogen and phosphorus in the Mississippi River 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 Mississippi River. Alexander, Smith, and Schwartz (1997) used model results to identify the area downstream of the confluence of the Ohio and Mississippi Rivers, including the Yazoo River Basin, as a significant source of nitrogen to the Gulf of Mexico, although other researchers (Goolsby and Battaglin 1993) did not reach this conclusion. The U.S. Environmental Protection Agency (USEPA) has concerns that more nitrogen may be contributed from farmland in the Yazoo River Basin on a per-unit-area basis 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 historical nitrogen and phosphorus loads from the Yazoo River Basin.

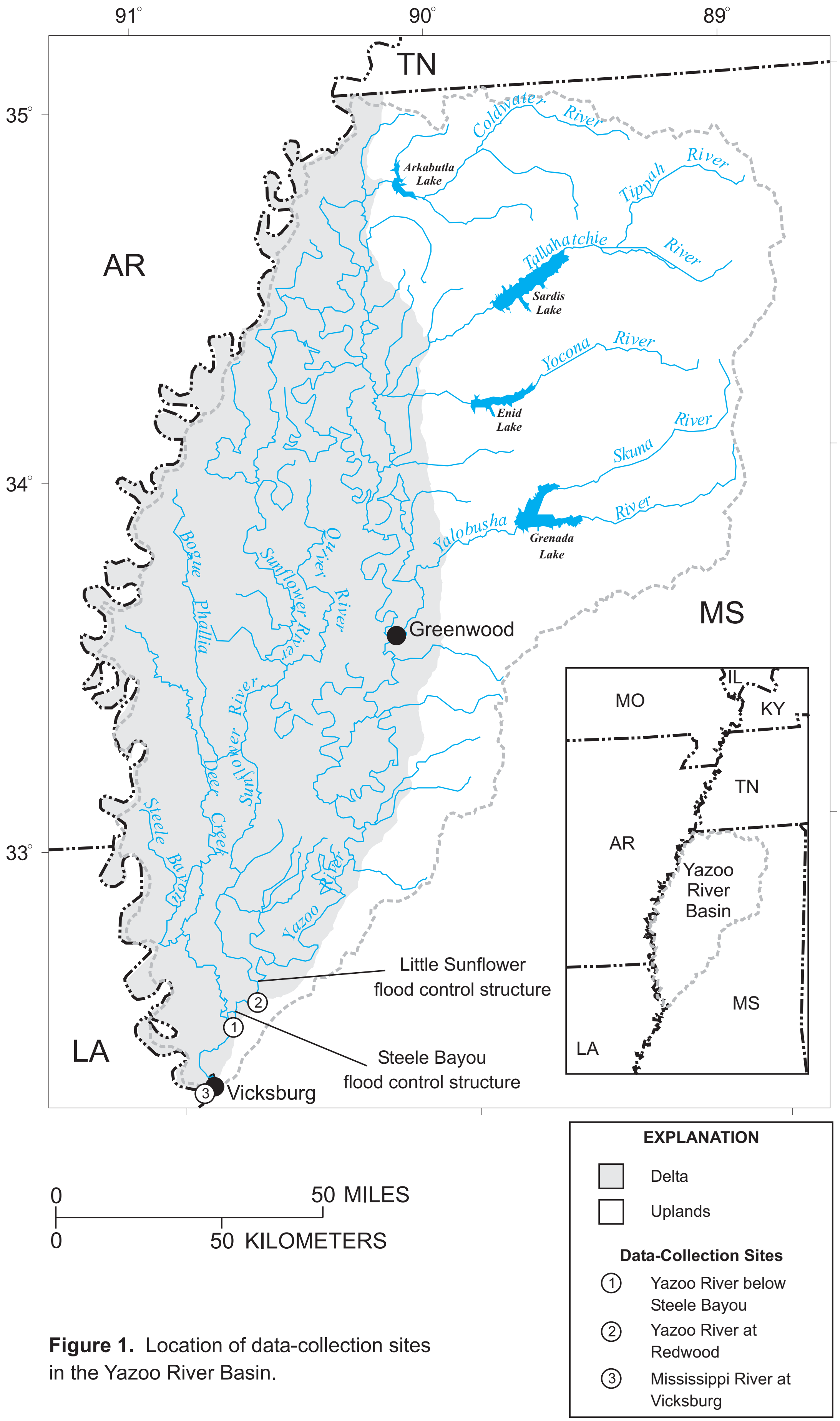


**Figure 1.** Location of data-collection sites in the Yazoo River Basin.

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 quantity and quality data that were collected are sufficient to calculate annual loads of nitrogen and phosphorus discharged from the Yazoo River to the Mississippi River from 1996 through 2000.

## Purpose and Scope

This report presents data concerning streamflow and concentrations and loads of nitrogen and phosphorus in the Yazoo River. The concentrations of nitrogen and phosphorus in the Yazoo River are compared to data collected earlier upstream of the current sampling site as well as data collected from the Mississippi River. The water-quality data are based on samples collected from the Yazoo River from February 1996 through December 2000. Annual loads of nitrogen and phosphorous were computed by using ESTIMATOR software.

## Description of the Study Area

The Yazoo River Basin, the largest river basin in Mississippi, encompasses about 37,000 $km^2$ (13,400 $mi^2$) (fig. 1). The basin is divided almost equally between lowlands in the Mississippi Alluvial Plain (locally 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 Yazoo River is formed by the confluence of the Tallahatchie and Yalobusha Rivers (fig. 1) and drains the entire Mississippi Alluvial Plain in Mississippi. The Yazoo River flows southward 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 in the northeastern part of the Yazoo River Basin. These reservoirs control the runoff from approximately two-thirds of the uplands of the Yazoo River Basin (about 4,400 $mi^2$).

Two floodgates control runoff from within the Delta (fig. 1), one at the mouth of Steele Bayou and one at the mouth of the Little Sunflower River. The U.S. Army Corps of Engineers (USACOE) operates these structures to help prevent extensive flooding in the lower reaches of the Yazoo River Basin. The sampling site is located on the Yazoo River approximately 1.5 mi downstream from the Steele Bayou control structure and approximately 9.5 mi from the Mississippi River (fig. 1).

During extreme low-flow conditions on the Mississippi River, the lower reaches of the Yazoo River flow freely. During normal low and medium flows on the Mississippi River, the flow in the lower reaches of the Yazoo River is affected by backwater from the Mississippi River. During high-flow conditions on the Mississippi River, flow in the lower reaches of the Yazoo River below Steele Bayou can be bi-directional or fully reversed.

## METHODS

The computation of continuous streamflow and the subsequent computation of nutrient loads for the lower Yazoo River requires an understanding of the river's complex flow regime. The non-uniform, varied streamflow conditions in the lower reaches of the Yazoo River have historically made the accurate measurement and computation of streamflow very difficult (Manning 1997; Turnipseed, Cooper, and Davis 1998). Remote sensing, acoustic, and conventional discharge measurement techniques were used to compute streamflow at the gaging station (Turnipseed, Cooper, and Davis 1998).

This section describes the methods used to collect and compute streamflow data, collect and analyze water-quality samples, and compute nutrient loads for the Yazoo River below Steele Bayou.

### Nutrient Data Collection and Analysis

Samples from the Yazoo River were collected from a boat by using established velocity-weighted, depth- and width-integrating techniques described by Shelton (1994). Sample collection began in February 1996 and continued on a biweekly schedule through January 1998. Samples were collected monthly from April 1998 through September 1999 and semi-monthly from October 1999 through December 2000. Up to 9 L of water were collected for each sample. Immediately after collection, the samples were subsampled by 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, CO for analysis by procedures described by Fishman and Friedman (1989). Water samples were analyzed for total ammonia, nitrite, nitrite plus nitrate, dissolved ammonia and organic nitrogen, total ammonia and organic nitrogen, total phosphorus, dissolved phosphorus, and orthophosphorus.

About 15 percent of the samples were quality-control samples, which included field equipment blanks to measure possible sample contamination and replicate samples to measure precision. Quality-control data collected during 1996 and 1997 indicated low-level contamination of some blanks for ammonia, nitrate, phosphorus, dissolved phosphorus, orthophosphate, and especially nitrite (Coupe 2001). The concentration and the frequency of detection were not of environmental significance for most constituents in this study. Precision data indicated that the relative percent differences (RPD) for the constituents of interest were all less than 20 percent, and most were less than 10 percent (Coupe 2001).

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

The multivariate regression calculations were made by using the ESTIMATOR program (Cohn et al. 1992). ESTIMATOR uses multivariate regression and the Minimum Variance Unbiased Estimator (MVUE) procedure to correct for log-transformation bias (Cohn et al. 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 (Goolsby et al. 1999). The regression equation for each constituent has the form

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

where

$C$ = concentration
$B_0$ = intercept
$B_1$, $B_2$, $B_3$, $B_4$ = regression coefficients
$Q$ = daily mean streamflow
$T$ = time, in decimal years, and
$p$ = 3.1416.

A second method of determining annual loads is to multiply the total annual volume of water discharged from 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 by 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).

## STREAMFLOW

During the study period (1996-2000), the annual daily mean discharge for the Yazoo River ranged from 12,000 $ft^3/s$ in 2000, to 24,600 $ft^3/s$ in 1997 (table 1). The average daily discharge for the 5-year period was 17,100 $ft^3/s$. The absence of long-term discharge record on the Yazoo River precludes knowing how well these discharges compare with long term discharges.

The long-term average daily discharge (1932-99) for the Mississippi River at Vicksburg, which includes the outflow from the Yazoo River, is 604,200 $ft^3/s$ (Plunkett et al. 1999). The average daily discharge for 1996-2000 was 617,000 $ft^3/s$ (Plunkett et al. 1997; Plunkett et al. 1998; Plunkett et al. 1999; Plunkett et al. 2000; Noble 2001). Discharge from the Yazoo River represented 2.8 percent of the flow of the Mississippi River at Vicksburg during the study period.

**Table 1**. Summary statistics for daily mean streamflow for the Yazoo River below Steele Bayou, 1996-2000

[No., number of days in the year; Max, maximum daily flow; Min, minimum daily Flow; $ft^3/s$, cubic feet per second]

| Calendar Year | No. days | Max ($ft^3/s$) | Mean ($ft^3/s$) | Min ($ft^3/s$) | Percentile ($ft^3/s$) 75th | 50th | 25th |
|---|---|---|---|---|---|---|---|
| 1996 | 366 | 51,800 | 14,200 | -3,750[1] | 51,800 | 12,000 | 8,760 |
| 1997 | 365 | 64,600 | 24,600 | 9,560 | 31,500 | 20,600 | 14,000 |
| 1998 | 365 | 62,400 | 17,400 | 920 | 29,000 | 10,500 | 7,260 |
| 1999 | 365 | 58,800 | 17,300 | 3,800 | 27,600 | 9,460 | 7,270 |
| 2000 | 366 | 71,000 | 12,000 | 690 | 11,500 | 5,705 | 4,120 |

[1]Negative flow, May 1996

During May 1996 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. The substitution of the small values should not affect the overall load calculation because there were only 8 days with negative flow and these flows were small compared to the annual (total) flow.

## NUTRIENTS

### Concentrations of Nitrogen and Phosphorus

Total nitrogen as used in this report is the sum of total ammonia plus organic nitrogen and nitrite plus nitrate. The concentrations of total nitrogen in water samples collected from the Yazoo River below Steele Bayou during February 1996 through December 2000 ranged from 0.54 to 3.3 mg/L, with a mean concentration of 1.3 mg/L (table 2). The lowest concentrations generally were measured during the low-flow period, August through November, of each year (fig. 2). The total nitrogen concentrations generally increased as discharge increased (fig. 3). The nitrite plus nitrate as nitrogen (throughout this report referred to as nitrate) concentrations in samples collected from the Yazoo River ranged from 0.05 to 1.2 mg/L, with a mean concentration of 0.44 mg/L. Nitrate was not well correlated with discharge (fig. 3), but there is a seasonal component as the highest nitrate concentrations occurred during the spring (fig. 2), corresponding to fertilizer application.

Total phosphorus concentrations in samples collected from the Yazoo River from February 1996 through December 2000 ranged from 0.11 to 0.94 mg/L, with a mean concentration of 0.29 mg/L (table 2). The lowest concentrations were measured during the extended low-flow period in late summer and early fall (fig. 2). Discharge was correlated with total phosphorus, as higher total phosphorus concentrations corresponded to higher discharge (fig. 3). The orthophosphorus concentrations in water samples collected from the Yazoo River below Steele Bayou ranged from below the 0.01 mg/L reporting limit to 0.10 mg/L (table 2), with a mean concentration of 0.043 mg/L. The lowest orthophophorus concentrations generally occurred in the late summer through early winter (fig. 2). For statistical purposes, the reporting limit was used as the concentration for samples with concentrations less than the reporting limit (Helsel and Hirsch, 1992).

The concentrations of total nitrogen, nitrate, total phosphorus, and orthophosphorus collected from the Yazoo River as part of this study were compared with the 10 years of data (1984-93) collected as part of the USGS National Stream Quality Accounting Network (NASQAN) program (table 2) (Alexander et al. 1996). The NASQAN samples were collected from the Yazoo River at Redwood, MS, and from the Mississippi River at Vicksburg, MS. The Yazoo River at Redwood sampling site is upstream from the current sampling site at the Yazoo River gage (fig. 1)

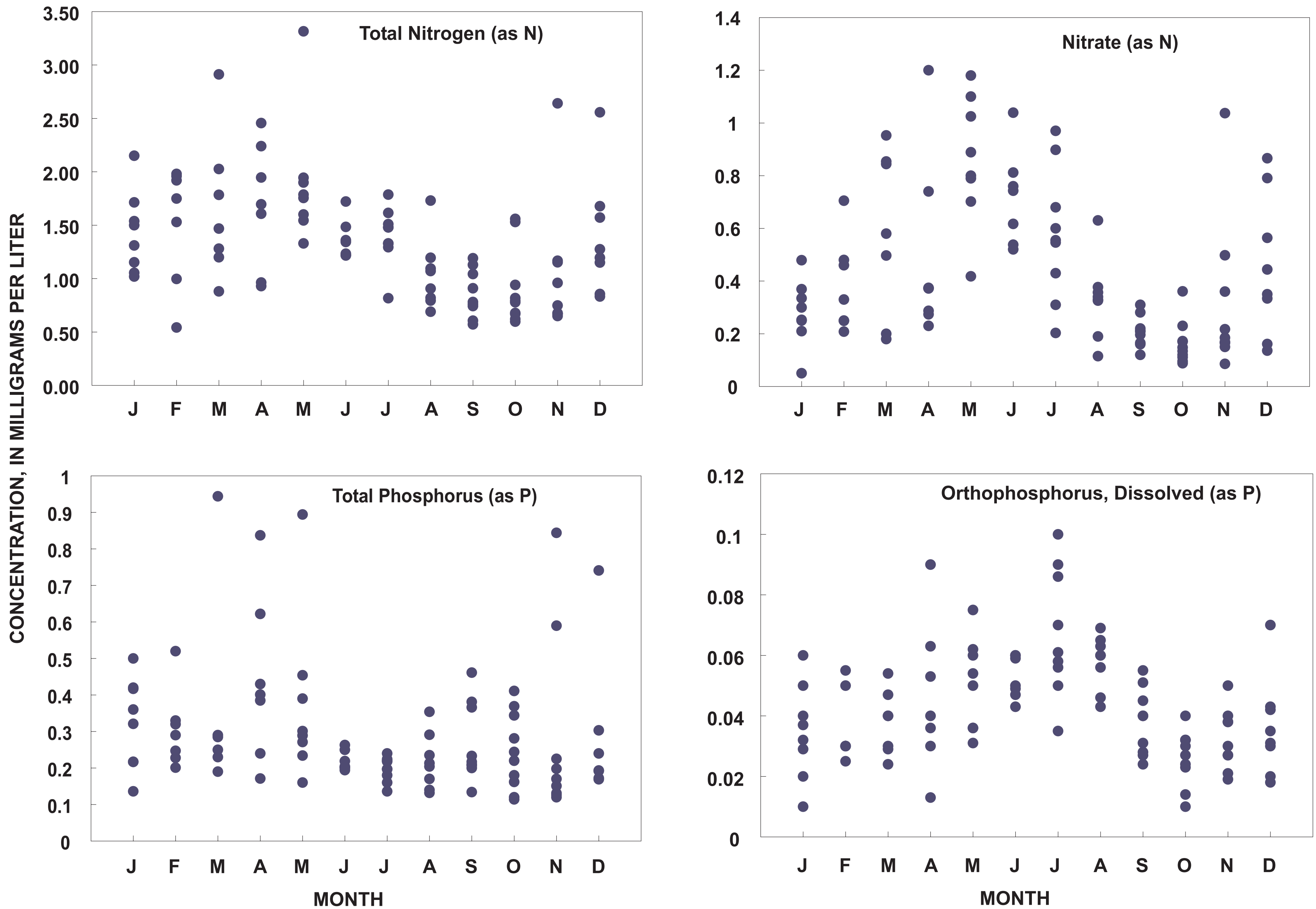


**Figure 2.** Concentrations of total nitrogen, nitrate, total phosphorus, and orthophosphorus, by month, in water samples from the Yazoo River below Steele Bayou, Mississippi, February 1996 through December 2000.

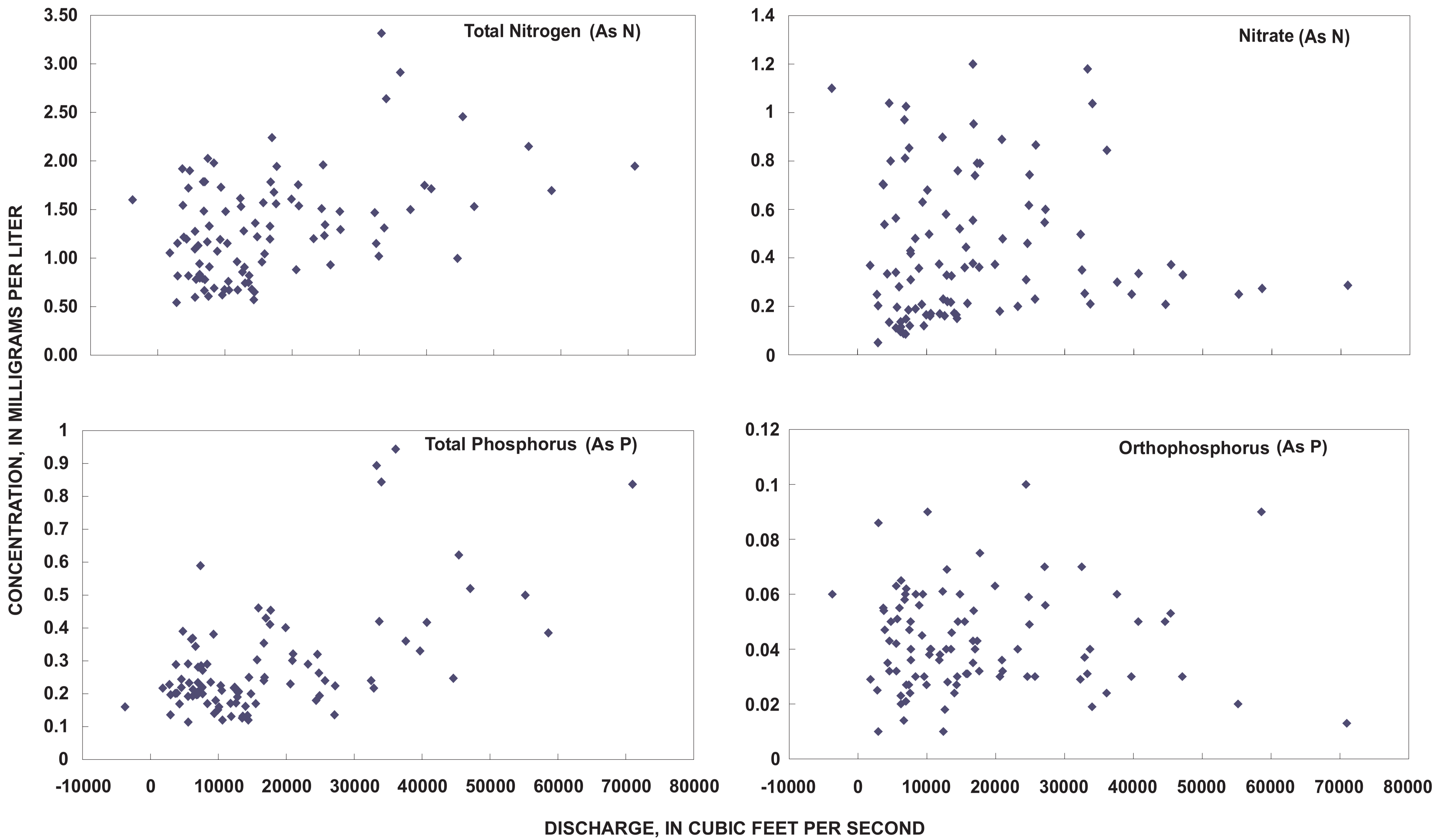


**Figure 3.** Concentrations of total nitrogen, nitrate, total phosphorus, and orthophosphorus, with discharge in water samples from the Yazoo River below Steele Bayou, Mississippi, February 1996 through December 2000.

and above the confluence with Steele Bayou. A summary of the NASQAN data from 1984 through 1993 and the NAWQA data from 1996 through 2000 is shown in table 2. The mean and median concentrations for total nitrogen and nitrate for both of the Yazoo River sites are about 1 mg/L less than the corresponding mean and median concentrations in the Mississippi River. Mean and median total phosphorus concentrations were higher in the Yazoo River than in the Mississippi River. Mean and median orthophosphorus concentrations were slightly lower in the Yazoo River than in the Mississippi River.

Mueller et al. (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 in water samples collected from the Yazoo River for this study were less than 0.61 mg/L. The low levels of nitrate in the Yazoo River Basin probably are 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 was about 68 percent of the total nitrogen in the Mississippi River at Vicksburg, whereas in the Yazoo River nitrate was about 28 percent based on the median concentrations presented in table 2. The dominant form of nitrogen was organic in the Yazoo River and nitrate in the Mississippi River.

Mueller et al. (1995) also indicated that concentrations of total phosphorus less than 0.1 mg/L could be considered a general baseline for indicating the absence of significant anthropogenic effects. All of the 95 water samples collected during 1996 2000 and analyzed for total phosphorus had concentrations greater than 0.1 mg/L. Total phosphorus concentrations are related to sediment concentration. The Yazoo River carries a large sediment load, a large percentage of which is fine material (<0.63 m), to which phosphorus can adsorb. The high phosphorus concentrations could be related to the natural fertility of the Delta soils. For example, during a 6-year study of surface runoff from an 46-acre watershed in the Delta planted in cotton, more than 77 percent of the water samples contained concentrations of total phosphorus exceeding 0.1 mg/L (McDowell, Willis, and Murphree 1989). No phosphorus fertilizer was applied to this watershed during the study.

**Table 2**. 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 | Max | Min | Mean | Percentile | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 75th | 50th | 25th |
| Total Nitrogen | Yazoo River below Steele Bayou | 97 | 1996-2000 | 3.3 | 0.54 | 1.3 | 1.6 | 1.2 | 0.88 |
| | Yazoo River at Redwood[1] | 54 | 1984-93 | 5.0 | 0.49 | 1.3 | 1.5 | 1.1 | 0.91 |
| | Mississippi River at Vicksburg[1] | 38 | 1984-93 | 3.8 | 1.1 | 2.3 | 2.6 | 2.2 | 1.9 |
| Nitrate | Yazoo River below Steele Bayou | 98 | 1996-2000 | 1.2 | 0.05 | 0.44 | 0.61 | 0.34 | 0.20 |
| | Yazoo River at Redwood | 56 | 1984-93 | 1.1 | 0.05 | 0.34 | 0.48 | 0.26 | 0.20 |
| | Mississippi River at Vicksburg | 38 | 1984-93 | 2.7 | 0.70 | 1.5 | 1.73 | 1.5 | 1.10 |
| Total phosphorus | Yazoo River below Steele Bayou | 96 | 1996-2000 | 0.94 | 0.11 | 0.29 | 0.33 | 0.23 | 0.19 |
| | Yazoo River at Redwood | 56 | 1984-93 | 0.83 | 0.01 | 0.20 | 0.23 | 0.17 | 0.13 |
| | Mississippi River at Vicksburg | 38 | 1984-93 | 0.38 | 0.04 | 0.16 | 0.21 | 0.16 | 0.11 |
| Ortho-phosphorus | Yazoo River below Steele Bayou | 97 | 1996-2000 | 0.100 | <0.01 | 0.043 | 0.055 | 0.040 | 0.030 |
| | Yazoo River at Redwood | 56 | 1984-93 | 0.080 | <.010 | 0.032 | 0.040 | 0.030 | 0.020 |
| | Mississippi River at Vicksburg | 38 | 1984-93 | 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).

Table 2b. Concentrations of ammonia + organic dissolved nitrogen, ammonia + total nitrogen, dissolved ammonia, dissolved nitrite, and dissolved phosphorus from water samples collected at the Yazoo River below Steele Bayou, 1996 – 2000

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

| Constituent | No. | Year | Max | Min | Mean | Percentiles | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 75th | 50th | 25th |
| Nitrogen, Ammonia + Organic Dissolved | 97 | 1996 - 2000 | 1.1 | 0.174 | 0.398 | 0.443 | 0.338 | 0.252 |
| Nitrogen, Ammonia + Organic, Total | 97 | 1996 - 2000 | 2.135 | 0.293 | 0.896 | 1.101 | 0.778 | 0.611 |
| Nitrogen, Ammonia, Dissolved | 97 | 1996 - 2000 | 0.287 | <0.015 | 0.059 | 0.081 | 0.045 | 0.023 |
| Nitrogen, Nitrite Dissolved | 97 | 1996 - 2000 | 0.115 | <0.01 | 0.019 | 0.020 | 0.012 | 0.01 |
| Phosphorus, Dissolved | 97 | 1996 - 2000 | 0.213 | <0.01 | 0.051 | 0.064 | 0.043 | 0.030 |

## Loads of Nitrogen and Phosphorus

The coefficient estimates and goodness of fit parameters for the nitrogen and phosphorus load models are listed in table 3. The total nitrogen model fit better than the nitrate, total phosphorus, and orthophosphorus models as indicated by a higher percentage of the variability and smaller standard errors. 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 5-year period, a relatively short period in which to distinguish changes in concentration over time from background variability. Sine or cosine parameters, or both, were significant for total nitrogen, nitrate, and orthophosphorus, indicating some level of seasonality.

**Table 3**. Coefficient estimates and goodness of fit parameters for nitrogen and phosphorus load models
[model: $\ln(\text{load}) = B_0 + B_1 \ln(Q) + B_2T + B_3\sin(2\pi T) + B_4\cos(2\pi T)$ 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 | 10.82 (**0.000**) | 1.1013 (**0.000**) | -0.0051 (0.874) | 0.3076 (**0.000**) | -0.1086 (**0.0031**) | 88.5 | 0.30 |
| nitrate as nitrogen | 9.53 (**0.000**) | 0.9263 (**0.000**) | -0.0438 (-.3703) | 0.4864 (**0.000**) | -0.4415 (**0.000**) | 78.1 | 0.47 |
| total phosphorus | 9.22 (**0.000**) | 1.1932 (**0.000**) | 0.0301 (0.5351) | 0.1209 (0.176) | -0.0092 (0.903) | 75.4 | 0.46 |
| ortho-phosphorus | 7.39 (**0.000**) | 1.1114 (**0.000**) | -0.0231 (0.5499) | 0.0710 (0.316) | -0.3142 (**0.000**) | 80.9 | 0.36 |

Loads of total nitrogen, nitrate, total phosphorus and orthophosphorus calculated by both methods are listed 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.

**Table 4**. Results of load calculations for the Yazoo River below Steele Bayou in metric tons per year, 1996-2000

[CI, 95 percent confidence interval of the load estimate; $Q^{\cdot}C$, annual mean concentration multiplied by total annual flow and a conversion factor, in bold if within the 95 percent confidence interval of the load estimate calculated by multivariate regression]

| Constituent | Annual nutrient loads | | | | |
|---|---|---|---|---|---|
| | 1996 | 1997 | 1998 | 1999 | 2000 |
| total nitrogen | 16,600 | 32,900 | 22,300 | 22,800 | 15,800 |
| CI | ±1,680 | ±3,020 | ±2,160 | ±2,400 | ±2,160 |
| $Q^{\cdot}C$ | **16,500** | 28,500 | 18,500 | 19,500 | **15,800** |
| nitrate as nitrogen | 5,420 | 9,840 | 6,170 | 6,270 | 4,390 |
| CI | ±839 | ±1,410 | ±929 | ±1,030 | ±928 |
| $Q^{\cdot}C$ | **6,220** | 8,100 | **6,660** | **5,810** | 5,360 |
| total phosphorus | 3,390 | 6,760 | 4,810 | 4,920 | 3,470 |
| CI | ±521 | ±965 | ±727 | ±802 | ±735 |
| $Q^{\cdot}C$ | 2,790 | **6,790** | 3,420 | **4,520** | **3,810** |
| Orthophosphorus | 552 | 1,020 | 646 | 639 | 442 |
| CI | ±65 | ±114 | ±77 | ±82 | ±82 |
| $Q^{\cdot}C$ | 622 | 832 | 748 | **595** | **452** |

The loads calculated by multiplying the annual mean concentration by the total annual flow ($Q^{\cdot}C$) agreed well with the annual loads calculated by ESTIMATOR using the 2-year data set and fell within the 95 percent confidence interval for all eight cases (table 5). However, with the data collected from 1998 through 2000 added to the data set, the loads calculated by multiplying the annual mean concentration by the annual flow fell within the 95 percent confidence interval calculated by ESTIMATOR for only 3 of 8 cases for 1996-97, and 10 of the 20 cases for 1996-2000 (table 4). The reduced likelihood of the $Q^{\cdot}C$ load falling within the 95 percent confidence interval of the ESTIMATOR model is due the reduction in size of the confidence interval that is associated with larger data sets, rather than a significant change in the ESTIMATOR loads.

The loads computed by ESTIMATOR for 1996-97 changed slightly from the 2-year data set to the 5-year data set. The loads calculated by ESTIMATOR for 1996-97 using the 2-year data set fell within the 95 percent confidence interval of the loads calculated using the 5-year data set, and the loads calculated using the 5-year data set were within the 95 percent confidence interval of the loads from the 2-year data set. However, the size of the confidence interval was reduced by 20 to 40 percent with the additional data (table 5).

**Table 5**. Results of load calculations for the Yazoo River below Steele Bayou in metric tons per year, for 1996 and 1997 using models based on 2- and 5-year data sets

[Q·C, 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 | | | | Q·C | | | |
| | 1996[1] | 1996[2] | 1997[1] | 1997[2] | 1996[1] | 1996[2] | 1997[1] | 1997[2] |
| total nitrogen | 18,200 | 16,600 | 32,500 | 32,900 | **16,500** | **16500** | **28,500** | 28,500 |
| CI | ±2,700 | ±1,680 | ±4,300 | ±3,020 | | | | |
| nitrate as nitrogen | 5,200 | 5,420 | 9,300 | 9,840 | **6,220** | **6220** | **8,100** | 8,100 |
| CI | ±1,060 | ±839 | ±1,800 | ±1,410 | | | | |
| total phosphorus | 3,400 | 3,390 | 7,300 | 6,760 | **2,790** | 2790 | **6,790** | **6,790** |
| CI | ±620 | ±521 | ±1,200 | ±965 | | | | |
| Orthophosphorus | 580 | 552 | 960 | 1,020 | **622** | 622 | **832** | 832 |
| CI | ±101 | ±65 | ±154 | ±114 | | | | |

[1]As reported by Coupe (1998), computed using 2-year data set (1996-97).
[2]Loads computed using 5-year data set (1996 – 2000).

The loads computed by ESTIMATOR for 1996-97 changed slightly from the 2-year data set to the 5-year data set. The loads calculated by ESTIMATOR for 1996-97 using the 2-year data set fell within the 95 percent confidence interval of the loads calculated using the 5-year data set, and the loads calculated using the 5-year data set were within the 95 percent confidence interval of the loads from the 2-year data set. However, the size of the confidence interval was reduced by 20 to 40 percent with the additional data (table 5).

Load calculations for the Yazoo River Basin can be compared with estimates of the average annual load for the Mississippi River. Goolsby et al. (1999) calculated loads of total nitrogen, nitrate, total phosphorus, and orthophosphorus from the Mississippi River into the Gulf of Mexico for the period 1980-96. Average annual loads for total nitrogen, nitrate, total phosphorus, and orthophosphorus were 1,567,900; 952,700; 136,500; and 41,770 metric tons, respectively. The average annual loads of total nitrogen, nitrate, total phosphorus, and ortho phosphorus from the Yazoo River for 1996-2000 were 22,800; 6,420; 4,670; and 660 metric tons, respectively, which represent 1.4, 0.7, 3.4, and 1.6 percent of the long-term average loads in the Mississippi River. 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 2.8 percent annual flow in the Mississippi River for 1996-2000. Based on these load estimates and computed discharges, the total nitrogen, nitrate, and orthophosphorus loads in the Yazoo River were less than expected, whereas the total phosphorus load was higher than expected based on discharge.

**SUMMARY**

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.

Streamflow for the Yazoo River below Steele Bayou is affected by backwater from the Mississippi River. Flow in the Yazoo River below Steele Bayou is non-uniform and varying, with bi-directional and reverse flows possible. Streamflow was computed by using remote sensing and acoustic and conventional discharge and velocity measurement techniques.

The average streamflow from the Yazoo River for 1996 - 2000 represented about 2.8 percent of the flow in the Mississippi River at Vicksburg.

Water samples were collected biweekly from February 1996 through January 1998, monthly from April 1998 through September 1999, and semi-monthly from October 1999 through December 2000. 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 orthophosphorus.

The concentrations of nitrogen and phosphorus in the Yazoo River during this study (1996-2000) 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.

Annual loads of total nitrogen, nitrate, total phosphorus, and orthophosphorus from the Yazoo River Basin for 1996-2000 were calculated by using two methods: a multivariate regression; and a simple product of the mean concentration, the total annual flow, and appropriate conversion factors. Results for the 1996 and 1997 loads and confidence intervals computed using a 5-year data set were compared to results for the same period obtained using a 2-year data set. The computed loads did not change significantly, but the confidence intervals given using the 5-year data set were between 20 and 40 percent lower than those given from the 2-year data set. Results from the simple product with conversion factors were within the 95 percent confidence interval of the load calculated by the multivariate regression method in 10 of 20 cases.

Average annual loads from the Yazoo River for 19962000 were compared to the average annual loads from the Mississippi River into the Gulf of Mexico. The contribution of total nitrogen, nitrate, total phosphorus, and orthophosphorus from the Yazoo River Basin were 1.4, 0.7, 3.4, and 1.6 percent, respectively, for 1996-2000. Because the Yazoo River contributed about 2.8 percent of the annual discharge of the Mississippi River at Vicksburg during the study period, the total nitrogen, nitrate, and orthophosphorus loads in the Yazoo River were lower than expected, and the total phosphorus load was higher than expected.

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Table of Contents