Streamflow and nutrient data for the Yazoo River below Steele Bayou near Long Lake, Mississippi, 1996–2000

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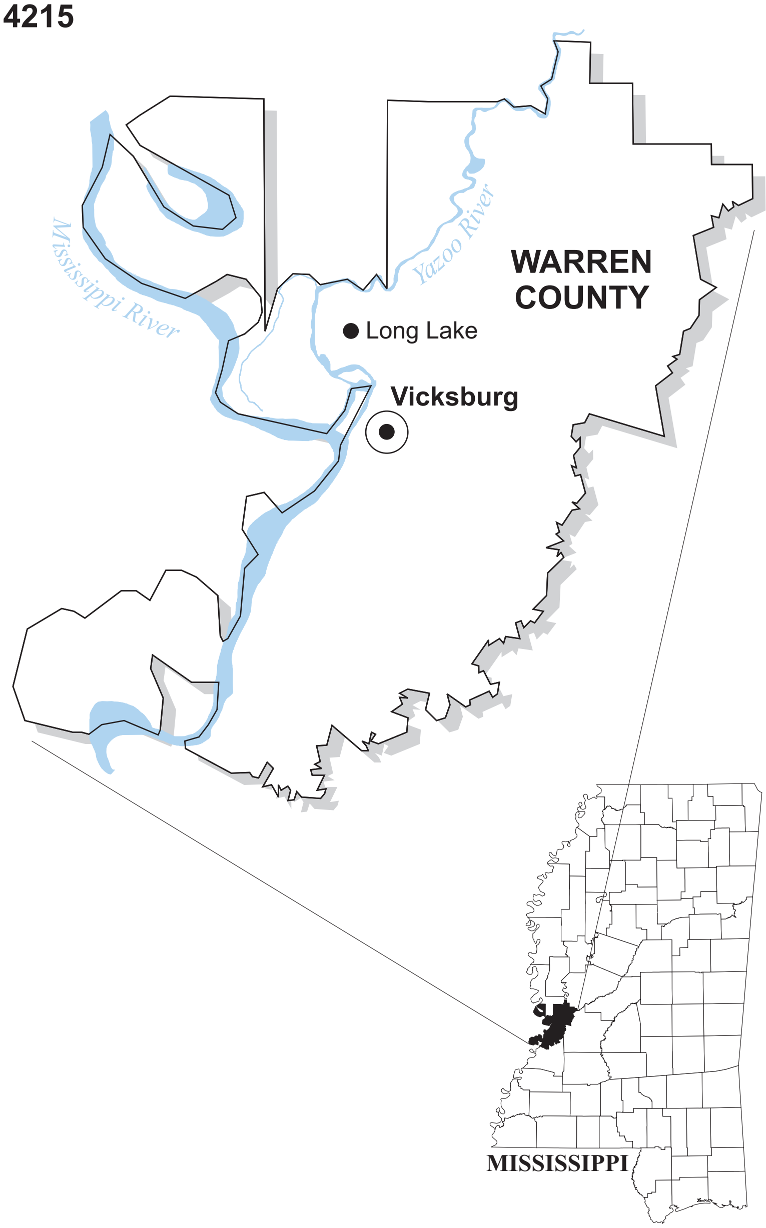
STREAMFLOW AND NUTRIENT DATA FOR THE YAZOO RIVER BELOW STEELE BAYOU NEAR LONG LAKE, MISSISSIPPI, 1996-2000

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 02–4215



National Water-Quality Assessment Program
Mississippi Embayment Study Unit

Cover: Measuring discharge on the Yazoo River using a boat-mounted acoustic Doppler current profiler (ADCP).

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By M.S. Runner, D.P. Turnipseed, and R.H. Coupe

U.S. Geological Survey

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National Water-Quality Assessment Program

Pearl, Mississippi
September 2002

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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http://water.usgs.gov/nawqa/

FOREWORD

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

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

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

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

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

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

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
gallon (gal)	3.785	liter
foot (ft)	0.3048	meter
acre	0.4047	hectare
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
pound, avoirdupois (lb)	0.4536	kilogram
pound, avoirdupois (lb)	0.0004536	metric ton
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound per acre (lb/acre)	112.1	kilogram per square kilometer
pound per acre per year [(lb/acre)/yr]	112.1	kilogram per square kilometer per year

Acronyms:

ADCP, *Acoustic doppler current profiler*

AVM, *Acoustic velocity meter*

CI, *Confidence interval*

DCP, *Data collection platform*

dpi, *Dots per inch*

GIS, *Geographic information system*

GPS, *Global positioning system*

MDOT, *Mississippi Department of Transportation*

MVUE, *Minimum variance unbiased estimator*

NASQAN, *National Stream Quality Accounting Network*

NAWQA, *National Water-Quality Assessment*

OLWR, *Office of Land and Water Resources*

Q, *Discharge*

RPD, *Relative percent difference*

USACOE, *U.S. Army Corps of Engineers*

USEPA, *U.S. Environmental Protection Agency*

USGS, *U.S. Geological Survey*

Abbreviations:

mg/L, milligram per liter
µm, micron

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Streamflow and Nutrient Data for the Yazoo River below Steele Bayou near Long Lake, Mississippi, 1996-2000

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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 Louisiana and Texas coast. The proximity of the Yazoo River Basin in northwestern Mississippi to the Gulf of Mexico, and the intensive agricultural activities in the basin have led to speculation that the Yazoo River Basin contributes a disproportionate amount of nitrogen and phosphorus to the Mississippi River and ultimately to the Gulf of Mexico. An empirical measurement of the flux of nitrogen and phosphorus from the Yazoo Basin has not been possible due to the hydrology of the lower Yazoo River Basin.

Streamflow for the Yazoo River below Steele Bayou is affected by backwater from the Mississippi River. Flow at the gage 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. Streamflow from the Yazoo River for the 1996-2000 period accounted for 2.8 percent of the flow of the Mississippi River for the same period.

Water samples from the Yazoo River were collected from February 1996 through December 2000 and were analyzed for total nitrogen, nitrate, total phosphorus, and orthophosphorus as part of the U.S. Geological Survey National Water-Quality Assessment Program. These data were used to compute annual loads of nitrogen and phosphorus discharged from the Yazoo River for the period 1996–2000.

Annual loads of nitrogen and phosphorus were calculated by two methods. The first method used multivariate regression and the second method 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 10 of 20 cases. The Yazoo River loads, compared to average annual loads in the Mississippi River, indicated that the Yazoo River was contributing 1.4 percent of the total nitrogen load, 0.7 percent of the nitrate load, 3.4 percent of the total phosphorus load, and 1.6 percent of the orthophosphorus load during 1996 - 2000. The total nitrogen, nitrate, and orthophosphorus loads in the Yazoo River Basin were less than expected, whereas the total phosphorus load was slightly higher than expected based on discharge.

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 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 die because they are unable to move to an area with sufficient oxygen. 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, estimates of the size of the hypoxic zone averaged about 3,860 mi^2. Following the 1993 flood of the Missouri and upper Mississippi Rivers, the hypoxic zone covered nearly 6,560 mi^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 close to the mouth of the Mississippi River. Alexander and others (1997) used a modeling approach 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 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 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 for 1996-2000.

Purpose and Scope

This report describes the complex hydrology of the lower Yazoo River and the methods and procedures used to compute streamflow, statistical descriptions of the concentrations of nitrogen and phosphorus in the Yazoo River, and the methods and results of load computations for nitrogen and phosphorus. The concentrations of nitrogen and phosphorus in the Yazoo River are compared to data collected earlier from a site upstream of the current location as well as data collected from the Mississippi River. The water-quality data are based on water samples collected from the Yazoo River from February 1996 through December 2000. Annual loads of nitrogen and phosphorous were computed by using ESTIMATOR software that uses multivariate regression.

Description of the Study Area

The Yazoo River Basin, the largest river basin in Mississippi, encompasses about 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, Miss., along the eastern edge of the alluvial valley until it reaches the Mississippi River at Vicksburg, Miss. 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).

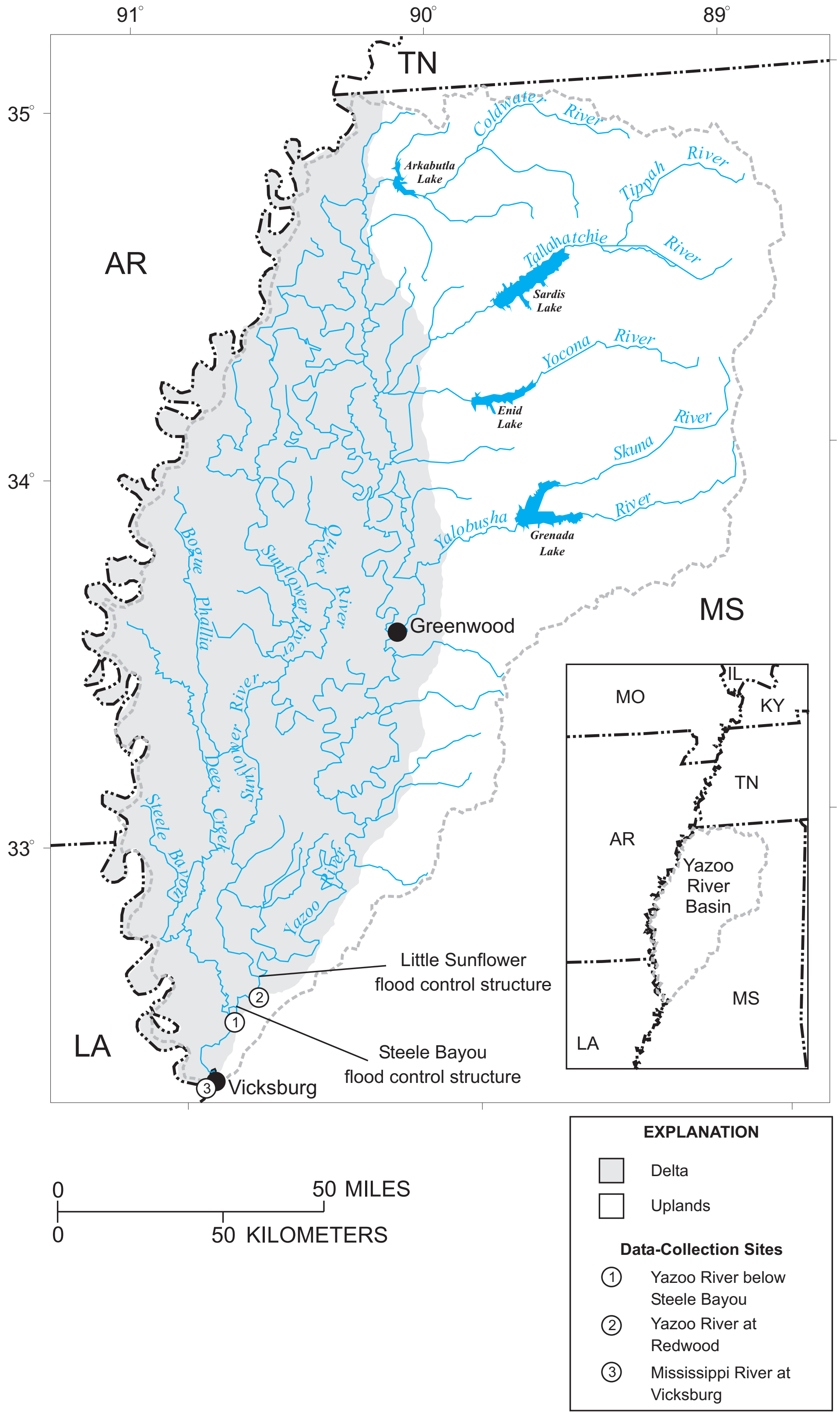


Figure 1. Location of data-collection sites in theYazoo River Basin.

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 Yazoo River below the Steele Bayou sampling site is located 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, medium, and high 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 physical attributes of the complex hydrology of the river. The non-uniform, varied streamflow conditions in the backwater-affected reaches of the Yazoo River have historically made the accurate measurement and computation of streamflow difficult and, in some circumstances, impossible. Remote sensing, acoustic, and conventional discharge measurement techniques are used to compute streamflow at the gaging station.

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.

Surface-Water Data Collection

Measurement of discharge on the lower Yazoo River began as early as 1874 (U.S. Engineer Office, 1941). The USGS began measuring river stage and discharge on the lower Yazoo River near Redwood, Miss. (fig. 1) in July 1928, and periodic discharge measurements were made at Redwood from 1928 through 1995. From January through September 1996, discharge measurements were made at least weekly on the Yazoo River below its confluence with Steele Bayou. Daily mean discharges for January through September 1996 were computed by linear interpolation between discharge measurements. In October 1996, the USGS, in cooperation with the Mississippi Department of Environmental Quality, Office of Land and Water Resources (OLWR) and the USACOE, constructed a gage to continuously record stage, velocity, and discharge at the Yazoo River below Steele Bayou near Long Lake, Miss. (hereafter referred to as the Yazoo River gage).

The USGS has recorded stage and velocity at 1-hour intervals using a data collection platform (DCP) at the Yazoo River gage since October 1996. Continuous river stage is measured by using a non-submersible pressure sensor attached to a steel-pipe pile cluster near the left (south) bank (fig. 2). The pressure sensor measures water pressure in pounds per square inch at the orifice end in the river, contrasts this to atmospheric pressure at the gage house, and then converts the pressure to feet of water and transmits this value to the DCP where it is recorded. Velocity is measured and transmitted to the DCP by using an acoustic velocity meter (AVM), which receives data from two transducers mounted on steel-pipe pile clusters near the left (south) bank near the gage and right (north) bank about 500 ft upstream of the gage (fig. 2). Discharge measurements have been made at the site at 1- to 2-week intervals since January 1996 with an accoustic doppler current profiler (ADCP) mounted to a boat. Infrequently, during low and medium flows, a standard current meter attached to a sounding weight from a boat has been used to make discharge measurements (Rantz and others 1982).

Through field reconnaissance and aerial photograph interpretation, it was determined that at river stages greater than about 91 ft above sea level at the Yazoo River gage, significant flow is diverted from the channel into the left (south) floodplain between Redwood and the Yazoo River gage. Analysis of the surface-water data collected at this gage, therefore, was conducted for two flow scenarios:

- Unsteady flow in the channel (less than 91 ft of stage at the Yazoo River gage); and
- Unsteady flow in the floodplain (greater than 91 ft of stage at the Yazoo River gage).

Both analyses required the use of conventional and unique computational processes to analyze the data.

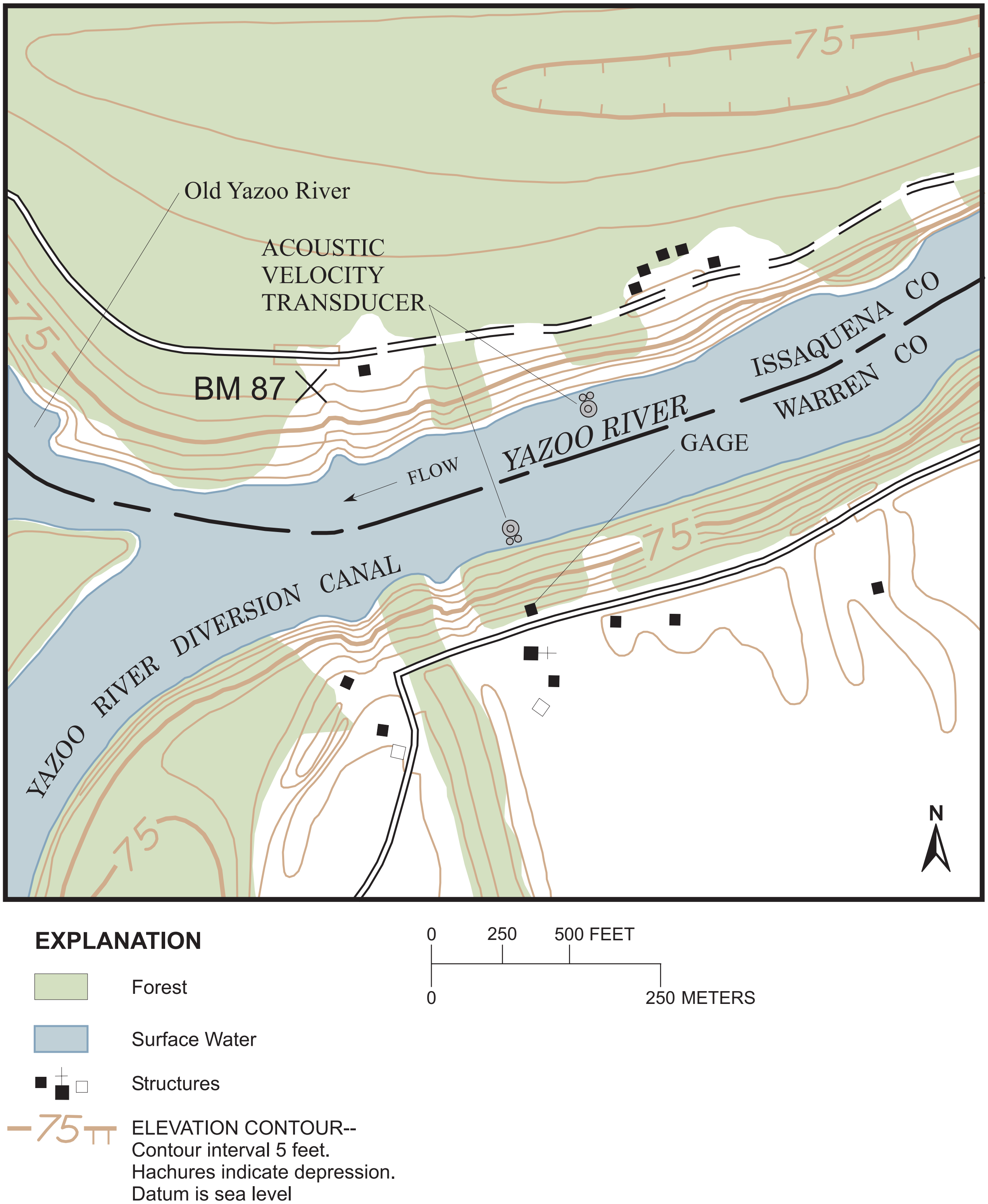


Figure 2. The vicinity of the Yazoo River below Steele Bayou near Long Lake, Mississippi.

Remote Sensing Data Collection

In February and March 1997, rainfall in the upper Ohio River Basin, in combination with rapidly melting snow pack in the upper Mississippi River Basin, resulted in flooding on the Mississippi River near Vicksburg, Miss., in late March 1997. The flooding recurrence interval at the USACOE streamgage on the Mississippi River at Vicksburg was about 10 years, based on a log-Pearson Type III distribution analysis by Landers and Wilson (1991). The Mississippi River, at this streamflow gage, rose more than 6 ft above flood stage and inundated many thousands of acres of land in the lower Yazoo River Basin. This flooding created extremely complex flow conditions in the lower Yazoo River. To protect the lower Yazoo River Basin from flooding by the Mississippi River, the Steele Bayou Drainage Control Structure was closed from March 7 through April 11, 1997, and the Little Sunflower River Drainage Control Structure was closed from February 8 through April 28, 1997 (Plunkett and others, 1998). Streamflow from the Delta region of the Yazoo River Basin accumulated behind the levees while the control structures were closed.

The USGS, in cooperation with the U.S. Department of Agriculture, Forest Service; the USACOE, Vicksburg District; the USACOE Waterways Experiment Station; and the USEPA, Region 4; contracted for procurement of aerial photography on March 22-23, 1997, of lower reaches of the Yazoo River Basin in Mississippi to help determine and document flow conditions during the March 1997 flood. Film from the over-flight was developed at a scale of 1:24,000 and processed into black-and-white photographs. The photographs were then scanned at a resolution of 600 dpi with a scale resolution of about 1 m. A mosaic of the photographs was then created to obtain a single coverage of the study area for entry into a geographic information system (GIS) and to help determine flow direction in the lower Yazoo River Basin during the March 1997 flood.

Unsteady Flow in the Channel

The law of continuity for unsteady flow requires consideration of time. Chow (1959), using the continuity equation, documented that discharge (***Q***) in cubic feet per second for steady or unsteady open-channel flow in a given channel section can be expressed as:

$$Q = VA, \tag{1}$$

where ***V*** is the mean velocity in feet per second, and ***A*** is the cross-sectional flow area in square feet normal to the direction of the flow. The AVM measures the water velocity by using the differential travel time of sound through water. The differential travel time is determined by making two series of successive measurements on a given path in each direction. The forward direction travel time is measured by logging the travel time of sound from the upstream to the downstream transducer; the reverse direction travel time measurement is the travel time of the sound from the downstream to the upstream transducer. Therefore, the arrival time of the sound signal from the forward direction measurement will be shortened in proportion to the water velocity. When the velocity is zero, the forward and reverse travel times are equal. The relation is defined as:

$$TF = L/(C + v\cos A) \tag{2}$$

$$TR = L/(C - v\cos A) \tag{3}$$

where

TF	is travel time in the forward (downstream) direction, in seconds;
TR	is travel time in the reverse (upstream) direction, in seconds;
L	is the path length between the two transducers, in feet;
C	is the speed of sound, in feet per second;
v	is the velocity of the water along the path, in feet per second; and
cos A	is the cosine of the path angle from the direction of flow.

Solving both equations for the speed of sound results in the following equation:

$$L/TF - v\cos A = L/TR + v\cos A. \tag{4}$$

The equation is further simplified by solving for ***v***:

$$v = L/2\cos A(1/TF - 1/TR). \tag{5}$$

Elimination of the speed of sound in equation 4 simplifies the computation of an instantaneous velocity and eliminates the need to measure other variables to account for changes in the speed of sound. Compensation was also made for signal delays due to cable length, transducer characteristics, and electronic hardware within the AVM. The AVM computes the instantaneous velocity using the travel time data from the transducers and equation 5. Velocity data are transmitted to a data logger on 1-hour intervals.

The ADCP has two transducers that transmit pulses of sound into the water. The transducers then measure the return sound as it is echoed from small ambient particles floating in the water. Using the Doppler principle, the ADCP converts the returned sound into components of velocity. The ADCP measures both the speed and direction of the water at multiple locations in the water column. Measurements made with the ADCP show that streamflow in the lower reaches of the Yazoo River can be fully downstream, bi-directional (downstream on the top, and upstream on the bottom), stratified (downstream on the surface and at the bottom, and upstream in the middle), or fully upstream (fig. 3). Comparison of nearly simultaneous discharge measurements made by personnel of the USGS has shown that the ADCP can measure discharge within 5 percent of the measurement obtained by using a standard current meter (Morlock, 1996).

The relation between the average velocity measured by the ADCP and conventional methods and instantaneous velocity measured by the AVM was used to develop a velocity rating for the Yazoo River gage (fig. 4). The velocity rating was developed by using linear regression techniques to find the best-fit equation with the average channel velocity as the dependent variable and the instantaneous acoustic path velocity as the independent variable. Discharge measurements made at 1- to 2-week intervals from October 1996 through September 2000 at the Yazoo River gage were used to develop this relation between average velocity across the measured channel-bed cross section and the instantaneous velocity measured by the AVM. This equation may be expressed as:

$$\boldsymbol{V = 0.773v + 0.0976}, \qquad (6)$$

where

$\boldsymbol{V}$ is the average velocity for the cross section,

0.773 is a dimensionless slope coefficient,

$\boldsymbol{v}$ is an instantaneous velocity measured by the AVM, in feet per second, and

0.0976 is the y-axis offset, in feet.

Average velocity is inversely proportional to area for a given constant discharge. Given this, and the unsteady nature of streamflow affected by backwater from the Mississippi River at the gage, slope and offset may change over time. For the purpose of this report, equation 6 is assumed to be valid for flow conditions during October 1996 through September 2000.

To compute average velocity from measured discharge, a stage versus area relation was developed by using a channel cross section surveyed on May 29, 1996. Cross-sectional area was computed at 1-ft elevation intervals to develop a stage versus area relation for stages up to 91 ft above sea level (fig. 5). Average velocity is computed by dividing the measured discharge by the area determined from the stage versus area relation. To compute discharge during periods of backwater-affected flow in the channel, the velocity relation (eq. 6) was used to compute mean velocity from instantaneous path velocity (fig. 6), which was then multiplied by the area determined from the stage versus area curve. The product of these two variables (mean velocity and area) is an instantaneous discharge.

Unsteady Flow in the Floodplain

Appropriate locations to measure discharge during unsteady flow conditions, as well as flow direction in the floodplain, were determined by using remote sensing and GPS technology. Measurement of discharge during floodplain flow situations is accomplished by using an ADCP. River levels rose more than 7 ft above the left (south) bank at the gage during the March 1997 flood. Streamflow at this stage (about 98 ft) could not be adequately computed at the existing gage by using the velocity-area method and, therefore, was determined by using the following three steps.

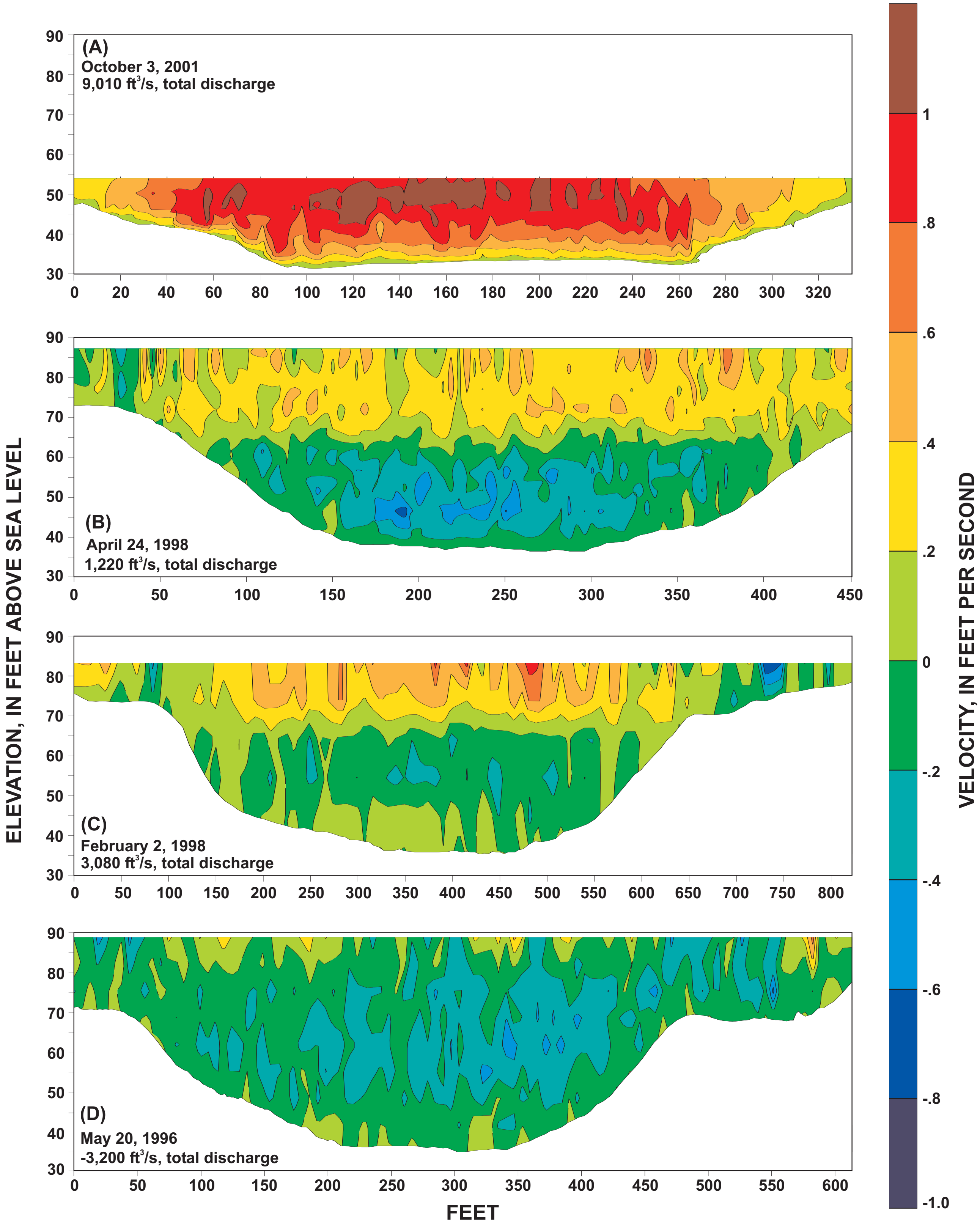


Figure 3. Cross sections showing velocity for the Yazoo River below Steele Bayou near Long Lake, Mississippi, for (A) full downstream flow, (B) bi-directional flow, (C) stratified flow, and (D) full upstream flow.

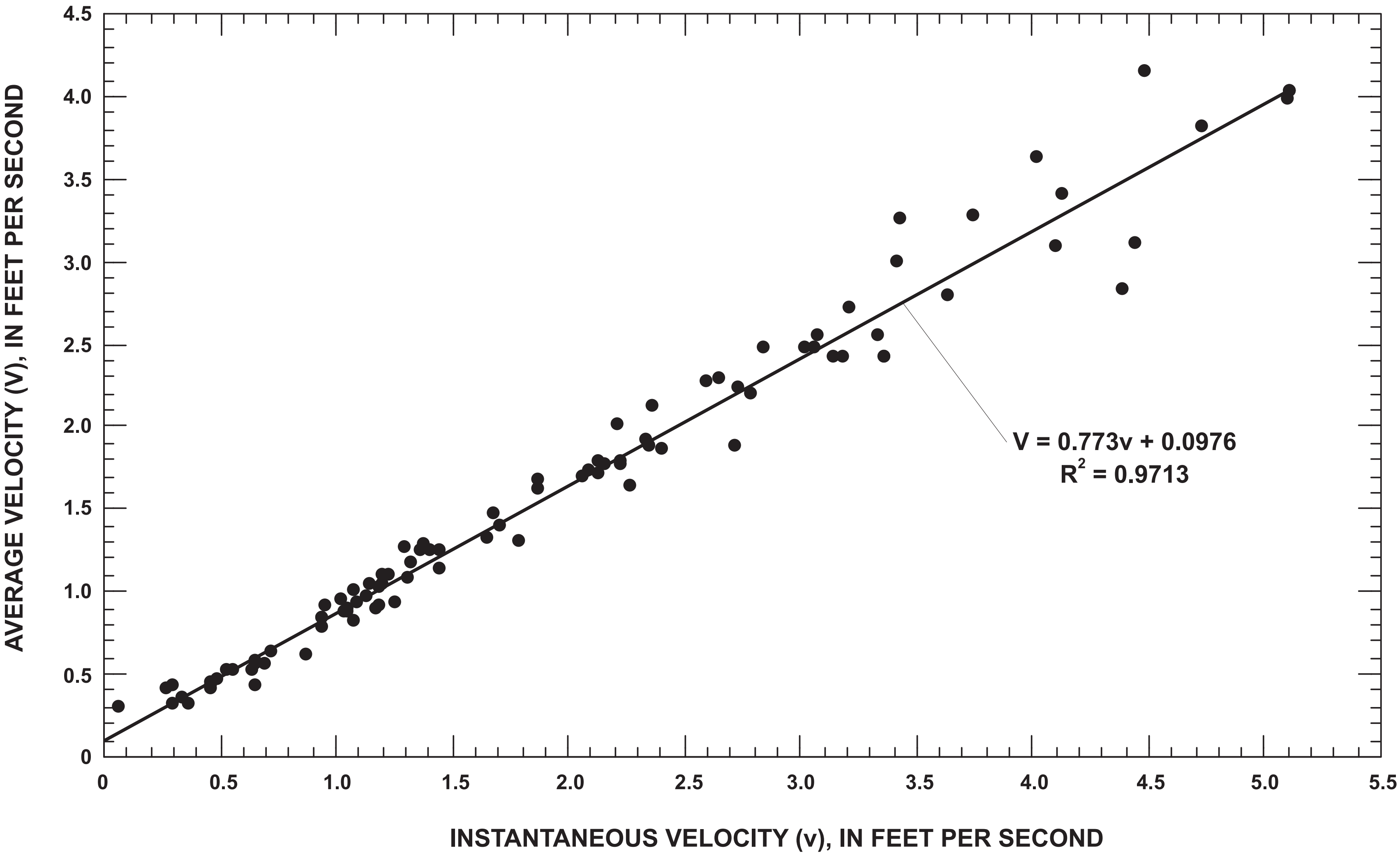


Figure 4. Relation between average velocity and instantaneous velocity used in discharge computations at Yazoo River below Steele Bayou near Long Lake, Mississippi, for data collected October 1996 through September 2001.

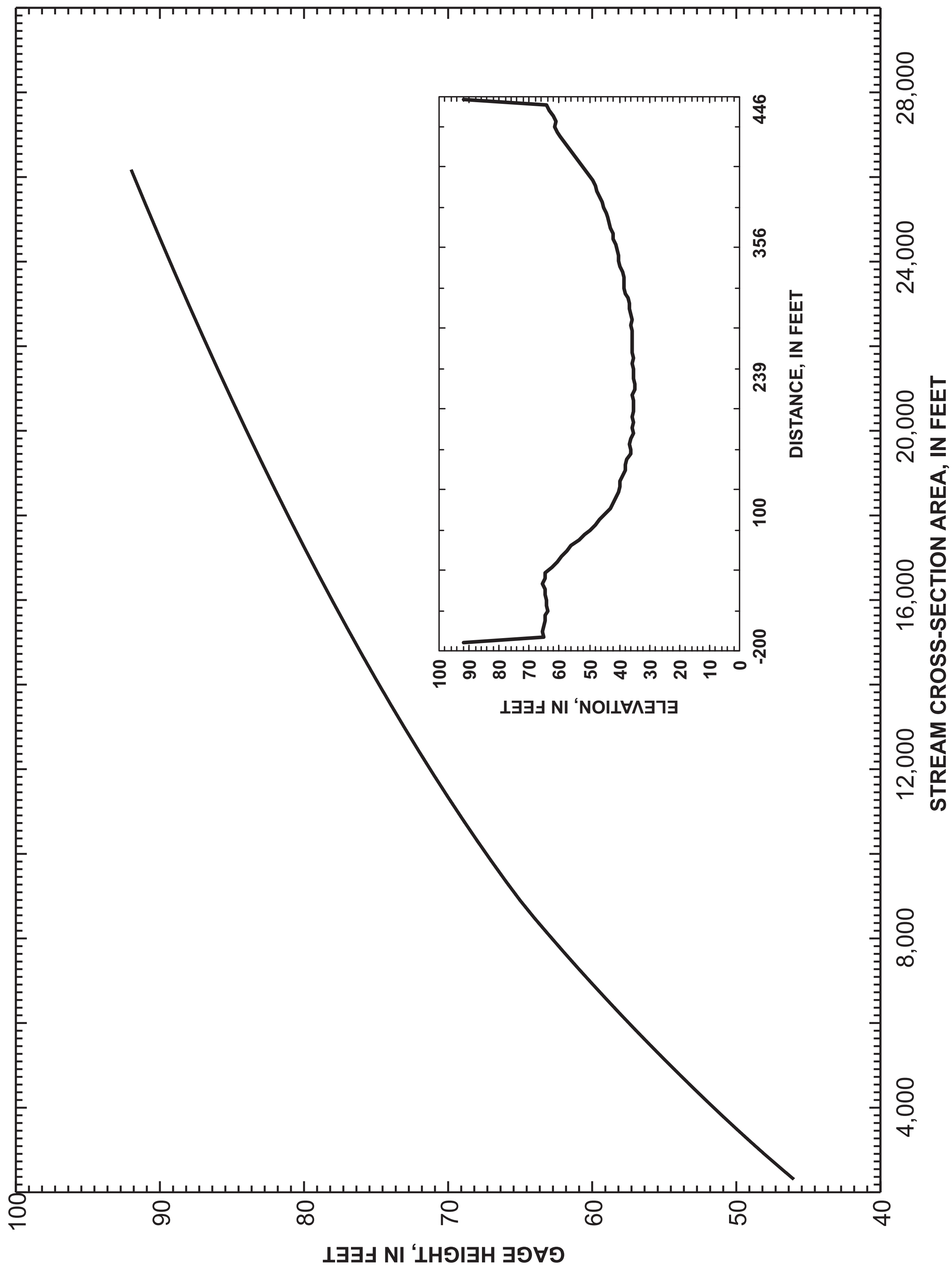


Figure 5. Relation between river stage and cross-sectional area at Yazoo River below Steele Bayou near Long Lake, Mississippi.

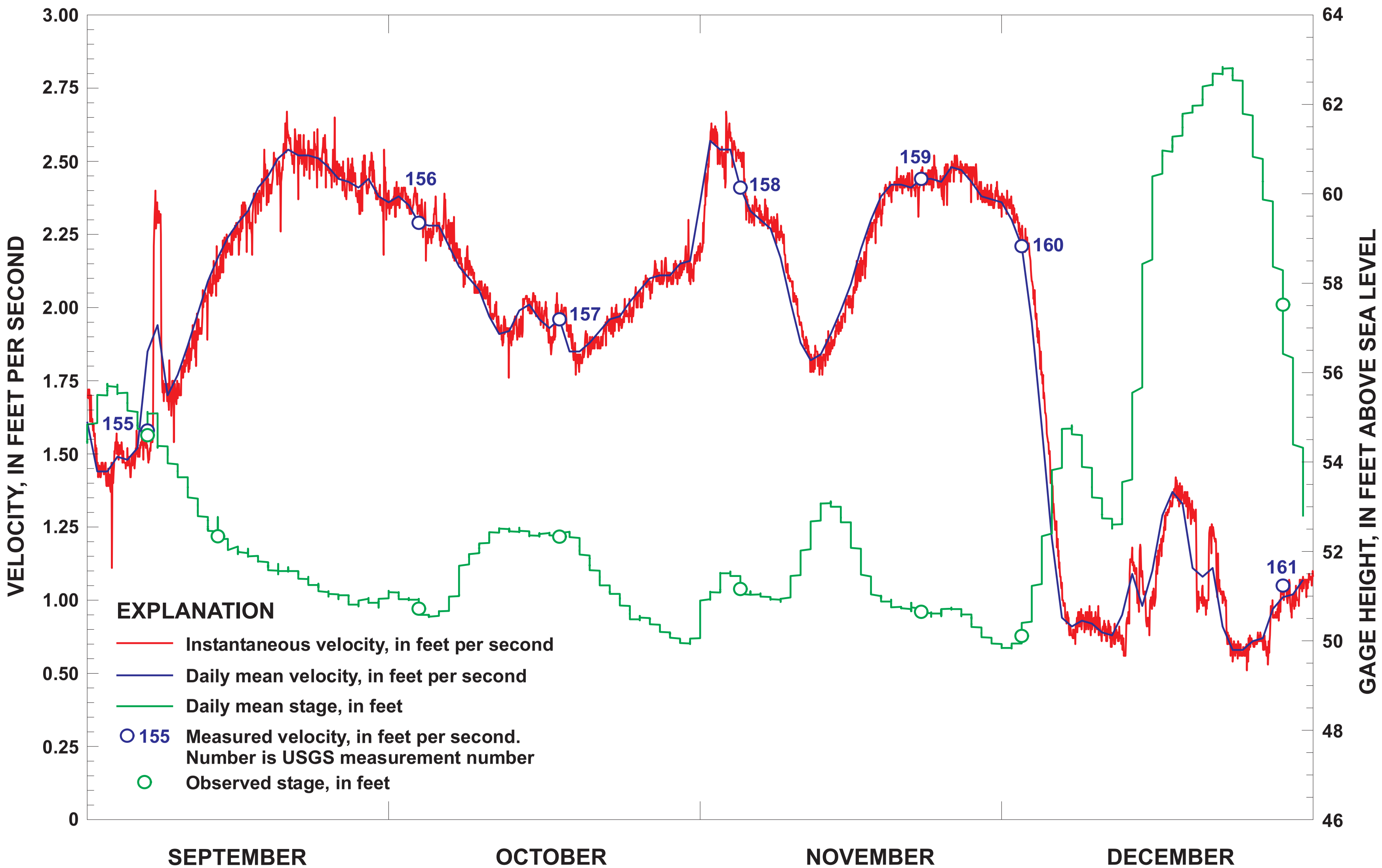


Figure 6. Instantaneous and daily mean velocity, and daily mean stage from September through December 1999 at the Yazoo River below Steele Bayou near Long Lake, Mississippi.

1) Determination of flow direction. To compute discharge during floodplain flow (stages greater than 91 ft), a determination of flow direction in this region was necessary not only for the March 1997 flood, but also for future reference. During the 1997 over-flight for aerial photography, crews were deployed in boats with GPS equipment and compasses to obtain flow direction at more than 20 locations in the lower reaches.

2) Determination of flow location. During the March 1997 flood in the lower Yazoo River Basin, crews were deployed at less than 1-week intervals to measure discharge and determine flow conditions at predetermined locations. Sixty discharge measurement transects were made by using an ADCP to help determine flow location, magnitude, and direction. Measurement transects were made at the following locations (fig. 7):

Channel cross sections from the Steele Bayou Drainage Control Structure to the top of the left (south) bank;

- Floodplain cross sections along Long Lake Road from the top of the left (south) bank to the Vicksburg Port levee; and
- Channel and floodplain cross sections at the U.S. Highway 61 crossing of the Yazoo River.

Measurements from these three locations were used to compute continuous discharge in the lower Yazoo River Basin during stages greater than 91 ft at the Yazoo River gage. Repeated measurements at these locations also helped determine when flow returned to within the channel banks and, therefore, when the AVM gage data could be used to compute continuous discharge for the river.

3) Continuous-discharge computations during floodplain flow. Linear interpolation between ADCP discharge measurements made from March 11 through April 17, 1997, in the lower Yazoo River Basin were used to compute daily mean discharges at the Yazoo River gage during the period (stage greater than 91 ft) when flow in the channel at the gage was not representative of flows for the basin (fig. 8).

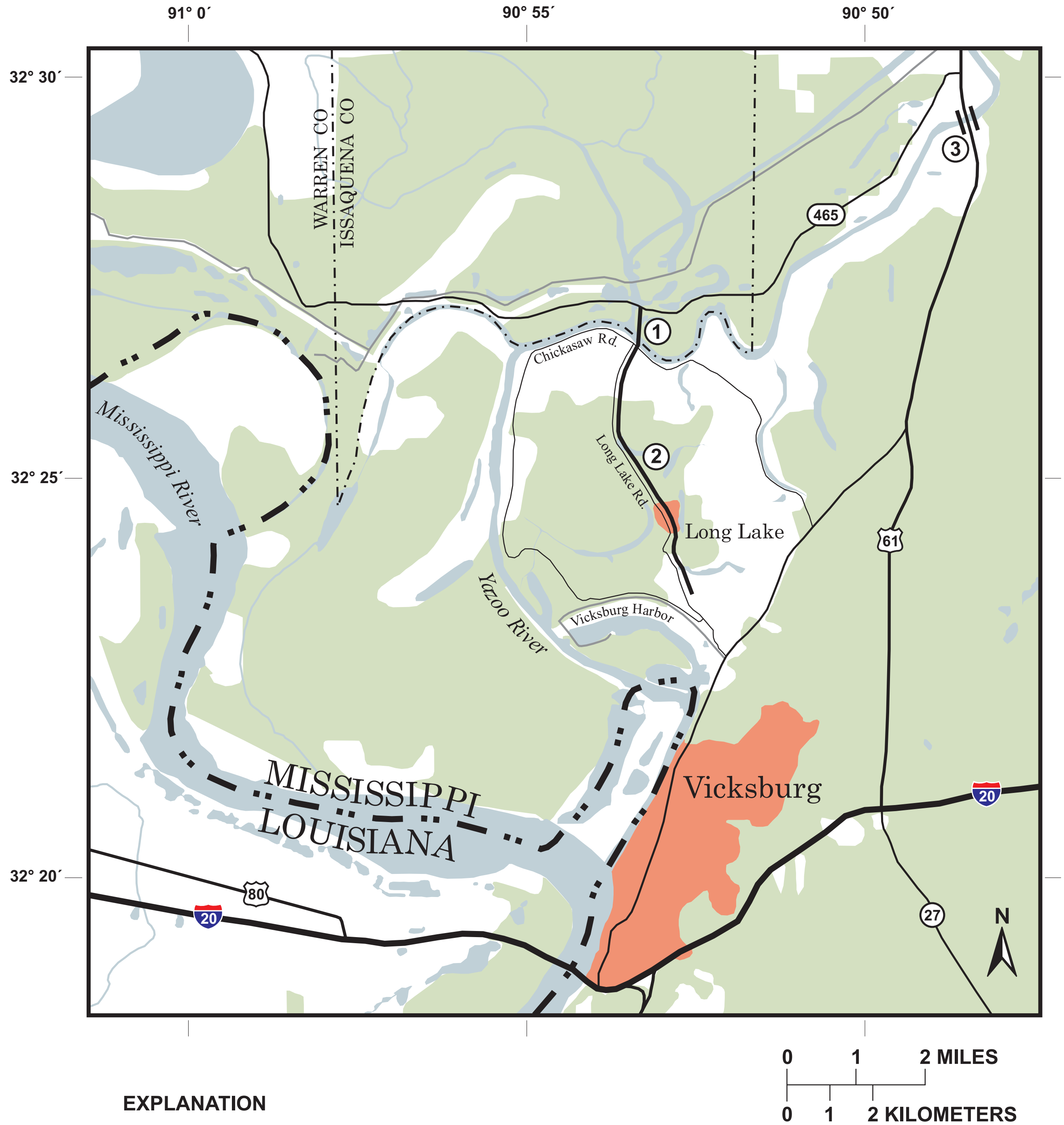
Nutrient Data Collection and Analysis

Samples from the Yazoo River were collected from a boat by using established velocity-weighted, depth- and width-integrating techniques (Shelton, 1994). Water samples were collected every two weeks from February 1996 through January 1998, once each month from April 1998 through September 1999, and twice each month 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, Colorado, for analysis by standard procedures (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, and total phosphorus, dissolved phosphorus, and orthophosphorus.

About 15 percent of the samples were quality-control samples, which included field equipment blanks to measure contamination and replicate samples to measure precision. Quality-control data collected during 1996 and 1997 indicated low-level contamination of some blanks by ammonia, nitrate, phosphorus, dissolved phosphorus, orthophosphate, and 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 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 performs 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. In agricultural areas, however, the application of nitrogen and



EXPLANATION

① Channel cross sections from the Steele Bayou Drainage Control Structure to the top of the left (south) bank

② Floodplain cross sections along Long Lake Road from the top of the left (south) bank to the Vicksburg Port levee

③ Channel and floodplain cross sections at the U.S. Highway 61 crossing of the Yazoo River

Figure 7. Location of high-flow (stage greater than 91 feet) measurement sections at the Yazoo River below Steele Bayou near Long Lake, Mississippi.

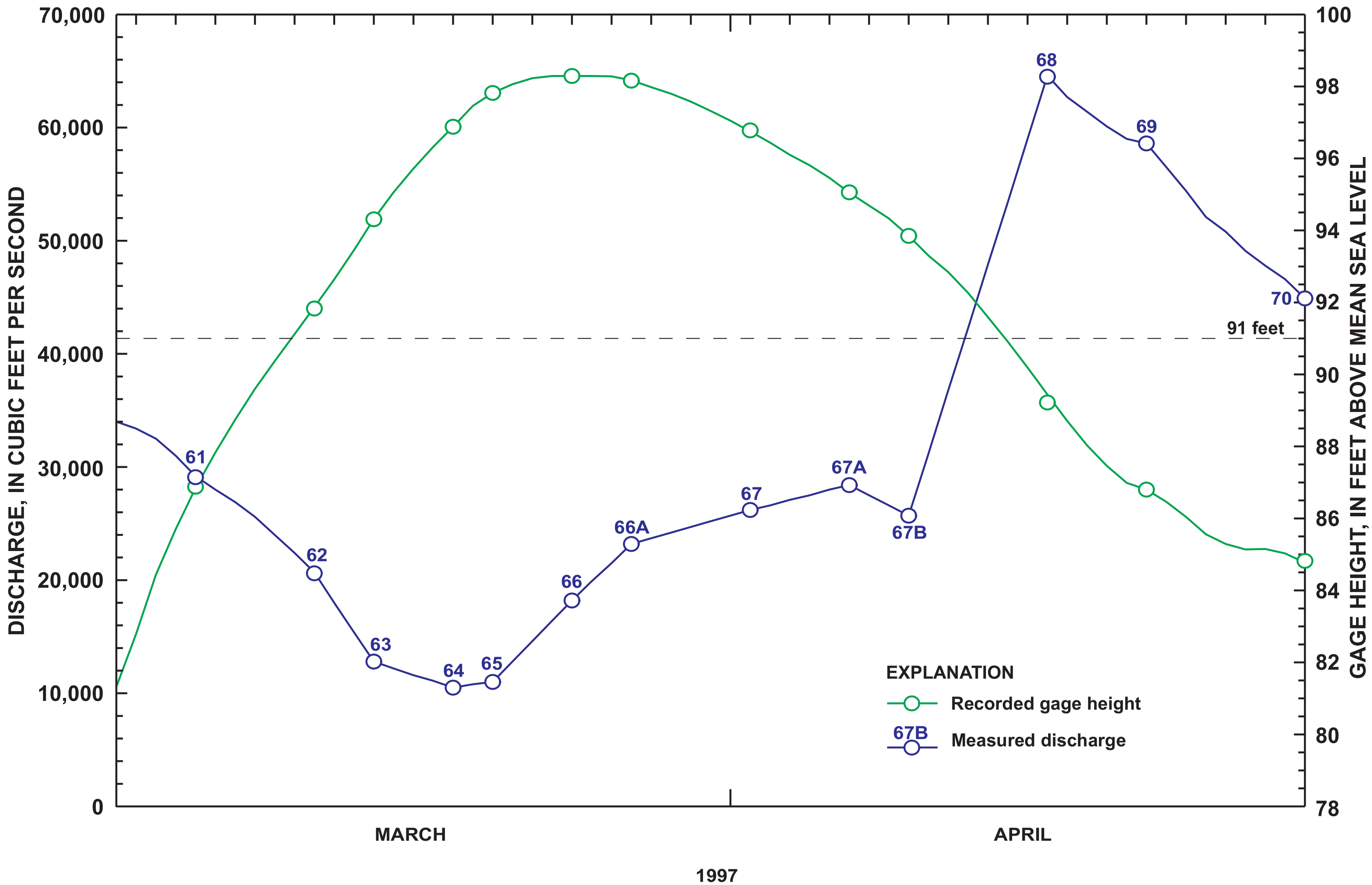


Figure 8. Computed daily mean stage and discharge from March through April 1997 at the Yazoo River below Steele Bayou near Long Lake, Mississippi.

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 and others, 1999). The regression equation for each constituent has the form:

$$\ln(CQ) = B_0 + B_1 \ln(Q) + B_2 T + B_3 \sin(2\pi T) + B_4 \cos(2\pi T) \qquad (7)$$

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

π = 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 when 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, the annual daily mean discharges for the Yazoo River ranged from 12,000 ft^3/s in 2000 to 24,600 ft^3/s in 1997 (table 1). Hydrographs showing daily mean discharge for the 1996 through 2000 calendar years are included in appendix I. The mean annual discharge for the 5-year period was 17,100 ft^3/s. Without long-term historical record on the Yazoo River, it is difficult to know how well these years represent long-term conditions.

The long-term annual mean discharge (1932-99) for the Mississippi River at Vicksburg, which includes the outflow from the Yazoo River, is 604,200 ft^3/s (Plunkett and others, 2000). The annual mean streamflow for 1996-2000 was 617,000 ft^3/s (Plunkett and others, 1997, 1998, 1999, 2000, 2001; Noble, H., U.S. Army Corps of Engineers, written commun., 2001). Discharge from the Yazoo River represented 2.8 percent of the flow of the Mississippi River at Vicksburg during the study period.

During May 1996, flow in the Yazoo River was reversed for a short time. The ESTIMATOR load model cannot use negative flows in its calculations. These values were replaced with very small positive values. This should not affect the overall load calculation because there were only 8 days of reverse flow.

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

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. 9). The total nitrogen concentrations generally increased as discharge increased (fig. 10). 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. 10), but there is a seasonal component as the highest nitrate concentrations occurred during the spring (fig. 9), 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. 9). Discharge was correlated with total phosphorus, as higher total phosphorus concentrations corresponded to higher discharge (fig. 10). The orthophosphorus concentrations in water samples collected from the Yazoo River below Steele Bayou ranged from less than 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. 9). For statistical purposes, the reporting limit was used as the concentration for samples with concentrations less than the reporting limit (Helsel and Hirsch, 1992). Additional nutrient data collected at the Yazoo River below Steel Bayou site are described in Appendix II.

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 and others, 1996). The NASQAN samples were collected from the Yazoo River at Redwood, Miss. and from the Mississippi River at Vicksburg, Miss. The Yazoo River at Redwood sampling site is upstream from the current sampling site at the Yazoo River gage (fig. 1) and upstream from 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 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 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, it 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 and others (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 substantial load of sediment, a large percentage of which is fine material (less than 0.63 μm), 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

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	Calendar Year	Max	Min	Mean	Percentile 75th	Percentile 50th	Percentile 25th
Total nitrogen	Yazoo River below Steele Bayou	21	1996	2.2	0.62	1.3	1.6	1.3	0.91
		26	1997	3.3	0.57	1.3	1.6	1.3	0.86
		11	1998	1.8	0.60	1.2	1.5	1.2	0.94
		15	1999	2.5	0.61	1.3	1.6	1.2	0.81
		24	2000	2.9	0.54	1.5	1.8	1.3	1.0
		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	22	1996	1.2	0.12	0.49	0.67	0.44	0.25
		26	1997	1.2	0.16	0.37	0.43	0.26	0.21
		11	1998	1.0	0.11	0.43	0.56	0.34	0.23
		15	1999	0.95	0.09	0.38	0.49	0.33	0.14
		24	2000	1.0	0.05	0.50	0.80	0.40	0.24
		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	21	1996	0.43	0.12	0.22	0.24	0.20	0.17
		26	1997	0.89	0.13	0.31	0.38	0.28	0.20
		11	1998	0.42	0.11	0.22	0.23	0.20	0.16
		15	1999	0.62	0.17	0.31	0.34	0.25	0.22
		23	2000	0.94	0.14	0.35	0.37	0.24	0.22
		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	21	1996	0.100	<0.01	0.05	0.06	0.05	0.04
		26	1997	0.090	0.018	0.038	0.042	0.034	0.030
		11	1998	0.070	0.027	0.048	0.061	0.045	0.036
		15	1999	0.075	0.014	0.039	0.054	0.032	0.026
		24	2000	0.086	<0.01	0.042	0.055	0.043	0.028
		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).

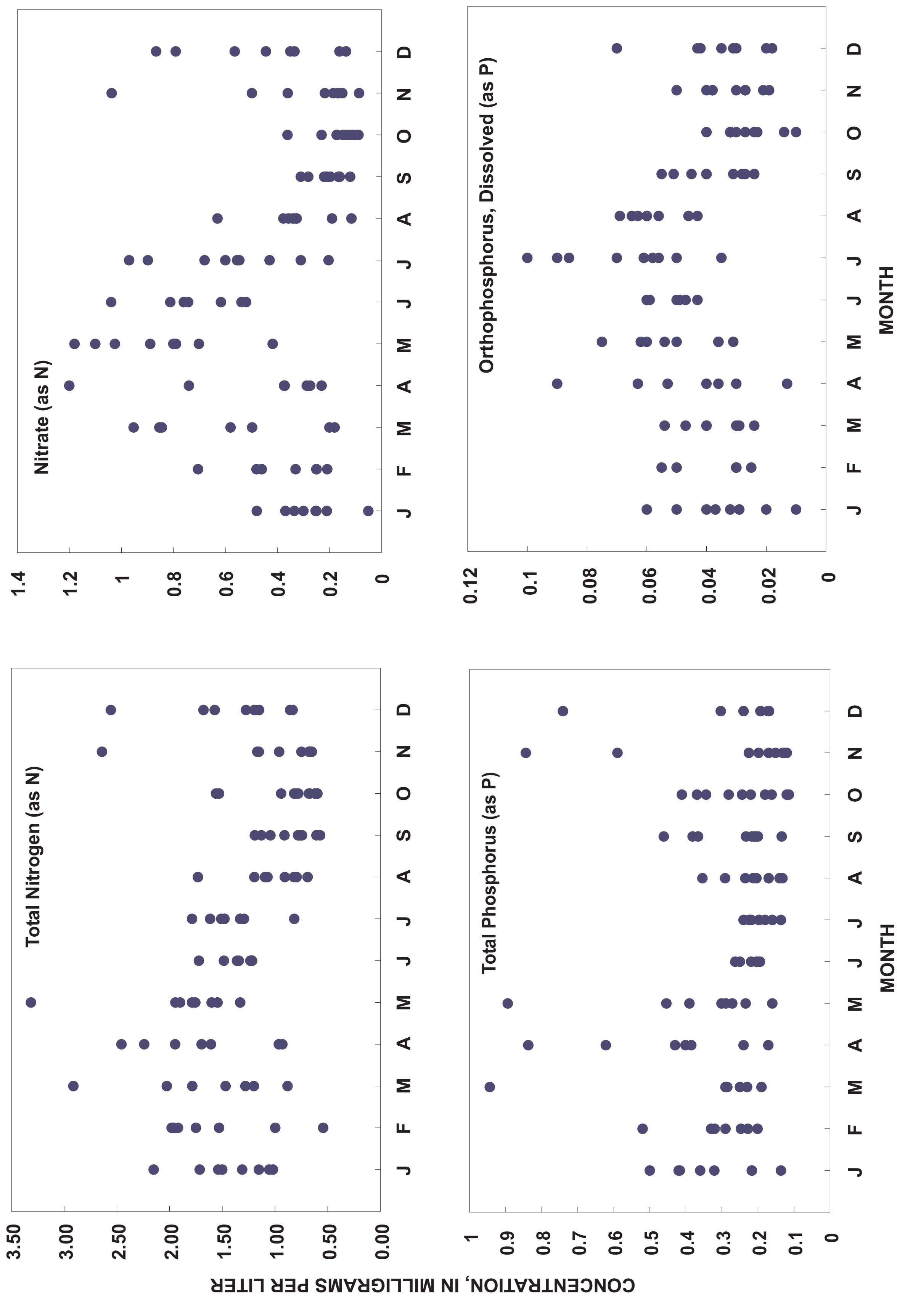


Figure 9. Concentrations of total nitrogen, nitrate, total phosphorus, and orthophosphorus, by month, in water samples from the Yazoo River below Steele Bayou near Long Lake, Mississippi, February 1996 through December 2000.

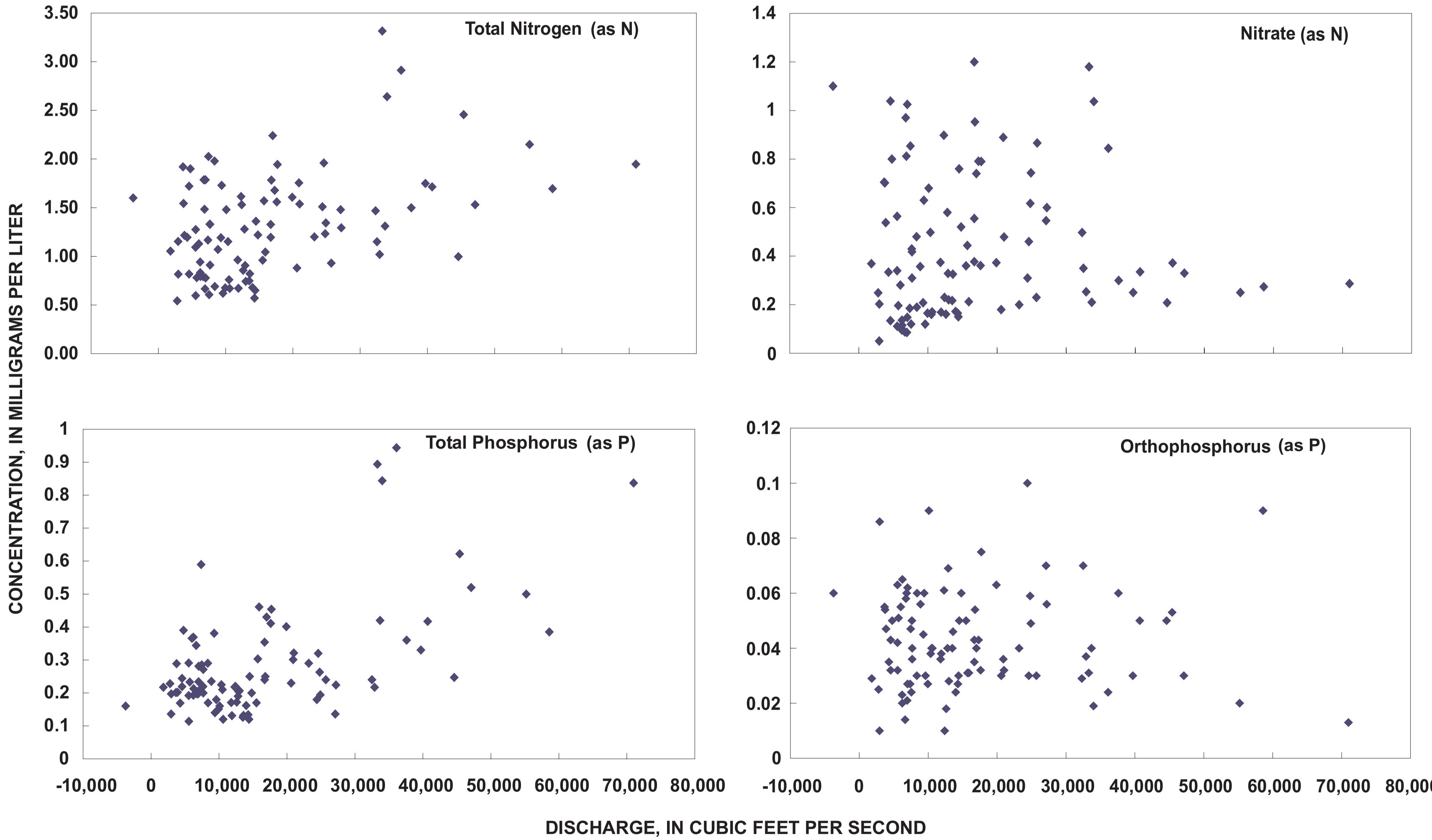


Figure 10. Concentrations of total nitrogen, nitrate, total phosphorus, and orthophosphorus, with discharge, in water samples from the Yazoo River below Steele Bayou, near Long Lake, Mississippi, February 1996 through December 2000.

surface runoff from an 18.7-ha watershed in the Delta planted to continuous cotton, more than 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 total nitrogen model fit better than the nitrate, total phosphorus, and orthophosphorus models as indicated by a higher percentage of the variability explained by the model and smaller standard errors (table 3). 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.

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 3. Coefficient estimates and goodness of fit parameters for nitrogen and phosphorus load models
[model: $\ln(\text{load}) = B_0 + B_1 \ln(Q) + B_2T + B_3\sin(2PT) + B_4\cos(2PT)$ 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

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

[CI, 95 percent confidence interval of the load estimate; 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]

Constituent	Annual nutrient load				
	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·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·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·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·C	622	832	748	**595**	**452**

The loads calculated by multiplying the annual mean concentration by the total annual flow (Q·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 computed loads (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 computed loads for 1996-97, and for 10 of the 20 computed loads for 1996-2000 (table 4). The reduced likelihood of the Q·C load falling within the 95 percent confidence interval of the ESTIMATOR model is due to 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).

Load calculations for the Yazoo River Basin can be compared with estimates of the average annual load for the Mississippi River. Goolsby and others (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 orthophosphorus 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 of the 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.

Table 5. Results of load calculations for the Yazoo River below Steele Bayou, Mississippi, 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).

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 led to speculation that the Yazoo River Basin contributes a disproportionate amount of nitrogen and phosphorus to the Mississippi River and ultimately to the Gulf of Mexico.

Streamflow for the Yazoo River below Steele Bayou is affected by backwater from the Mississippi River. Flow at the gage 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.

Stage and velocity data, as well as data for other channel characteristics, have been collected and processed, and discharge has been computed since January 1996 for the USGS continuous recording streamgage at the Yazoo River below Steele Bayou near Long Lake, Mississippi.

During a flood event in March 1997 on the Mississippi River, aerial photography was obtained of the lower Yazoo River Basin. These photographs were digitized, assembled into a photo-mosaic and entered into a GIS. The processing of digitized and assembled black-and-white aerial photography, which included spectrally classified land and water along with flow direction at selected locations during a significant flood on the Mississippi River and the lower Yazoo River Basin, provided reference to flow characteristics in the basin during the March 1997 flood, as well as documentation for future studies of the area.

Since October 1996, a single-path AVM has been successfully deployed on the Yazoo River and used to compute continuous discharge by calibrating the average velocity measured at a known stage below the water surface against the measured mean channel velocity computed by using standard stream gaging techniques and (or) an ADCP. The discharge rating procedure for the AVM gage involved developing ratings for both cross-sectional area and mean channel velocity. Data required to develop these ratings were a stage-area relation, acoustic path velocities, and the mean velocities through the discharge measurement cross section for a range of flows and stages. A velocity rating was developed by using linear regression techniques to find the best-fit equation with the instantaneous mean channel velocity as the dependent variable, and the instantaneous acoustic path velocity as the independent variable. Average velocity was measured for unsteady flow conditions at the gage by using an ADCP and/or conventional velocity-measuring instruments. During all in-channel flows, discharge is computed by multiplying the instantaneous mean channel velocity predicted from the best-fit equation, and the channel's cross-sectional area, which was determined by using the stage-area relation.

The annual mean 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 every two weeks from February 1996 through January 1998, once each month from April 1998 through September 1999, and twice each month 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 by using a 5-year data set were compared to results for the same period obtained by 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 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 1996–2000 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, 3.1, 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, Miss., 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.

REFERENCES

Alexander, R.B, Ludtke, A.S., Fitzgerald, K.K., and Schertz, T.L., 1996, Data from selected U.S. Geological Survey National Stream Water-Quality Monitoring Networks (WQN) on CD-ROM: U.S. Geological Survey Open-File Report 96-337, 79 p.

Alexander, R.B, Smith, R.A., and Schwarz, G.E., 1997, The regional transport of point and nonpoint-source nitrogen to the Gulf of Mexico: Proceedings of the First Gulf of Mexico Hypoxia Management Conference, December 5-6, 1995, Kenner, Louisiana: U.S. Environmental Protection Agency, EPA-55-R-97-001, p. 127-132.

Chow, V.T., 1959, Open channel hydraulics: McGraw-Hill Publishing Company, 680 p

Cohn, T.A, DeLong, L.L, Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937-942.

Cohn, T.A, Caulder, D.L, Gilroy, E.J., Zynjuk, L.D., and Summers, R.M., 1992, The validity of a simple statistical model for estimating fluvial constituent loads: an empirical study involving nutrient loads entering Chesapeake Bay: Water Resources Research, v. 28, no. 9, p. 2353-2363.

Coupe, R.H., 1998, 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, 17 p.

Coupe, R.H., 2001, 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, 65 p.

Dunn, D.D., 1996, Trends in nutrient inflows to the Gulf of Mexico from streams draining the conterminous United States, 1972-93: U.S. Geological Survey Water-Resources Investigations Report 96-4113, 58 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chapter A1, 545 p.

Goolsby, D.A., and Battaglin, W.A., 1993, Occurrence, distribution and transport of agricultural chemicals in surface waters of the Midwestern United States, *in* Goolsby, D.A., Boyer, L.L., and Mallard, G.E., *eds*., Selected papers on agricultural chemicals in waters resources of the Midcontinental United States: U.S. Geological Survey Open-File Report 93-418, p. 1-25.

Goolsby, D.A., Battaglin, W.A., Lawrence, G.B., Artz, R.S., Aulenbach, B.T., Hooper, R.P., Keeney, D.R., and Stensland, G.J., 1999, Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin: Topic 3 report for the integrated assessment on hypoxia in the Gulf of Mexico: NOAA Coastal Program Decision Analysis Series No. 17, NOAA Coastal Ocean Program, Silver Springs, MD, 130 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Elsevier Publishing, New York, p. 522.

Justic, Dubravko, Rabalais, N.N., Turner, R.E., and Wiseman, W.J., Jr., 1993, Seasonal coupling between riverborne nutrients, net productivity and hypoxia: Marine Pollution Bulletin, v. 26, no. 4, p. 184-189.

Kopfler, F.C., 1998, The oxygen depleted (hypoxic) area in the Gulf of Mexico and Mississippi River: Proceedings of the Delta Conference: August 13-16 1996, Memphis, Tennessee, p. 543-549.

Landers, M.L., and Wilson, K.V., Jr., 1991, Flood characteristics of Mississippi streams: U.S.

Geological Survey Water-Resources Investigations Report 91-4037, 82 p.

McDowell, L.L., Willis, G.H., and Murphree, C.E., 1989, Nitrogen and phosphorus yields in run-off from silty soil in the Mississippi Delta: Agriculture, Ecosystems and Environment AEENDO v. 25, no. 2-3, p. 119-137.

Morlock, S.E., 1996, Evaluation of Acoustic Doppler Current Profiler measurements of river discharge: U.S. Geological Survey Water-Resources Investigations Report 95-4218, 37 p.

Mueller, D.K., Hamilton, P.A., Helsel, D.R., Hitt, K.J., and Ruddy, B.C., 1995, Nutrients in ground water and surface water of the United States—an analysis of data through 1992: U.S. Geological Survey Water-Resources Investigations Report 95-4031, 74 p.

Plunkett, M.L., Morris, Fred, Oakley, W.T., and Turnipseed, D.P., 1997, Water resources data for Mississippi, water year 1996: U.S. Geological Survey Water-Data Report MS-96-1.

-----1998, Water resources data for Mississippi, water year 1997: U.S. Geological Survey Water-Data Report MS-97-1.

-----1999, Water resources data for Mississippi, water year 1998: U.S. Geological Survey Water-Data Report MS-98-1.

-----2000, Water resources data for Mississippi, water year 1999: U.S. Geological Survey Water-Data Report MS-99-1.

Plunkett, M.L., Morris, Fred, and Turnipseed, D.P., 2001, Water resources data for Mississippi, water year 2000: U.S. Geological Survey Water-Data Report MS-00-1.

Rabalais, N.N., Turner, R.E., and Wiseman, W.J., Jr., 1997, Hypoxia in the Northern Gulf of Mexico: Past, Present and Future: Proceedings of the First Gulf of Mexico Hypoxia Management Conference, December 5-6, 1995, Kenner, Louisiana, U.S. Environmental Protections Agency EPA-55-R-97-001, p. 25-40.

Rabalais, N.N., Wiseman, Jr., W.J., Turner, R.E., Justic, D., Sen Gupta, B.K., and Dortch, Q., 1996, Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf: Estuaries, v. 19, no. 2B, p 386-407.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: Volume 1.Measurement of stage and discharge and Volume 2. Computation of discharge: U.S.Geological Survey Water-Supply Paper 2175, 681 p.

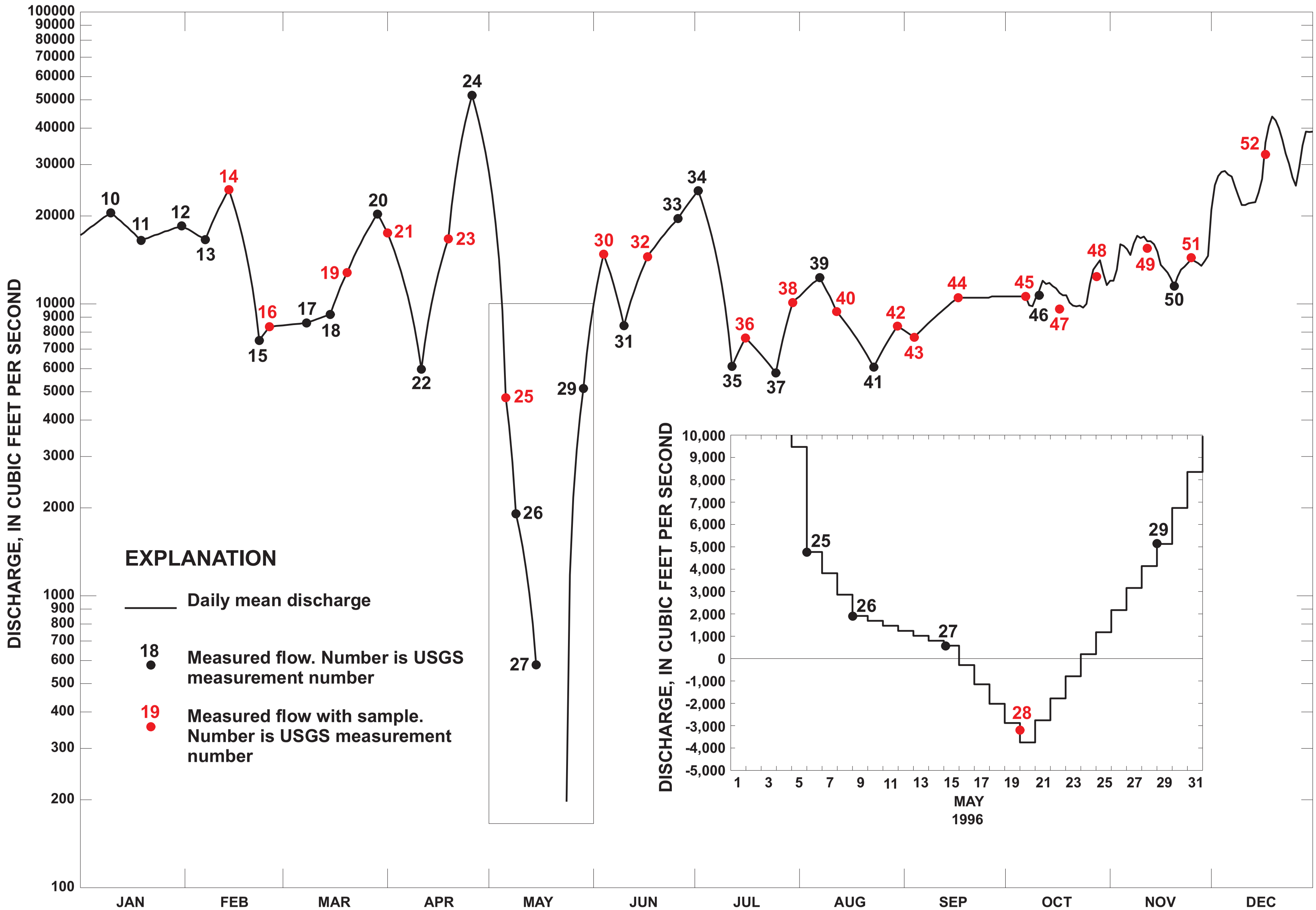
Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S Geological Survey Open-File Report 94-455, 42 p.

Turner, R.E., and Rabalais, N.N., 1991, Changes in Mississippi River water quality this century: Journal of Bioscience v. 41, no. 3, p. 140-147.

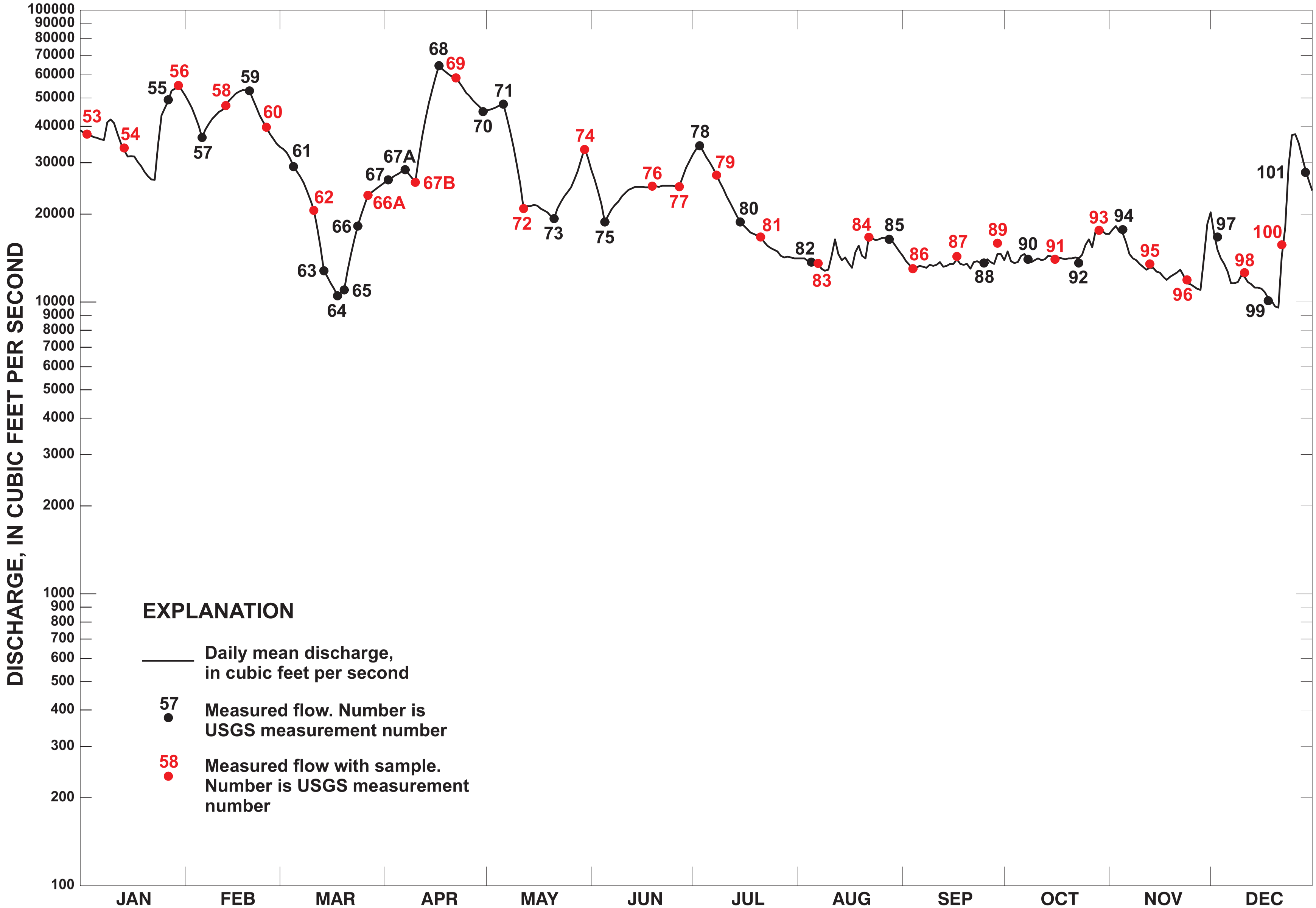
U.S. Engineer Office, 1941, Observed and daily discharge for the Yazoo and Big Black River Basins in the Vicksburg Engineer District for the period 1928-1938, inclusive: U.S. Engineer Office, Vicksburg, Mississippi, 401 p.

U.S. Geological Survey, 1990, USGeoData 1:250,000 and 1:100,000 Scale Land Use and Land Cover and Associated Maps Digital Data: Reston, Virginia.

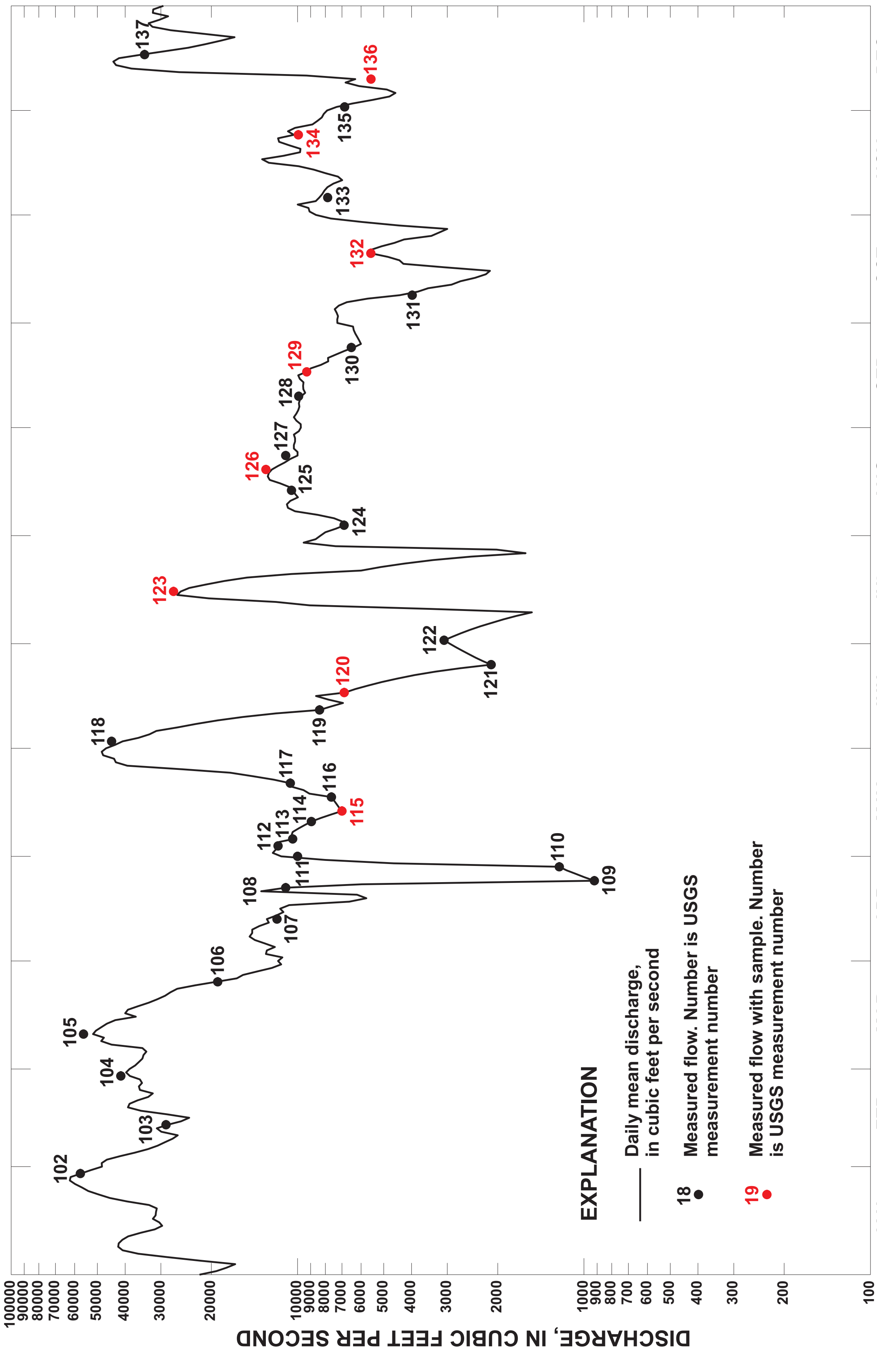
Appendix I: Daily mean discharge hydrographs for Yazoo River Below Steele Bayou near Long Lake, Mississippi, 1996–2000.



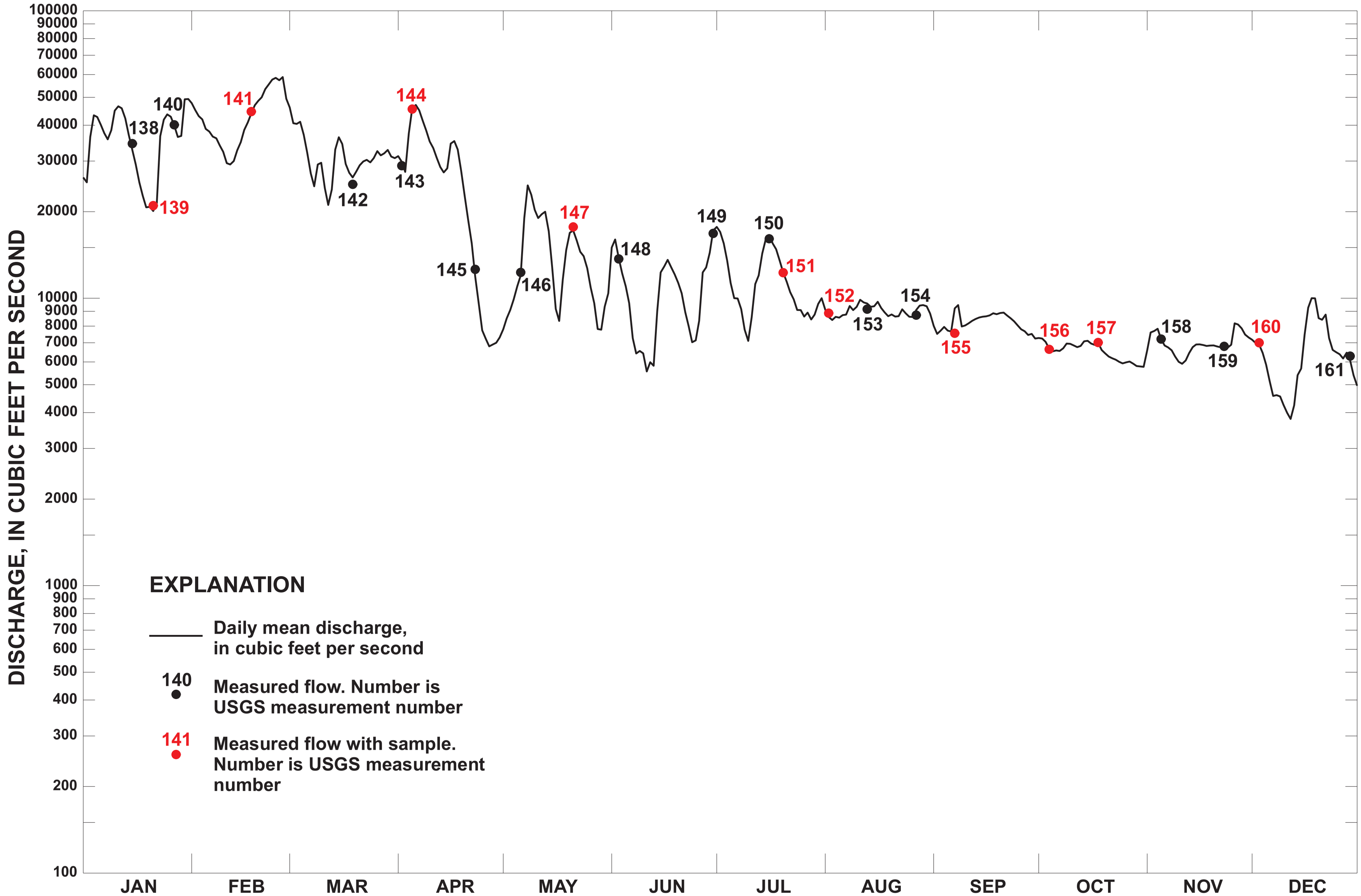
Daily mean discharge hydrograph for Yazoo River below Steele Bayou near Long Lake, Mississippi, 1996.



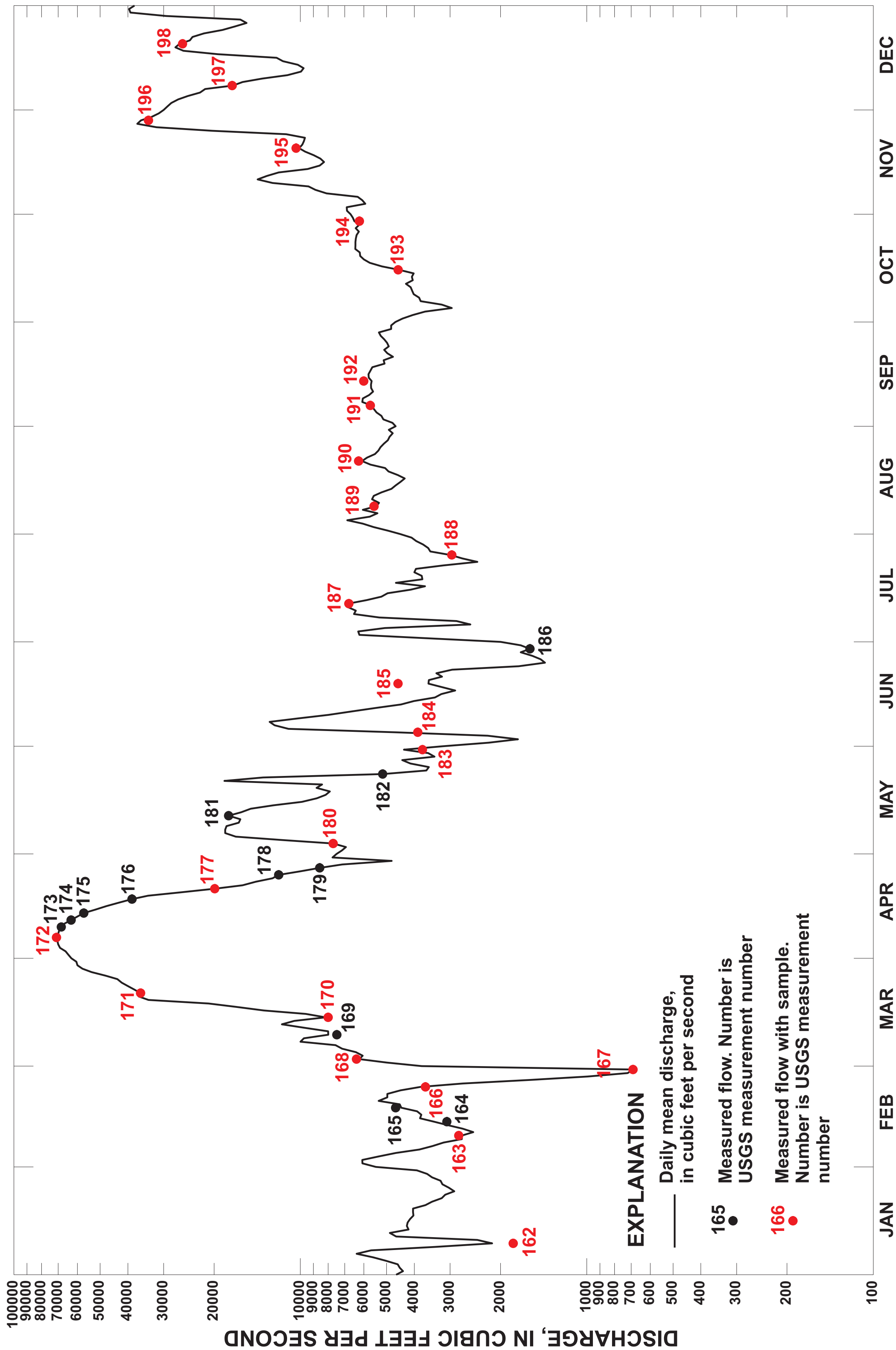
Daily mean discharge hydrograph for Yazoo River below Steele Bayou near Long Lake, Mississippi, 1997.



Daily mean discharge hydrograph for Yazoo River below Steele Bayou near Long Lake, Mississippi, 1998.



Daily mean discharge hydrograph for Yazoo River below Steele Bayou near Long Lake, Mississippi, 1999.



Daily mean discharge hydrograph for Yazoo River below Steele Bayou near Long Lake, Mississippi, 2000.

APPENDIX II: Maximum, minimum, mean, median, and 75th and 25th percentile data for concentrations of nutrients in water samples collected in the Yazoo River below Steele Bayou, 1996–2000.

Maximum, minimum, mean, and 75th, 50th, and 25th percentile data for concentrations of nutrients in water samples collected in the Yazoo River below Steele Bayou, 1996–2000

Constituent	Calendar year	No.	Max	Min	Mean	Percentile 75th	Percentile 50th	Percentile 25th
Nitrogen, ammonia + organic, dissolved (mg/L as N)	1996	21	1.1	0.2	0.51	0.7	0.4	0.3
	1997	26	1.079	<0.2	0.362	0.389	0.3	0.215
	1998	11	0.493	0.202	0.312	0.351	0.293	0.243
	1999	15	0.904	0.174	0.355	0.392	0.338	0.230
	2000	24	0.798	0.236	0.407	0.453	0.368	0.276
	1996-2000	97	1.1	0.174	0.398	0.443	0.338	0.252
Nitrogen, ammonia + organic, total (mg/L as N)	1996	21	1.5	0.5	0.86	1.1	0.7	0.6
	1997	26	2.135	0.406	0.925	1.180	0.796	0.604
	1998	11	1.379	0.486	0.761	0.850	0.711	0.583
	1999	15	2.084	0.486	0.884	0.976	0.789	0.700
	2000	24	2.068	0.293	0.967	1.182	0.844	0.681
	1996-2000	97	2.135	0.293	0.896	1.101	0.778	0.611
Nitrogen, ammonia, dissolved (mg/L as N)	1996	21	0.14	0.02	0.06	0.09	0.05	0.03
	1997	26	0.15	<0.015	0.041	0.044	0.024	<0.015
	1998	11	0.164	<0.02	0.072	0.077	0.059	0.052
	1999	15	0.188	<0.02	0.054	0.525	0.042	0.295
	2000	24	0.287	<0.02	0.070	0.104	0.045	0.023
	1996-2000	97	0.287	<0.015	0.059	0.081	0.045	0.023
Nitrogen, nitrite, dissolved (mg/L as N)	1996	21	0.10	<0.01	0.02	0.03	0.02	0.01
	1997	26	0.031	<0.01	0.014	0.02	<0.01	<0.01
	1998	11	0.107	<0.01	0.022	0.018	0.017	<0.01
	1999	15	0.155	<0.01	0.02	0.017	<0.01	<0.01
	2000	24	0.085	<0.01	0.02	0.023	0.013	<0.01
	1996-2000	97	0.115	<0.01	0.019	0.020	0.012	0.01
Phosphorus, dissolved (mg/L as P)	1996	21	0.18	0.02	0.06	0.07	0.05	0.03
	1997	26	.105	<0.01	0.037	0.05	0.03	0.024
	1998	11	0.064	0.033	0.05	0.056	<0.05	<0.05
	1999	15	0.213	0.027	0.059	0.064	0.043	0.034
	2000	24	0.11	0.012	0.056	0.072	0.054	0.039
	1996-2000	97	0.213	<0.01	0.051	0.064	0.043	0.030

Runner and others

STREAMFLOW AND NUTRIENT DATA FOR THE YAZOO RIVER BELOW STEELE BAYOU NEAR LONG LAKE, MISSISSIPPI, 1996-2000

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