Sources, Instream Transport, and Trends of Nitrogen, Phosphorus, and Sediment in the Lower Tennessee River Basin, 1980-96

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FOREWORD

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

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

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

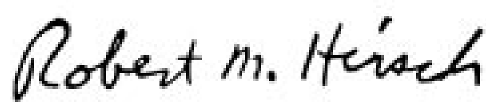
- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

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

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

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

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



Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound (lb)	0.4536	kilogram
pound per day (lb/d)	0.4536	kilogram per day
pound per year (lb/yr)	0.4536	kilogram per year
ton per year (ton/yr)	0.9072	metric ton per year
ton per square mile per year [$(ton/mi^2)/yr$]	0.003503	metric ton per hectare per year
ton per acre (ton/acre)	2.242	metric ton per hectare
pound per acre (lb/acre)	1.121	kilogram per hectare
million gallons per day (Mgal/d)	0.04381	cubic meter per second

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

ABBREVIATIONS AND ACRONYMS

ADEM	Alabama Department of Environmental Management
FCWP	Flint Creek Watershed Project
GSA	Geological Survey of Alabama
KDEP	Kentucky Department for Environmental Protection
LOWESS	Locally weighted scatter-plot smoothing
LTEN	Lower Tennessee
NAWQA	National Water-Quality Assessment
ORSANCO	Ohio River Valley Sanitation Commission
STORET	STOrage and RETrieval data base of the U.S. Environmental Protection Agency
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WATSTORE	WATer STOrage and REtrieval system data base of the U.S. Geological Survey

GLOSSARY

Export. Equivalent to yield, and used in place of that term in comparisons with input to a watershed.

Flow-weighted mean concentration. The ratio of instream load of a constituent to the mean discharge during the period of transport (dimensions of mass per volume); and equivalent computationally to the flow-weighted mean of the model estimates of daily concentration. Expressed in units of concentration [milligrams per liter (mg/L)]. This quantity is used, in place of load or yield, for evaluating average water-quality conditions at the site, and for comparing water quality among sites with differing discharge characteristics.

Instream delivery processes. Processes such as channel storage and aquatic biological assimilation that control how much of the stream input is transported along the channel and is exported from the watershed.

Instream load. The mass of a constituent moving past a specified point in a channel (for example, the mouth of a river basin) during a specified period of time. The instream load can be estimated by monitoring the concentration of the constituent periodically, and streamflow continuously, at the specified point.

Land-water delivery processes. Transport of a portion of land-phase inputs, overland or in the subsurface, from the point of deposition or application on the land surface to the stream channel (Smith and others, 1997). Some of the factors influencing land-water delivery include distance to the channel, land slope and runoff characteristics, soil-drainage characteristics, biological processing or storage within the vegetative cover or soil, and hydrogeology.

Land-phase input. The mass of a constituent deposited on (through natural processes or human activities) or derived from (through erosion of natural materials) the land surface in the watershed. Land-phase inputs are the basis for estimating the contribution from most nonpoint sources of constituents, inputs from which cannot be otherwise quantified. Only a portion of the land-phase input reaches the stream channel by overland or subsurface transport processes, referred to as land-water delivery processes.

Nonpoint source. A source of a water-quality constituent that is not discharged directly to the stream channel at a discrete location, but rather originates as land-phase inputs to broad source areas. An unknown percentage of a nonpoint-source input is transported overland or subsurface and reaches the stream channel as diffuse input.

Point source. A source of a water-quality constituent that is discharged directly to the stream channel from a discrete location (for example a pipe, tank, or pit).

Stream input. The mass of a constituent delivered to the stream channel from sources in the watershed. Stream inputs include inputs discharged directly from sources to the stream channel (such as wastewater discharges), as well as the portion of land-phase input that reaches the stream channel.

Trend. The change in the concentration of a water-quality constituent over time.

Yield. The ratio of instream load of a constituent to the area of the watershed (dimensions of mass per time per area). This area-normalized load is used, in place of load, to compare instream loads among watersheds with different drainage areas, and to compare with inputs to the watershed.

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By Anne B. Hoos, John A. Robinson, Robert A. Aycock, Rodney R. Knight, *and* Michael D. Woodside

Abstract

In 1997, the U.S. Geological Survey (USGS) began an assessment of the lower Tennessee River Basin as part of the National Water-Quality Assessment Program. Existing nutrient and sediment data from 1980 to 1996 were compiled, screened, and interpreted to estimate watershed inputs from nutrient sources, provide a general description of the distribution and transport of nutrients and sediments in surface water, and evaluate trends in nutrient and sediment concentrations in the lower Tennessee (LTEN) River Basin.

Nitrogen inputs from major sources varied widely among tributary basins in the LTEN River Basin. Point source wastewater discharges contributed between 0 and 0.61 tons per square mile per year [(tons/mi^2)/yr]. Of the nonpoint sources of nitrogen for which inputs were estimated (atmospheric deposition, nitrogen fixation, fertilizer application, and livestock waste) livestock waste contributed the largest input in about two-thirds (7 out of 11) of the tributary basins, and fertilizer application contributed the largest input in the remaining 4 basins. Nitrogen input from fertilizer application was the most variable spatially among the nonpoint sources of nitrogen, ranging from 1.5 to 23 (tons/mi^2)/yr. Atmospheric deposition estimates varied the least from basin to basin, ranging from 1.6 to 2.0 (tons/mi^2)/yr. Estimates of nitrogen input from livestock waste ranged between 2.0 to 13 (tons/mi^2)/yr. The percentage of the input from each of these nonpoint sources that entered the surface-water system is not known.

Wastewater discharge contributed between 0 and 0.14 (ton/mi^2)/yr of phosphorus to tributary basins. Livestock waste contributed most of the input in 8 out of the 11 basins, and fertilizer application contributed the most in the remaining 3 basins. Estimates of phosphorus input for fertilizer application ranged from 0.35 to 5.1 (tons/mi^2)/yr and from 0.62 to 4.3 (tons/mi^2)/yr from livestock waste.

Reservoirs on the main stem of the Tennessee River and on the Duck and Elk Rivers affect nutrient transport because hydrodynamic conditions in the reservoirs promote assimilation by aquatic plants and deposition of particulate matter. Observed decreases in total nitrite plus nitrate and dissolved-orthophosphorus concentrations in reservoirs or at sites downstream of reservoirs during summer months were probably related to seasonality of plant growth.

Nutrient and sediment data used to estimate annual instream loads and yields were compiled from various water-quality monitoring programs and represent the best available data in the LTEN River Basin, but these data have several characteristics that limit accuracy of load estimates. Many of the monitoring programs were not designed with the objective of annual load estimation, and data representing storm transport are, therefore, sparse; sampling and analytical methods varied through time and among the monitoring programs, hampering spatial and temporal comparisons. The load estimates computed from

these data are useful for evaluating broad spatial patterns of instream load, and comparisons of instream load to inputs, but may not be sufficiently accurate for local-scale evaluations of water quality.

Estimates of the mean annual instream load of total nitrogen entering (Chattanooga, Tenn.) and leaving (Paducah, Ky.) the LTEN River Basin were 29,000 and 60,000 tons per year (tons/yr), respectively. These estimates represent a gain of 31,000 tons/yr, on average, across the area (18,930 mi^2) between these inlet and outlet sites. The sum of the mean annual instream load from gaged tributaries to the main stem within the study unit was 14,000 tons/yr; however, this number cannot be directly compared with the gain between the inlet and outlet sites because (1) the gaged area represents only 30 percent of the total area and (2) the period of record at many tributary sites did not correspond with the period of record at the inlet or outlet sites.

Estimates of mean annual instream load of total phosphorus at the inlet and outlet sites of the LTEN River Basin were 1,300 and 5,000 tons/yr, respectively, representing a gain of 3,700 tons/yr, on average, across the study unit. The sum of the gaged tributary load, representing only 28 percent of the area contributing to the main stem, was 4,300 tons/yr. Although this number cannot be closely compared with the gain throughout the study unit, for the same reasons given for total nitrogen, a general comparison suggests that the main stem of the Tennessee River and the tributary embayments along the main stem function as a sink for total phosphorus, removing a substantial amount from the water column through deposition or assimilation.

The estimates of inputs can be compared and correlated with yields (area-normalized instream loads); significant correlations between estimates of inputs and yields might be useful as predictive tools for instream water quality where monitoring data are not available. Yields of nitrogen correlated moderately well with inputs from nonpoint sources, based on 1992 estimates. Nitrogen yield was highest [3.5 (tons/mi^2)/yr] for Town Creek, for which the balance of nonpoint-source inputs to agricultural lands (fertilizer application plus nitrogen fixation plus livestock waste minus harvest) was also the highest [15 (tons/mi^2)/yr]. Nitrogen yield was low [1.0 (tons/mi^2)/yr] for the Buffalo River, for which the balance of agricultural nonpoint-source input was correspondingly low [3.2 (tons/mi^2)/yr, the second lowest]. Correlation of wastewater discharge with yield was poor, and contrasted with the significant correlation between wastewater discharge and median nitrogen concentration during low streamflow. The poor correlation between wastewater discharge and annual yield was expected, however, as wastewater discharge is a small fraction compared with annual yield.

In contrast with nitrogen, phosphorus yield did not correlate well with any estimated inputs or land-use types for the tributary basins. Phosphorus yield was highest [1.1 and 0.93 (tons/mi^2)/yr] at two sites along the Duck River and at Elk River near Prospect [0.89 (ton/mi^2)/yr]; however, estimates of inputs at these sites were in the middle of their respective ranges. The influence of the outcrop of phosphatic limestone formations of the brown-phosphate districts in the lower Duck and lower Elk River Basins might be responsible for the poor correlation between estimated inputs and yields of phosphorus. The outcrop pattern of these phosphatic limestones are an important factor to consider as regional boundaries are established for attainable, region-specific water-quality criteria for total phosphorus.

Estimates of sediment input from cropland soil erosion in 1992 ranged from 51 to 540 (tons/mi^2)/yr among the major hydrologic units in the LTEN River Basin. Information was not available to estimate this input for individual tributaries. Sediment yield estimates ranged from 65 to 263 (tons/mi^2)/yr for the three tributary monitoring basins for which instream data were available, and from 17 to 26 (tons/mi^2)/yr for the Tennessee River at South Pittsburg and at Pickwick Landing Dam, respectively. Lower sediment yields for the main stem sites compared with the tributary sites is probably due to sediment deposition in the main stem of the Tennessee River and tributary embayments along the main stem.

Most of the significant trends in nutrient concentrations from about 1985 to about 1995 were decreasing trends, except for total nitrite plus nitrate, which increased at one site on the Elk River. The spatial distribution of decreasing trends of total nitrogen and total ammonia corresponds with the spatial variation among basins in wastewater loading rate. The time period of observed trends corresponds to the period of improvements in municipal treatment, thus decreases in wastewater effluent concentrations of nitrogen might be responsible for the decreasing trend in instream concentrations at these sites. Concentrations of total phosphorus did not decrease during this period at these sites, as might have been expected considering the reductions in wastewater input of phosphorus during this period.

INTRODUCTION

In 1997, the U.S. Geological Survey (USGS) began an assessment of the lower Tennessee (LTEN) River Basin as part of the National Water-Quality Assessment (NAWQA) Program. The lower Tennessee River Basin corresponds to the lower half of the Tennessee River Valley (fig. 1). Surface-water-quality data collected in the LTEN River Basin from 1980 to 1996 have been compiled, screened, and evaluated to provide a general description of water-quality conditions, to identify trends in selected water-quality constituents, and to assist the design of NAWQA data-collection activities within the LTEN River Basin. Assessment efforts have been focused on nitrogen, phosphorus, and suspended sediment because these water-quality constituents have been identified by Federal, State, and local resource-management and regulatory agencies in the basin as the issues of greatest concern to the quality of surface-water resources.

State water-quality regulatory agencies within the LTEN River Basin have documented that although the quality of surface water in the basin is generally good, poor water quality impairs beneficial uses locally in 109 stream segments and 3 lakes (Alabama Department of Environmental Management, 1996; Georgia Department of Natural Resources, 1996; Kentucky Natural Resources and Environmental Protection Cabinet, 1996; Mississippi Department of Environmental Quality, 1996; Tennessee Department of Environment and Conservation, 1996). Nutrient overenrichment is listed as causing impairment in 37 stream segments and 2 lakes. Although nitrogen and phosphorus are essential nutrients for plant and animal growth, nutrient overenrichment of streams and lakes can promote excessive growth of algae and other aquatic plants. The subsequent decay of this growth in organic matter may deplete dissolved oxygen and adversely affect fish and other aquatic life. Excessive growth of algae and other aquatic plants also is accompanied by increased levels of dissolved organic matter that may cause taste and odor problems. These problems increase water-treatment costs and thus impair the use of the water resource as a drinking-water supply.

Although nutrient overenrichment is a major cause of impairment, siltation and suspended sediment are the dominant causes of impairment in streams throughout the LTEN River Basin. Siltation and suspended sediment are listed by State water-quality regulatory agencies as causing impairment in 63 of the 109 impaired stream segments in the basin. The increased turbidity associated with elevated suspended-sediment concentrations reduces light penetration and primary productivity of the water bodies. In addition, excessive sediment deposition (siltation) on streambeds degrades habitat for benthic organisms and reduces spawning grounds for fish. Excessive sediment deposition in reservoirs interferes with recreational use (in the tributary embayments), obstructs commercial navigation channels, and reduces storage capacity (D. Meinert, Tennessee Valley Authority, written commun., 1998).

Purpose and Scope

The purposes of this report are to (1) describe and quantify the major sources of nitrogen and phosphorus to surface waters in the LTEN River Basin; (2) describe the seasonal and spatial patterns and temporal trends of concentrations and loads of nitrogen, phosphorus, and sediment; and (3) relate spatial and temporal patterns of nutrient concentrations and loads to spatial and temporal variation in sources and other environmental factors. The analyses presented in this report are based on historical water-quality data collected at 49 monitoring sites during the period October 1979-September 1996 (water years 1980-96), and on information on nutrient sources for several years during this period. Comparison of nutrient sources with loads is based on data from 1992. The water-quality

Figure 1. Location of the lower Tennessee River Basin NAWQA study unit.

data were obtained from various monitoring programs and special studies conducted by the Alabama Department of Environmental Management (ADEM), Flint Creek Watershed Project (FCWP), Geological Survey of Alabama (GSA), Kentucky Department for Environmental Protection (KDEP), Ohio River Valley Sanitation Commission (ORSANCO), Tennessee Department of Environment and Conservation (TDEC), Tennessee Valley Authority (TVA), and USGS. Water-quality constituents used in the analyses included total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, total ammonia nitrogen, total phosphorus, dissolved orthophosphorus, and suspended sediment. The data analyses included graphic summaries of nutrient concentrations, regression analysis of nutrient and sediment concentrations to estimate instream loads and trends, and correlation analysis of instream nutrient loads with watershed inputs.

Description of the Lower Tennessee River Basin

The LTEN River Basin NAWQA study unit covers a 19,500-square-mile (mi^2) area in the lower half of the Tennessee River Valley (fig. 1). The study unit upstream boundary, which coincides with the downstream boundary of the upper Tennessee River Basin study unit, is located at river mile 465 on the main stem of the Tennessee River at Chattanooga, Tennessee. The study unit encompasses parts of Tennessee, Georgia, Alabama, Mississippi, and Kentucky that drain to the Tennessee River and its tributaries between river mile 465 and the confluence with the Ohio River at Paducah, Kentucky (Woodside and Mitchell, 1998).

The LTEN River Basin is subdivided into 14 major hydrologic units (fig. 2). Seven of these units, representing 37 percent of the basin area, make up the drainage areas of five major tributaries to the Tennessee River: the Elk (two units), Duck (two units), Sequatchie, and Buffalo Rivers, and Bear Creek. The remaining units, representing 63 percent of the basin, correspond to direct drainage to the main stem of the Tennessee River, or to groupings of minor tributaries to the main stem (no individual tributary draining more than 600 mi^2, or 3 percent of the basin).

The spatial variation in concentrations and loads of nitrogen, phosphorus, and sediment within hydrologic units is affected by both natural and anthropogenic factors. Natural factors that affect water quality include geology, physiography, soils, land cover, climate, and hydrology. Kingsbury and others (1999) used geologic and physiographic boundaries to divide the LTEN River Basin into subunits in which natural factors affecting water quality are relatively homogeneous (fig. 2).

Anthropogenic factors that affect water quality include reservoirs, land use, population distribution, and urban, industrial, and agricultural activities. The distribution of urban and agricultural land use in the LTEN River Basin (fig. 3) corresponds to the distribution and amount of **nonpoint sources** (terms in **bold** can be found in the Glossary) of nitrogen, phosphorus, and sediment in the basin. The influence of certain urban and industrial activities is represented by the distribution of **point-source** discharges of wastewater (fig. 4). A more thorough discussion of the environmental setting of the LTEN River Basin is given in Kingsbury and others (1999).

Previous Investigations

Although many investigators have reported nutrient and sediment concentration data from ambient monitoring sites in the LTEN River Basin (Tennessee Valley Authority, 1972; Carriker and others, 1981; Meinert, 1991; Parr, 1991; Meinert and Fehring, 1992), few reports have presented estimates of **instream loads**, **yields**, or **trends**. Parr (1991) reported streamflow-concentration relations and temporal trends for selected water-quality constituents, including nutrients, in data collected during 1986-89 at sites in the TVA fixed-station tributary monitoring network. Trimble and Carey (1984) combined reservoir sediment-accumulation data with suspended-sediment load data from samples from the 1930’s, 1960’s, and from 1975 to 1982 to estimate instream sediment loads for several subbasins in Tennessee, including part of the LTEN River Basin. Estimates of sediment yields for central and eastern Tennessee basins (including those in the LTEN River Basin) were about 800 tons per square mile per year [(tons/mi^2)/yr], whereas sediment yields for western Tennessee basins, which are intensively agricultural and channelized, ranged from 700 to 1,000 (tons/mi^2)/yr. The similarities in these values did not match the expected result that sediment yields for western Tennessee basins would far exceed sediment yields for central and eastern Tennessee

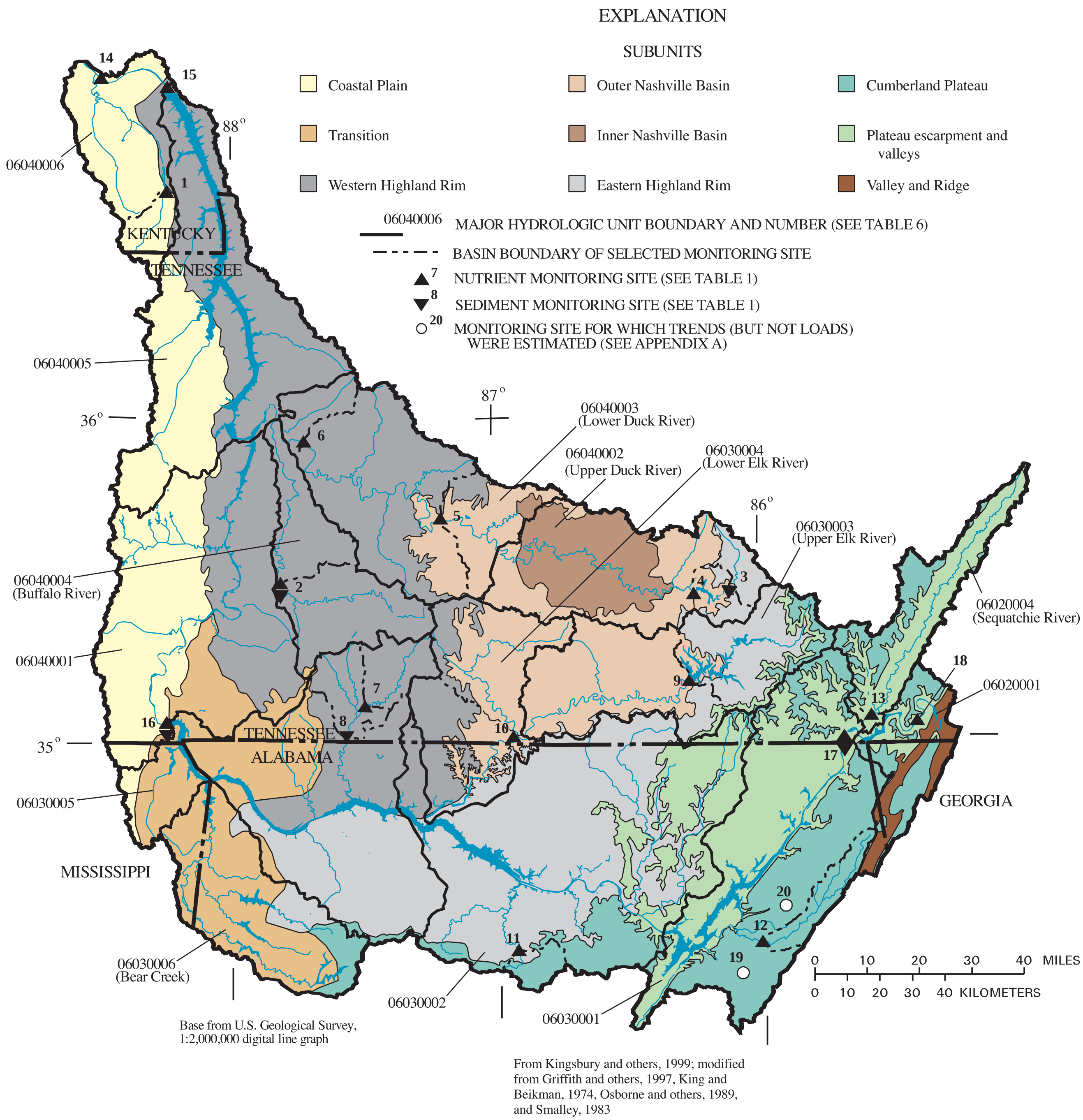
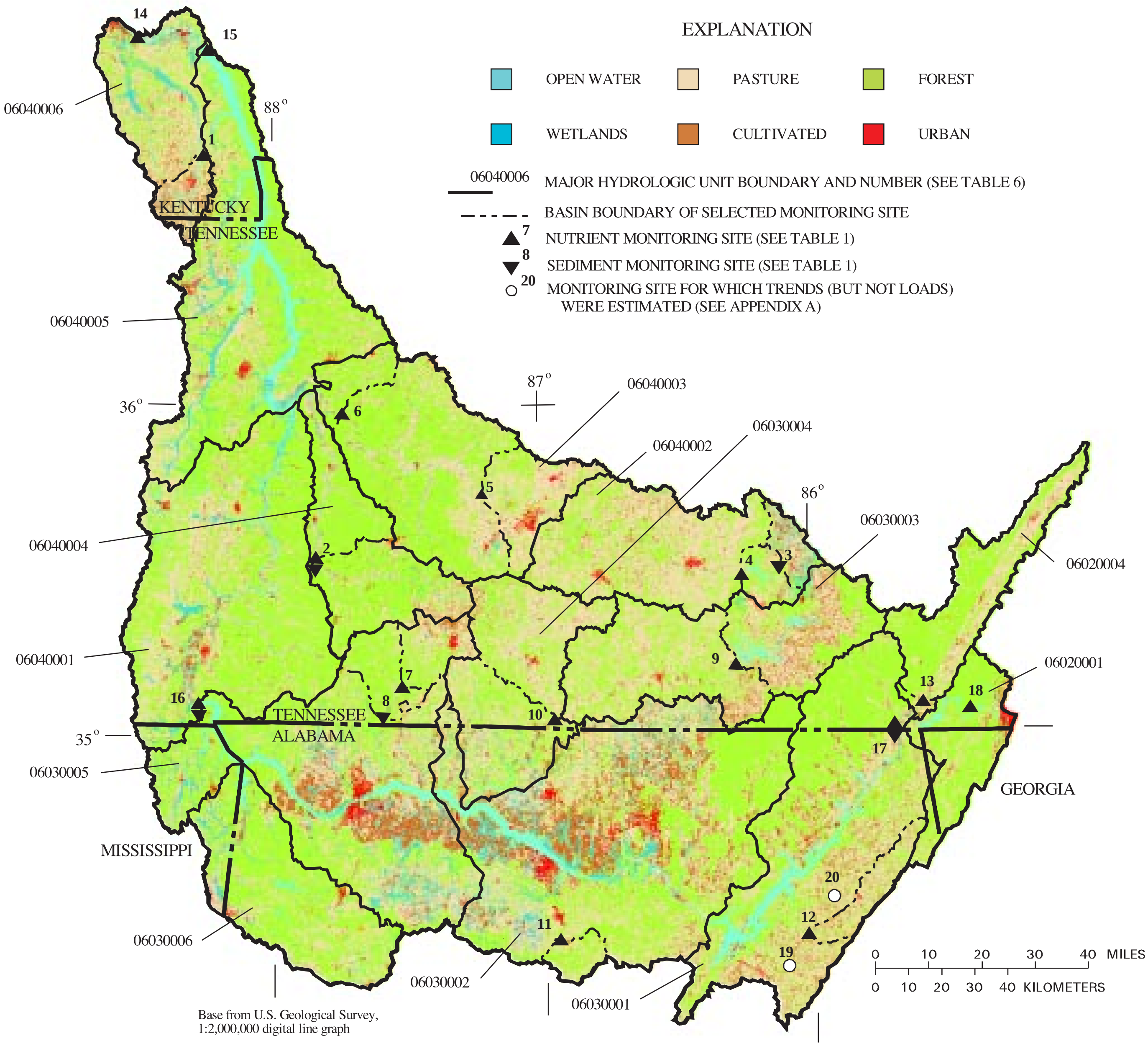


Figure 2. Subunits, major hydrologic units, and location of selected monitoring sites and basin boundaries in the lower Tennessee River Basin.



Land use and land cover digital data provided by TVA (Frank Sagona, TVA, written commun., 1998). Land cover data were derived spectrally from satellite imagery (from period 1989-92), and ground truthed using infrared aerial photography. Boundaries for certain land-use classifications (urban and wetland areas) were digitized from topographic maps.

Figure 3. Land use and land cover, major hydrologic units, and location of selected monitoring sites and basin boundaries in the lower Tennessee River Basin.

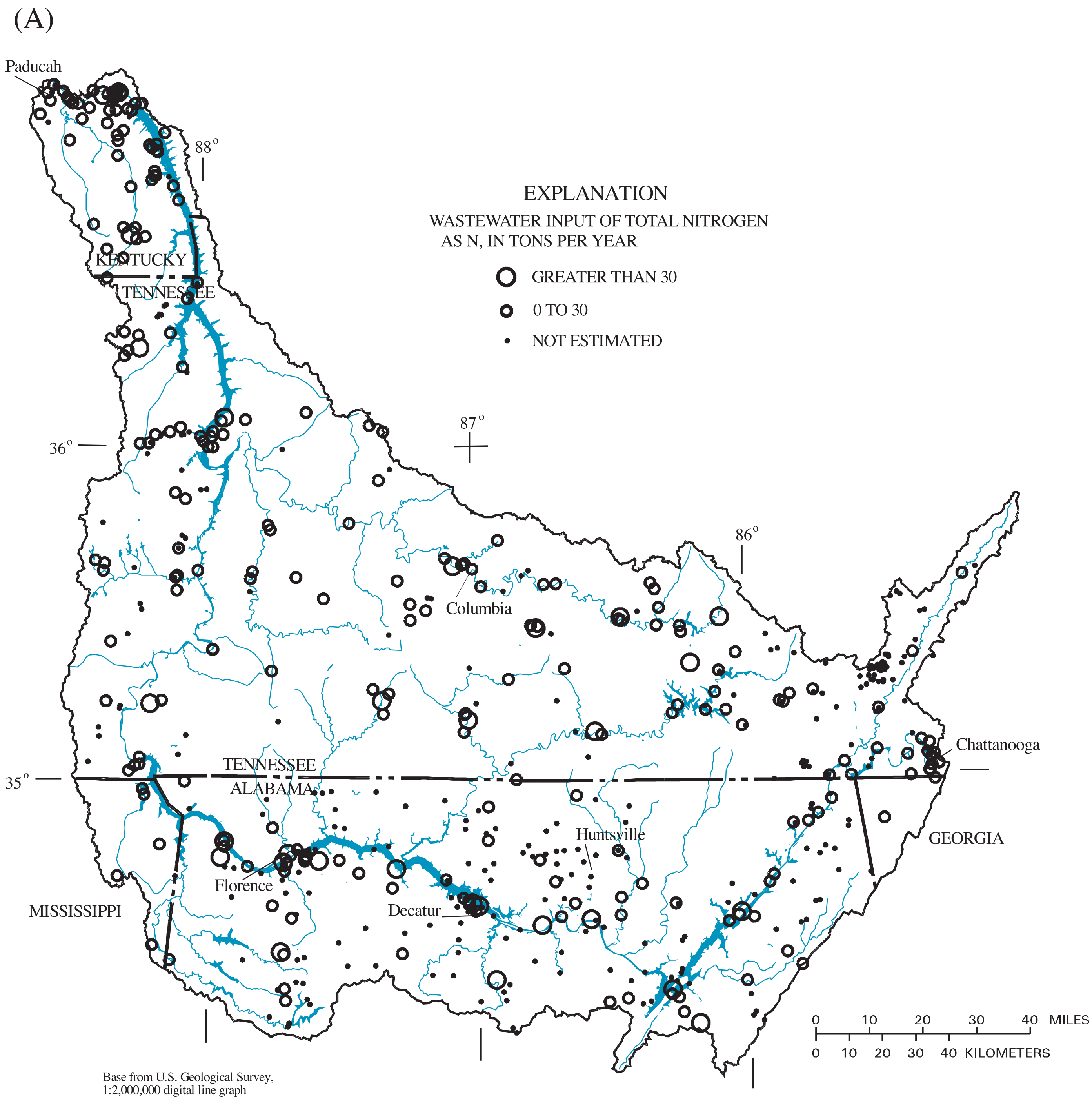


Figure 4. Location of wastewater dischargers and estimated wastewater input of (A) total nitrogen and (B) total phosphorus in the lower Tennessee River Basin in 1995.

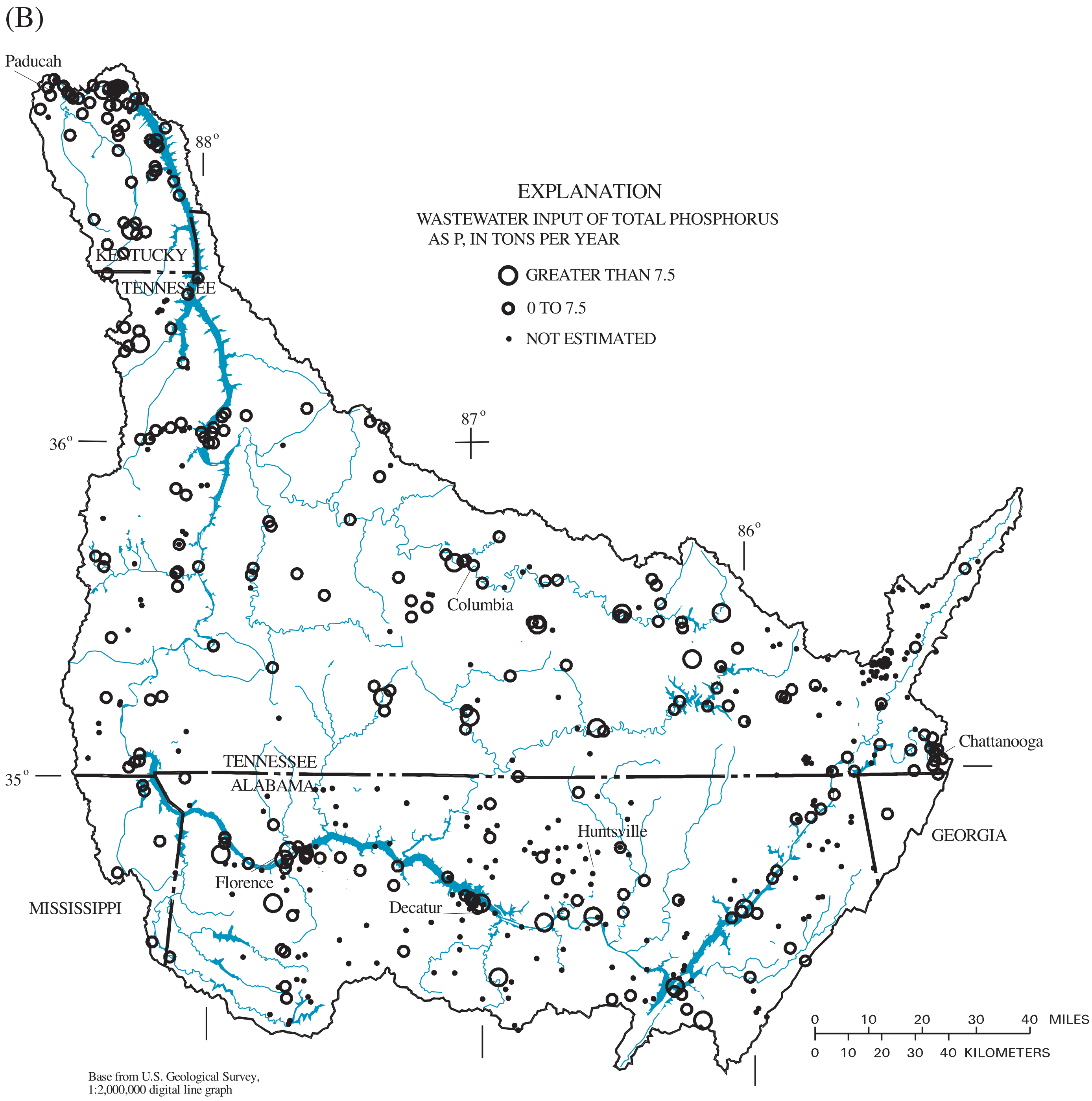


Figure 4. Location of wastewater dischargers and estimated wastewater input of (A) total nitrogen and (B) total phosphorus in the lower Tennessee River Basin in 1995—Continued.

basins because of the greater availability of loose sediment in western Tennessee watersheds compared with other parts of the State. Trimble and Carey (1984) explained these results by citing the regional differences in **land-water** and **instream delivery processes**.

Acknowledgments

The authors gratefully acknowledge the following Federal and State agencies for their cooperation in providing data and interpretations used in this report: Tennessee Valley Authority (TVA), Tennessee Department of Environment and Conservation (TDEC), Alabama Department of Environmental Management (ADEM), Kentucky Department for Environmental Protection (KDEP), Ohio River Valley Sanitation Commission (ORSANCO), Geological Survey of Alabama (GSA), Mississippi Department of Environmental Quality (MDEQ), and Georgia Department of Natural Resources (GDNR). Sherry Wang of TDEC, Frank Sagona and Dennis Meinert of TVA, and M.W. Treece and Douglas Harned of USGS provided excellent technical guidance and review throughout this effort. The authors also thank several individuals who gave special assistance in compiling the data: E.A. Thornton and Glenda Gose of TVA; Steve Fishel and Jack Hughes of TDEC; Hubert Savoy of the University of Tennessee, Agricultural Extension Service; Steve Foster, Tom Cleveland, and Mike Reif of ADEM; Sydney DeJarnette of GSA; Glen Odom of MDEQ; and Vicky Prather of KDEP.

APPROACH AND METHODS

During the period 1980-96, Federal, State, and local agencies and universities collected water-quality samples at more than 700 stream and reservoir sites in the LTEN River Basin. Most of the water-quality data analyzed in this report were collected as part of ambient monitoring programs conducted by TVA, TDEC, ADEM, KDEP, ORSANCO, and USGS. Some additional data were collected as part of special studies conducted by ADEM and TVA (Sweatt, 1996), the FCWP (1996), and as part of a sediment data-collection network conducted by USGS.

Data from the ambient monitoring programs of TVA, ORSANCO, and State agencies were obtained from the STOrage and RETrieval (STORET) data base of the U.S. Environmental Protection Agency (U.S. EPA). Data from USGS monitoring programs were obtained from the WATer data STOrage and REtrieval system (WATSTORE) data base of USGS.

Instream loads of nutrients and sediment were estimated for water-quality monitoring sites for which samples were collected at least quarterly for a period of 5 consecutive years during which daily streamflow data also were collected (or could be adapted from a nearby gage). Sites that met these criteria are shown in figures 2 and 3 and are listed as sites 1-18 in Appendix A. Most of these sites were sampled quarterly, but four sites (sites 1, 11, 12, and 18) were sampled monthly.

Instream nutrient loads were estimated at 16 of the sites (all sites except 3 and 8, where only sediment data were collected). Streamflow data for 11 of the 18 sites were collected by USGS; TVA provided streamflow data for the remaining sites (E.A. Thornton, Tennessee Valley Authority, written commun., March 1998). Additional information for the streamflow-gaging sites is provided in table 1. Instream loads of sediment were estimated at five of the USGS sites (sites 2, 3, 8, 16, and 17).

Of the 18 sites for which loads were computed, 11 are in free-flowing, or riverine, reaches of tributaries to the Tennessee River, 2 are on flow-regulated sections of tributaries (sites 4 and 9), and 5 are on flow-regulated sections along the main stem of the Tennessee River (sites 14-18). Each drainage basin contributing to the tributary sites (sites 1-13) is shown in relation to environmental setting (figs. 2 and 3) to illustrate the composition of each basin with respect to subunits and land use/land cover. Summaries of subunit and land use/land cover for each tributary basin are shown in figure 5. The combined percentage in pasture, cultivated, and urban land use/land cover in this set of basins ranges from 29 percent (site 2, Buffalo River near Flat Woods) to 80 percent (site 1, Clarks River at Almo). Land use and subunit summaries are not shown for the sites along the main stem of the Tennessee River (sites 14-18) because the many large impoundments along the main stem in both the upper and lower parts of the Tennessee River alter the instream transport of nutrients and sediment, confounding comparison between basin characteristics and water quality for those sites.

Eight of the 18 water-quality monitoring sites were not colocated with a corresponding streamflow-gaging station, but were located some distance upstream or downstream from a gaging station (drainage areas listed in table 1 indicate a difference for the

Table 1. Streamflow characteristics of sites in the lower Tennessee River Basin where instream loads were estimated

[mi^2, square miles; ft^3/s, cubic feet per second; in., inches; R (riverine), tributary site at which streamflow is not regulated or a major component of the streamflow is not regulated; FR (flow-regulated), site located in an impoundment or at which streamflow is strongly influenced by an upstream impoundment; USGS, U.S. Geological Survey; TVA, Tennessee Valley Authority; CY, current year; period of load and trend computation varies slightly among constituents]

Site identification (fig. 2)	Surface-water station/site location		Drainage area (mi^2)	Type of site	Related streamflow gaging site								
					Streamflow gaging station			Period of record (water year)	Streamflow characteristics for period of record		Period of load and trend computation (water year)	Streamflow characteristics for period of computation	
	Number	Name			Number	Agency	Drainage area (mi^2)		Median flow (ft^3/s)	Median runoff (in.)		Median flow (ft^3/s)	Median runoff (in.)
1	PRI038	Clarks River at Almo, Ky.	134	R	03610200	USGS	134	1982-CY	31.8	3.2	1985-95	29.1	3.0
2	03604000	Buffalo River near Flat Woods, Tenn.	447	R	03604000	USGS	447	1921-CY	392	11.9	1982-95	461	14.0
3	03596000	Duck River below Manchester, Tenn.	107	R	03596000	USGS	107	1935-87	64.1	8.1	1979-83	65	8.3
4	001025	Duck River below Normandy Dam, Tenn.	195	FR	Dam tail-water	TVA	195	1922-31, 73-75, 87-CY	155	10.7	1986-95	155	10.8
5	001065	Duck River at Williamsport, Tenn.	1,448	R	03599500	USGS	1,208	1905-08, 21-CY	709	8.0	1981-94	684	7.7
6	475793	Duck River above Hurricane Mills, Tenn.	2,557	R	03603000	TVA	2,557	1926-CY	1,823	9.7	1986-94	1,864	9.9
7	002395	Shoal Creek at Highway 43 near Lawrenceburg, Tenn.	176	R	03588500	USGS	348	See entry for site 8			1983-94	360	14.0
8	03588500	Shoal Creek at Iron City, Tenn.	348	R	03588500	USGS	348	1926-94	324	12.7	1979-83	383	15.0
9	001207	Elk River below Tims Ford Dam, Tenn.	529	FR	Dam tail-water	TVA	529	1967-75, 82-CY	409	10.4	1983-94	366	9.4

Table 1. Streamflow characteristics of sites in the lower Tennessee River Basin where instream loads were estimated—Continued

Site identification (fig. 2)	Surface-water station/site location		Drainage area (mi^2)	Type of site	Related streamflow gaging site: Streamflow gaging station			Period of record (water year)	Streamflow characteristics for period of record		Period of load and trend computation (water year)	Streamflow characteristics for period of computation	
	Number	Name			Number	Agency	Drainage area (mi^2)		Median flow (ft^3/s)	Median runoff (in.)		Median flow (ft^3/s)	Median runoff (in.)
10	475796	Elk River near Prospect, Tenn.	1,784	R	03584600	TVA	1,805	1905-07, 20-CY	1,441	10.8	1986-94	1,441	10.9
11	FLCR7	Flint Creek near Falkville, Ala.	86.3	R	03576500	USGS	86.3	1953-70, 93-97	41.5	6.5	1993-97	60.2	9.5
12	TOWN CREEK 15[a]	Town Creek near Geraldine, Ala.	157	R	03572900	TVA	141	1958-CY	129	12.4	1988-96	147	14.1
13	002375	Sequatchie River at Valley Road, Tenn.	578	R	03571000	USGS	402	1921-94	341	11.5	1983-95	381	12.8
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	40,330	FR	03609500	TVA	40,200	1890-1984	43,700	14.6	1980-84	41,340	14.0
15	202832	Tennessee River at mile 23, Ky.	40,200	FR	03609500	TVA	40,200	See entry for site 14			1990-94	45,210	15.3
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	32,820	FR	03593500	USGS	33,140	1931-CY	40,794	16.7	1980-96	39,890	16.4
17	03571850	Tennessee River at South Pittsburg, Tenn.	22,640	FR	03571850	USGS	22,640	1931-87	31,121	18.6	1980-86	34,108	20.7
18	003315	Tennessee River below Raccoon Mountain, Tenn.	21,730	FR	03568000	USGS	21,400	1875-CY	29,288	18.6	1981-94	28,305	18.0

[a]Station number in Alabama Department of Environmental Management study is t5.

Site number (fig. 2)	Surface-water station name	Percentage of basin area in subunit or land use/land cover												
		Subunit								Land use/land cover				
											Agriculture			
		Coastal Plain	Transition	Western Highland Rim	Outer Nashville Basin	Inner Nashville Basin	Eastern Highland Rim	Cumberland Plateau	Plateau Escarpment and Valleys	Forest	Pasture	Cultivated	Urban	Other
1	Clarks River at Almo, Ky.	95	0	5	0	0	0	0	0	14	58	20	3	5
2	Buffalo River near Flat Woods, Tenn.	0	1	99	0	0	0	0	0	68	25	4	0	3
3	Duck River below Manchester, Tenn.	0	0	0	1	0	99	0	0	18	45	16	1	20
4	Duck River below Normandy, Tenn.	0	0	0	34	0	65	0	0	35	42	9	1	13
5	Duck River at Williamsport, Tenn.	0	0	1	49	39	11	0	0	34	56	5	1	4
6	Duck River above Hurricane Mills, Tenn.	0	0	34	36	24	7	0	0	47	45	4	1	3
7	Shoal Creek at Highway 43 near Lawrenceburg, Tenn.	0	0	100	0	0	0	0	0	42	46	8	2	2
8	Shoal Creek at Iron City, Tenn.	0	1	99	0	0	0	0	0	59	34	4	1	2
9	Elk River below Tims Ford Dam, Tenn.	0	0	0	11	0	64	14	12	42	41	11	1	5
10	Elk River near Prospect, Tenn.	0	0	7	61	0	24	5	3	44	47	6	0	3
11	Flint Creek near Falkville, Ala.	0	0	0	0	0	14	0	85	56	40	2	0	2
12	Town Creek near Geraldine, Ala.	0	0	0	0	0	0	0	100	31	57	10	0	2
13	Sequatchie River at Valley Road, Tenn.	0	0	0	0	0	0	64	36	67	29	2	0	2

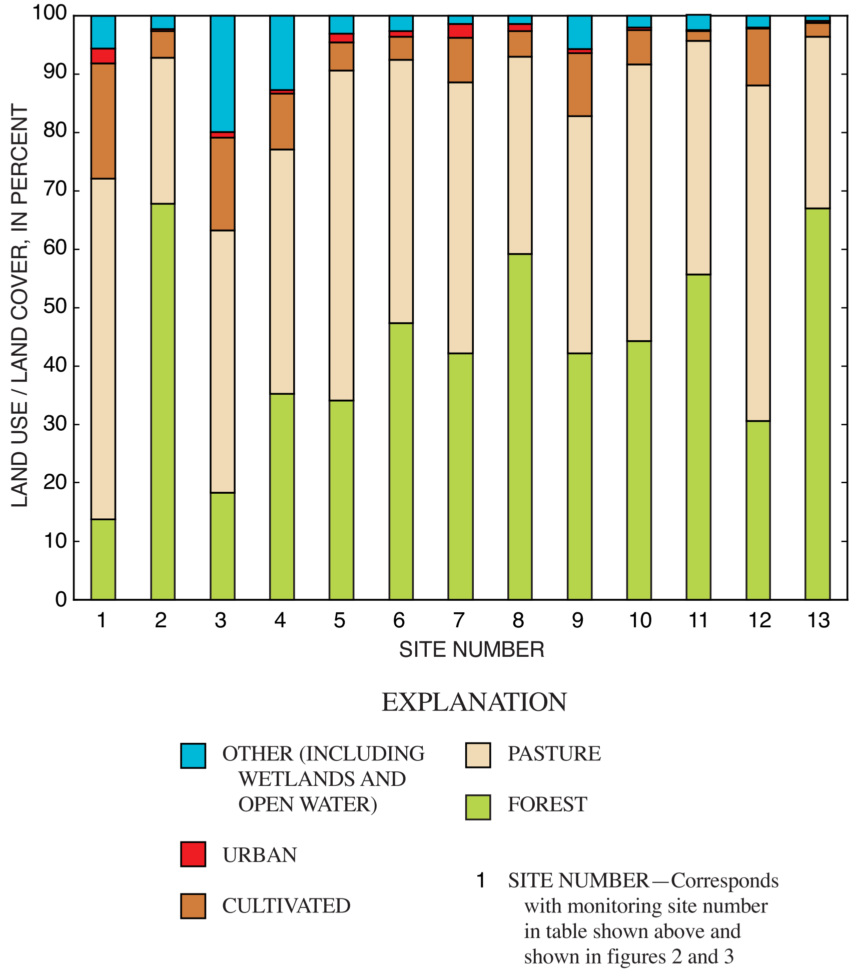


Figure 5. Basin characteristics of tributary sites in the lower Tennessee River Basin where instream loads were estimated.

eight sites). To adjust for these differences in drainage areas, the estimates of instream load at these eight water-quality monitoring sites were multiplied by the ratios between the drainage areas of the paired streamflow and water-quality monitoring sites. A ratio within 0.8 to 1.2 was considered to be acceptable. Two of the sites, however, fell outside of this criterion: Sequatchie River at Valley Road (site 13), and Shoal Creek at Highway 43 (site 7), had ratios of 1.4 and 0.5, respectively. These sites were included in the set of instream-load computation sites to provide representation for a particular combination of land use and subunit for which no other sites were available (as shown by combinations in fig. 5), but the load estimates are presented with the qualifier that the estimation error may be significantly larger than for other sites.

Trends in concentration were estimated at sites for which samples were collected at least quarterly for 5 consecutive years, and for which streamflow data were available for each sample (either from a nearby continuous-recording streamflow gage or from measurements of instantaneous streamflow concurrent with sample collection) so that concentrations could be adjusted based on streamflow. Flow adjustment of concentration data eliminates variation in concentration related to streamflow, allowing for more accurate detection of time trends in water quality. The sites that met the data requirements for this analysis were the 18 instream-load computation sites (table 1), and sites 19 and 20 (figs. 2 and 3 and Appendix A) sampled as part of a special study conducted by ADEM and TVA in the Cumberland Plateau area in Alabama (Sweatt, 1996).

Downstream variations in nutrient concentrations along the Tennessee and Duck Rivers were evaluated by summarizing data from numerous monitoring sites along the rivers where at least 20 samples had been collected during 1980-96 and with record extending past 1989. (The last criterion was relaxed to 1985 in screening for sites on the Duck River, where only a few sites had data extending past 1985.) Of the more than 400 monitoring sites located on the main stem Tennessee River and Duck River (based on nutrient data in the STORET or WATSTORE data bases), 37 sites met this criterion and are listed in Appendix A.

Data were reviewed to ensure comparability between data from the different monitoring networks, despite variations in analytical methods and data-reporting levels among agencies. Analytical data derived from various analytical procedures were grouped when appropriate (table 2) to construct the most complete nutrient data sets possible. Differences in minimum reporting levels (MRL) among sites tend to confound spatial comparisons of instream loads, thus load estimates for sites and constituents with high MRL's (compared with other sites) are reported with a qualifier.

Instream load of nitrogen, phosphorus, and sediment was calculated as the product of daily streamflow and estimated daily concentration using the Cohn's Estimator model (Cohn and others, 1989; Cohn and others, 1992; Gilroy and others, 1990). This model includes a seven-parameter log-linear regression analysis of constituent concentrations against measured environmental variables:

$$\begin{aligned} \ln[C] = \beta0 &+ \beta1(\ln[Q/Q'] + \beta2(\ln[Q/Q'])^2 \\ &+ \beta3[T-T'] + \beta4[T-T']^2 + \beta5\text{sine}[2\pi T] \\ &+ \beta6\text{cosine}[2\pi T] + e \end{aligned} \tag{1}$$

where

- $\ln[\,]$ is natural logarithm function;
- C is estimated daily concentration, in milligrams per liter;
- Q is daily streamflow, in cubic feet per second;
- T is time, in decimal years;
- π is 3.14169;
- $\beta0$ - $\beta6$ are calibration coefficients of the regression model;
- e is model error;
- Q' is centering variable defined so that $\beta1$ and $\beta2$ are statistically independent; and
- T' is centering variable defined so that $\beta3$ and $\beta4$ are statistically independent.

The regression analysis assumes that model errors (e) are independent and normally distributed, with zero mean and variance. The Minimum Variance Unbiased Estimator (Bradu and Mundlak, 1970) is included in the model to correct for the retransformation bias associated with log-linear regression models; the model also employs the Adjusted Maximum Likelihood Estimator (Cohn, 1988), which statistically addresses censored data and multiple reporting limits. Additional information about the data requirements of Cohn's Estimator model is given in Appendix B.

Variations in concentrations of nitrogen, phosphorus, and sediment with season, streamflow, and time were displayed for sites 1 to 20 with scatterplots, and quantified with the multivariate log-linear regression component of Cohn's Estimator model. A significance level of 0.05 was used as the criterion for statistical significance to interpret regression analyses and correlations.

Table 2. Summary of procedures used to combine nutrient constituent data from different analytical methods

[Modified from Frick and others, 1996; mg/L, milligrams per liter; N, nitrogen; P, phosphorus]

Nutrient constituent	Parameter from source data bases		Procedure	Load-computation sites for which parameter was used (see Appendix A for detailed site description)
	Parameter code	Parameter name		
Total nitrite plus nitrate, as N	00630	Nitrogen, nitrite plus nitrate, total (mg/L as N)	Use if available	All sites except 2, 14, 16, 17
	00631	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Use if 00630 not available	2, 14, 16, 17
Total ammonia, as N	00610	Nitrogen, ammonia, total (mg/L as N)	Use if available	All sites except 11, 16, 18
	00608	Nitrogen, ammonia, dissolved (mg/L as N)	Use if 00610 not available	11, 16, 18
Total ammonia plus organic nitrogen, as N	00625	Nitrogen, ammonia plus organic, total (mg/L as N)	Use if available	2, 11,12,14,16,17
	00635	Nitrogen, ammonia plus organic, single determination (mg/L as N)	Use if 00625 not available	4, 5, 7, 9, 13, 18
	00605+00610	Nitrogen, organic, total (mg/L as N) + **total ammonia, as N**[a]	Use if 00625 and 00635 not available	1, 6, 10, 15
Total nitrogen, as N	00600	Nitrogen, total (mg/L as N)	Use if available	Not used at any sites (not consistently populated)
	[total nitrite plus nitrate, as N] + [total ammonia plus organic nitrogen, as N][a]		Use if 00600 not available	All sites
Total phosphorus, as P	00665	Phosphorus, total (mg/L as P)	Use if available	All sites
Dissolved orthophosphorus, as P	00671	Phosphorus, orthophosphate, dissolved (mg/L as P)	Use if available	All sites except 6, 10
	00666	Phosphorus, dissolved (mg/L as P)	Use if 00671 not available	6, 10

[a] Nutrient constituent derived from another combination procedure.

SOURCES OF NITROGEN AND PHOSPHORUS

Inputs from several sources of nitrogen and phosphorus were compiled to compare the magnitude of inputs among the various sources, to identify areas in the basin with higher nitrogen and phosphorus inputs, and to compare inputs with instream loads. Two distinct types of input estimates are presented: **land-phase inputs** (mass applied to the land surface of the watershed) and **stream inputs** (mass discharged directly to the stream channel). Estimates of land-phase inputs cannot be compared directly to estimates of stream inputs or instream loads.

Sources of nutrients to watersheds and to streams and reservoirs include both **point sources** (wastewater and stormwater discharge, combined sewer overflows) and **nonpoint sources** (atmospheric deposition, fertilizer application, livestock waste, urban runoff, failing septic systems, contaminated ground water, and natural sources). Inputs from wastewater discharge, atmospheric deposition, fertilizer application, and livestock waste were quantified for 11 sites on the tributary streams and reservoirs and for the major hydrologic units in the LTEN River Basin (tables 3, 4, 5, and 6). Inputs from wastewater discharge are direct stream inputs, and inputs from nonpoint sources are land-phase inputs. Data from 1992 were used to estimate inputs where possible because more data were available in the data sets for sources, land use, and instream loads during this period than in any other period. Inputs from the other listed sources are discussed in the section “Additional Sources of Nitrogen and Phosphorus” but are not quantified in this report.

Sites on the main stem of the Tennessee River were excluded from the analysis of inputs because the main stem of the lower Tennessee River carries considerable load from the upper Tennessee (UTEN) River Basin, and the intent of this report is to interpret sources and transport only in the LTEN River Basin. Treece and Johnson (1997) and Johnson and Treece (1998) describe nitrogen and phosphorus sources, yields, and trends for the upper Tennessee River Basin. In addition, the many large impoundments along the main stem in both the upper and lower parts of the Tennessee River alter the instream transport of nutrients and sediment, confounding direct comparison of inputs with instream loads for the main stem sites.

Point Sources

Point sources discharge directly to the stream channel from a discrete location and include municipal and industrial wastewater discharges, municipal and industrial stormwater discharges, and sanitary and combined sewer overflows. Data were not available to estimate nutrient inputs from stormwater discharges and sewer overflows; therefore, the only point-source inputs estimated in this report are municipal and industrial wastewater discharge.

Wastewater Discharge

In 1992, an estimated 730 municipal and industrial facilities discharged wastewater into streams and reservoirs in the LTEN River Basin. Nitrogen and phosphorus inputs were estimated for the individual wastewater discharges (fig. 4) using methods described in Appendix C and summarized in table 7. These estimates were then summed for the tributary basins and the major hydrologic units. The input estimates were normalized by watershed drainage area to allow comparisons among basins and hydrologic units.

Estimated inputs of nitrogen from wastewater discharge for selected tributary monitoring basins (table 3) ranged from 0 (ton/mi^2)/yr (site 11, Flint Creek near Falkville) to 0.61 (ton/mi^2)/yr (site 1, Clarks River at Almo), and of phosphorus (table 4), from 0 (ton/mi^2)/yr (site 11, Flint Creek near Falkville) to 0.14 (ton/mi^2)/yr (site 1, Clarks River at Almo). Estimated inputs of nitrogen for major hydrologic units (table 5) ranged from 0.021 (tons/mi^2)/yr (hydrologic unit 06020004, Sequatchie River basin) to 5.5 (tons/mi^2)/yr (hydrologic unit 06040006, area contributing to below Kentucky Dam) and of phosphorus (table 6), from 0.005 (ton/mi^2)/yr (hydrologic unit 06020004, Sequatchie River basin) to 0.11 (ton/mi^2)/yr (hydrologic unit 06030002, area contributing to Wheeler Reservoir).

Nonpoint Sources

Nonpoint-source inputs to a watershed have diffuse source areas, ranging from a few square miles to the entire watershed area. Only a part of the input from these sources reaches the stream channel; the remainder accumulates within the watershed or is lost through processes such as crop harvest and export and denitrification. Nonpoint-source inputs of nutrients estimated in this report (atmospheric deposition, fertilizer application, and livestock waste) primarily are related to human activities.

Table 3. Nitrogen inputs and export for selected basins in the lower Tennessee River Basin

[Inputs and export reported in tons per year of nitrogen; unit-area inputs and yield reported in tons per square mile per year; --, not estimated; <, less than; -, negative number because crop harvest represents a nutrient sink; balance of land-phase input is calculated as the sum of inputs from fertilizer application, nitrogen fixation, and livestock waste, minus removal as crop harvest; export was estimated for 1992 at sites where record was available for that year]

Site identi-fication (fig. 2)	Surface-water station		Stream input: Wastewater discharge (1995 or 1992)		Land-phase input: Atmospheric deposition (1992)		Fertilizer application (1991)		Nitrogen fixation (1992)		Harvest (crop) uptake) (1992)		Livestock waste (1992)		Balance of land-phase input to agri-cultural land		Export (1992)	
	Number	Name	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Load	Yield
		Tributary sites																
1	PRI038	Clarks River at Almo, Ky.	82	0.61	210	1.6	3,000	23	1,000	7.6	-3,300	-24	500	3.7	1,300	9.7	320	2.4
2	03604000	Buffalo River near Flat Woods, Tenn.	26	.06	800	1.8	1,600	3.6	130	.3	-1,200	-2.6	880	2.0	1,400	3.2	460	1.0
4	001025	Duck River below Normandy Dam, Tenn.	52	.27	350	1.8	890	4.5	290	1.5	-990	-5.1	990	5.1	1,200	6.1	200	1.0
5	001065	Duck River at Williamsport, Tenn.	300	.21	2,600	1.8	5,200	3.6	1,100	.8	-6,000	-4.2	9,500	6.6	9,800	6.8	3,000	2.1
6	475793	Duck River above Hurricane Mills, Tenn.	320	.12	4,600	1.8	6,700	2.6	1,300	.5	-8,000	-3.1	12,000	4.7	12,000	4.6	4,500	1.7
7	002395	Shoal Creek at Highway 43, near Lawrenceburg, Tenn.	75	.43	320	1.8	1,200	6.6	100	.6	-850	-4.8	730	4.1	1,100	6.5	500	2.9
9	001207	Elk River below Tims Ford Dam, Tenn.	93	.18	960	1.8	3,200	6.0	850	1.6	-3,200	-6.0	3,100	5.9	3,900	7.5	530	1.0
10	475796	Elk River near Prospect, Tenn.	160	.092	3,200	1.8	7,600	4.3	1,700	1.0	-7,800	-4.4	11,000	5.9	12,000	6.7	5,300	3.0
11	FLCR7	Flint Creek near Falkville, Ala.	0	.00	160	1.9	180	2.1	34	.4	-150	-1.8	1,100	12	1,100	13	[a]200	[a]2.4
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	0.55	<.01	310	2.0	730	4.7	96	.6	-490	-3.1	2,000	13	2,400	15	550	3.5
13	002375	Sequatchie River at Valley Road, Tenn.	13	.02	1,000	1.8	860	1.5	200	.3	-960	-1.7	1,300	2.2	1,400	2.4	820	1.4
		Main stem sites																
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	[b]56,000	[b]1.4
15	202832	Tennessee River at mile 23, Ky.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	38,000	0.94
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	36,000	1.1
17	03571850	Tennessee River at South Pittsburg, Tenn.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	[b]43,000	[b]1.9
18	003315	Tennessee River below Raccoon Mountain, Tenn.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20,000	0.94

[a] Estimate for 1994.

[b] Estimate for 1982.

Table 4. Phosphorus inputs and export, and ratio of nitrogen to phosphorus export, for selected basins in the lower Tennessee River Basin

[Inputs and export reported in tons per year of phosphorus; unit-area inputs and yield reported in tons per square mile per year; --, not estimated; -, negative number because crop harvest represents a nutrient sink; balance of land-phase input calculated as the sum of inputs from fertilizer application and livestock waste, minus removal as crop harvest; export was estimated for 1992 at sites where record was available for that year]

Site identi-fica-tion (fig. 2)	Surface-water station		Stream input: Wastewater discharge (1995 or 1992)		Land-phase input: Atmospheric deposition (1992)		Fertilizer application (1991)		Nitrogen fixation (1992)		Harvest (crop uptake) (1992)		Livestock waste (1992)		Balance of land-phase input to agri-cultural land		Export (1992)		Ratio of nitro-gen to phosphorus export
	Number	Name	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Load	Yield	
		Tributary sites																	
1	PRI038	Clarks River at Almo, Ky.	19	0.14	--	--	690	5.1	--	--	-430	-3.2	170	1.2	430	3.2	40	0.30	8:1
2	03604000	Buffalo River near Flat Woods, Tenn.	6	.014	--	--	410	.93	--	--	-140	-.32	280	.62	550	1.2	20	.044	23:1
4	001025	Duck River below Normandy Dam, Tenn.	10	.050	--	--	230	1.2	--	--	-120	-.60	280	1.4	390	2.0	16	.082	12:1
5	001065	Duck River at Williamsport, Tenn.	67	.046	--	--	1,300	.92	--	--	-700	-.48	2,700	1.9	3,300	2.3	1,300	.93	2:1
6	475793	Duck River above Hurricane Mills, Tenn.	71	.028	--	--	1,700	.67	--	--	-930	-.36	3,500	1.4	4,200	1.7	2,900	1.1	2:1
7	002395	Shoal Creek at Highway 43, near Lawrenceburg, Tenn.	13	.072	--	--	300	1.7	--	--	-100	-.61	220	1.2	400	2.3	26	.15	19:1
9	001207	Elk River below Tims Ford Dam, Tenn.	22	.042	--	--	820	1.5	--	--	-400	-.76	980	1.8	1,400	2.6	18	.034	29:1
10	475796	Elk River near Prospect, Tenn.	39	.022	--	--	1,900	1.1	--	--	-950	-.53	3,100	1.7	4,100	2.3	1,600	.89	3:1
11	FLCR7	Flint Creek near Falkville, Ala.	0	.00	--	--	30	.35	--	--	-17	-.19	320	3.7	340	3.9	--	--	
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	0.15	.001	--	--	120	.77	--	--	-61	-.39	680	4.3	740	4.7	--	--	
13	002375	Sequatchie River at Valley Road, Tenn.	3	.005	--	--	220	.38	--	--	-110	-.19	390	.68	500	.87	--	--	
		Main stem sites																	
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
15	202832	Tennessee River at mile 23, Ky.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3,200	.08	12:1
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3,900	.12	9:1
17	03571850	Tennessee River at South Pittsburg, Tenn.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	[a]1,600	[a].07	27:1
18	003315	Tennessee River below Raccoon Mountain, Tenn.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	

[a] Instream estimate for 1982.

Table 5. Nitrogen inputs for major hydrologic units in the lower Tennessee River Basin

[Inputs reported in tons per year of nitrogen; unit-area inputs reported in tons per square mile per year; -, negative number because crop harvest represents a nutrient sink; balance of land-phase input is calculated as the sum of inputs from fertilizer application, nitrogen fixation, and livestock waste, minus removal as crop harvest]

Major hydrologic unit		Stream input		Land-phase input											
		Wastewater discharge (1995 or 1992)		Atmospheric deposition (1992)		Fertilizer application (1991)		Nitrogen fixation (1992)		Harvest (crop) uptake) (1992)		Livestock waste (1992)		Balance of land-phase input to agri-cultural land	
Hydrologic unit code	Name	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input
06020001	Area contributing to Nickajack Reservoir	34	0.073	880	1.9	540	1.1	68	0.14	-440	-0.94	1,300	2.7	1,500	3.1
06020004	Sequatchie River basin	13	.021	1,100	1.8	860	1.5	200	.34	-970	-1.6	1,300	2.2	1,400	2.3
06030001	Area contributing to Guntersville Reservoir	330	.16	3,900	2.0	6,400	3.2	1,900	.93	-5,900	-2.9	14,000	7.0	16,000	8.2
06030002	Area contributing to Wheeler Reservoir	7,400	2.5	5,500	1.9	16,000	5.6	3,500	1.2	-10,500	-3.6	13,000	4.6	22,000	7.7
06030003	Upper Elk River basin	130	.10	2,300	1.8	6,000	4.6	1,500	1.2	-6,100	-4.8	7,700	6.0	9,000	7.0
06030004	Lower Elk River basin	36	.038	1,800	1.8	3,000	3.1	410	.43	-2,500	-2.6	4,500	4.7	5,400	5.6
06030005	Area contributing to Pickwick/ Wilson Reservoir	930	.41	4,100	1.8	10,000	4.5	1,000	.44	-4,800	-2.1	6,900	3.0	13,000	5.9
06030006	Bear Creek basin	39	.042	1,700	1.8	1,300	1.4	220	.23	-790	-.83	3,500	3.7	4,200	4.5
06040001	Area contributing to upper Kentucky Reservoir	72	.035	3,300	1.6	3,700	1.8	960	.46	-3,700	-1.7	3,700	1.8	4,700	2.3
06040002	Upper Duck River basin	190	.16	2,100	1.8	4,400	3.7	920	.78	-5,000	-4.2	8,000	6.8	8,300	7.0
06040003	Lower Duck River basin	130	.088	2,600	1.7	2,500	1.6	450	.30	-3,300	-2.2	4,300	2.8	3,900	2.6
06040004	Buffalo River basin	37	.049	1,300	1.7	1,900	2.5	180	.24	-1,600	-2.1	1,200	1.6	1,700	2.3
06040005	Area contributing to lower Kentucky Reservoir	290	.16	2,900	1.6	3,500	1.9	1,000	.55	-3,900	-2.1	2,800	1.5	3,400	1.8
06040006	Area contributing to below Kentucky Dam	3,800	5.5	1,100	1.6	7,300	10	2,800	4.0	-8,500	-12	2,500	3.6	4,100	5.9

Table 6. Phosphorus and sediment inputs for major hydrologic units in the lower Tennessee River Basin

[Inputs reported in tons per year; unit-area inputs reported in tons per square mile per year; --, not estimated; -, negative number because crop harvest represents a nutrient sink; balance of land-phase input calculated as the sum of inputs from fertilizer application and livestock waste, minus removal as crop harvest; rates of soil erosion by wind and water on cropland (U.S. Department of Agriculture, Natural Resources Conservation Service, 1997) were multiplied by area of cropland in the major hydrologic unit]

Major hydrologic unit		Phosphorus														Sediment	
		Stream input		Land-phase input													
		Wastewater discharge (1995 or 1992)		Atmospheric deposition (1992)		Fertilizer application (1991)		Nitrogen fixation (1992)		Harvest (crop) uptake) (1992)		Livestock waste (1992)		Balance of land-phase input to agri-cultural land		Soil erosion by wind and water (1992)	
Hydrologic unit code	Name	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input	Input	Unit-area input
06020001	Area contributing to Nickajack Reservoir	8.1	0.017	--	--	110	0.24	--	--	-51	-0.11	400	0.85	460	0.97	--	--
06020004	Sequatchie River basin	3.0	.0050	--	--	220	.38	--	--	-110	-.19	390	.67	500	.85	30,000	51
06030001	Area contributing to Guntersville Reservoir	71	.036	--	--	1,100	.55	--	--	-700	-.35	4,500	2.2	4,900	2.4	570,000	290
06030002	Area contributing to Wheeler Reservoir	300	.11	--	--	2,800	.96	--	--	-1,300	-.44	4,000	1.4	5,500	1.9	1,600,000	540
06030003	Upper Elk River basin	30	.023	--	--	1,500	1.2	--	--	-760	-.59	2,300	1.8	3,100	2.4	230,000	180
06030004	Lower Elk River basin	8.5	.0088	--	--	690	.71	--	--	-300	-.31	1,300	1.4	1,700	1.8	110,000	120
06030005	Area contributing to Pickwick/Wilson Reservoirs	130	.059	--	--	1,800	.80	--	--	-610	-.27	2,100	.94	3,300	1.5	1,100,000	460
06030006	Bear Creek basin	10	.010	--	--	200	.21	--	--	-92	-.10	1,100	1.1	1,200	1.2	74,000	78
06040001	Area contributing to upper Kentucky Reservoir	17	.0081	--	--	930	.45	--	--	-450	-.21	1,400	.67	1,900	.90	130,000	63
06040002	Upper Duck River basin	40	.034	--	--	1,100	.95	--	--	-580	-.49	2,300	1.9	2,800	2.4	160,000	140
06040003	Lower Duck River basin	31	.021	--	--	640	.42	--	--	-400	-.26	1,300	.85	1,600	1.0	110,000	70
06040004	Buffalo River basin	9.1	.012	--	--	490	.64	--	--	-200	-.26	400	.53	690	.91	74,000	97
06040005	Area contributing to lower Kentucky Reservoir	33	.018	--	--	860	.47	--	--	-500	-.27	960	.52	1,300	.72	100,000	55
06040006	Area contributing to below Kentucky Dam	72	.10	--	--	1,600	2.3	--	--	-1,100	-1.5	840	1.2	1,400	2.0	210,000	300

Table 7. Summary of methods for quantifying inputs of nitrogen and phosphorus to tributary basins and major hydrologic units

[NADP/NTN, National Atmospheric Deposition Network/National Trends Network; mg/L, milligrams per liter; lb/acre, pounds per acre; lb/bushel, pounds per bushel]

Nitrogen or phosphorus source	Methods		
	Description of spatial data	Description of calculations	Coefficients used in calculations
Wastewater discharge	Annual mean flow rate and (where available) effluent concentration data from wastewater dischargers.	Multiply annual mean flow rate by reported effluent concentration, or (for nitrogen) by empirically adjusted effluent ammonia concentration, or by typical concentration of nitrogen and phosphorus for discharge categories.	Typical concentration for municipal wastewater: nitrogen - 15 mg/L, phosphorus - 3.5 mg/L, for industrial wastewater, estimates from National Oceanic and Atmospheric Administration (1993).
Atmospheric deposition	Precipitation chemistry data from the NADP/NTN network.	Weight NADP/NTN nitrate and ammonia wet deposition rates to each basin; multiply weighted nitrate wet deposition rate for each basin by regional coefficient to calculate nitrate dry deposition rate; combine wet and dry deposition rates to arrive at total nitrogen deposition rate; no deposition rate calculated for phosphorus.	Regional dry nitrate coefficients; Tennessee: 0.7826 Alabama: 0.8571 Kentucky: 0.8333.
Fertilizer application—sales.	County estimates of commercial sales of nitrogen and phosphorus fertilizers.	No calculations	No coefficients
Fertilizer application—recommended rates.	County estimates of harvested acreage, by crop type.	Multiply harvested acreage by recommended fertilizer application rates for medium-soil test results.	Recommended fertilizer application rates, varying by crop: nitrogen—rates range from 0 (soybeans) to 200 (tobacco) lb/acre phosphorus—rates range from 20 (soybeans) to 90 (tobacco) lb/acre.
Nitrogen fixation	County estimates of harvested acreage of soybeans.	Multiply harvested acreage of soybean crop by nitrogen fixation rate.	Nitrogen-fixation rate for soybeans: 105 lb/acre.
Crop uptake	County estimates of harvested amount, by crop type.	Multiply harvested amount by coefficients of nitrogen and phosphorus uptake rates, expressed as pounds per acre of nutrient removed per harvested amount per acre; simplify to pounds per harvested amount.	Nitrogen and phosphorus uptake rates, varying by crop; nitrogen—rates range from 1.75 (corn) to 5.15 (soybeans) lb/bushel phosphorus—rates range from 0.22 (corn) to 0.46 (soybeans) lb/bushel.
Livestock waste	County estimates of nitrogen and phosphorus in livestock waste, by livestock class.	Sum estimates for each livestock class.	

Atmospheric Deposition

More than 3.2 million tons of nitrogen is deposited in the United States each year from atmospheric deposition (Puckett, 1994). The combustion of fossil fuels such as coal and oil is the major source of nitrogen in atmospheric deposition. Atmospheric deposition of nitrogen may be in a wet form as rain, snow, hail, fog, and freezing rain, or in a dry form as particulates, gases, and droplets. Atmospheric deposition of phosphorus is not considered a significant source of phosphorus to watersheds in general and is not estimated for this report; however, atmospheric deposition may contribute significant amounts of phosphorus in some locales (Harned, 1995).

The methods used for developing estimates of inputs of nitrogen from atmospheric deposition are described in Appendix C and summarized in table 7. Estimated inputs of nitrogen for selected tributary monitoring basins (table 3) ranged from 1.6 (tons/mi^2)/yr (site 1, Clarks River at Almo) to 2.0 (tons/mi^2)/yr (site 12, Town Creek near Geraldine). Estimated inputs of nitrogen for major hydrologic units (table 5) covered this same range; from 1.6 (tons/mi^2)/yr (areas contributing to lower and upper Kentucky Reservoir and to below Kentucky Dam, hydrologic units 06040001, 06040005, and 06040006, respectively) to 2.0 (tons/mi^2)/yr (area contributing to Guntersville Reservoir, hydrologic unit 06030001). These estimates fall near the upper part of the range [0.9-1.8 (tons/mi^2)/yr] reported in a national assessment (Puckett, 1994).

Inputs to Agricultural Lands

Agricultural lands are associated with major nutrient sources and sinks at the land surface. Major sources include fertilizer application to crop, nitrogen fixation by leguminous crops, and livestock waste released from feedlots and husbandry operations (fig. 6). Part of the nutrient mass applied to cropland (in both inorganic fertilizer and livestock manure) is utilized by plants and incorporated into plant biomass.

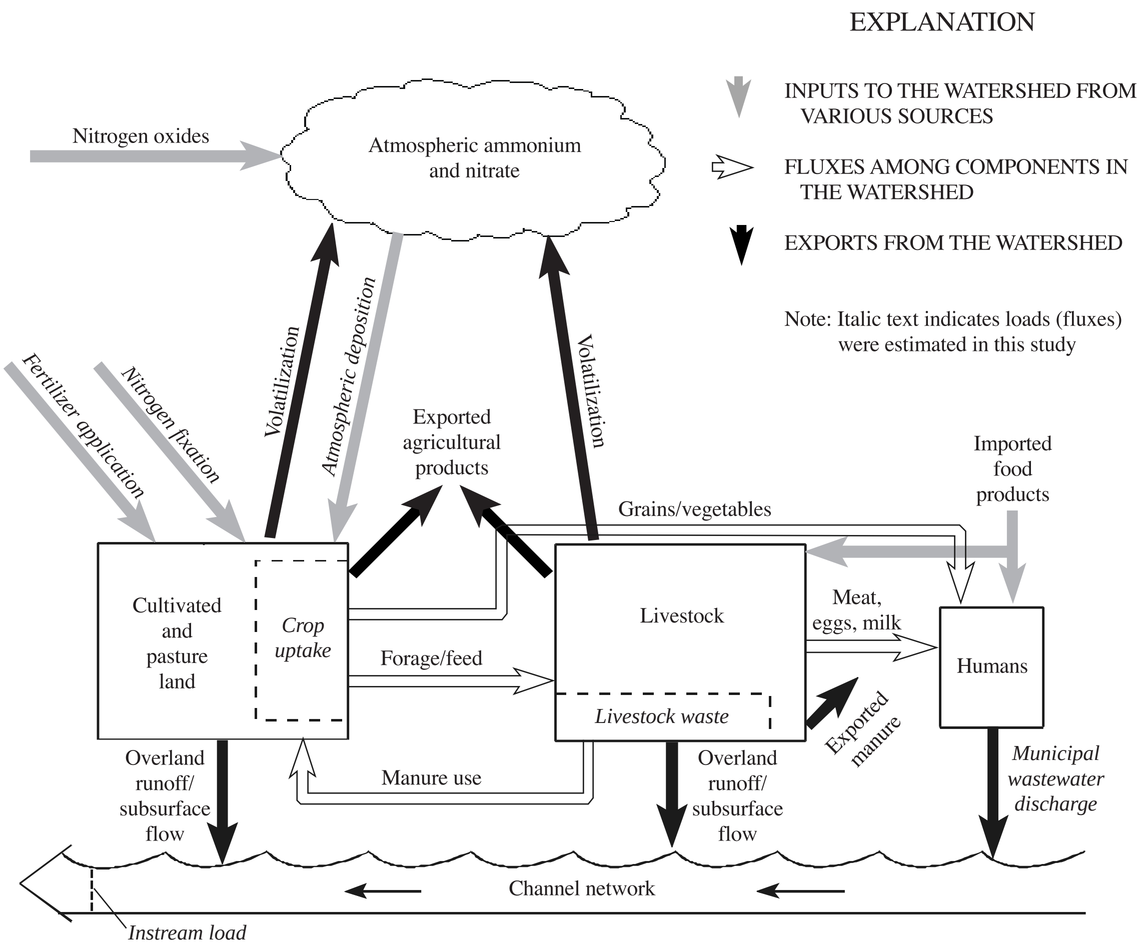


Figure 6. Anthropogenic sources and fluxes of nitrogen within an agricultural watershed (modified from Jordan and Weller, 1996).

This mass, along with the amount of nitrogen assimilated through biological fixation, is removed from the basin when crop plants are harvested and exported. The amount of applied nutrient not removed from the basin by crop uptake and harvest may be transported, overland or in the subsurface, to the stream channel. To obtain a general estimate of the balance of sources and sinks available to enter the overland and subsurface transport phase, the estimate of crop uptake is subtracted from the sum of estimates of fertilizer application, nitrogen fixation, and livestock waste. However, this estimate does not reflect other processes, such as accumulation or denitrification in the soil, which may represent major components of the nutrient budget in agricultural lands.

Fertilizer Application

Commercial nitrogen fertilizer is applied as either ammonia or nitrate. Part of the nitrogen is absorbed by the growing crop, part is released in gaseous form to the atmosphere, and part remains as nitrate in the soil. Nitrate is soluble in water and readily leached from soils, allowing the rapid transport of nitrate into streams and ground-water systems. Phosphorus fertilizer is commonly applied as phosphate, which readily adheres to clay particles and is relatively insoluble in water. Soil erosion and transport is, therefore, the primary process by which significant amounts of particulate phosphate travel to streams.

The methods used to quantify inputs of nitrogen and phosphorus from fertilizer application are described in Appendix C and summarized in table 7. Input estimates of nitrogen for selected tributary monitoring basins (table 3) ranged from 1.5 (tons/mi^2)/yr (site 13, Sequatchie River at Valley Road) to 23 (tons/mi^2)/yr (site 1, Clarks River at Almo), and of phosphorus (table 4), from 0.35 (tons/mi^2)/yr (site 11, Flint Creek near Falkville) to 5.1 (tons/mi^2)/yr (site 1, Clarks River at Almo). Estimated inputs of nitrogen (table 5) for major hydrologic units ranged from 1.1 (tons/mi^2)/yr (area contributing to Nickajack Reservoir, hydrologic unit 06020001) to 10 (tons/mi^2)/yr (area contributing to below Kentucky Dam, hydrologic unit 06040006), and of phosphorus (table 6), from 0.21 (tons/mi^2)/yr (Bear Creek basin, hydrologic unit 06030006) to 2.3 (tons/mi^2)/yr (area contributing to below Kentucky Dam, hydrologic unit 06040006). The spatial distribution of nitrogen and phosphorus inputs generally corresponds to the distribution of cultivated land (figs. 3 and 5).

Nitrogen Fixation

Leguminous crops, such as soybeans, absorb atmospheric nitrogen from Rhizobium bacteria which infect their roots (nitrogen fixation). The mass of nitrogen fixed by crops through biological fixation was estimated because this mass is part of the balance between applied fertilizer, livestock manure, and crop uptake, but is not an expected input to water bodies.

The methods used to quantify inputs of nitrogen from nitrogen fixation are described in Appendix C and summarized in table 7. Estimated inputs of nitrogen for selected tributary monitoring basins (table 3) ranged from 0.30 (ton/mi^2)/yr (site 2, Buffalo River near Flat Woods, and site 13, Sequatchie River at Valley Road) to 7.6 (tons/mi^2)/yr (site 1, Clarks River at Almo). Input estimates for the major hydrologic units (table 5) ranged from 0.14 (tons/mi^2)/yr (area contributing to Nickajack Reservoir, hydrologic unit 06020001) to 4.0 (tons/mi^2)/yr (area contributing to below Kentucky Dam, hydrologic unit 06040006).

Crop Uptake

The nutrient mass applied to cropland as fertilizer, along with the mass fixed biologically, is partly removed from the land surface when crops are harvested. Part of the plant remains on the land as residue after harvest; therefore, the mass removed as harvested crop is somewhat less than crop uptake. The methods used to quantify nutrient removed as harvested crop are described in Appendix C, and summarized in table 7. Estimates are reported as negative values because harvest represents removal of nitrogen. Crop uptake estimates of nitrogen for selected tributary monitoring basins (table 3) ranged from -1.7 (tons/mi^2)/yr (site 13, Sequatchie River at Valley Road) to -24 (tons/mi^2)/yr (site 1, Clarks River at Almo), and of phosphorus (table 4), from -0.19 (tons/mi^2)/yr (site 11, Flint Creek near Falkville and site 13, Sequatchie River at Valley Road) to -3.2 (tons/mi^2)/yr (site 1, Clarks River at Almo). Crop uptake estimates of nitrogen for major hydrologic units (table 5) ranged from -0.83 (tons/mi^2)/yr (Bear Creek basin, hydrologic unit 06030006) to -12 (tons/mi^2)/yr (area contributing to below Kentucky Dam, hydrologic unit 06040006), and of phosphorus (table 6), from -0.10 (tons/mi^2)/yr (Bear Creek basin, hydrologic unit 06030006) to -1.5 (tons/mi^2)/yr (area contributing to below Kentucky Dam, hydrologic unit 06040006).

Livestock Waste

Nationwide, approximately 7 billion farm animals generate millions of tons of manure containing some 6.5 million tons of nitrogen and 2 million tons of phosphorus each year. Organic nitrogen and urea in the manure are converted to ammonia (part of which volatilizes) and ultimately to nitrate (Mueller and Helsel, 1996). Most organic phosphorus is converted to phosphate, which adheres to soil particles and may become mobile through soil erosion. Confined animal feeding operations, which concentrate animals, feed, and manure on a small land area, have a greater potential to contribute nutrients to surface runoff and ground water. Manure produced by these operations may be applied to pasture land and crop land, becoming available for either crop uptake or losses to the environment (fig. 6).

The methods used to quantify inputs of nitrogen and phosphorus from livestock waste are described in Appendix C and summarized in table 7. Estimated inputs of nitrogen for selected tributary monitoring basins (table 3) ranged from 2.0 (tons/mi^2)/yr (site 2, Buffalo River near Flat Woods) to 13 (tons/mi^2)/yr (site 12, Town Creek near Geraldine), and of phosphorus (table 4), from 0.62 (tons/mi^2)/yr (site 2, Buffalo River near Flat Woods) to 4.3 (tons/mi^2)/yr (site 12, Town Creek near Geraldine). Input estimates of nitrogen (table 5) for major hydrologic units ranged from 1.5 (tons/mi^2)/yr (area contributing to lower Kentucky Reservoir, hydrologic unit 06040005) to 7.0 (tons/mi^2)/yr (area contributing to Guntersville Reservoir, hydrologic unit 06030001), and of phosphorus (table 6), from 0.52 (tons/mi^2)/yr (area contributing to lower Kentucky Reservoir, hydrologic unit 06040005) to 2.2 (tons/mi^2)/yr (area contributing to Guntersville Reservoir, hydrologic unit 06030001). The spatial distribution of nitrogen and phosphorus input generally corresponds to the distribution of pasture land (figs. 3 and 5).

Additional Sources of Nitrogen and Phosphorus

Several other sources of nutrients have been identified, but quantitative information for these sources is not available. Urban runoff and combined sewage overflow are potentially large sources of nutrients from urban areas, but may be comparatively small sources in the LTEN River Basin because of the relatively small urban component in the basin. Nutrient contribution from natural sources, such as weathering and erosion of geologic materials in the watershed, may be significant, but is difficult to quantify.

Nutrient contribution from leachate from failing septic systems may be significant in residential areas experiencing high rates of failure. A general estimate of nutrient loads in surface runoff from these areas (presented in this section) is derived from runoff-monitoring data from a residential area near Scottsboro, Alabama, which experienced a high rate (60 percent) of septic-system failure during the period 1983-85 (Sagona, 1988). Surface-runoff loads of total nitrogen and total phosphorus during 1985 in this area were 1.9 and 0.34 (lbs/acre)/storm event, respectively. These estimates were adjusted to account for other nutrient sources, such as lawn fertilizer, by subtracting the estimate for average runoff load from an adjacent residential area with a lower rate of septic-system failure (45 percent).

Annual estimates of unit-area surface-runoff load from failing septic systems were calculated by multiplying the adjusted average runoff load by the average number of runoff events per year for the area (Steurer and Nold, 1986) as 42 (tons/mi^2)/yr nitrogen, and 6.7 (tons/mi^2)/yr phosphorus. These estimates may be conservative due to sampling bias: the period of runoff monitoring at the high-failure-rate site did not include the wet season, when leachate amounts are highest; and the presence of some septic-system leachate in the samples from the adjacent, lower-failure-rate site probably caused the adjustment for background to be too large.

The estimates from the residential area near Scottsboro are at least an order of magnitude higher than estimates of unit-area input from wastewater discharge for most of the tributary basins (tables 3 and 4). However, these rates cannot be compared directly because the septic system loading rates apply to local areas with high failure rate, which may represent only a small part of the watershed area, whereas the wastewater discharge loading rates apply to the entire watershed. Because watershed-wide data on septic-system failure rates for unsewered areas were not available, extrapolation of these rates to produce basin estimates of nitrogen and phosphorus inputs, similar to the other sources in this report, was not possible.

SOURCES OF SEDIMENT

Sediment is transported into streams by the erosion of uplands as a stream naturally evolves. The rate of erosion can be increased by natural disturbances, such as fires and floods, and by human disturbances, such as agricultural and construction activities. These disturbances can change the geomorphology of a stream by increasing the erosion of stream banks and beds, which serves as an additional source of sediment.

The Natural Resources Conservation Service has estimated rates of annual soil erosion from cropland, by major hydrologic unit, using the universal soil loss equation (U.S. Department of Agriculture, Natural Resources Conservation Service, 1997). Unit-area annual erosion rates from cropland for 1992 ranged from 2,200 (tons/mi^2 of cropland)/yr (hydrologic unit 06020004, Sequatchie River Basin) to 5,200 (tons/mi^2 of cropland)/yr (hydrologic unit 06030005, area contributing to Pickwick/Wilson reservoirs). These rates were multiplied by the percentage of cropland in each major hydrologic unit in 1992 to obtain an estimate of sediment input from cropland soil erosion to the hydrologic unit (table 6); estimates ranged from 51 to 540 (tons/mi^2)/yr.

Quantification of the various natural and human inputs of sediment presents a complex challenge because few sources of ancillary data can be related to the numerous potential sources of sediment. An extensive analysis of the sources of sediment was not compiled for the selected monitoring basins because the limited data set of instream sediment loads (at three tributary sites) was insufficient for input/instream load comparisons. Furthermore, only one of these three sites drained basin areas large enough to compare with the estimates of sediment inputs based on major hydrologic unit.

INSTREAM TRANSPORT OF NITROGEN, PHOSPHORUS, AND SEDIMENT

The following three sections describe spatial and temporal variations in instream transport of nutrients and sediment. The first section examines the relation of nutrient transport to the environmental variables: season, hydrologic condition at the time of sample collection, and physical location along the stream channel. The second section describes estimated nutrient and sediment instream loads. The third section compares nutrient yields to inputs from nutrient sources and other factors influencing transport.

Relation of Concentrations to Season, Streamflow, and Reach Location

Interpretation of the relation of nutrient and sediment concentrations to season and streamflow is confounded because season and streamflow variables generally do not operate independently of one another. For example, an observed seasonal pattern in nutrient concentration may be caused by correlation between concentration and streamflow, rather than directly by seasonal change in water-quality processes. A stratified statistical analysis, such as multiple linear regression, provides a way to identify the confounding effects of different variables. In this approach, the influence of each variable is interpreted independently by examining the statistical significance of each regression coefficient (Cohn and others, 1992). The results of seven-parameter log-linear regressions of nutrient and sediment concentration data are organized by constituent for each of the 20 water-quality monitoring sites (table 8). The period of record used in the regression analysis varied among sites and is indicated in table 8 along with the statistical significance and sign (positive or negative) of the regression coefficients.

Statistical significance of $\beta 1$ indicates that streamflow, independent of other influences, is a good predictor of concentration. Statistical significance of both $\beta 5$ and $\beta 6$ indicates a significant seasonal pattern in concentration data (fitted to a simple sine wave function), independent of other influences. Temporal trends in nutrient and sediment concentration are interpreted based on the statistical significance of $\beta 3$; these are discussed in the section “Trends of Nitrogen, Phosphorus, and Sediment.”

Relation of Concentrations to Season

Seasonal variation in nutrient concentrations is commonly attributed to assimilation by algae and aquatic macrophytes. During the summer months, concentrations of bioavailable forms of nitrogen and phosphorus may decrease as a result of aquatic plant growth in water bodies with long hydraulic-residence time. Other possible causes of seasonal variation include seasonal fertilizer application, temperature-driven nitrification and volatilization, and seasonal flow variation. The extent to which seasonal processes

Table 8. Calibration results for the seven-parameter log-linear regression model of nutrient and sediment concentrations for selected sites in the lower Tennessee River Basin

[The numerical values of the coefficients β1-β6 are not shown; rather, the table entries indicate the time period spanned by the calibration data sets, which varied among sites and constituents; the colors of the numbers indicate the statistical significance and the sign (positive or negative) of the regression coefficients β1-β6 (see eq. 1); 1985-95, coefficient significant and positive; 1985-95, coefficient significant and negative; 1985-95, coefficient not significant; β1 significant and positive (negative) indicates that concentrations increase (decrease) with increasing streamflow; β3 significant and positive (negative) indicates an increasing (decreasing) temporal trend in concentration; β5 and β6 significant indicate that concentrations vary in a seasonal pattern, the patterns are illustrated at the bottom of the table; additional interpretation of the significance and sign of each coefficient is explained in the text; other regression statistics, such as coefficient of determination and standard error, are reported with load estimates in table 9; --, not estimated, and results not shown on fig. 19 because record during common period was insufficient; entries in italics are subject to larger error than the other entries, for various reasons (described in footnotes); R (riverine), tributary site at which streamflow is not regulated, or at which a major component of streamflow is not regulated; FR (flow regulated), site located in an impoundment or where streamflow is strongly influenced by an upstream impoundment; common period, the time span of the calibration data set used to obtain trend estimates for this common period is indicated in the table entries]

Site identi-fication (fig. 2)	Surface-water station/site location Number	Surface-water station/site location Name	Site type	β1 (Logarithm of streamflow)	β3 (Decimal time)	β5 (Sine {2 * π * time})	β6 (Cosine {2 * π * time})	Common period β3 (Decimal time)
Total nitrogen as N								
1	PR1038	Clarks River at Almo, Ky.	R	1985-95	1985-95	1985-95	1985-95	1985-94
2	03604000	Buffalo River near Flat Woods, Tenn.	R	1982-95	1982-95	1982-95	1982-95	1985-94
4	001025	Duck River below Normandy Dam, Tenn.	FR	1986-95	1986-95	1986-95	1986-95	--
5	001065	Duck River at Williamsport, Tenn.	R	1982-94	1982-94	1982-94	1982-94	1982-94
6	475793	Duck River above Hurricane Mills, Tenn.	R	1986-93	1986-93	1986-93	1986-93	1985-94
7	*002395*	*Shoal Creek at Highway 43 near Lawrenceburg, Tenn.* [a]	*R*	*1983-92*	*1983-92*	*1983-92*	*1983-92*	--
9	001207	Elk River below Tims Ford Dam, Tenn.	FR	1984-94	1984-94	1984-94	1984-94	1985-94
10	475796	Elk River near Prospect, Tenn.	R	1987-92	1987-92	1987-92	1987-92	--
11	FLCR7	Flint Creek near Falkville, Ala.	R	1993-97	1993-97	1993-97	1993-97	--
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	R	1988-96	1988-96	1988-96	1988-96	--
13	*002375*	*Sequatchie River at Valley Road, Tenn.* [a]	*R*	*1983-95*	*1983-95*	*1983-95*	*1983-95*	*1985-94*
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	FR	1980-84	1980-84	1980-84	1980-84	--
15	*202832*	*Tennessee River at mile 23, Ky.* [b]	*FR*	*1990-94*	*1990-94*	*1990-94*	*1990-94*	--
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	FR	1980-96	1980-96	1980-96	1980-96	1985-94
17	03571850	Tennessee River at South Pittsburg, Tenn.	FR	1980-85	1980-85	1980-85	1980-85	--
18	003315	Tennessee River below Raccoon Mountain, Tenn.	FR	1981-94	1981-94	1981-94	1981-94	1985-94
Total ammonia as N								
1	PRI038	Clarks River at Almo, Ky.	R	1985-95	1985-95	1985-95	1985-95	1986-94
2	03604000	Buffalo River near Flat Woods, Tenn.	R	1987-92	1987-92	1987-92	1987-92	--
4	001025	Duck River below Normandy Dam, Tenn.	FR	1987-95	1987-95	1987-95	1987-95	--
5	001065	Duck River at Williamsport, Tenn.	R	1984-94	1984-94	1984-94	1984-94	1986-94
6	475793	Duck River above Hurricane Mills, Tenn.	R	1987-94	1987-94	1987-94	1987-94	--

Table 8. Calibration results for the seven-parameter log-linear regression model of nutrient and sediment concentrations for selected sites in the lower Tennessee River Basin—Continued

Site identification (fig. 2)	Surface-water station/site location Number	Name	Site type	β1 (Logarithm of streamflow)	β3 (Decimal time)	β5 (Sine {2 * π * time})	β6 (Cosine {2 * π * time})	Common period β3 (Decimal time)
Total ammonia as N—Continued								
7	*002395*	*Shoal Creek at Highway 43 near Lawrenceburg, Tenn.* [a]	*R*	*1984-94*	*1984-94*	*1984-94*	*1984-94*	*1986-94*
9	001207	Elk River below Tims Ford Dam, Tenn.	FR	1984-94	1984-94	1984-94	1984-94	1986-94
10	475796	Elk River near Prospect, Tenn.	R	1987-94	1987-94	1987-94	1987-94	--
11	FLCR7	Flint Creek near Falkville, Ala.	R	1993-97	1993-97	1993-97	1993-97	--
12	*TOWNCREEK15*	*Town Creek near Geraldine, Ala.* [c]	*R*	*1988-96*	*1988-96*	*1988-96*	*1988-96*	--
13	*002375*	*Sequatchie River at Valley Road, Tenn.* [a]	*R*	*1983-95*	*1983-95*	*1983-95*	*1983-95*	*1986-94*
15	*202832*	*Tennessee River at mile 23, Ky.* [b]	*FR*	*1990-94*	*1990-94*	*1990-94*	*1990-94*	--
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	FR	1980-96	1980-96	1980-96	1980-96	--
17	03571850	Tennessee River at South Pittsburg, Tenn.	FR	1980-86	1980-86	1980-86	1980-86	--
19	SCARHAMCREEK03	Scarham Creek near Kilpatrick, Ala.	R	1988-96	1988-96	1988-96	1988-96	--
Total ammonia plus organic nitrogen as N								
1	PRI038	Clarks River at Almo, Ky.	R	1985-95	1985-95	1985-95	1985-95	1986-93
2	03604000	Buffalo River near Flat Woods, Tenn.	R	1982-95	1982-95	1982-95	1982-95	1986-93
4	001025	Duck River below Normandy Dam, Tenn.	FR	1986-95	1986-95	1986-95	1986-95	--
5	001065	Duck River at Williamsport, Tenn.	R	1981-92	1981-92	1981-92	1981-92	1986-93
6	475793	Duck River above Hurricane Mills, Tenn.	R	1986-93	1986-93	1986-93	1986-93	1986-93
7	*002395*	*Shoal Creek at Highway 43, near Lawrenceburg, Tenn.* [a]	*R*	*1983-94*	*1983-94*	*1983-94*	*1983-94*	*1986-93*
9	001207	Elk River below Tims Ford Dam, Tenn.	FR	1984-94	1984-94	1984-94	1984-94	1986-93
10	475796	Elk River near Prospect, Tenn.	R	1986-93	1986-93	1986-93	1986-93	1986-93
11	FLCR7	Flint Creek near Falkville, Ala.	R	1993-97	1993-97	1993-97	1993-97	--
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	R	1988-96	1988-96	1988-96	1988-96	--
13	*002375*	*Sequatchie River at Valley Road, Tenn.* [a]	*R*	*1983-95*	*1983-95*	*1983-95*	*1983-95*	*1986-93*
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	FR	1980-84	1980-84	1980-84	1980-84	--
15	*202832*	*Tennessee River at mile 23, Ky.* [b]	*FR*	*1990-94*	*1990-94*	*1990-94*	*1990-94*	--
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	FR	1986-93	1986-93	1986-93	1986-93	1986-93
17	03571850	Tennessee River at South Pittsburg, Tenn.	FR	1980-85	1980-85	1980-85	1980-85	--
18	003315	Tennessee River below Raccoon Mountain, Tenn.	FR	1981-94	1981-94	1981-94	1981-94	1986-93
19	SCARHAMCREEK03	Scarham Creek near Kilpatrick, Ala.	R	1988-96	1988-96	1988-96	1988-96	--

Table 8. Calibration results for the seven-parameter log-linear regression model of nutrient and sediment concentrations for selected sites in the lower Tennessee River Basin—Continued

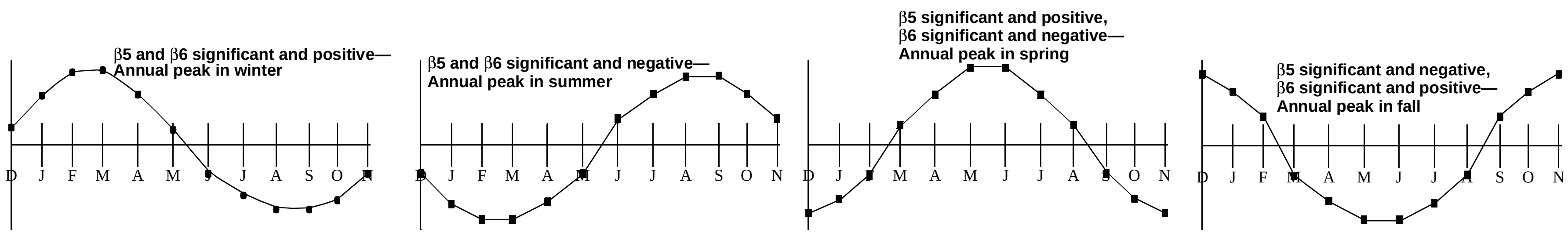
Site identi-fication (fig. 2)	Surface-water station/site location: Number	Surface-water station/site location: Name	Site type	β1 (Logarithm of streamflow)	β3 (Decimal time)	β5 (Sine {2 * π * time})	β6 (Cosine {2 * π * time})	Common period β3 (Decimal time)
Total nitrite plus nitrate as N								
1	PRI038	Clarks River at Almo, Ky.	R	1985-95	1985-95	1985-95	1985-95	1985-94
2	03604000	Buffalo River near Flat Woods, Tenn.	R	1986-93	1986-93	1986-93	1986-93	1985-94
4	001025	Duck River below Normandy Dam, Tenn.	FR	1987-95	1987-95	1987-95	1987-95	--
5	001065	Duck River at Williamsport, Tenn.	R	1982-93	1982-93	1982-93	1982-93	--
6	475793	Duck River above Hurricane Mills, Tenn.	R	1987-93	1987-93	1987-93	1987-93	--
7	*002395*	*Shoal Creek at Highway 43, Tenn.* [a]	*R*	*1983-94*	*1983-94*	*1983-94*	*1983-94*	*1985-94*
9	001207	Elk River below Tims Ford Dam	FR	1984-94	1984-94	1984-94	1984-94	1985-94
10	475796	Elk River near Prospect, Tenn.	R	1987-93	1987-93	1987-93	1987-93	--
11	FLCR7	Flint Creek near Falkville, Ala.	R	1993-97	1993-97	1993-97	1993-97	--
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	R	1988-96	1988-96	1988-96	1988-96	--
13	*002375*	*Sequatchie River at Valley Road, Tenn.* [a]	*R*	*1983-95*	*1983-95*	*1983-95*	*1983-95*	*1985-94*
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	FR	1980-84	1980-84	1980-84	1980-84	--
15	*202832*	*Tennessee River at mile 23, Ky.* [b]	*FR*	*1990-94*	*1990-94*	*1990-94*	*1990-94*	--
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	FR	1980-96	1980-96	1980-96	1980-96	1985-94
17	03571850	Tennessee River at South Pittsburg, Tenn.	FR	1980-85	1980-85	1980-85	1980-85	--
18	003315	Tennessee River below Raccoon Mountain, Tenn.	FR	1981-94	1981-94	1981-94	1981-94	1985-94
19	SCARHAMCREEK03	Scarham Creek near Kilpatrick, Ala.	R	1988-96	1988-96	1988-96	1988-96	--
20	SOUTHSAUTYCK03	South Sauty Creek, Ala.	R	1988-96	1988-96	1988-96	1988-96	--
Total phosphorus as P								
1	PRI038	Clarks River at Almo, Ky.	R	1985-95	1985-95	1985-95	1985-95	1985-93
2	03604000	Buffalo River near Flat Woods, Tenn.	R	1983-95	1983-95	1983-95	1983-95	1985-93
4	001025	Duck River below Normandy Dam, Tenn.	FR	1987-94	1987-94	1987-94	1987-94	--
5	001065	Duck River at Williamsport, Tenn.	R	1981-93	1981-93	1981-93	1981-93	1985-93
6	475793	Duck River above Hurricane Mills, Tenn.	R	1988-93	1988-93	1988-93	1988-93	--
7	*002395*	*Shoal Creek at Highway 43 near Lawrenceburg, Tenn.* [a]	*R*	*1983-94*	*1983-94*	*1983-94*	*1983-94*	*1985-93*
9	001207	Elk River below Tims Ford Dam, Tenn.	FR	1983-94	1983-94	1983-94	1983-94	1985-93
10	475796	Elk River near Prospect, Tenn.	R	1986-94	1986-94	1986-94	1986-94	--
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	FR	1980-84	1980-84	1980-84	1980-84	--
15	*202832*	*Tennessee River at mile 23, Ky.* [b]	*FR*	*1990-94*	*1990-94*	*1990-94*	*1990-94*	--

Table 8. Calibration results for the seven-parameter log-linear regression model of nutrient and sediment concentrations for selected sites in the lower Tennessee River Basin—Continued

Site identification (fig. 2)	Surface-water station/site location: Number	Name	Site type	β1 (Logarithm	Number	β5	β6	Common period
Total phosphorus as P—Continued								
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	FR	1980-93	1980-93	1980-93	1980-93	1985-93
17	03571850	Tennessee River at South Pittsburg, Tenn.	FR	1980-86	1980-86	1980-86	1980-86	--
Dissolved orthophosphorus as P								
2	03604000	Buffalo River near Flat Woods, Tenn.	R	1984-95	1984-95	1984-95	1984-95	--
6	475793	Duck River above Hurricane Mills, Tenn.	R	1986-91	1986-91	1986-91	1986-91	--
10	475796	Elk River near Prospect, Tenn.	R	1987-91	1987-91	1987-91	1987-91	--
11	*FLCR7*	*Flint Creek near Falkville, Ala.* [c]	*R*	*1993-97*	*1993-97*	*1993-97*	*1993-97*	--
12	*TOWNCREEK15*	*Town Creek near Geraldine, Ala.* [c]	*R*	*1988-96*	*1988-96*	*1988-96*	*1988-96*	--
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	FR	1983-93	1983-93	1983-93	1983-93	--
15	*202832*	*Tennessee River at mile 23, Ky.* [b]	*FR*	*1990-94*	*1990-94*	*1990-94*	*1990-94*	--
19	SCARHAMCREEK03	Scarham Creek near Kilpatrick, Ala.	R	1988-96	1988-96	1988-96	1988-96	--
Suspended sediment								
2	03604000	Buffalo River near Flat Woods, Tenn.	R	1982-95	1982-95	1982-95	1982-95	--
3	03596000	Duck River below Manchester, Tenn. [d]	R	1979-83	1979-83	1979-83	1979-83	--
8	03588500	Shoal Creek at Iron City, Tenn. [d]	R	1979-83	1979-83	1979-83	1979-83	--
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	FR	1980-93	1980-93	1980-93	1980-93	--
17	03571850	Tennessee River at South Pittsburg, Tenn.	FR	1980-86	1980-86	1980-86	1980-86	--

[a] Regression results are subject to error because streamflow-measurement and water-quality-sampling sites were not colocated.
[b] Regression results are subject to error due to grab sampling methods at this vertically stratified site.
[c] Regression results are subject to error due to variable minimum reporting level and large percentage of observations below minimum reporting level.
[d] The calibration data set included data from 1979 in order to have sufficient length of record.

Seasonal patterns:



influence nutrient transport in the LTEN River Basin is indicated by the significance of the seasonal regression coefficients ($\beta 5$ and $\beta 6$) for the bioavailable forms of nutrients (total nitrite plus nitrate and dissolved orthophosphorus, table 8). These results will indicate seasonal effects independent of flow variation, which is accounted for by the regression coefficient $\beta 1$.

Statistically significant seasonal variation of total nitrite plus nitrate concentrations was observed at 9 of the 18 sites tested. Seasonal variation was closely correlated with site type: 7 of the 9 sites showing significant seasonal variation were in reservoirs or were influenced by reservoir tailwater, suggesting strong seasonal influence by aquatic plants in water bodies with long hydraulic-residence times. The seasonal pattern of total nitrite plus nitrate for most of the sites influenced by reservoirs was annual maximum concentrations in winter and annual minimum concentrations in summer.

Significant seasonal variation was observed at less than half of the sites for the other nutrient constituents, except for dissolved orthophosphorus. Of the eight sites with dissolved-orthophosphorus data, four showed statistically significant seasonal variation of this constituent. The detected pattern at the reservoir sites (sites 16 and 15, Tennessee River at Pickwick Landing Dam and at river mile 23, respectively) was slightly offset (annual maximum concentrations in fall rather than winter, and annual minimum concentrations in the spring) from the pattern for total nitrite plus nitrate, but may be caused by the same phenomenon of aquatic-plant assimilation.

Scatterplots of concentration and time of year of sampling (fig. 7) illustrate seasonal patterns in nitrate and total phosphorus at a few selected sites. Comparison of these patterns with the regression result (statistical significance of $\beta 5$ and $\beta 6$, also shown on fig. 7) illustrates how the regression analysis isolates the influences of different environmental variables. For example, concentrations of nitrite plus nitrate appear to indicate a seasonal pattern at site 2 (Buffalo River at Flat Woods); however, the regression analysis did not detect a statistically significant pattern. The apparent pattern may be caused instead by a seasonal bias in sampled streamflow conditions (five of the six highest streamflows sampled occurred during the month of January) combined with a strong correlation between concentration and streamflow ($\beta 1$ is significant and positive, table 8).

A separate possible cause of seasonal variations in nutrient concentrations, the agricultural planting cycle, may cause episodic increases in concentrations of nutrients derived from fertilizer application and of suspended sediment following periods of soil preparation and fertilizer application and when storm runoff is frequent (during April through June). The relation between the planting cycle and instream nutrient transport is not examined in this report, however, because the data from most of the sites are from quarterly monitoring programs rather than from programs designed to detect episodic, storm-related increases in concentrations.

Relation of Concentrations to Streamflow

The variation of nutrient concentrations with streamflow generally reflects the dominant sources in the watershed (point versus nonpoint sources). Transport of nonpoint-source-derived constituents mainly occurs during periods of high surface runoff and high base flow; therefore, higher concentrations are expected during high streamflow in watersheds dominated by nonpoint sources. Point-source discharges are generally independent of runoff; consequently, instream concentrations of constituents from these sources are expected to decrease during high streamflow.

Scatterplots of concentration and streamflow are shown (fig. 8), along with regression results for $\beta 1$ (coefficient on streamflow), for total nitrite plus nitrate and total phosphorus at a few selected monitoring sites. Scatterplots and model regression results are included for the full set of load-computation sites for total nitrite plus nitrate, total ammonia, total phosphorus, and dissolved orthophosphorus (Appendix D). Interpretation of the relation of concentration to streamflow at flow-regulated sites is of less interest than at riverine sites in this examination of dominant sources in the watershed because at flow-regulated sites the observed streamflow-concentration relation reflects controlled impoundment releases rather than hydrologic processes such as runoff. Therefore, regression results are not shown on the concentration-streamflow scatterplots for flow-regulated sites in Appendix D. The flow corresponding to maximum turbine capacity is indicated on the scatterplots for these sites as a cutoff below which a relation based on hydrologic conditions in the contributing watershed is unlikely; above this cutoff, at least some component of streamflow reflects hydrologic conditions upstream

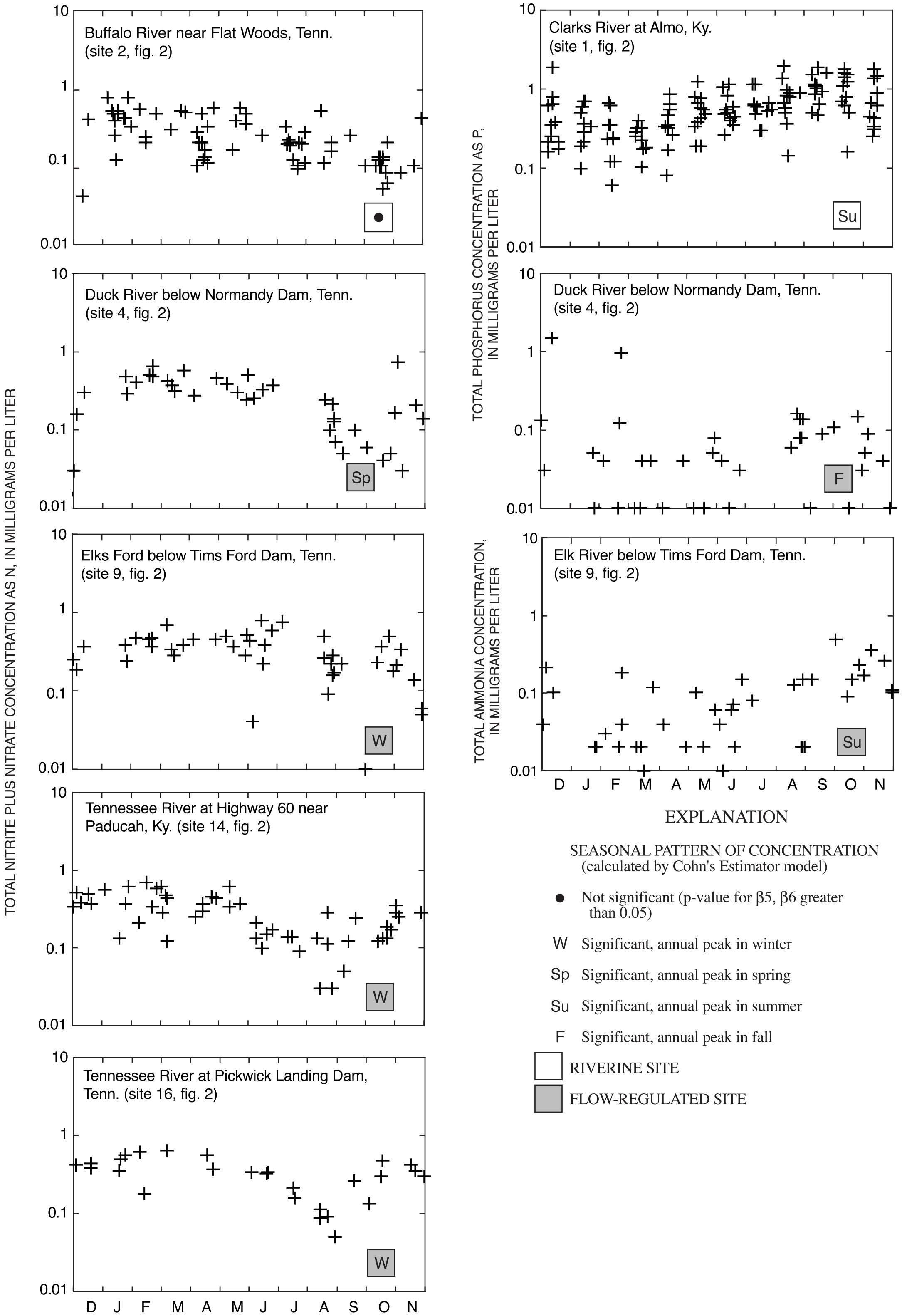


Figure 7. Seasonal variation in nutrient concentrations and model estimate of seasonal pattern at selected sites in the lower Tennessee River Basin, 1980-96.

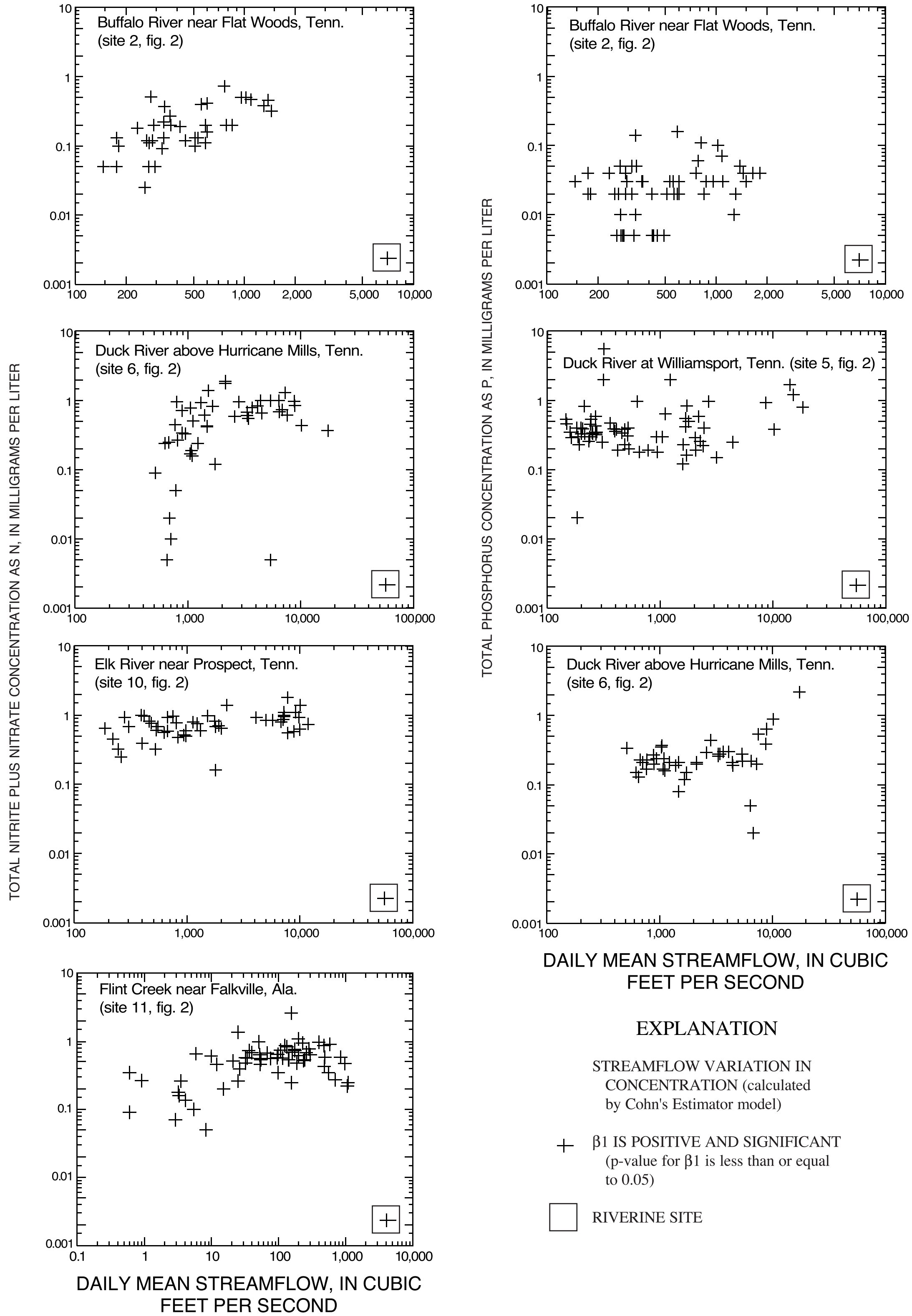


Figure 8. Variation in total nitrite plus nitrate and total phosphorus concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96.

from the impoundment (E.A. Thornton and D.L. Meinert, Tennessee Valley Authority, written commun., 1998).

Comparison between the relative influence of nonpoint sources and point sources on instream water quality in the selected tributary basins can be examined by comparing the statistical significance of the streamflow regression coefficient, $\beta1$ (table 8 and fig. 8) with a ranking of these basins according to estimates of inputs from these sources. For total nitrite plus nitrate, $\beta1$ was significant and positive at 5 sites (sites 2, 6, 10, 11, and 20) of the 11 riverine sites tested, and was positive in all of these cases, suggesting that nonpoint sources were the dominant source of input for total nitrite plus nitrate during the periods spanned by the calibration data sets. These results match the ranking of basins by nitrogen input reasonably well; the largest nitrogen inputs from nonpoint sources (the sum of atmospheric deposition and fertilizer application and livestock waste) relative to point sources (wastewater discharge) were for sites 11, 20, 12, 13, 10, and 2. $\beta1$ was significant and positive for total phosphorus at three of the six riverine sites (sites 2, 5, and 6), suggesting that nonpoint sources are the dominant source of phosphorus input in these watersheds. The nonpoint source might be a natural source, as for sites 5 and 6; suspended sediment at these sites is naturally phosphate rich as a result of phosphatic limestone in the watershed. The regression results for total phosphorus might, therefore, be explained by movement of sediment during high flows.

Dominance of point sources, such as wastewater discharge, is indicated by a negative concentration-streamflow relation, that is, by a significant and negative value for $\beta1$. $\beta1$ was significant and negative for total phosphorus concentrations at site 1 (Clarks River at Almo), suggesting dominance of point-source discharges or some other runoff-independent source at this site. Clarks River at Almo was ranked second out of 11 based on the ratio of point-source input (wastewater discharge) to nonpoint-source inputs of phosphorus. Data for dissolved orthophosphorus, which might have provided additional information about the influence of wastewater sources, were not available for this site.

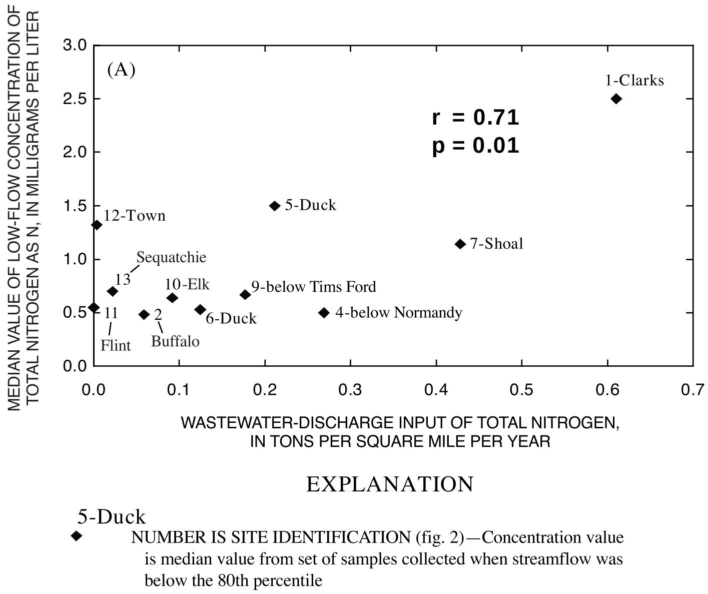
The relation between nutrient concentration and streamflow has important implications for resource management apart from the issue of the relative contributions of nonpoint and point sources to nutrient load. The occurrence of high concentrations during low streamflows and the sources that cause high concentrations during low streamflows (for example, wastewater discharges) may not be significant for characterizing annual nutrient transport. However, these occurrences and sources of high concentration are of particular concern for evaluating impairment of a water body caused by constituent concentrations at harmful levels for short periods, for example during critical low streamflow periods. Although the monitoring networks from which these data were collected were not designed to detect impairment during critical periods, some insight as to where these conditions might occur can be gained by comparing concentrations of nitrogen constituents during low streamflows.

The median concentration of total nitrogen from the set of samples collected when streamflow was below the 80th percentile (the flow exceeded 80 percent of the time at that site) was plotted against estimated input of total nitrogen from wastewater in the watershed (fig. 9a). The correlation between these variables is significant ($r = 0.71$, $p = 0.01$) and suggests that wastewater discharges are significant contributors to the amount of nitrogen in transport during periods of low streamflow. That wastewater-discharge input is large (almost equal to or exceeding) compared to the median of observed daily loads during low streamflow (calculated as the product of observed concentration and daily streamflow) at most sites supports this conclusion (fig. 9b).

Downstream Variations in Concentrations

Box plots of nutrient concentrations at different water-quality sites along a river reach illustrate how nutrient concentrations vary with distance. Downstream variations in nutrient concentrations are illustrated as truncated box plots (Helsel and Hirsch, 1992) for the main stem Tennessee River (fig. 10) and for the Duck River, the largest tributary within the LTEN River Basin (fig. 11). Data from eight of the load-computation sites on the main stem Tennessee and the Duck Rivers were included in these graphical displays, in addition to data from 29 additional long-term monitoring sites on these rivers (as described in the section “Approach and Methods”).

Median total nitrogen concentrations were generally less than 0.7 mg/L throughout the main stem of the Tennessee River (fig. 10B) compared to median values greater than 1.0 mg/L at many sites on the Duck River (fig. 11B). Variation of nitrite plus nitrate concentrations throughout the main stem of the Tennessee River was closely correlated with reservoir forebay areas (immediately upstream from the dams, fig. 10C). The range in concentration at a site reflects the seasonal variation of nitrite plus nitrate in reservoirs; concentrations decreased to below the minimum reporting level (MRL) during the summer months in the forebay



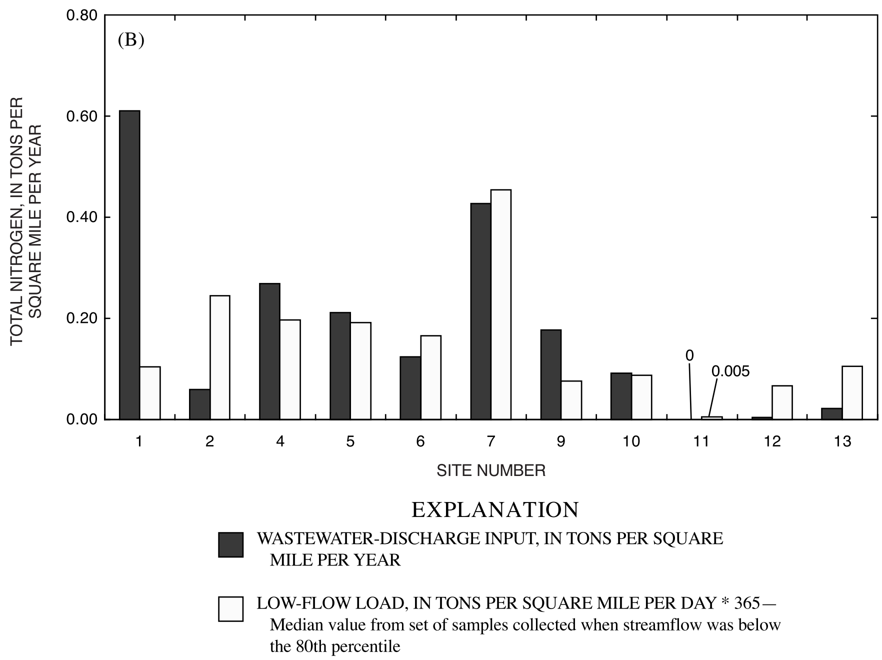


Figure 9. Relation of (A) median value of total nitrogen concentrations during low streamflow conditions and (B) median value of total nitrogen load during low streamflow conditions to wastewater-discharge input to the watershed.

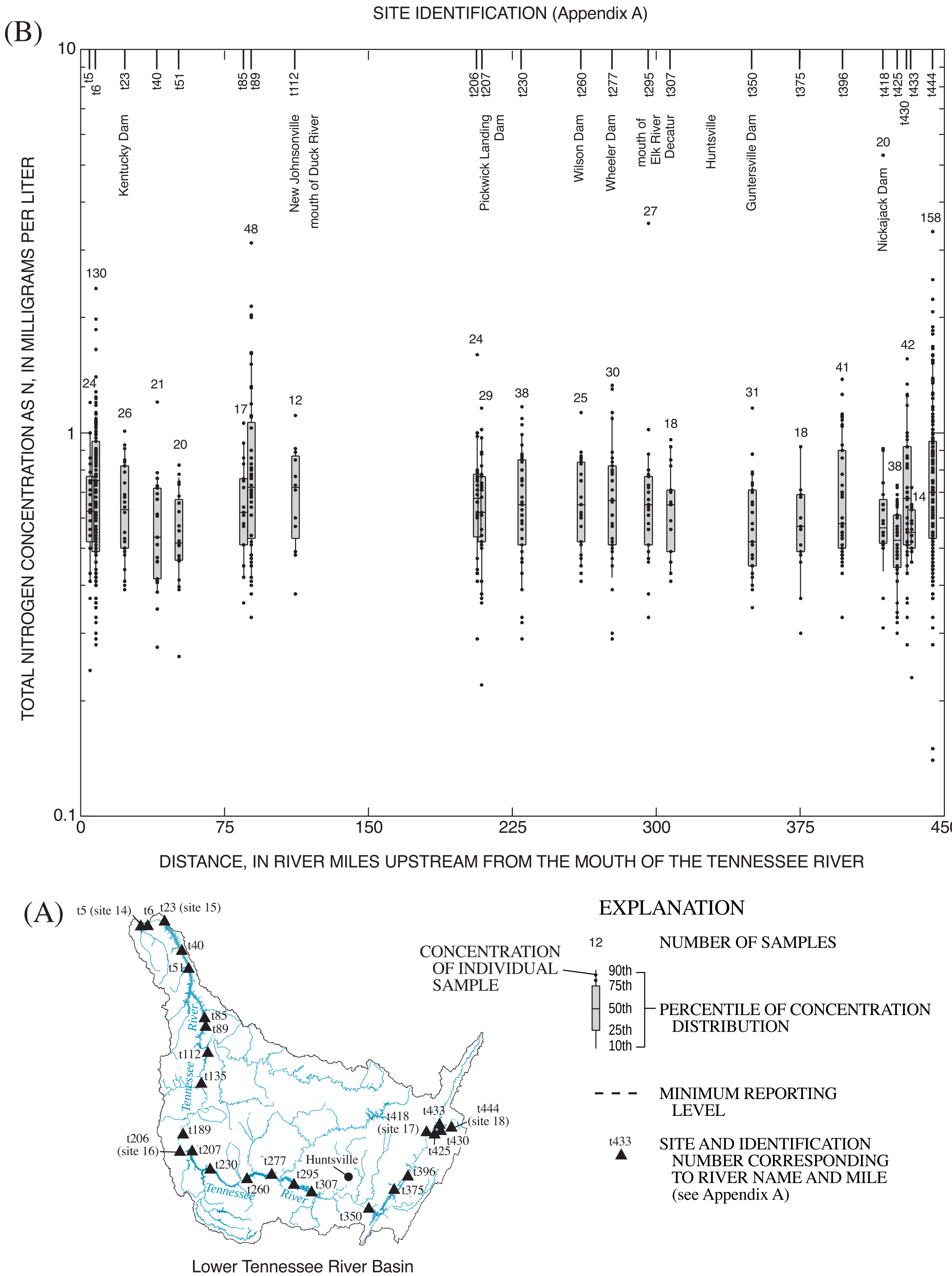


Figure 10. Nutrient concentrations (A) at selected sites on the Tennessee River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus.

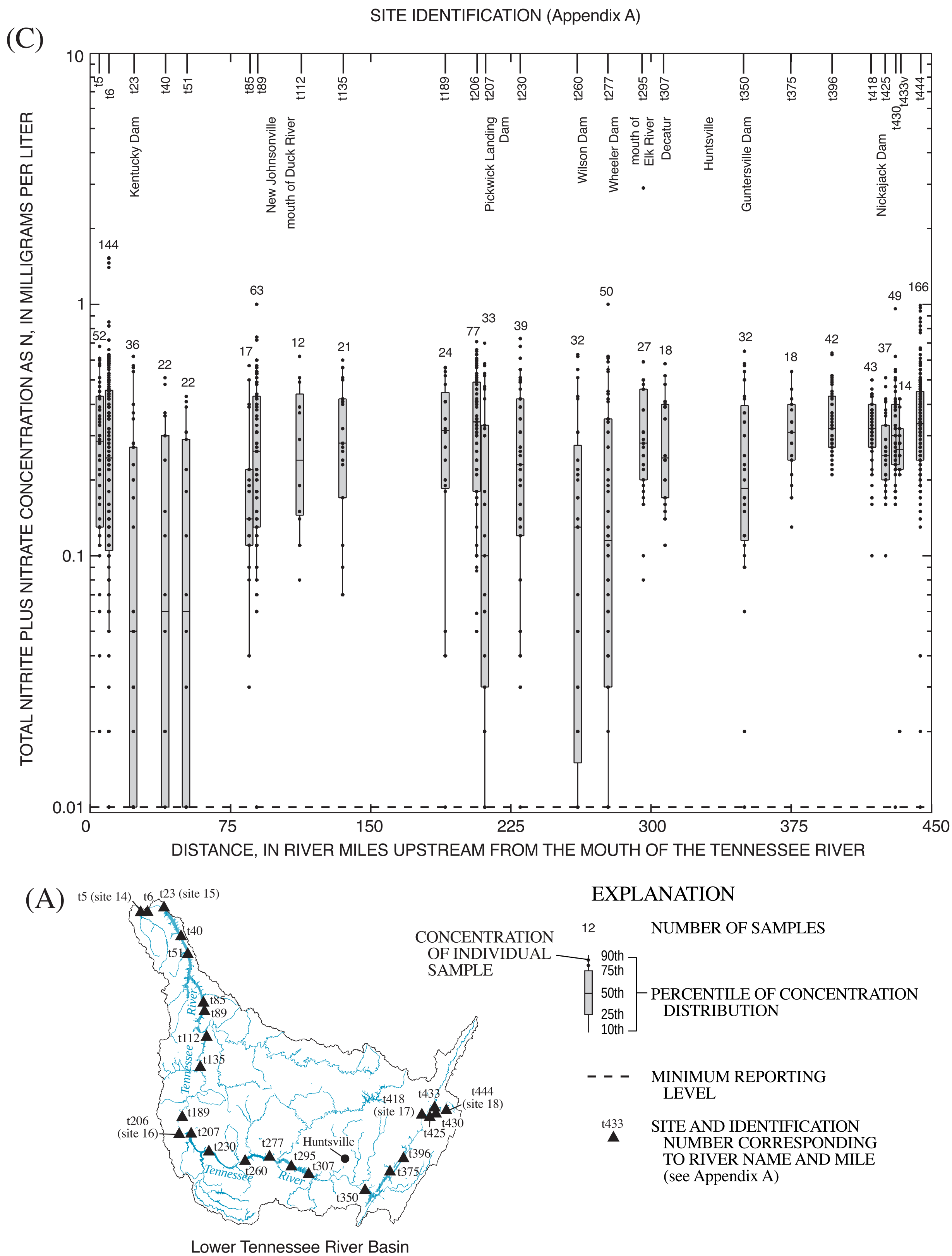


Figure 10. Nutrient concentrations (A) at selected sites on the Tennessee River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus—Continued.

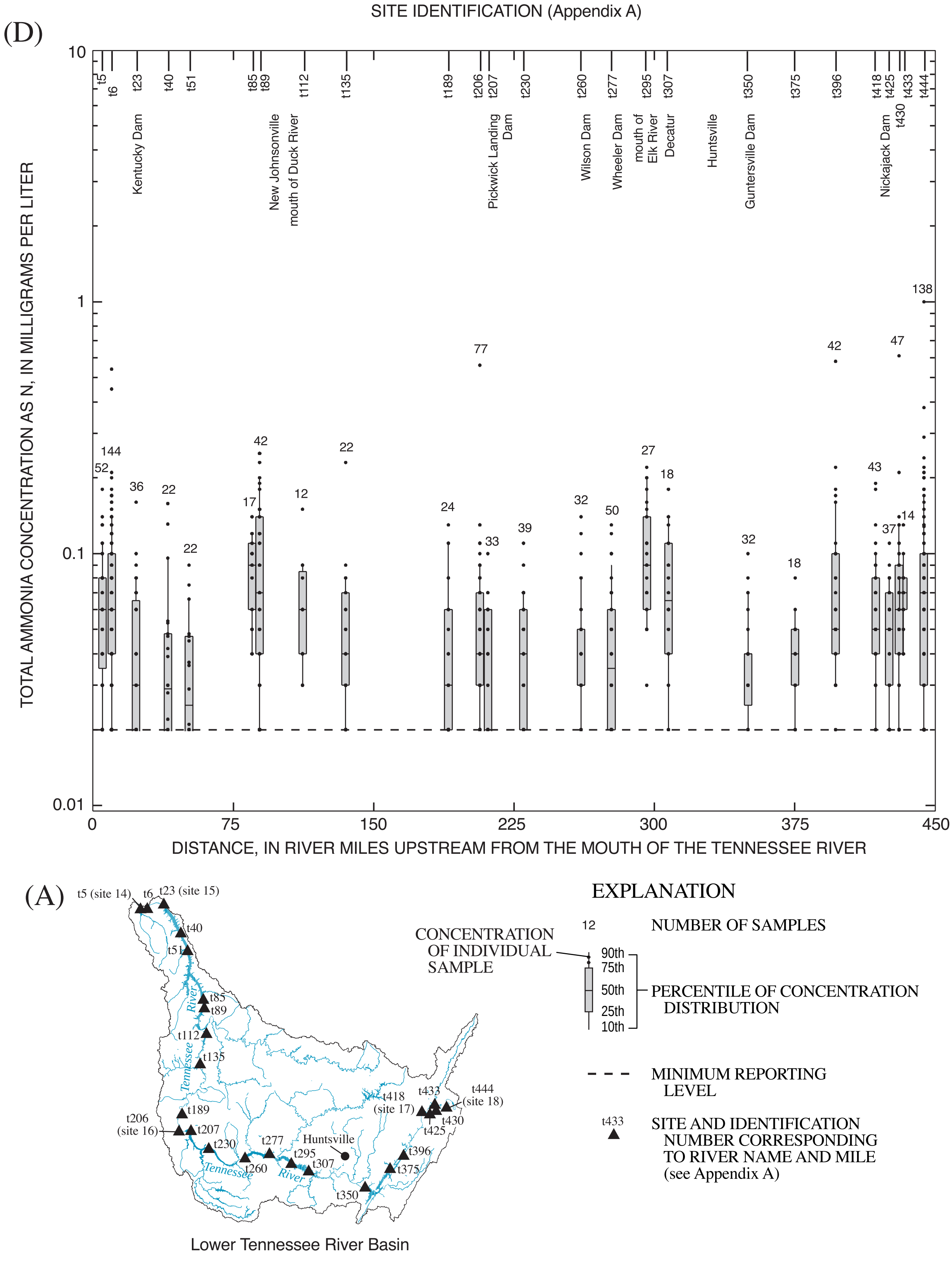
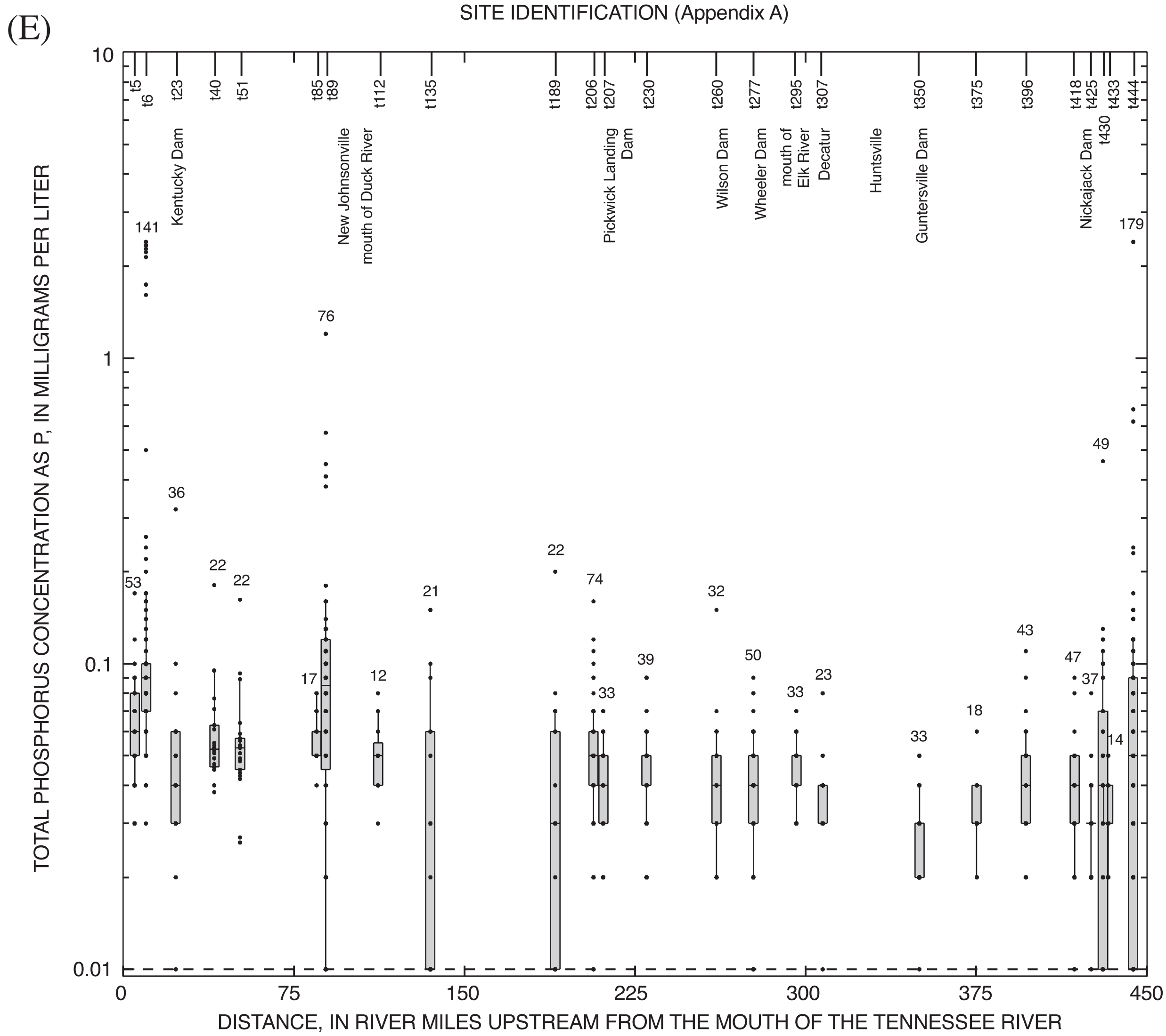


Figure 10. Nutrient concentrations (A) at selected sites on the Tennessee River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus—Continued.



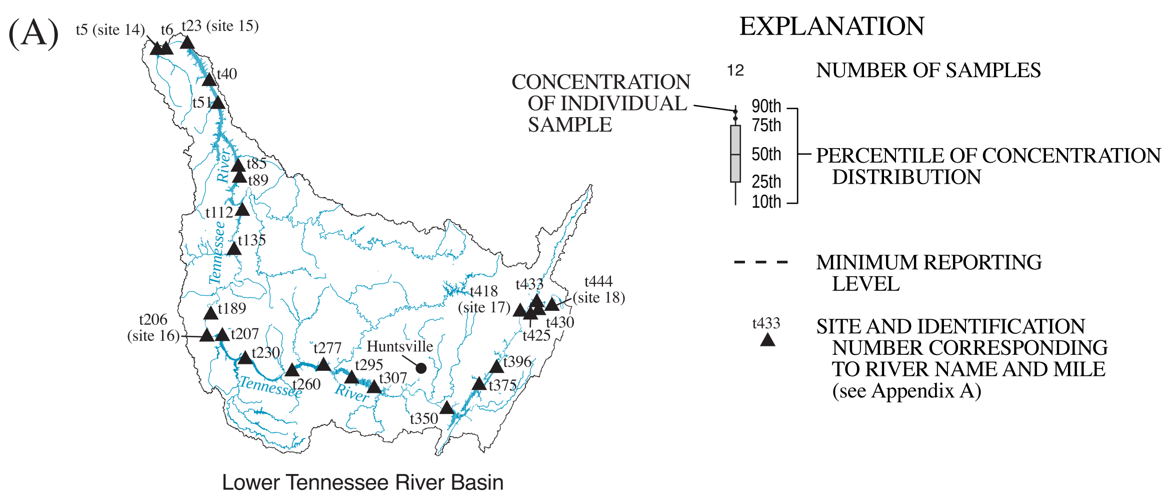
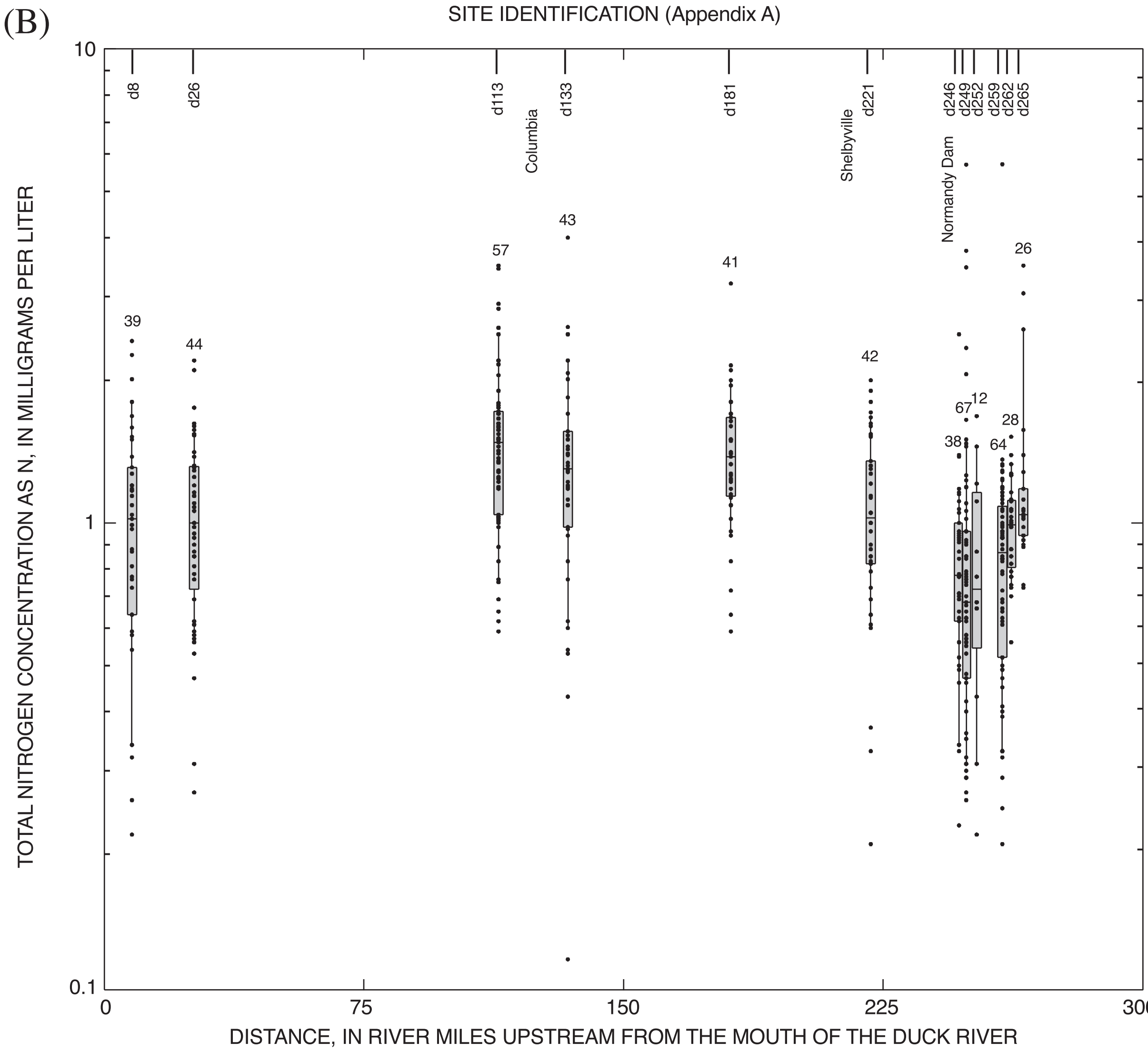


Figure 10. Nutrient concentrations (A) at selected sites on the Tennessee River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus—Continued.



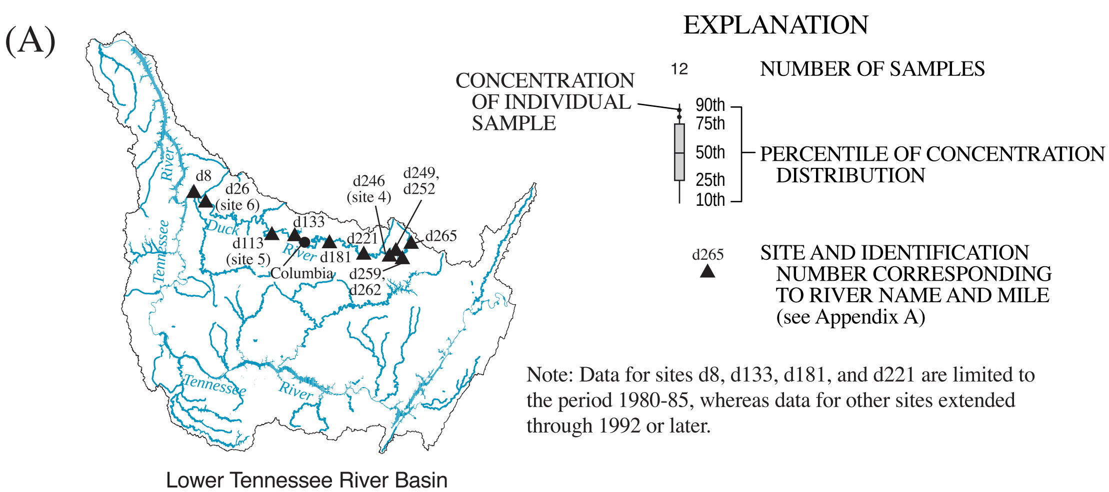
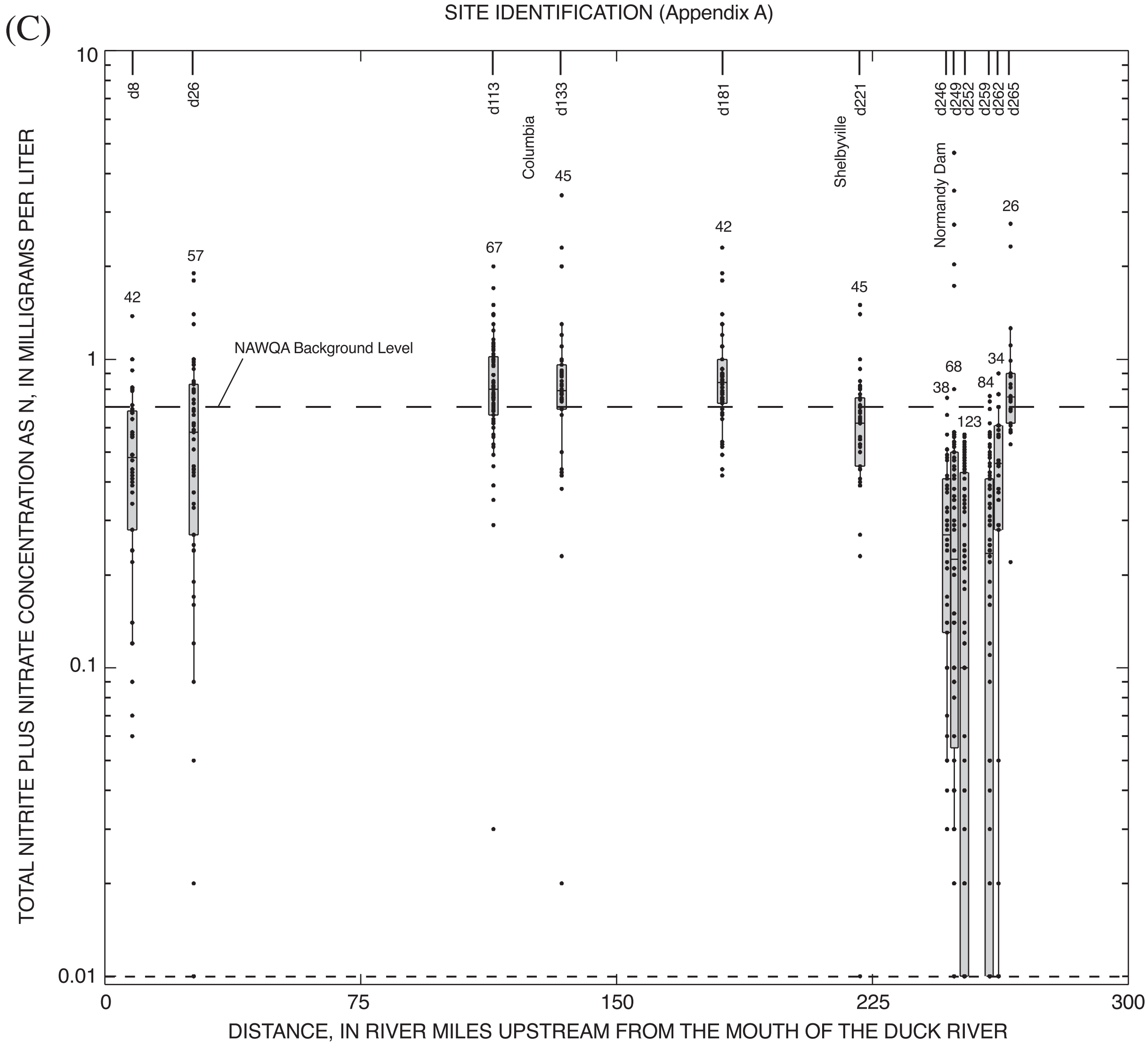
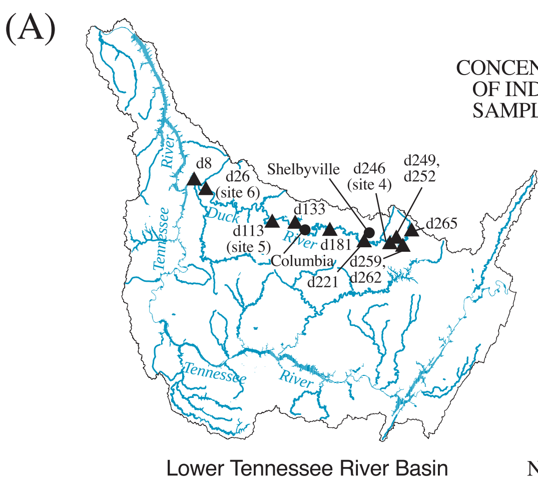
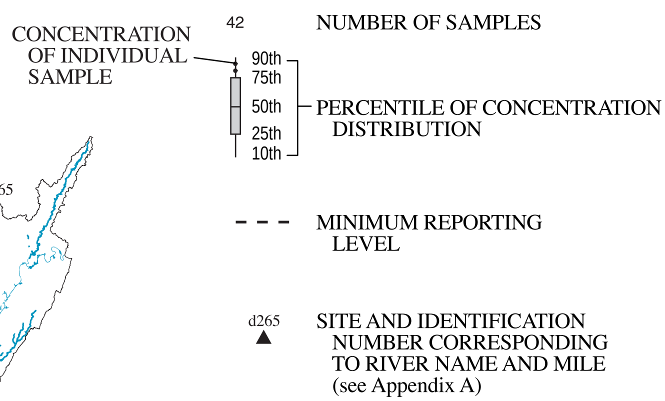


Figure 11. Nutrient concentrations (A) at selected sites on the Duck River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus.



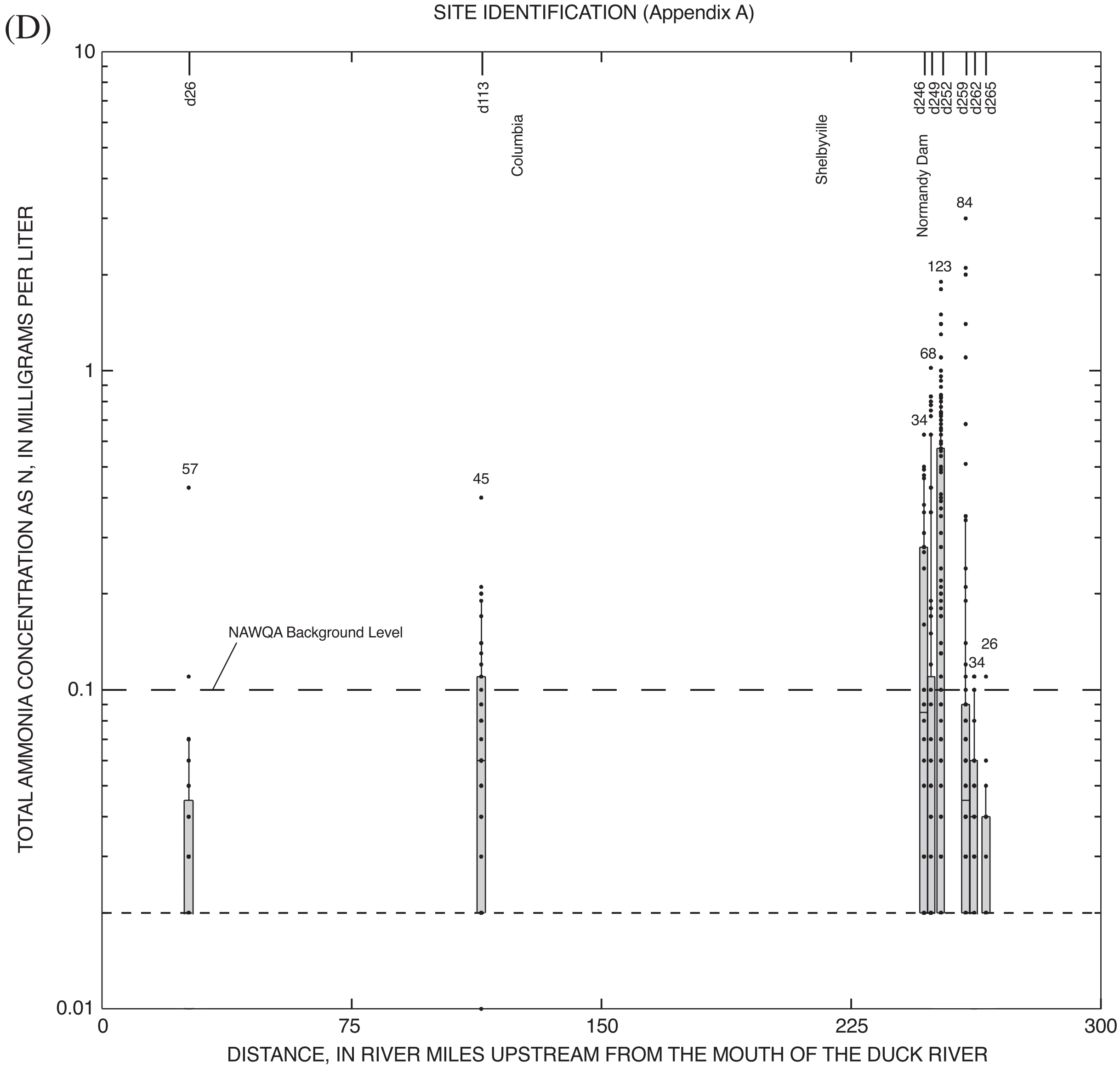


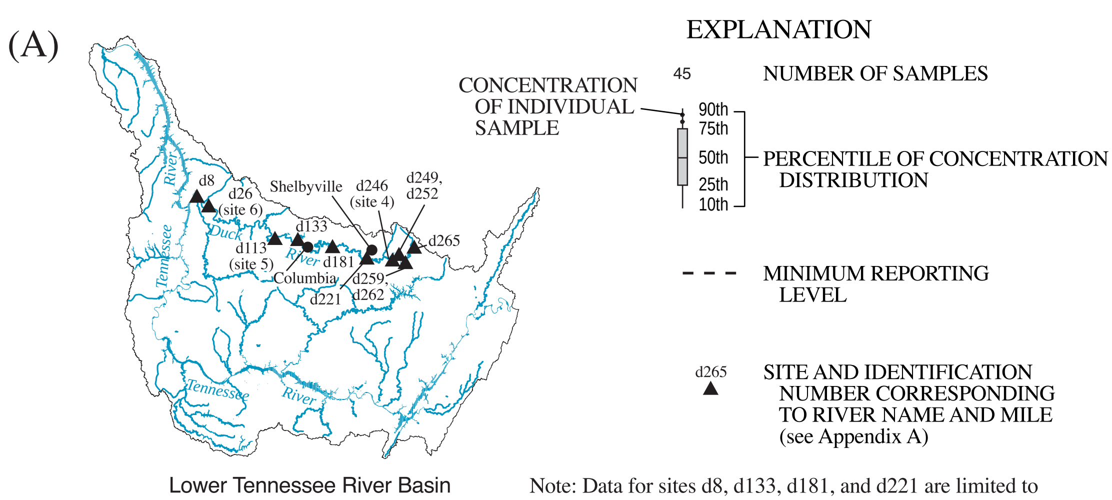
EXPLANATION



Note: Data for sites d8, d133, d181, and d221 are limited to the period 1980-85, whereas data for other sites extended through 1992 or later.

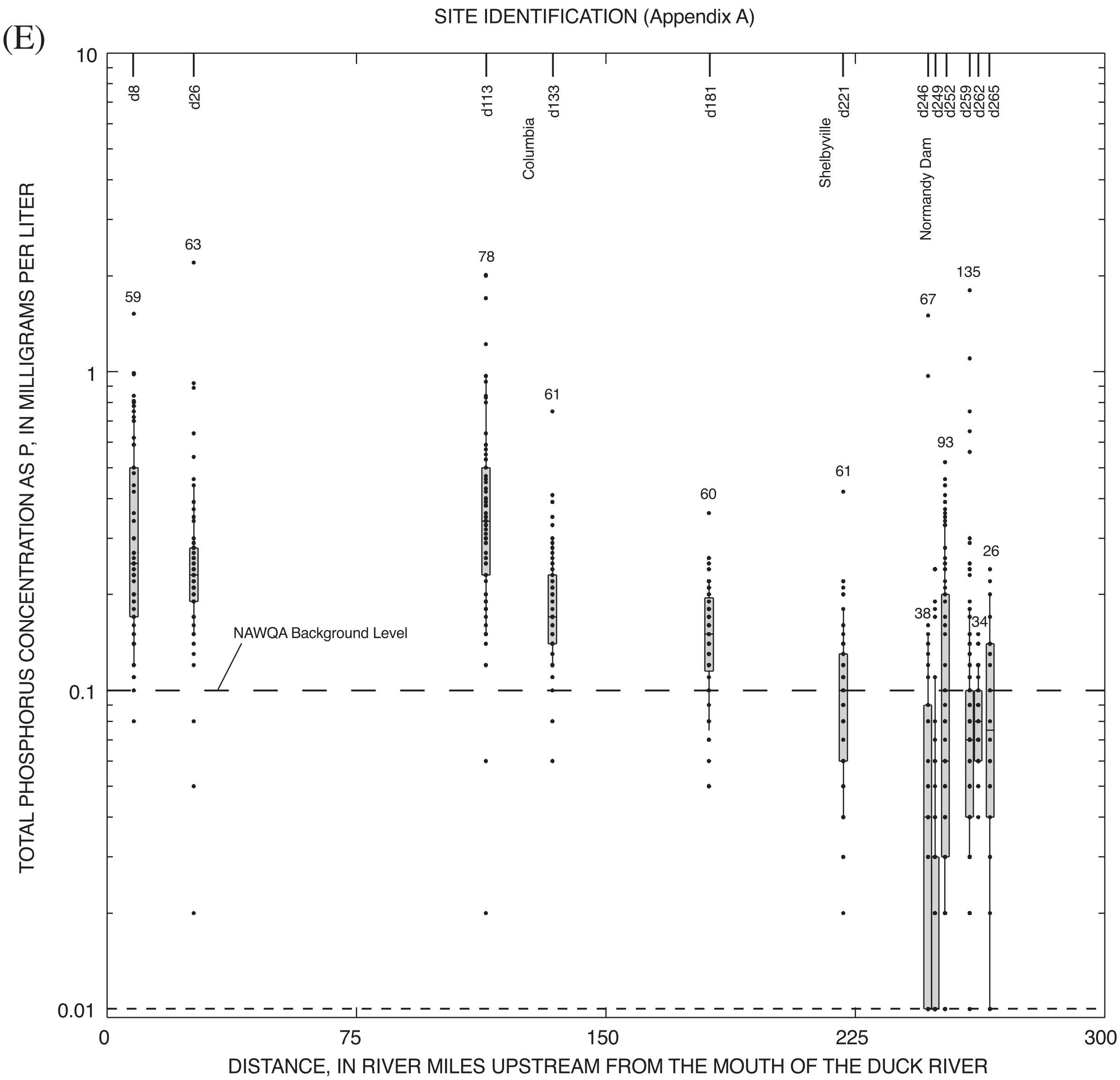
Figure 11. Nutrient concentrations (A) at selected sites on the Duck River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus—Continued.

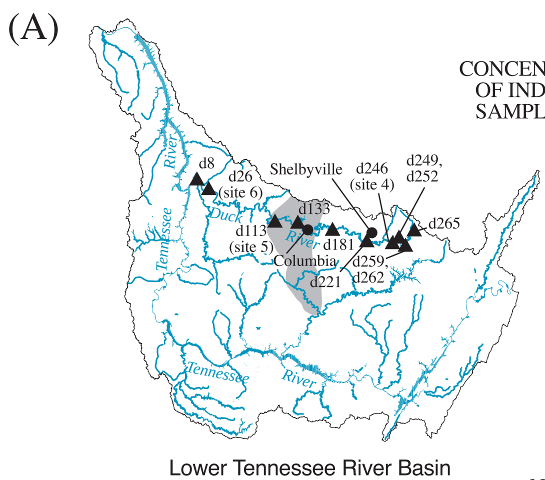




Note: Data for sites d8, d133, d181, and d221 are limited to the period 1980-85, whereas data for other sites extended through 1992 or later.

Figure 11. Nutrient concentrations (A) at selected sites on the Duck River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus—Continued.





EXPLANATION

60 NUMBER OF SAMPLES

CONCENTRATION OF INDIVIDUAL SAMPLE

90th, 75th, 50th, 25th, 10th — PERCENTILE OF CONCENTRATION DISTRIBUTION

BROWN PHOSPHATE DISTRICT (Smith and Whitlatch, 1940)

MINIMUM REPORTING LEVEL

d265 ▲ SITE AND IDENTIFICATION NUMBER CORRESPONDING TO RIVER NAME AND MILE (see Appendix A)

Note: Data for sites d8, d133, d181, and d221 are limited to the period 1980-85, whereas data for other sites extended through 1992 or later.

Figure 11. Nutrient concentrations (A) at selected sites on the Duck River, 1980-96, for (B) total nitrogen, (C) total nitrite plus nitrate, (D) total ammonia, and (E) total phosphorus—Continued.

areas. In contrast, concentrations of ammonia and total phosphorus did not vary much longitudinally (figs. 10D and 10E); instead they fluctuated for short distances (for example, near Tennessee River miles 100 and 300), possibly in response to point- or non-point-source inputs.

Concentrations of all nutrient constituents varied widely with distance along the Duck River, and appear to be strongly influenced by Normandy Reservoir (from river mile 248.6 to 265.4, fig. 11). Median nitrite plus nitrate concentrations were less than 0.3 mg/L within the reservoir, compared with median values of 0.6 mg/L or greater upstream and downstream from the reservoir (fig. 11C); total nitrogen concentrations were somewhat lower in the reservoir with median values less than 0.7 mg/L, compared with median values of 1.0 mg/L or greater upstream and downstream of the reservoir. Median total phosphorus concentrations were as low as 0.01 mg/L within the reservoir, compared with a range in median values of 0.08 to 0.3 mg/L at sites upstream and downstream from the reservoir (fig. 11E). This pattern probably reflects depletion of these nutrients caused by assimilation by aquatic plants in the reservoir during the summer months and, in the case of total phosphorus, by settling associated with sediment. A study of the nutrient balance in Normandy Reservoir by Broach and others (1995, p. 70) found that the reservoir functions as a sink for nitrite plus nitrate and organic nitrogen, but that ammonia outflow from the reservoir exceeds inflow by about threefold. The illustration of variation in total nitrogen (fig. 11B), which shows tailwater concentrations about equal to upstream concentrations, suggests that the reservoir may not be a sink for total nitrogen. The high concentrations of ammonia within Normandy Reservoir and in the tailwater (median value as high as 0.1 mg/L, fig. 11D) might be due to nitrate reduction and ammonification in the oxygen-deficient layer of the reservoir during summer months (Broach and others, 1995).

Background levels for nitrate, ammonia, and total phosphorus for 20 NAWQA study units are included to compare water quality in the Duck River with other rivers in the Nation (fig. 11). Average concentration for “undeveloped” basins was summarized as 0.7 mg/L for nitrate and 0.1 mg/L for ammonia and total phosphorus (Mueller and others, 1995). These background levels were not compared with concentrations on the main stem Tennessee River (fig. 10) because the levels do not reflect the effects of instream processing of nutrients in large rivers.

The median values of concentrations of total nitrite plus nitrate and total phosphorus observed for many of the riverine sites on the Duck River exceeded NAWQA background levels of 0.7 mg/L for nitrate and 0.1 mg/L for total phosphorus (figs. 11C and 11E). The high phosphorus concentrations (greater than 0.2 mg/L) relative to the NAWQA background level in the lower reach of the river (from near Duck River Mile 120 to the mouth) were probably caused by contribution of phosphate-rich sediment, from soils formed on the outcrop of phosphatic limestones in the brown-phosphate districts (figs. 11A and 11E) of middle Tennessee (Smith and Whitlatch, 1940). Ammonia data were sparse in the riverine sections downstream and upstream of the Normandy Reservoir; median values at the five riverine sites with data were below the NAWQA background level of 0.1 mg/L (fig. 11D).

Instream Loads

This section presents estimates of nutrient and sediment instream loads and yields for 18 sites in the LTEN River Basin (table 9). These estimates are used in interpretations of spatial patterns of instream loads and comparisons of instream loads with inputs. Instream loads were calculated for total nitrogen (16 sites), total ammonia (13 sites), total ammonia plus organic nitrogen (16 sites), total nitrite plus nitrate nitrogen (16 sites), total phosphorus (12 sites), dissolved orthophosphorus (7 sites), and suspended sediment (5 sites). Several estimates of annual load were produced for each site-constituent combination. The first set of estimates—mean, minimum, and maximum annual load for the available period of record for load computation (concurrent water-quality and streamflow record)—is provided to indicate long-term transport conditions at the site. Load estimates can vary significantly in years with low or high annual streamflows. At each of the 18 sites where loads were estimated, streamflow durations during the period of load estimation were compared with long-term streamflow duration (Appendix E). At most sites, streamflows during these two periods were similar.

Transport of nutrients into the LTEN River Basin near Chattanooga, Tennessee, is characterized by the instream load estimate at site 18 (Tennessee River below Raccoon Mountain). Transport out of the basin is characterized by the estimate at site 14 (Tennessee

Table 9. Instream load, yield, and flow-weighted mean concentration for selected constituents and basins in the lower Tennessee River Basin, 1980-1996

[r^2, coefficient of determination; s, standard deviation, in log units; MRL, minimum reporting limit of the analytical method; mi^2, square miles; mg/L, milligrams per liter; entries in italics are subject to larger estimation error than the other entries, for various reasons (described in footnotes); <, less than; --, not estimated; regression statistics r^2 and s are from the multivariate log-linear regression model of concentration against streamflow, season, and time; annual load, yield, and flow-weighted mean concentration were estimated for a common period: water year 1992. Where water-quality record was not available for that year, data from a year with similar hydrologic conditions to 1992 were used instead; the width of the model-calculated confidence interval partly indicates the error associated with the estimate; however, several sources of error are not accounted for in this interval, including sampling bias and data sparseness (see Appendix B)]

Site identi-fication (fig. 2)	Surface-water station/site location: Number	Surface-water station/site location: Name	Period of record for load estimates	No. of observations: Less than MRL	No. of observations: Total	Regression statistics: r^2	Regression statistics: s	Annual load: For the period of available record: Mean (tons)	Annual load: For the period of available record: Minimum (tons)	Annual load: For the period of available record: Maximum (tons)	Annual load: For a single year (tons)	95-percent confidence interval: Lower limit (tons)	95-percent confidence interval: Upper limit (tons)	Annual yield: Single year (tons/mi^2)	Flow-weighted mean concentration: Annual, single year (mg/L)	Flow-weighted mean concentration: Seasonal (March-July), single year (mg/L)
Total nitrogen																
1	PRI038	Clarks River at Almo, Ky.	1985-95	0	132	0.15	0.38	490	220 [1987]	1,000 [1989]	320 [1992]	240	400	2.4	2.8	1.2
2	03604000	Buffalo River near Flat Woods, Tenn.	1982-95	0	36	.20	.55	490	280 [1986]	710 [1983]	460 [1992]	310	600	1.0	.55	.28
4	001025	Duck River below Normandy Dam, Tenn.	1986-95	0	27	.28	.41	220	84 [1988]	280 [1989]	200 [1992]	140	250	1.0	.53	.36
5	001065	Duck River at Williamsport, Tenn.	1982-94	0	52	.36	.33	3,800	1,500 [1986]	6,400 [1983]	3,000 [1992]	2,100	4,000	2.1	1.2	.47
6	475793	Duck River above Hurricane Mills, Tenn.	1986-93	0	44	.48	.36	4,700	2,200 [1986]	7,600 [1989]	4,500 [1992]	3,200	5,800	1.8	1.1	.40
7	*002395*	*Shoal Creek at Highway 43, near Lawrenceburg, Tenn.* [a]	*1983-92*	*0*	*32*	*.31*	*.39*	*480*	*200 [1988]*	*950 [1983]*	*500 [1992]*	*230*	*780*	*2.9*	*1.5*	*.62*
9	001207	Elk River below Tims Ford Dam, Tenn.	1984-94	0	36	.32	.37	620	160 [1988]	1,100 [1994]	530 [1992]	370	680	.99	.61	.30
10	475796	Elk River near Prospect, Tenn.	1987-92	0	43	.64	.30	6,600	1,600 [1988]	10,000 [1989]	5,300 [1992]	3,600	7,000	3.0	1.8	.49
11	FLCR7	Flint Creek near Falkville, Ala.	1993-97	0	67	.32	.57	220	140 [1995]	290 [1997]	200 [1994]	110	290	2.4	1.1	.45
12	TOWNCREEK15b	Town Creek near Geraldine, Ala.	1988-96	0	72	.47	.40	880	550 [1992]	1,900 [1989]	550 [1992]	460	640	3.5	2.3	.78
13	*002375*	*Sequatchie River at Valley Road, Tenn.* [a]	*1983-94*	*0*	*39*	*.32*	*.44*	*960*	*370 [1988]*	*1,500 [1982]*	*810 [1992]*	*620*	*1,000*	*1.4*	*.70*	*.40*
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	1980-84	0	30	.53	.36	60,000	21,000 [1981]	89,000 [1983]	56,000 [1982]	45,000	68,000	1.4	.95	.41
15	202832	Tennessee River at mile 23, *Ky.* [c]	1990-94	0	26	.61	.20	52,000	38,000 *[1992]*	65,000 *[1991]*	38,000 *[1992]*	32,000	44,000	.94	.68	.29
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	1980-95	0	64	.53	.28	43,000	20,000 [1988]	66,000 [1990]	36,000 [1992]	29,000	42,000	1.1	.71	.29
17	03571850	Tennessee River at South Pittsburg, Tenn.	1980-85	0	37	.15	.58	38,000	21,000 [1981]	53,000 [1984]	43,000 [1982]	23,000	63,000	1.9	1.1	.45
18	003315	Tennessee River below Raccoon Mountain, Tenn.	1981-94	0	152	.39	.49	29,000	10,000 [1988]	51,000 [1982]	20,000 [1992]	17,000	23,000	.94	.59	.24

Table 9. Instream load, yield, and flow-weighted mean concentration for selected constituents and basins in the lower Tennessee River Basin, 1980-1996—Continued

Site identi-fication (fig. 2)	Surface-water station/site location: Number	Surface-water station/site location: Name	Period of record for load estimates	No. of observations: Less than MRL	No. of observations: Total	Regression statistics: r^2	Regression statistics: s	Annual load: For the period of available record: Mean (tons)	Annual load: For the period of available record: Minimum (tons)	Annual load: For the period of available record: Maximum (tons)	Annual load: For a single year (tons)	95-percent confidence interval: Lower limit (tons)	95-percent confidence interval: Upper limit (tons)	Annual yield: Single year (tons/mi^2)	Flow-weighted mean concentration: Annual, single year (mg/L)	Flow-weighted mean concentration: Seasonal (March-July), single year (mg/L)
Total ammonia																
1	PRI038	Clarks River at Almo, Ky.	1985-95	70	133	.19	1.13	25	11 [1993]	53 [1989]	11 [1992]	<1	23	.09	.10	.05
2	03604000	Buffalo River near Flat Woods, Tenn.	1987-92	3	28	.39	.52	15	8.0 [1988]	18 [1989]	17 [1992]	7.7	26	.04	.02	.01
4	001025	Duck River below Normandy Dam, Tenn.	1987-95	0	27	.70	.92	40	21 [1995]	45 [1990]	38 [1992]	18	58	.20	.10	.06
5	001065	Duck River at Williamsport, Tenn.	1984-94	7	43	.47	.82	250	100 [1994]	540 [1984]	160 [1992]	45	270	.11	.06	.02
6	475793	Duck River above Hurricane Mills, Tenn.	1987-94	12	53	.12	1.10	230	110 [1993]	400 [1989]	220 [1992]	<1	590	.09	.06	.01
7	*002395*	*Shoal Creek at Highway 43, near Lawrenceburg, Tenn.* [a]	*1984-94*	*14*	*38*	*.41*	*.95*	*29*	*6.1 [1993]*	*56 [1983]*	*31 [1992]*	*<1*	*110*	*.18*	*.09*	*.02*
9	001207	Elk River below Tims Ford Dam, Tenn.	1984-94	8	37	.45	1.00	120	17 [1988]	220 [1984]	130 [1992]	11	260	.25	.15	.02
10	475796	Elk River near Prospect, Tenn.	1987-94	8	57	.30	.87	820	57 [1988]	2,700 [1991]	720 [1992]	<1	2,000	.40	.24	.03
11	FLCR7	Flint Creek near Falkville, Ala.	1993-97	4	66	.30	.86	10	5.0 [1995]	14 [1993]	10 [1994]	3.1	17	.12	.05	.03
12	*TOWNCREEK15*	*Town Creek near Geraldine, Ala.* [d]	*1988-96*	*40*	*77*	*.14*	*1.27*	*30*	*17 [1992]*	*55 [1989]*	*17 [1992]*	*5.5*	*28*	*.11*	*.07*	*.03*
13	*002375*	*Sequatchie River at Valley Road,* Tenn. [a]	*1983-94*	*12*	*41*	*.37*	*1.06*	*99*	*19* [1988]	*400* [1983]	*50* [1992]	*19*	*81*	*.09*	*.04*	*.02*
15	202832	Tennessee River at mile 23, Ky. [c]	1990-94	5	33	.33	.91	5,000	2,900 [1990]	8,700 [1994]	4,000 [1992]	770	7,200	.10	.07	.02
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	1980-92	2	45	.35	.58	2,300	880 [1988]	4,700 [1980]	1,900 [1992]	1,100	2,700	.06	.04	.02
Total ammonia plus organic nitrogen																
1	PRI038	Clarks River at Almo, Ky.	1986-93	0	101	.29	.43	200	76 [1987]	550 [1989]	100 [1992]	62	140	.76	.89	2.3
2	03604000	Buffalo River near Flat Woods, Tenn.	1982-95	21	61	.32	.83	200	73 [1995]	400 [1983]	140 [1992]	86	190	.32	.17	.09
4	001025	Duck River below Normandy Dam, Tenn.	1987-95	0	27	.20	.53	140	59 [1988]	170 [1989]	140 [1992]	81	190	.70	.36	.19
5	001065	Duck River at Williamsport, Tenn.	1981-92	1	53	.29	.62	2,300	500 [1981]	4,900 [1983]	1,700 [1992]	220	3,100	1.2	.67	.19
6	475793	Duck River above Hurricane Mills, Tenn.	1986-93	1	47	.33	.59	2,800	930 [1986]	5,400 [1989]	2,600 [1992]	130	5,200	1.0	.66	.17

Table 9. Instream load, yield, and flow-weighted mean concentration for selected constituents and basins in the lower Tennessee River Basin, 1980-1996—Continued

Site identi-fication (fig. 2)	Surface-water station/site location: Number	Surface-water station/site location: Name	Period of record for load estimates	No. of observations: Less than MRL	No. of observations: Total	Regression statistics: r^2	Regression statistics: s	Annual load, for the period of available record: Mean (tons)	Annual load, for the period of available record: Minimum (tons)	Annual load, for the period of available record: Maximum (tons)	Annual load: For a single year (tons)	95-percent confidence interval: Lower limit (tons)	95-percent confidence interval: Upper limit (tons)	Annual yield: Single year (tons/mi^2)	Flow-weighted mean concentration: Annual, single year (mg/L)	Flow-weighted mean concentration: Seasonal (March-July), single year (mg/L)
Total ammonia plus organic nitrogen—Continued																
7	*002395*	*Shoal Creek at Highway 43, near Lawrenceburg, Tenn.* [a]	*1983-94*	*0*	*39*	*.52*	*.66*	*140*	*49 [1993]*	*380 [1983]*	*94 [1992]*	*<1*	*200*	*.53*	*.27*	*.07*
9	001207	Elk River below Tims Ford Dam, Tenn.	1984-94	3	39	.39	.64	280	77 [1988]	620 [1984]	190 [1992]	94	290	.37	.23	.09
10	475796	Elk River near Prospect, Tenn.	1986-93	0	49	.60	.53	2,900	570 [1988]	5,900 [1989]	2,800 [1992]	960	4,600	1.6	.91	.17
11	FLCR7	Flint Creek near Falkville, Ala.	1993-97	4	60	.28	.72	82	49 [1995]	160 [1997]	69 [1994]	35	100	.80	.37	.15
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	1988-96	4	76	.51	.56	140	63 [1995]	430 [1988]	78 [1992]	60	96	.50	.33	.12
13	002375	Sequatchie River at Valley Road, Tenn. [a]	1983-94	4	42	.24	.79	300	100 [1988]	660 [1983]	220 [1992]	120	300	.37	.19	.09
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	1980-84	0	41	.24	.49	37,000	14,000 [1981]	53,000 [1984]	30,000 [1982]	22,000	37,000	.73	.50	.23
15	*202832*	*Tennessee River at mile 23, Ky.* [c]	*1990-94*	*0*	*32*	*.34*	*.31*	*24,000*	*16,000 [1992]*	*32,000 [1990]*	*16,000 [1992]*	*12,000*	*20,000*	*.40*	*.29*	*<.01*
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	1986-93	3	36	.45	.41	16,000	11,000 [1988]	22,000 [1989]	14,000 [1992]	11,000	17,000	.42	.27	.15
17	03571850	Tennessee River at South Pittsburg, Tenn.	1980-85	3	40	.18	.94	23,000	9,500 [1981]	35,000 [1984]	25,000 [1982]	3,900	46,000	1.1	.65	.22
18	003315	Tennessee River below Raccoon Mountain, Tenn.	1981-94	4	158	.39	.66	16,000	5,000 [1988]	31,000 [1983]	9,300 [1992]	7,500	11,000	.43	.27	.12
Total nitrite plus nitrate nitrogen																
1	PRI038	Clarks River at Almo, Ky.	1985-95	0	133	.16	.55	320	150 [1987]	580 [1989]	220 [1992]	150	290	1.6	1.9	.79
2	03604000	Buffalo River near Flat Woods, Tenn.	1986-93	5	38	.47	.58	230	120 [1986]	400 [1989]	220 [1992]	82	350	.48	.26	.10
4	001025	Duck River below Normandy Dam, Tenn.	1987-95	0	27	.78	.50	89	22 [1988]	140 [1991]	69 [1992]	47	91	.36	.18	.18
5	001065	Duck River at Williamsport, Tenn.	1982-93	0	56	.16	.30	1,900	780 [1986]	2,700 [1983]	1,800 [1992]	1,300	2,300	1.2	.71	.34
6	475793	Duck River above Hurricane Mills, Tenn.	1987-93	2	48	.41	1.09	3,200	2,200 [1988]	4,700 [1987]	2,800 [1992]	1,200	4,400	1.1	.70	.25
7	*002395*	*Shoal Creek at Highway 43, near Lawrenceburg, Tenn.* [a]	*1983-94*	*0*	*40*	*.25*	*.37*	*280*	*140 [1988]*	*460 [1983]*	*250 [1992]*	*200*	*300*	*1.4*	*.74*	*.38*
9	001207	Elk River below Tims Ford Dam, Tenn.	1984-94	0	39	.42	.68	450	70 [1988]	1,500 [1994]	420 [1992]	160	690	.80	.49	.23
10	475796	Elk River near Prospect, Tenn.	1987-93	0	51	.22	.41	3,100	1,000 [1988]	4,700 [1991]	2,700 [1992]	2,000	3,500	1.5	.89	.33
11	FLCR7	Flint Creek near Falkville, Ala.	1993-97	1	67	.69	.57	150	100 [1995]	200 [1997]	140 [1994]	48	230	1.6	.74	.33
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	1988-96	0	77	.46	.60	570	440 [1992]	790 [1989]	440 [1992]	330	550	2.8	1.8	.64

Table 9. Instream load, yield, and flow-weighted mean concentration for selected constituents and basins in the lower Tennessee River Basin, 1980-1996—Continued

Site identi-fication (fig. 2)	Surface-water station/site location: Number	Surface-water station/site location: Name	Period of record for load estimates	No. of observations: Less than MRL	No. of observations: Total	Regression statistics: r^2	Regression statistics: s	Annual load: For the period of available record: Mean (tons)	Annual load: For the period of available record: Minimum (tons)	Annual load: For the period of available record: Maximum (tons)	Annual load: For a single year (tons)	Annual load: 95-percent confidence interval: Lower limit (tons)	Annual load: 95-percent confidence interval: Upper limit (tons)	Annual yield: Single year (tons/mi^2)	Flow-weighted mean concentration: Annual, single year (mg/L)	Flow-weighted mean concentration: Seasonal (March-July), single year (mg/L)
Total nitrite plus nitrate nitrogen—Continued																
13	002375	Sequatchie River at Valley Road, Tenn. [a]	1983-94	12	43	.15	.71	680	250 [1988]	1,400 [1994]	640 [1992]	400	870	1.1	.55	.32
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	1980-84	0	41	.58	.55	27,000	7,400 [1981]	38,000 [1984]	23,000 [1982]	15,000	31,000	.57	.39	.13
15	202832	Tennessee River at mile 23, Ky. [c]	1990-94	8	33	.77	.95	79,000	41,000 [1990]	120,000 [1994]	62,000 [1992]	<1	130,000	1.5	1.1	.27
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	1980-94	6	77	.70	.39	24,000	8,500 [1988]	40,000 [1980]	18,000 [1992]	13,000	23,000	.56	.36	.13
17	03571850	Tennessee River at South Pittsburg, Tenn.	1980-85	0	38	.37	.24	13,000	8,000 [1981]	16,000 [1983]	14,000 [1982]	12,000	16,000	.62	.37	.15
18	003315	Tennessee River below Raccoon Mountain, Tenn.	1981-94	0	158	.43	.40	13,000	4,700 [1988]	19,000 [1982]	11,000 [1992]	9,900	12,000	.52	.32	.13
Total phosphorus																
1	PRI038	Clarks River at Almo, Ky.	1985-95	0	132	.57	.49	62	29 [1995]	160 [1989]	40 [1992]	27	53	.30	.35	.14
2	03604000	Buffalo River near Flat Woods, Tenn.	1983-95	9	56	.25	.74	27	12 [1995]	52 [1983]	19 [1992]	9	29	.04	.02	.01
4	001025	Duck River below Normandy Dam, Tenn.	1987-95	6	24	.68	.91	20	3.0 [1994]	34 [1990]	15 [1992]	<1	32	.08	.04	.01
5	001065	Duck River at Williamsport, Tenn.	1981-93	0	68	.11	.86	1,700	390 [1981]	3,300 [1983]	1,300 [1992]	120	2,600	.93	.53	.18
6	475793	Duck River above Hurricane Mills, Tenn.	1988-93	0	43	.33	.63	2,900	1,500 [1993]	4,700 [1991]	2,900 [1992]	<1	6,500	1.1	.73	.16
7	002395	Shoal Creek at Highway 43, near Lawrenceburg, Tenn. [a]	1983-94	2	39	.30	.93	39	14 [1994]	60 [1983]	26 [1992]	10	42	.15	.08	.02
9	001207	Elk River below Tims Ford Dam, Tenn.	1983-94	16	41	.68	1.10	68	2.0 [1994]	140 [1987]	17 [1992]	<1	40	.03	.02	<.01
10	475796	Elk River near Prospect, Tenn.	1986-94	0	56	.31	.60	1,400	290 [1988]	3,100 [1991]	1,600 [1992]	330	2,800	.89	.52	.10
14	03609750	Tennessee River at Highway 60 near Paducah, Ky.	1980-84	0	31	.50	.31	5,000	2,000 [1981]	6,900 [1980]	4,800 [1982]	3,900	5,700	.12	.08	.03
15	202832	Tennessee River at mile 23, Ky. [c]	1990-94	0	34	.40	.41	4,900	3,200 [1992]	6,300 [1989]	3,200 [1992]	2,100	4,300	.08	.06	.02
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	1980-93	1	71	.16	.48	3,600	1,300 [1988]	6,500 [1991]	3,900 [1992]	2,300	5,400	.12	.08	.02
17	03571850	Tennessee River at South Pittsburg, Tenn.	1980-86	2	40	.23	.45	1,300	520 [1986]	2,000 [1980]	1,600 [1982]	1,200	2,000	.07	.04	.02

Table 9. Instream load, yield, and flow-weighted mean concentration for selected constituents and basins in the lower Tennessee River Basin, 1980-1996—Continued

Site identification (fig. 2)	Surface-water station/site location: Number	Surface-water station/site location: Name	Period of record for load estimates	No. of observations: Less than MRL	No. of observations: Total	Regression statistics: r^2	Regression statistics: s	Annual load: For the period of available record: Mean (tons)	Annual load: For the period of available record: Minimum (tons)	Annual load: For the period of available record: Maximum (tons)	Annual load: For a single year (tons)	95-percent confidence interval: Lower limit (tons)	95-percent confidence interval: Upper limit (tons)	Annual yield: Single year (tons/mi^2)	Flow-weighted mean concentration: Annual, single year (mg/L)	Flow-weighted mean concentration: Seasonal (March-July), single year (mg/L)
Dissolved orthophosphorus																
2	03604000	Buffalo River near Flat Woods, Tenn.	1984-95	18	54	.26	.43	10	4.5 [1986]	18 [1989]	11 [1992]	3.2	19	.03	.01	.01
6	475793	Duck River above Hurricane Mills, Tenn.	1986-91	0	38	.25	.43	870	220 [1986]	1,500 [1989]	940 [1990]	81	1,800	.37	.23	.07
10	475796	Elk River near Prospect, Tenn.	1987-91	0	38	.22	.45	800	230 [1988]	1,300 [1989]	820 [1987]	300	1,400	.46	.27	.07
11	FLCR7	Flint Creek near Falkville, Ala. [d]	1993-97	15	62	.73	.39	12	5.5 [1995]	16 [1993]	13 [1994]	9.0	17	.16	.07	.02
12	TOWNCREEK15	Town Creek near Geraldine, Ala. [d]	1988-96	29	74	.28	1.55	47	21 [1992]	110 [1996]	21 [1992]	2.1	40	.13	.09	.04
15	202832	Tennessee River at mile 23, Ky. [c]	1990-94	1	33	.64	.56	3,200	1,900 [1990]	4,200 [1991]	3,500 [1992]	1,300	5,800	.09	.06	.01
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	1983-93	11	49	.49	.52	2,200	520 [1988]	5,000 [1991]	2,600 [1992]	700	4,400	.08	.05	.09
Suspended sediment																
2	03604000	Buffalo River near Flat Woods, Tenn.	1982-95	0	65	.50	.71	29,000	9,800 [1986]	92,000 [1983]	20,000 [1992]	<1	55,000	[f]65	[f]35	--
3	03596000	Duck River below Manchester, Tenn. [e]	1979-83	0	30	.71	.46	11,000	820 [1981]	17,000 [1980]	16,000 [1982]	<1	47,000	[f]100	[f]72	--
8	03588500	Shoal Creek at Iron City, Tenn. [e]	1979-83	1	29	.56	.74	91,000	3,900 [1981]	240,000 [1983]	41,000 [1982]	<1	110,000	[f]260	[f]140	--
16	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	1980-93	0	68	.09	.71	850,000	260,000 [1986]	1,800,000 [1991]	1,000,000 [1992]	330,000	1,700,000	[f]26	[f]17	--
17	03571850	Tennessee River at South Pittsburg, Tenn.	1980-86	0	43	.22	.61	390,000	140,000 [1986]	600,000 [1980]	480,000 [1982]	260,000	690,000	[f]17	[f]10	--

[a] Estimates are subject to error because streamflow-gaging and water-quality-sampling sites were not colocated.
[b] Station number in Alabama Department of Environmental Management study is t5.
[c] Load estimates are subject to error due to grab sampling methods at this vertically stratified site.
[d] Load estimates are subject to error due to variable MRL (ranging from 0.03 to 0.2 mg/L), and the large percentage of observations below MRL.
[e] Included data from 1979 for calibration and load estimation, in order to have sufficient length of record.
[f] Annual yield and flow-weighted mean concentration for sediment were estimated for the period of available record, rather than for the single year, because a common overlapping period was not available.

River at Highway 60 near Paducah), except that the watershed for this site does not include the Clarks River drainage. Estimates of mean annual instream load of total nitrogen at the inlet (site 18) and outlet (site 14) were 29,000 tons/yr (for the period 1981-94) and 60,000 tons/yr (for the period 1980-84), respectively (table 9), representing a gain of 31,000 tons/yr, on average, across the area (18,930 mi^2) between these two sites. The sum of the mean annual instream load from gaged tributaries to the main stem within the study unit was 14,000 tons/yr (period variable); however, this number cannot be compared with the gain between the inlet and outlet sites because the gaged area represents only 30 percent of the total area and the period of record at many tributary sites did not correspond with the period of record at the inlet or outlet sites.

Estimates of mean annual instream load of total phosphorus at the inlet (site 17) and outlet (site 14) were 1,300 tons/yr (1980-86) and 5,000 tons/yr (1980-84), respectively, representing a gain of 3,700 tons/yr, on average, across the study unit (table 9). For this comparison, site 17 (Tennessee River at South Pittsburg) was substituted as the inlet site because total phosphorus load was not estimated at site 18. The sum of the gaged tributary load, representing only 28 percent of the area contributing to the main stem between sites 17 and 14, was 4,300 tons/yr (period variable). Although this number cannot be closely compared with the gain throughout the study unit, for the same reasons given for total nitrogen, a general comparison suggests that the main stem of the Tennessee River and the tributary embayments along the main stem function as a sink for total phosphorus, removing a substantial amount from the water column through assimilation or deposition.

Load and yield estimates for a single water year also are presented for each site (table 9) to provide a common period for better spatial comparisons among sites. Data from 1992 were used for comparison where possible because more data were available on instream loads and sources during 1992 than for any other year. Hydrologic conditions during 1992 were close to average at all sites (except for Clarks River at Almo, which had relatively low flow in 1992). For those sites without load estimates for 1992, the estimate from a hydrologically similar year was used.

The range between the upper and lower limits of the 95-percent confidence intervals (table 9) indicates precision of the model estimates and is an important consideration for interpreting these data. The load estimates are useful for evaluating broad spatial patterns of instream load, and comparisons of instream load to inputs, but may not be sufficiently accurate for local-scale evaluations of water quality. A discussion of limitations of the data and error in the model estimates is contained in Appendix B.

An additional consideration in spatial interpretation is the extent to which the set of monitoring sites represent conditions in the LTEN River Basin. The gaged tributary area represents a relatively small part of the study unit (less than 30 percent for most constituents); therefore, spatial extrapolations must be made with caution. In addition, the tributary sites in Alabama were monitored as part of special studies of known water-quality problems, compared to tributary sites in other states that were part of ambient monitoring networks, which may bias conclusions about basin-wide water quality.

To facilitate spatial comparisons of instream loads at sites draining watersheds of greatly differing size and streamflow characteristics, the load estimates at each site were normalized in two ways: by dividing each estimate by the watershed area (producing an estimate of yield in tons per square mile), and by dividing each estimate by the mean streamflow at the site for the load-computation period (producing the equivalent of **flow-weighted mean** of the model-estimated daily **concentrations**, in milligrams per liter). The model-estimated daily concentrations are used rather than the set of observed concentrations to derive the estimate of flow-weighted mean concentration because the former account for flux during unsampled periods and are considered to better represent average concentration during a specified period.

Estimates of flow-weighted mean concentration are useful for evaluating average water-quality conditions at the site and for comparisons (which follow) with national data sets and guidelines; estimates of yield are useful for comparisons with inputs in a mass balance analysis. Both yields and flow-weighted mean concentrations are reported in table 9 and displayed graphically in figures 12 and 13, and estimates of yield of total nitrogen and total phosphorus are displayed on maps in figures 14 and 15. Because runoff characteristics for site 1, Clarks River at Almo (median runoff for period of load computation is 3.0 in., table 1), differed from the other tributary sites (median runoff ranges from 8 to 13 in.), the ranking of this site for constituent transport estimated by flow-weighted mean concentration differs substantially from the ranking based on yield estimates (compare in figure 12).

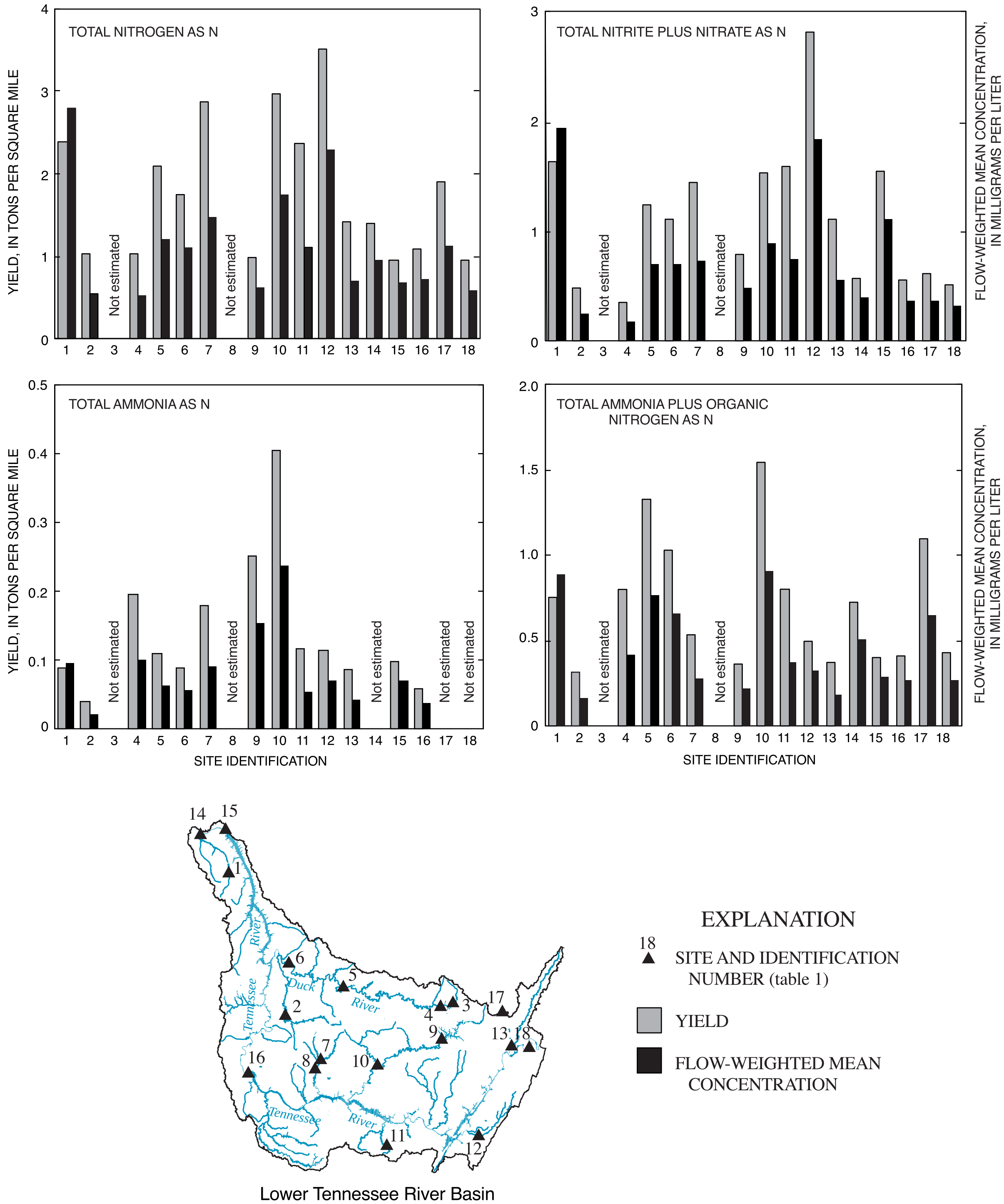


Figure 12. Annual yield and flow-weighted mean concentration of total nitrogen, total nitrite plus nitrate, total ammonia, and total ammonia plus organic nitrogen at selected sites in the lower Tennessee River Basin.

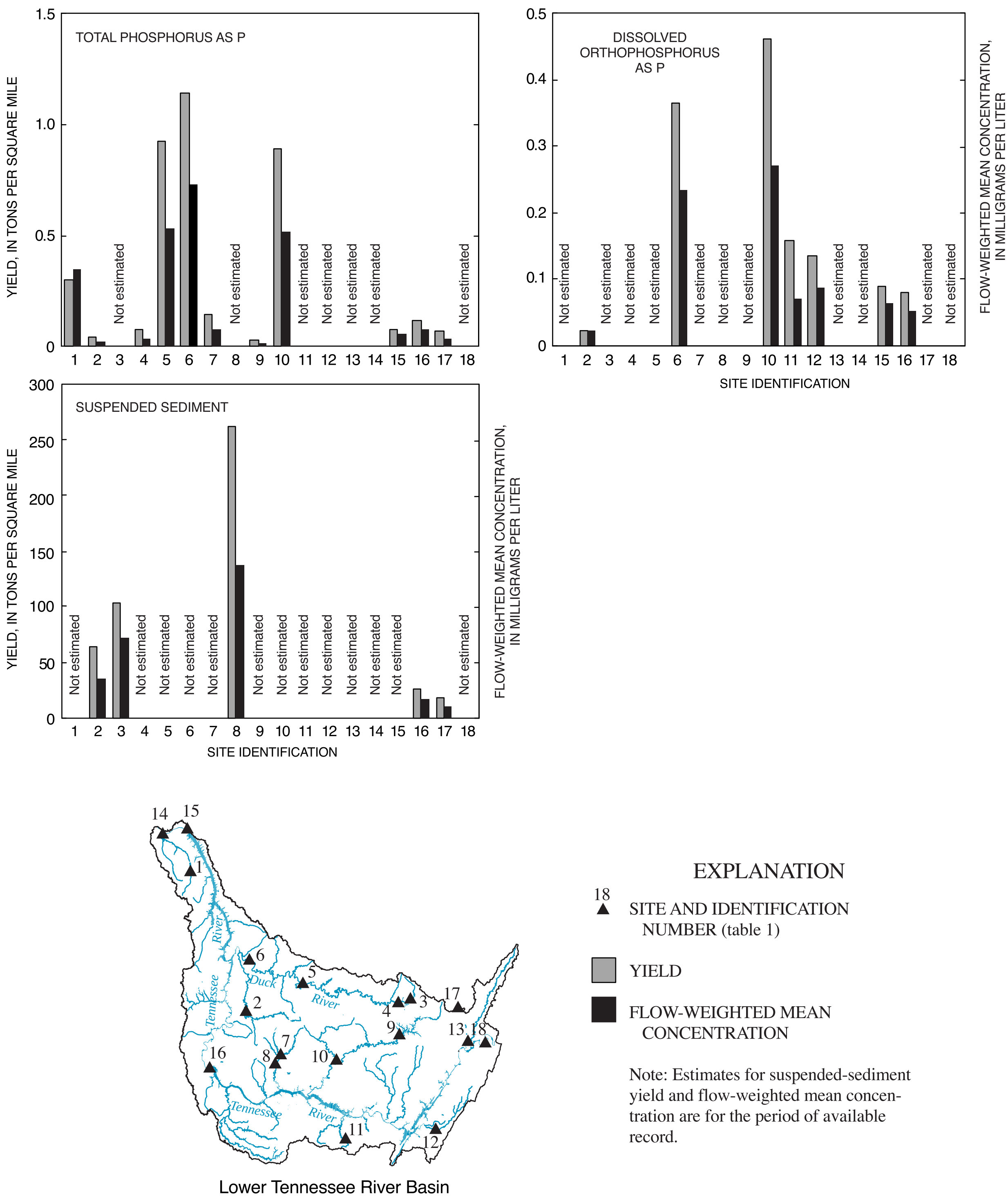


Figure 13. Annual yield and flow-weighted mean concentration of total phosphorus, dissolved orthophosphorus, and suspended sediment at selected sites in the lower Tennessee River Basin.

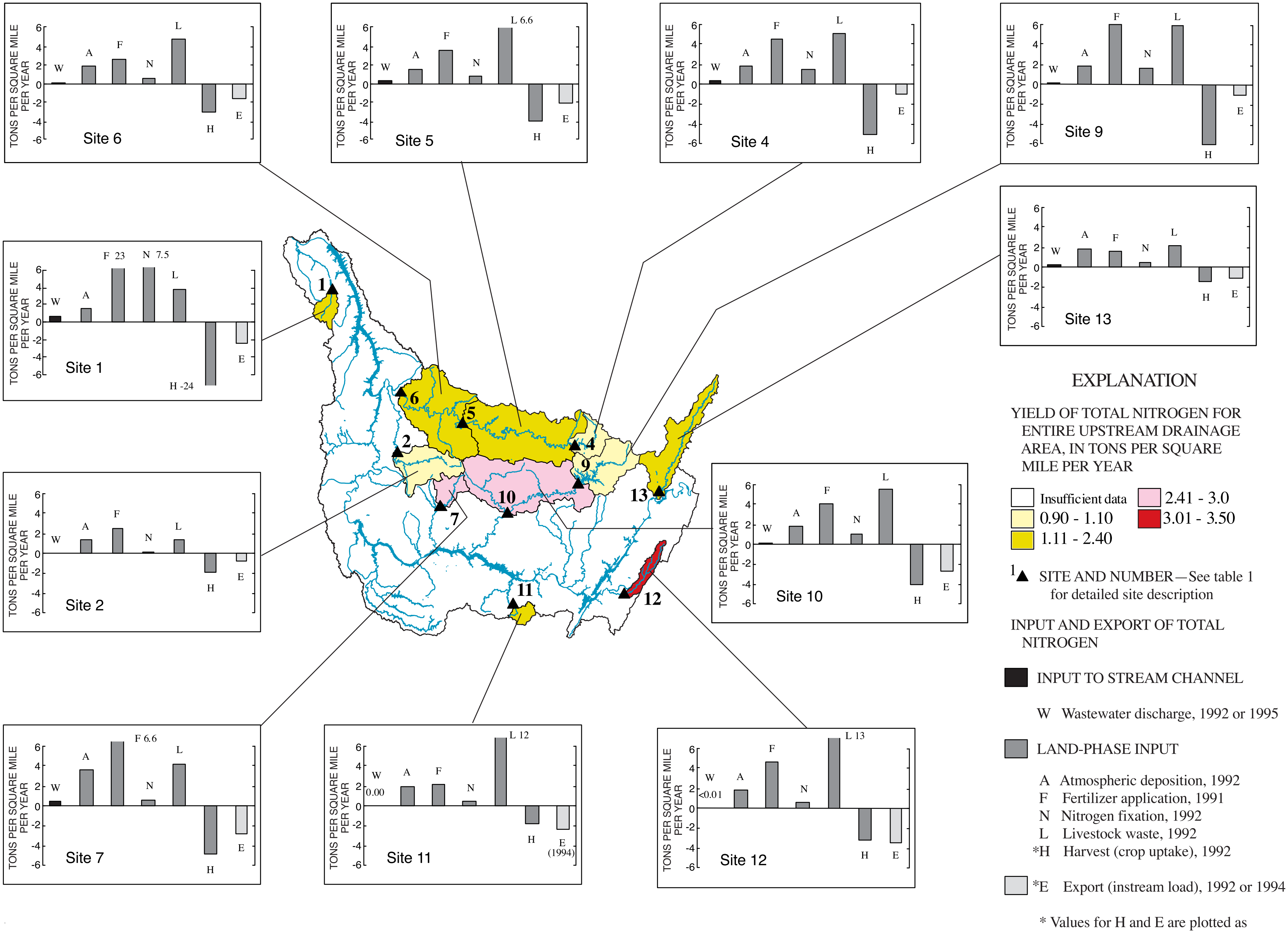


Figure 14. Total nitrogen input and export at selected sites in the lower Tennessee River Basin.

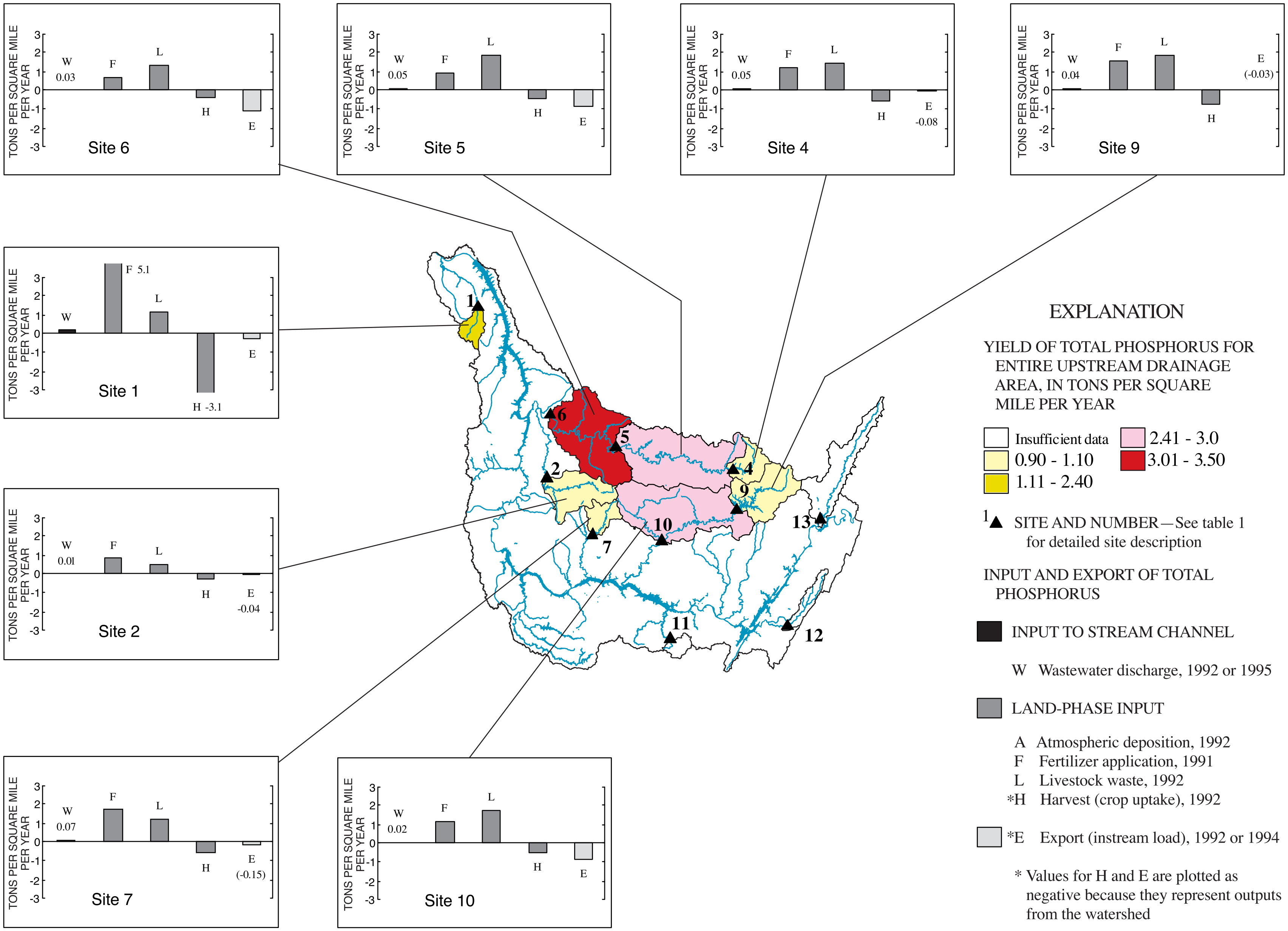


Figure 15. Total phosphorus input and export at selected sites in the lower Tennessee River Basin.

Estimates of annual flow-weighted mean concentration of total nitrogen range from 0.53 to 2.8 mg/L as nitrogen (table 9), representing a fivefold difference among the watersheds. The smallest estimates were at site 2 (Buffalo River near Flat Woods) and site 4 (Duck River below Normandy Dam), which represent a minimally developed watershed (with 29 percent combined urban and agricultural land use, fig. 5) and tailwater from a tributary reservoir, respectively. The largest estimate, at site 1 (Clarks River at Almo), is from the watershed with the largest areal percentages of urban and agricultural land use (corresponding to 80 percent combined urban and agricultural land use, fig. 5), and with the largest amount of wastewater discharge (table 3), suggesting that human activity increases instream transport of total nitrogen by as much as fivefold. The difference in flow-weighted mean concentration at sites 1 and 2 might not be caused by human activity alone, however, because the natural basin characteristics also differ for these two sites (fig. 2).

Estimates of annual flow-weighted mean concentration of total phosphorus range from 0.02 to 0.73 mg/L as phosphorus (table 9), representing a fortyfold difference among the watersheds. The smallest estimate was for site 2 (Buffalo River near Flat Woods), which is a minimally-developed watershed. The largest three estimates, 0.73, 0.53, and 0.52 mg/L (from sites 6 and 5 on the Duck River and site 10 on the Elk River, respectively), probably represent a natural source: the phosphatic limestone formations of the brown-phosphate district outcrop in the watersheds for these three sites (figs. 11A and 11E). The outcrop pattern of these phosphatic limestones is an important factor to consider as regional boundaries are established for attainable region-specific water-quality criteria for total phosphorus (U.S. Environmental Protection Agency, 1998). The estimate of 0.35 mg/L for site 1 (Clarks River at Almo) is a twentyfold difference from site 2 and better indicates to what extent human activity has increased instream transport of total phosphorus in the LTEN River Basin.

The range of annual flow-weighted mean concentration for each constituent can be placed in national context by comparing with the statistical distribution of estimated values of annual flow-weighted mean concentration from about 200 basins monitored during 1993-94 as part of the NAWQA program (D. Mueller, U.S. Geological Survey, written commun., 1998). The distributions for total ammonia, dissolved orthophosphorus, and total nitrite plus nitrate at the LTEN River Basin sites match the national distributions reasonably well (fig. 16); median values for the LTEN River Basin sites fall within the 45 to 65 percentile range of the national distribution. Distributions for total nitrogen and total phosphorus at LTEN River Basin sites, however, depart more from the national distributions (fig. 16); median values for the LTEN River Basin sites are lower (corresponding to the 35 percentile in both cases). The maximum value of total phosphorus flow-weighted mean concentration (0.73 mg/L for site 6, Duck River above Hurricane Mills, table 9) falls at the high end of the national distribution. The nine sites in the national data base with higher values than for site 6 were predominantly from western States or were from small (drainage area less than 80 mi^2), intensively cultivated, watersheds (D. Mueller, USGS, written commun., 1998). The flow-weighted mean concentration of total phosphorus for site 6 is an extreme value within the context of both the national and the regional (LTEN River Basin) distributions, and further emphasizes the significance of the phosphatic limestone formations in the basin for this site. Flow-weighted mean concentrations for site 5 (Duck River at Williamsport, 0.53 mg/L) and site 10 (Elk River near Prospect, 0.52 mg/L) also are extreme.

The spatial distribution of tributary annual flow-weighted mean concentration indicates which areas of the basin contribute more nutrients, on a discharge-weighted basis, to downstream receiving waters and, therefore, which water bodies may be at greatest risk for eutrophication and consequent ecological disruption. Although the trophic status of a water body relates not only to nutrient influx but also to assimilative capacity (which includes factors such as light attenuation and residence time), nutrient influx is a major factor. Watersheds contributing the largest amounts of total nitrogen on a discharge-weighted basis are sites 1, 12, and 10 (Clarks River at Almo, Town Creek near Geraldine, and Elk River near Prospect, respectively, table 9). Watersheds contributing the largest amounts of total phosphorus, on a discharge-weighted basis, are sites 6, 5, and 10 (Duck River above Hurricane Mills and at Williamsport and Elk River near Prospect, respectively). These sites also have small nitrogen-to-phosphorus (N:P) ratios (less than 4:1, compared to a range of 8:1 to 29:1 for the other tributary sites, table 4; values greater than 7:1 indicate that phosphorus is the limiting nutrient).

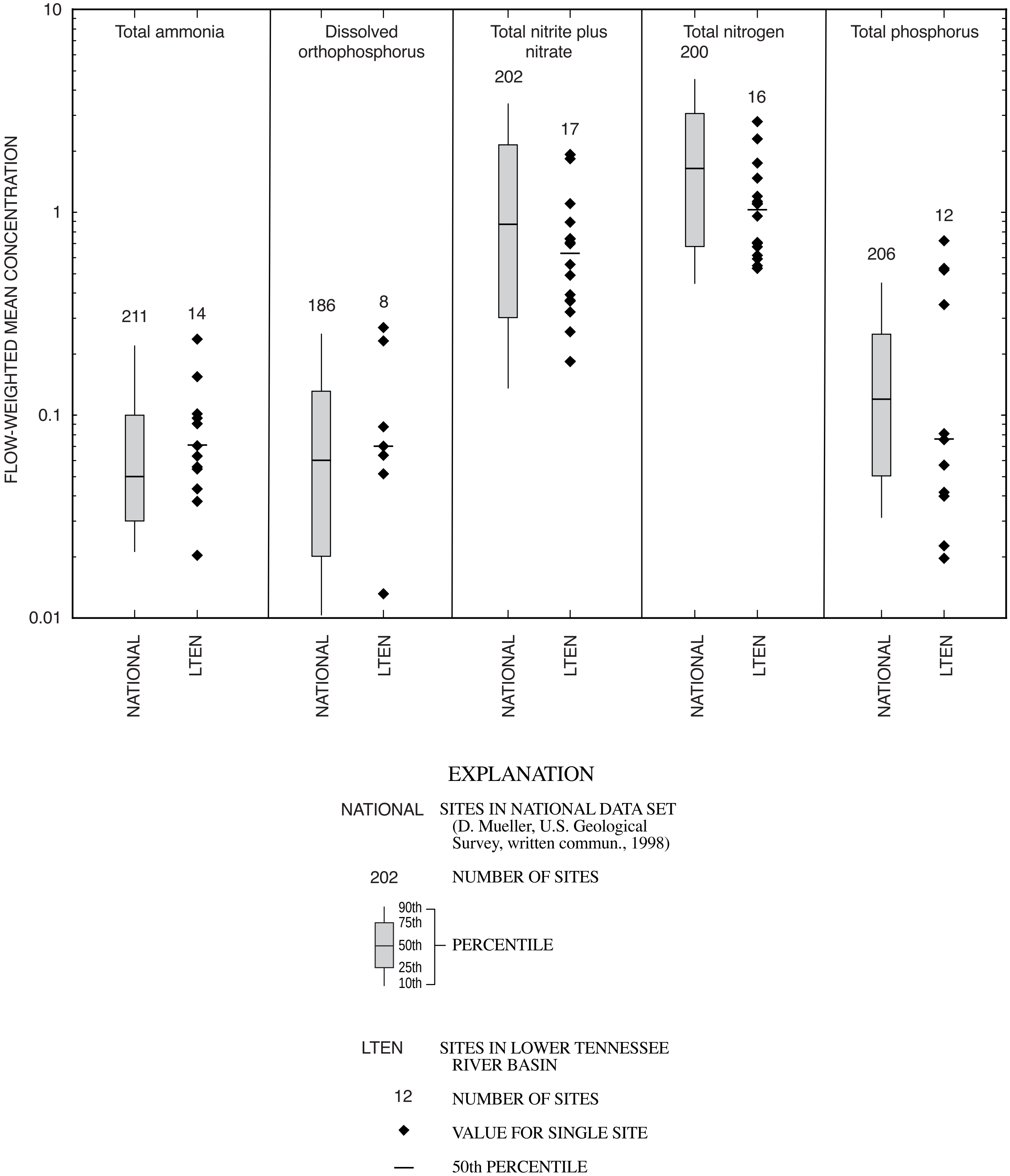


Figure 16. Comparison of distribution of flow-weighted mean concentrations at lower Tennessee River Basin sites with national distribution.

Furthermore, inflow from these tributaries appears to cause a decreasing trend of N:P ratio along the main stem of the Tennessee River (27:1 at site 17, Tennessee River at South Pittsburg, compared with 12:1 at site 15 near the mouth), towards a less phosphorus-limited system.

Although water-quality criteria limiting nutrient influx have not been established, the National Technical Advisory Committee (1968) recommendation of 0.05 mg/L phosphorus for waters entering impoundments can be compared with the annual estimate of phosphorus flow-weighted mean concentrations at each monitoring site (table 9). The annual flow-weighted mean concentrations exceeded the recommended value at five of the eight tributary sites and three of the four main stem Tennessee River sites. Furthermore, these phosphorus concentrations exceeded the value of 0.1 mg/L, recommended by Mackenthun (1969) to prevent algal blooms in streams, by threefold or more at four of the eight tributary sites. The phosphorus influx to consider for evaluating ecological risk to water bodies may not be the annual mean influx, however, but rather the influx during spring and summer, which is the season of algae and macrophyte growth. Mean rates of influx for this period are different from the mean annual rate, due to seasonal variation in loading rate (illustrated in fig. 17).

Estimates of flow-weighted mean concentration of nutrients during the period March-July are reported in table 9 along with the annual estimates to illustrate differences in annual influx and seasonal influx. Estimates of seasonal flow-weighted mean concentration were about 50 percent lower than annual estimates; the range for the tributary sites was from 0.28 mg/L (site 2, Buffalo River near Flat Woods) to 1.2 mg/L (site 1, Clarks River at Almo) of total nitrogen, and from less than 0.01 mg/L (site 9, Elk River below Tims Ford Dam) to 0.18 mg/L (site 5, Duck River at Williamsport) of total phosphorus. The seasonal estimate of total phosphorus flow-weighted mean concentration was above the value of 0.05 mg/L, recommended for water entering impoundments, at four of the eight tributary sites, but was much closer to this value than the corresponding annual estimates.

Whereas water-quality impairment from eutrophication is related to excessive nutrient influx over a period of weeks or months, other types of impairment (for example, acute toxicity of ammonia) result from short-term fluctuations of concentrations. The estimates of annual or seasonal yield and flow-weighted mean concentration are not useful for addressing this latter type of water-quality impairment. Information about the spatial distribution of ammonia concentration during prolonged periods of low streamflow, similar to the information presented in figure 9A,

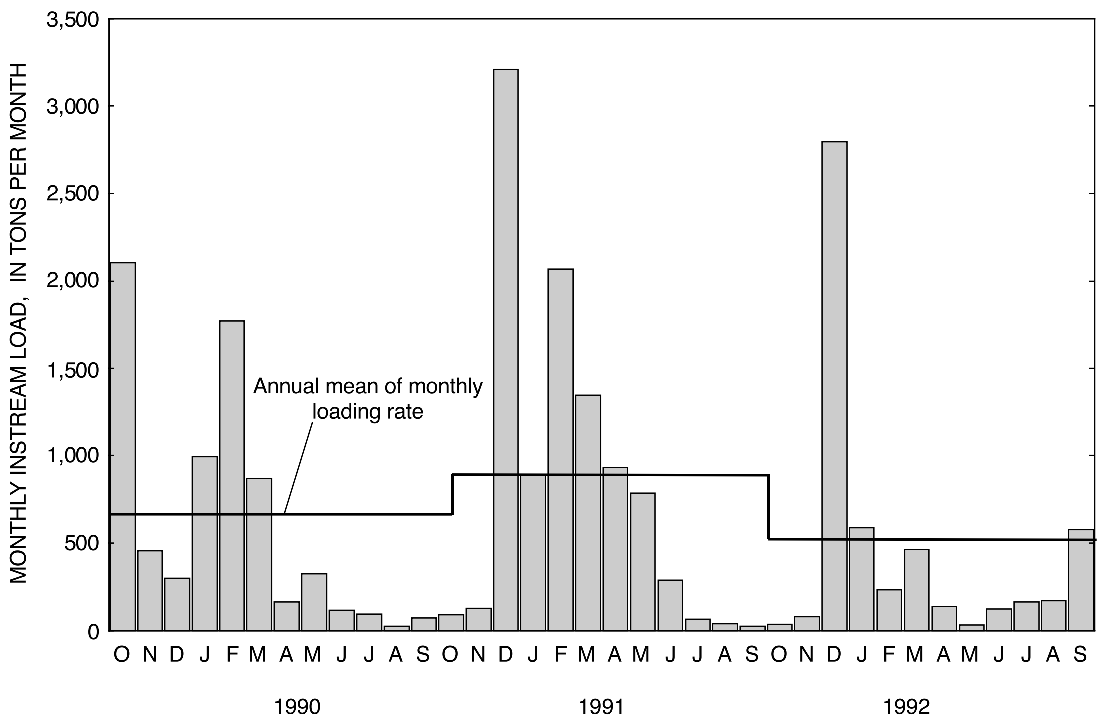


Figure 17. Monthly instream load of total nitrogen at Elk River near Prospect, Tennessee, water years 1990-92.

would be more useful in assessing where impairment caused by ammonia toxicity is likely to occur.

Sediment yield estimates ranged from 65 (tons/mi^2)/yr (site 2, Buffalo River near Flat Woods) to 260 (tons/mi^2)/yr (site 8, Shoal Creek at Iron City) for the three tributary monitoring basins for which data were available, and from 17 to 26 (tons/mi^2)/yr for the two main stem sites (Tennessee River at South Pittsburg and Tennessee River at Pickwick Landing Dam, respectively, table 9). Lower sediment yields for the main stem sites compared with the tributary sites is probably due to sediment deposition in the main stem of the Tennessee River and tributary embayments along the main stem. The sediment yield estimates for the tributary sites are lower than the estimate from Trimble and Carey (1984) of 800 (tons/mi^2)/yr for basins in central and eastern Tennessee.

Comparison of Inputs from Nutrient Sources with Nutrient Yields

The estimates of nitrogen and phosphorus loading from major sources varied widely among the 11 tributary basins for which estimates were prepared, and are expected to represent the variability in these sources across the LTEN River Basin (figs. 14 and 15). Of the sources of land-phase nitrogen inputs (atmospheric deposition, fertilizer application, and livestock waste), livestock waste contributed the largest input in about two thirds (7 out of 11) of the load-computation basins (table 3 and fig. 14), and fertilizer application contributed the largest input in the remaining four basins (sites 1, 2, 7, and 9). Estimates of nitrogen input from fertilizer application were the most variable spatially among the land-phase nitrogen inputs, ranging from 1.5 to 23 (tons/mi^2)/yr. Atmospheric deposition estimates varied the least from basin to basin, ranging from 1.6 to 2.0 (tons/mi^2)/yr. The balance of land-phase nitrogen inputs on agricultural lands (fertilizer application plus nitrogen fixation plus livestock waste minus harvest) ranged from 2.4 to 15 (tons/mi^2)/yr of nitrogen (table 3). Wastewater discharge contributed between 0 and 0.61 (tons/mi^2)/yr of nitrogen (table 3); wastewater input of nitrogen is therefore equivalent to a relatively small part (less than 27 percent) of the annual instream nitrogen load, whereas the contribution of wastewater discharge during low flow is much more significant (fig. 9B).

The estimates of inputs can be compared and correlated with **export** yields; significant correlations between estimates of inputs and exports might be useful as predictive tools for instream water quality where monitoring data are not available. Export of nitrogen correlated moderately well with the balance of land-phase inputs to agricultural lands for the tributary sites (fig. 18). For example, nitrogen export was highest [3.5 (tons/mi^2)/yr] for site 12 (Town Creek near Geraldine), for which the balance of agricultural land-phase input was also the highest [15 (tons/mi^2)/yr]. Nitrogen export was low [1.0 (tons/mi^2)/yr] for site 2 (Buffalo River at Flat Woods), for which the balance of agricultural land-phase input was correspondingly low [3.2 (tons/mi^2)/yr, the second lowest]. The matrix of Pearson correlation for nutrient input, percentage land use and land cover, and export is shown in table 10. Among all the estimated nitrogen inputs and land-use types, there were significant correlations between the balance of agricultural land-phase input and export ($r = 0.65$, $p = 0.03$, shown in fig. 18) and between percentage pasture land and export ($r = 0.67$, $p = 0.03$). Nonparametric rank correlation analysis showed similar results, addressing the concern that the large values of export, livestock-waste input, and percentage pasture land at site 12 (Town Creek near Geraldine) might skew the correlation results. Correlation of wastewater discharge with nitrogen export was poor ($r = 0.06$), and contrasts with the significant correlation ($r = 0.71$, $p = 0.01$, fig. 9A) between wastewater discharge and nitrogen concentration during low streamflow. The poor correlation between wastewater discharge and annual export was expected, however, as wastewater discharge is a small fraction compared with annual instream nitrogen load.

The relation between total nitrogen export and the balance of agricultural land-phase input is shown in figure 18, with a line fitted to the data points using a simple linear regression. The y-intercept of the fitted line, 0.95 (ton/mi^2)/yr, could be interpreted as the expected nitrogen export from a watershed without agricultural inputs. The results from sites 4 and 9 (Duck River below Normandy Dam and Elk River below Tims Ford Dam, respectively) represent the largest residuals from the regression line, and may reflect the effects of the reservoirs on instream delivery processes. Large residuals for sites 7 and 10 (Shoal Creek at Highway 43 and Elk River near Prospect, respectively) could be due to a difference in the land-water delivery process (such as different soil-drainage characteristics) in the watersheds for these sites, as compared with the other sites in the data set.

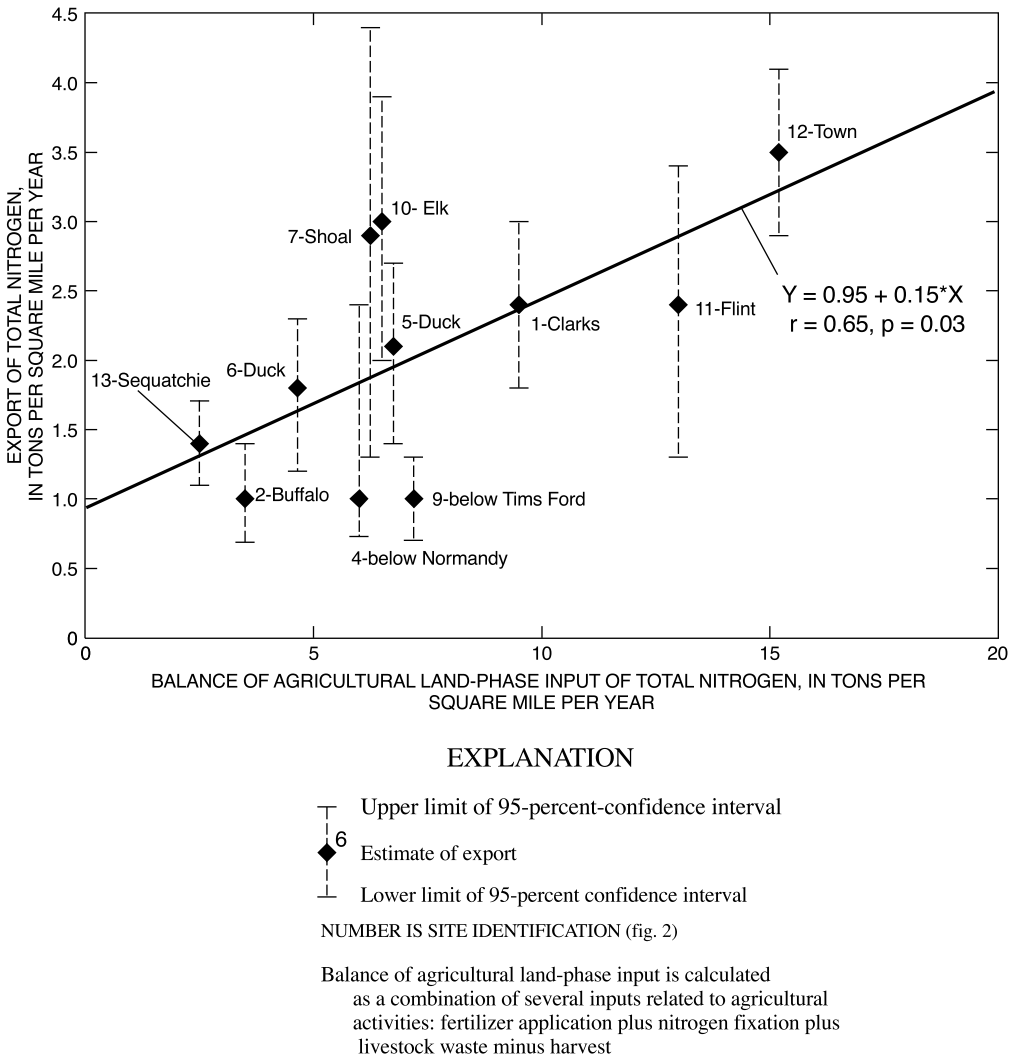


Figure 18. Relation of total nitrogen export to the balance of land-phase inputs to agricultural land.

Among the sources of land-phase phosphorus inputs (fertilizer application and livestock waste), livestock waste contributed most of the total input in 8 out of the 11 tributary basins (fig. 15 and table 4), and fertilizer application contributed most in the basins for sites 1, 2, and 7 (Clarks River at Almo, Buffalo River near Flat Woods, and Shoal Creek at Highway 43, respectively). The balance of agricultural land-phase inputs of phosphorus ranged from 0.87 (tons/mi^2)/yr (site 13, Sequatchie River at Valley Road) to 4.7 (tons/mi^2)/yr (site 12, Town Creek near Geraldine). Wastewater discharge contributed from 0 to 0.14 (tons/mi^2)/yr, equal to as much as 1.2 times (site 9, Elk River below Tims Ford Dam) the corresponding phosphorus export from the basin.

In contrast with nitrogen, phosphorus export did not correlate well with any estimated inputs or land-use types (table 10). Phosphorus export was highest [1.1 and 0.93 (tons/mi^2)/yr] for sites 6 and 5 (on the Duck River) and at site 10 [0.89 (tons/mi^2)/yr, Elk River near Prospect]; however, estimates of inputs and percentage of each land-use type at these sites were not in the high end of respective ranges (table 4). The influence of a known natural source, outcrop of phosphatic limestone formations of the brown phosphate district, in the lower Duck and lower Elk River Basins (fig. 11A and 11E) was examined by removing sites 5, 6, and 10 from the correlation data set. The significant correlations between phosphorus export and wastewater discharge ($r = 0.97$) and between phosphorus export and fertilizer application ($r = 0.94$) for this

Table 10. Pearson correlation coefficients among 1992 export, inputs, and other factors

[n, number of observations in the correlation data set; --, not estimated; **, correlation significant (p-value < 0.05); sites with known natural source of phosphorus (excluded from n=5 data set) are sites 5, 6, and 10 (Duck River at Williamsport, Duck River above Hurricane Mills, and Elk River near Prospect, respectively)]

Input, land use, or other factor	Correlation coefficient (r)		
	Total nitrogen export (n = 11)	Total phosphorus export	
		All sites (n = 8)	Excluding sites with known natural source (n = 5)
Wastewater discharge	0.06	-0.24	0.97**
Atmospheric deposition	.29	--	--
Fertilizer application	.17	-.27	.94**
Livestock waste	.57	.40	-.06
Balance of agricultural land-phase input [a]	.65**	-.14	.70
Percent forest land	-.41	-.06	-.80
Percent cultivated land	.14	-.42	.82
Percent pasture land	.67**	.46	.85
Percent urban land	.18	-.04	.90**
Site type (riverine = 1, flow-regulated = 2)	-.58	-.52	-.53

[a] Calculated for nitrogen as the sum of inputs from fertilizer application and nitrogen fixation and livestock waste, minus removal as crop harvest; calculated for phosphorus as the sum of inputs from fertilizer application and livestock waste, minus removal as crop harvest.

trimmed data set (table 10) should be interpreted with caution because of the small number of sites (n = 5). Two related conclusions are suggested: (1) inputs from wastewater discharge and fertilizer application are strongly linked with instream transport of phosphorus in watersheds where the natural phosphorus source is not present and (2) the natural source, where it is present, might be the largest contributor to instream transport of phosphorus. A regression equation was not developed between total phosphorus export and any of these sources due to the small number of sites in the trimmed data set.

That the correlation between phosphorus export and percentage of pasture land (r = 0.85) is very different from the correlation between export and livestock waste (r = -0.06) is difficult to explain because the estimate for livestock waste is partly derived from distribution of pasture land; however, the estimate for livestock waste also accounts for distribution of animal populations, and, because of feedlot operations, this distribution may differ substantially from the distribution of pasture land. The apparent contradiction in correlation results might indicate that pasture land influences instream loads of phosphorus through processes apart from runoff from land areas with livestock waste, or that some controlling factor is coincidentally correlated with percentage pasture land.

The spatial pattern of estimated inputs and exports may be influenced by several factors other than sources and transport processes. These other factors, some of which are listed below, may confound meaningful interpretation of the correlation results:

1. Inaccuracy in estimates of export caused by sparseness of monitoring data and lack of flow-stratified sampling for load estimation (discussed in Appendix B).
2. Low variability in export, which reduces the ability to detect spatial patterns. For example, the relatively low variability in nitrogen export (only one half of an order of magnitude) may reflect conditions throughout the basin, or may result from network bias (lack of representation of the full range of conditions in the basin or lack of sufficiently homogeneous basins). Phosphorus export, ranging through almost two orders of magnitude, was more variable than was nitrogen export.
3. Other sources of nutrients not quantified in this analysis (such as urban runoff, failing septic

systems, or natural sources) might be responsible for much of the observed variability in export.

4. The pairwise correlation analysis (table 10) allows examination of correlations of export with individual input variables, but does not test the correlation with co-occurrence of variables. The small size of the data set prevented testing combinations of variables using stepwise multiple regression analysis.
5. Regional variability in soil and other geologic factors causes variability in land-water delivery processes and therefore affects the relation between sources (particularly land-phase loads) and export. The influence of regional differences in natural environmental setting on interactions between sources and exports could be examined with a larger set of monitoring sites, provided that the monitoring network was sufficiently stratified by environmental setting (that is, included several watersheds representing each type of environmental setting).

TRENDS OF NITROGEN, PHOSPHORUS, AND SEDIMENT

An objective of this analysis of historical data is to describe temporal trends in nutrient and sediment concentrations during the period 1980-96 and to interpret the trends with respect to changes in sources during this period. Although quantitative data on temporal variation of sources are sparse, a comparison of general information about source changes with observed trends of instream concentration is possible.

Trends of Inputs

The primary sources of nitrogen and phosphorus for which data are available for the LTEN River Basin are wastewater discharge, fertilizer, and livestock waste (tables 3 and 4). The volume of wastewater discharge increased during the period 1980-96 as a result of population growth. Concentrations of nitrogen and phosphorus in wastewater decreased during this period, however, because of legislated control of municipal-effluent quality implemented through construction and upgrading of treatment plants to bring all dischargers to secondary or tertiary treatment standards. Concentrations of phosphorus in wastewater decreased dramatically starting around 1988, when reductions in the phosphate content of commercially-available detergents were made to reduce the phosphorus input to wastewater treatment plants (S. Fishel, Tennessee Department of Environment and Conservation, oral commun., 1997).

Significant changes have occurred in effluent concentration of certain constituents of total nitrogen; specifically in the relative amounts of reduced and oxidized forms of nitrogen. Because the reduced forms of nitrogen (organic nitrogen and ammonia) deplete instream oxygen levels and because ammonia is toxic to fish and aquatic life, advanced treatment processes have focused on converting ammonia and organic nitrogen to nitrate (U.S. Environmental Protection Agency, 1993). These processes have resulted in decreases in effluent loads of ammonia and increases in effluent loads of nitrate.

Changes in stream inputs of nitrogen and phosphorus from fertilizer and livestock waste between 1980 and 1996 are more difficult to estimate, even qualitatively. As with wastewater, these land-phase inputs increased during this period, based on pounds of fertilizer applied and animal census data; however, the extent to which improvements in nonpoint-source controls have offset the increased inputs by reducing delivery of land-phase to stream inputs is impossible to generalize.

Trends of Instream Concentration

Trends of instream concentration of nitrogen, phosphorus, and sediment were quantified with the multivariate log-linear regressions included in Cohn's Estimator program (Cohn, 1988). Trends were estimated by examining the statistical significance of the coefficient on time ($\beta3$ in equation 1). The direction (increasing or decreasing) of significant trends was determined from the sign of $\beta3$. Positive values of $\beta3$ indicate an increasing trend; negative values of $\beta3$ indicate a decreasing trend. Trend results are reported for two separate periods—the period of available record between 1980-96 and a common period of record (last column of table 8).

The trend results for the period of available record constitute a larger data set and span a longer time period, compared with results for the common period of record, and thus are more useful for at-site interpretations of instream trends with respect to trends in sources. The trend results for the common period of record, however, are more useful for comparing results among sites (fig. 19). The common period used for this second set of tests (generally from mid-1980's to mid-1990's) differed slightly among constituents but is consistent for results at all sites for a

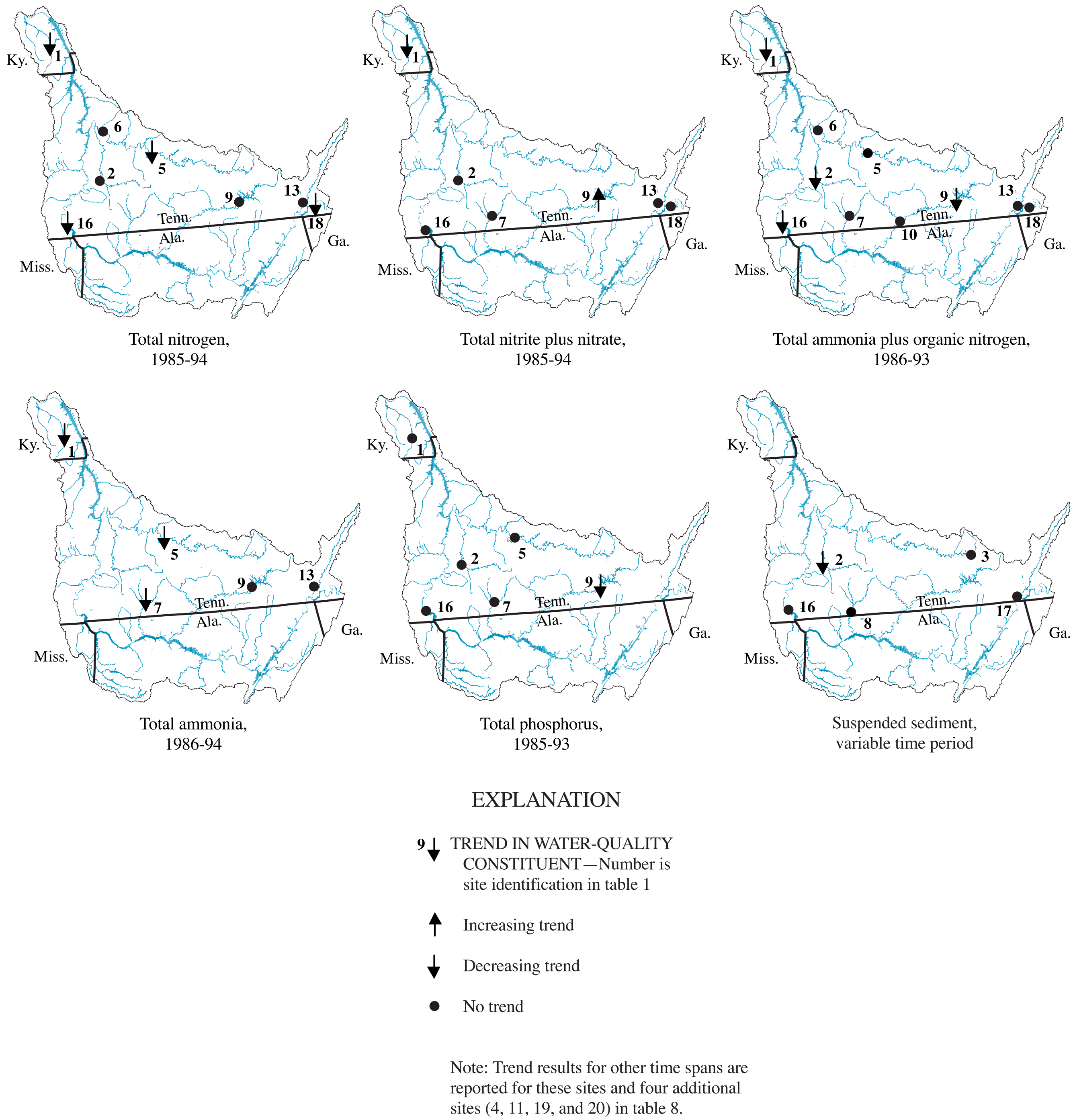


Figure 19. Trends of instream concentrations of nitrogen, phosphorus, and suspended sediment in the lower Tennessee River Basin.

constituent. Trend tests could not be done for a common period of record for suspended sediment, however, because there were too few sites and the periods of available record generally did not overlap.

The time series of concentration residuals (from a regression against flow and season) for selected sites and constituents are shown in figure 20. Use of residuals, rather than actual concentrations, in these displays shows more clearly how concentration varies with time, independent of other influences (season and streamflow). A smoothed curve of the residuals calculated by locally weighted scatter-plot smoothing (LOWESS) is displayed with the residuals to illustrate the trend pattern. The trend estimate from the analysis of the common period of record is also shown on these plots in the inset boxes, for comparison.

All significant trends in nutrient concentrations during the common period of record (mid-1980’s to mid-1990’s) were decreasing trends, except for total nitrite plus nitrate, which increased at site 9 (Elk River below Tims Ford Dam). The constituents for which significant downward trends were most commonly observed were total ammonia and total nitrogen. Sites with decreasing trends in ammonia concentration during the period 1986-94 were also sites which ranked relatively high (compared with the other sites) in wastewater inputs compared to other inputs, and the timeframe of the observed trends spans the period of changes in wastewater loading. These lines of evidence suggest that the ammonia trends at site 1 (Clarks River at Almo), site 5 (Duck River at Williamsport), and site 7 (Shoal Creek at Highway 43) result from decreases in wastewater effluent concentrations. Concentrations of total phosphorus did not decrease during the period 1985-93 at the sites with decreasing ammonia trends, however, as might have been expected considering reductions in wastewater loading of phosphorus during this period.

The common-period trend results for site 18, Tennessee River below Raccoon Mountain, are apparently contradictory (fig. 19); no significant trend is in concentrations of nitrite plus nitrate or ammonia plus organic nitrogen, but a significant decreasing trend exists in total nitrogen concentration, which is calculated as the sum of concentrations of the first two constituents. This discrepancy can be explained by the slightly different time periods used as the common period for each constituent: 1986-93 for ammonia plus organic nitrogen, and 1985-94 for nitrite plus nitrate and for total nitrogen. Decreasing trends for site 18 for all three nitrogen constituents for the period of available record (1981-94, table 8) are reasonable: decreasing trends exist in concentrations of all three constituents.

The trend results include periods other than the common period used for spatial interpretation (table 8). Total ammonia increased at site 15 (Tennessee River at mile 23) during the period 1990-94, dissolved orthophosphorus increased at sites 12 and 19 (Town Creek near Geraldine and Scarham Creek near Kilpatrick) during the period 1988-96, and total nitrogen increased at site 14 (Tennessee River at Highway 60 near Paducah) during the period 1980-84. The increasing trends in dissolved orthophosphorus at the Town and Scarham Creek sites (12 and 19) were not expected, because the period of trend analysis (1988-96) corresponds to a period of many recognized improvements in management of poultry-waste runoff in the watershed for the sites. This suggests that the predominant input of phosphorus in these basins is from another source(s). A separate explanation, however, is that the improvements in source control may have had the desired effect of causing decreases in instream concentrations and loads of total phosphorus and particulate phosphorus, but with a corresponding conversion of part of the particulate-phase phosphorus to dissolved forms (for example, in sediment detention areas), thus causing the increasing trend in dissolved orthophosphorus (Holt and others, 1970). Unfortunately, this hypothesis cannot be tested because of insufficient data for total phosphorus at these sites.

It is important to emphasize that these trend results only describe the net change in concentrations between the start and end of the period of analysis. Temporary fluctuations in concentration, caused by temporary changes in sources, for example, are not detected by these trend tests. These fluctuations are evident, however, in the time series of concentration residuals (fig. 20). The time series and LOWESS-smoothed line of total ammonia and total nitrogen concentrations at site 9 (Elk River at Tims Ford Dam) suggest a temporary decline in the late 1980’s, but then an increase and return to early 1980’s levels, with no net change or trend. This pattern might be caused by increases in sources other than wastewater during this period, superposed on and offsetting declines in wastewater in the early part of the period; or this pattern might correspond with temporary reductions in nonpoint-source loads because of decreased runoff during the drought of 1985-88.

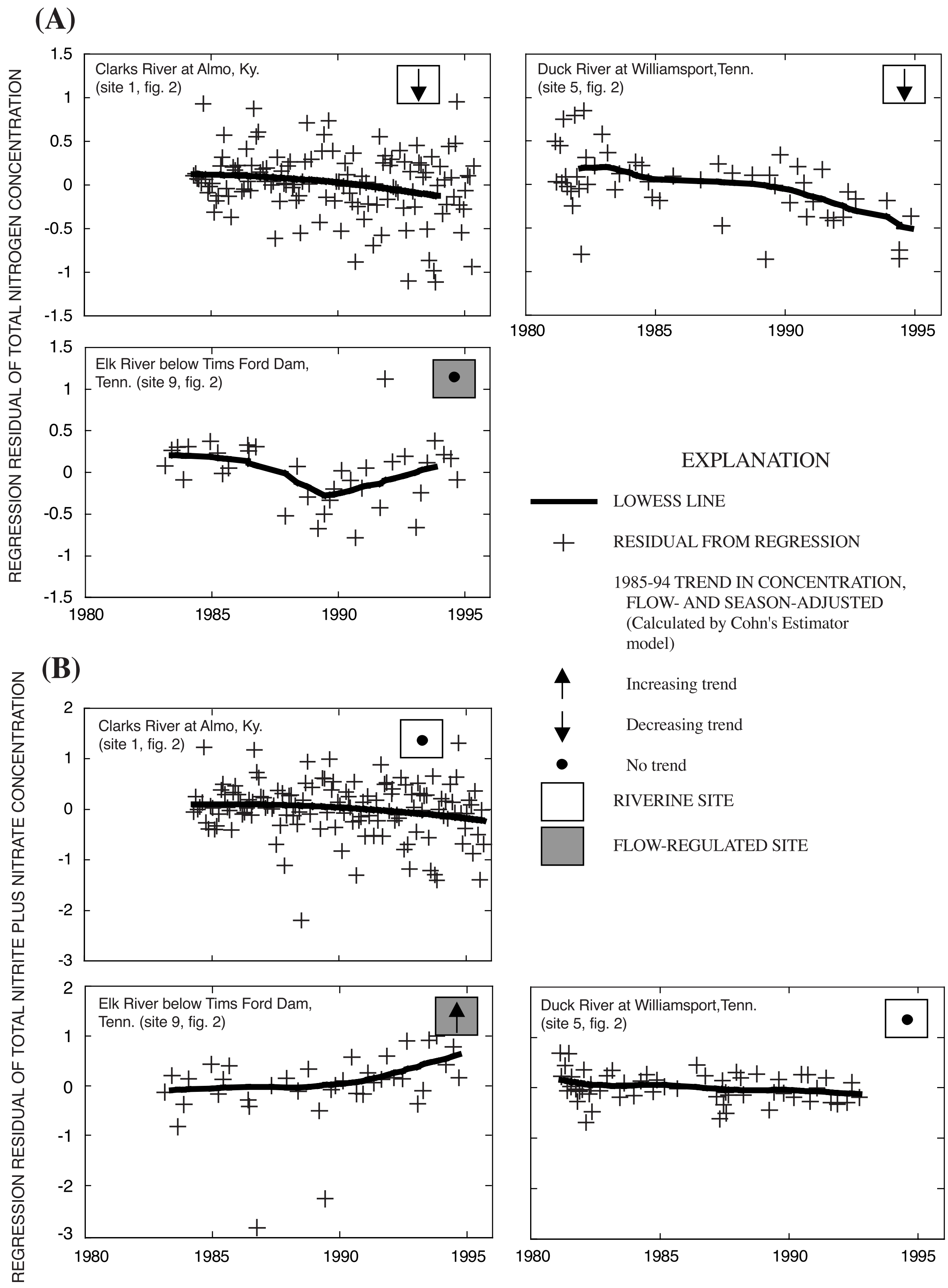


Figure 20. Temporal variation in nutrient concentrations during 1980-96 and model estimate of trend at selected sites in the lower Tennessee River Basin for (A) total nitrogen, (B) total nitrite plus nitrate, (C) total ammonia, and (D) total phosphorus.

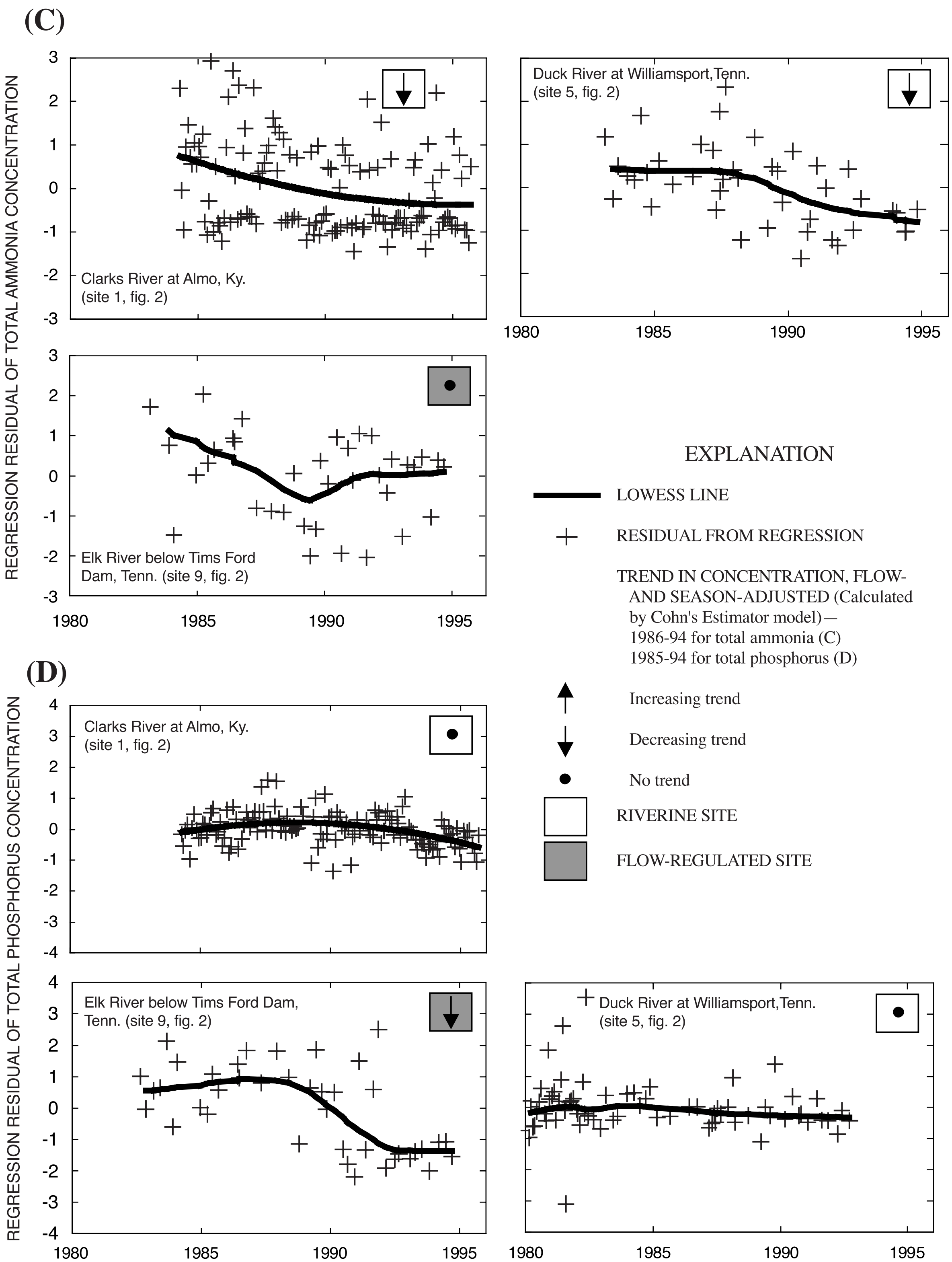


Figure 20. Temporal variation in nutrient concentrations during 1980-96 and model estimate of trend at selected sites in the lower Tennessee River Basin for (A) total nitrogen, (B) total nitrite plus nitrate, (C) total ammonia, and (D) total phosphorus—Continued.

CONCLUSIONS

Implications for Data Collection and Analysis

By their nature, ambient water-quality monitoring programs cover large geographic areas and operate over long time periods. This broad spatial and temporal coverage makes them well suited to broad-scale assessment of transport of constituents in a large river basin, but can also restrict interpretations of these data. Resource limitations and logistics in operating a large, long-term monitoring network often force difficult design trade-offs, favoring a sampling design that is prescribed more by schedule than by targeting a wide variety of environmental conditions. Use of the data for interpreting constituent transport as a function of environmental conditions is, therefore, hampered. Heterogeneous characteristics of the large watersheds contributing to many of the ambient monitoring sites confound spatial comparisons of input to export; meaningful comparisons require a network of sites draining watersheds that are homogeneous with respect to both natural and human-influenced environmental setting.

Data-collection requirements depend on the water-quality evaluation to be made: the important water-quality indicator for evaluating risk to the ecological health of a receiving water body caused by nutrient overenrichment is nutrient loading rate from its tributaries, rather than concentrations in these tributaries. Estimation of loading rate requires continuous streamflow record at the tributary sampling site and requires a fully stratified sampling program that covers all possible combinations of season and runoff condition. Evaluation of ecological risk may also require estimates of loading rates during the period of the year when growth of aquatic plants responds most rapidly to nutrient influx: the period of long hydraulic-residence time and warm, clear water in the receiving water body. Although the data sets used in this report are sufficiently large for estimating annual loading rates, they are too sparse when stratified by season to allow accurate estimation of loading rate during a specified, critical season. Accurate estimation of transport during a critical season requires targeting sampling efforts to cover the full range of runoff and streamflow conditions during that season. Data from a fully stratified sampling program will also produce more accurate estimates of temporal trends and can be used to distinguish between loading patterns of nonpoint sources and loading patterns of point sources.

Implications for Resource Management

Estimates of 1992 annual flow-weighted mean concentration of total nitrogen ranged from 0.53 to 2.8 mg/L as nitrogen, representing a fivefold difference in instream transport among watersheds in the LTEN River Basin. The smallest estimate was for a minimally developed watershed, and the largest estimate was for a watershed with the largest areal percentages of urban and agricultural land use and largest amounts of wastewater discharge, suggesting that human activity increased exports of total nitrogen by as much as fivefold. The range in estimates of annual flow-weighted mean concentration of total phosphorus, from 0.02 to 0.73 mg/L as phosphorus, represents nearly a fortyfold difference in instream transport among the watersheds. The largest three estimates, 0.73, 0.53, and 0.52 mg/L, probably represent a natural source in those watersheds: the phosphatic limestones of the brown-phosphate districts. The outcrop pattern of these phosphatic limestones may be an important factor to consider as regional boundaries are established for attainable region-specific water-quality criteria for total phosphorus (U.S. Environmental Protection Agency, 1998).

Nutrient overenrichment caused impairment in 37 of the 109 impaired stream segments in the LTEN River Basin in 1996. Impairment is caused by influx of nutrients and growth of algae and aquatic macrophytes during critical periods of the year; therefore, estimates of seasonal flow-weighted mean concentration may be more useful than annual estimates in evaluating ecological risk to water bodies, and in establishing water-quality criteria. Seasonal estimates of flow-weighted mean concentration generally were less than half of the annual estimates, and ranged from 0.28 to 1.2 mg/L total nitrogen, as nitrogen, and from less than 0.01 to 0.18 mg/L total phosphorus, as phosphorus.

Nitrogen from wastewater discharge represents a small part (less than 27 percent) of the annual nitrogen export in 11 tributary basins, and variability in wastewater discharge among basins correlates poorly with annual export. Wastewater discharge may account for a larger part of nitrogen yield during low streamflow, however, and does correlate well ($r = 0.71$, $p = 0.01$) with total nitrogen concentration during low streamflow. Phosphorus from wastewater discharge represents as much as 1.2 times the annual phosphorus export, and correlates well with annual export except in watersheds with outcrops of the phosphatic limestones.

The estimates of input from other sources (atmospheric deposition, fertilizer application, and livestock waste) cannot be compared as a fraction of export in the same way as for wastewater discharges because these estimates are the land-phase inputs from these sources, rather than inputs directly to the stream channel. The fraction of export contributed by a source may be inferred indirectly based on correlations between inputs and export. The significant correlation ($r = 0.65$, $p = 0.03$) between the estimate of agricultural land-phase input within a watershed and exported nitrogen might mean that these sources contribute to annual instream loads in significant amounts.

Concentrations of total ammonia and total nitrogen decreased during the period 1985-94 at about half of the sites where temporal trends could be tested. The spatial distribution of decreasing trends corresponds with the spatial variation among basins in wastewater input, and the time period of observed trends corresponds to the period of improvements in municipal treatment; thus, decreases in wastewater effluent concentrations of nitrogen might be responsible for the decreasing trend in instream concentrations at these sites.

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Appendixes

Appendix A. Sites where historical water-quality data collected from water year 1980 to 1996 are included in nutrient- and sediment-data analyses, lower Tennessee River Basin

[Period of record represents entire period of record in source data base as of 1996; however, only data since October 1979 were included in data analysis in this report; sites included only in the downstream-variation analyses (DS) are shown only in figs. 10 and 11, all other sites are shown in fig. 2; d246, denotes Duck River and river mile; t5, denotes Tennessee River and river mile; TRM, Tennessee River Mile; DRM, Duck River mile; ADEM-TMN and ADEM-SS, Alabama Department of Environmental Management trend monitoring network and special study, respectively; KDEP-AMP and KDEP-SS, Kentucky Department for Environmental Protection ambient monitoring program and special study, respectively; TDEC-AMN, Tennessee Department of Environment and Conservation ambient monitoring network; TVA-FSN, TVA-VS, and TVA-SS, Tennessee Valley Authority fixed station monitoring network, vital-signs monitoring network, and special study, respectively; USGS-NASQAN and USGS-S, U.S. Geological Survey National Stream-Quality Accounting Network and suspended-sediment network, respectively; ORSANCO-MN, Ohio River Valley Sanitation Commission monitoring network; FCWP-SS, Flint Creek Watershed Project special study; S, seasonal variation in nutrient concentration; Q, variation in nutrient concentration with streamflow; DS, downstream variation in nutrient concentration; IL, annual input loads; EL, annual export loads; T, trend estimation; STORET, STOrage and RETrieval data base of the U.S. Environmental Protection Agency; WATSTORE, WATer STOrage and REtrieval system data base of the U.S. Geological Survey; GSA, digital file from Geological Survey of Alabama; ADEM, digital file from Alabama Department of Environmental Management]

Hydrologic cataloging unit code (for sites 1-20)	Site identification (fig. 2, 10, or 11)	Surface-water station/Site location: Number	Surface-water station/Site location: Name	Agency and monitoring network	River mile	Period of record (water year)	Data analyses included in this report	Source data base
	Site identification (fig. 2)							
06040006	1	PRI038	Clarks River at Almo, Ky.	KDEP-AMP	53.5	1981-95	S,Q,IL,EL,T	STORET
06040004	2	03604000	Buffalo River near Flat Woods, Tenn.	USGS-NASQAN	58.7	1963-95	S,Q,IL,EL,T	STORET
06040002	3	03596000	Duck River below Manchester, Tenn.	USGS-S	265.4	1967-89	EL,T	WATSTORE
06040002	4, d246[a]	001025	Duck River below Normandy Dam, Tenn.	TDEC-AMN	246.9	1981-96	S,Q,DS,IL,EL,T	STORET
06040003	5, d113[a]	001065	Duck River at Williamsport, Tenn.	TDEC-AMN	113.9	1978-95	S,Q,DS,IL,EL,T	STORET
06040003	6, d26[a]	475793	Duck River above Hurricane Mills, Tenn.	TVA-FSN	26.0	1973-95	S,Q,DS,IL,EL,T	STORET
06030005	7	002395	Shoal Creek at Highway 43 near Lawrenceburg, Tenn.	TDEC-AMN	32.2	1982-95	S,QIL,EL,T	STORET
06030005	8	03588500	Shoal Creek at Iron City, Tenn.	USGS-S	22.3	1974-94	EL,T	WATSTORE
06030003	9	001207	Elk River below Tims Ford Dam, Tenn.	TDEC-AMN	133.0	1982-96	S,Q,IL,EL,T	STORET
06030004	10	475796[b]	Elk River near Prospect, Tenn.	TVA-FSN	41.5	1971-95	S,Q,IL,EL,T	STORET
06030002	11	FLCR7	Flint Creek near Falkville, Ala.	FCWP-SS	33.4	1993-96	S,Q,IL,EL,T	GSA
06030001	12	TOWNCREEK15[c]	Town Creek near Geraldine, Ala.	ADEM-SS	14.1	1980-90	S,Q,IL,EL,T	GSA
06020004	13	002375	Sequatchie River at Valley Road, Tenn.	TDEC-AMN	6.3	1988-96	S,Q,IL,EL,T	ADEM
(multiple)	14, t5[d]	03609750	Tennessee River at Highway 60 near Paducah, Ky.	USGS-NASQAN	5	1974-88	S,Q,DS,EL,T	WATSTORE
(multiple)	15, t23[d]	202832	Tennessee River at mile 23, Ky.	TVA-VS	23	1960-95	S,Q,DS,EL,T	STORET

Appendix A. Sites where historical water-quality data collected from water year 1980 to 1996 are included in nutrient- and sediment-data analyses, lower Tennessee River Basin—Continued

Hydro-logic cat-aloging unit code (for sites 1-20)	Site identifi-cation (fig. 2, 10, or 11)	Surface-water station/Site location		Agency and monitoring network	River mile	Period of record (water year)	Data analyses included in this report	Source data base
		Number	Name					
	Site identification (fig. 2)—Continued							
(multiple)	16, t206[d]	03593005	Tennessee River at Pickwick Landing Dam, Tenn.	USGS-NASQAN	206.7	1975 -96	S,Q,DS,EL,T	WATSTORE
(multiple)	17, t418[d]	03571850	Tennessee River at South Pittsburg, Tenn.	USGS-NASQAN	418.2	1967-87	S,Q,DS,EL,T	WATSTORE
(multiple)	18, t444[d]	003315	Tennessee River below Raccoon Mountain, Tenn.	TDEC-AMN	444	1978-96	S,Q,DS,EL,T	STORET
06030001	19	SCARHAMCREEK03[e]	Scarham Creek near Kilpatrick, Ala.	ADEM-SS	7.7	1988-96	T	ADEM
06030001	20	SOUTHSAUTYCK03[f]	South Sauty Creek, Ala.	ADEM-SS	16.7	1988-96	T	ADEM
	Site identification (fig. 10)		**Sites on the Tennessee River main stem (in addition to sites 14-18)**					
	t6	TR-6.0M, and TR-5.0M	Tennessee River at Paducah (TRM 5 and 6)	ORSANCO-MN	5	1971-95	DS	STORET
	t40	CLN132	Jonathan Creek embayment (TRM 40.0)	KDEP-SS	40.0	1990-93	DS	STORET
	t51	CLN130	Blood River embayment (TRM 51.3)	KDEP-SS	51.3	1990-93	DS	STORET
	t85	477403	Kentucky Reservoir (TRM 85.0)	TVA-VS	85.0	1990-96	DS	STORET
	t89	003610	Tennessee River at Shirley’s Light (TRM 89.0)	TDEC-AMN	89.0	1970-95	DS	STORET
	t112	475015	Kentucky Reservoir (TRM 112.0)	TVA-VS	112.0	1960-95	DS	STORET
	t135	003460	Tennessee River (circa TRM 135)	TDEC	135	1960-95	DS	STORET
	t189	003455	Tennessee River (TRM 189.9)	TDEC	189.9	1990-95	DS	STORET
	t207	476799	Pickwick Forebay (TRM 207.3)	TVA-VS	207.3	1981-96	DS	STORET
	t230	016923	Pickwick Reservoir (TRM 230.0)	TVA-VS	230.0	1960-96	DS	STORET
	t260	016912	Tennessee River upstream from Wilson Dam (TRM 260.8)	TVA-VS	260.8	1960-96	DS	STORET
	t277	016900	Tennessee River upstream from Wheeler Dam (TRM 277.0)	TVA-VS	277.05	1960-95	DS	STORET
	t295	017009	Tennessee River/Wheeler Lake below Fox Creek (TRM 295.87)	TVA-VS	295.87	1960-95	DS	STORET
	t307	017012	Tennessee River/ Wheeler Lake (TRM 307.52, near Decatur)	TVA-VS	307.52	1960-91	DS	STORET
	t350	017261	Tennessee River/Guntersville Lake at Honey Bluff (TRM 350.0)	TVA-VS	350.0	1980-96	DS	STORET

Appendix A. Sites where historical water-quality data collected from water year 1980 to 1996 are included in nutrient- and sediment-data analyses, lower Tennessee River Basin—Continued

Hydro-logic cat-aloging unit code (for sites 1-20)	Site identifi-cation (fig. 2, 10, or 11)	Surface-water station/Site location		Agency and monitoring network	River mile	Period of record (water year)	Data analyses included in this report	Source data base
		Number	Name					
	Site identification (fig. 10)—Continued		**Sites on the Tennessee River main stem (in addition to sites 14-18)—Continued**					
	t375	017522	Tennessee River/Guntersville Res at Mink Creek (TRM 375.2)	TVA-VS	375.2	1980-96	DS	STORET
	t396	017101	Tennessee River/Guntersville Res at Coffee Ferry (TRM 396.8)	TVA-VS	396.8	1971-91	DS	STORET
	t425	476344	Tennessee River/Nickajack Reser-voir (TRM 425.5)	TVA-VS	425.5	1980-95	DS	STORET
	t430	003325	Tennessee River below Hales Bar Light (TRM 430.7, Nickajack Reservoir)	TDEC-AMN	430.7	1981-95	DS	STORET
	t433	476239	Tennessee River/Nickajack Reser-voir (TRM 433.0)	TVA-VS	433.0	1970-91	DS	STORET
	Site identification (fig. 11)		**Sites on the Duck River main stem (in addition to sites 4, 5, and 6)**					
	d8	001135	Duck River at Waverly Waterworks Intake (DRM 8.0)	TDEC-AMN	8	1970-85	DS	STORET
	d133	001050	Duck River (DRM 133.92)	TDEC-AMN	133	1960-85	DS	STORET
	d181	001040	Duck River (DRM 181.0)	TDEC-AMN	181.0	1960-85	DS	STORET
	d221	001030	Duck River (DRM 221.41)	TDEC-AMN	221.41	1960-85	DS	STORET
	d249	NORMANDY01	Normandy Reservoir at the Dam (DRM 249)	TDEC-SS	249	1991-92	DS	STORET
	d252	476244	Normandy Reservoir - Riley Creek (DRM 252.0)	TVA-SS	252.0	1980-95	DS	STORET
	d259	476172	Normandy Reservoir - Anthony Branch (DRM 259.4)	TVA-SS	259.4	1971-92	DS	STORET
	d262	476429	Normandy Reservoir (DRM 262.0)	TVA-SS	262.0	1981-95	DS	STORET
	d265	TN001019	Duck River at Powers Bridge (DRM 265.5)	TDEC-SS	265.5	1991-92	DS	STORET

[a] Site has an additional identification in figure 11, including river mile.
[b] Site is a composite of site 475796 (river mile 41.5) and site 477330 (river mile 36.5).
[c] Station number in ADEM study is t5.
[d] Site has an additional identification in figure 10, including river mile.
[e] Station number in ADEM study is sc3.
[f] Station number in ADEM study is ss3.

Appendix B. Limitations of instream load estimates

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Most of the nutrient and sediment water-quality data used in this assessment are from monitoring networks that were not designed for estimating transport. This section examines the validity of load estimates from these data sets by evaluating the issues of sampling error caused by sparse data and sampling bias, the suitability of the data sets to Cohn’s Estimator model assumptions, and calibration error.

Successful calibration of a regression model requires a minimum number of observations for each regression variable—a general rule of thumb for data sufficiency is 10 observations for each variable (or regression coefficient), with at least 20 percent of the observations above the minimum reporting level, or MRL (T.A. Cohn, U.S. Geological Survey, written commun., 1995). This data-sufficiency criterion translates to a minimum of 70 observations for the seven-parameter regression analysis in Cohn’s Estimator model. This requirement was relaxed for this application because many of the data sets had fewer than (in some cases, less than half) the prescribed 70 observations; the accuracy of the load estimates for these data sets is expected to be lower. The estimates of dissolved orthophosphorus at site 11 (Flint Creek near Falkville) are subject to substantial error because fewer than 20 percent of observations were above the MRL.

The data sets are relatively unbiased with respect to season of sampling (fig. B1), because samples were collected on a quarterly basis. Quarterly sampling leaves to chance the representation of high flow events: the hydrologic condition during which a large percentage of transport at riverine sites occurs for many nutrient species. Examination of the distribution of nutrient samples within the streamflow distribution (fig. B2) shows that the data sets are biased against higher streamflows (the 0-10 deciles of streamflow). The under-representation of higher streamflows, especially noticeable at site 6 (Duck River above Hurricane Mills) among the riverine sites, reduces the accuracy of model calibration for high streamflows, and thus substantially reduces the accuracy of load estimates.

Regression results were examined for two standard assumptions in least squares theory (Draper and Smith, 1981): normality of residuals and constancy in error variance throughout the range of values of regression variables (homoscedasticity). These assumptions were satisfied in only about half of the data sets examined, which leads to uncertainty that the log-linear regressions were able to adequately model constituent transport from these data. Data sparseness and sampling bias may contribute to this problem.

The calibration error statistics of Cohn’s Estimator regression models can be used as a partial indication of model accuracy and precision, although these statistics cannot account for the errors introduced by sampling bias, data sparseness, and data characteristics that do not match model assumptions. The coefficient of determination, r^2, represents the amount of variance in the concentration data that is explained by the regression variables; therefore, the value of r^2 is a measure of the fit of the regression model to the data. A high value of r^2 indicates that the regression equation can estimate daily concentration, and thus daily and annual load, with a high degree of accuracy. The standard error, s, is the estimate of standard deviation about the regression. The smaller the value of s, the more precise the estimates of daily concentration and load. The upper and lower bounds of the 95-percent confidence interval for each load estimate are calculated from s, and are similar measures of the precision of the estimate given the values of the independent variables. The values of r^2 ranged from 0.09 to 0.78, and the values of s (log units) ranged from 0.20 to 1.55. Although load estimates are reported for all data sets, regardless of values of r^2 and s, the estimates from data sets with small r^2 and large s are probably less accurate.

Despite these limitations, the accuracy of the estimates of instream load presented in this report are considered to be the best possible based on the available data. The model-calculated errors in individual estimates generally are less than differences among sites for a single year, and among years with different hydrologic conditions (wet, dry). Therefore, interpretations with these data of broad spatial patterns of instream load and comparison of instream load to input are considered valid.

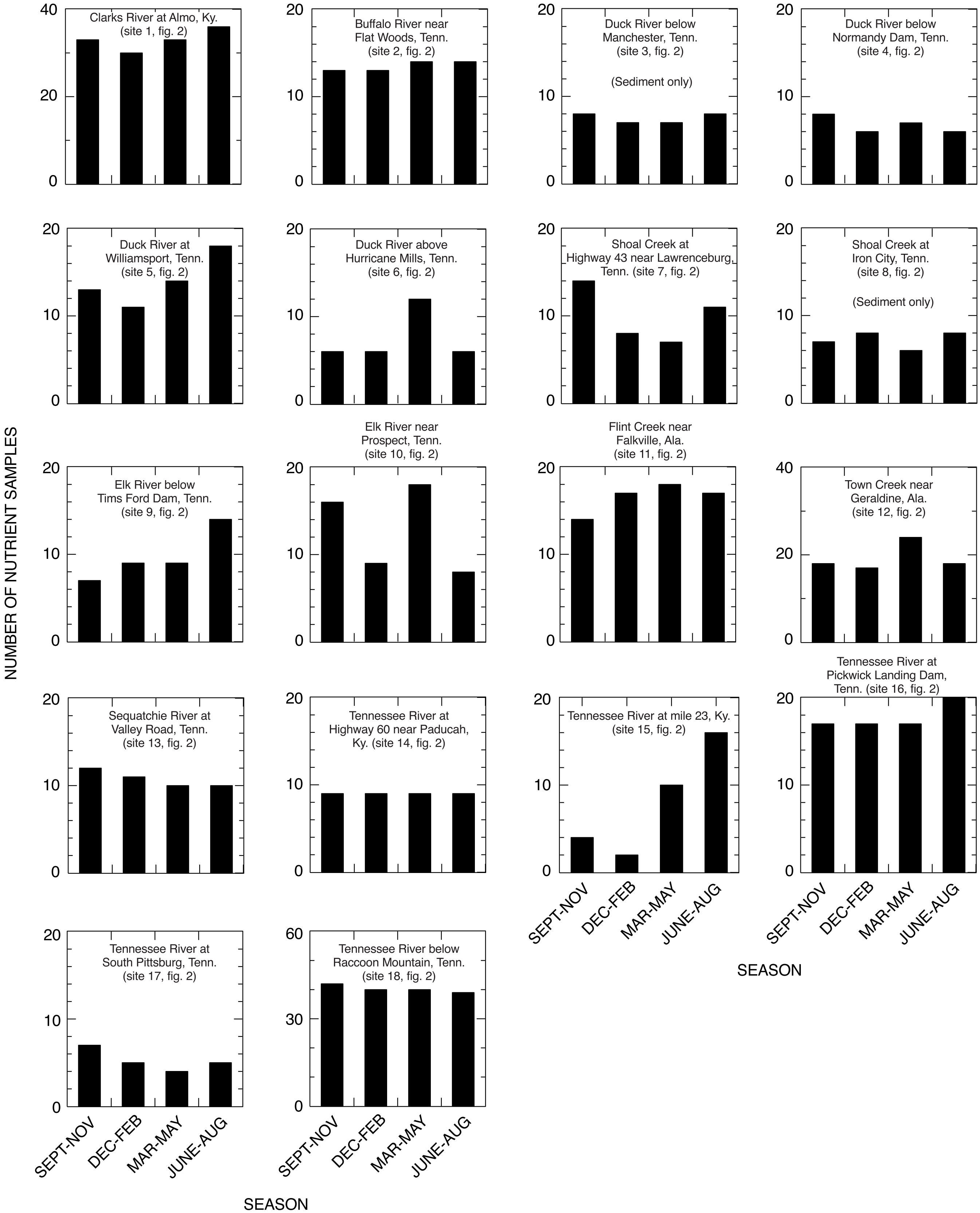

Figure B1. Distribution of nutrient samples within season classes for load-computation sites in the lower Tennessee River Basin, 1980-96.

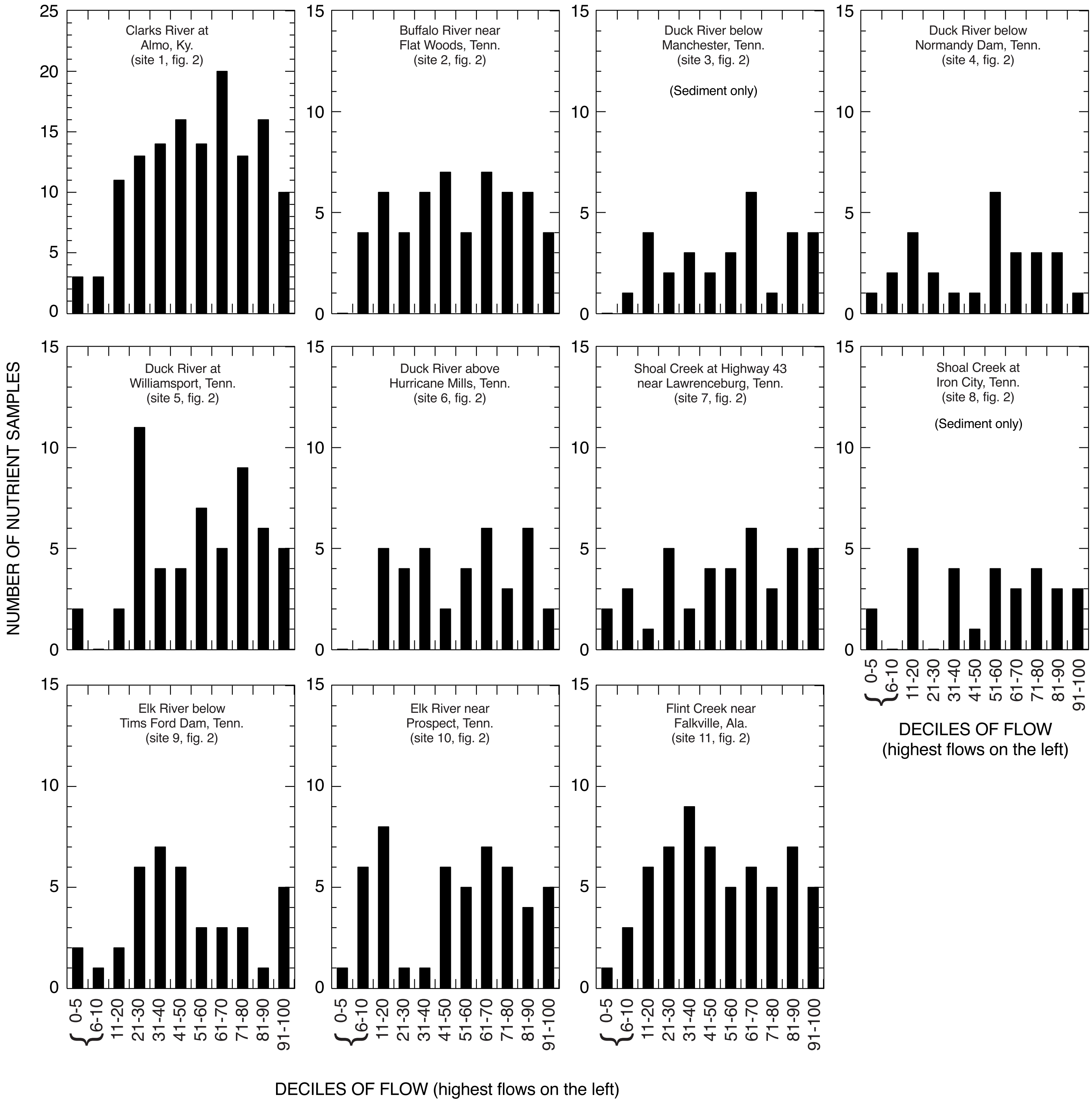

Figure B2. Distribution of nutrient samples within decile-flow classes for load-computation sites in the lower Tennessee River Basin, 1980-96.

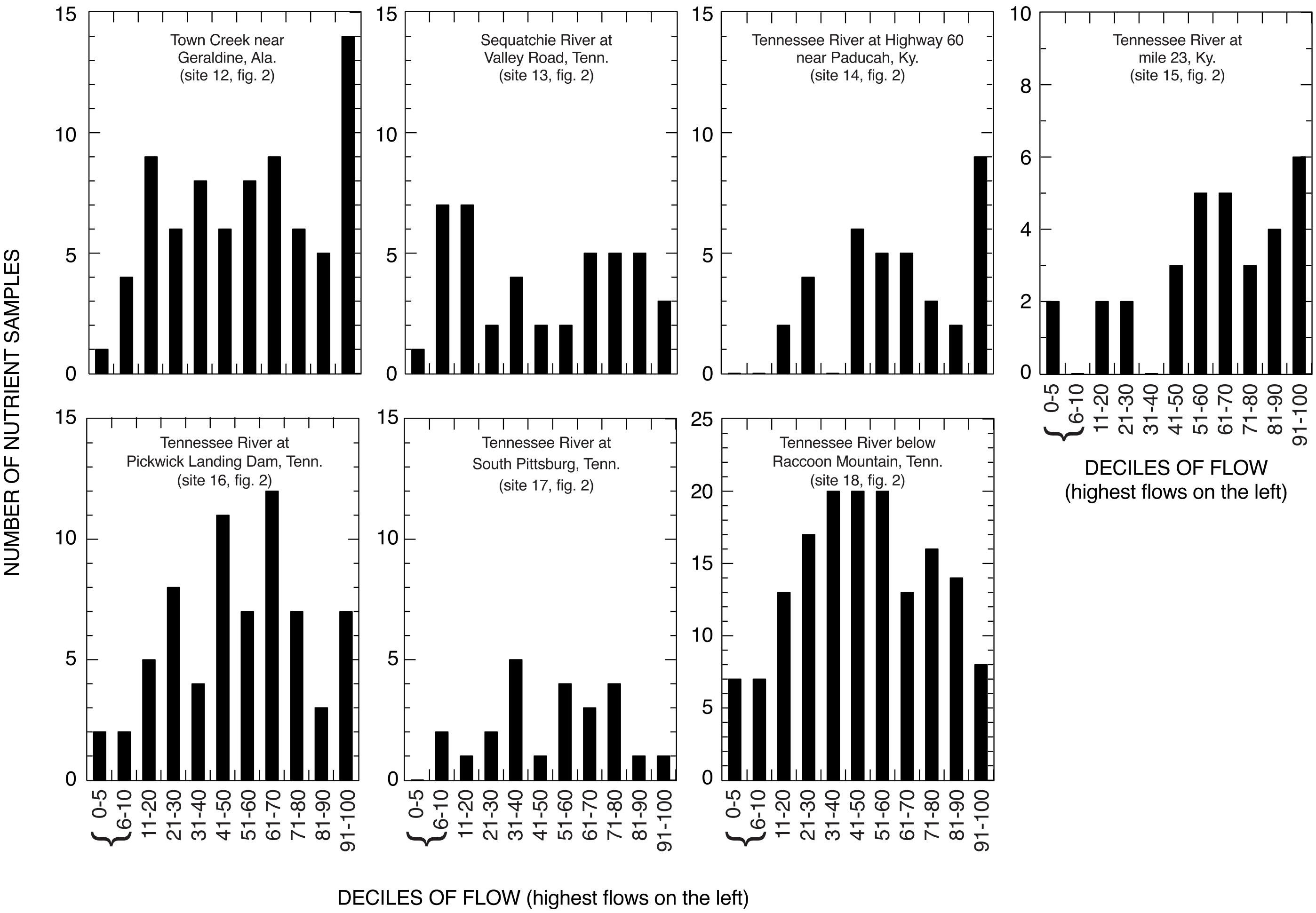

Figure B2. Distribution of nutrient samples within decile-flow classes for load-computation sites in the lower Tennessee River Basin, 1980-96—Continued.

Appendix C. Methods for quantifying inputs of nitrogen and phosphorus from point and nonpoint sources

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Wastewater Discharge

Nitrogen and phosphorus inputs from wastewater discharge were calculated from effluent monitoring data reported to State agencies by permitted wastewater dischargers in the LTEN River Basin. State agencies provided discharger-reported monitoring data (effluent-quality sampling data and effluent flow-measurement data for 1992 or 1995) and Standard Industrial Codes (SIC) for 729 permitted wastewater dischargers (J. Hughes, TDEC, written commun., 1998; M. Rief and T. Cleveland, ADEM, written commun., 1998; V. Prather, KDEP, written commun., 1998; G. Odom, MDEQ, written commun., 1998). Annual mean concentrations of total nitrogen and total phosphorus were estimated from self-reported concentrations or, where complete data were not available, were estimated using one of the following methods.

Where ammonia-nitrogen (NH_3-N) concentration data were reported but total nitrogen (TN) data were lacking, a regression equation was used to calculate TN from NH_3-N. The regression equation was developed from more than 800 observations of effluent concentrations from municipal wastewater treatment plants in Virginia and North Carolina, and thus applies only to municipal wastewater. This equation took the form:

$$TN = 11.97 + 0.55\,(NH_3\text{-}N) \qquad (2)$$

where concentrations are given in milligrams per liter, as nitrogen (McMahon and Lloyd, 1995, p. 70-71).

In the absence of ammonia-nitrogen and total nitrogen concentration data, the average value of 15 mg/L, as nitrogen, was assumed for total nitrogen concentration of municipal wastewater effluent. In the absence of phosphorus data, a concentration of 3.5 mg/L, as phosphorus, was assumed for total phosphorus concentration of municipal wastewater effluent (S. Fishel, TDEC, oral commun., 1998). Values from literature were used for industrial wastewater when data were lacking. National Oceanic and Atmospheric Administration (1993) provides tables with average wastewater effluent concentrations of total nitrogen and total phosphorus based on the type of industry and the SIC of the facility.

Nutrient loads were estimated as the product of effluent annual mean concentration (estimated or measured) and effluent annual mean discharge (estimated or measured). Effluent discharge data were obtained from self-reported information from 264 of the 729 dischargers in the LTEN River Basin (representing the 264 sites for which effluent discharge data were available in digital format). At these sites, the annual mean discharge for calendar year 1992 (or 1995 in some cases) was calculated from daily, monthly, or semi-annual effluent discharge measurements. Of the 264 dischargers with digital discharge data, 64 were classified as major dischargers [that is, they discharged more than 1 million gallons per day (Mgal/d) each, or were industrial facilities with specific process wastewater of concern]. These 64 major dischargers contributed 13,000 Mgal/d (90 percent) of the total wastewater discharge, 9,000 tons/yr (68 percent) of the nitrogen load, and 640 tons/yr (83 percent) of the phosphorus load from all 264 dischargers.

Most of the remaining unestimated discharges (465 sites, fig. 4) are small domestic and commercial dischargers, such as trailer parks and schools, discharging less than 0.1 Mgal/d each. The contributions of discharge and nutrient load from these dischargers should be negligible in comparison with the contributions from the 264 estimated dischargers (S. Fishel, TDEC, written commun., 1998).

Atmospheric Deposition

Deposition data were obtained from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), a national system of precipitation chemistry monitoring stations operated in cooperation between State agricultural experiment stations, USGS, U.S. Department of Agriculture, and numerous other governmental and private entities. Data from several NADP/NTN monitoring stations in proximity to the LTEN River Basin were selected to calculate atmospheric deposition calculations: these included data from Dixon Springs Agricultural Center, Illinois (IL63); Land between the Lakes, Kentucky (KY38); Walker Branch Watershed, Tennessee (TN00); Hatchie National Wildlife Refuge, Tennessee (TN14); and Wilburn Chapel, Tennessee (TN98). Deposition data were retrieved for each of these NADP/NTN monitoring stations for 1992 to coincide with the most recent data for other sources.

Atmospheric deposition of total nitrogen was calculated as the sum of nitrate wet and dry deposition and ammonia wet deposition. Nitrate dry deposition rates were calculated from nitrate wet deposition rates, by multiplying the wet values by a dry/wet deposition ratio determined by Sisterson (1990). Because high-elevation (> 610 meters) terrain and urban areas were of very limited areal extent in the LTEN River Basin, nitrate droplet deposition, nitrate urban wet deposition, and nitrate urban dry deposition were assumed to be negligible and were not included in the analysis. Organic-nitrogen deposition was not monitored at the NADP/NTN stations and therefore was not included in this analysis; however, monitoring studies in other parts of the Nation (for example, Harned, 1995) indicate that this may be a significant component of wet deposition of nitrogen.

Wet deposition rates for the selected NADP/NTN monitoring stations ranged from 0.33 to 0.68 kilogram per hectare (kg/ha) for ammonia, and from 0.53 to 0.73 kg/ha for nitrate. This variability among stations preempted selection of a single basin-wide average deposition rate for the LTEN River Basin. Instead, the total nitrogen deposition rates calculated for each NADP/NTN monitoring station (in tons per square mile per year) were weighted to each of the tributary basins and major hydrologic units, based on the station's distance to the centroid of each basin and major hydrologic unit.

Fertilizer Application

Estimates of fertilizer inputs to agricultural lands in the LTEN River Basin were calculated using two sources of information: fertilizer sales data and fertilizer application recommendations. County-level estimates of the amount of nitrogen fertilizer sold were computed by Jerald Fletcher (West Virginia University, written commun., 1992), by disaggregating state-level estimates of the amount of fertilizer sold in 1991 (obtained from the National Fertilizer and Environmental Research Center of TVA) to county-level estimates. Disaggregation was done by multiplying the state-level estimates by a ratio of county-to-state expenditures based on the 1987 Census of Agriculture (U.S. Department of Commerce, 1989).

Fertilizer application recommendations were selected after comparing published recommended application recommendations for Tennessee (Savoy and Joines, 1998) and Alabama (Adams and others, 1994) with the recommendations made by county agricultural extension agents. Published fertilizer application recommendations are based on crops and soil-test results, which are used to determine the availability of common agricultural nutrients, including nitrogen, phosphorus, and potassium. Agricultural extension agents from a number of counties across the LTEN River Basin were interviewed to determine typical soil ratings for the basin. Because of the great variability in soil-test results within individual counties, agents suggested using a medium soil rating to arrive at a basin-wide average fertilizer application recommendation for each crop.

Application recommendations for selected crops (corn, wheat, tobacco, soybeans, cotton, and hay) were multiplied by 1992 county-level data on harvested acreage (U.S. Department of Commerce, 1994) to derive an estimate of applied fertilizer for nitrogen and phosphorus for each crop in each county for 1992. The estimates were then summed by crop to provide a single fertilizer application estimate for each county.

County-level input estimates from both methods were weighted to provide estimates for selected basins. The weighting algorithm apportions the county input to each basin based on the portion of cultivated land, by county, encompassed within each basin. Estimates of nitrogen and phosphorus fertilizer inputs were also calculated for each major hydrologic unit using the same land-use weighting approach. This weighting approach may give inaccurate results in areas where cropping practices vary greatly across the agricultural land within a county, but the error introduced in this step is not significant for larger basins (those that include large parts of one or more counties).

A comparison of basin-level input estimates from the two computation methods (table C1) reveals significant differences in results for some basins. Sales-based nitrogen inputs were consistently higher than crop application recommendations (ranging from 6 to 49 percent higher). Sales-based estimates for phosphorus differed from crop application recommendations by as much as 46 percent, but were not consistently higher or lower across all the basins. Several factors may contribute to these differences:

1. Estimates based on application recommendation are calculated for fertilizer applied to harvested acres only, not to total agricultural lands. The areas for which nitrogen sales-based estimates are almost 50 percent higher than application recommendation-based estimates may

Table C1. Comparison of results from two methods of estimating fertilizer inputs of nitrogen and phosphorus for selected basins in the lower Tennessee River Basin

[Estimates are reported in tons per year of nitrogen (N) or phosphorus (P); fertilizer sales method [A] based on State and county sales information (J. Fletcher, West Virginia University, written commun., 1992; fertilizer application recommendation method [B] based on recommendations from Savoy and Joines (1998), Adams and others (1994); difference between estimates calculated as [A-B]/[A], in percent]

Site identi-fica-tion (fig. 2)	Surface-water station/site location		Estimated input from fertilizer sales method (1991) A		Estimated input from fertilizer application recommendation method (1992) B		Difference in estimated inputs (in percent) (A-B)/A	
	Number	Name	N	P	N	P	N	P
1	PRI038	Clarks River at Almo, Ky.	3,042	689	2,554	589	16	14
2	03604000	Buffalo River near Flat Woods, Tenn.	1,613	414	1,083	379	33	8
4	001025	Duck River below Normandy Dam, Tenn.	885	227	706	224	20	1
5	001065	Duck River at Williamsport, Tenn.	5,192	1,333	4,617	1,775	11	-33
6	475793	Duck River above Hurricane Mills, Tenn.	6,651	1,707	6,245	2,401	6	-41
7	002395	Shoal Creek at Highway 43, near Lawrenceburg, Tenn.	1,158	297	764	249	34	16
9	001207	Elk River below Tims Ford Dam, Tenn.	3,178	816	2,414	714	24	12
10	475796	Elk River near Prospect, Tenn.	7,591	1,948	6,061	2,032	20	-4
11	FLCR7	Flint Creek near Falkville, Ala.	182	30	94	44	48	-46
12	TOWNCREEK15	Town Creek near Geraldine, Ala.	730	121	372	116	49	4
13	002375	Sequatchie River at Valley Road, Tenn.	862	221	667	259	23	-17

correspond to areas where farmers apply commercial nitrogen fertilizer to pasture land.

2. Application recommendation-based estimates are calculated based on medium soil-test results, but soils in some parts of the LTEN River Basin do not match that result. Application recommendation-based estimates for phosphorus may exceed sales-based estimates for soils that have high natural phosphorus content, such as in the basins for sites 5 and 6 (Duck River at Williamsport and above Hurricane Mills).
3. The use of manure to fertilize agricultural areas is not taken into account in the sales-based estimates. This may account for smaller estimates of phosphorus based on sales for areas where manure is commonly applied.
4. Estimates based on fertilizer sales do not account for the possibility that fertilizer may be purchased in one county but applied in another county.

Sales-based input estimates were generally viewed as the more reliable of the two estimates and were used in comparison among sources for the selected basins and for major hydrologic units.

Nitrogen Fixation

Estimates of nitrogen input were adopted from literature values for nitrogen fixation and county-level estimates of 1992 harvested acreage for soybeans (the only legume with significant acreage in the LTEN River Basin). The rate of nitrogen fixation by soybeans was based on comparison of rates reported in Tennessee, Alabama, Kentucky, and North Carolina agricultural literature. Reported rates varied little geographically. A rate of 105 lb/acre was applied throughout the study area (Craig and Kuenzler, 1983). The rate was multiplied by 1992 harvested acres for soybeans (U.S. Department of Commerce, 1994) to estimate the amount of biologically fixed nitrogen, in tons. Estimates were then converted from county to basin level using the same land-use weighting algorithm described for fertilizer application.

Crop Uptake

The mass of nutrients incorporated into crop biomass was calculated using literature values of rates of nutrient uptake and 1992 county-level data of harvested amounts. Nutrient uptake rates varied among literature sources (Savoy, 1999; Mitchell, 1998; McMahon and Lloyd, 1995), but because most of the LTEN River Basin is located within Tennessee, rates reported by the University of Tennessee Agricultural Extension Service (Savoy, 1999) were used for this analysis. To derive the mass of nutrient removal for each harvested crop, the nutrient uptake rate (pounds per acre for the harvested amount per acre) was multiplied by the harvested amount (in pounds, bushels, or tons) (U.S. Department of Commerce, 1994). Estimates of nutrient removal in tons per year were totaled by county for all crops, then converted from county level to basin level by using the same land-use weighting algorithm described for fertilizer application.

Livestock Waste

County-level estimates of the mass of nutrients from livestock waste have been compiled for all livestock categories, including cattle, hogs, and chickens (U.S. Department of Commerce, 1994). These estimates were calculated for each livestock category from county-level animal census data and from estimates of the nutrient content of daily wastes (Barth and others, 1992), by using the following equation:

$$\text{[nutrient mass in livestock waste, in pounds per year]} = \text{[census estimate of number of animals]} \times \text{[average weight of animal per 1,000 pounds]} \times \text{[nutrient content of waste, in pounds per day per 1,000 pounds animal]} \times \text{[365 days per year]} \quad (3)$$

Nutrient mass estimates for 1992 were converted from county level to basin level using a land-use weighting algorithm similar to the one used for weighting fertilizer application, except that the weighting was based on the distribution of pasture land.

Estimates of nutrient input from livestock waste are associated with two separate double-counting problems in a mass-balance analysis of sources and sinks. First, if the livestock producing the waste are fed fertilized crops grown within the watershed, the nutrient input is double-counted as both applied fertilizer and produced waste. Second, the ammonia volatilized from manure contributes to atmospheric nitrogen, so that nutrient input may be double-counted as both produced waste and measured atmospheric deposition. These discrepancies cannot be accounted for with the available data.

Appendix D. Variation in nutrient concentrations with streamflow, and model estimate of streamflow variation in concentration, at selected sites in the lower Tennessee River Basin, 1980-1996

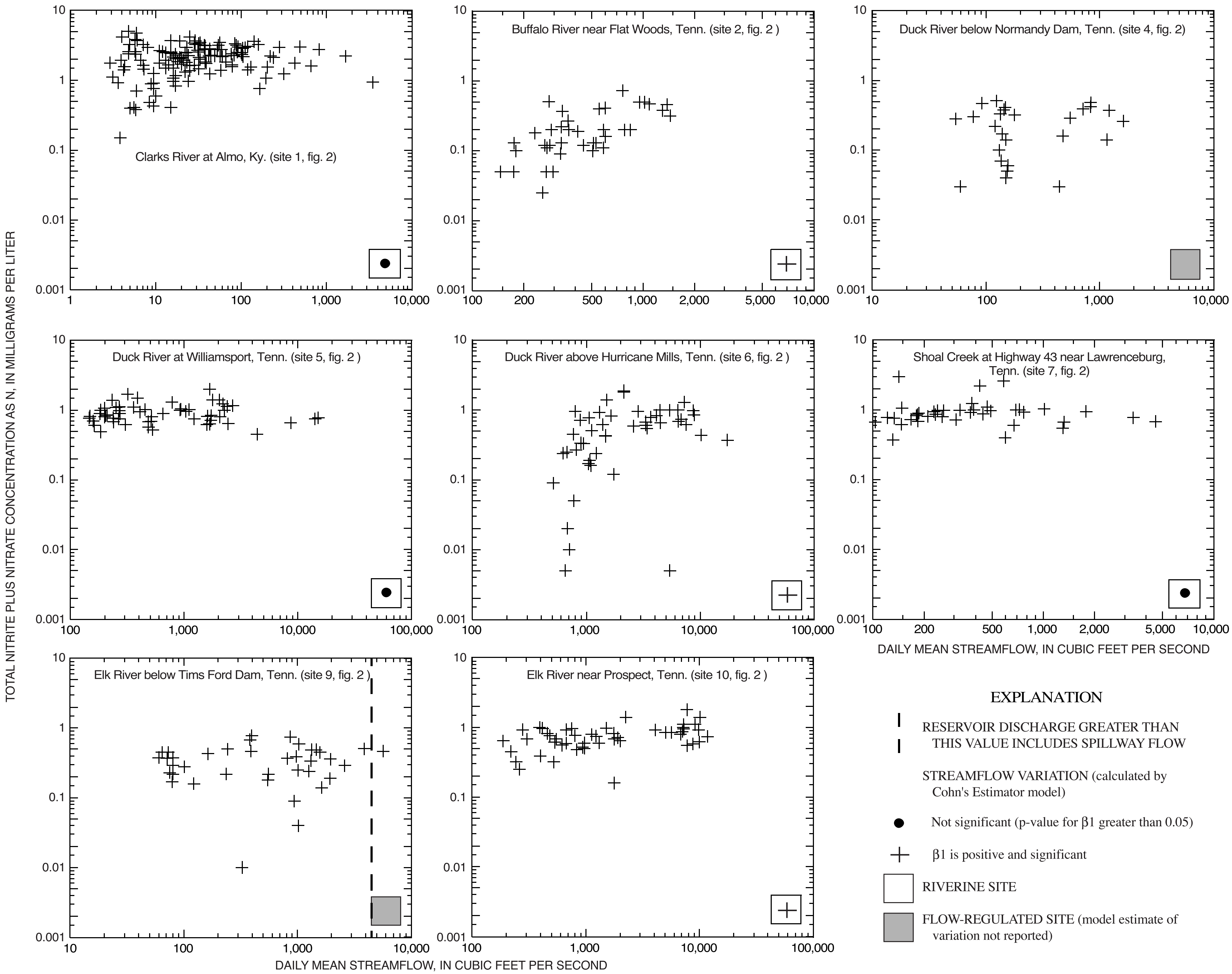


Figure D1. Variation in total nitrite plus nitrate concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96.

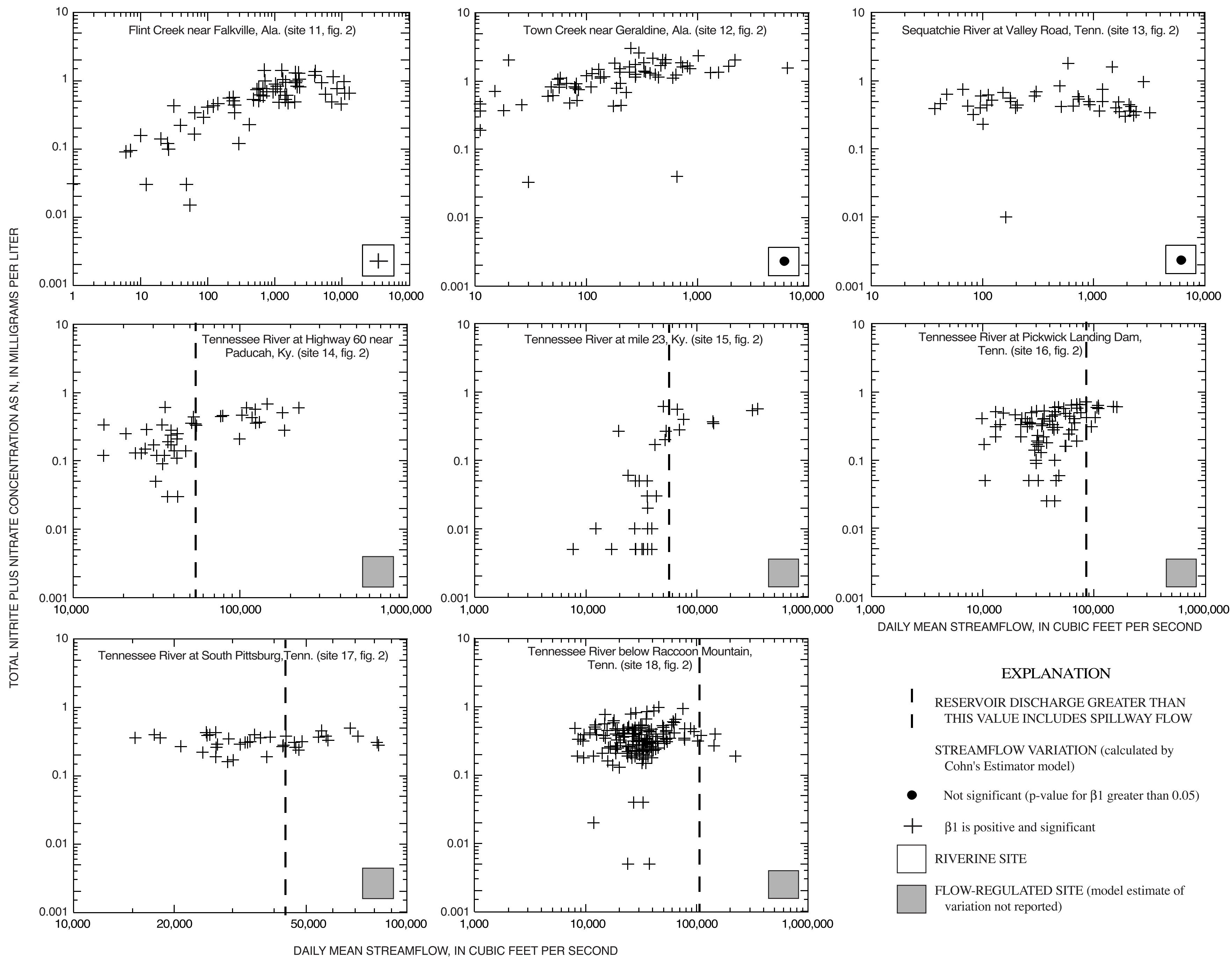


Figure D1. Variation in total nitrite plus nitrate concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96—Continued.

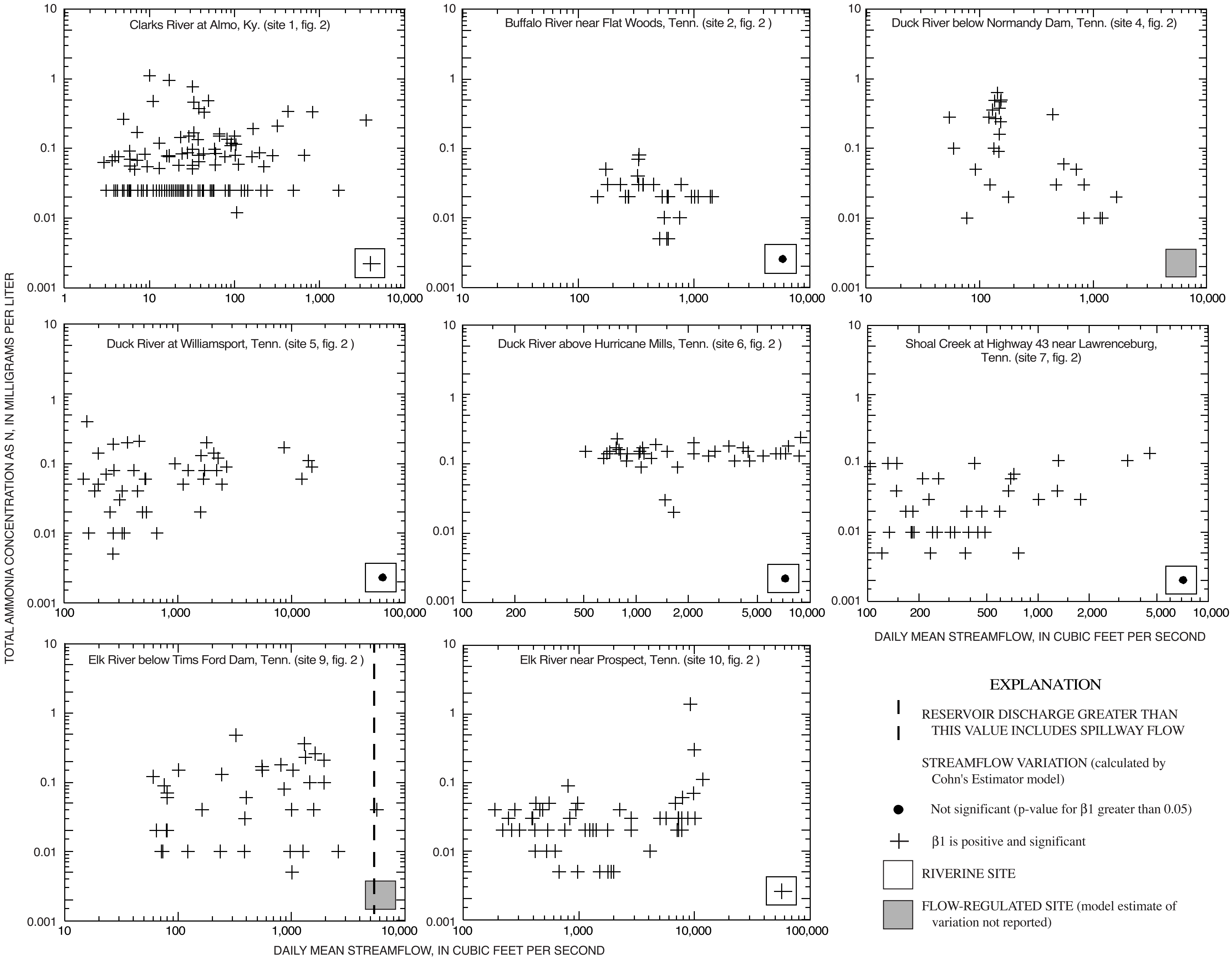


Figure D2. Variation in total ammonia concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96.

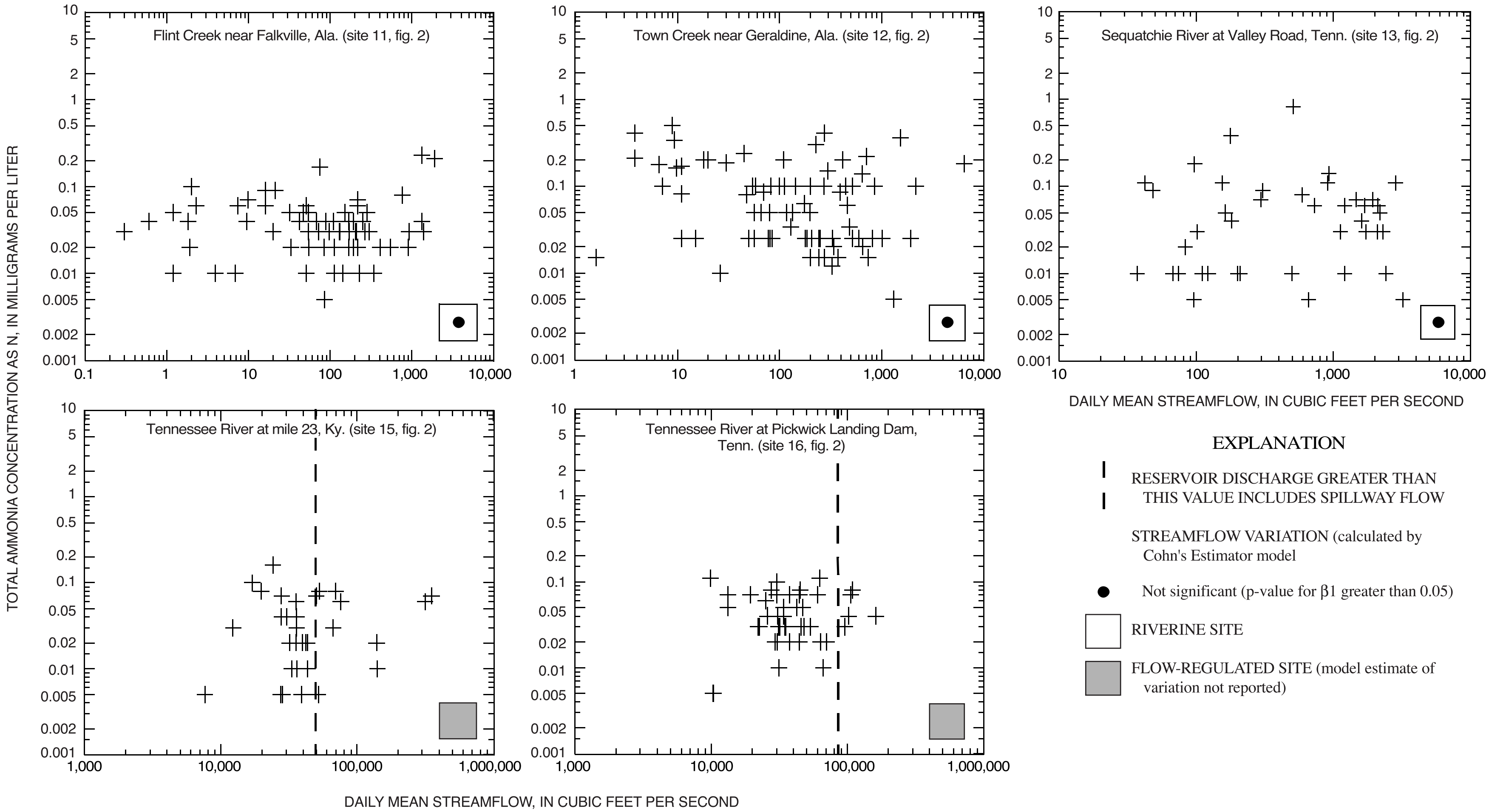


Figure D2. Variation in total ammonia concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96—Continued.

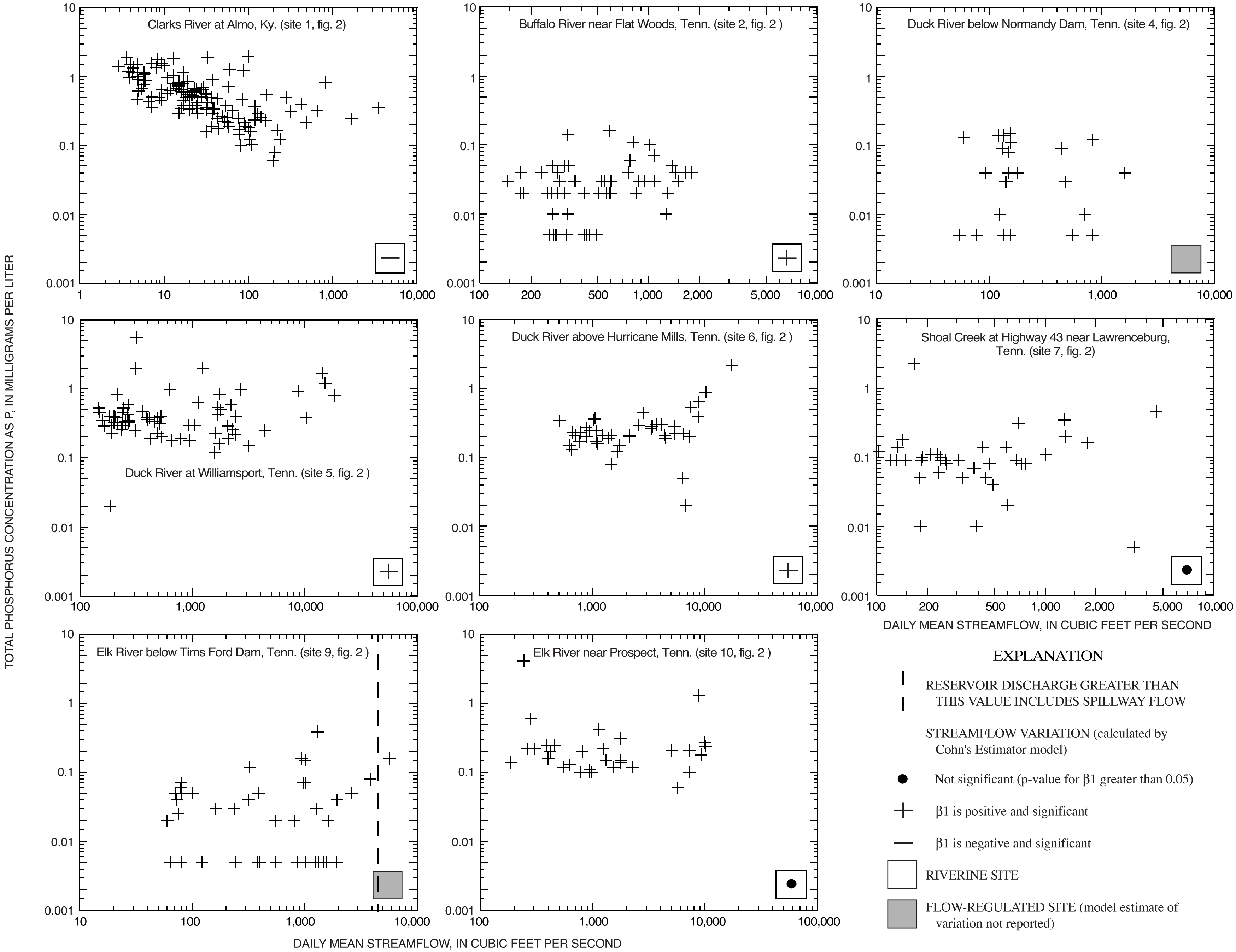


Figure D3. Variation in total phosphorus concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96.

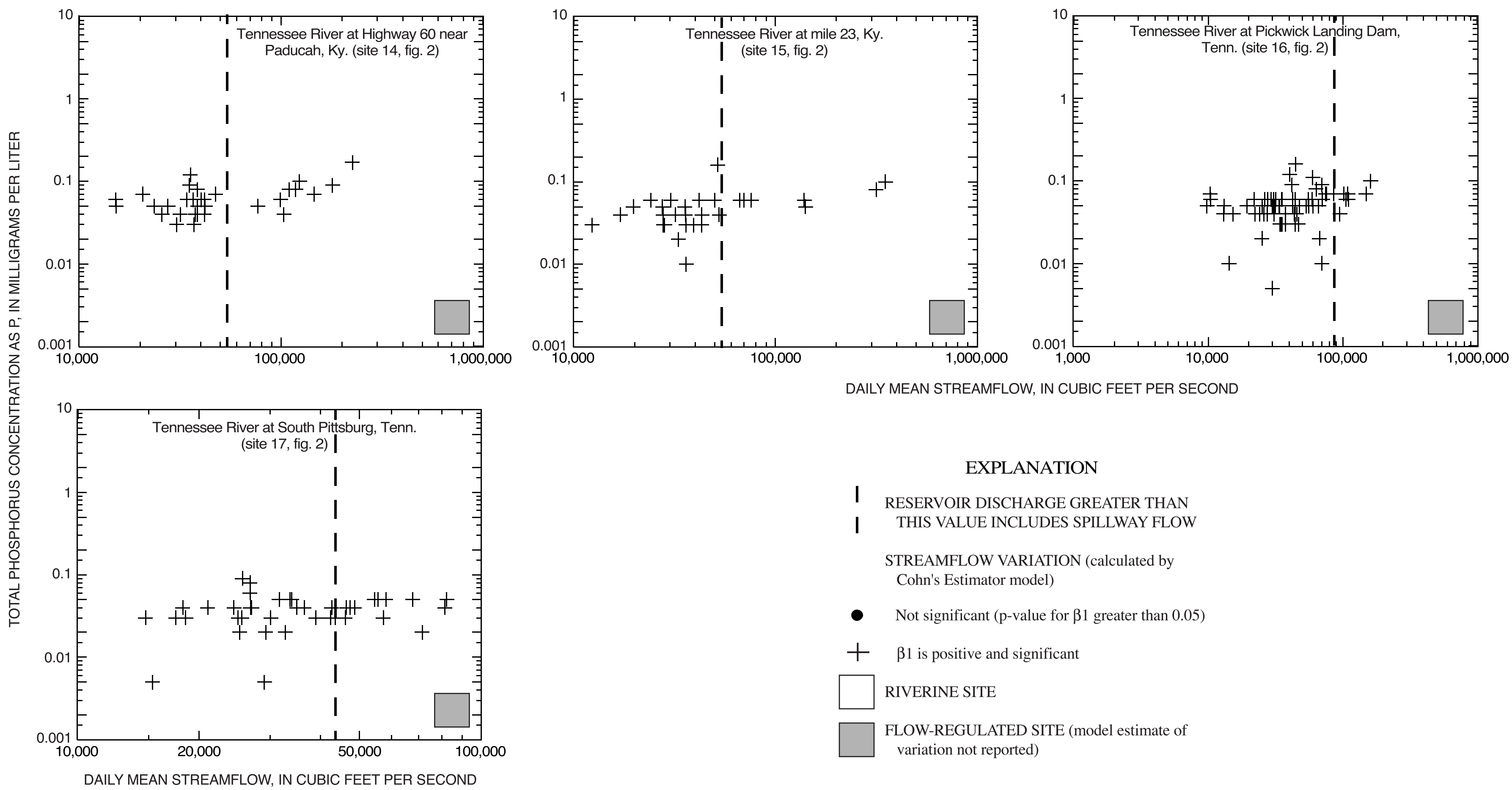


Figure D3. Variation in total phosphorus concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96—Continued.

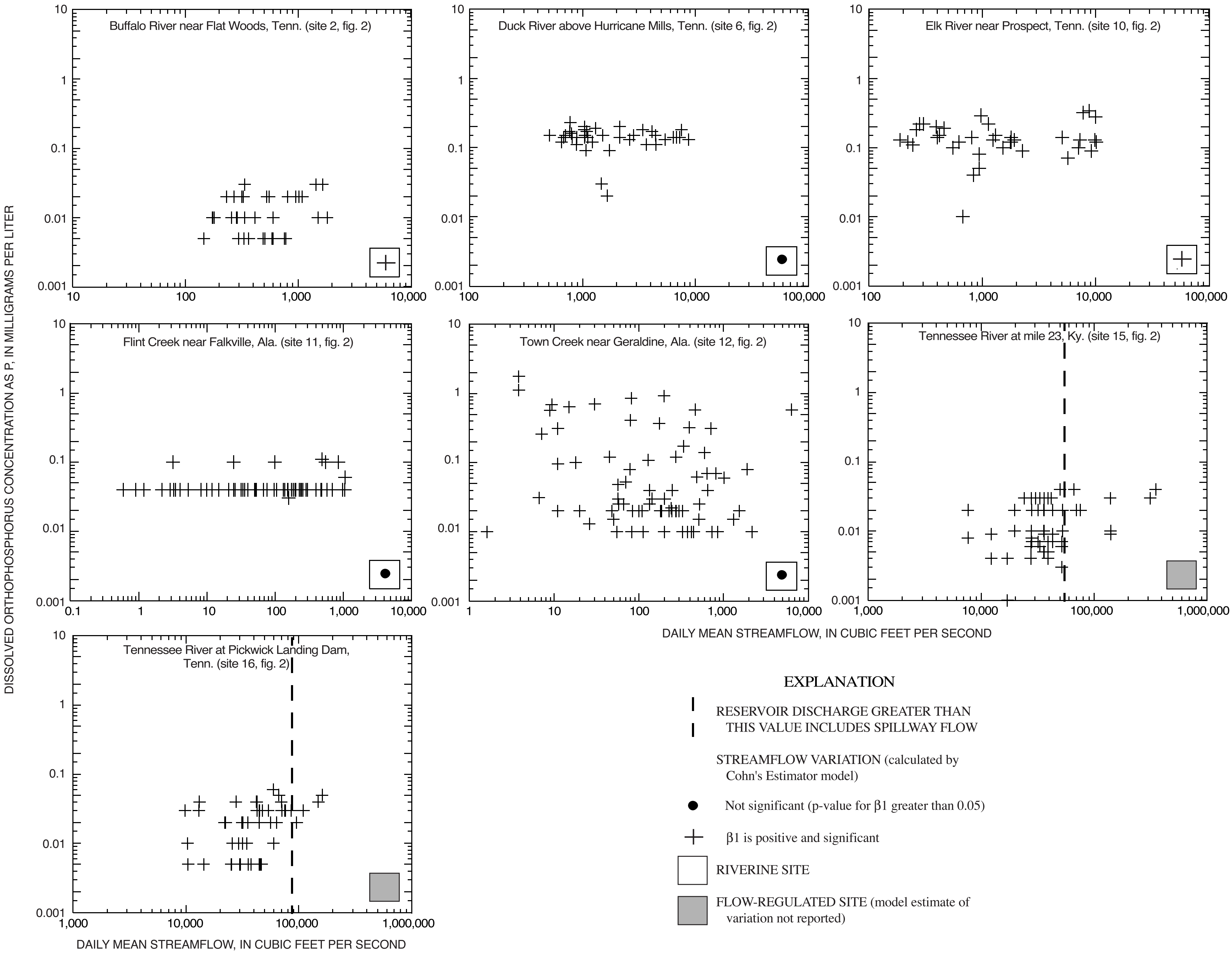
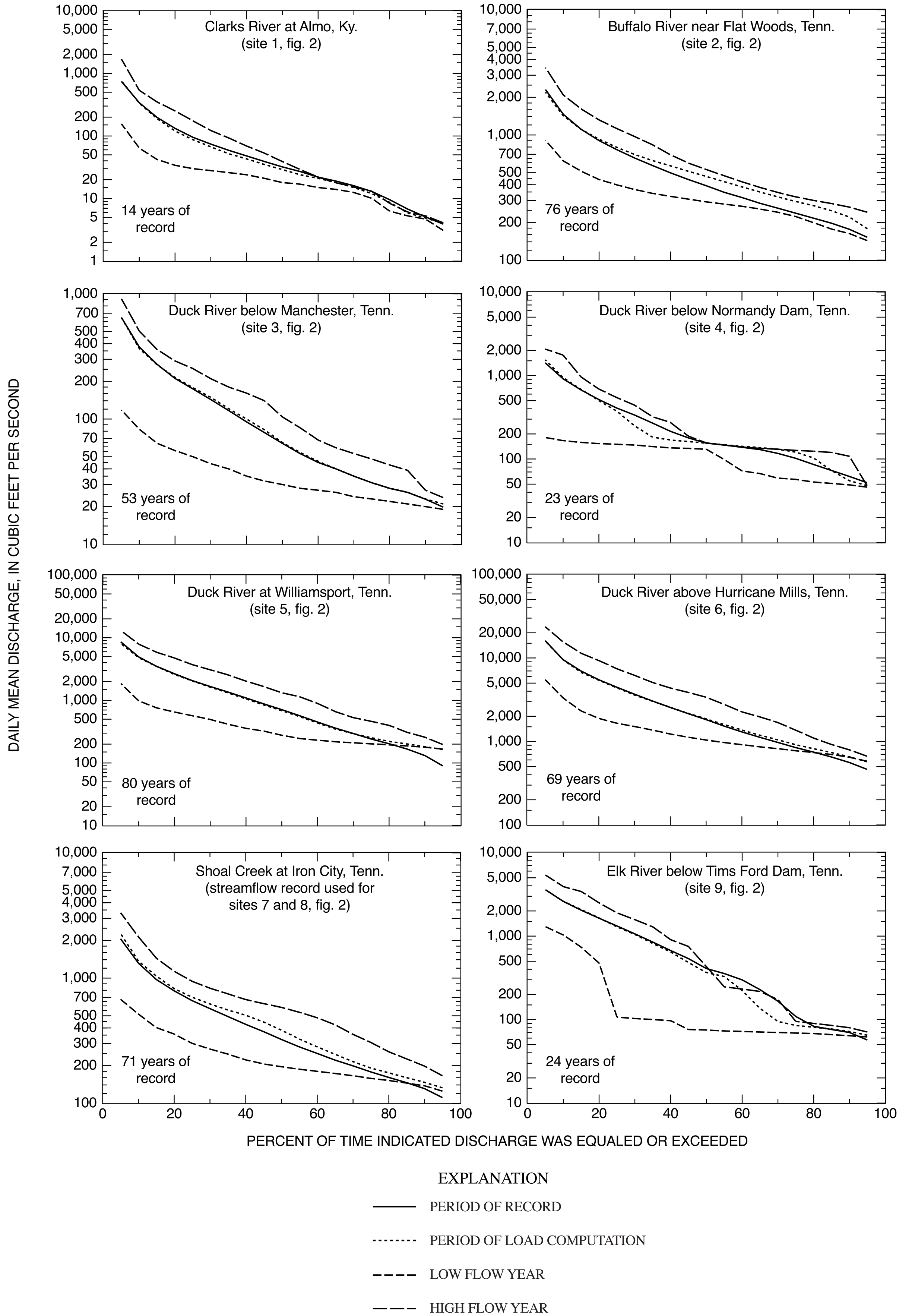
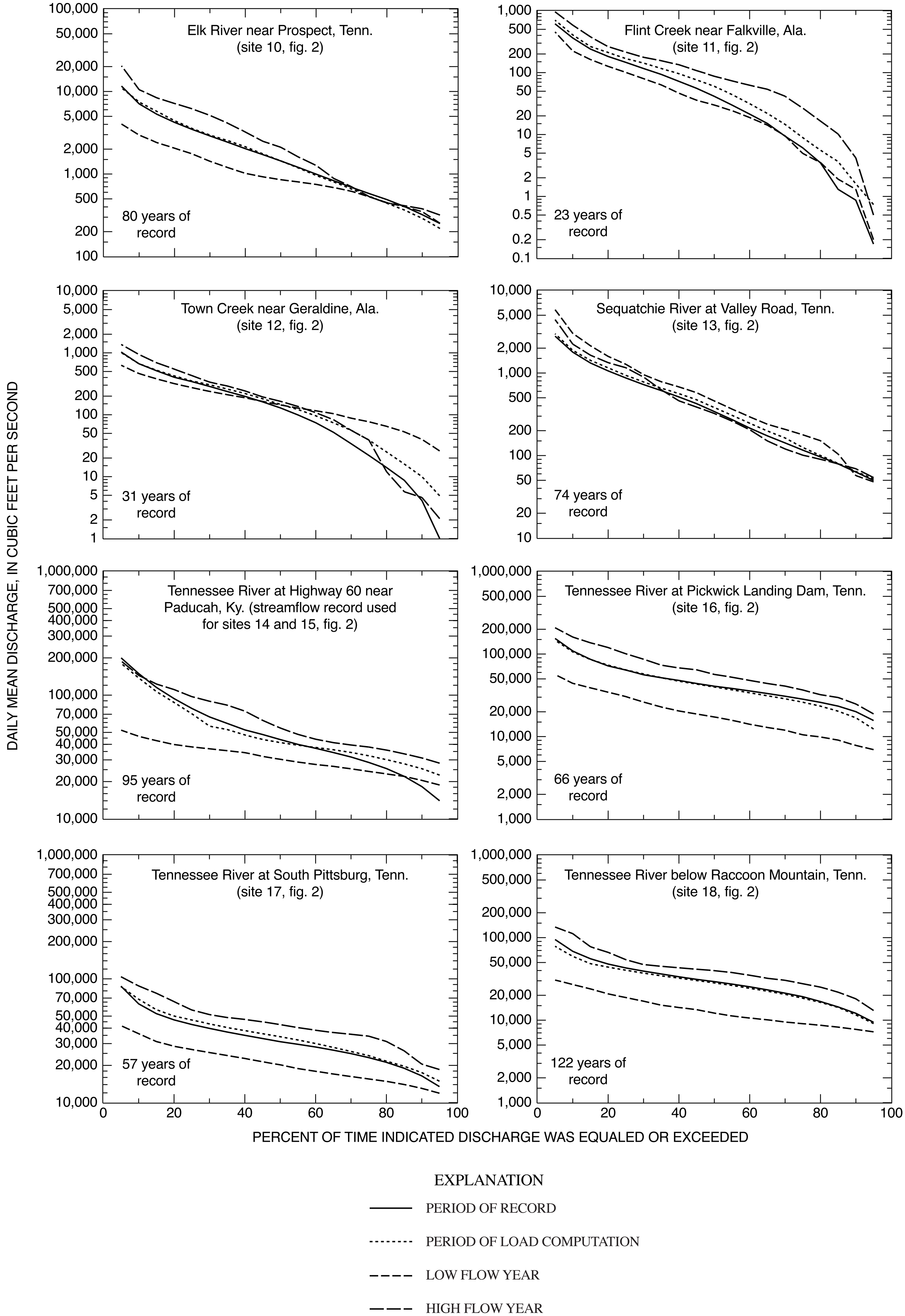


Figure D4. Variation in dissolved orthophosphorus concentrations with streamflow and model estimate of streamflow variation in concentration at selected sites in the lower Tennessee River Basin, 1980-96.



Appendix E. Streamflow-duration characteristics for period of streamflow record, compared with characteristics for period of load computation, for load-computation sites in the lower Tennessee River Basin.



Appendix E. Streamflow-duration characteristics for period of streamflow record, compared with characteristics for period of load computation, for load-computation sites in the lower Tennessee River Basin—Continued.