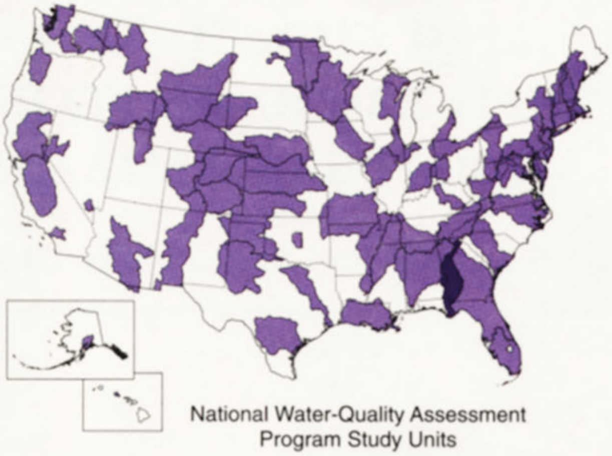
Nutrient Sources and Analysis of Nutrient Water-Quality Data, Apalachicola–Chattahoochee–Flint River Basin, Georgia, Alabama, and Florida, 1972–90



National Water-Quality Assessment Program Study Units

Poultry litter

Municipal-wastewater effluent

Fertilizer

Sediment

Atmospheric deposition

U.S. Geological Survey
Water-Resources Investigations Report 96-4101

The authors appreciate the extraordinary efforts of the editorial and cartography staff of the Georgia District, including Caryl J. Wipperfurth, Carolyn A. Casteel, Willis G. Hester, and Eric A. Steinnagel.

Cover photographs: (1) interior of a chicken house in northern Georgia; (2) application of farm chemicals, (3) skyline of Metropolitan Atlanta, Georgia; (4) a wastewater-treatment facility on the Chattahoochee River, Atlanta, Georgia; and (5) sediment discharging from the mouth of Suwanee Creek into the Chattahoochee River near Atlanta, Georgia.

NUTRIENT SOURCES AND ANALYSIS OF NUTRIENT WATER-QUALITY DATA, APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN, GEORGIA, ALABAMA, AND FLORIDA, 1972–90

By Elizabeth A. Frick, Gary R. Buell, and Evelyn E. Hopkins

U.S. GEOLOGICAL SURVEY

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National Water-Quality Assessment Program

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1996

U.S. DEPARTMENT OF THE INTERIOR

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FOREWORD

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

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

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

- describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers;
- describe how water quality is changing over time; and
- improve understanding of 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.

Information regarding the NAWQA Program is available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resources Locator (URL) at:

<URL:http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html>

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ILLUSTRATIONS—Continued

ILLUSTRATIONS—Continued

TABLES

CONVERSION FACTORS AND ACRONYMS AND ABBREVIATIONS

CONVERSION FACTORS

Multiply	by	to obtain
Length		
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
Area		
square mile (mi^2)	2.590	square kilometer
Mass		
tons	907.1847	kilograms
tons per square mile ($tons/mi^2$)	350.26	kilograms per square kilometer
Rate		
cubic foot per second (ft^3/s)	0.2832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meters per second
tons per year (tons/yr)	907.1847	kilograms per year

Temperature

Temperature, in degrees Fahrenheit (° F), can be converted to degrees Celsius (° C) as follows:

$$° F = 1.8 (° C) + 32$$

ACRONYMS

ACF	Apalachicola–Chattahoochee–Flint
ADEM	Alabama Department of Environmental Management
ARC	Atlanta Regional Commission
CSO	combined sewer overflow(s)
FGFWFC	Florida Game and Fresh Water Fish Commission
FLDER	Florida Department of Environmental Regulation
GEPD	Georgia Environmental Protection Division
GGS	Georgia Geologic Survey
GWIS	Ground Water Information System
GWUDS	Georgia Water-Use Data System
LOWESS	LOcally WEighted Scatterplot Smoothing
MCL	maximum contaminant level(s)
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NAWQA	National Water-Quality Assessment
NPDES	National Pollution Discharge Elimination System
NWIS	National Water Information System
PCS	Permit Compliance System
SSO	sanitary sewer overflow(s)
STORET	STOage and PETrieval System
STP	Sewage Treatment Plant
USACOE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WPCP	Water Pollution Control Plant
WSFPA	Water, Sewer, and Fire Protection Association
WWTF	wastewater-treatment facility (facilities)

ABBREVIATIONS

mg/L	milligram per liter
mg/L/yr	milligram per liter per year
µg/L	microgram per liter
N	nitrogen
NH_3	ammonia
NH_3 plus NH_4^+	total ammonia
NH_4^+	ammonium
NO_3^-	nitrate
NO_2^-	nitrite
P	phosphorus
PO_4	phosphate

NUTRIENT SOURCES AND ANALYSIS OF NUTRIENT WATER-QUALITY DATA, APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN, GEORGIA, ALABAMA, AND FLORIDA, 1972–90

By Elizabeth A. Frick, Gary R. Buell, and Evelyn H. Hopkins

ABSTRACT

In 1991, the U.S. Geological Survey began full-scale implementation of the National Water-Quality Assessment (NAWQA) program. One of the initial tasks of the NAWQA program is to compile and evaluate existing data from individual study units. Available nutrient data from 1972 through 1990 water years were used to estimate nutrient sources to the Apalachicola–Chattahoochee–Flint (ACF) River basin and describe the presence, distribution, and transport of nutrients in surface and ground waters.

In 1990, about 2,500 tons of nitrogen and 1,100 tons of phosphorus were discharged as point-source loads by 127 municipal wastewater-treatment facilities (WWTF). Nonpoint-source inputs, an unknown percentage of which entered the hydrologic system, included about 120,000 tons of nitrogen and 28,000 tons of phosphorus from animal manure; 82,000 tons of nitrogen and 20,000 tons of phosphorus applied as fertilizer; and 24,000 tons of nitrogen from atmospheric deposition. Estimates of nutrient input to the ACF River basin were not made for natural sources and for the following anthropogenic sources: industrial-wastewater effluent; storm drains; sanitary and combined sewer outflows; and runoff from agricultural, urban, and suburban areas. Nutrient outflow from the Apalachicola River into Apalachicola Bay, Fla., was about 13 percent of estimated nitrogen sources and about 3 percent of estimated total-phosphorus sources in the ACF River basin.

For 1972–90, nutrient concentrations in surface water were high enough to warrant concerns about accelerated eutrophication based on total-phosphorus concentrations and to warrant concerns intermittently about toxicity to fish based on dissolved-ammonia concentrations downstream of wastewater-treatment outfalls from Metropolitan Atlanta and LaGrange, Ga. Many improvements to the water quality of the Chattahoochee and Flint Rivers in the 1980's and early 1990's can be directly attributed to improvements in WWTF, legislation directed at decreasing point-source loads of phosphorus, and changes in locations of wastewater-treatment outfalls. However, limited data indicate that nonpoint-source inputs increased upstream of Atlanta and in the Chipola River watershed.

Significant increases in nutrient concentrations, loads, and yields occurred from upstream to downstream of the metropolitan areas of Atlanta, Ga.; Columbus, Ga., and Phenix City, Ala.; and Albany, Ga. The highest mean-annual yields estimated in the ACF River basin for total nitrogen (2.9 tons per square mile (tons/mi^2)), total-inorganic nitrogen (2.0 tons/mi^2), dissolved ammonia (1.1 tons/mi^2), and total phosphorus (0.75 tons/mi^2) were downstream of Atlanta.

Most significant trends in nutrient-concentration data from 1980–90 in the Chattahoochee River and the Middle and Lower Flint River basins were increasing, except dissolved ammonia which decreased at several sampling sites in reaches downstream of Atlanta, Columbus and Phenix City, and Albany. At sampling sites on the Chattahoochee and Flint Rivers downstream of Atlanta and Albany, decreasing trends in dissolved-ammonia concentration and increasing trends in dissolved-nitrate concentration were the result of improved wastewater treatment at WWTF. Dissolved-ammonia concentrations decreased and dissolved-nitrate concentrations increased along river reaches downstream of wastewater-treatment facility outfalls for Atlanta and Albany because of nitrification of ammonia to nitrate. Increasing trends in total-phosphorus concentrations are an accurate representation of data for the period 1980–90. However, legislated restrictions on the use of phosphate detergents and improvements to WWTF in the late 1980's and early 1990's, resulted in substantial reductions of phosphorus concentrations in wastewater effluent and in rivers at many locations in the 1990's.

Reservoirs affect nutrient transport because of uptake by phytoplankton and aquatic plants, denitrification, and accumulation of phosphorus associated with sediment in reservoirs. Yields of total-inorganic nitrogen, dissolved ammonia, dissolved nitrate, and total phosphorus decreased between sampling sites upstream and downstream of four reservoirs on the Chattahoochee River. The only exception was the yield of dissolved ammonia increased slightly from upstream to downstream of Lake Sidney Lanier. Much of the nutrient load in the Chattahoochee River downstream of Atlanta is utilized by algae or settles out primarily in West Point Lake, and to a lesser extent, in Lake Harding and Walter F. George Reservoir. In general, the Flint River arm of Lake Seminole had significantly higher concentrations of nutrients than the Chattahoochee River arm of Lake Seminole, which may be the result of the large percentage of the Middle and Lower Chattahoochee River in backwater from reservoirs, the absence of reservoirs on the Flint River downstream of Albany until Lake Seminole, and nonpoint-source inputs of nutrients from intensively farmed areas in the Lower Flint River basin. Decreases in dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations in reservoirs and backwater along the Chattahoochee River from West Point Lake to Lake Seminole during summer months are related to the seasonality of phytoplankton production.

The Chipola River had the highest yields of dissolved nitrate (1.2 tons/mi^2) estimated in the ACF River basin. Estimated loads of dissolved nitrate increased fairly steadily from 500 to 1,500 tons per year from 1972−90. These factors strongly suggest an agricultural nonpoint source of elevated dissolved-nitrate concentrations from increased irrigated agriculture and fertilizer applications in the Chipola River watershed.

Analyses of nutrients in ground water within the ACF River basin for 1972−90 water years were restricted because of limited available data. The distribution of nitrate concentrations in the ACF River basin for 1972−90 water years included 10 percent of wells and 6 percent of springs with concentrations that probably have elevated nitrate concentrations (3.1 to 10 milligrams per liter (mg/L)), and 1 percent of wells with median nitrate concentrations exceeding the maximum contaminant level of 10 mg/L. Dissolved-nitrate concentrations were significantly lower in the Providence aquifer than in the Floridan aquifer system and the crystalline-rock aquifers. Dissolved-nitrate concentrations in wells used for public supply were significantly lower than in wells used for domestic use or unused wells.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began full-scale implementation of the National Water-Quality Assessment (NAWQA) program. The three major objectives of the program are to provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources; define long-term trends (or lack thereof); and identify, describe, and explain the major factors that affect observed water-quality conditions and trends (Hirsch and others, 1988; Leahy and others, 1990). The NAWQA program, when fully implemented, will include investigations of hydrologic systems in 60 study units that include parts of most major river basins and aquifer systems in the United States. Study units range in size from 1,200 to about 65,000 square miles (mi^2), and incorporate 60 to 70 percent of the Nation's water use and population served by public water-supply systems. The Apalachicola−Chattahoochee−Flint (ACF) River basin was among the first 20 NAWQA study units selected for study under the full-scale implementation plan (Wangsness and Frick, 1991).

One of the initial tasks of the NAWQA program is to compile and evaluate existing data from individual study units. These data provide an historical perspective on the water quality in a study unit, strengths and weaknesses of available information, and implications for water-quality issues, study priorities, and study design. In addition to analyzing historical data on a regional scale, nutrients (Puckett, 1994; Puckett, 1995; Mueller and others, 1995) and pesticides (Barbash and Resek, 1996; Larson, S.J., Capel, P.D., and Majewski, M.S., U.S. Geological Survey, written commun., 1996; Majewski and Capel, 1995; Nowell, L.H., Dileanis, P.D., and Capel, P.D., U.S. Geological Survey, written commun., 1996) are the first two topics being investigated on a national scale to evaluate differences among various regions of the country. Stell and others (1995) describes use and occurrence of pesticides in the ACF River basin. This report describes and evaluates available nutrient data in the ACF River basin.

Nutrients, particularly nitrogen and phosphorus, are important because their availability can regulate or limit the productivity of organisms in freshwater-aquatic systems. High concentrations of nitrogen and phosphorus can adversely affect surface-water quality through eutrophication (abundant accumulation of nutrients causing excessive aquatic-plant growth) and toxicity to aquatic life. High concentrations of nitrate, found primarily in ground water, can be toxic to warm-blooded animals that drink the water.

Purpose and Scope

The purposes of this report are to (1) quantify nutrient sources to the ACF River basin and (2) present graphical and statistical analyses describing regional variations in the presence, distribution, and transport of nutrients in surface and ground waters of the ACF River basin. Where possible, variations in nutrient water quality are related to hydrologic, environmental, and anthropogenic factors. This evaluation is intended to provide a historical description of nutrient water-quality conditions in the ACF River basin, help guide the intensive sampling phase of the ACF NAWQA study with respect to nutrients, and provide regional interpretation of nutrient distribution in the ACF for the national synthesis on nutrients. It is outside the scope of this report to attempt to explain specific chemical processes affecting nutrients within the ACF River basin.

This evaluation is based on available and accessible nutrient data collected from the ACF River basin during 1972–90 water years[1/]. Nutrient sources to the ACF River basin were estimated for 1990. Analyzed nutrient water-quality data were from three computerized data bases—the USGS National Water Information System (NWIS), U.S. Environmental Protection Agency (USEPA) STOrage and RETrieval System (STORET), and Florida Department of Environmental Regulation (FLDER) Ground Water Information System (GWIS). Some discharge and concentration data from major wastewater-treatment facilities (WWTF) were computerized from paper files.

Description of the Apalachicola–Chattahoochee–Flint River basin

The following three sections provide a brief description of the environmental setting of the ACF River basin. A more thorough description is in Couch and others (1996).

Location and Physiography

The ACF River basin NAWQA study area (fig. 1) is about 20,400 mi^2. This number includes the drainage area at the mouth of the Apalachicola River (19,600 mi^2) (U.S. Army Corps of Engineers, 1985); the New River watershed (about 510 mi^2) (U.S. Geological Survey digital files); and the Apalachicola Bay and surrounding coastal areas and barrier islands (about 270 mi^2) (U.S. Geological Survey digital files). The Chattahoochee and Flint Rivers merge in Lake Seminole to form the Apalachicola River, which flows through the panhandle of Florida into the Apalachicola Bay, and discharges into the Gulf of Mexico. The ACF River basin NAWQA study area is further subdivided according to 14 cataloging units shown on hydrologic unit maps (U.S. Geological Survey 1975a,b,c). The cataloging units, referred to as subbasins in this report (fig. 2), have differing physiography, climate, hydrologic characteristics, population densities, and land and water uses resulting in differences in surface-water and ground-water quality. Wherever possible, information in this report is presented at the subbasin, major river basin, and study-unit scales.

The ACF River basin lies in three physiographic provinces: the Blue Ridge Province, which includes the headwaters of the Chattahoochee River in the northwestern part of the study area; the Piedmont Province, which includes the Upper and Middle Chattahoochee River subbasins and the Upper Flint River subbasin; and the Coastal Plain Province, which includes approximately the southern half of the basin (fig. 1). The Fall Line, a physiographic boundary rather than a geologic boundary in most areas, approximates the boundary between older crystalline rocks of the Piedmont and younger sedimentary rocks and unconsolidated sediments of the Coastal Plain.

Climate and Hydrologic Setting

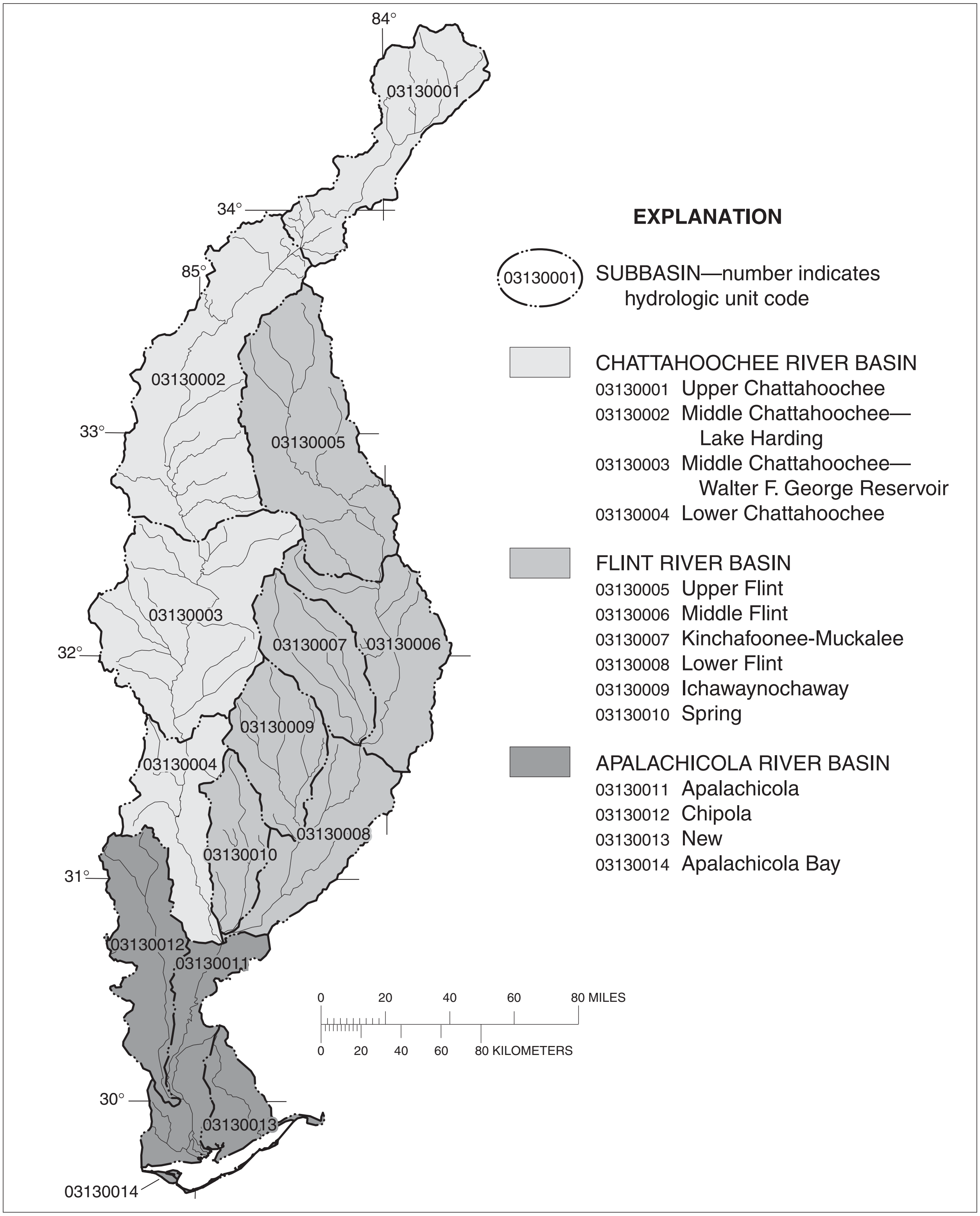
The ACF River basin is in a warm, temperate, subtropical climate zone that is moist year round and has hot summers. Average annual precipitation ranges from 45 to 60 inches (in.), primarily as rainfall (Hodler and Schretter, 1986). Average annual runoff ranges from approximately 12 to 40 in. (Stokes and McFarlane, 1993; U.S. Geological Survey, 1993; Pearman and others, 1993). Average annual temperatures range from 60 °F in the northern part to 70 °F in the southern part of the basin. Evapotranspiration ranges from about 32 to 42 in., and generally increases from north to south (Hodler and Schretter, 1986).

Within the Piedmont (fig. 1), the course of the upper Chattahoochee River is strongly controlled by geologic structures (primarily faults) and has a rectangular drainage pattern; whereas, the Flint River has a dendritic drainage pattern. In the Coastal Plain, the rivers and their tributaries are incised into the underlying aquifers and receive substantial amounts of ground water from these aquifers. The Chattahoochee River drains 8,770 mi^2 and flows 430 mi and the Flint River drains 8,460 mi^2 and flows 350 mi (U.S.

[1/] Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1990, is called the "1990 water year."

Base from U.S. Geological Survey digital files

Figure 1. Location of the Apalachicola-Chattahoochee-Flint River basin including physiographic provinces.



Base from U.S. Geological Survey digital files

Figure 2. Location of subbasins and corresponding hydrologic unit codes, Apalachicola-Chattahoochee-Flint River basin (from U.S. Geological Survey, 1975a,b,c).

Army Corps of Engineers, 1985). The confluence of the Chattahoochee and Flint Rivers is the headwaters of the Apalachicola River. The Apalachicola River flows unimpeded for 108 mi from its headwaters just below Jim Woodruff Lock and Dam to the Apalachicola Bay. With a mean annual discharge of 25,960 cubic feet per second (ft^3/s) from 1978–92, the Apalachicola River is the largest river in Florida and the 21st largest river in the conterminous United States (Leitman and others, 1983). Its width ranges from several hundred feet when confined to its banks to nearly 4-1/2 mi during flood stage in winter months (Leitman and others, 1983; Leitman and others, 1991).

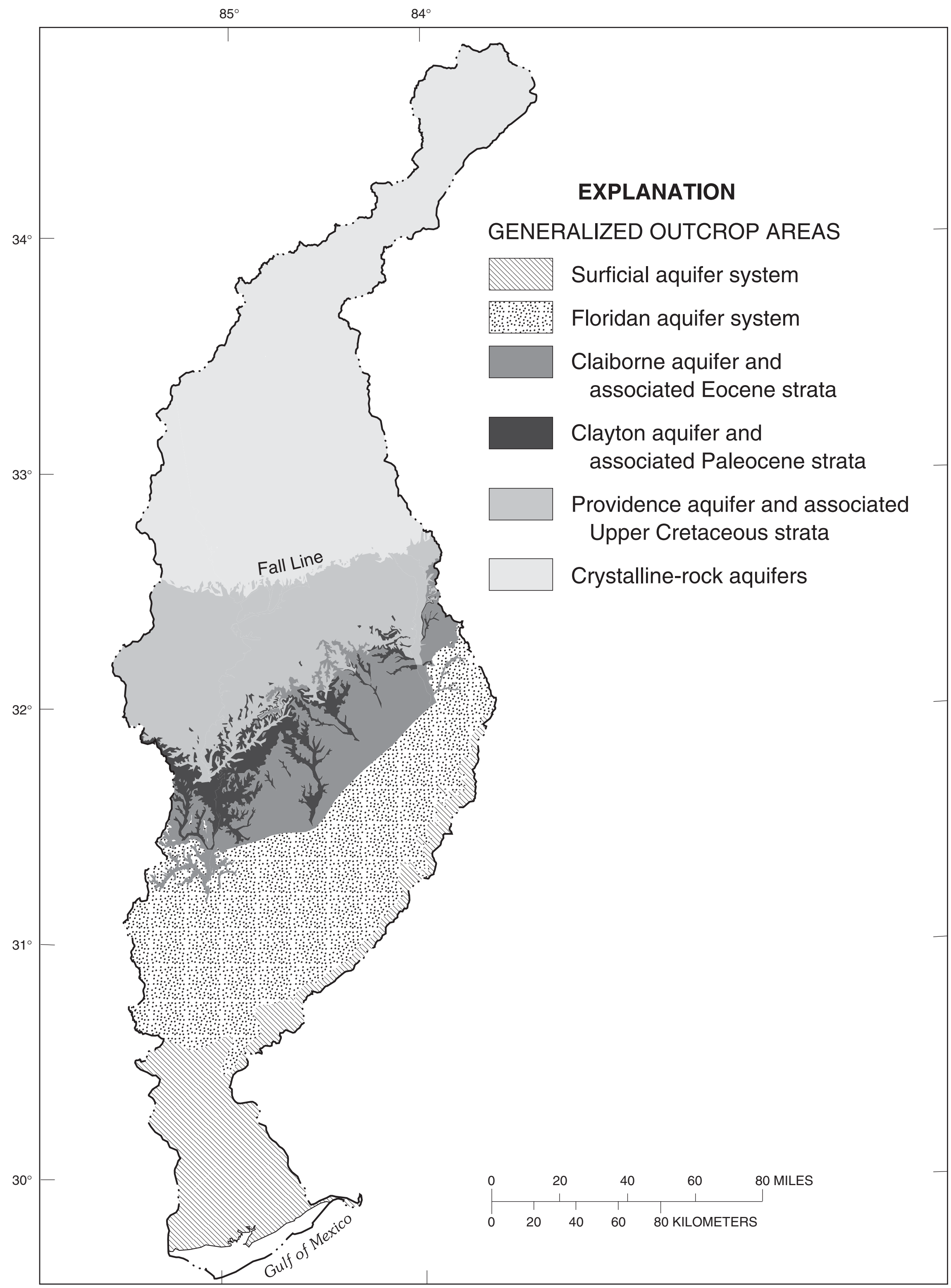
The Middle and Lower Flint subbasins are underlain by the highly transmissive Floridan aquifer system and these subbasins tend to have higher recharge rates and lower runoff than the rest of the ACF River basin. Baseflow measurements and ground-water modeling results (Torak and others, 1993, p. 15 and 32) indicate that the Flint River acts as a major regional drain for the Upper Floridan aquifer from Lake Worth to Newton, Ga.

Sixteen reservoirs have altered the natural streamflow and riverine ecosystems within the study area. The Chattahoochee River has three major reservoirs—Lake Sidney Lanier, West Point Lake, and Walter F. George Reservoir—that account for approximately 99 percent of the surface-storage capacity in the ACF River basin. Nine of 10 other reservoirs on the Chattahoochee River are run-of-the-river reservoirs with little or no storage capacity (U.S. Army Corps of Engineers, 1984). The Flint River has two reservoirs—Lake Blackshear and Lake Worth. Jim Woodruff Dam forms Lake Seminole at the headwaters of the Apalachicola River. All reservoirs in the ACF River basin were built prior to 1972 except West Point Lake, which began to be filled in October 1974 and reached maximum power pool in June 1975. Effects of reservoirs on annual flow distributions are overshadowed by natural variations in the ACF River basin (Leitman and others, 1991, p. 230). However, the six reservoirs with storage capacity affect downstream flows over shorter time scales and moderate extreme low and high flows. Where historical data were sufficient, changes in nutrient chemistry as a result of lacustrine environments created by man-made impoundments on the mainstem rivers were evaluated by comparing nutrient data upstream and downstream of dams.

For this report, the ACF River basin is subdivided into six aquifers (fig. 3) within geologic units of different ages, lithology, and physical characteristics, all of which can influence chemical characteristics of ground water. The crystalline-rock aquifers are composed of Pre-Cambrian to Permian metamorphic and igneous rocks of the Blue Ridge and Piedmont. In general, these rocks supply small amounts of ground water, although increasing population is causing renewed interest in developing ground water as a source of public supply. From the Fall Line to the Gulf of Mexico, progressively younger Coastal Plain sediments crop out and overlie older sediments, stratigraphic thicknesses of units generally increase, and vertical and areal facies changes occur within units. The regional direction of ground flow in the Coastal Plain physiographic province within the ACF River basin is from north to south; however, there are local variations in ground-water flow direction, especially in the vicinity of major streams and in areas of large ground-water withdrawals. Aquifer boundaries are not always coincident with stratigraphic boundaries and naming conventions for stratigraphic units and aquifers are not uniform across state lines within the study area. Aquifer names in this report conform primarily to those used in the literature discussing geology and hydrogeology in Georgia. From youngest to oldest, aquifers within the Coastal Plain of the ACF River basin include the: surficial aquifer system, Floridan aquifer system, Claiborne aquifer, Clayton aquifer, and Providence aquifer (fig. 4). The surficial aquifer system outcrop includes sediments deposited in a variety of fluvial and marine environments including river terraces, floodplain, delta, and coastal scarps. Coastal Plain aquifers within the ACF River basin are composed primarily of Upper Cretaceous to Quaternary inter-bedded sand, clay, limestone, and marl that are heavily used for domestic, industrial, and agricultural water supplies.

Population, Land Use, and Water Use

In 1990, the population of the ACF River basin was about 2.64 million people (table 1). Population estimates for the study area were made using a geographic information system to total U.S. Bureau of the Census population estimates for census tracts by subbasin. Population densities were highest in the Upper and Middle Chattahoochee subbasins, which include much of the Metropolitan Atlanta area. Sixty percent of the population of the study area live in the Metropolitan Atlanta area. However, southeast Atlanta and the eastern and northwestern suburbs of the Atlanta area are outside the study area (in the Ocmulgee and Etowah subbasins). Other large population centers in the basin include Columbus, Ga.; Phenix City, Ala.; Albany, Ga.; and the eastern part of Dothan, Ala. (fig. 1). Most other cities and towns in the ACF River basin have populations of less than 50,000 people. Population within the study area grew by approximately 16 percent from 1970–80, and by 13 percent from 1980–90, although populations of



Base modified from U.S. Geological Survey digital files

Figure 3. Generalized outcrop areas for geologic and hydrogeologic units underlying the Apalachicola-Chattahoochee-Flint River basin (modified from Georgia Geologic Survey, 1976; Miller, 1986; and Geological Survey of Alabama, 1989).

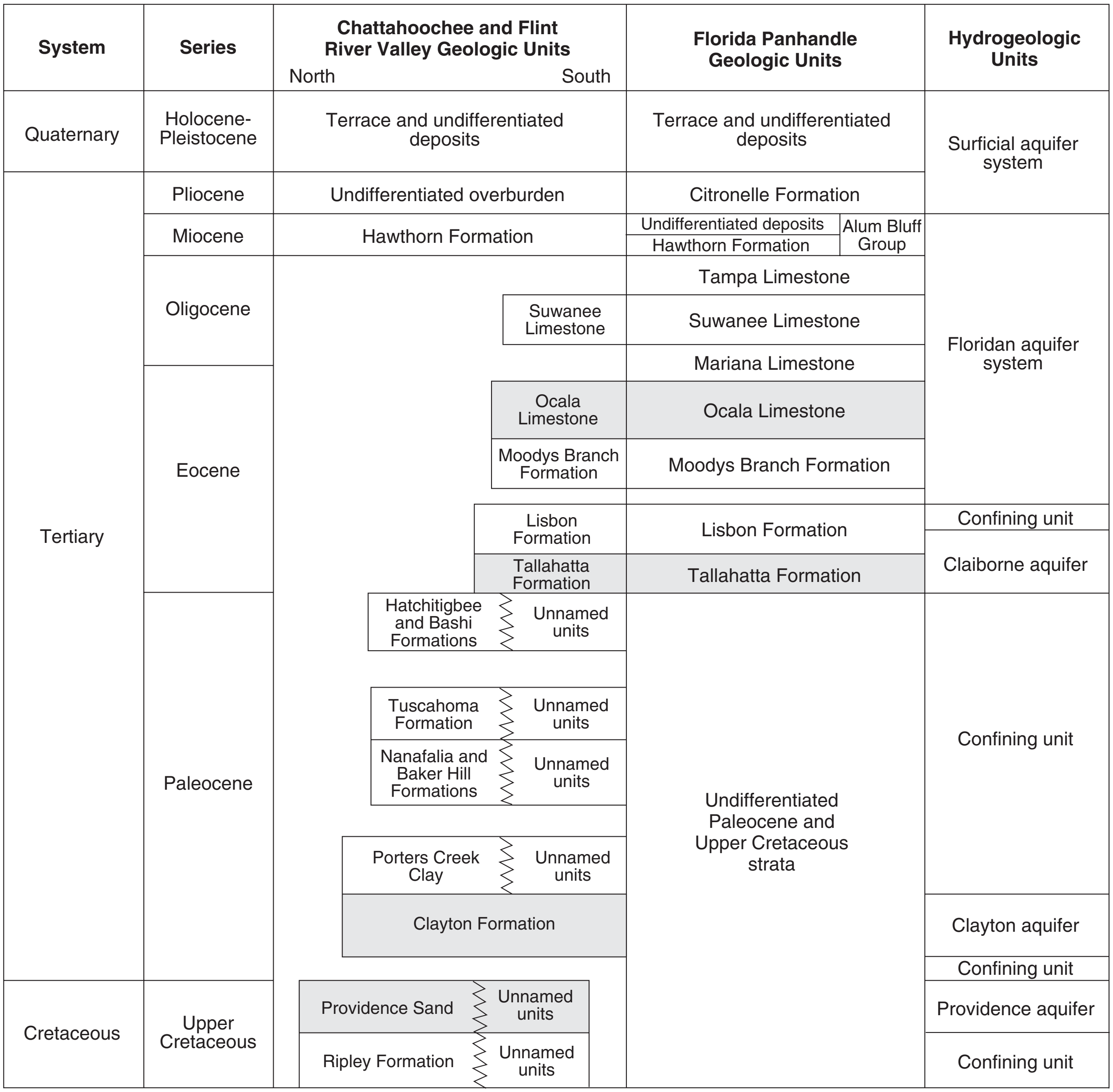


Figure 4. Generalized geologic and hydrogeologic units in the Coastal Plain of the Apalachicola–Chattahoochee–Flint River basin. Gray area represents principle water-bearing strata; blank area represents missing strata (modified from Wagner and Allen,1984; Faye and Mayer, 1996; and Georgia Geologic Survey, written communication, 1996).

several subbasins in the southern and more rural part of the study area have decreased in the last 20 years (table 1).

Forest and agriculture were the dominant land cover and land use within the ACF River basin, accounting for 59 and 29 percent of the study area, respectively (table 2). Land-use and land-cover estimates listed in table 2 and shown in figure 5 are based on 1972−78 high-altitude aerial photography (U.S. Geological Survey, 1979a−f, 1980a−c), with urban areas updated to include all census tracts with population densities greater than 1,000 people per square mile in 1990 (U.S. Bureau of Census, 1991a,b, c; Hitt, 1994). This method of updating urban land use increased estimates of urban land use in the Upper and Middle Chattahoochee subbasins (predominantly in the Metropolitan Atlanta area) from 440 mi^2 for 1972−78 to 640 mi^2 for 1990. The increase in urban land use for the entire basin was from about 820 to 1,100 mi^2 (4.1 to 5.3 percent of the study area). On a regional scale, changes in land use from the mid-1970's to the early 1990's were primarily the result of urban growth around Atlanta and conversion of row-crop agricultural land to pine trees in the Coastal Plain. Most agricultural land in the Upper and Middle

Table 1. Population distribution, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1970, 1980, and 1990
[Numbers may not add to totals because of independent rounding]

Hydrologic unit code (figure 2)	Subbasin name	Population			Percent of 1990 population	Average population density, 1990 (people per square mile of land)
		[1]1970	[2]1980	[3]1990		
03130001	Upper Chattahoochee	683,000	809,000	905,000	34	600
03130002	Middle Chattahoochee–Lake Harding	469,000	555,000	691,000	26	230
03130003	Middle Chattahoochee–Walter F. George Reservoir	263,000	267,000	276,000	10	99
03130004	Lower Chattahoochee	37,300	44,800	51,400	1.9	42
	Subtotal—Chattahoochee River basin	**1,450,000**	**1,680,000**	**1,920,000**	**73**	**230**
03130005	Upper Flint	210,000	273,000	354,000	13	140
03130006	Middle Flint	57,400	63,900	66,600	2.5	43
03130007	Kinchafoonee-Muckalee	39,000	44,000	52,300	2.0	48
03130008	Lower Flint	110,000	124,000	117,000	4.4	92
03130009	Ichawaynochaway	25,900	26,500	22,500	0.8	20
03130010	Spring	23,900	26,600	22,300	0.8	29
	Subtotal—Flint River basin	**466,000**	**558,000**	**634,000**	**24**	**76**
03130011	Apalachicola	18,300	20,700	25,800	1.0	24
03130012	Chipola	49,600	60,000	52,800	2.0	41
03130013	New	[4]4,500	[4]4,960	3,760	0.1	7
03130014	Apalachicola Bay	[4]	[4]	2,770	0.1	42
	Subtotal—Apalachicola River basin	**72,400**	**85,700**	**85,200**	**3.2**	**29**
0313	**TOTAL—Apalachicola–Chattahoochee–Flint River basin**	**1,990,000**	**2,320,000**	**2,640,000**	**100**	**130**

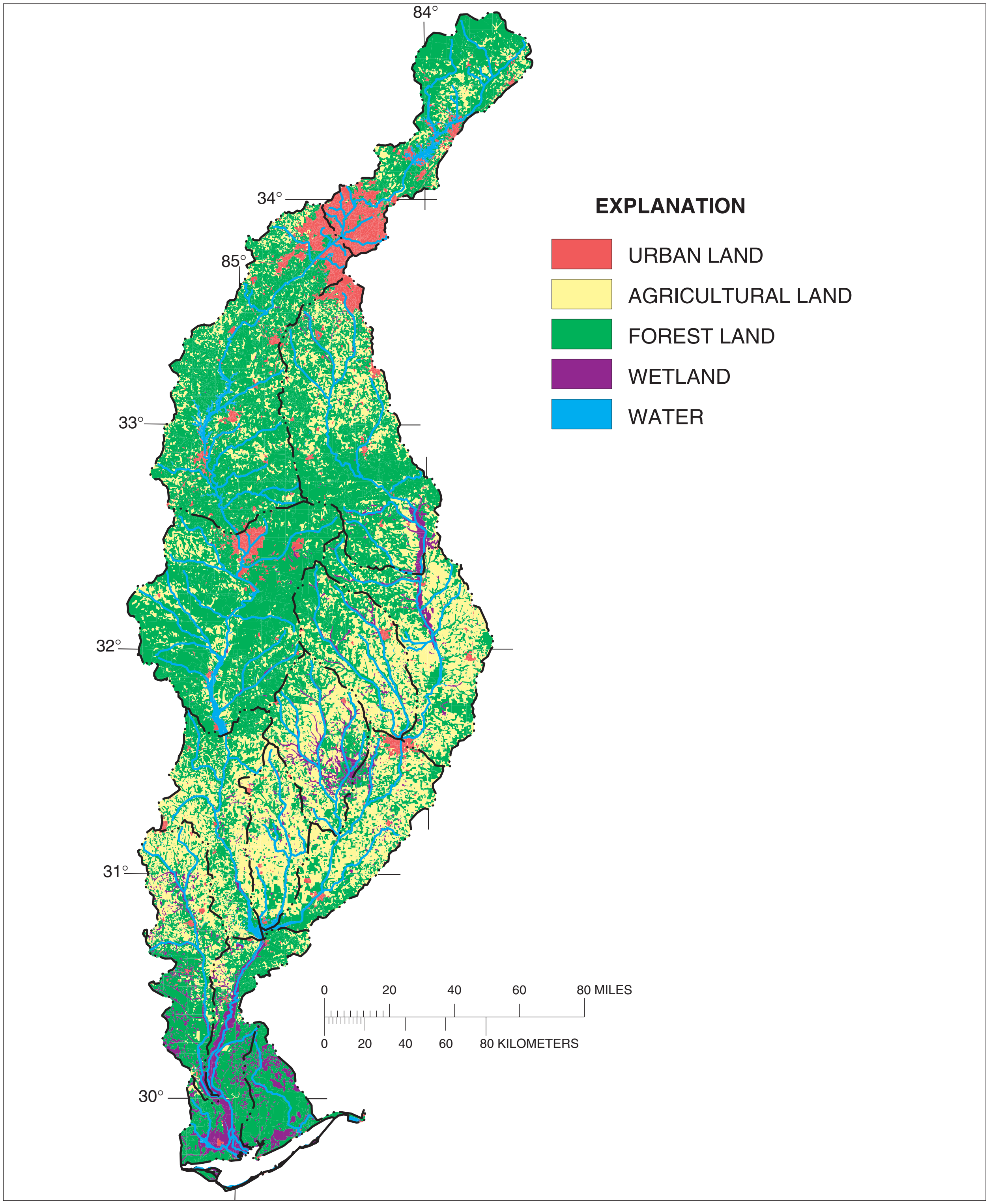
[1]Modified from U.S. Bureau of the Census 1970 population estimates by county, U.S. Bureau of the Census, 1981d; and U.S. Geological Survey, 1975a,b,c.
[3]Modified from U.S. Bureau of the Census, 1981d; and U.S. Geological Survey, 1975a,b,c.
[3]Modified from U.S. Bureau of the Census, 1991a,b,c; and U.S. Geological Survey, 1975a,b,c.
[4]Population estimates for 1970 and 1980 in the New and Apalachicola Bay subbasins are both included in New (03130013) subbasin.

Table 2. Land-use and land-cover distributions, by subbasin, Apalachicola–Chattahoochee–Flint River basin

[mi^2, square miles; <, less than; numbers may not add to totals because of independent rounding; updates of land-use data in urban areas based on U.S. Bureau of the Census 1990 population estimates; rangeland accounts for less than nine square miles (less than 0.1 percent) in the Apalachicola–Chattahoochee–Flint River basin; modified from U.S. Geological Survey (1979a–f, 1980a–c) and U.S. Bureau of the Census (1991)]

Hydrologic unit code (figure 2)	Subbasin name	Anderson Level I—Land-Use and Land-Cover Classifications												Total of classifications	
		Urban or built-up land		Agricultural land		Forest land		Water		Wetland		Barren land			
		(mi^2)	(percent)	(mi^2)	(percent)	(mi^2)	(percent)	(mi^2)	(percent)	(mi^2)	(percent)	(mi^2)	(percent)	(mi^2)	(percent)
03130001	Upper Chattahoochee	350	22	220	14	930	59	56	3.6	<1	<0.1	17	1.1	1,600	7.7
03130002	Middle Chattahoochee–Lake Harding	280	9.2	460	15	2,200	72	76	2.5	2	0.1	26	0.9	3,000	15
03130003	Middle Chattahoochee–Walter F. George Reservoir	130	4.6	420	15	2,200	77	70	2.5	20	0.7	15	0.5	2,800	14
03130004	Lower Chattahoochee	18	1.4	570	46	610	49	32	2.5	20	1.6	3	0.2	1,200	6.1
	Subtotal—Chattahoochee River basin	**780**	**9.0**	**1,700**	**19**	**5,900**	**68**	**230**	**2.7**	**42**	**0.5**	**61**	**0.7**	**8,700** [1/]8,770	**43**
03130005	Upper Flint	140	5.2	670	25	1,700	65	10	0.4	98	3.7	14	0.5	2,600	13
03130006	Middle Flint	28	1.8	790	50	660	42	15	1.0	67	4.3	2	0.1	1,600	7.7
03130007	Kinchafoonee-Muckalee	20	1.8	480	44	540	49	2	0.2	53	4.8	2	0.2	1,100	5.4
03130008	Lower Flint	53	4.1	640	50	530	41	18	1.4	43	3.3	5	0.4	1,300	6.4
03130009	Ichawaynochaway	8	0.8	550	49	400	36	3	0.3	150	14	1	0.1	1,100	5.4
03130010	Spring	9	1.2	470	61	240	32	16	2.1	26	3.3	5	0.6	770	3.8
	Subtotal—Flint River basin	**250**	**3.0**	**3,600**	**43**	**4,100**	**48**	**65**	**0.8**	**440**	**5.2**	**28**	**0.3**	**8,500** [1/]8,460	**42**
03130011	Apalachicola	13	1.2	120	10	650	58	26	2.3	310	28	4	0.3	1,100	5.5
03130012	Chipola	23	1.8	450	35	650	50	9	0.7	160	12	7	0.6	1,300	6.4
03130013	New	4	0.9	<1	<0.1	380	74	9	1.7	120	22	1	0.1	510	2.5
03130014	Apalachicola Bay	5	1.8	<1	<0.1	44	16	200	75	15	5.4	3	1.3	270	1.3
	Subtotal—Apalachicola River basin	**45**	**1.4**	**570**	**18**	**1,700**	**54**	**240**	**7.6**	**600**	**19**	**15**	**0.5**	**3,200**	**16**
0313	**TOTAL—Apalachicola–Chattahoochee–Flint River basin**	**1,100**	**5.3**	**5,800**	**29**	**11,700**	**58**	**540**	**2.7**	**1,100**	**5.3**	**100**	**0.5**	**20,400**	**100**

[1/]Unrounded drainage areas (U.S. Army Corps of Engineers, 1985).



Base from U.S. Geological Survey digital files

Figure 5. Land use, Apalachicola-Chattahoochee-Flint River basin. Barren land (120 square miles) and range land (9 square miles) are not visible at this scale (modified from U.S. Geological Survey land use and land cover digital data, 1972–78; urban areas expanded based on U.S. Bureau of the Census 1990 population estimates).

Chattahoochee and Upper Flint River subbasins is used for pastures, and to a lesser extent, poultry production, while most agricultural land in the southern ACF River basin is used for row crops and, to a lesser extent, orchards. Wetland areas accounted for about 5.4 percent of the entire basin, and as much as 14 percent of the Ichawaynochaway subbasin and 28 percent of Apalachicola subbasin. Range land, barren land, and water accounted for the remaining area.

Approximately 2,100 million gallons per day (Mgal/d) of freshwater were withdrawn from the ACF River basin in 1990, of which about 17 percent was consumptively used (Marella and others, 1993). Surface-water withdrawals were approximately 1,790 Mgal/d (85 percent of all withdrawals). Of the surface-water withdrawals, about 860 (48 percent) were for thermoelectric power generation and about 388 Mgal/d (22 percent) were for public supply in the Chattahoochee River basin (table 3). Ground-water withdrawals accounted for 303 Mgal/d (14 percent of all withdrawals), about 129 Mgal/d (43 percent) of which were for agriculture in the Flint River basin. The Floridan aquifer system supplied 44 percent of the ground water withdrawn in 1990, followed by the Claiborne, Clayton, and crystalline-rock aquifers (Marella and others, 1993, p. 11). Thermoelectric power generation accounted for 51 percent of all water withdrawals in the ACF River basin in 1990; however, less than one percent was consumed (Fanning and others, 1991, p. 24–25). Public supply accounted for 23 percent of all water withdrawals which was followed by agriculture (12 percent), self-supplied commercial and industrial (12 percent), and self-supplied domestic (2 percent); (table 3). Total water withdrawals increased by 42 percent between 1970–90; primarily because ground-water withdrawals for irrigation increased by more than 2,000 percent and surface-water withdrawals for public supply increased by more than 300 percent. Marella and others (1993) provide a more detailed description of water use in the ACF River basin in 1990 and trends in water use from 1970–90.

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NUTRIENT SOURCES

Major sources of nutrients to the ACF River basin estimated in this report include municipal-wastewater effluent, animal manure, fertilizer, and atmospheric deposition. Estimates of point-source loads and nonpoint-source inputs of nutrients for 1990 (table 4) are based on data of varying accuracy and completeness from Federal, State, and local agencies. Estimates of nutrient input to the ACF River basin from the following sources were not made: ground water flowing into the basin; leeching of nutrients from soils to ground water; organic compounds used in the basin which contain nitrogen and phosphorus; runoff from agricultural, urban, and suburban areas; septic systems; decomposition of organic matter; industrial-wastewater effluent; storm drains; and sanitary and combined sewer overflows.

Point-Source Loads

Point sources discharge directly to surface or ground water or are applied to land surface in a confined area or point. Point sources of nutrients in the ACF River basin include municipal- and industrial-storm drains, wastewater effluent, sanitary and combined sewer overflows, and untreated wastes or runoff from illegal outfall pipes. However, the only nutrient point-source loads estimated in this report were for municipal-wastewater effluent. Effluent from municipal facilities contained about one percent of estimated nitrogen sources and about two percent of estimated phosphorus sources to the ACF River basin in 1990 (table 4). While these are small percentages of the estimated nutrient sources to the basin, they are very important because unlike nonpoint-source inputs, all point-source loads of nutrients directly enter the hydrologic system.

Point-source nutrient loads from storm drains, sanitary sewer overflows (SSO), and combined sewer overflows (CSO) are not included in estimates in table 4. Storm drains transport storm runoff from streets, parking lots, and other impervious surfaces. Sanitary sewers primarily transport raw sewage to WWTF and have overflow mechanisms where excess sewage spills to streams rather than backs up into buildings and homes. During dry periods, combined sewers primarily transport raw sewage to WWTF. During and after rain events, combined sewers transport a combination of raw sewage and storm runoff. Storm runoff often exceeds the capacity of combined sewers causing a mixture of untreated sewage and storm runoff to overflow directly into streams at CSO. Data were not available to estimate nutrient loads from storm drains and SSO.

Table 3. Water withdrawals by principal water-use categories, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990

[Withdrawals are in million gallons per day; <, less than; numbers may not add to totals because of independent rounding; modified from Marella and others, 1993]

Hydrologic unit code (figure 2)	Subbasin name	Public supply		Self-supplied domestic		Self-supplied commercial and industrial		Agricultural		Thermoelectric power generation		Total freshwater withdrawals			
		Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Total	Percent of basin
03130001	Upper Chattahoochee	2.42	243	6.88	0	1.03	3.96	0.90	5.26	0	0	11.2	252	263	13
03130002	Middle Chattahoochee–Lake Harding	1.66	96.7	6.72	0	1.20	26.9	1.48	4.08	0	761	11.1	888	899	43
03130003	Middle Chattahoochee–Walter F. George Reservoir	1.70	48.3	0.94	0	0.13	37.0	1.75	6.01	0	0	4.52	91.3	95.8	4.6
03130004	Lower Chattahoochee	6.40	0	1.27	0	0.49	107	18.1	7.01	0	98.8	26.3	213	240	11
	Subtotal—Chattahoochee River basin	**12.2**	**388**	**15.8**	**0**	**2.85**	**175**	**22.3**	**22.4**	**0**	**860**	**53.1**	**1,440**	**1,500**	**71**
03130005	Upper Flint	4.35	33.5	6.20	0	0.43	2.93	6.48	7.88	0	0	17.5	44.3	61.8	2.9
03130006	Middle Flint	3.88	0	1.70	0	9.50	9.43	14.9	10.4	0	15.0	30.0	34.8	64.8	3.1
03130007	Kinchafoonee-Muckalee	5.39	0	1.42	0	1.01	0	13.0	7.48	0	0	20.8	7.48	28.3	1.3
03130008	Lower Flint	22.5	0	1.30	0	11.0	0	46.5	8.50	0	92.8	81.3	101	183	8.7
03130009	Ichawaynochaway	2.69	0	0.65	0	0.31	0	18.4	8.80	0	0	22.0	8.80	30.8	1.5
03130010	Spring	2.21	0	0.82	0	0.20	0	29.6	3.99	0	0	32.8	3.99	36.8	1.8
	Subtotal—Flint River basin	**41.0**	**33.5**	**12.1**	**0**	**22.5**	**12.4**	**129**	**47.0**	**0**	**108**	**204**	**201**	**405**	**19**
03130011	Apalachicola	1.64	0	2.16	0	2.55	0	11.1	4.78	0.37	108	17.8	113	131	6.2
03130012	Chipola	8.09	0	2.76	0	0.06	32.9	15.1	3.57	0	0	26.0	36.5	62.4	3.0
03130013	New	0.68	0	0.07	0	0	0	0	0	0	0	0.75	0	0.75	<0.1
03130014	Apalachicola Bay	0.95	0	0.07	0	0	0	0	0	0	0	1.02	0	1.02	<0.1
	Subtotal—Apalachicola River basin	**11.4**	**0**	**5.06**	**0**	**2.61**	**33.9**	**26.1**	**8.35**	**0.37**	**108**	**45.5**	**149**	**195**	**9.3**
0313	**TOTAL—Apalachicola-Chattahoochee-Flint River basin**	**64.5**	**421**	**33.0**	**0**	**27.9**	**221**	**177**	**77.8**	**0.37**	**1,080**	**303**	**1,790**	**2,100**	**100**
TOTAL–by principal water-use category		**486**		**33.0**		**248**		**255**		**1,080**		**2,100**			
PERCENT–by principal water-use category		**23**		**1.6**		**12**		**12**		**51**		**100**			

Table 4. Point-source loads and nonpoint-source inputs of nutrients, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990
[–, no available data; numbers may not add to totals because of independent rounding]

Hydrologic unit code (figure 2)	Subbasin name	Nitrogen, in tons				Phosphorus, in tons			
		Point-source loads	Non-point source inputs			Point-source loads	Non-point source inputs		
		Municipal wastewater effluent (Ammonia as nitrogen)	Animal manure (Total nitrogen)	Fertilizer (Total nitrogen)	Atmospheric deposition (Nitrate plus ammonium as nitrogen)	Municipal wastewater effluent (Total phosphorus)	Animal manure (Total phosphorus)	Fertilizer (Total phosphorus)	Atmospheric deposition (Total phosphorus)
03130001	Upper Chattahoochee	310	86,000	1,900	1,900	48	19,000	490	–
03130002	Middle Chattahoochee–Lake Harding	1,500	10,000	4,200	3,600	770	2,500	790	–
03130003	Middle Chattahoochee–Walter F. George Reservoir	390	3,300	5,200	3,400	140	870	890	–
03130004	Lower Chattahoochee	78	1,700	8,900	1,500	14	520	2,400	–
	Subtotal—Chattahoochee River basin	2,200	100,000	20,000	10,000	970	23,000	4,500	–
03130005	Upper Flint	58	7,600	5,500	3,100	32	1,800	910	–
03130006	Middle Flint	18	4,500	12,000	1,800	18	1,100	3,000	–
03130007	Kinchafoonee-Muckalee	21	2,300	6,800	1,300	10	590	1,700	–
03130008	Lower Flint	62	1,800	12,000	1,500	54	510	3,000	–
03130009	Ichawaynochaway	9	750	7,600	1,300	4	220	1,900	–
03130010	Spring	14	850	10,000	910	6	260	2,900	–
	Subtotal—Flint River basin	180	18,000	55,000	10,000	120	4,500	13,000	–
03130011	Apalachicola	11	210	1,500	1,300	5	64	680	–
03130012	Chipola	28	1,700	6,100	1,500	6	480	1,700	–
03130013	New	2	7	74	650	1	2	19	–
03130014	Apalachicola Bay	5	0	5	39	2	0	1	–
	Subtotal—Apalachicola River basin	46	1,900	7,700	3,500	14	550	2,400	–
0313	**TOTAL—Apalachicola–Chattahoochee–Flint River basin**	2,500	120,000	82,000	24,000	1,100	28,000	20,000	–

CSO discharge into the following tributaries of the Chattahoochee River in Metropolitan Atlanta—Peachtree (three), Proctor (two), and Utoy Creeks (two) (Atlanta Regional Commission, 1989). Available nutrient concentration and discharge data for these CSO (Atlanta Regional Commission, 1989; Georgia Department of Natural Resource and U.S. Environmental Protection Agency, 1987; Black, Crow, & Eidness, Inc., and Jordan, Jones, & Goulding, Inc., 1975) are too limited to accurately estimate annual nutrient loads from CSO.

In 1990, the Georgia Legislature amended the Water Quality Control Act to require cities to eliminate CSO or treat the overflow to meet State water-quality standards. From 1985–97, the city of Atlanta has implemented or has plans to implement the following three abatement methods to treat overflow from or eliminate CSO:

- screen combined sewage to remove trash and solids and add chlorine to overflow to kill bacteria before discharging wastewater;
- off-line storage of combined sewage for later treatment at WWTF; and
- separate combined sewers into sanitary sewers and storm drains (Peter R. Maye, Georgia Department of Natural Resources, written commun., 1996).

The city of Columbus has two main CSO with vortex separators treating overflow (Peter R. Maye, Georgia Department of Natural Resources, oral commun., 1996).

Municipal-wastewater effluent

Average monthly discharge and nutrient concentrations for treated municipal-wastewater effluent were obtained from monthly Discharge Monitoring Reports filed with Georgia Environmental Protection Division (GEPD), Alabama Department of Environmental Management (ADEM), and FLDER. USEPA Permit Compliance System (PCS) was used to a lesser extent. Monthly average discharge data from the above sources were augmented by the USGS Georgia Water-Use Data System (GWUDS); and discharge and nutrient-concentration data were augmented from interviews and paper files at 7 of the 8 WWTF that discharged more than 10 Mgal/d in 1990.

Nearly complete monthly average discharge records exist since 1976 for all municipal WWTF operating in the ACF River basin that discharge more than 1 Mgal/d (1.547 ft^3/s), as a result of monitoring and reporting required by the National Pollution Discharge Elimination System (NPDES). Ammonia- and phosphorus-concentration data were much less complete, partially because of varied NPDES monitoring and reporting frequency requirements among facilities. In 1976, only one municipal wastewater-treatment facility in the ACF River basin reported monthly average ammonia and phosphorus concentrations. However, by 1980, most major municipal facilities with a design capacity larger than 1 Mgal/d reported monthly average ammonia concentrations; and by 1986, all major facilities between Buford Dam (Lake Sidney Lanier) and West Point Lake reported monthly average phosphorus concentrations. Testing for nitrate, nitrite, total Kjeldahl nitrogen, total-organic nitrogen, and dissolved orthophosphate is infrequently required, and rarely performed by WWTF.

In 1990, an estimated 356 Mgal/d of treated municipal effluent (table 5) was discharged to streams or applied to land surfaces in the ACF River basin by approximately 127 municipal facilities (modified from Marella and others, 1993). Thirty-one major municipal facilities (table 6, fig. 6) accounted for about 330 Mgal/d (92 percent) and the six largest WWTF located in the Middle Chattahoochee subbasin accounted for 218 Mgal/d (61 percent) of all treated municipal effluent discharged into the ACF River basin in 1990. Effluent discharged from ten municipal WWTF that discharge more than 1 Mgal/d into the Chattahoochee River and its tributaries within Metropolitan Atlanta increased from 1980 to 1995 (fig. 7). Although not completely comparable because of differences in county boundaries and service-area boundaries for municipal wastewater, increases in discharge approximately paralleled increases in population for the five Metropolitan Atlanta counties where these WWTF discharge.

Table 5. Municipal wastewater discharges, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990
[Mgal/d, million gallons per day; numbers may not add to totals because of independent rounding; modified from Marella and others, 1993

Hydrologic unit code (figure 2)	Subbasin name	Municipal wastewater discharge information, 1990					
		Land application of effluent			Effluent discharged to surface water		
		Permitted amount[1/] (Mgal/d)	Discharge[2/]		Permitted amount[1/] (Mgal/d)	Discharge	
			Mgal/d	Percent		Mgal/d	Percent
03130001	Upper Chattahoochee	1.75	1.75	10.8	40.3	29.8	8.8
03130002	Middle Chattahoochee–Lake Harding	9.49	9.49	58.7	277	237	69.6
03130003	Middle Chattahoochee–Walter F. George Reservoir	0.02	0.02	0.1	45.3	30.3	8.9
03130004	Lower Chattahoochee	0	0	0	4.13	4.54	1.3
	Subtotal–Chattahoochee River basin	**11.3**	**11.3**	**69.6**	**366**	**301**	**88.5**
03130005	Upper Flint	[3/]3.93	[3/]3.55	[3/]22.0	11.6	6.71	2.0
03130006	Middle Flint	0.75	0.75	4.6	8.83	3.93	1.0
03130007	Kinchafoonee-Muckalee	0	0	0	4.82	3.28	1.0
03130008	Lower Flint	0	0	0	27.2	17.5	5.2
03130009	Ichawaynochaway	0	0	0	1.81	1.25	0.4
03130010	Spring	0	0	0	2.52	2.08	0.6
	Subtotal–Flint River basin	**[3/]4.68**	**[3/]4.30**	**[3/]26.6**	**56.7**	**34.8**	**10.2**
03130011	Apalachicola	0.50	0.31	1.9	2.40	1.31	0.4
03130012	Chipola	0	0	0	4.37	2.22	0.7
03130013	New	0.55	0.30	1.9	0	0	0
03130014	Apalachicola Bay	0	0	0	1.00	0.71	0.2
	Subtotal–Apalachicola River basin	**1.05**	**0.61**	**3.8**	**7.77**	**4.24**	**1.2**
0313	**TOTAL–Apalachicola–Chattahoochee–Flint River basin**	**[3/]17.0**	**[3/]16.2**	**[3/]100**	**431**	**340**	**100**

[1/] Permitted discharges are set by individual States as part of the National Pollution Discharge Elimination System (NPDES) administered by the U.S. Environmental Protection Agency.
[2/] For land-application systems where discharge data were not available, 1990 permitted amount was used as an estimate of 1990 discharge.
[3/] Includes the Shoal Creek water-pollution control plant in Spalding County, which uses land application for six months, May to October, and discharges to Shoal Creek for the remaining six months of each year.

Table 6. Nutrient loads from municipal wastewater facilities discharging more than one million gallons per day, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990

[Mgal/d, million gallons per day; mg/L, milligrams per liter; NPDES, National Pollution Discharge Elimination System; STP, Sewage Treatment Plant; WPCP, Water Pollution Control Plant; WSFPA, Water, Sewer, and Fire Protection Authority; WWTP, Waste Water Treatment Plant; –, no available data;
Data sources: Alabama Department of Environmental Management; Florida Department of Environmental Regulation; Georgia Environmental Protection Division; U.S Environmental Protection Agency, Permit Compliance System data base; U.S. Geological Survey, Georgia Water Use Data System; Individual plant Monthly Operating Reports]

Location number (figure 6)	City or county	State	NPDES permit number	Facility name	River mile upstream of the mouth of the Apalachicola River	Facility discharge information, 1990				
						Name of receiving water body or disposal system method	Permitted amount[1/] (Mgal/d)	Discharge (Mgal/d)	Nutrient loads[2/]	
									Ammonia as nitrogen (tons)	Total phosphorus (tons)
				Upper Chattahoochee (03130001)						
1	Cornelia, City of	Georgia	GA0021504	Cornelia WPCP	[3/]499.37	South Fork Mud Creek	3.0	1.39	[4/]28.0	–
2	Gainesville, City of	Georgia	GA0020168	Gainesville WPCP No 2 (Linwood Drive)	[5/]477.8	Lake Sidney Lanier	3.0	1.5	[6/]22.3	–
3	Gainesville, City of	Georgia	GA0021156	Gainesville WPCP No 1 (Flat Creek)	[7/]466.77	Flat Creek	7.0	4.2	186	3.55
4	Gwinnett County	Georgia	GA0026433	Crooked Creek WPCP	[8/]432.92	Chattahoochee River	6.5	4.6	0.51	2.39
5	Fulton County	Georgia	GA0030686	Johns Creek WPCP	[8/]431.77	Chattahoochee River	5.0	5.47	11.7	6.46
6	Fulton County	Georgia	GA0024333	Big Creek WPCP	[8/]422.88	Chattahoochee River	11.0	9.96	31.5	13.4
				Middle Chattahoochee–Lake Harding (03130002)						
7	Cobb County	Georgia	GA0026140	R.L. Sutton WPCP	[8/]408.22	Chattahoochee River	28.5	29.6	190	90.5
8	Atlanta, City of	Georgia	GA0021482	R.M. Clayton WPCP	[9/]408.17	Chattahoochee River	101	82.	730	334
9	Cobb County	Georgia	GA0026158	South Cobb WPCP	[8/]402.11	Chattahoochee River	28.0	24.4	25.4	45.4
10	Atlanta, City of	Georgia	GA0021458	Utoy Creek WPCP	[8/]399.31	Chattahoochee River	37.0	29.8	125	59.9
11	Atlanta, City of	Georgia	GA0024040	South River WPCP	[10/]399.11	Chattahoochee River	41.0	39.3	116	119
12	Fulton County	Georgia	GA0025381	Camp Creek WPCP	[8/]391.30	Chattahoochee River[11/]	13.0	12.29	115	29.8
13	Douglasville, City of	Georgia	GA0030341	Douglasville South WPCP	[7/]389.32	Annewakee Creek	1.7	1.41	10.3	2.53
14	Carroll County	Georgia	GAU020071	Carroll County Water Authority	—	Land disposal	9.45	9.45	–	–
15	Lanett, City of	Alabama	AL0023159	Lanett WWTP	[12/]304.8	Chattahoochee River	5.0	1.10	–	–
16	La Grange, City of	Georgia	GA0047244	Long Cane Creek WPCP	[7/]302.65	Long Cane Creek[13/]	8.2	7.34	20.6	–
17	Chambers County	Alabama	AL0024724	East Alabama WSFPA	[12/]298.4	Chattahoochee River	4.0	2.74	–	–
				Middle Chattahoochee–Walter F. George Reservoir (03130003)						
18	Phenix City	Alabama	AL0022209	Phenix City WWTP	[12/]264.6	Chattahoochee River	7.60	4.5	–	–
19	Columbus, City of	Georgia	GA0020516	Columbus South WPCP	[5/]262.9	Chattahoochee River	35.0	23.8	346	117
20	Eufaula, City of	Alabama	AL0020583	Eufaula WWTP	[12/]200.4	Chattahoochee River	2.0	1.33	–	–

Table 6. Nutrient loads from municipal wastewater facilities discharging more than one million gallons per day, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[Mgal/d, million gallons per day; mg/L, milligrams per liter; NPDES, National Pollution Discharge Elimination System; STP, Sewage Treatment Plant; WPCP, Water Pollution Control Plant; WSFPA, Water, Sewer, and Fire Protection Authority; WWTP, Waste Water Treatment Plant; –, no available data;
Data sources: Alabama Department of Environmental Management; Florida Department of Environmental Regulation; Georgia Environmental Protection Division; U.S Environmental Protection Agency, Permit Compliance System data base; U.S. Geological Survey, Georgia Water Use Data System; Individual plant Monthly Operating Reports]

Location number (figure 6)	City or county	State	NPDES permit number	Facility name	River mile upstream of the mouth of the Apalachicola River	Facility discharge information, 1990: Name of receiving water body or disposal system method	Permitted amount[1/] (Mgal/d)	Discharge (Mgal/d)	Nutrient loads[2/]: Ammonia as nitrogen (tons)	Total phosphorus (tons)
				Lower Chattahoochee (03130004)						
21	Dothan, City of	Alabama	AL0022764	Dothan Omusee Creek WWTP	[7/]155.57	Omusee Creek	4.0	4.26	77.5	–
				Upper Flint (03130005)						
22	Spalding County	Georgia	GA0047040	Shoal Creek WPCP[14/]	[15/]413.67	Shoal Creek (January–April, November, December) Land disposal (May–October)	1.5	[16/]1.12 [16/]0.98	–	–
23	Peachtree City	Georgia	GA0035777	Line Creek WPCP	[7/]404.15	Line Creek	2.0	1.1	0.39	–
24	Griffin, City of	Georgia	GA0030791	Potato Creek WPCP	[7/]358.07	Potato Creek	2.0	1.07	5.96	–
25	Thomaston, City of	Georgia	GA0020079	Bell Creek WPCP	[17/]358.07	Bell Creek	1.0	1.1	2.78	–
				Middle Flint (03130006)						
26	Cordele, City of	Georgia	GA0024503	Cordele WPCP	[7/]250.97	Gum Creek	5.0	2.20	1.14	[18/]10.1
				Kinchafoonee-Muckalee (03130007)						
27	Americus, City of	Georgia	GA0047767	Mill Creek WPCP[19/]	[20/]212.10 [20/]211.62	Muckalee Creek near the confluence with Mill Creek	4.4	3.04	19.6	–
				Lower Flint (03130008)						
28	Albany, City of	Georgia	GA0020991	Albany WPCP	[21/]206.9	Flint River	20.0	14.52	[22/]25.5	–
29	Camilla, City of	Georgia	GA0020362	Camilla WPCP	[7/]139.57	Big Slough	3.0	[23/]0.9	0.64	–
30	Bainbridge, City of	Georgia	GA0024678	Bainbridge WPCP	[5/]135.75	Flint River	2.5	1.32	[24/]30.3	–
				Chipola (03130012)						
31	Marianna, City of	Florida	FL0020117	Marianna STP	[25/]43.60 [25/]28.20	Chipola River	2.7	1.43	[26/]22.0	3.77
TOTAL–Effluent discharged by 31-municipal wastewater facilities[23/] that discharged more than 1 Mgal/d in 1990							**405**	**328**		
PERCENT OF—Municipal wastewater effluent discharged into the Apalachicola–Chattahoochee–Flint River basin by 31-municipal wastewater facilities[23/] discharging more than 1 Mgal/d, 1990							**90** (in percent)	**92** (in percent)		

1/ Permitted discharge (average) for individual wastewater-treatment plants. Permits are set by state regulatory agencies as part of the U.S. Environmental Protection Agency's NPDES program.

2/ Nutrient loads are estimated using the following formula:
Sum January to December (average monthly discharge (Mgal/d) x average monthly concentration (mg/L) x number of days in month x conversion factor (0.00416394)) = tons, in 1990;
Load estimates are footnoted when average monthly discharge and(or) average monthly concentration are missing for one or more months in 1990.

3/ South Fork Mud Creek flows into Mud Creek which flows into the Chattahoochee River. River mile listed is for the confluence of Mud Creek and the Chattahoochee River (U.S. Army Corps of Engineers, 1985).

4/ For Cornelia WPCP, 10 months of missing ammonia concentration data for 1990 were estimated using the average ammonia concentration for January and September 1990.

5/ River mile estimated from Victoria Trent, Georgia Geologic Survey, written commun., 1996; U.S. Army Corps of Engineers, 1985; and 1:24,000 scale topographic map.

6/ For Gainesville WPCP No 2, nine months of missing ammonia concentration data for 1990 were estimated using the average ammonia concentration for June, November, and December 1990.

7/ River mile listed is for the confluence of the tributary receiving effluent and the main stem river (Chattahoochee, Flint, or Apalachicola Rivers) (U.S. Army Corps of Engineers, 1985).

8/ Georgia Department of Natural Resources, 1994.

9/ U.S. Army Corps of Engineers, 1985; Georgia Department of Natural Resources, 1994.

10/ The Three Rivers Return outfall pipes effluent from the South River WPCP (east of the Apalachicola–Chattahoochee–Flint River basin) to the Chattahoochee River. River mile is from Georgia Department of Natural Resources, 1994.

11/ Effluent discharged to Chattahoochee River; from 1988–90 also used land disposal of sludge (Chris Crittenden, Camp Creek WPCP Supervisor, oral commun., 1993).

12/ River mile estimated from Will S. Mooty, U.S. Geological Survey, written commun, 1996; U.S. Army Corps of Engineers, 1985; and 1:24,000 scale topographic map.

13/ Long Cane Creek WPCP moved its effluent discharge location to the Chattahoochee River approximately one mile below the confluence between the Chattahoochee River and Long Cane Creek in September 1993 (Anne Westmoreland, Long Cane Creek WPCP, oral commun., 1994).

14/ Two Shoal Creeks flow from the east toward the Flint River. Shoal Creek Plant in Clayton County (NPDES Permit Number GAU020236) discharged less than 1 Mgal/d in 1990 using land application of their effluent near a reservoir near the confluence of Shoal Creek and the Flint River. Shoal Creek WPCP in Spalding County (NPDES Permit Number GA0047040) alternates between land application of effluent in the summer and discharge of effluent into Shoal Creek (which flows into Wildcat Creek, a tributary of the Flint River) in the winter.

15/ Shoal Creek flows into Wildcat Creek, which flows into the Flint River. River mile listed is for the confluence of Wildcat Creek and the Flint River (U.S. Army Corps of Engineers, 1985).

16/ In 1990, Shoal Creek WPCP in Spalding County discharged an average of 1.26 Mgal/d of effluent to Shoal Creek for the six months January to April, November, and December. Average effluent discharged to the land-application system for the six months from May to October was 0.98 Mgal/d.

17/ Bell Creek flows into Potato Creek which flows into the Flint River. River mile listed is for the confluence of Potato Creek and the Flint River (U.S. Army Corps of Engineers, 1985).

18/ For Cordele WPCP, January, February, March, and April missing total-phosphorus concentration data were estimated using average total-phosphorus concentration for seven of the eight remaining months of 1990. The July total-phosphorus concentration was 6.9 mg/L (two to three times greater than in the other seven months reported), and it was not used to estimate the four months with missing concentrations because it appears there was a problem with phosphorus removal in July.

19/ In 1990, the city of Americus Mill Creek WPCP (NPDES Permit Number GA0047767) replaced the city of Americus Muckalee Creek WPCP (NPDES Permit Number GA0025801) and Willetts Branch WPCP (NPDES Permit Number GA0025090), which both were out of service by February 1990.

20/ Muckalee Creek flows into Muckafoonee Creek, which flows into Lake Worth on the Flint River. The first river mile listed is for the confluence of the cut off to the Muckafoonee Creek and Lake Worth and the second river mile listed is for the confluence of Muckafoonee Creek and the Flint River (U.S. Army Corps of Engineers, 1985).

21/ River mile estimated from Julia L. Fanning, U.S. Geological Survey, written commun, 1996; U.S. Army Corps of Engineers, 1985; and 1:24,000 scale topographic map.

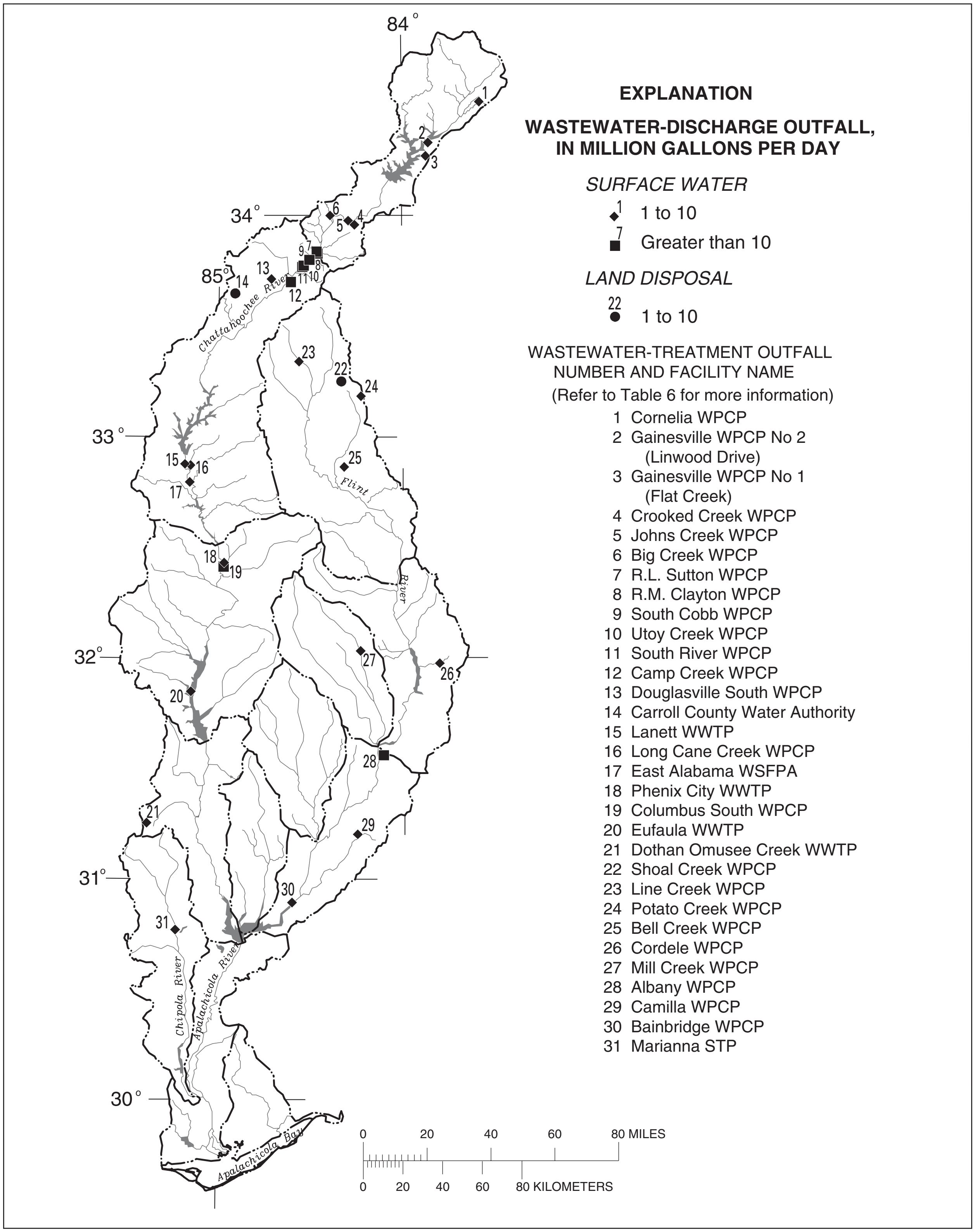
22/ For Albany WPCP, seven months of missing ammonia concentration data for 1990 were estimated using the average ammonia concentrations for January, April, July, October, and December 1990.

23/ Although effluent discharged by the Camilla WPCP was less than 1 Mgal/d in 1990, the plant is included in this table because discharges in 1989 and 1991 were larger than 1 Mgal/d (1.32 and 1.25 Mgal/d, respectively) and ammonia concentration data are available.

24/ For Bainbridge WPCP, 12 months of missing ammonia concentration data for 1990 were estimated using the average ammonia concentration for January and July 1991.

25/ The first river mile listed is for the confluence of the Chipola Cut off and the Apalachicola River and the second river mile listed is for the confluence of the Chipola River and the Apalachicola River (U.S. Army Corps of Engineers, 1985).

26/ For Marianna STP, September 1990, ammonia concentration was estimated using the average ammonia concentration for August and October 1990.



Base from U.S. Geological Survey digital files

Figure 6. Location of municipal-wastewater outfalls having discharges greater than one million gallons per day, Apalachicola-Chattahoochee-Flint River basin, 1990.

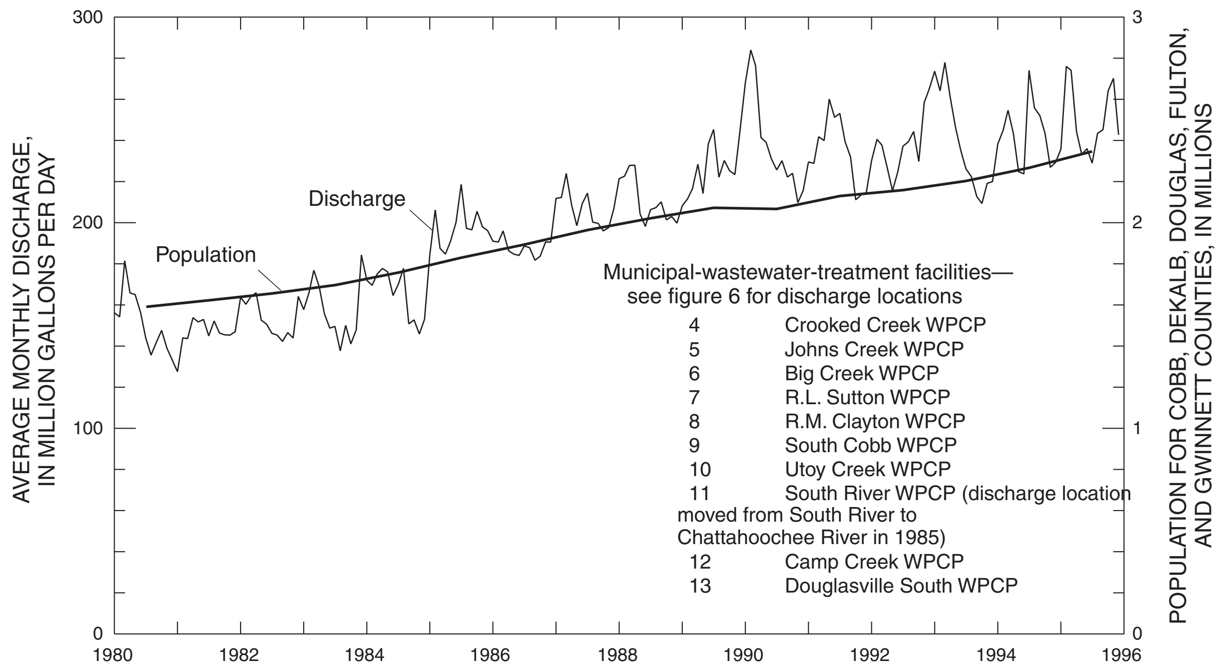


Figure 7. Effluent discharge from ten municipal-wastewater-treatment facilities that discharge more than 1 million gallons per day into the Chattahoochee River and its tributaries and population of the five counties where these facilities discharge, Metropolitan Atlanta, 1980–95 (written communications from Georgia Environmental Protection Division, 1980–95, and Atlanta Regional Commission, 1996).

Many changes in wastewater treatment and discharge within the ACF River basin occurred from 1972–90. These changes affect water quality within the basin and include, but are not limited to:

- upgrades in treatment technology;
- increased treatment capacity;
- consolidation of treatment facilities;
- opening new and closing old WWTF;
- diversion of effluent disposal from tributaries to larger streams having more assimilative capacity;
- diversion of effluent disposal from the headwaters of the Flint River, Intrenchment Creek (tributary to the South River), and the South River (part of the Ocmulgee River basin) to the Chattahoochee River; and
- increased use of land disposal of treated effluent.

The Three Rivers Water-Quality Program was implemented between 1981–85 to improve water quality in the Flint and South Rivers by diverting discharges of municipal effluent from small headwater streams to the Chattahoochee River which has more assimilative capacity. Three Rivers Water-Quality Program involved three major components: (1) abandoning the Atlanta Flint River Water Pollution Control Plant (WPCP) and piping effluent from it to the South River WPCP, (2) linking the Intrenchment Creek WPCP to the South River WPCP to treat effluent during wet weather conditions, and (3) upgrading the South River WPCP and piping its effluent to the Chattahoochee River beginning May 1985 (Atlanta Regional Commission, 1984, p. 40–44).

In 1990, municipal WWTF discharged an estimated 2,500 tons of ammonia as nitrogen and 1,100 tons of phosphorus into the ACF River basin (table 4; modified from Frick and others, 1993, p. 38). Nutrient load estimates for 1990 were calculated for 25 and 14 major municipal WWTF that reported monthly average ammonia and phosphorus concentrations, respectively (table 6). The frequency of NPDES required nutrient testing for municipal facilities within the ACF River generally ranges from five times per week for the largest WWTF to two times per year for smaller WWTFs with no drinking-water intakes downstream (James Summerville, Georgia Environmental Protection Division, oral commun., 1994). NPDES permitting at many facilities within the ACF River basin allows discharge of higher ammonia concentrations within treated effluent during the high-flow season (approximately December through May). For municipal WWTF that did not report nutrient concentrations in their effluent, average concentrations (based on ammonia-concentration data for 86 percent and phosphorus-concentration data for 76 percent of effluent discharged within the basin in 1990; modified from Frick and others, 1993, p. 38) were multiplied by the quantity of effluent discharged by these plants in 1990 to calculate loads. Although included in load estimates from WWTFs, land application of wastewater is a nonpoint-source input because much of the nutrients applied to the land surface do not reach the hydrologic system.

The combined annual phosphorus and ammonia loads from the six largest Metropolitan Atlanta area municipal WWTF that discharge into the Middle Chattahoochee subbasin declined from 1988 to 1992, even though the effluent discharge increased (Wangsness and others, 1994) (fig. 8). Phosphorus loads decreased from about 1,500 tons in 1988 to about 270 tons in 1993 because of restricted use of phosphate detergents and upgraded treatment of municipal wastewater. Amendments to the Georgia Water Quality Control Act in 1990, set standards limiting the amount of phosphorus in various household and commercial detergents and the average monthly concentration of phosphorus discharged into the Chattahoochee River between Buford Dam and West Point Lake was restricted to less than or equal to 0.75 milligrams per liter (mg/L) beginning January 1, 1992. This restriction applies to discharges permitted for 1 Mgal/d or more by the National Pollutant Discharge Elimination System. Ammonia loads from the same six Metropolitan Atlanta plants also decreased from about 2,690 tons in 1988 to about 720 tons in 1992 (fig. 8), but increased to about 970 tons in 1993, possibly a result of continually increasing volumes of treated effluent from WWTF.

Nonpoint-Source Inputs

Nonpoint-source inputs have broad source areas, ranging in areal extent from less than a square mile to thousands of square miles. A small, but often unknown, percentage of nonpoint-source inputs of nutrients enters the hydrologic system by leaching, runoff, or deposition on water surfaces. Examples of nonpoint-source inputs of nutrients from natural sources include loss of sediment-bound phosphorus from forested areas, detritus from riparian vegetation, dissolution from nitrogen-bearing minerals in aquifer materials, and leaching of nitrogen from natural soil. No attempt was made in this report to estimate nutrient input to the hydrologic system from natural

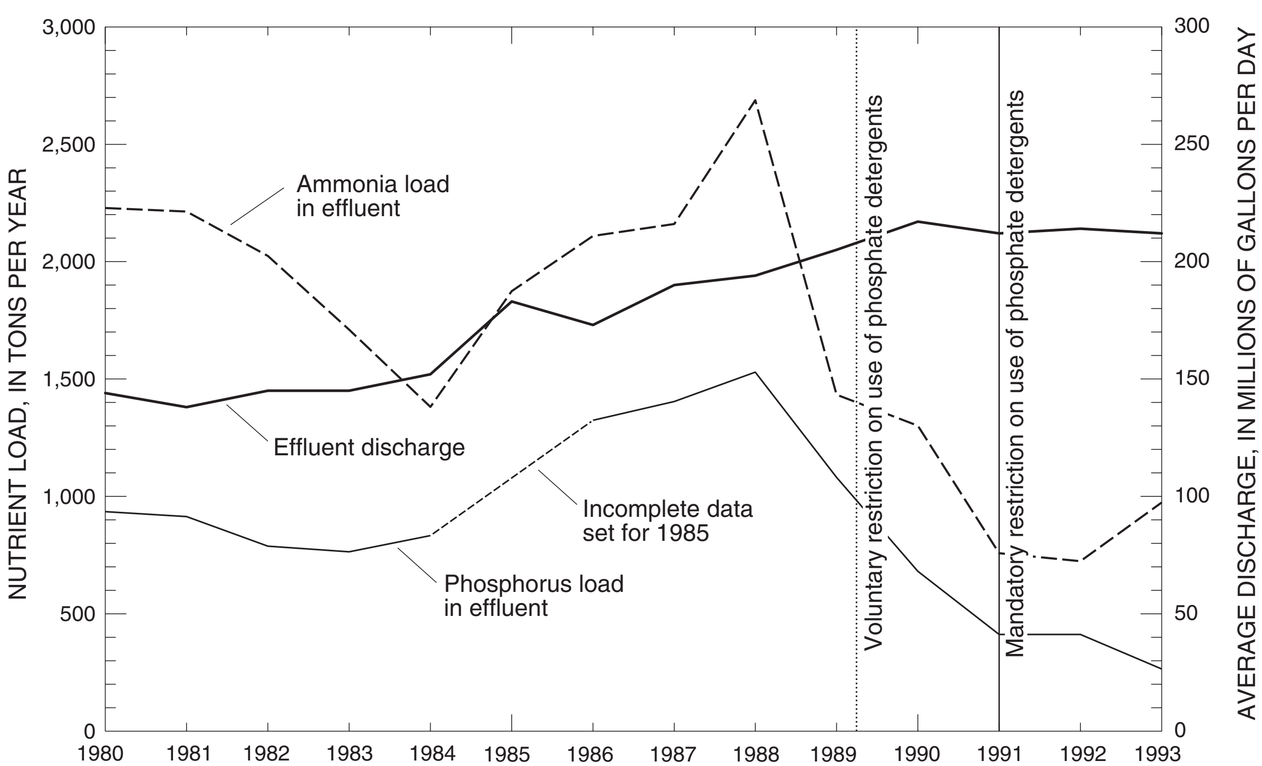


Figure 8. Effluent discharge and ammonia and phosphorus loads from the six largest municipal-wastewater-treatment facilities, Middle Chattahoochee-Lake Harding subbasin, 1980–93 (modified from Wangsness and others, 1994).

nonpoint sources. Nonpoint-source inputs of nutrients estimated in this report, which all have primarily anthropogenic sources, are animal manure, fertilizer, and atmospheric deposition. Nutrient inputs estimated in this report do not reflect volatilization, uptake by plants, nitrification, or other potential losses. Therefore, the reader should evaluate estimates of nonpoint-source inputs of nutrients as the estimated input to land and water surfaces, and realize that only some portion of that input enters surface- and ground-water resources. No attempt was made in this report to estimate runoff from agriculture, urban, suburban, and other land-use areas.

Animal manure

Animal manure, for the purpose of this report, is the aggregate of manure from poultry, cows and calves, and hogs and pigs. Agricultural statistics available for much of the period from 1974–90 indicate a substantial increase in poultry production in the ACF River basin—from about 92 million birds in 1974 to about 250 million birds in 1990. During the same time period, there was a slight decrease in the numbers of cows and calves, and hogs and pigs in the basin (U.S. Bureau of Census, 1981a,b,c, and 1989a,b,c; Alabama Agricultural Statistics Service, 1991; Florida Agricultural Statistics Service, 1991a, b; Georgia Agricultural Statistics Service, 1990 and 1991; Strong, 1990; Strong and others, 1990). Because of the large increase in poultry production, animal manure has become an increasingly important source of nutrients to the ACF River basin.

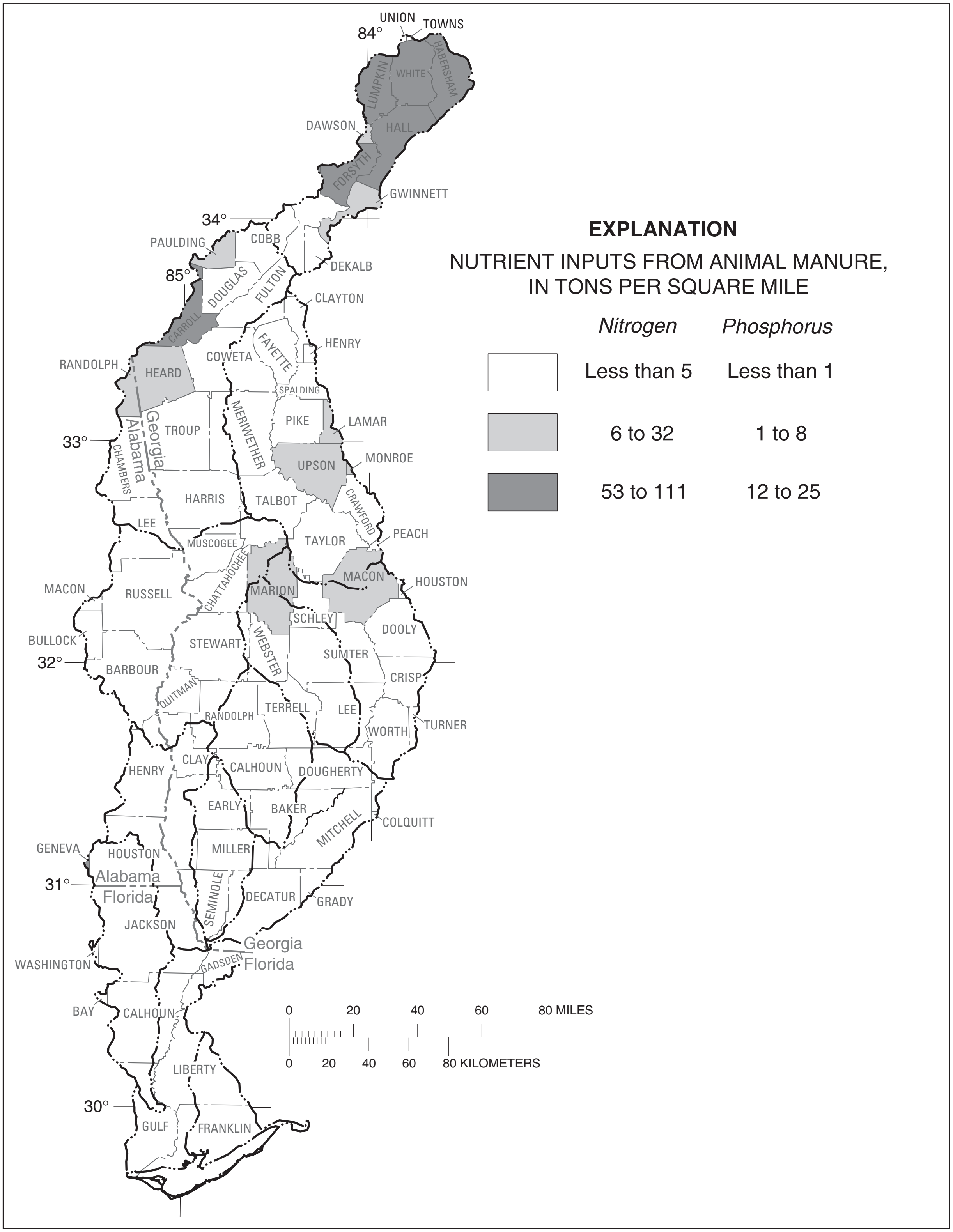
Estimates of the number of animals per county for 1990 were reported by the Alabama (1991), Florida (1991a,b), and Georgia Agricultural Statistical Services (1991). To facilitate the computation of nutrient nonpoint-source inputs from each of the three animal groups, a simplifying assumption was made that animals were distributed uniformly within each county. Estimates of the average weight of animals, the amount of manure generated per 1,000 pounds live weight of animals, and the average nitrogen and phosphorus content of manure were made using information reported by the Georgia Agricultural Statistical Service (1990, 1991) and Strong (1990). Estimates of tons of nutrients in manure generated per 1,000 pounds of live weight animals do not account for losses from volatilization that ranges from 25 to 80 percent for nitrogen, and from 5 to 15 percent for phosphorus (Kay and Hammond, 1985; McIntosh and others, 1992, p. 2–25). These estimates also do not account for variations in nutrient content when manure is applied to fields as a result of storage time and storage method. Nitrogen and phosphorus inputs from animal manure generated annually within each county were calculated by summing the results of the following equation for poultry, cows and calves, and hogs and pigs:

nitrogen or phosphorus input in tons from manure generated by the specified animal group = (number of animals in the county) x (percent of the county within the ACF River basin) x (average animal weight) x (tons of nitrogen or phosphorus in manure generated per 1,000 pounds live weight)/ (1,000 pounds). (1)

In 1990, the manure generated by about 250 million chickens, 500,000 cows and calves, and 225,000 hogs and pigs in the ACF River basin contained about 120,000 tons of nitrogen and 28,000 tons of phosphorus (table 4) (Frick and others, 1993, p. 37). Inputs from poultry and livestock manure primarily are nonpoint-source inputs to the land surface. Poultry accounts for 89 percent of the nutrient input from manure in the ACF River basin. Poultry production in 1990 was concentrated in a five-county area in the headwaters of the Chattahoochee River (fig. 9). Agricultural land use in this five-county area (Upper Chattahoochee subbasin) was predominantly pasture land used for grazing cattle and for disposing poultry manure. Estimated application rates in tons per square mile (tons/mi^2) of nitrogen and phosphorus (fig. 9) were higher than application rates for other categories of nonpoint-source inputs of nutrients, partly because of the large concentration of poultry production in a relatively small part of the basin.

Fertilizer

Nitrogen and phosphorus inputs from fertilizers were estimated for 1990 using commercial fertilizer sales figures by county (Janice T. Berry, National Fertilizer and Environmental Research Center, Tennessee Valley Authority, written commun., 1993). An average of 1989 and 1991 fertilizer sales estimates were used for Georgia, because 1990 estimates are not available. These fertilizer sales estimates were generated by a combination of sales tonnages reported by fertilizer dealers and farm expenditures for fertilizer. The following uncertainties in fertilizer-sales data increase the uncertainty of input estimates for commercial fertilizer: (1) fertilizer was not necessarily used in the same year and county where it was purchased, (2) fertilized land was not evenly distributed within counties, and (3) Georgia, Alabama, and Florida used different methods to report non-farm sales and total sales of fertilizer.



Base from U.S. Geological Survey digital files

Figure 9. Nitrogen and phosphorus inputs from animal manure, by county, Apalachicola-Chattahoochee-Flint River basin, 1990 (data from Agricultural Statistics Service of Alabama, 1991, Florida, 1991a,b, and Georgia, 1990,1991; and Strong, 1990).

In 1990, about 82,000 tons of nitrogen and 20,000 tons of phosphorus were applied as fertilizer to lands in the ACF River basin (table 4) (Frick and others, 1993, p. 37). The lower part of the basin, predominantly the row-crop agricultural areas of the Middle and Lower Flint subbasins, received the greatest input of nitrogen and phosphorus from commercial fertilizer (fig. 10).

Although not apparent from figure 10, fertilizer applications can be substantial in urban and suburban areas; however, few data are available from which to estimate nitrogen and phosphorus inputs. Fertilizer-sales data above reflect total sales without regard to farm and non-farm use. Inclusion of fertilizer sales from nurseries and retail stores in urban areas varies from state to state. Georgia did not differentiate between non-farm and farm sales of fertilizer, Alabama reported less than one percent of fertilizer sales were non-farm related, and Florida reported more than 20 percent of fertilizer sales were non-farm related (Janice T. Berry, Tennessee Valley Authority, oral commun., 1994).

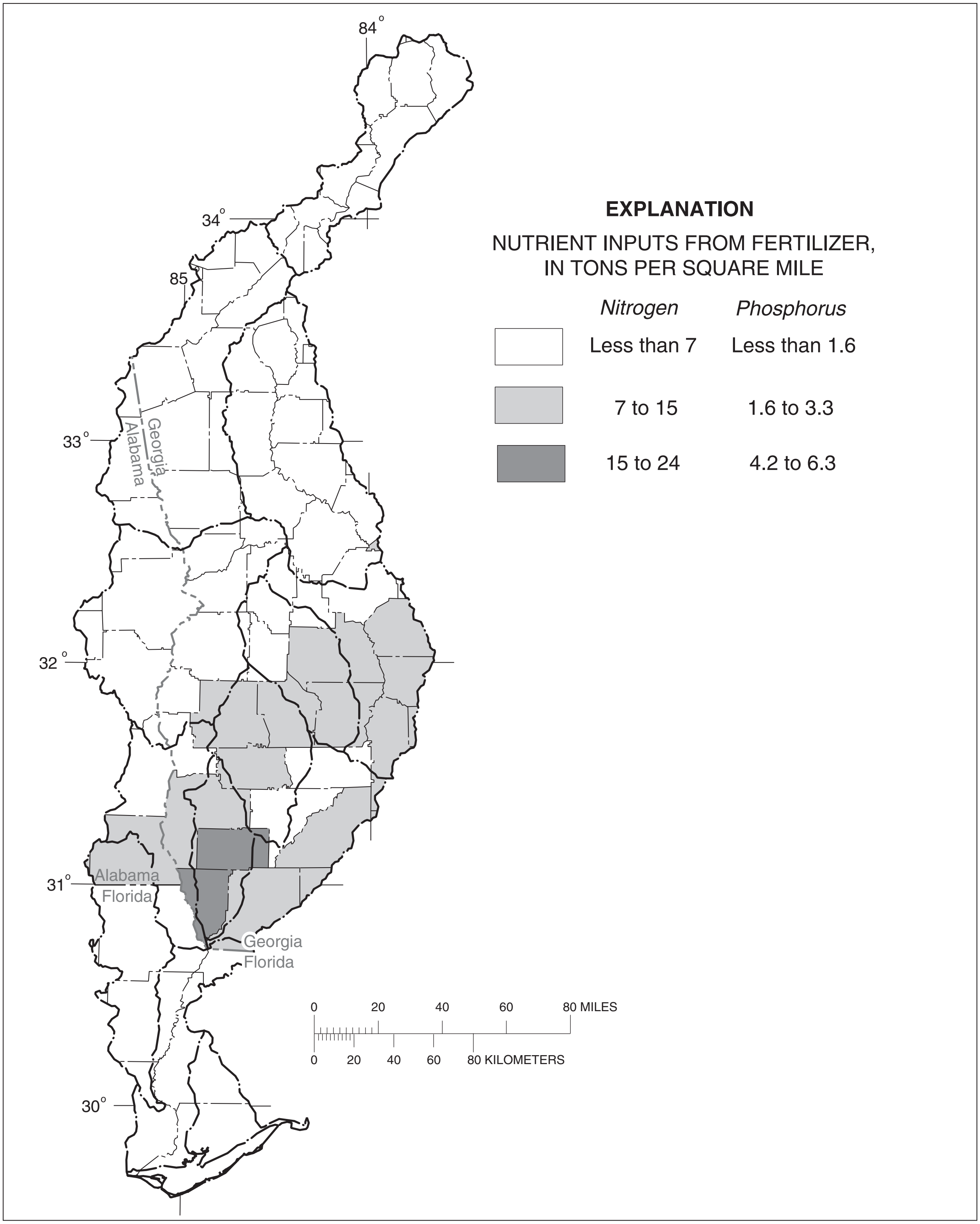
A conservative estimate of nitrogen and phosphorus input from fertilizer applied to urban and suburban lands in the ACF River basin is about 8,600 tons/yr and 2,500 tons/yr, respectively. Fertilizer application rates were based on recommended application rates for Cobb County (Tetra Tech, 1992), partially within the ACF River basin in the northwestern part of Metropolitan Atlanta. The minimum estimates reported by Tetra Tech (1992) were converted to tons of nitrogen and phosphorus per square mile of urban and suburban land and multiplied by urban-land area listed in table 2. Because several assumptions were made to derive these estimates and data were not provided at the county level for all counties, the values are not included as part of the nutrient input listed in table 4 and density estimates were not shown on figure 10. The conservative estimate of nitrogen and phosphorus inputs from fertilizer in urban and suburban areas would increase the estimate of total nutrient inputs from fertilizer by about 10 percent.

Atmospheric deposition

Nutrients from atmospheric deposition, unlike other estimated nutrient inputs, were distributed throughout the entire study area. The primary source of nitrogen in atmospheric deposition is nitrogen oxide emissions from combustion of fossil fuels. The rate of atmospheric deposition is a function of topography, nutrient sources, and spatial and temporal variations in climatic conditions.

Wet deposition of nitrogen was calculated from precipitation-chemistry data for ammonium (NH_4^+) and nitrate (NO_3^-) ion concentrations collected weekly (Colorado State University, written commun., 1993) at six National Atmospheric Deposition Program/National Trends Network (NADP/NTN) stations (fig. 11) in or near the ACF River basin. The estimate of NO_3^- wet deposition was adjusted for urban effects and droplet deposition at high altitudes (Sisterson, 1990; L.J. Puckett, U.S. Geological Survey, written commun., 1993). Dry deposition of NO_3^- (which was estimated to be nearly half of wet deposition of NO_3^-) was calculated based on wet-deposition estimates for NO_3^-, and ratios of wet and dry deposition for Alabama, Florida, and Georgia (Sisterson, 1990). Only wet-deposition estimates were made for NH_4^+ because of lack of dry-deposition estimates on a national basis; therefore, input estimates may underestimate total nitrogen deposition. No attempt was made in this report to estimate atmospheric deposition of organic nitrogen. Data are not available nationally to estimate phosphorous input from the atmosphere; however, atmospheric deposition of phosphorus probably is minor, especially compared to nitrogen (R.P. Hooper, U.S. Geological Survey, oral commun., 1993).

Atmospheric deposition of nitrogen was about 24,000 tons in 1990 calendar year (table 4) (water-year estimate used in Frick and others, 1993, p. 38), which accounts for 10 percent of nitrogen inputs estimated in this report (table 4). For 1990, estimated nitrogen deposition rates were 1.2 tons/mi^2 throughout the ACF River basin. This deposition rate was the same regardless if deposition rates were spatially averaged using an inverse-weighted average of the distance from each NADP/NTN station to a central point within four regions defined primarily by physiographic provinces or to a central point within the ACF River basin. Estimated annual atmospheric input of nitrogen to the ACF River basin from 1985 to 1991 ranged from a low of about 22,000 tons in 1988 to a high of about 36,000 tons in 1991. These are equivalent to deposition rates of 1.1 to 1.8 tons/mi^2.



Base from U.S. Geological Survey digital files

Figure 10. Nitrogen and phosphorus inputs from fertilizer, by county, Apalachicola-Chattahoochee-Flint River basin, 1990 (data from National Fertilizer and Environmental Research Center, Tennessee Valley Authority).

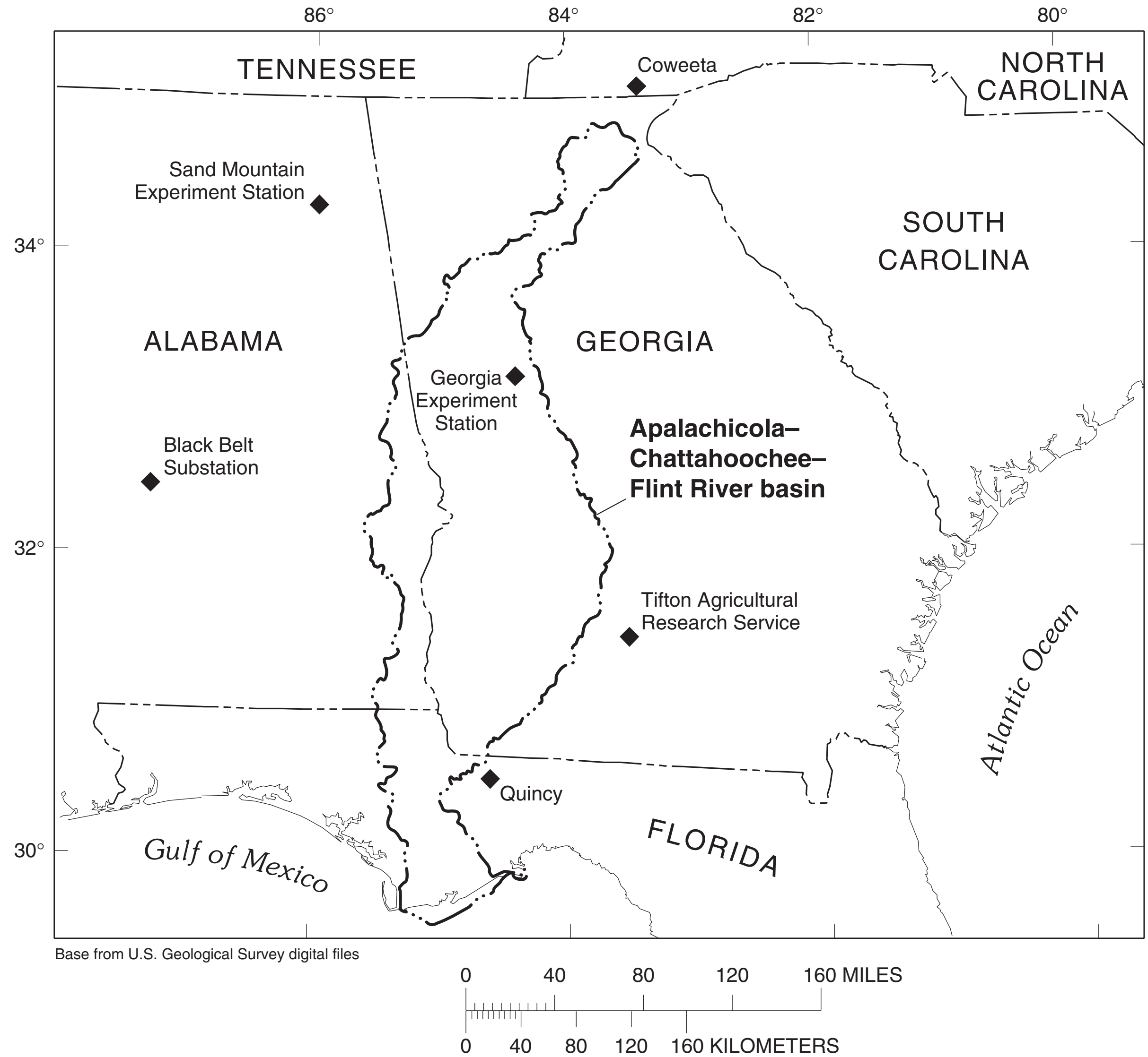


Figure 11. Location of National Atmospheric Deposition Program precipitation stations used to estimate nitrogen input from atmospheric deposition within the Apalachicola–Chattahoochee–Flint River basin.

ANALYSIS OF NUTRIENT WATER-QUALITY DATA

The emphasis of the analysis of nutrient water-quality data section of this report is to present graphical and statistical analyses describing regional variations in the presence, distribution, and transport of nutrients in surface and ground water of the ACF River basin. Nutrient water-quality standards, health advisories, and criteria are presented to help put nutrient concentrations in context. Brief descriptions of sources of nutrient water-quality data and the assessment approached used are also included.

Nutrient Water-Quality Standards, Health Advisories, and Criteria

Nitrate and nitrate plus nitrite have maximum contaminant levels (MCL) in drinking water of 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1990, 1995). Drinking water with more than 10 mg/L nitrate poses the most threat to infants because the reduction of nitrate to nitrite in their intestinal systems may prevent the transport of sufficient oxygen in their bloodstream (“blue baby syndrome” or methemoglobinemia). The draft life-time health advisory for ammonia in adults is 30 mg/L as N (U.S. Environmental Protection Agency, 1995).

Criteria for maximum ammonia concentrations in surface water are based on chronic and acute exposure of aquatic organisms to un-ionized ammonia (NH_3). These criteria vary with pH and temperature and currently are only available for surface waters with pH between 6.5 and 9.0 and temperature between 0 and 30 ^{o} C. In general, the criteria for ammonia are exceeded at lower concentrations as pH and temperature increase. At temperatures warmer than 20 ^{o} C, criteria are slightly more restrictive for surface waters where cold water species such as trout are present (Upper Chattahoochee River basin) than where cold water species are absent (Lower Chattahoochee, Flint, and Apalachicola River basins). Chronic criteria for total-ammonia (NH_3 plus NH_4^+) concentrations range from a maximum of 2.1 mg/L as N for surface waters with a pH of 6.5 and temperature of 0 ^{o} C, to 0.07 mg/L as N for surface waters with cold water species of fish present and a pH of 9.0 and temperature of 30 ^{o} C (U.S. Environmental Protection Agency, 1986).

National criteria have not been established for concentrations of phosphorus compounds in water; however, the USEPA makes the following recommendations to control eutrophication:

- total phosphorus should not exceed 0.05 mg/L (as P) where a stream enters a lake or reservoir, and
- total phosphorus should not exceed 0.1 mg/L in flowing waters that do not discharge directly into lakes or impoundments (U.S. Environmental Protection Agency, 1986).

Sources of Nutrient Water-Quality Data

A large amount of nutrient water-quality data have been collected within the ACF River basin by Federal, State, and local governments, colleges and universities, and other organizations. These water-quality data were collected to meet diverse objectives over varying temporal and spatial scales. Data reviewed and analyzed for this report were from readily available computerized data bases, except for discharge and concentration data from major WWTF, which in some cases, were computerized from paper files. No attempt was made to computerize data from other paper files or reports.

Computerized data bases used were USGS NWIS, USEPA STORET, and FLDER GWIS. Water-quality data collected or analyzed by the USGS were obtained from NWIS. STORET contains some, but not all, data collected by USEPA; USEPA contractors; other Federal agencies; and many State agencies that deal with natural resources and environmental regulation. Almost all water-quality data from GEPD and ADEM were stored in STORET. FLDER surface-water-quality data were obtained from STORET and ground-water-quality data were obtained from GWIS.

Assessment Approach

Although available nutrient water-quality data for the ACF River basin are not ideally suited to a comprehensive water-quality assessment, the data can be used to make preliminary assessments of presence, distribution, and transport of nutrients within the study area. Common limitations of existing nutrient water-quality data that can bias water-quality assessments include:

- unknown or limited information on quality-control procedures related to sample collection, laboratory analysis, and data storage;
- varying or unknown sampling, preservation, and analytical techniques used among and, in some cases, within agencies;
- varying accuracy of reported sampling locations;
- uneven areal, vertical, and temporal distribution;
- clustering of samples around known or suspected contamination or event sampling;
- missing information on flow conditions and sample type (grab, composite, depth integrated) for surface-water samples; and
- lack of data on well construction, sampling depth, water level, and aquifer characteristics for ground-water samples.

Grab samples may provide biased results if concentrations of dissolved and suspended constituents are not homogeneous in the cross section at the sampling sites. Limitations that primarily affect load and trend calculations, and subsequent comparisons among surface-water sites include: (1) varying sampling frequencies, (2) different periods of record, and (3) insufficient sampling of high flow events, the hydrologic condition during which a major percentage of transport occurs for many nutrient species.

Graphical and nonparametric statistical methods were used to analyze the nutrient data in this report. Nonparametric statistical methods use ranks of the data rather than the data themselves, involve robust techniques that are less sensitive to extreme values than standard parametric statistics, do not require artificial substitutions for censored data, and do not require assumptions about the distribution or variance of the data. Analyses of water-quality data are better suited to nonparametric than parametric statistical methods because distributions of water-quality data are rarely known, but are often log-normally distributed and may vary among constituents, time periods, and locations (Helsel, 1990, p. 1769).

Data compilation and screening

The three computerized data bases used in this report store water-quality data by parameter codes. Data stored by many of these parameter codes are similar enough that, for the purposes of this report, data were reformatted and combined to reduce the number of nutrient constituent groups analyzed and to increase spatial and temporal distribution of available data for each nutrient constituent group analyzed. Six constituent groups for nitrogen (total nitrogen, total-inorganic nitrogen, total-organic nitrogen, dissolved ammonia, dissolved nitrate, and dissolved-organic nitrogen) and two constituent groups for phosphorus (total phosphorus and dissolved orthophosphate) were created by using algorithms to reformat and combine data stored by similar parameter codes within and among the three computerized data bases (table 7). Algorithms used to transform source data into selected nutrient constituent groups included (1) converting concentrations reported in radical form to elemental form (such as PO_4 to as P), (2) converting to consistent units of measure (such as from µg/L to mg/L), (3) assuming the predominant form of a nutrient species for some constituent groups (such as assuming most ammonia is dissolved so that total ammonia is a reasonable approximation of dissolved ammonia), and (4) adding or subtracting data stored in two or more parameter codes to estimate the concentration of a nutrient species that was not directly measured (such as total nitrogen equals ammonia plus organic nitrogen plus nitrate plus nitrite).

For each of the eight constituent groups, a single censoring limit had to be selected so data could be ranked. This censoring limit, listed in table 7, was either the highest analytical reporting limit or the most common analytical reporting limit. All nutrient analyses with reported values smaller than the censoring limit were changed to “less than” the censoring limit, and the few analyses with “less-than” values larger than the censoring limit were changed to missing values.

Nutrient analyses stored in more than one data base were combined to eliminate duplicates. Unusually high or low concentrations (outliers) were checked against published reports and original data bases. If typographical errors were obvious, values were corrected; otherwise, all outliers were included in graphical and statistical analyses. Because of the lack of information on sample collection purpose, attempts were not made to omit data collected as part of local contamination assessment studies. Data known to be from intensive sampling over a short period of time and not representative of the 1972−90 period of interest were not used for some graphical and statistical analyses.

Nutrient data from 1972−90 for any individual well or spring in the study area were insufficient for trend analyses. To eliminate spatial bias of data from wells and springs having multiple-nutrient samples, the median concentration for each well and spring was used for each nutrient constituent group.

Nutrient data from 1972−90 water years for the ACF River basin are summarized in table 8 by nutrient constituent group, by agency, and by source of water (streams, reservoirs and lakes, wells, and springs). In surface water, total phosphorus, dissolved ammonia, dissolved nitrate, and total-inorganic nitrogen have the most available nutrient data. Ground-water-nutrient data are much more limited, in terms of collecting agencies, spatial and temporal distribution, and nutrient constituents. Most available ground-water-nutrient data were dissolved-nitrate concentrations.

Distribution of sampling sites

Temporal distribution of nutrient water-quality samples from surface water (streams, and reservoirs and lakes) and ground water (wells and springs) for 1972−90 water years are shown in figure 12. The increase in the number of nutrient samples collected from streams in 1976−77 was primarily the result of the USGS Upper Chattahoochee River Quality Assessment (Cherry and others, 1980). The increase in the number of nutrient samples collected in reservoirs and lakes in 1978−79 primarily was the result of several Water Quality Management Studies funded by the U.S. Army Corps of Engineers (Diane Findley, U.S. Army Corps of Engineers, oral commun., 1994). The increase in the number of nutrient samples collected in wells from 1985 to 1990 was the result of statewide ground-water-monitoring programs in Georgia and Florida.

Table 7. Summary of algorithms used to transform source data collected in the Apalachicola–Chattahoochee–Flint River basin into selected nutrient constituent groups

[mg/L, milligrams per liter; µg/L, microgram per liter; mg/kg, milligram per kilogram; N, nitrogen; NO_2, nitrite; NO_3, nitrate; NH_3, ammonia; P, phosphorus; PO_4, phosphate]

Selected nutrient constituent groups (censoring limit, mg/L)	Constituents from source data bases[1/]		Algorithm used to transform data from source data bases
	Parameter name	Parameter code	
Dissolved ammonia	Nitrogen, ammonia, dissolved (mg/L as N)	00608	Use if available.
(0.02)	Nitrogen, ammonia, dissolved (mg/L as NH_3)	71846	If p00608 is null, then use p71846 x 0.776486.
	Nitrogen, ammonia, total (mg/L as N)	00610	If p00608 and p71846 are null, then use p00610.
	Nitrogen, ammonia, total (mg/L as NH_3)	71845	If p00608, p71846, and p00610 are null, then use p71845 x 0.776486.
	Ammonia, un-ionized (mg/L as N)	00619	If p00608, p71846, p00610, and p71845 are null, then use p00619 x 0.822443.
	Ammonia, un-ionized, total (mg/L as N)	00612	If p00608, p71846, p00610, p71845, and p00619 are null, then use p00612.
Total-organic nitrogen	Nitrogen, organic, total (mg/L as N)	00605	Use if available.
(0.1)	Nitrogen, ammonia plus organic, total (mg/L as N) - dissolved ammonia	00625 - **dissolved ammonia**	If p00605 is null, then use p00625 - **dissolved ammonia**.
Total nitrogen	Nitrogen, total (mg/L as N)	00600	Use if available.
(0.12)	Nitrogen, ammonia plus organic, total (mg/L as N) + Nitrogen, nitrite plus nitrate, total (mg/L as N)	00625 + 00630	If p00600 is null, then use p00625 + p00630.
	(Nitrogen, nitrite, total (mg/L as N) or Nitrogen, nitrite, total (mg/L as NO_2) or Nitrogen, nitrite, dissolved (mg/L as N) or Nitrogen, nitrite, dissolved (mg/L as NO_2)) + (Nitrogen, nitrate, total (mg/L as N) or Nitrogen, nitrate, total (mg/L as NO_3) or Nitrogen, nitrate, dissolved (mg/L as N) or Nitrogen, nitrate, dissolved (mg/L as NO_3))	(00615 or 71855 or 00613 or 71856) + (00620 or 71850 or 00618 or 71851)	If p00630 is null, then substitute one of the following in the above equation for p00630: (p00615 or (p71855 x 0.304457) or p00613 or (p71856 x 0.304457)) + (p00620 or (p71850 x 0.225897) or p00618 or (p71851 x 0.225897)) or
	Nitrogen, inorganic (NO_2 + NO_3 + NH_3), total (mg/L as N) - **dissolved ammonia**	00640 - **dissolved ammonia**	p00640 - **dissolved ammonia** or
	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	00631	p00631 or
	Nitrogen, nitrate, total (mg/L as N) or Nitrogen, nitrate, total (mg/L as NO_3) or Nitrogen, nitrate, dissolved (mg/L as N) or Nitrogen, nitrate, dissolved (mg/L as NO_3)	00620 or 71850 or 00618 or 71851	p00620 or (p71850 x 0.225897) or p00618 or (p71851 x 0.225897) or
	Nitrogen, nitrite, total (mg/L as N) or Nitrogen, nitrite, total (mg/L as NO_2) or Nitrogen, nitrite, dissolved (mg/L as N) or Nitrogen, nitrite, dissolved (mg/L as NO_2)	00615 or 71855 or 00613 or 71856	p00615 or (p71855 x 0.304457) or p00613 or (p71856 x 0.304457).

Table 7. Summary of algorithms used to transform source data collected in the Apalachicola–Chattahoochee–Flint River basin into selected nutrient constituent groups—Continued

[mg/L, milligrams per liter; µg/L, microgram per liter; mg/kg, milligram per kilogram; N, nitrogen; NO_2, nitrite; NO_3, nitrate; NH_3, ammonia; P, phosphorus; PO_4, phosphate]

Selected nutrient constituent groups (censoring limit, mg/L)	Constituents from source data bases[1/]		Algorithm used to transform data from source data bases
	Parameter name	Parameter code	
	Nitrogen, inorganic ($NO_2 + NO_3 + NH_3$), total (mg/L as N) + **total-organic nitrogen**	00640 + **total-organic nitrogen**	If **total nitrogen** is null, then substitute p00640 + **total-organic nitrogen**.
Total-inorganic nitrogen	Nitrogen, inorganic, total (mg/L as N)	00640	Use if available.
(0.04)	Nitrogen, nitrite plus nitrate, total (mg/L as N) + dissolved ammonia	00630 + **dissolved ammonia**	If p00640 is null, then use p00630 (or its substitutes as calculated for **total nitrogen**) + **dissolved ammonia**.
Dissolved-organic nitrogen (0.1)	Nitrogen, ammonia plus organic, dissolved (mg/L as N) - dissolved ammonia	00623 - **dissolved ammonia**	Use if available.
Dissolved nitrate	Nitrogen, nitrate, dissolved (mg/L as N)	00618	Use if available.
(0.01)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) - Nitrogen, nitrite, dissolved (mg/L as N)	00631 - 00613	If p00618 is null, then use p00631 - p00613.
	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	00631	If **dissolved nitrate** is null, then use p00631.
	Nitrogen, nitrite plus nitrate, total (mg/L as N) - Nitrogen, nitrite, total (mg/L as N)	00630 - 00615	If **dissolved nitrate** is null, then use p00630 - p00615.
	Nitrogen, nitrate, total (mg/L as N)	00620	If **dissolved nitrate** is null, then use p00620.
	Nitrogen, nitrite plus nitrate, total (mg/L as N)	00630	If **dissolved nitrate** is null, then use p00630.
	Nitrogen, inorganic, total (mg/L as N) - **dissolved ammonia**	00640 - **dissolved ammonia**	If **dissolved nitrate** is null, then use p00640 - **dissolved ammonia**.
Total phosphorus	Phosphorus, total (mg/L as P)	00665	Use if available.
(0.02)	Phosphorus total (mg/L as PO_4)	71886	If p00665 is null, then use p71886 x 0.326138.
	Phosphate, total (mg/L as PO_4)	00650	If p00665 and p71886 are null, then use p00650 x 0.326138.
	Phosphate, poly, total (mg/L as PO_4)	00655	If p00665, p71886, and p00650 are null, then use p00655 x 0.326138.
	Phosphorus (P), water, total recoverable µg/L	00662	If p00665, p71886, p00650, and p00655 are null, then use 00662 x 0.001.
	Phosphate, total, colorimetric method (mg/L as P); water, total	70505	If p00665, p71886, p00650, p00655, and p00662 are null, then use p70505.
	Phosphorus orthophosphate, total (mg/L as P)	70507	If p00665, p71886, p00650, p00655, p00662, and p70505 are null, then use p70507.
Dissolved orthophosphate	Phosphorus, orthophosphate, dissolved (mg/L as P)	00671	Use if available.
(0.02)	Phosphate, ortho, soluble, (mg/L as PO_4); water, total	71889	If p00671 is null, then use p71889 x 0.326138.
	Phosphate, dissolved (mg/L as PO_4)	00653	If p00671 and p71889 are null, then use p00653 x 0.326138.
	Phosphate, ortho, dissolved (mg/L as PO_4)	00660	If p00671, p71889, and p00653 are null, then use p00660 x 0.326138.
	Phosphorus, dissolved (mg/L as P)	00666	If p00671, p71889, p00653, and p00660 are null, then use p00666.

Table 7. Summary of algorithms used to transform source data collected in the Apalachicola–Chattahoochee–Flint River basin into selected nutrient constituent groups—Continued

[mg/L, milligrams per liter; µg/L, microgram per liter; mg/kg, milligram per kilogram; N, nitrogen; NO_2, nitrite; NO_3, nitrate; NH_3, ammonia; P, phosphorus; PO_4, phosphate]

Selected nutrient constituent groups (censoring limit, mg/L)	Constituents from source data bases[1/]		Algorithm used to transform data from source data bases
	Parameter name	Parameter code	
Data available for the Apalachicola-Chattahoochee-Flint River basin, but not used is this report	Nitrogen, dissolved (mg/L as N)	00602	Not used.
	Nitrogen, organic, dissolved (mg/L as N)	00607	Not used.
	Nitrogen, ammonia plus organic, suspended, total (mg/L as N)	00624	Not used.
	Nitrogen, ammonia plus organic, dissolved, one determination (mg/L as N)	00636	Not used.
	Total ammonia nitrogen, 30 day, total (mg/L as N)	00609	Not used—30-day statistic.
	Total Kjeldahl nitrogen, 30 day, total (mg/L as N)	00622	Not used—30-day statistic.
	Phosphorous, total, 30 day, (mg/L as P)	00664	Not used—30-day statistic.
	Nitrogen, ammonia total in bottom material, dry weight (mg/kg as N)	00611	Not used—bottom material.
	Nitrogen, ammonia plus organic total in bottom material, dry weight (mg/kg as N)	00626	Not used—bottom material.
	Nitrogen, nitrite plus nitrate total in bottom material, dry weight (mg/kg as N)	00633	Not used—bottom material.
	Nitrogen, Kjeldahl in total bottom material dry weight mg/kg	00627	Not used—bottom material.
	Phosphorus, total in bottom material, dry weight (mg/kg as P))	00668	Not used—bottom material.

[1/]U.S. Geological Survey, National Water Information System (NWIS); U.S. Environmental Protection Agency, Storage and Retrieval data base (STORET); Florida Department of Environmental Regulation, Ground Water Information System (GWIS)

Table 8. Compilation of the number of sites and nutrient analyses from Federal and State sources of digital data, by media type, Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years

[–, no available data; USGS, U.S. Geological Survey; USACOE, U.S. Army Corps of Engineers; USEPA, U.S. Environmental Protection Agency; USFS, U.S. Forest Service; GEPD, Georgia Environmental Protection Division; FLDER, Florida Department of Environmental Regulation; FGFWFC, Florida Game and Fresh Water Fish Commission; ADEM, Alabama Department of Environmental Management]

Nutrient constituent	USEPA		USACOE		USFS		USGS		FLDER		FGFWFC		GEPD		ADEM		Total	
	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses
Streams																		
TOTAL–sites and analyses	**104**	**893**	**4**	**83**	**15**	**198**	**192**	**2,308**	**81**	**502**	**38**	**309**	**134**	**7,672**	**29**	**394**	**597**	**12,359**
Total nitrogen	66	814	4	76	6	48	171	1,956	34	217	–	–	17	530	28	124	326	3,765
Total-inorganic nitrogen	67	837	4	58	1	1	180	2,161	78	460	38	299	124	5,940	18	61	510	9,817
Total-organic nitrogen	66	805	4	59	4	18	171	2,005	35	210	–	–	16	516	18	58	314	3,671
Dissolved ammonia	67	838	4	58	5	6	183	2,240	79	470	38	304	132	6,481	18	60	526	10,457
Dissolved nitrate	104	875	4	83	6	13	185	2,223	75	483	38	304	124	6,586	29	381	565	10,948
Dissolved-organic nitrogen	–	–	–	–	–	–	61	809	–	–	–	–	–	–	–	–	61	809
Total phosphorus	71	851	4	82	15	197	189	2,181	81	495	38	302	127	7,550	29	349	554	12,007
Dissolved orthophosphate	99	833	4	82	–	–	73	1,268	11	62	38	301	7	67	1	6	233	2,619
Reservoirs and Lakes																		
TOTAL–sites and analyses	**28**	**365**	**51**	**659**	**8**	**33**	**36**	**666**	**11**	**164**	**10**	**88**	**49**	**2,420**	**22**	**184**	**215**	**4,579**
Total nitrogen	19	281	51	389	2	10	11	312	6	55	–	–	20	497	22	173	131	1,717
Total-inorganic nitrogen	20	353	49	572	6	13	35	475	10	131	10	84	45	2,261	22	172	197	4,061
Total-organic nitrogen	19	280	51	324	1	5	11	465	6	50	–	–	18	431	22	171	128	1,726
Dissolved ammonia	20	352	49	572	6	13	35	659	10	132	10	85	45	2,265	22	171	197	4,249
Dissolved nitrate	28	319	51	613	8	23	35	468	10	136	10	87	49	2,308	22	182	213	4,136
Dissolved-organic nitrogen	–	–	–	–	–	–	22	122	–	–	–	–	–	–	–	–	22	122
Total phosphorus	28	360	51	651	8	33	16	487	11	163	10	85	49	2,399	22	183	195	4,361
Dissolved orthophosphate	18	219	51	655	–	–	30	630	5	17	10	86	16	287	19	96	149	1,990

Table 8. Compilation of the number of sites and nutrient analyses from Federal and State sources of digital data, by media type, Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[–, no available data; USGS, U.S. Geological Survey; USACOE, U.S. Army Corps of Engineers; USEPA, U.S. Environmental Protection Agency; USFS, U.S. Forest Service; GEPD, Georgia Environmental Protection Division; FLDER, Florida Department of Environmental Regulation; FGFWFC, Florida Game and Fresh Water Fish Commission; ADEM, Alabama Department of Environmental Management]

Nutrient constituent	USEPA		USACOE		USFS		USGS		FLDER		FGFWFC		GEPD		ADEM		Total	
	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses	Number of sites	Number of analyses
Wells																		
TOTAL–sites and analyses	–	–	–	–	–	–	127	161	30	49	–	–	43	152	4	15	[1]185	377
Total nitrogen	–	–	–	–	–	–	37	38	–	–	–	–	–	–	2	3	[1]38	41
Total-inorganic nitrogen	–	–	–	–	–	–	52	54	–	–	–	–	–	–	3	6	[1]53	60
Total-organic nitrogen	–	–	–	–	–	–	22	22	–	–	–	–	–	–	2	5	[1]23	27
Dissolved ammonia	–	–	–	–	–	–	62	64	–	–	–	–	–	–	3	8	[1]63	72
Dissolved nitrate	–	–	–	–	–	–	121	151	30	49	–	–	43	152	4	12	[1]185	364
Dissolved-organic nitrogen	–	–	–	–	–	–	32	33	–	–	–	–	–	–	–	–	32	33
Total phosphorus	–	–	–	–	–	–	24	24	27	33	–	–	–	–	4	9	[1]53	66
Dissolved orthophosphate	–	–	–	–	–	–	54	57	4	13	–	–	–	–	–	–	58	70
Springs																		
TOTAL–sites and analyses	–	–	–	–	–	–	14	16	–	–	–	–	–	–	2	3	16	19
Total nitrogen	–	–	–	–	–	–	2	2	–	–	–	–	–	–	1	1	3	3
Total-inorganic nitrogen	–	–	–	–	–	–	2	3	–	–	–	–	–	–	1	1	3	4
Total-organic nitrogen	–	–	–	–	–	–	1	1	–	–	–	–	–	–	2	3	3	4
Dissolved ammonia	–	–	–	–	–	–	2	3	–	–	–	–	–	–	2	3	4	6
Dissolved nitrate	–	–	–	–	–	–	14	16	–	–	–	–	–	–	1	1	15	17
Dissolved-organic nitrogen	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	1	1
Total phosphorus	–	–	–	–	–	–	1	2	–	–	–	–	–	–	1	1	2	3
Dissolved orthophosphate	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	1	1

[1]Less than the sum of the number of sites from each agency because of duplicate sites.

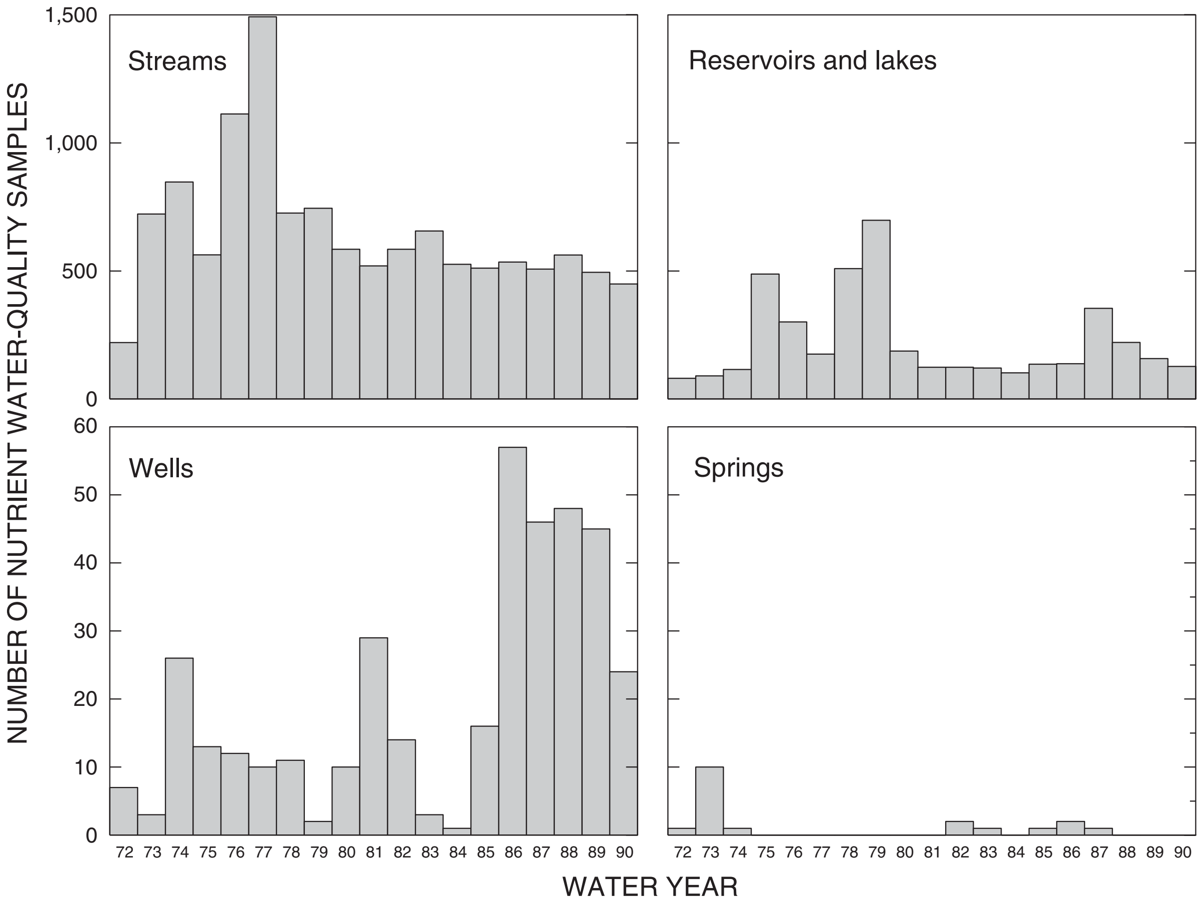


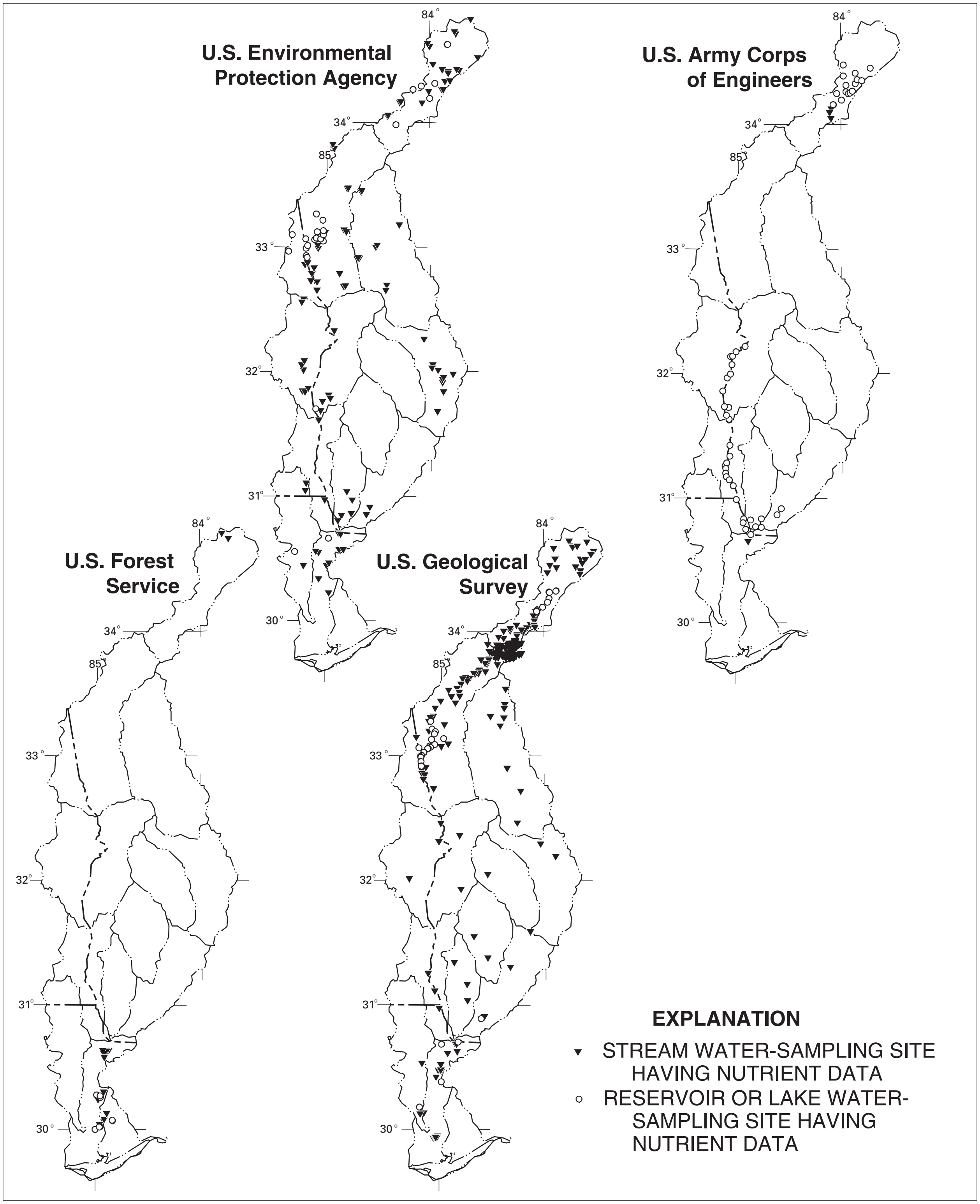
Figure 12. Number of nutrient water-quality samples analyzed from streams, reservoirs and lakes, wells, and springs, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years.

Spatial distribution of nutrient sampling sites by collection agency for 1972–90 water years are shown in figure 13 for streams, and reservoirs and lakes, and figure 14 for wells and springs. The number of nutrient analyses at each surface-water site, the temporal distribution and frequency of those analyses, and the availability of ancillary data, such as instantaneous and mean daily streamflow, determined the types of graphical and statistical analyses that were done with data from each site. Graphical and statistical analyses, number of nutrient analyses, and number of sites used for each are listed in table 9.

Nutrients in Surface Water

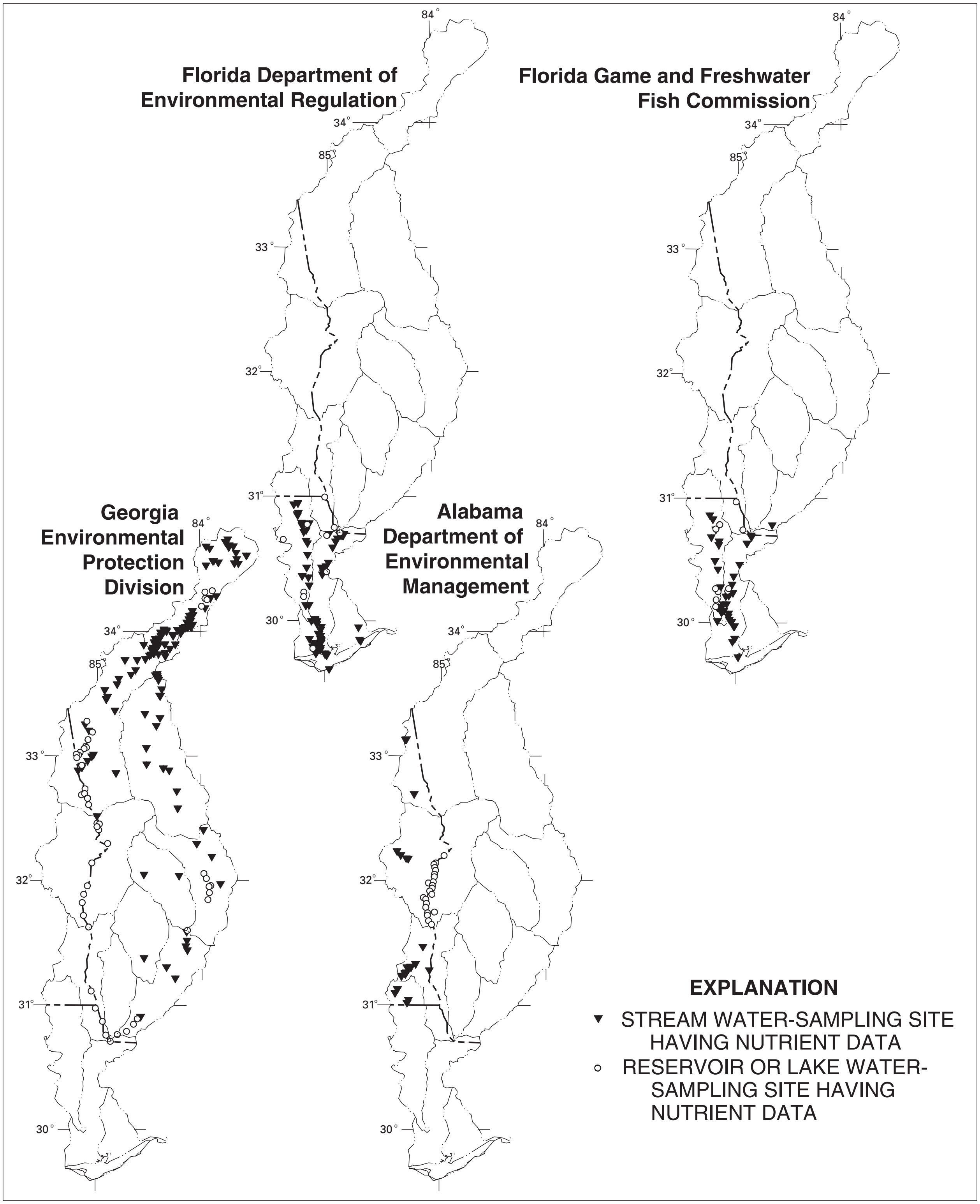
Nutrients in surface waters of the ACF River basin are of concern because high concentrations and(or) loads can be toxic to aquatic organisms and cause eutrophication of streams, lakes, and reservoirs within the basin. Nutrient outflow from the basin affects the biological productivity in Apalachicola Bay, Fla., through changes in the amount and seasonal patterns of nutrient loading to the Bay. The distribution and transport of nutrients in surface water within the ACF River basin are influenced by many factors including watershed characteristics and nutrient sources described in earlier sections of this report.

Reservoirs modify streamflow characteristics by converting riverine environments to lacustrine environments, particularly along the mainstem of the Chattahoochee River. Although ranges of nutrient concentrations for eight nutrient constituent groups measured from 1972–90 in streams (fig. 15a) are similar to ranges measured in reservoirs and lakes (fig. 15b), reservoirs potentially have a large influence on the distribution and transport of nutrients in surface water within the study area.



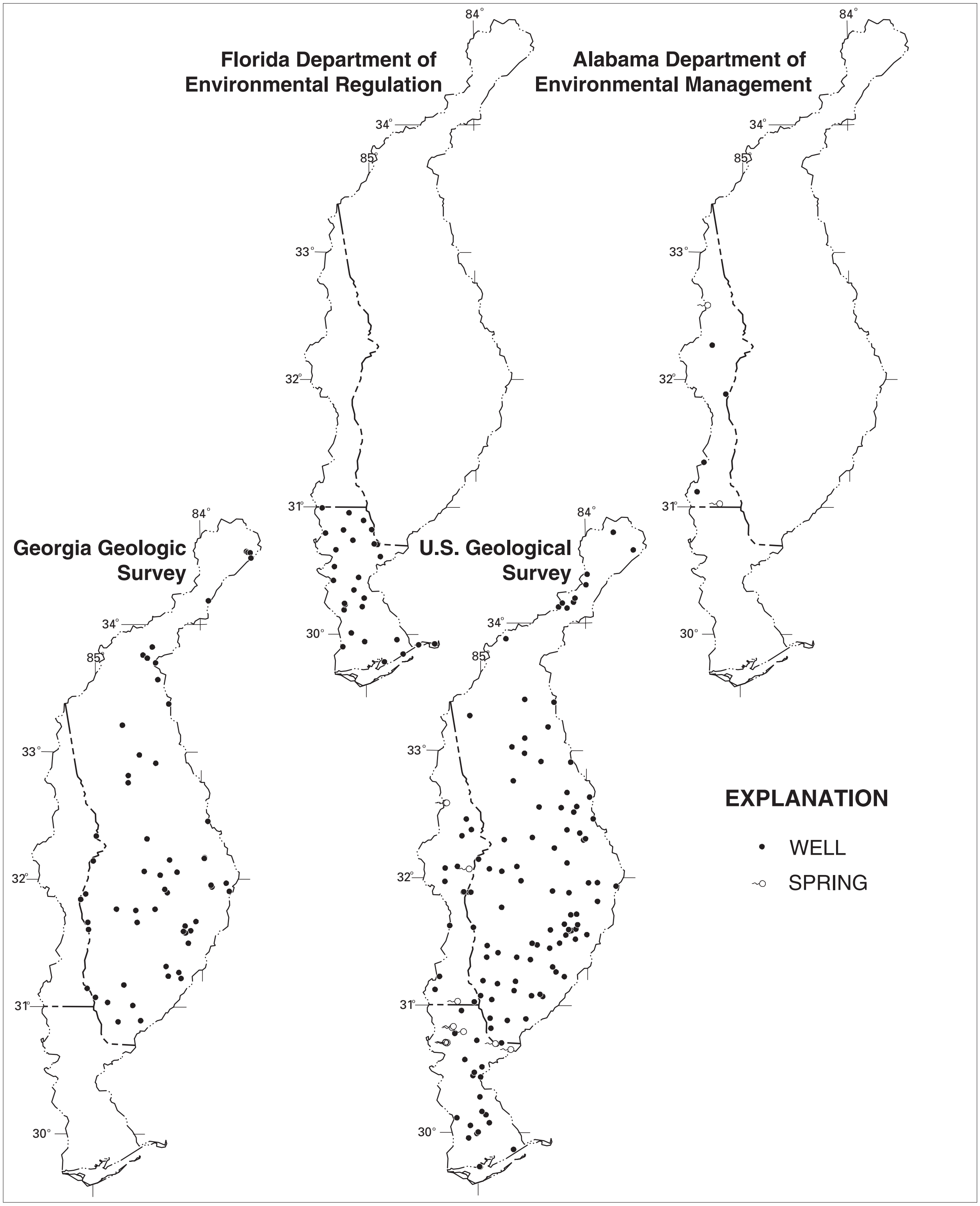
Base from U.S. Geological Survey digital files

Figure 13. Distribution of stream, reservoir, and lake water-sampling sites having nutrient data, by collection agency, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years.



Base from U.S. Geological Survey digital files

Figure 13. Distribution of stream, reservoir, and lake water-sampling sites having nutrient data, by collection agency, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years—Continued.



Base from U.S. Geological Survey digital files

Figure 14. Distribution of ground-water sampling sites having nutrient data, by collection agency, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years.

Table 9. Summary of graphical and statistical analyses of nutrient data, by media type, Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years
[–, no available data; >, greater than;
<u>*Sources of data*</u>: USEPA, U.S. Environmental Protection Agency; USACOE, U.S. Army Corps of Engineers; USFS, U.S. Forest Service;
USGS, U.S. Geological Survey; FLDER, Florida Department of Environmental Regulation; FGFWFC, Florida Game and Fresh Water Fish Commission;
GEPD, Georgia Environmental Protection Division; ADEM, Alabama Department of Environmental Management; GGS, Georgia Geologic Survey]

Type of graphical or statistical analysis	Sources of data	Period of record (water years)	Minimum number of samples per site	Number of nutrient analyses and sites (number of sites in parentheses)								
				Total nitrogen	Total-inorganic nitrogen	Total-organic nitrogen	Dissolved ammonia	Dissolved nitrate	Dissolved-organic nitrogen	Total phosphorus	Dissolved ortho-phosphate	Total nutrient analyses and sites
Streams												
Spatial distribution and graphical summary (boxplots) of concentrations by constituent groups (figure 15a)	USEPA, USACOE, USFS, USGS, FLDER, FGFWFC, GEPD, ADEM	1972–90	1	3,675 (326)	9,817 (510)	3,671 (314)	10,457 (526)	10,948 (565)	809 (61)	12,007 (554)	2,619 (233)	12,359 (597)
Relation of concentration to stream discharge (figures 17–20)	USGS, GEPD	1972–90	25	—	—	—	2,401 [1/] (13)	2,470 [1/] (13)	—	2,514 [1/] (13)	—	2,526 [1/] (13)
Graphical summary (boxplots) of concentrations by river mile (figures 22–29)	USGS, GEPD, ADEM, FLDER	1972–90	15	1,067 (15)	5,253 (33)	1,057 (15)	5,314 (33)	5,499 (34)	197 (5)	5,582 (34)	426 (9)	>5,582 (34)
Seasonal variation (figures 30–35)	USGS, GEPD	1972–90	25	—	—	—	2,034 (11)	2,084 (11)	—	2,124 (11)	—	2,136 (11)
Temporal trends (figures 36–42; table 15)	USGS, GEPD[2/], FLDER	1980–90	[3/] 32	664 (11)	3,667 (34)	640 (10)	3,947 (34)	4,073 (34)	—	4,717 (34)	137 (3)	4,750 (34)
Annual loads (figures 43–45; table 16)	USGS, GEPD, FLDER	1972–90	[4/] 40	906 (13)	4,358 (26)	893 (13)	4,411 (26)	4,493 (26)	—	4,584 (26)	323 (7)	4,608 (26)
Reservoirs and Lakes												
Spatial distribution and graphical summary (boxplots) of concentrations by constituent groups (figure 15b)	USEPA, USACOE, USFS, USGS, FLDER, FGFWFC, GEPD, ADEM	1972–90	1	1,717 (131)	4,061 (213)	1,726 (128)	4,249 (197)	4,136 (197)	122 (22)	4,361 (195)	1,990 (149)	4,579 (215)
Graphical summary (boxplots) of concentrations by river mile (figures 22–29)	USGS, GEPD	1972–90	15	1,610 [5/] (5)	3,787 [5/] (6)	1,626 [5/] (5)	3,974 [5/] (6)	3,842 [5/] (7)	122 [5/] (2)	4,042 [5/] (7)	1,740 [5/] (5)	>4,042 [5/] (7)
Seasonal variation (figures 30–35)	USGS, GEPD	1972–90	25	—	—	—	1,163 (6)	1,191 (6)	—	1,215 (6)	—	1,223 (6)
Temporal trends (figures 36–42; table 15)	USGS, GEPD	1980–90	[3/] 32	241 (5)	762 (6)	219 (5)	764 (6)	800 (6)	—	817 (6)	74 (2)	822 (6)

Table 9. Summary of graphical and statistical analyses of nutrient data, by media type, Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[–, no available data; >, greater than;

Sources of data: USEPA, U.S. Environmental Protection Agency; USACOE, U.S. Army Corps of Engineers; USFS, U.S. Forest Service;
USGS, U.S. Geological Survey; FLDER, Florida Department of Environmental Regulation; FGFWFC, Florida Game and Fresh Water Fish Commission;

Type of graphical or statistical analysis	Sources of data	Period of record (water years)	Minimum number of samples per site	Number of nutrient analyses and sites (number of sites in parentheses)								
				Total nitrogen	Total-inorganic nitrogen	Total-organic nitrogen	Dissolved ammonia	Dissolved nitrate	Dissolved-organic nitrogen	Total phosphorus	Dissolved ortho-phosphate	Total nutrient analyses and sites
Wells[6/]												
Spatial distribution and graphical summary (boxplots) of concentrations by constituent groups (figure 47a)	USGS, ADEM, FLDER, GGS	1972–90	1	38 (38)	53 (53)	23 (23)	63 (63)	185 (185)	32 (32)	53 (53)	58 (58)	185 (185)
Graphical summary (boxplots) of concentrations by aquifer (figure 49)	USGS, ADEM, FLDER, GGS	1972–90	1	—	—	—	62 (62)	182 (182)	—	51 (51)	—	185 (185)
Graphical summary (boxplots) of concentrations by water use (figure 50)	USGS, ADEM, FLDER, GGS	1972–90	1	—	—	—	56 (56)	176 (176)	—	52 (52)	—	181 (181)
Springs[6/]												
Spatial distribution and graphical summary (boxplots) of concentrations by constituent groups (figure 47b)	USGS, ADEM	1972–74, 1982–83, 1985–87	1	3 (3)	3 (3)	3 (3)	4 (4)	15 (15)	1 (1)	2 (2)	1 (1)	16 (16)

[1/] Data were analyzed from 13 sites; however, only 11 are present among figures 17 to 20.
[2/] Includes data collected by DeKalb County, Georgia, and obtained from Georgia Environmental Protection Division.
[3/] Minimum of eight years of quarterly data.
[5/] Samples collected from all sampling sites within a given reservoir are shown in a single boxplot for that reservoir in figures 22 to 29; sampling sites in Lake Seminole are divided between the Chattahoochee River arm and the Flint River arm of the reservoir.
[6/] If more than one nutrient analysis was available for a well or spring, then to reduce spatial bias, the median nutrient concentration was used.

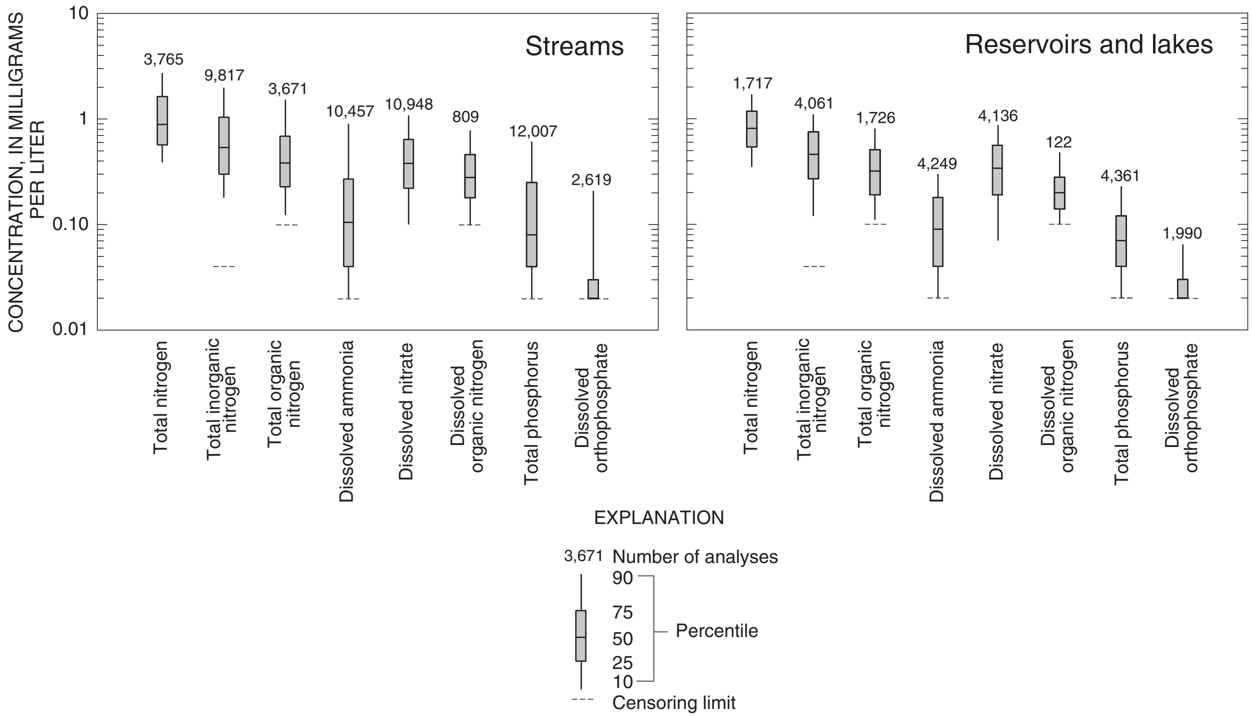


Figure 15. Distribution of nutrient concentrations in streams and reservoirs and lakes by nutrient-constituent groups, Apalachicola-Chattahoochee-Flint River basin, 1972–90 water years.

From 1972–90, nitrate concentrations in surface-water samples from the ACF River basin did not exceed the USEPA MCL of 10 mg/L nitrate as N in drinking water. However, total-phosphorus concentrations in more than 40 percent of the surface-water samples exceeded the USEPA recommendation of 0.1 mg/L total phosphorus, a concentration threshold established to control eutrophication in flowing waters. About 70 percent of surface-water samples exceeded the USEPA more restrictive recommendation of 0.05 mg/L total phosphorus, a concentration threshold recommended to control eutrophication where streams enter a lake or reservoir. About one percent of dissolved-ammonia concentrations in surface-water samples exceeded 2.1 mg/L as N, a concentration USEPA based on chronic exposure of aquatic organisms to un-ionized ammonia for most natural surface waters.

Graphical and statistical analyses of nutrients in surface water in the rest of this report are limited to sampling sites where 15 or more nutrient samples were collected during 8 or more years from 1972–90 (table 10, fig. 16). In addition to nutrient sampling sites, many gaging stations that are close enough to reasonably approximate streamflow at sampling sites are included in table 10 and figure 16. Streamflow data collected at these sites are used in trend and(or) load estimations. Characteristics such as river miles, drainage area, mean annual flow and runoff, provide information to help put nutrient data in context to the hydrologic flow system at each sampling site. Low-flow statistics, such as the 7-day, 10-year low flow of a stream, also are listed because they are often used as measures of dependable flow during periods of moderate drought and in permitting waste discharges. Location numbers in table 10 and figure 16 are used throughout the remaining surface-water tables and figures.

Relation of concentration to stream discharge

In general, as stream discharge increases at a specific location, concentration of constituents associated with point-source loads decreases in the stream because of dilution resulting in a negative relation between concentration and discharge. In contrast, concentration of constituents associated with nonpoint-source inputs generally increase as discharge increases because of runoff and stormwater-drain flow resulting in a positive relation between concentration and discharge. These very simplified relations between concentration and discharge are effected by many factors including antecedent

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
Analyses of data in this report: S, instantaneous or mean daily discharge used to estimate loads at this station or a nearby station; (S), instantaneous and(or) mean daily discharge available only prior to 1972 (prior to period of record of interest for this report); C, concentration data plotted in boxplots; (C), concentration data were combined with other concentration data collected from other locations in the same reservoir and were plotted in one boxplot per reservoir; L, annual loads reported for years with variances in load estimates less than 30 percent; T, 1980–90 trends;
Surface-water station number and name sources: A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station		River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record		Mean annual[3/]		7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s)			Index of variability[3/]
		Number	Name (Reservoir name, if applicable)			Streamflow	Nutrient measurements	Flow (ft^3/s)	Runoff (in/yr)		90	50 median	10	
			Upper Chattahoochee (03130001)											
1	S,C,L,T	02331600[U] 12030001[G]	Chattahoochee River near Cornelia, Ga.[U] Chattahoochee River - FAS 1759 down-stream from Soque River[G]	509.2	315	1957–90	1968–90	821	35.40	196	324	666	1,350	1.5
2	(C),T	12038001[G]	Chattahoochee River - Georgia Highway 369, Browns Bridge[G] (Lake Sidney Lanier)	467.7	—	—	1977–90	—	—	—	—	—	—	—
3a	S	02334430[U]	Chattahoochee River at Buford Dam near Buford, Ga.[U]	455.9	[5/]1,040	[6/]1942–55, 1956–90	1976	[6/]2,173 1,982	[6/]28.39 25.89	—[7/]	[6/]850 526	[6/]1,650 1,320	[6/]3,710 4,350	[6/]1.7 2.9
3	C,L,T	12050001[G]	Chattahoochee River - Gwinnett County Water Intake[G]	445.9	1,101	—	1974–90	—	—	—	—	—	—	—
4a	S	02335000[U]	Chattahoochee River near Norcross, Ga.[U]	438.5	[5/]1,170	[6/]1902–46, 1956–90	1976	[6/]2,265 2,259	[6/]26.31 26.24	—[7/]	[6/]860 733	[6/]1,680 1,700	[6/]4,020 4,530	[6/]1.9 2.2
4	C,L,T	12055001[G]	Chattahoochee River - DeKalb County Water Intake[G]	433.2	1,201	—	1974–90	—	—	—	—	—	—	—
5a	S	02335700[U]	Big Creek near Alpharetta, Ga.[U]	425.1 (9.3)	[5/]72	1960–90	1974–76	112	21.14	5.9	26	69	199	2.5
5	C,L,T	12060001[G]	Big Creek - Roswell Water Intake[G]	425.1 (2)	103	—	1975–90	—	—	8.4	—	—	—	—
6	C,L,T	12070001[G]	Chattahoochee River - Cobb County Water Intake[G]	418.3	1,373	—	1974–90	—	—	—	—	—	—	—

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
Analyses of data in this report: S, instantaneous or mean daily discharge used to estimate loads at this station or a nearby station; (S), instantaneous and(or) mean daily discharge available only prior to 1972 (prior to period of record of interest for this report); C, concentration data plotted in boxplots; (C), concentration data were combined with other concentration data collected from other locations in the same reservoir and were plotted in one boxplot per reservoir; L, annual loads reported for years with variances in load estimates less than 30 percent; T, 1980–90 trends;
Surface-water station number and name sources: A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station		River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record		Mean annual[3/]		7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s)			Index of variability[3/]
		Number	Name (Reservoir name, if applicable)			Streamflow	Nutrient measurements	Flow (ft^3/s)	Runoff (in/yr)		90	50 median	10	
6a, 7a	S	02336000[U]	Chattahoochee River at Atlanta, Ga.[U]	410.7	[5/]1,450	[6/]1928–31, [6/]1936–55, 1956–90	1974–89	[6/]2,567 2,524	[6/]24.05 23.65	— [7/]	[6/]901 1,040	[6/]1,890 1,880	[6/]4,530 4,950	[6/]1.9 2.1
7	C,L,T	12080001[G]	Chattahoochee River - Atlanta Water Intake[G]	408.3	1,587	—	1972–90	—	—	—	—	—	—	—
8	T	12081001[G]	North Fork Peachtree Creek - Pleasantdale Road near Doraville[D]	408.3 (—)	—	—	1975–90	—	—	—	—	—	—	—
9	T	12083001[G]	Arrow Creek - Plaster Road near Peachtree-DeKalb Airport[D]	408.3 (—)	—	—	1975–90	—	—	—	—	—	—	—
10	T	12085001[G]	North Fork Peachtree Creek - U.S. Highway 23[D]	408.3 (—)	—	—	1975–90	—	—	—	—	—	—	—
11	T	12087001[G]	South Fork Peachtree Creek - Johnson Road in Atlanta[D]	408.3 (—)	28.7	—	1975–90	—	—	1.1	—	—	—	—
12	S,C,L,T	02336300[U] 12090001[G]	Peachtree Creek at Atlanta, Ga.[U] Peachtree Creek - Northside Drive in Atlanta[G]	408.3 (4)	86.8	1958–90	1969–72 1975–90	137	21.37	9.5	23	60	268	4.1
13	T	12090201[G]	Nancy Creek - bridge 0.2 miles downstream from Chamblee-Dunwoody Road [D]	408.3 (—)	9.42	—	1975–90	—	—	—	—	—	—	—
14	T	12090401[G]	Nancy Creek - at Johnsons Ferry Road near Chamblee[D]	408.3 (—)	17.8	—	1975–90	—	—	—	—	—	—	—

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
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Surface-water station number and name sources: A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station		River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record		Mean annual[3/]		7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s)			Index of variability[3/]
		Number	Name (Reservoir name, if applicable)			Streamflow	Nutrient measurements	Flow (ft^3/s)	Runoff (in/yr)		90	50 median	10	
			Middle Chattahoochee—Lake Harding (03130002)											
15a	S	02336490[U]	Chattahoochee River at State Highway 280, near Atlanta, Ga.[U]	406.5	1,591	1981–90	1976–77	2,544	21.60	—	1,130	1,740	4,740	2.1
15	C, L, T	02336502[U] 12105001[G]	Chattahoochee River at I-285, at Atlanta, Ga.[U] Chattahoochee River - I-285 upstream from Proctor Creek[G]	405.5	1,592	—	1975–90	—	—	—	—	—	—	—
16	S, C, L, T	02337000[U] 12120001[G]	Sweetwater Creek near Austell, Ga.[U] Sweetwater Creek - Interstate Highway 20[G]	396.3 (5.5)	246	1904-05, 1913, 1937-90	1968–90	335	18.49	15	61	194	660	3.1
17	S, C, L, T	02337170[U] 12140001[G]	Chattahoochee River near Fairburn, Ga.[U] Chattahoochee River-Georgia Highway 92[G]	389.6	2,056	1965–90	1968–72, 1974–90	3,565	23.51	—	1,520	2,640	6,770	2.0
18	S, C	02337500[U]	Snake Creek near Whitesburg, Ga.[U]	369.5 (7)	35.5	1954–90	1968–79, 1990	56.0	21.45	9.2	17	39	92	1.9
19	S, C, L, T	02338000[U] 12150001[G]	Chattahoochee River near Whitesburg, Ga.[U] Chattahoochee River-Georgia Highway 16[G]	367.6	[5/]2,430	[6/]1938–54, 1965–90	1968–72, 1975–90	[6/]3,740 4,082	[6/]20.91 22.83	— [7/]	[6/]1,200 1,750	[6/]2,730 3,090	[6/]6,920 7,530	[6/]2.1 1.9
20	(C), T	02338500[U] 12170001[G]	Chattahoochee River at Franklin, Ga.[U] Chattahoochee River - U.S. Highway 27[G] (inflow to West Point Lake)	343.2	[5/]2,680	—	1975–90	—	—	—	—	—	—	—

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
<u>*Analyses of data in this report*</u>: S, instantaneous or mean daily discharge used to estimate loads at this station or a nearby station; (S), instantaneous and(or) mean daily discharge available only prior to 1972 (prior to period of record of interest for this report); C, concentration data plotted in boxplots; (C), concentration data were combined with other concentration data collected from other locations in the same reservoir and were plotted in one boxplot per reservoir; L, annual loads reported for years with variances in load estimates less than 30 percent; T, 1980–90 trends;
<u>*Surface-water station number and name sources:*</u> A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station: Number	Surface-water station: Name (Reservoir name, if applicable)	River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record: Streamflow	Period of record: Nutrient measurements	Mean annual[3/]: Flow (ft^3/s)	Mean annual[3/]: Runoff (in/yr)	7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s): 90	50 median	10	Index of variability[3/]
21	(C),T	12180001[G]	Chattahoochee River - LaGrange Water Intake[G] (West Point Lake)	323.2	—	—	1973–90	—	—	—	—	—	—	—
22	S,C,L,T	02339500[U] 12200001[G]	Chattahoochee River at West Point, Ga.[U] Chattahoochee River - 1.0 mile upstream from U.S. Highway 29[G]	306.7	[5/]3,550	[6/]1896–55, 1955–90	1968–90	[6/]5,625 5,469	[6/]21.53 20.93	— [7/]	[6/]1,660 1,050	[6/]3,840 4,310	[6/]10,800 10,000	[6/]2.4 2.1
23	C,T	02339720[U] 12190001[G]	Long Cane Creek near West Point, Ga.[U] Long Cane Creek - FAS 1765 North of West Point[G]	302.7 (5.6)	[5/]74.8	—	1974–90	—	—	8.5	—	—	—	—
24	(C),T	12210001[G]	Chattahoochee River - Upstream from Bartletts Ferry Dam[G] (Lake Harding)	>285	—	—	1972–90	—	—	—	—	—	—	—
Middle Chattahoochee—Walter F. George Reservoir (03130003)														
25	C,L,T	12212001[G]	Chattahoochee River - Columbus Water Intake[G]	[5/]271	—	—	1972–90	—	—	—	—	—	—	—
25a	S	02341500[U]	Chattahoochee River at Columbus, Ga.[U]	267.7	[5/]4,670	1929–90	1972	6,742	19.62	[7/]	1,830	5,080	12,200	2.0
26	C,T	12216001[G]	Chattahoochee River - Downstream from Columbus WTF[G] (affected by backwater from Walter F. George Reservoir)	[5/]262	—	—	1974–90	—	—	—	—	—	—	—
27	C, T	12218001[G]	Chattahoochee River - Downstream Oswichee Creek[G] (affected by backwater from Walter F. George Reservoir)	[5/]248	—	—	1974–90	—	—	—	—	—	—	—

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
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Surface-water station number and name sources: A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station		River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record		Mean annual[3/]		7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s)			Index of variability[3/]
		Number	Name (Reservoir name, if applicable)			Streamflow	Nutrient measurements	Flow (ft^3/s)	Runoff (in/yr)		90	50 median	10	
28	C, T	12219001[G]	Chattahoochee River - Seaboard Coast Line Railway, Omaha[G] (affected by backwater from Walter F. George Reservoir)	227.9	—	—	1972-90	—	—	—	—	—	—	—
Lower Chattahoochee (03130004)														
29	(S), C	02343500[G] CHA1[A]	Chattahoochee River at Columbia, Ala.[G] Chattahoochee River at Highway 52 bridge at the Georgia-Alabama state line[A]	156.7	—	1928–60	1975-83	—	—	—	—	—	—	—
30	S, C, L	02343801[UN]	Chattahoochee River near Columbia, Ala.[UN]	154.3	[5/]8,210	1975–90	1982–90	10,630	17.59	—	1,400	8,470	21,500	2.4
31	(C), T	02344040[U] 12230001[G]	Chattahoochee River near Steam Mill, Ga.[U] Chattahoochee River - Georgia Highway 91[G] (inflow to Lake Seminole, Chattahoochee Arm)	131.5	—	—	1974–90	—	—	—	—	—	—	—
Upper Flint (03130005)														
32	C,L,T	02344180[U] 11011001[G]	Flint River near Jonesboro, Ga.[U] Flint River - Georgia Highway 138[G]	445.9	39.1	—	1975–90	—	—	—	—	—	—	—
33	C,L,T	02344190[U] 11013001[G]	Flint River near Fayetteville, Ga.[U] Flint River - Georgia Highway 54[G]	441.5	49	—	1975–90	—	—	—	—	—	—	—

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
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Surface-water station number and name sources: A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station		River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record		Mean annual[3/]		7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s)			Index of variability[3/]
		Number	Name (Reservoir name, if applicable)			Streamflow	Nutrient measurements	Flow (ft^3/s)	Runoff (in/yr)		90	50 median	10	
32a, 33a, 34a	S	02344350[U]	Flint River near Lovejoy, Ga.[U]	433.5	130	1985–90	1988	167	17.42	—	29	83	346	3.8
34	C,L,T	02344380[U] 11015001[G]	Flint River near Inman, Ga.[U] Flint River - Ackert Road near Inman[G]	430.1	158	—	1975–90	—	—	—	—	—	—	—
35	C,L,T	02344400[U] 11018001[G]	Flint River above Griffin, Ga.[U] Flint River - Georgia Highway 92[G]	421.0	194	—	1975–90	—	—	—	—	—	—	—
35a	S	02344500[U]	Flint River near Griffin, Ga.[U]	412.2	272	1937–90	1972	344	17.21	15	60	188	717	3.5
36	S,C,L	02347500[U] 11050001[G]	Flint River near Culloden, Ga.[U] Flint River - U.S. Highway 19 near Culloden[G]	346.2	[5/]1,850	1911–23, 1928–31, 1937–90	1968–79, 1990	2,325	17.08	180	450	1,340	4,820	3.3
Middle Flint (03130006)														
37	S,C,L,T	02349500[U] 11060001[G]	Flint River at Montezuma, Ga.[U] Flint River - Georgia Highways 26 and 49[G]	288.4	[5/]2,900	1904–12, 1930–90	1968–74, 1976–90	3,534	16.56	680	1,070	2,350	7,030	2.5
38	(C), T	02350001[U] 11061301[G]	Flint River near Vienna, Ga.[U] Flint River - Georgia Highway 27 near Vienna[G] (inflow to Lake Blackshear)	261.9	3,390	—	1979–90	—	—	—	—	—	—	—
Kinchafoonee-Muckalee (03130007)														
39	C	02350600[U] 11065001[G]	Kinchafoonee Creek at Preston, Ga.[U] Kinchafoonee Creek- Georgia Highway 41[G]	211.6 (—)	197	—	1969–70, 1971–90	—	—	—	—	—	—	—

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
Analyses of data in this report: S, instantaneous or mean daily discharge used to estimate loads at this station or a nearby station; (S), instantaneous and(or) mean daily discharge available only prior to 1972 (prior to period of record of interest for this report); C, concentration data plotted in boxplots; (C), concentration data were combined with other concentration data collected from other locations in the same reservoir and were plotted in one boxplot per reservoir; L, annual loads reported for years with variances in load estimates less than 30 percent; T, 1980–90 trends;
Surface-water station number and name sources: A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station: Number	Surface-water station: Name (Reservoir name, if applicable)	River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record: Streamflow	Period of record: Nutrient measurements	Mean annual[3/]: Flow (ft^3/s)	Mean annual[3/]: Runoff (in/yr)	7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s): 90	Streamflow for indicated exceedence frequency[3/] (ft^3/s): 50 median	Streamflow for indicated exceedence frequency[3/] (ft^3/s): 10	Index of variability[3/]
						Lower Flint (03130008)								
40, 41a	S,C,L,T	02352500[U] 11090001[G]	Flint River at Albany, Ga.[U] Flint River - Georgia Northern Railway, Albany[G]	211.2	[5/]5,310	1901–21, 1929–90	1968–90	6,158	15.76	[7/]	1,780	4,140	13,000	2.7
41	C,L,T	02352790[U] 11100001[G]	Flint River near Putney, Ga.[U] Flint River - Plant Mitchell Intake[G]	198.6	[5/]5,340	—	1974–90	—	—	—	—	—	—	—
42	S,C,L	02353000[UN]	Flint River at Newton, Ga.[UN]	177.3	[5/]5,740	1938–50, 1956–90	1968–79, 1983–90	6,538	15.48	—	2,190	4,710	13,100	2.3
43	(C),T	02356015[U] 11110001[G]	Flint River below Bainbridge, Ga.[U] Flint River - 0.8 miles downstream from State Docks[G] (inflow to Lake Seminole, Flint Arm)	134.3	[5/]7,570	—	1974–90	—	—	—	—	—	—	—
						Ichawaynochaway (03130009)								
44	S,C	02353500[U] 11106001[G]	Ichawaynochaway Creek at Milford, Ga.[U] Ichawaynochaway Creek - Georgia Highway 216 near Milford[G]	160.6 (—)	[5/]640	1905–07, 1939–90	1970–90	773	16.94	—	242	547	1,530	2.4

Table 10. Streamflow and basin characteristics for surface-water sites where data were used in nutrient analyses, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1990—Continued

[—, no available data; ft^3/s, cubic feet per second; >, greater than; exceedence frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th- minus the 90th-percent exceedence frequency discharge divided by the median discharge;
Analyses of data in this report: S, instantaneous or mean daily discharge used to estimate loads at this station or a nearby station; (S), instantaneous and(or) mean daily discharge available only prior to 1972 (prior to period of record of interest for this report); C, concentration data plotted in boxplots; (C), concentration data were combined with other concentration data collected from other locations in the same reservoir and were plotted in one boxplot per reservoir; L, annual loads reported for years with variances in load estimates less than 30 percent; T, 1980–90 trends;
Surface-water station number and name sources: A, Alabama Department of Environmental Management; D, DeKalb County, Ga., monitoring network; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division trend-monitoring network; U, U.S. Geological Survey; UN, U.S. Geological Survey National Stream-Quality Accounting Network]

Location number[1/] (figure 16)	Analyses of data in this report	Surface-water station: Number	Surface-water station: Name (Reservoir name, if applicable)	River mile upstream of the mouth of the Apalachicola River[2/]	Drainage area (in square miles)	Period of record: Streamflow	Period of record: Nutrient measurements	Mean annual[3/]: Flow (ft^3/s)	Mean annual[3/]: Runoff (in/yr)	7-day, 10-year low flow[4/] (ft^3/s)	Streamflow for indicated exceedence frequency[3/] (ft^3/s): 90	50 median	10	Index of variability[3/]
					Apalachicola (03130011)									
45	S,C,L,T	02358000[UN]	Apalachicola River at Chattahoochee, Fla.[UN]	106	[5/]17,200	1928–90	1962–72, 1974–90	22,080	17.44	5,250	8,920	16,200	43,500	2.1
46a	S	02359170[U]	Apalachicola River near Sumatra, Fla.[U]	20.6	[5/]19,200	1977–90	1979–80	25,960	18.37	6,890	9,840	19,600	48,300	2.0
46	C,L,T	31010022[F]	Apalachicola River, Buoy 40, mile 11A[F]	11.0	—	—	1974–90	—	—	—	—	—	—	—
					Chipola (03130012)									
47	S,C,L,T	02359000[UN]	Chipola River near Altha, Fla.[UN]	28.2 (54)	781	1912–13, 1921–27, 1929–31, 1943–90	1962–72, 1974–90	1,492	25.95	425	619	1,110	2,760	1.9

[1/] Surface water-quality sampling sites are numbered consecutively; surface-water gaging stations that are paired with water-quality sampling sites either upstream or downstream of the gage location are designated with a letter "a."

[2/] For tributary streams, the river mile of the confluence between the tributary and the Chattahoochee, Flint, or Apalachicola Rivers is listed first and the distance upstream from the confluence is listed in parentheses.

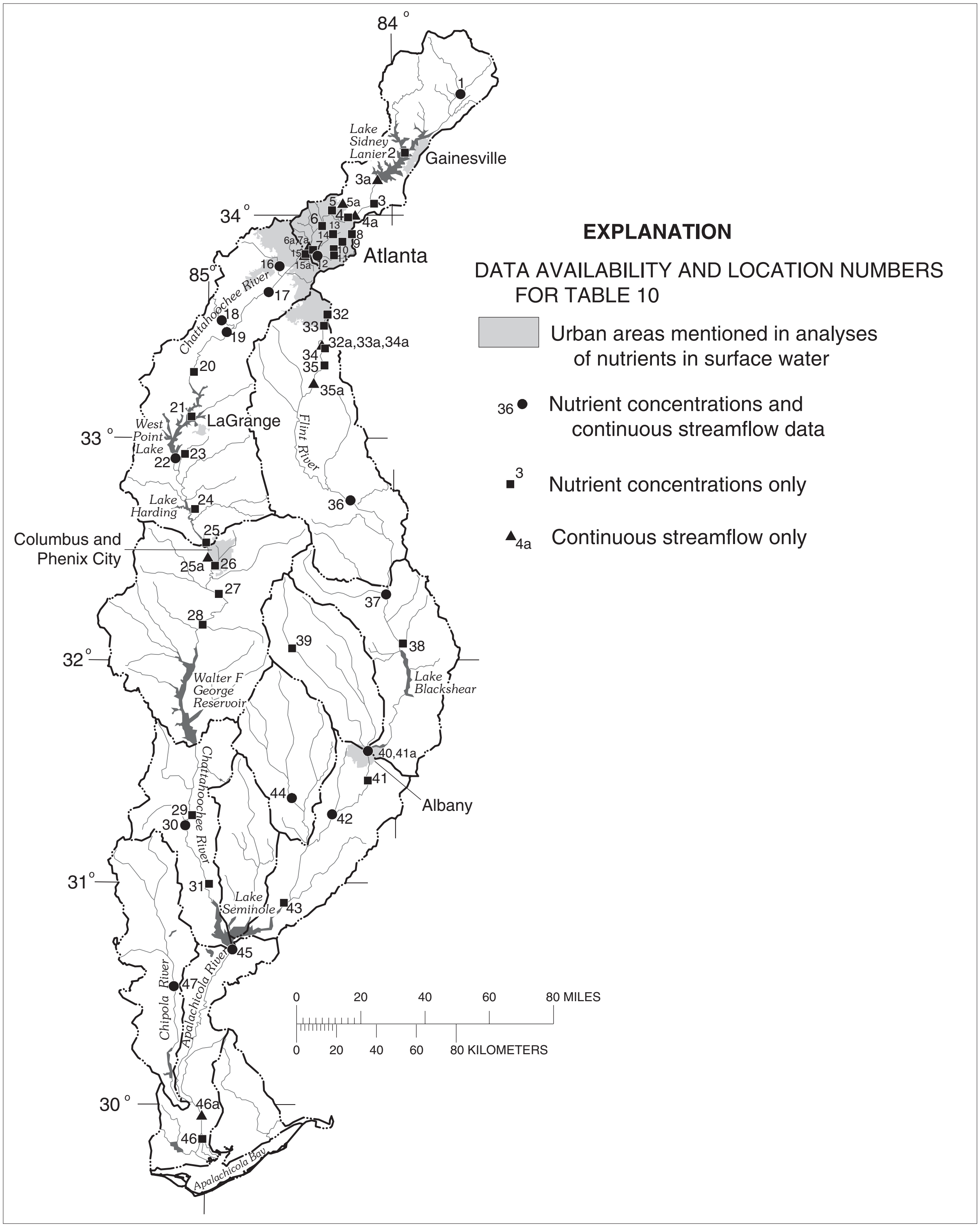
[3/] Statistics calculated for the period of record through 1992 water year.

[4/] _Data sources for 7-day, 10-year low flow_: Upper Chattahoochee River (Carter and others, 1989); Upper Flint River (Carter and others, 1986, and Carter and Putnam, 1978); Apalachicola and Chipola Rivers (Marvin Franklin, U.S. Geological Survey, Florida District, oral commun., 1994).

[5/] Approximate.

[6/] Prior to regulation.

[7/] Flow is regulated by upstream reservoir(s). Low-flow estimates prior to 1974 are available in Carter and Putnam (1978).



Base from U.S. Geological Survey digital files

Figure 16. Locations of surface-water sites where data were used in nutrient analyses, Apalachicola-Chattahoochee-Flint River basin, 1990.

conditions; location, duration, and intensity of precipitation; modification or regulation of discharge by reservoirs; mixture of point and nonpoint sources; land use and land cover in the upstream watershed; topography; and streamflow conditions (rising limb, peak, falling limb, baseflow) when samples were collected. The result of these and other factors is often an unclear relation between concentration and stream discharge.

It is difficult to separate the effects of point and nonpoint sources of nutrients on a regional scale based on historic data collected for various purposes. However, as part of the Upper Chattahoochee River Quality Assessment, Stamer and others (1979) sampled a 4-day storm period in 1976 and 2-day low-flow period in 1977 to separate point and nonpoint sources for nutrients and several other constituents. During the storm period, in the Atlanta-to-Fairburn reach, urban nonpoint-source inputs to Peachtree Creek (location 12) were about an order-of-magnitude greater than rural nonpoint-source inputs to Big Creek (location 5a) or forested nonpoint-source inputs to Snake Creek (location 18) (Stamer and others, 1979, p. 31). During the low-flow period, five municipal point sources contributed 97 percent of ammonia, 78 percent of total nitrogen, and 90 percent of total-phosphorus loads at Chattahoochee River at Franklin (location 20) (Stamer and others, 1979, p. 62).

Ideally, water-quality samples are collected at times that represent the range of flow conditions for each sampling site. It is particularly important to have water-quality samples that are representative of high-flow conditions because, for many constituents, much of the transport (load) occurs during high-flow conditions, and there is generally more variance in concentrations during high-flow conditions than during low-flow conditions. A good sampling design includes collecting more samples during conditions likely to have the most variance in concentrations of the constituents of interest. Distributions of nutrient samples by decile of flow for nine surface-water sampling sites indicate that most flow conditions were well represented by sampling from 1972–90 (fig. 17). Minor under-sampling of low flows at the Gwinnett County Water Intake (location 3) and the Columbus Water Intake (location 25) on the Chattahoochee River occurred because these sites are downstream of reservoirs that are operated for peaking hydropower generation. Lowest power demand and, therefore, lowest releases are generally on weekends; whereas, routine monitoring samples are generally collected Monday through Friday. The distribution of fewer samples collected in the highest decile of flow at Peachtree Creek at Atlanta (location 12) is fairly typical of tributary streams because high-flow events are generally shorter in duration and, therefore, more difficult to sample in small watersheds.

Using concentration data for 1972–90 water years, most surface-water sampling sites in the ACF River basin have weak, indeterminate, or no relations between concentrations of dissolved ammonia, dissolved nitrate, and total phosphorus and the logarithm of discharge. Nutrient concentration and logarithm of discharge are plotted along with a LOWESS line (LOcally WEighted Scatterplot Smoothing) for two mainstem and four tributary sites (figs. 18–20). LOWESS lines emphasize the shape of the relation between concentration and discharge and are computed by fitting 2^n weighted least-square equations, which is a robust method to compute a moving average (Helsel and Hirsch, 1992, p. 288–291). Kendall’s tau is a rank correlation coefficient that indicates monotonically increasing or decreasing relations between two variables. Statistically significant correlations (at the 95-percent confidence level) between ranked concentrations of dissolved ammonia, dissolved nitrate, and total phosphorus and ranked discharge are listed in figures 18–20. The higher the absolute value of tau, the stronger the positive or negative correlation.

Decreasing relations among dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations and discharge at Chattahoochee River near Fairburn (downstream of Atlanta) are indicative that point sources account for much of the load. Relatively small decreases in dissolved-nitrate concentrations as stream discharge increases at Flint River near Putney (downstream from Albany; location 41) could be from dilution of baseflow or dilution of point-source loads. At Chipola River near Altha (location 47), decreases in dissolved-nitrate concentration as stream discharge increases may be the result of diluting nitrate concentrations in baseflow, which is predominantly from ground water. The Chipola River drains largely agricultural areas in karst environments that have relatively high transmissivities in the aquifer, which increases the likelihood of elevated nitrate concentrations in ground water. Strong negative relations between dissolved-ammonia (fig. 18) and total-phosphorus (fig. 20) concentrations and discharge in Long Cane Creek are indications that the primary source for these nutrient constituent groups during 1972–90 was point-source loads. For this time period, the city of LaGrange discharged effluent into Long Cane Creek. As of September 1993, the discharge location was moved to the Chattahoochee

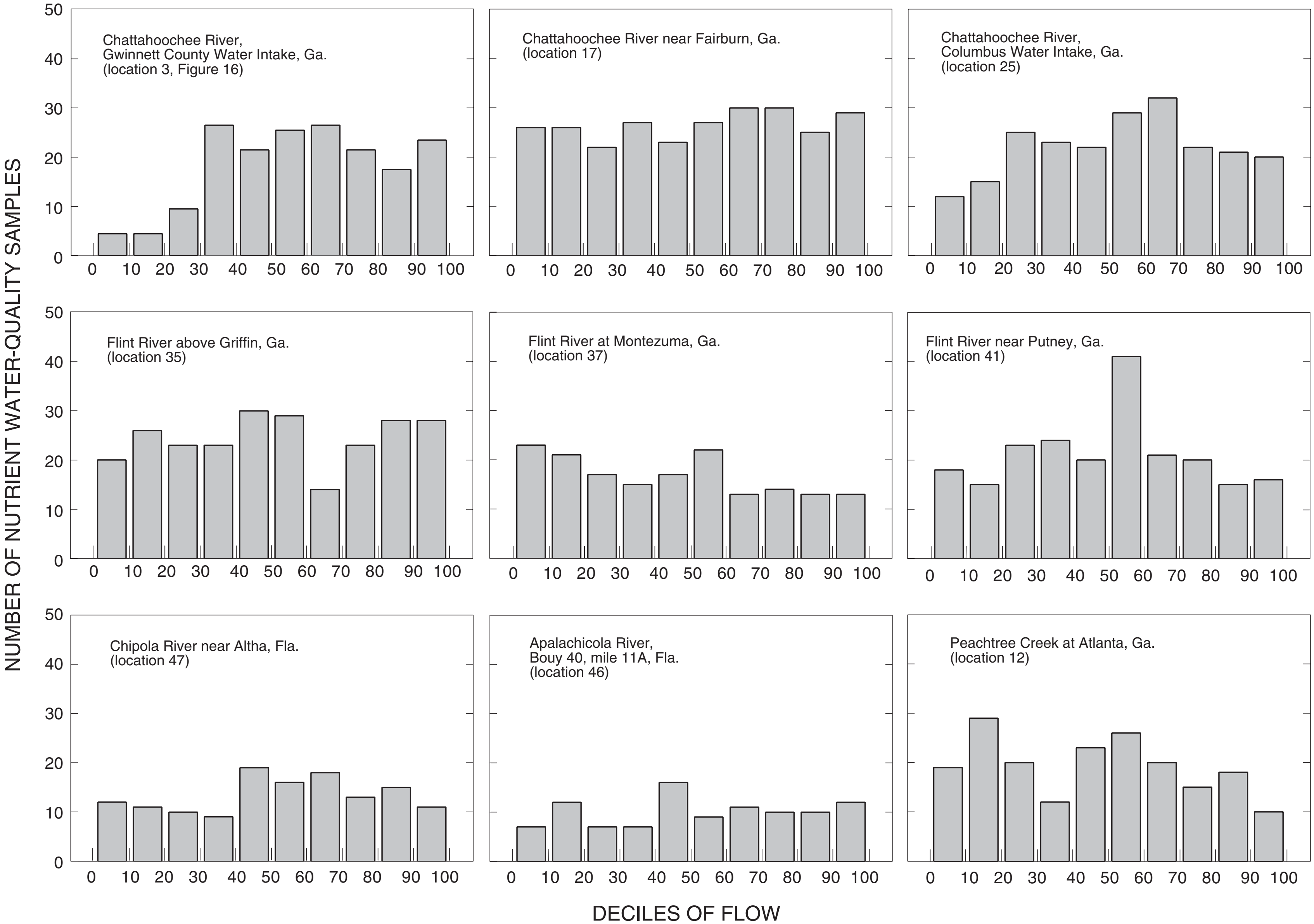


Figure 17. Distribution of nutrient samples within decile-flow classes for nine stream-sampling sites, Apalachicola-Chattahoochee-Flint River basin , 1972–90 water years.

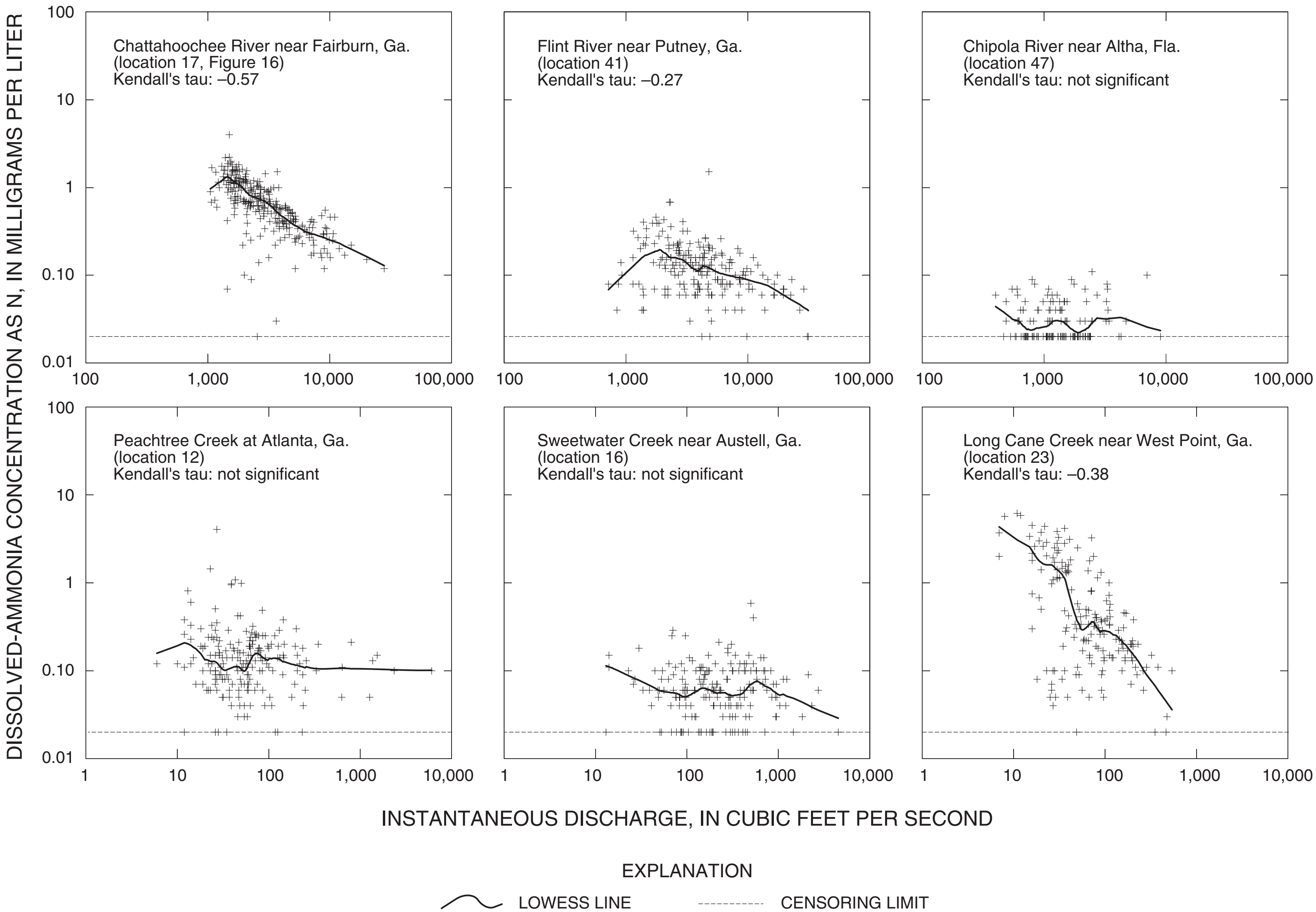


Figure 18. Relation between dissolved-ammonia concentration and discharge for two mainstem and four tributary sampling sites, Apalachicola-Chattahoochee-Flint River basin, 1972–90 water years.

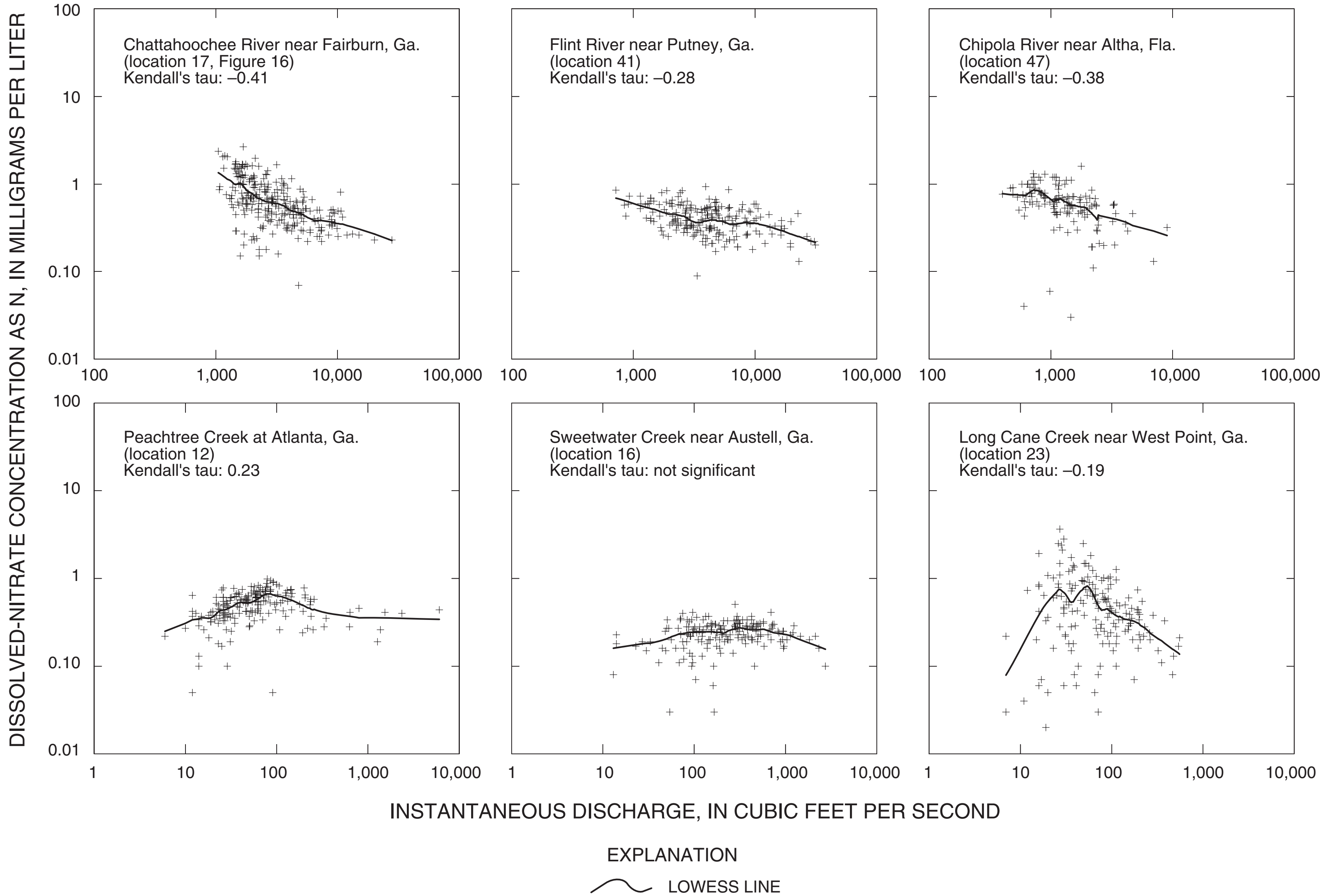


Figure 19. Relation between dissolved-nitrate concentration and discharge for two mainstem and four tributary sampling sites, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years.

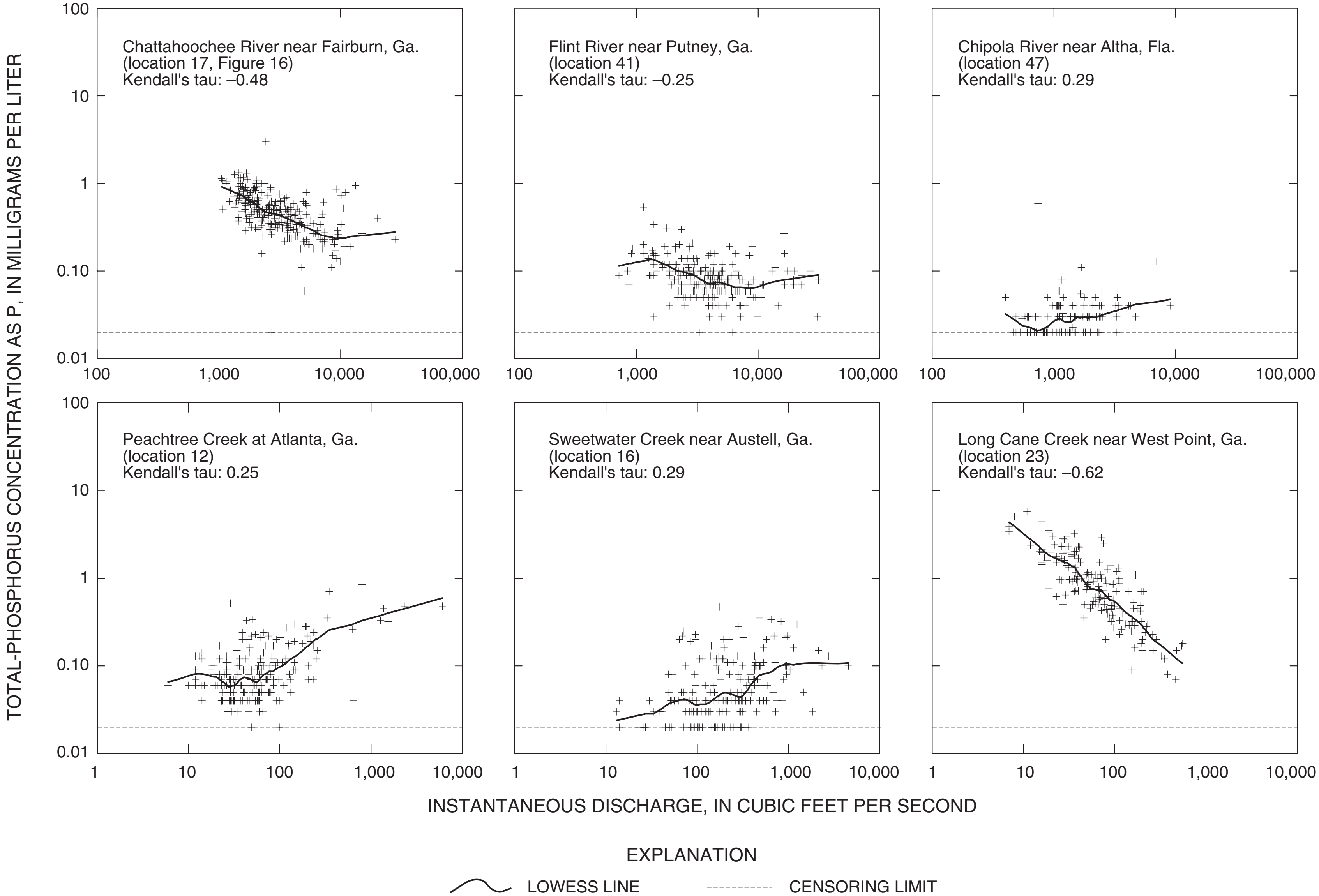


Figure 20. Relation between total-phosphorus concentration and discharge for two mainstem and four tributary sampling sites, Apalachicola-Chattahoochee-Flint River basin, 1972–90 water years.

River about one mile below the confluence of Long Cane Creek and the Chattahoochee River (Anne Westmoreland, Long Cane Creek WPCP, oral commun., 1994). By contrast, Peachtree and Sweetwater Creeks have relatively weak positive relations between total phosphorus and discharge (fig. 20). Transport of phosphorus is often closely related to transport of suspended sediment, which is usually a nonpoint-source dominated phenomena. In addition to typical urban nonpoint sources, Peachtree Creek has three combined sewer overflows, which are point sources that have significantly larger discharge during high-flow events.

Downstream variations in concentrations

Possible causes for increases in nutrient concentrations from an upstream sampling site to a downstream sampling site in the ACF River basin include:

- point sources of nutrients,
- land use and land cover that has a higher nonpoint-source yield of nutrients,
- inflow of ground water with higher concentrations of a nutrient species than the surface water (most commonly nitrate),
- suspension of sediments and nutrients from stream or reservoir bottoms,
- rupture of phytoplankton cells as they are transported from lacustrine to riverine environments,
- die off of phytoplankton in the fall and winter because of cooler water temperatures, and
- aquatic weed or detritus input.

The most common causes for decreases in nutrient concentrations as surface water flows downstream within the ACF River basin include settling of sediments and associated phosphorus, settling of detritus (mostly organic nitrogen), inflow from tributaries with lower nutrient concentrations (dilution), and uptake by phytoplankton in reservoirs (particularly in the spring and summer). In addition to net increases or decreases in nutrients, it is common for ammonia to be converted to nitrate in surface waters downstream of WWTF outfalls. Therefore, in reaches downstream of large cities, ammonia concentrations often decrease while nitrate concentrations increase.

This section focuses on differences in nutrient concentrations in surface water within the study area based on 19 years of concentration data (1972–90 water years). Instantaneous discharge when nutrient samples were collected (fig. 21) and nutrient concentrations (figs. 22 to 29) are summarized in boxplots by river mile upstream of the mouth of the Apalachicola River. Each boxplot represents the 10^{th}, 25^{th}, 50^{th} (median), 75^{th}, and 90^{th} percentile distribution of the data. Nutrient data from different sampling sites and depths within individual reservoirs were compiled and plotted as single boxplots at the downstream end of each reservoir. Lake Seminole data are plotted either on the Chattahoochee or Flint River basin figures depending on the arm of the reservoir in which they were collected. The mouths of the Chattahoochee and Flint Rivers join at Lake Seminole to form the headwaters of the Apalachicola River. Data from the Apalachicola River are shown downstream of the Chattahoochee River data and are repeated downstream of the Flint River data. Mann-Whitney tests, a nonparametric t-test involving rank-transformed data (Inman and Conover, 1983, p. 280–281), were used to determine if nutrient concentrations at paired upstream and downstream sites were statistically different. Boxplots were used to show if statistically different concentrations distributions increase or decrease in the downstream direction.

In general, the Chattahoochee, Flint, and Apalachicola Rivers are gaining rivers throughout their extent (fig. 21). The ACF River basin does not have major changes in nutrient concentrations that are primarily the result of large inflows or diversions of water.

Concentrations of nutrients significantly increased from upstream to downstream of the three major cities (Atlanta, locations 6–17; Columbus and Phenix City, locations 25 and 26; and Albany, locations 40 and 41) in the ACF River basin (table 11). These increases were expected because of urban and suburban point and nonpoint sources of nutrients. Atlanta, Columbus and Phenix City, and Albany were the only metropolitan areas with municipal discharges larger than 10 Mgal/d in 1990 in the ACF River basin (fig. 6). Significant increases in concentrations of total nitrogen (fig. 22; Atlanta only), total-inorganic nitrogen (fig. 23), total-organic nitrogen (fig. 24; Atlanta only), dissolved ammonia (fig. 25), dissolved nitrate (fig. 26), and total phosphorus (fig. 28) are common below WWTF discharge locations; however, it is not known how much of the increases are the result of point versus nonpoint sources. There were

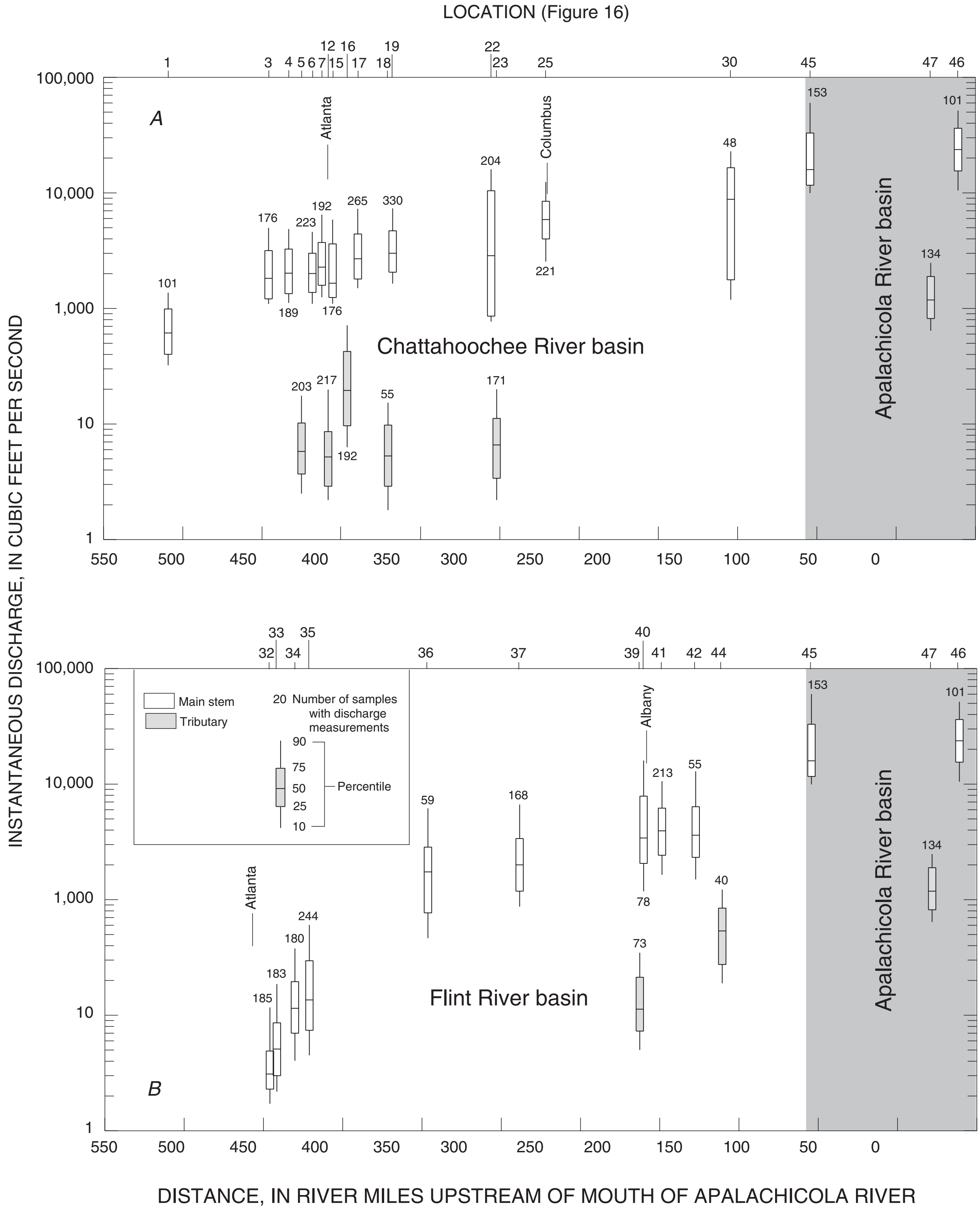


Figure 21. Instantaneous discharge when nutrient samples were collected in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

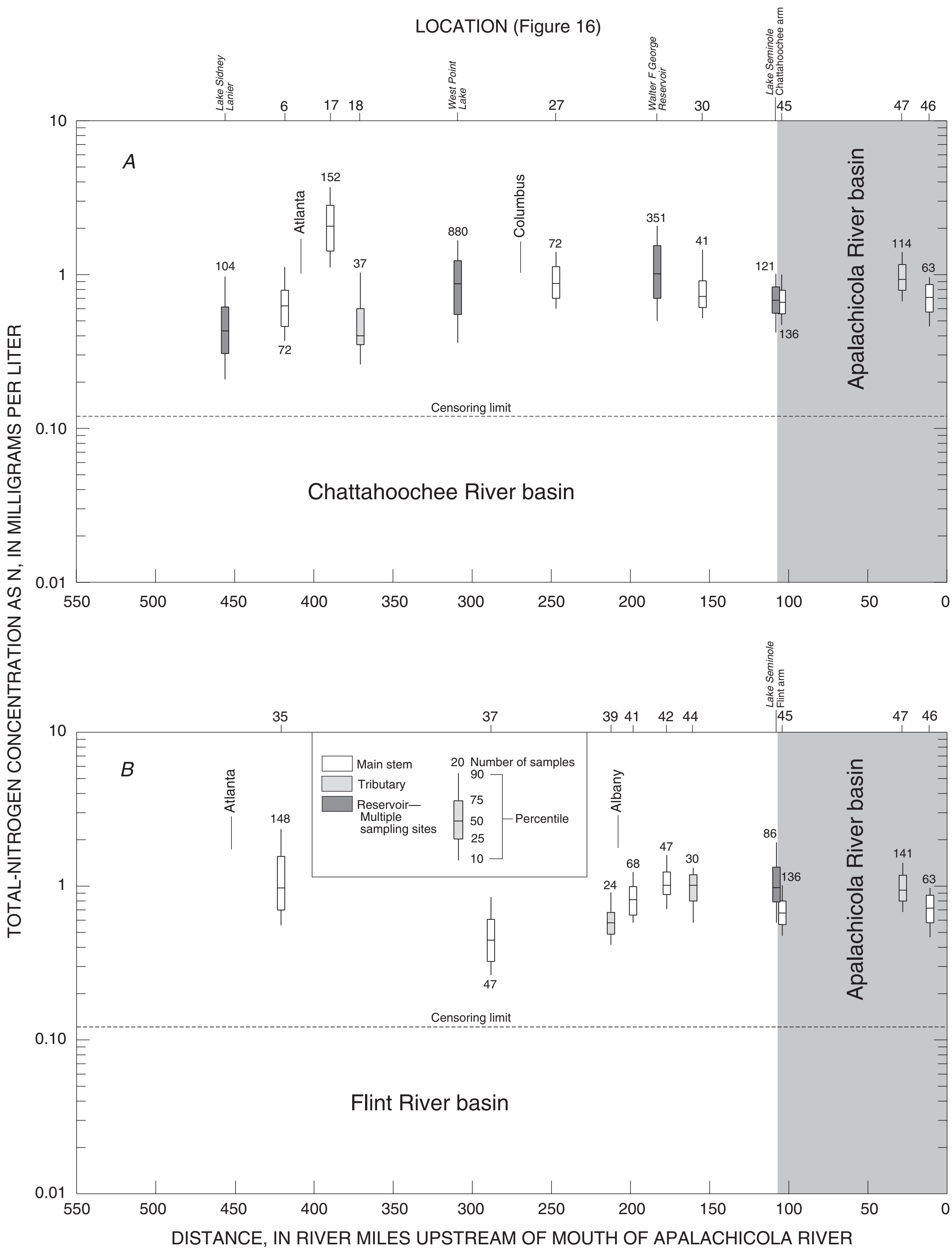


Figure 22. Downstream variation in total-nitrogen concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

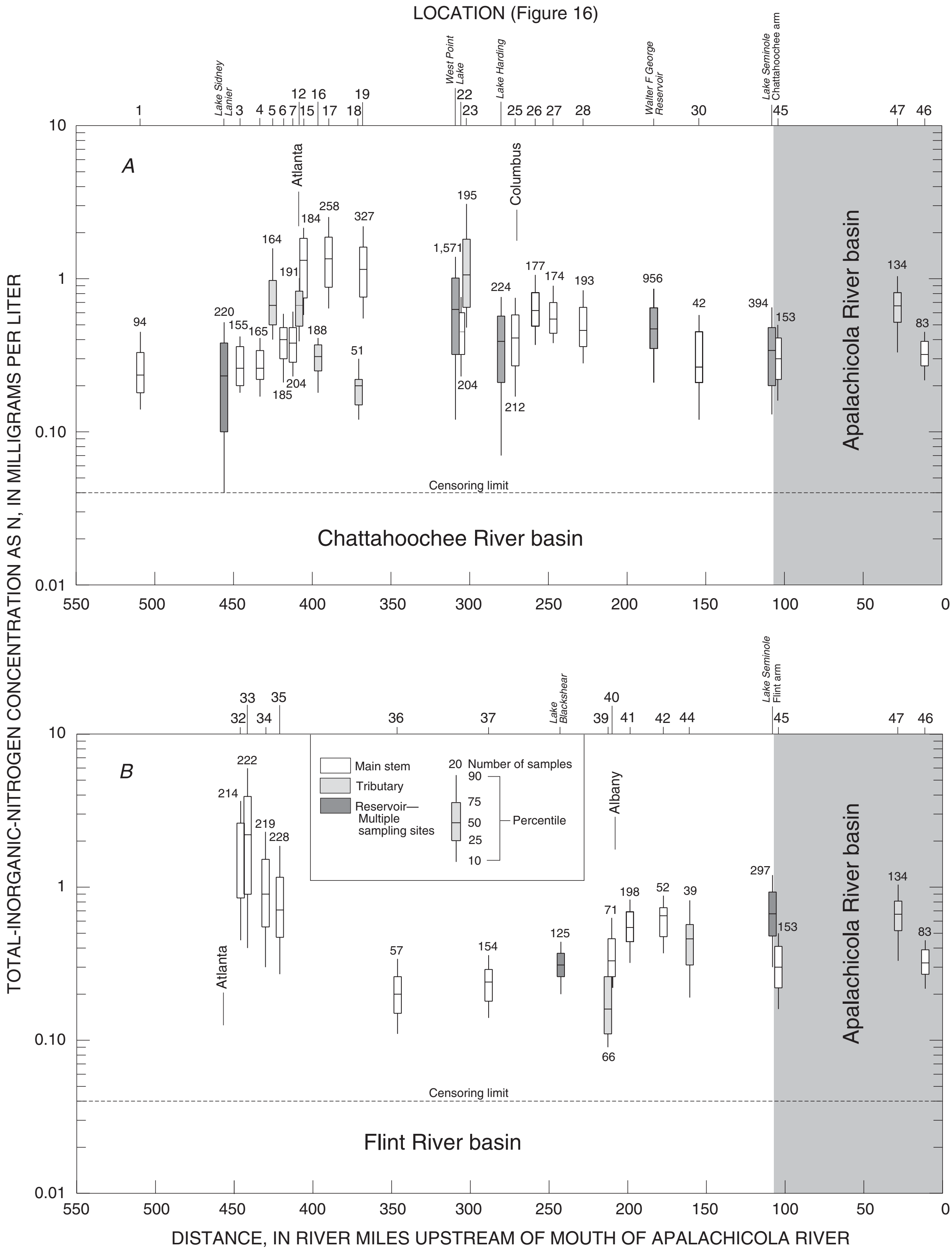


Figure 23. Downstream variation in total-inorganic-nitrogen concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

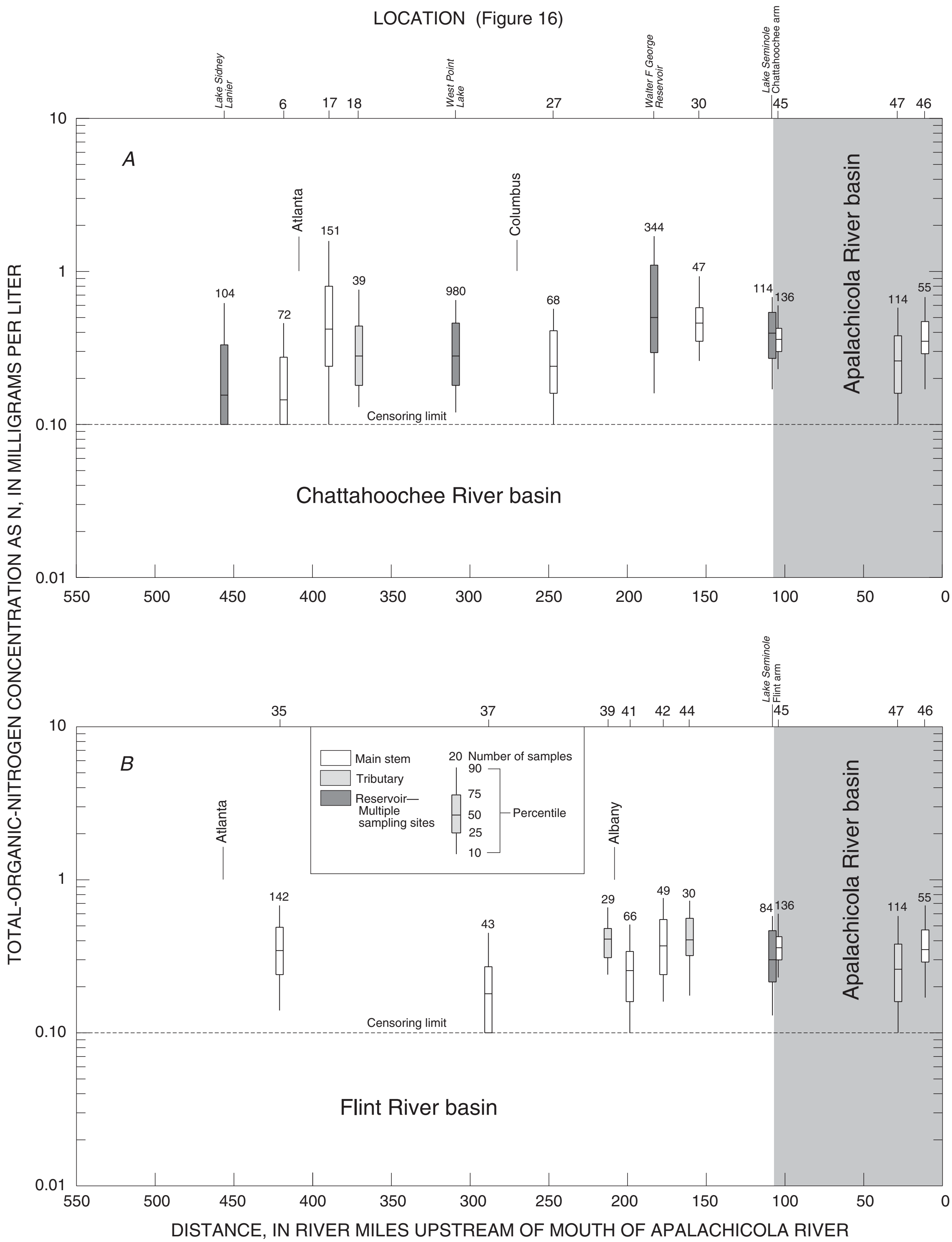


Figure 24. Downstream variation in total-organic-nitrogen concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

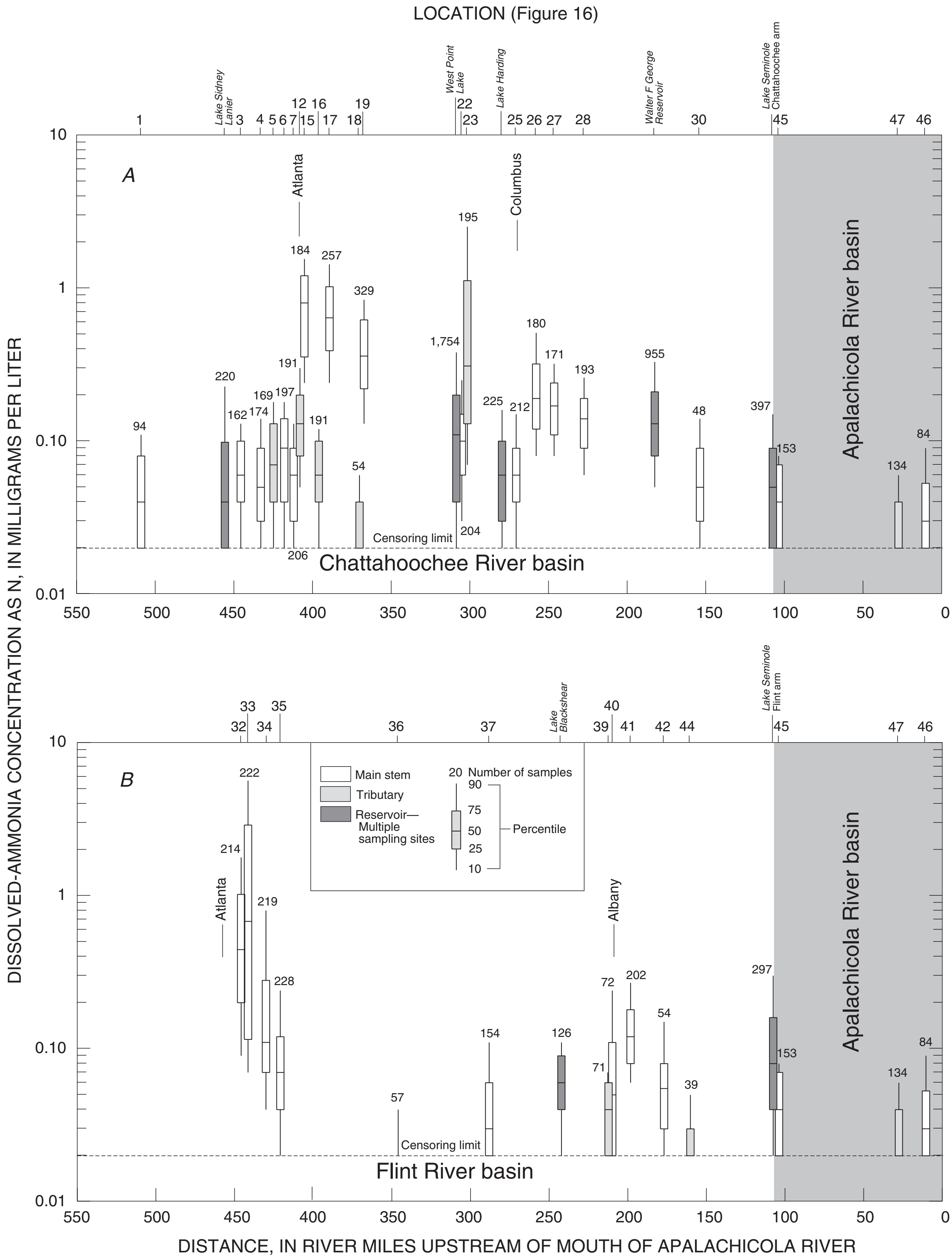


Figure 25. Downstream variation in dissolved-ammonia concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

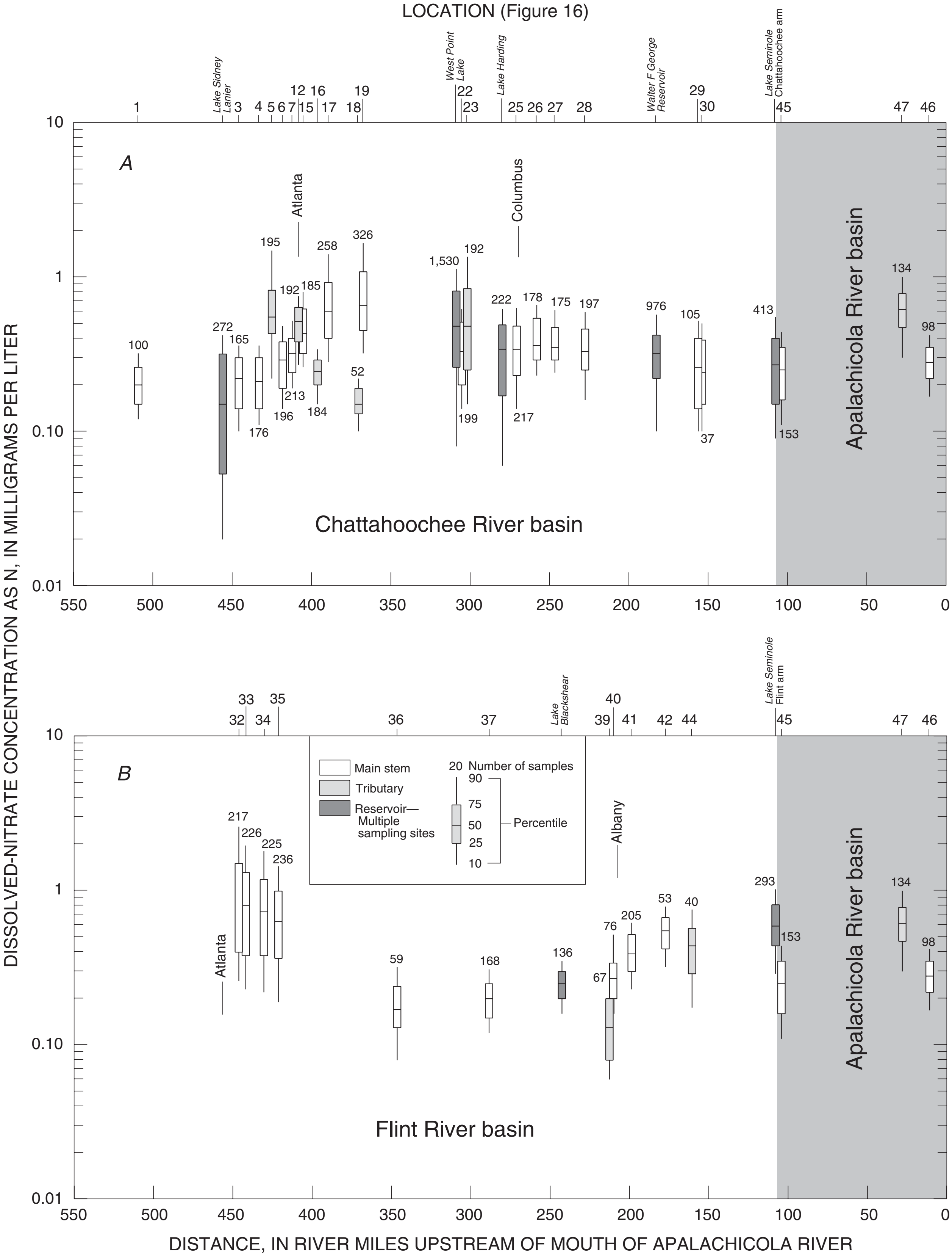


Figure 26. Downstream variation in dissolved-nitrate concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years. (U.S. Environmental Protection Agency's maximum contaminant level for nitrate is 10 milligrams per liter.)

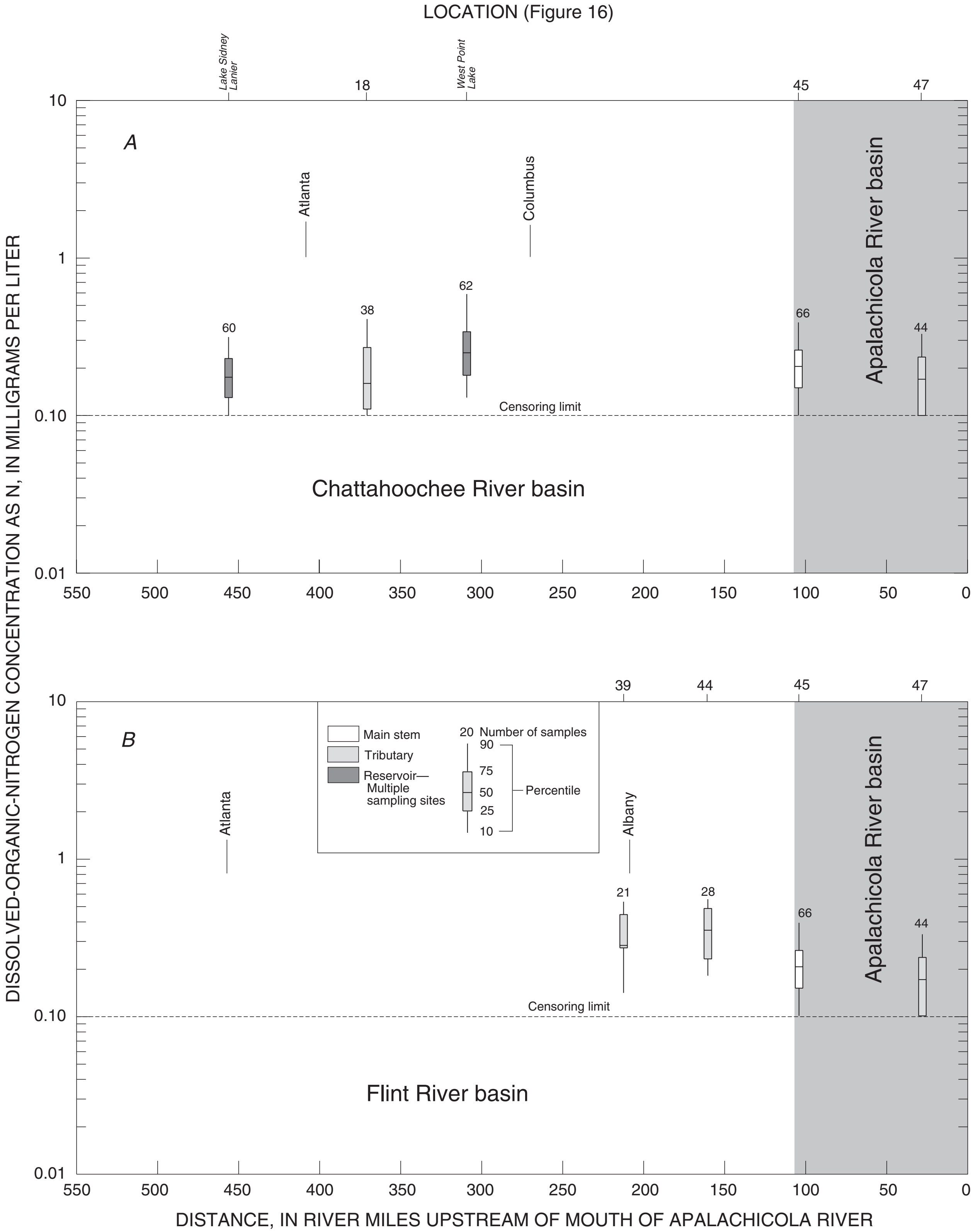


Figure 27. Downstream variation in dissolved-organic-nitrogen concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

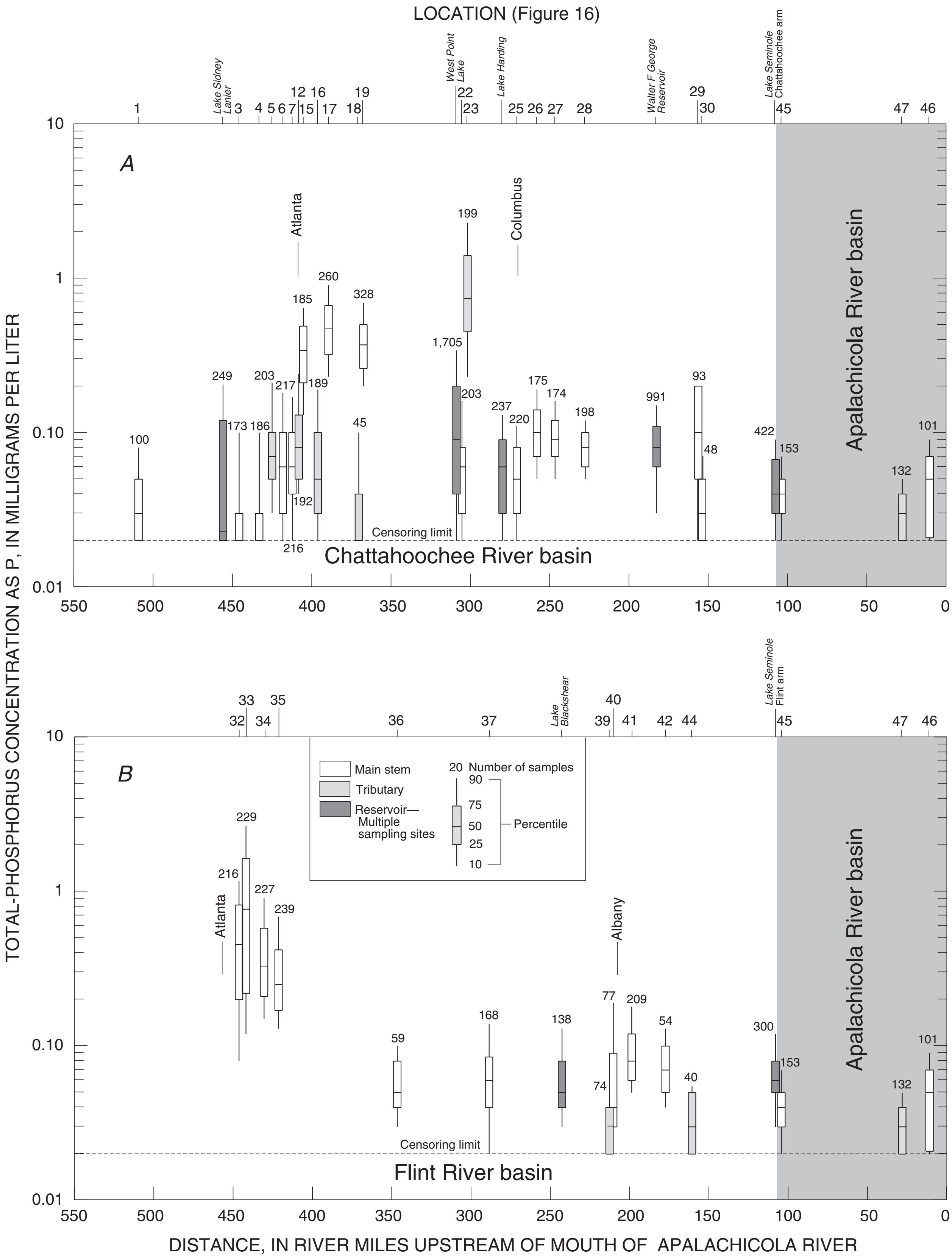


Figure 28. Downstream variation in total-phosphorus concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

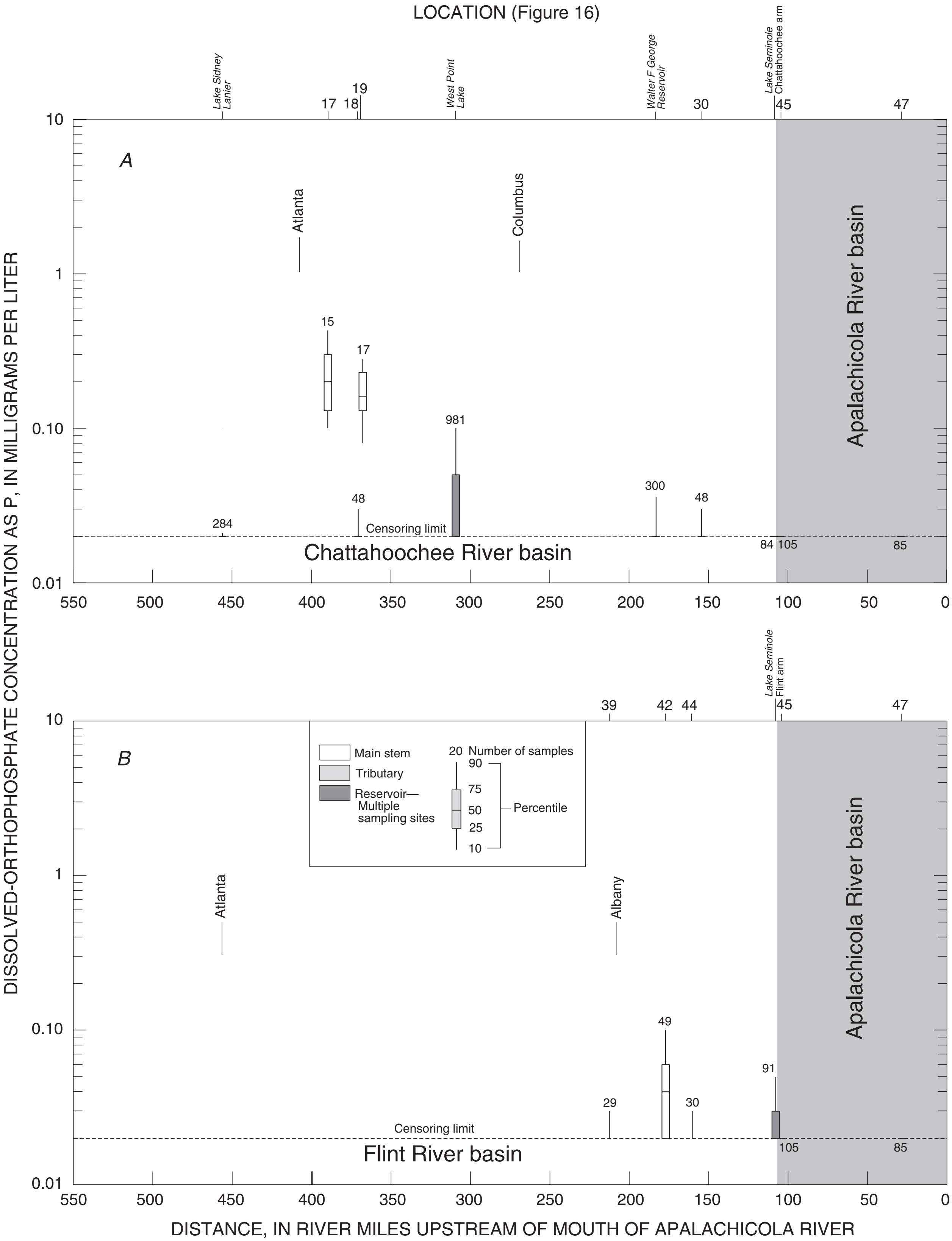


Figure 29. Downstream variation in dissolved-orthophosphate concentrations in (*A*) Chattahoochee and Apalachicola, and (*B*) Flint and Apalachicola River basins, 1972–90 water years.

Table 11. Comparison[1/] of nutrient concentrations at sampling sites upstream and downstream of major cities, Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years
[–, no available data; ↑ , concentration significantly increased from upstream to downstream of city]

Location number (figure 16)	Comparison sites in downstream order	Nutrient constituents					
		Total nitrogen (figure 22)	Total-inorganic nitrogen (figure 23)	Total-organic nitrogen (figure 24)	Dissolved ammonia (figure 25)	Dissolved nitrate figure 26)	Total phosphorus (figure 28)
	Atlanta						
6	Chattahoochee River - Cobb County Water Intake	↑	↑	↑	↑	↑	↑
17	Chattahoochee River near Fairburn, Ga.						
	Columbus and Phenix City						
25	Chattahoochee River - Columbus Water Intake	–	↑	–	↑	↑	↑
26	Chattahoochee River - Downstream from Columbus WTF						
	Albany						
40	Flint River at Albany, Ga.	–	↑	–	↑	↑	↑
41	Flint River near Putney, Ga.						

[1/] An increase between two sampling sites was based on results from Mann-Whitney rank-sum tests (Inman and Conover, 1983). The confidence level for significant differences was the 95th percentile.

insufficient data to determine changes in dissolved-organic-nitrogen and dissolved-orthophosphate concentrations for all three metropolitan areas, and for total-nitrogen and total-organic-nitrogen concentrations for Columbus and Phenix City and Albany.

Concentrations upstream and downstream of point sources could not be compared for the headwaters of the Flint River (downstream of Atlanta, locations 32 to 35) and Long Cane Creek (downstream of LaGrange, location 23) because there were no nutrient-sampling sites upstream of the point-source discharge. However, total-inorganic-nitrogen, dissolved-ammonia, dissolved-nitrate, and total-phosphorus (figs. 23, 25, 26, and 28) concentrations during 1972–90 water years at these sites were elevated to levels similar to those downstream of major point sources in Atlanta, Columbus and Phenix City, and Albany. For the headwaters of the Flint River, Long Cane Creek, and for Flat Creek (Gainesville WPCP No 1) and South Fork Little Mud Creek (Cornelia WPCP) in the Upper Chattahoochee subbasin (fig. 6), concentrations for the same four nutrients probably were elevated because of municipal effluent being discharged into relatively small streams with low waste-assimilation capacity. Recent (late 1980’s to 1994) concentrations of total-inorganic nitrogen, dissolved ammonia, dissolved nitrate, and total phosphorus in Long Cane Creek (location 23), and in four sites in the headwaters of the Flint River (locations 32–35) are about an order-of-magnitude less than concentrations shown for 1972–90 water years as a result of removing discharges of municipal effluent from those stream reaches.

From 1972–90, chronic exposure of aquatic organisms to un-ionized ammonia potentially was a problem in the Chattahoochee and Flint Rivers downstream of wastewater-treatment outfalls for Metropolitan Atlanta, and in Long Cane Creek downstream of the wastewater-treatment outfall for LaGrange. Although chronic exposure criteria for ammonia concentrations in surface water were not available prior to 1986 (U.S. Environmental Protection Agency, 1986), comparison of dissolved-ammonia concentration, pH, and water temperature data from 1972–90 provides an indication of where ammonia concentrations possibly were detrimental to aquatic organisms such as fish and invertebrates. At least 17 percent of samples at Long Cane Creek near West Point (location 23), 7 percent of samples at Chattahoochee River at I-285 (location 15), and 3 percent of samples at Chattahoochee River near Fairburn (location 17) exceeded the chronic criteria for ammonia toxicity (fig. 25a). In the Upper Flint River, at least 23 percent of samples at Flint River near Fayetteville (location 33), 9 percent of samples at Flint River near Jonesboro (location 32), 2 percent of samples at Flint River near Inman (location 34), and 0.4 percent of samples at Flint River above

Griffin (location 35) exceeded the chronic criteria for ammonia toxicity (fig. 25b). These percentages of exceedence are minimums because 1) pH and(or) water temperature are not available for all ammonia measurements, 2) about 2 percent of available pH values are less than 6.5 (the lower limit for which criteria apply), and 3) one water temperature is greater than 30 ° C (the upper limit for which criteria apply). There also are some uncertainties in converting criteria for un-ionized ammonia concentrations, the principal toxic form of ammonia, to criteria for total-ammonia concentrations because the equilibrium of un-ionized ammonia and the toxicity of un-ionized ammonia changes as pH and temperature change.

From 1972–90, total-phosphorus concentrations frequently were above recommended concentrations to control eutrophication in the Chattahoochee and Flint Rivers downstream of wastewater-treatment outfalls for Metropolitan Atlanta and in Long Cane Creek downstream of the wastewater-treatment outfall for LaGrange. Only two surface-water sampling locations (locations 39 and 44) had no total phosphorus samples that exceeded the USEPA recommendation of 0.1 mg/L as P to control eutrophication in flowing water. Surface-water sampling locations downstream of wastewater-treatment outfalls for Metropolitan Atlanta on the Chattahoochee River (locations 15, 17, and 19) and the Flint River (locations 33, 34, and 35), for LaGrange on Long Cane Creek (location 23) exceeded 0.1 mg/L total phosphorus more than 95 percent of the time (fig 28).

Increases in dissolved-ammonia and total-phosphorus concentrations that occurred from upstream to downstream of major cities and their WWTF, significantly decreased in most river reaches downstream of major municipal outfall locations from Atlanta (locations 15, 17 and 19), Columbus and Phenix City (locations 26–28), and Albany (locations 41 and 42) (table 12). Conversion of dissolved ammonia to dissolved nitrite and then to dissolved nitrate occurs in well-oxygenated surface water (nitrification) and is the most likely explanation for significant decreases in dissolved-ammonia (fig. 25) and significant increases in dissolved-nitrate concentrations (fig. 26). Significant decreases in total-

Table 12. Comparison[1/] of nutrient concentrations at sampling sites in river reaches downstream of major municipal point-source inputs, Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years

[ns, concentrations not significantly different; ↑, concentration significantly increased between two sites represented by bracket; ↓, concentration significantly decreased between two sites represented by bracket]

Location number (figure 16)	Comparison sites in downstream order	Nutrient constituents: Dissolved ammonia (figure 25)	Dissolved nitrate (figure 26)	Total phosphorus (figure 28)
	Atlanta			
15	Chattahoochee River at I-285, at Atlanta, Ga.[2/]			
17	Chattahoochee River near Fairburn, Ga.	] ns] ↓	] ↑] ↑	] ↑] ns
19	Chattahoochee River near Whitesburg, Ga.	] ↓	] ↑	] ↓
	Columbus and Phenix City			
26	Chattahoochee River - Downstream from Columbus WTF			
27	Chattahoochee River - Downstream Oswichee Creek	] ↓] ↓	] ns] ↓	] ns] ↓
28	Chattahoochee River - Seaboard Coast Line Railway, Omaha	] ↓	] ns	] ↓
	Albany			
41	Flint River near Putney, Ga.			
42	Flint River at Newton, Ga.	] ↓	] ↑	] ↓

[1/] Increases or decreases among three sampling sites were based on results from Kruskal-Wallis tests followed by Mann-Whitney rank-sum tests (Inman and Conover, 1983). An increase or decrease between two sampling sites was based on results from Mann-Whitney rank-sum tests. The confidence level for significant differences was the 95th percentile.

[2/] Chattahoochee River at I-285, at Atlanta, Ga. is downstream of much of the Metropolitan Atlanta area. However, in addition to some of Metropolitan Atlanta being downstream, there also are several major wastewater treatment plant discharges to the Chattahoochee River downstream of this sampling site.

phosphorus concentrations (fig. 28) are probably the result of biological uptake of orthophosphate, slow hydrolysis of polyphosphates to orthophosphate forms, decomposition of organic phosphorus and conversion to orthophosphate (Lynard and Field, 1980), and settling out of phosphorus associated with suspended sediment. The pattern of decreasing dissolved-ammonia and total-phosphorus concentrations continues downstream of Atlanta to upstream of Columbus (locations 17 to 19 to 22 to 25), downstream of Columbus to the headwaters of the Apalachicola River (locations 26 to 27 to 28 to 30 to 45) and downstream of Albany to the headwaters of the Apalachicola River (locations 41 to 42 to 45) (figs. 25 and 28).

Exceptions to the above patterns of increases in dissolved-nitrate concentrations, and decreases in dissolved-ammonia and total-phosphorus concentrations in the Atlanta area river reach (table 12) were primarily the result of several major WWTF outfalls between Chattahoochee River at I-285 (location 15) and Chattahoochee River near Fairburn (location 17). Although dissolved-nitrate concentrations significantly increased as expected between locations 15 and 17, dissolved-ammonia concentrations did not significantly decrease because additional dissolved ammonia was discharged into this reach. Total phosphorus was also discharged to the Chattahoochee River between locations 15 and 17, which caused the significant increase in concentration from location 15 to 17 and prevented a significant decrease in concentration from location 15 to 19. Exceptions to the above patterns also occurred in the river reach downstream of Columbus and Phenix City (locations 26 to 28), where concentrations of dissolved nitrate significantly decreased (fig. 26a; table 12) rather than increased. Although, these sampling sites were affected by backwater from Walter F. George Reservoir, it is not known why dissolved-nitrate concentrations appeared to decrease slightly in this river reach. As WWTF in the ACF River basin continue to upgrade their facilities, more nitrification is likely to occur at WWTF rather than in stream reaches downstream from the plants. This could help the overall health of stream reaches below effluent-discharge locations by reducing biochemical oxygen demand to these reaches, although it would not change the nitrogen load to receiving waters.

Comparisons of nutrient concentrations at sampling sites in and downstream of reservoirs in the ACF River basin indicate that concentrations were not significantly different for over half of the comparisons, significantly decreased in 15 comparisons, and significantly increased only downstream of Lake Sidney Lanier for total-inorganic nitrogen and dissolved nitrate (table 13). It is common for nutrient concentrations to be lower in rivers downstream from reservoirs than in the reservoirs because of uptake by phytoplankton and aquatic plants, denitrification, and accumulation of phosphorus associated with sediment in reservoirs. Total-phosphorus concentrations significantly decreased downstream in four out of six pairs of reservoir data and downstream data (Lake Sidney Lanier, West Point Lake, Lake Harding, and the Flint River arm of Lake Seminole) (fig. 28; table 13). Four nutrient species significantly decreased downstream of Walter F. George Reservoir and six nutrient species significantly decreased downstream of the Flint River arm of Lake Seminole. Lake Blackshear, a fairly shallow run-of-the-river reservoir, and the Chattahoochee River arm of Lake Seminole had no significant changes between concentrations measured in the reservoirs and concentrations measured downstream of the reservoirs.

Total-nitrogen, dissolved-nitrate, total-inorganic-nitrogen, dissolved-ammonia, total-phosphorus, and dissolved-orthophosphate concentrations significantly decreased from the Flint River arm of Lake Seminole to the Apalachicola River at Chattahoochee (location 45); however, nutrient concentrations were very similar in the Chattahoochee River arm of Lake Seminole to the same location on the Apalachicola River (figs. 22, 23, 25, 26, 28, and 29; table 13). Total-organic-nitrogen concentrations were similar in both arms of Lake Seminole and the Apalachicola River at Chattahoochee (fig. 24). Higher nutrient concentrations in the Flint River arm of Lake Seminole than in the Chattahoochee River arm of Lake Seminole may be the result of the large percentage of the Middle and Lower Chattahoochee River in backwater from reservoirs, the absence of reservoirs downstream of Albany until Lake Seminole, and nonpoint sources of nutrients from intensively farmed areas in the Lower Flint River basin. Based on available data, it is not possible to determine how much of the decrease in nutrient concentrations from the Flint River arm of Lake Seminole to the Apalachicola River at Chattahoochee resulted from (1) mixing of waters from the Chattahoochee and Flint Rivers, (2) changes in nutrient concentrations in upstream reservoirs on the Chattahoochee River, (3) loss from sedimentation in the Flint River arm of Lake Seminole, and (4) utilization by aquatic plants. Aquatic weeds are a widespread problem throughout Lake Seminole (Gholson, 1984a, b).

Table 13. Comparison[1/] of nutrient concentrations at sampling sites in and downstream of reservoirs, Apalachicola-Chattahoochee-Flint River basin, 1972–90 water years

[–, no available data; ns, concentrations not significantly different; ↓, concentration significantly decreased from the reservoir to downstream of the reservoir: ↑ , concentration significantly increased from the reservoir to downstream of the reservoir

Location number[2/] (figure 16)	Comparison sites in downstream order	Nutrient constituents						
		Total nitrogen (figure 22)	Total-inorganic nitrogen (figure 23)	Total-organic nitrogen (figure 24)	Dissolved ammonia (figure 25)	Dissolved nitrate (figure 26)	Total phosphorus (figure 28)	Dissovled orthophosphate (figure 29)
3	Lake Sidney Lanier Chattahoochee River - Gwinnett County Water Intake	–	↑	–	ns	↑	↓	–
22	West Point Lake Chattahoochee River at West Point, Ga.	–		–	ns	↓	↓	–
25	Lake Harding Chattahoochee River - Columbus Water Intake	–	ns	–	ns	ns	↓	–
29 and 30	Walter F. George Reservoir Chattahoochee River at (and near) Columbia, Ala.	↓	↓	ns	↓	↓	[3/]	ns
40	Lake Blackshear Flint River at Albany, Ga.	–	ns	–	ns	ns	ns	–
45	Lake Seminole, Chattahoochee arm Apalachicola River at Chattahoochee, Fla.	ns	ns	ns	ns	ns	ns	ns
45	Lake Seminole, Flint arm Apalachicola River at Chattahoochee, Fla.	↓	↓	ns	↓	↓	↓	↓

[1/] An increase or decrease between two sampling sites was based on results from Mann-Whiteny rank-sum tests (Inman and Conover, 1983). The confidence level for significant differences was the 95^{th} percentile.

[2/] Nutrient data for multiple sampling sites within each reservoir were used in statistical comparisons rather than data from a single reservoir sampling site.

[3/] Comparison between total-phosphorus concentrations in Walter F. George Reservoir and downstream sites were not made because total-phosphorus concentrations measured at Chattahoochee River at Columbia from 1975 to 1983 (river mile 156.7, location 29) were significantly higher than at Chattahoochee River near Columbia from 1982 to 1990 (river mile 154.3, location 30) (figure 28a). It is not know if total-phosphorus concentrations in the river were different for the two periods of record, or if the differeences were due to different sample colleciton techniques and(or) laboratory analyses methods used by Alabama Department of Environmental Management (location 29) and the U.S. Geological Survey (location 30).

Concentrations of total phosphorus at Chattahoochee River at West Point (just below West Point Lake; location 22) prior to the beginning of storage in West Point Lake (October 16, 1974) and after the reservoir reached maximum power pool (June 10, 1975) provides a good example of reservoirs reducing total-phosphorus concentrations. Median and minimum total-phosphorus concentrations decreased from 0.19 and 0.04 mg/L, respectively, prior to the beginning of storage in West Point Lake (1968–74) to 0.05 and 0.02 mg/L, respectively, after the reservoir was in full operation (1975–90). Similar changes in concentrations did not occur for dissolved ammonia or dissolved nitrate.

Discharges from eight tributary streams with available nutrient-concentration data have undetectable effects on the nutrient concentrations of the receiving mainstem rivers (figs. 22–29). Unlike mainstem sampling sites which have mixed land use within their watersheds, Peachtree Creek was almost 99 percent urban and Snake Creek was about 83 percent forested (table 14). The other six tributaries have mixed land use including urban components in Big Creek, Sweetwater Creek, and Long Cane Creek; a dominant agriculture component in Ichawaynochaway Creek and Chipola River; and a dominant forest component in Kinchafoonee Creek. Total-inorganic-nitrogen and dissolved-nitrate concentrations were very low in forest dominated tributaries (Snake and Kinchafoonee Creeks) (figs. 23, 26; table 14). The four tributaries with an urban component of land use (Big, Peachtree, Sweetwater, and Long Cane Creeks) had moderate to high concentrations of dissolved ammonia, dissolved nitrate (except Sweetwater Creek), and total phosphorus (figs. 25, 26, 28). Long Cane Creek had very elevated concentrations of these three constituents for the period 1972–90; however, improvements to the Long Cane Creek WPCP including advanced treatment in 1986, phosphorus removal in 1994, and relocation of the effluent discharge to the Chattahoochee River in 1993 (Anne Westmoreland, Long Cane Creek WPCP, oral commun., 1994) have resulted in much smaller nutrient concentrations in Long Cane Creek. By contrast, concentrations of these three nutrient species and dissolved orthophosphate (fig. 29) were very low in four tributaries with little or no urban land use—Snake, Kinchafoonee, Ichawaynochaway Creeks, and Chipola River—with the exception of moderate to high dissolved-nitrate concentrations relative to other concentrations in Ichawaynochaway Creek and Chipola River in the ACF River basin. Agriculture was the predominant land use in Ichawaynochaway Creek and Chipola River and elevated dissolved-nitrate concentrations in these two tributaries may be from inflow of ground water with elevated dissolved-nitrate concentrations.

Organic-nitrogen-concentration data were available for only a limited number of sites, so it is not clear if downstream changes in concentrations of total-organic nitrogen (fig. 24) or dissolved-organic nitrogen (fig. 27) occurred within the study area. Dissolved-orthophosphate concentrations (fig. 29) were about an order-of-magnitude higher at Chattahoochee River near Fairburn and near Whitesburg (locations 17 and 19), downstream from Atlanta, than at other locations in the ACF River basin. More than half of the dissolved-orthophosphate concentrations were below the reporting limit of 0.02 mg/L at 11 of 14 surface-water sampling sites where it was measured routinely. Dissolved-orthophosphate concentrations were less than the reporting limit for all data from the Chattahoochee River arm of Lake Seminole and for about 75 percent of data from the Flint River arm of Lake Seminole.

Two sampling sites on the Chattahoochee River are located within 2.4 river miles of each other and have non-overlapping periods of record. Distribution of dissolved-nitrate concentrations (fig. 26a) were very similar, but total-phosphorus concentrations (fig. 28a) measured at Chattahoochee River at Highway 52 from 1975 to 1983 (river mile 156.7, location 29) were significantly higher than at Chattahoochee River near Columbia from 1982 to 1990 (river mile 154.3, location 30). It is not known if total-phosphorus concentrations in the river were different for the two periods of record, or if the differences were because of different sample collection techniques and(or) laboratory analyses methods used by ADEM (location 29) and the USGS (location 30).

Seasonal variations in concentrations

Nutrient concentrations in streams and reservoirs within the ACF River basin can vary seasonally because of seasonal changes in growth and decay of vegetation (particularly in the Apalachicola floodplain; Mattraw and Elder, 1984), changes in temperature which in turn effects phytoplankton growth in reservoirs (Cherry and others, 1978), nitrification of ammonia to nitrate (Ehlke, 1978); seasonal applications of fertilizers; and other environmental factors. Dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations were plotted by time of year for surface-water samples collected during 1972–90 water years. Seasonal variations or lack of seasonal variations are highlighted by LOWESS lines for nine stream- and reservoir-sampling sites along the Chattahoochee River (figs. 30–32) and for six stream- and reservoir-sampling sites along the Flint River, one site on the Chipola River, and one site near the mouth of the Apalachicola River (figs. 33 to 35).

In the ACF River basin, summer decreases in concentrations of nutrients in reservoirs, and stream sites directly affected by reservoirs, were related to seasonality of phytoplankton production in reservoirs. In late spring, water temperatures, and therefore, phytoplankton growth rates, begin to increase. Phytoplankton utilize dissolved nitrogen for cell growth; and thus, convert dissolved nitrogen to particulate form until cells die and break apart. As

Table 14. Land use and land cover, median nutrient concentrations, and mean annual yield for eight tributary streams, Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years
[–, no available data; <, less than]

Location number (figure 16)	Tributary stream	Land use and land cover[1/], in percent			Median nutrient concentration[2/], in milligrams per liter (mean annual yield, in tons per square mile of drainage area)							
		Urban	Agri-cultural	Forest	Total nitrogen (figure 22)	Total-inorganic nitrogen (figure 23)	Total-organic nitrogen (figure 24)	Dissolved ammonia (figure 25)	Dissolved nitrate (figure 26)	Dissolved-organic nitrogen (figure 27)	Total phosphorus (figure 28)	Dissolved ortho-phosphate (figure 29)
							Urban					
12	Peachtree Creek	99	0	1	– (–)	0.67 (1.0)	– (–)	0.13 (0.23)	0.52 (0.78)	– (–)	0.08 (0.30)	– (–)
							Mixed, Urban					
16	Sweetwater Creek	24	23	51	– (–)	0.31 (0.55)	– (–)	0.06 (0.16)	0.25 (0.34)	– (–)	0.05 (0.17)	– (–)
5	Big Creek	18	24	57	– (–)	0.67 (1.0)	– (–)	0.07 (0.11)	0.55 (0.72)	– (–)	0.07 (0.15)	– (–)
23	Long Cane Creek	12	19	68	– (–)	1.06 (–)	– (–)	0.31 (–)	0.48 (–)	– (–)	0.74 (–)	– (–)
							Mixed, Agricultural					
44	Ichawaynochaway Creek	1	52	36	1.0 (–)	0.46 (–)	0.41 (–)	0.02 (–)	0.44 (–)	0.35 (–)	0.03 (–)	<0.02 (–)
47	Chipola River	2	50	39	0.93 (1.9)	0.67 (1.3)	0.26 (0.74)	0.02 (0.06)	0.62 (1.2)	0.17 (–)	0.03 (0.07)	<0.02 (0.03)
							Mixed, Forest					
39	Kinchafoonee Creek	<1	32	62	0.57 (–)	0.16 (–)	0.41 (–)	0.04 (–)	0.13 (–)	0.28 (–)	0.03 (–)	<0.02 (–)
							Forest					
18	Snake Creek	1	16	83	0.40 (–)	0.20 (–)	0.28 (–)	0.02 (–)	0.15 (–)	0.16 (–)	0.02 (–)	<0.02 (–)

[1/] 1972–78; percentages do not add up to 100 because rangeland, wetland, water, and barren land are not listed.
[2/] Subset of 1972–90 water years, see tables 10 and 16 for exact years.

part of the Upper Chattahoochee River Quality Assessment, it was observed that concentrations of phytoplankton (diatoms, green algae, and blue-green algae) increased as water temperatures increased at all four sites sampled in West Point Lake; and biologically available nutrients, as measured by algal growth potential assays, decreased in response to increased phytoplankton concentrations (Cherry and others, 1978, p. 5, 19).

Seasonal variations in nutrient concentrations in the Chattahoochee River are strongly influenced by the 13 reservoirs on the river, particularly in the reach of the river from West Point Lake to Lake Seminole. Dissolved-nitrogen concentrations were generally lower in warm, summer months from the inflow of West Point Lake (location 20) to Lake Seminole (location 31) for ammonia (fig. 30) and from the center of West Point Lake (location 21) to Lake Seminole for nitrate (fig. 31). Total-phosphorus concentrations also seems to be lower in summer and early fall in the Middle and Lower Chattahoochee River (fig. 32), although the pattern is not as pronounced as for dissolved ammonia and dissolved nitrate. However, in the Upper Chattahoochee River, it is difficult to identify seasonal variations in nutrient concentrations in Lake Sidney Lanier (location 2) because the frequency of nutrient-data collection was quarterly. It is not known if the late-summer early-fall peak in dissolved-nitrate concentrations at Chattahoochee River at the Gwinnett County Water Intake (location 3) (fig. 31) mirrored seasonal variation in Lake Sidney Lanier or was the result of changes in dissolved-nitrate concentrations in the 23 mi reach between the Lake Sidney Lanier and the Gwinnett County sampling sites.

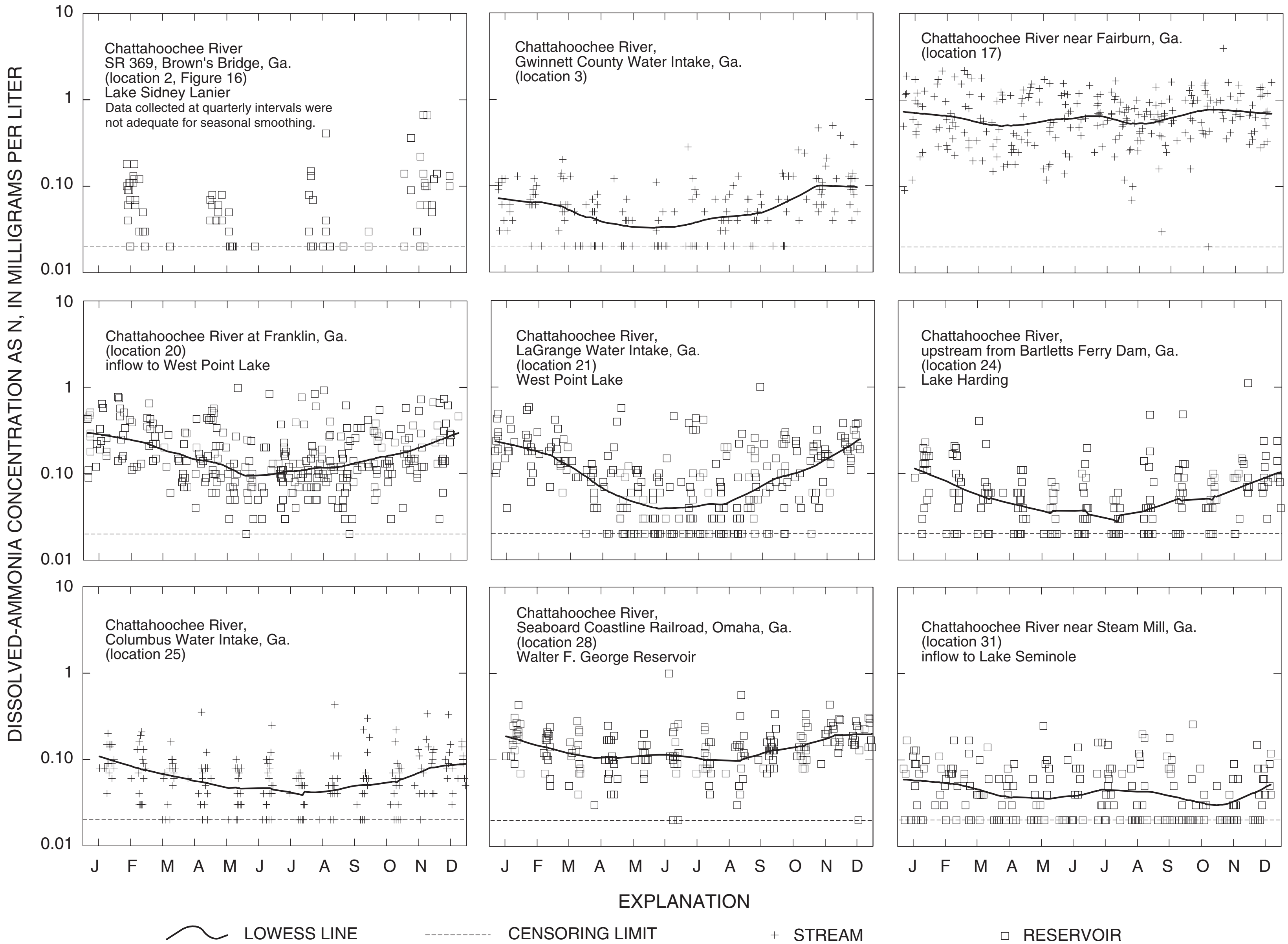


Figure 30. Seasonal variation in dissolved-ammonia concentrations for selected streams and reservoirs, Chattahoochee River, 1972–90 water years.

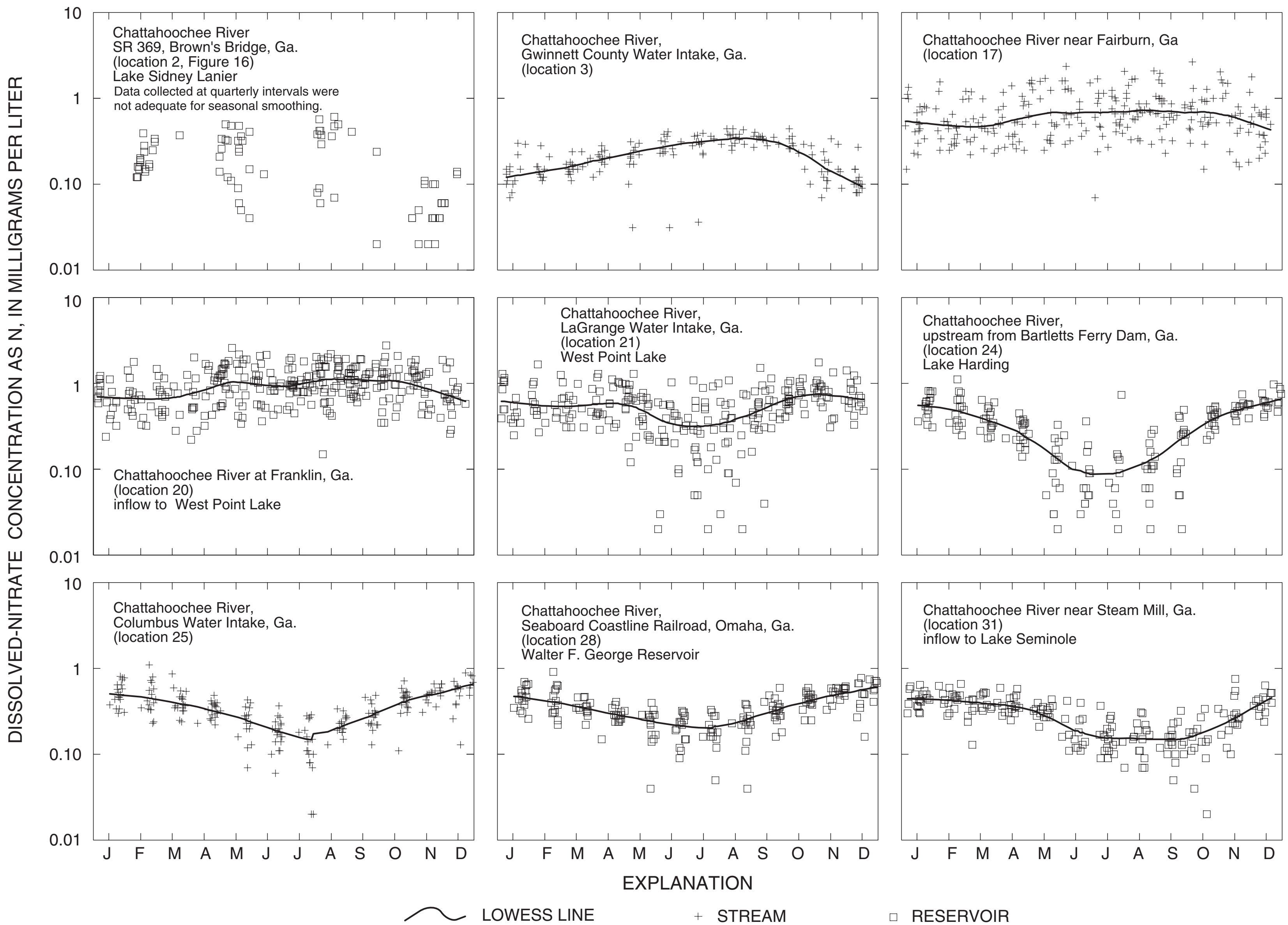


Figure 31. Seasonal variation in dissolved-nitrate concentrations for selected streams and reservoirs, Chattahoochee River, 1972–90 water years.

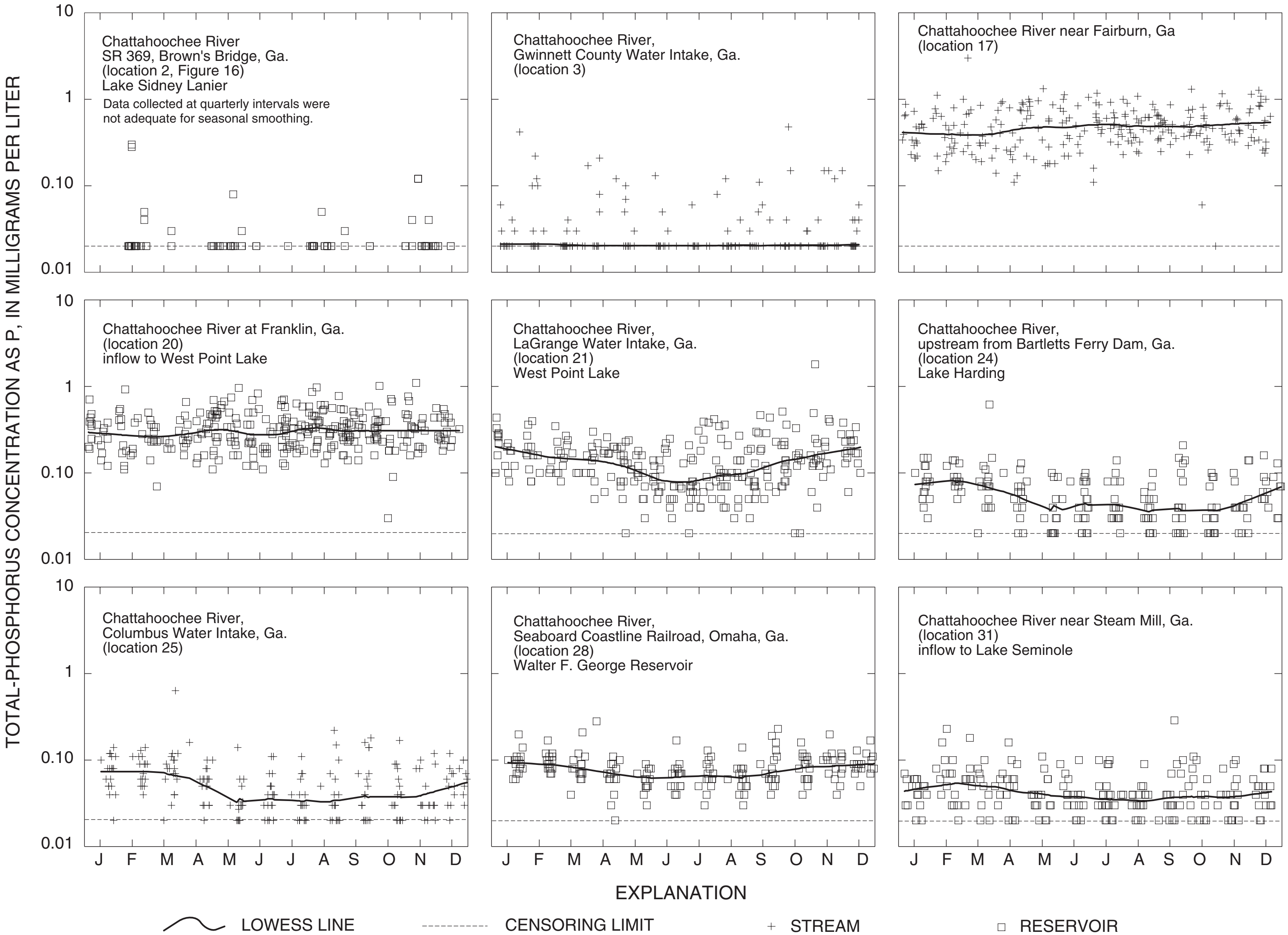


Figure 32. Seasonal variation in total-phosphorus concentrations for selected streams and reservoirs, Chattahoochee River, 1972–90 water years.

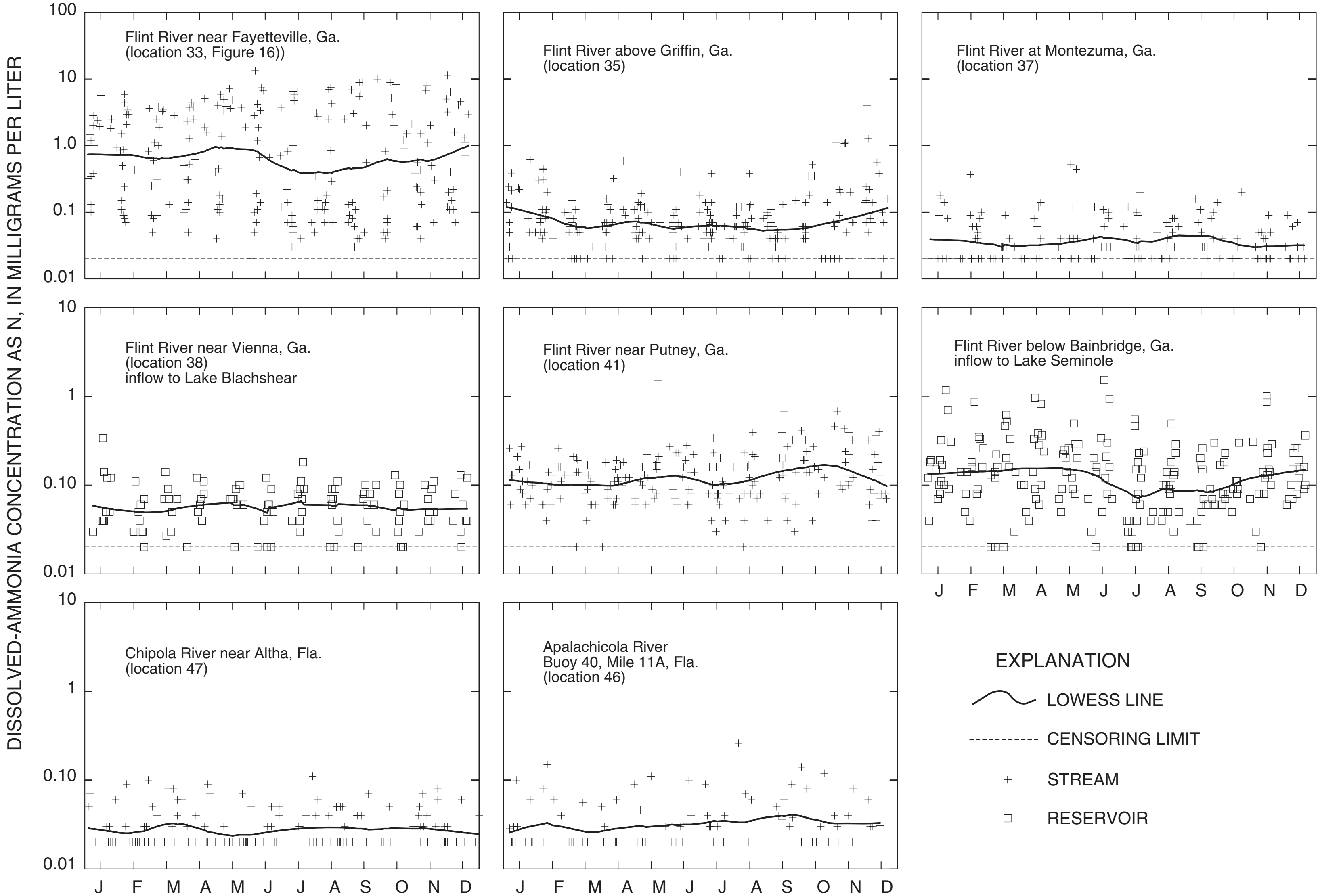


Figure 33. Seasonal variation in dissolved-ammonia concentrations for selected streams and reservoirs, Flint, Chipola, and Apalachicola Rivers, 1972–90 water years. (Locations 33, 35, and 37 are plotted with 4-log cycle scales.)

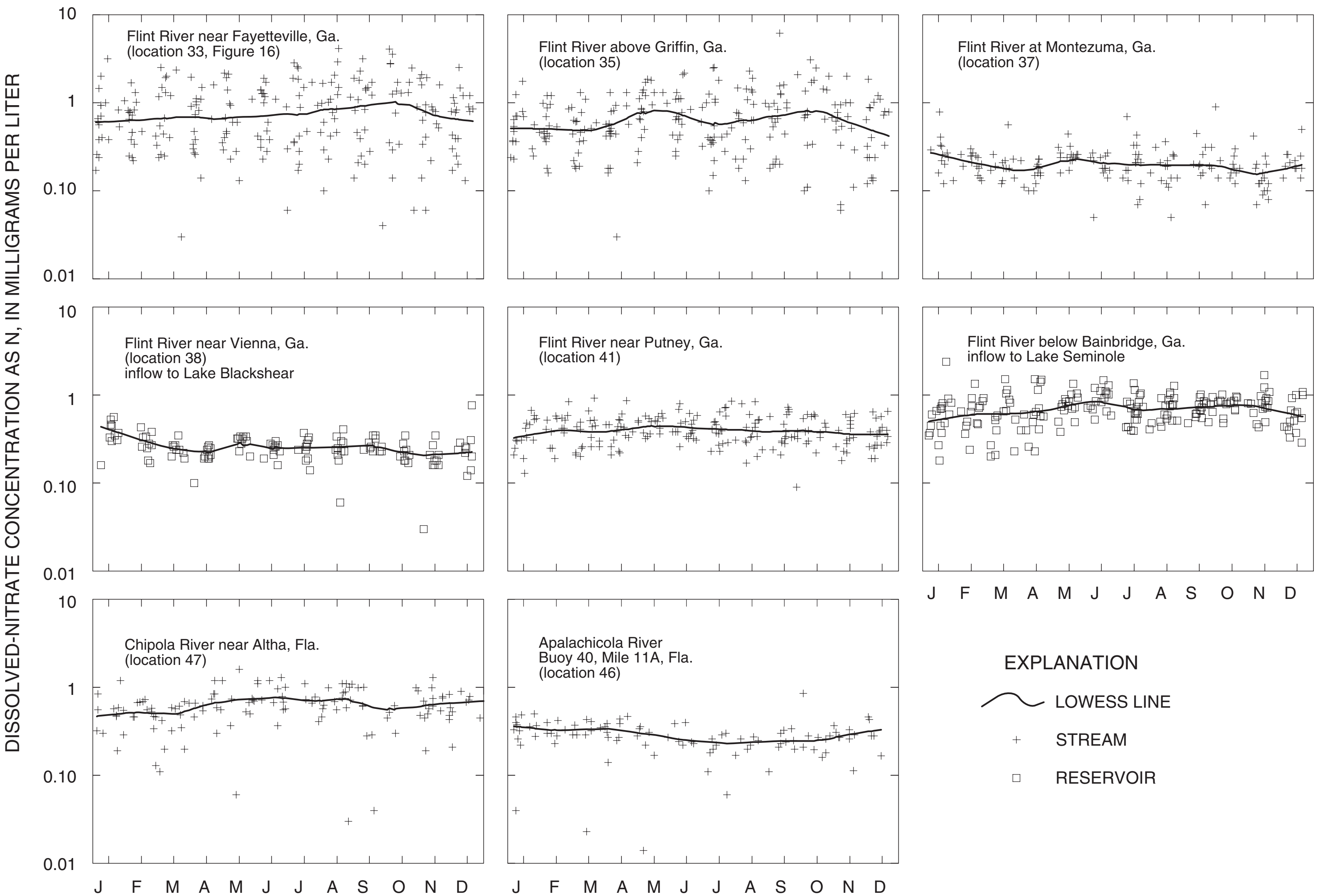


Figure 34. Seasonal variation in dissolved-nitrate concentrations for selected streams and reservoirs, Flint, Chipola, and Apalachicola Rivers, 1972–90 water years.

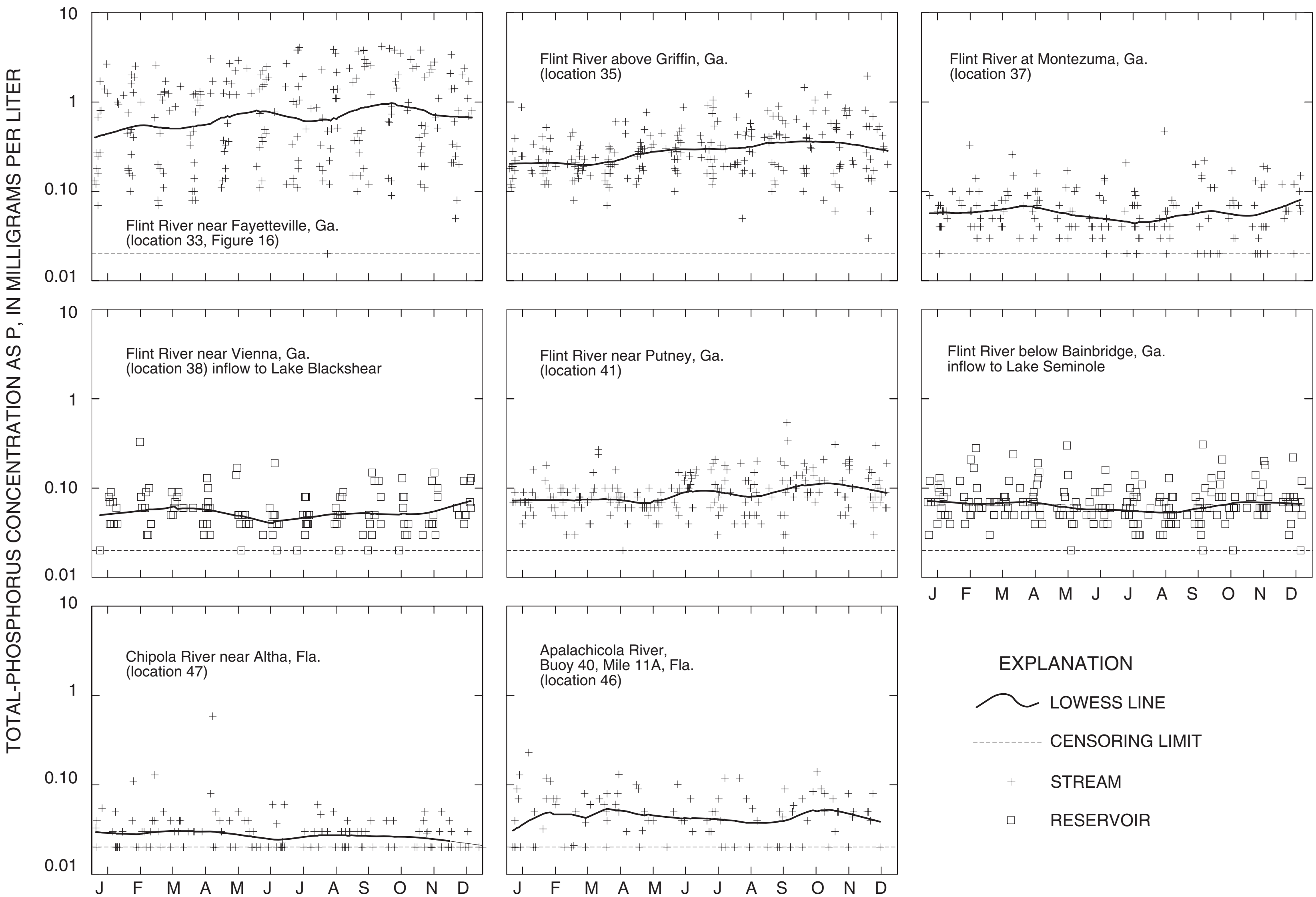


Figure 35. Seasonal variation in total-phosphorus concentrations for selected streams and reservoirs, Flint, Chipola, and Apalachicola Rivers, 1972–90 water years.

In contrast to the Chattahoochee River, seasonal patterns in nutrient concentrations in the Flint, Chipola, and Apalachicola Rivers either were not present or were less apparent (figs. 33–35). In the Chattahoochee River, reservoirs seem to control seasonal variations; however, in the Flint, Chipola, and Apalachicola Rivers, which have few reservoirs, there may be several factors influencing seasonal variation of nutrient concentrations offsetting one another.

Temporal trends in concentrations

Nutrient data from 47 sampling sites were analyzed for trends (table 15, fig. 36). Three sites on the Chattahoochee River were affected by backwater (locations 26, 27, and 28) and seven sites were located in reservoirs (locations 2, 20, 21, 24, 31, 38, and 43). The period of record for trend tests were 1980–90 water years at all sites so that comparisons among trends at different sites would be valid. The period 1980–90 was chosen because more sites within the ACF River basin had available nutrient data for that time period than longer periods, and the 1980–90 time period is of interest for comparison of results across the nation (Dennis Helsel, U.S. Geological Survey, written commun., 1993). From the late 1980's to 1993, improvements to several WWTF and phosphate detergent bans resulted in decreased nutrient concentrations (especially in the Upper and Middle Chattahoochee River subbasins) which were not reflected in the results of 1980–90 trend tests (Wangsness and others, 1994; DeVivo and others, 1995).

Seasonal Kendall test (Hirsch and others, 1982), a nonparametric or distribution free test, was used to determine if changes in concentrations of seven nutrient constituent groups were generally increasing or decreasing at each surface-water site. The test compares concentrations in each month with concentrations in that same month in other years or by seasons when data are collected less frequently than monthly. The 12 monthly tests (or fewer seasonal tests) are combined to form an overall test for trend (Helsel, 1993, p. 98). This enables trends over several years to be more easily separated from seasonal variations in nutrient water quality. Trends in flow-adjusted concentrations also were calculated to test for trends caused by factors other than streamflow (such as from point-source loads and nonpoint-source inputs). Flow-adjusted concentrations were determined by first constructing a LOWESS line to represent the relation between nutrient concentration and streamflow, and then by calculating a residual, which is the difference between concentrations from the LOWESS line and the measured concentration (Hirsch and others, 1991). As long as the relation between concentration and streamflow has not changed during the period of the trend test, a trend in residuals implies a trend in concentration independent of streamflow conditions (Helsel, 1993, p. 98). A 90-percent confidence level was used for all trend results.

Sites where trends were calculated have a minimum of eight years of quarterly nutrient data, and at least one-half of nutrient analyses were from samples collected in the first and last third of the 1980–90 period (Lanfear and Alexander, 1990). Data were insufficient to calculate trends for dissolved-organic nitrogen at all sites. Flow-adjusted trends are not reported for reservoir sites, three sites in the Chattahoochee River affected by backwater, and tributary sites in the Metropolitan Atlanta area sampled as a part of the DeKalb County monitoring network because streamflow data were not available. Table 15 lists all surface-water sites where trends were calculated; positive or negative trends, where significant; and rate of change in concentration, in milligrams per liter per year (mg/L/yr). Figure 36 shows the locations where trends in concentrations (as opposed to trends in flow-adjusted concentrations) were calculated for dissolved ammonia, dissolved nitrate, and total phosphorus; and the direction of trends, if significant.

All significant trends in nutrient concentrations in the Chattahoochee River were increasing, except dissolved ammonia (fig. 36) and total-inorganic-nitrogen trends (table 15), which decreased at several sites in the reach downstream of Atlanta and downstream of Columbus and Phenix City. All significant trends in nutrient concentrations at sites on the Upper Flint River were decreasing, and at a larger rate of change than in other reaches in the ACF River basin. Most changes in nutrient concentrations in the Upper Flint River basin were the result of diverting discharges of municipal-wastewater effluent to the Chattahoochee River, the South River (outside the ACF River basin), and to land application areas. All significant trends in the Middle and Lower Flint River basins were increasing, except the trend in dissolved-ammonia concentration, which decreased at Flint River near Putney (location 41). All significant trends in the Apalachicola River were decreasing, except the trend in dissolved-nitrate concentration at Apalachicola River, Buoy 40, mile 11A (location 46). At sites on the Chattahoochee and Flint Rivers downstream of Atlanta and Albany, decreasing trends in dissolved-ammonia concentration and increasing trends in dissolved-nitrate concentration were the result of improved wastewater treatment at WWTF in these urban areas.

Table 15. Trend-test results for nutrient concentrations for selected surface-water sampling sites, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1980–90 water years

[All trends are results of seasonal Kendall tests for time trends from 1980–90 water years. Data were insufficient to calculate trends for dissolved-organic nitrogen at all sites within the Apalachicola–Chattahoochee–Flint River basin. C, concentration; FAC, flow-adjusted concentration; —, trend test could not be performed
Surface-water station name sources: D, DeKalb County, Georgia; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Surface-water station name (Reservoir name, if applicable)	Average rate of change, 1980–90 water years, in milligrams per liter per year													
		Total nitrogen		Total-inorganic nitrogen		Total-organic nitrogen		Dissolved ammonia		Dissolved nitrate		Total phosphorus		Dissolved orthophosphate	
		C	FAC	C	FAC	C	FAC	C	FAC	C	FAC	C	FAC	C	FAC
	Upper Chattahoochee (03130001)														
1	Chattahoochee River near Cornelia, Ga.[U]	—	—	+.020	+.021	—	—	+.008	+.002	+.013	+.013	+.004	+.002	—	—
2	Chattahoochee River - Georgia Highway 369, Browns Bridge[G] (Lake Sidney Lanier)	—	—	1/	2/	—	—	+.007	2/	1/	2/	3/	2/	3/	2/
3	Chattahoochee River - Gwinnett County Water Intake[G]	—	—	+.003	+.005	—	—	+.003	+.002	+.003	+.006	3/	2/	—	—
4	Chattahoochee River - DeKalb County Water Intake[G]	—	—	+.008	+.009	—	—	+.003	+.002	+.005	+.007	3/	2/	—	—
5	Big Creek - Roswell Water Intake[G]	—	—	+.089	+.088	—	—	+.003	+.003	+.080	+.077	+.008	+.006	—	—
6	Chattahoochee River - Cobb County Water Intake[G]	—	—	+.026	+.021	—	—	1/	1/	+.023	+.019	+.010	+.002	—	—
7	Chattahoochee River - Atlanta Water Intake[G]	—	—	+.026	+.021	—	—	+.003	+.002	+.025	+.019	+.010	+.006	—	—
8	North Fork Peachtree Creek - Pleasantdale Road near Doraville[D]	—	—	1/	2/	—	—	1/	2/	1/	2/	+.006	2/	—	—
9	Arrow Creek - Plaster Road near Peachtree-DeKalb Airport[D]	—	—	1/	2/	—	—	+.015	2/	1/	2/	+.002	2/	—	—
10	North Fork Peachtree Creek - U.S. Highway 23[D]	—	—	—	—	—	—	1/	2/	1/	2/	+.003	2/	—	—
11	South Fork Peachtree Creek - Johnson Road in Atlanta[D]	—	—	—	—	—	—	—	—	1/	2/	+.005	2/	—	—
12	Peachtree Creek at Atlanta, Ga.[U]	—	—	1/	+.011	—	—	1/	1/	1/	+.009	+.003	+.004	—	—
13	Nancy Creek - bridge 0.2 miles downstream from Chamblee-Dunwoody Road [D]	—	—	—	—	—	—	+.009	2/	—	—	+.003	2/	—	—
14	Nancy Creek - at Johnsons Ferry Road near Chamblee[D]	—	—	—	—	—	—	1/	2/	—	—	1/	2/	—	—
	Middle Chattahoochee—Lake Harding (03130002)														
15	Chattahoochee River at I-285, at Atlanta, Ga.[U]	—	—	1/	1/	—	—	1/	–.014	+.035	+.022	+.020	+.007	—	—
16	Sweetwater Creek near Austell, Ga.[U]	—	—	1/	1/	—	—	+.004	+.002	1/	1/	1/	1/	—	—
17	Chattahoochee River near Fairburn, Ga.[U]	1/	1/	+.040	+.037	1/	1/	1/	–.012	+.043	+.046	+.020	+.015	—	—

Table 15. Trend-test results for nutrient concentrations for selected surface-water sampling sites, by subbasin, Apalachicola–Chattahoochee–Flint River basin, 1980–90 water years—Continued

[All trends are results of seasonal Kendall tests for time trends from 1980–90 water years. Data were insufficient to calculate trends for dissolved-organic nitrogen at all sites within the Apalachicola–Chattahoochee–Flint River basin. C, concentration; FAC, flow-adjusted concentration; —, trend test could not be performed
Surface-water station name sources: D, DeKalb County, Georgia; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

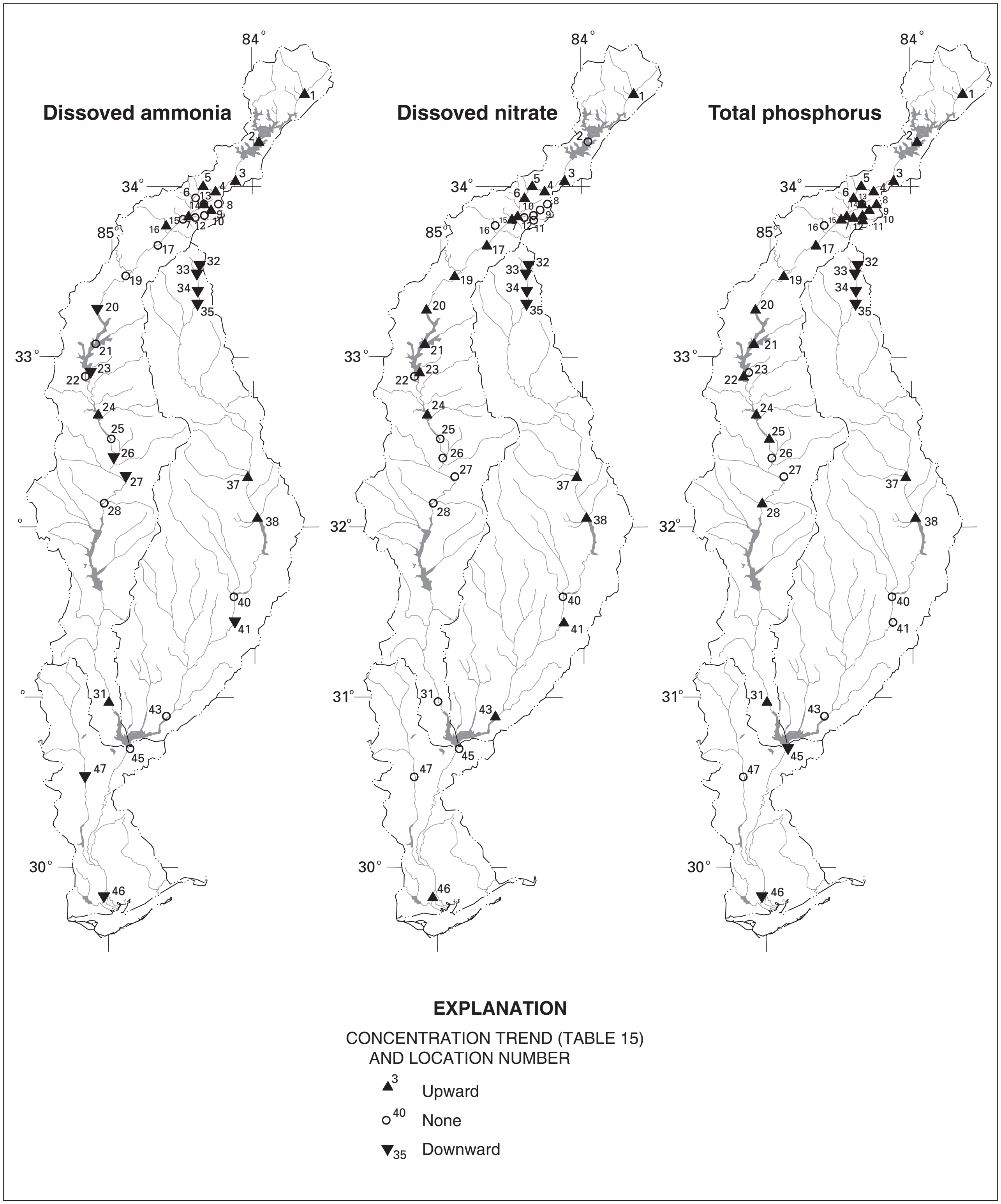
Location number (figure 16)	Surface-water station name (Reservoir name, if applicable)	Average rate of change, 1980–90 water years, in milligrams per liter per year													
		Total nitrogen		Total-inorganic nitrogen		Total-organic nitrogen		Dissolved ammonia		Dissolved nitrate		Total phosphorus		Dissolved orthophosphate	
		C	FAC	C	FAC	C	FAC	C	FAC	C	FAC	C	FAC	C	FAC
19	Chattahoochee River near Whitesburg, Ga.[U]	—	—	+.080	+.035	—	—	1/	–.010	+.090	+.045	+.030	+.017	—	—
20	Chattahoochee River at Franklin, Ga.[U] (inflow to West Point Lake)	—	—	+.048	2/	—	—	–.005	2/	+.045	2/	+.021	2/	—	—
21	Chattahoochee River - LaGrange Water Intake[G] (West Point Lake)	—	—	+.042	2/	—	—	1/	2/	+.030	2/	+.010	2/	—	—
22	Chattahoochee River at West Point, Ga.[U]	—	—	1/	1/	—	—	1/	1/	1/	1/	+.004	+.004	—	—
23	Long Cane Creek near West Point, Ga.[U]	—	—	+.042	1/	—	—	–.023	1/	+.078	+.078	1/	1/	—	—
24	Chattahoochee River - Upstream from Bartletts Ferry Dam[G] (Lake Harding)	—	—	+.010	2/	—	—	+.003	2/	+.008	2/	+.002	2/	—	—
	Middle Chattahoochee—Walter F. George Reservoir (03130003)														
25	Chattahoochee River - Columbus Water Intake[G]	—	—	1/	1/	—	—	1/	1/	1/	1/	+.003	+.003	—	—
26	Chattahoochee River - Downstream from Columbus WTF[G] (affected by backwater from Walter F. George Reservoir)	—	—	–.013	2/	—	—	–.015	2/	1/	2/	1/	2/	—	—
27	Chattahoochee River - Downstream Oswichee Creek[G] (affected by backwater from Walter F. George Reservoir)	—	—	–.007	2/	—	—	–.008	2/	1/	2/	1/	2/	—	—
28	Chattahoochee River - Seaboard Coast Line Railway, Omaha[G] (affected by backwater from Walter F. George Reservoir)	—	—	1/	2/	—	—	1/	2/	1/	2/	+.003	2/	—	—
	Lower Chattahoochee (03130004)														
31	Chattahoochee River near Steam Mill, Ga.[U] (inflow to Lake Seminole, Chattahoochee Arm)	—	—	+.010	2/	—	—	+.004	2/	1/	2/	+.001	2/	—	—
	Upper Flint (03130005)														
32	Flint River near Jonesboro, Ga.[U]	—	—	–.272	–.279	—	—	–.058	–.061	–.139	–.145	–.072	–.066	—	—
33	Flint River near Fayetteville, Ga.[U]	—	—	–.349	–.332	—	—	–.068	–.096	–.116	–.114	–.094	–.089	—	—
34	Flint River near Inman, Ga.[U]	—	—	–.130	–.134	—	—	–.010	–.011	–.097	–.092	–.028	–.035	—	—

Table 15. Trend-test results for nutrient concentrations for selected surface-water sampling sites, by subbasin, Apalachicola−Chattahoochee−Flint River basin, 1980–90 water years—Continued

[All trends are results of seasonal Kendall tests for time trends from 1980–90 water years. Data were insufficient to calculate trends for dissolved-organic nitrogen at all sites within the Apalachicola−Chattahoochee−Flint River basin. C, concentration; FAC, flow-adjusted concentration; —, trend test could not be performed
Surface-water station name sources: D, DeKalb County, Georgia; F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Surface-water station name (Reservoir name, if applicable)	Average rate of change, 1980–90 water years, in milligrams per liter per year													
		Total nitrogen		Total-inorganic nitrogen		Total-organic nitrogen		Dissolved ammonia		Dissolved nitrate		Total phosphorus		Dissolved orthophosphate	
		C	FAC	C	FAC	C	FAC	C	FAC	C	FAC	C	FAC	C	FAC
35	Flint River above Griffin, Ga.[U]	–.113	–.111	–.082	–.090	–.016	–.016	–.003	–.003	–.077	–.080	–.018	–.024	—	—
	Middle Flint (03130006)														
37	Flint River at Montezuma, Ga.[U]	—	—	+.008	+.010	—	—	+.003	+.002	+.007	+.008	+.004	+.004	—	—
38	Flint River near Vienna, Ga.[U] (inflow to Lake Blackshear)	—	—	+.015	2/	—	—	+.001	2/	+.010	2/	+.003	2/	—	—
	Lower Flint (03130008)														
40	Flint River at Albany, Ga.[U]	—	—	1/	1/	—	—	1/	1/	1/	1/	1/	1/	—	—
41	Flint River near Putney, Ga.[U]	—	—	1/	1/	—	—	–.011	–.011	+.016	+.013	1/	1/	—	—
43	Flint River below Bainbridge, Ga.[U] (inflow to Lake Seminole, Flint Arm)	—	—	+.016	2/	—	—	1/	2/	+.017	2/	1/	2/	—	—
	Apalachicola (03130011)														
45	Apalachicola River at Chattahoochee, Fla.[U]	1/	1/	1/	1/	1/	1/	1/	1/	1/	1/	–.001	–.002	1/	2/
46	Apalachicola River, Buoy 40, mile 11A[F]	1/	1/	1/	1/	1/	1/	–.002	1/	+.010	1/	–.005	–.001	—	—
	Chipola (03130012)														
47	Chipola River near Altha, Fla.[U]	1/	1/	1/	1/	1/	1/	–.003	2/	1/	1/	1/	2/	4/	2/

1/ Trends were calculated, but were not significant at the 90-percent confidence level.
2/ Data could not be flow adjusted.
3/ Trends were significantly increasing at the 90-percent confidence level; however, average rates of change could not be calculated because of high percentage of censored data.
4/ Trends were significantly decreasing at the 90-percent confidence level; however, average rates of change could not be calculated because of high percentage of censored data.



Base from U.S. Geological Survey digital files

Figure 36. Summary of trends for concentration of dissolved ammonia, dissolved nitrate, and total phosphorus in surface water, Apalachicola-Chattahoochee-Flint River basin, 1980-90 water years.

Increasing trends in total-phosphorus concentrations are an accurate representation of temporal changes in this constituent for the period 1980−90. However, in February 1989, the Georgia Environmental Protection Division issued an Administrative Order requiring all major WWTF (larger than 1 Mgal/d) between Lake Sidney Lanier (upstream of Atlanta) and West Point Lake (downstream of Atlanta) to reduce average concentration of phosphorus in effluent to 0.75 mg/L or less. By 1993, nine municipal and one industrial WWTF were in compliance of the Order (David Kamps, Georgia Environmental Protection Division, oral commun., 1994). The three remaining WWTF in this reach of the Chattahoochee River are owned by the city of Atlanta, which negotiated an extension until July 4, 1996, in exchange for agreeing to meet a more restrictive limit of 0.64 mg/L average phosphorus concentration. Point-source loads of phosphorus from the 13 major WWTF that discharge into the Chattahoochee River between Buford Dam and West Point Lake decreased from a high of 1,670 tons in 1988 to 298 tons in 1993 (David Kamps, Georgia Environmental Protection Division, written commun., 1994). This large decrease in point-source loads was primarily the result of legislated restrictions on use of phosphate detergents and improvements to WWTF. Restrictions of the use of phosphate detergents decreased phosphate concentrations of influent to WWTF and helped improve efficiency of phosphorus removal within the WWTF (DeVivo and others, 1995). Total-phosphorus loads upstream of Metropolitan Atlanta (Chattahoochee River–Gwinnett County Water Intake; location 3) continued to increase from 47 tons in 1988 to 200 tons in 1993, because of increases in nonpoint-source inputs. Although volume of effluent discharged continued to increase, total-phosphorus loads downstream from Metropolitan Atlanta (Chattahoochee River near Whitesburg; location 19) peaked at 1,760 tons in 1984, and decreased from 1,190 tons in 1988 to 550 tons in 1993, primarily because of the large decrease in point-source loads (Wangsness and others, 1994).

In addition to statistical trend tests, time-series plots of nutrient concentrations can provide additional information on temporal variability at individual water-quality sites and among sites. Time-series plots of dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations, LOWESS lines, and results of trend tests are shown in figures 37−39 for eight river and reservoir sites in the Chattahoochee River basin. Concentration data were used in these figures rather than residuals of flow-adjusted concentrations so direct comparisons could be made between river and reservoir sites (flow-adjusted trend results cannot be calculated for reservoirs). Trends were calculated using data for the period 1980−90 to be consistent nationally; however, LOWESS lines were calculated using data for the period 1972−90 to be consistent with data presented in this report. Chattahoochee River near Steam Mill (location 31) is an example of a site having an increasing trend in dissolved-ammonia concentrations and Chattahoochee River at Franklin (location 20) is an example of a decreasing trend site (fig. 37). All trends in dissolved-nitrate concentration on the Chattahoochee River either were increasing or not significant at the 90-percent confidence level (table 15, fig. 38). Trend rates in dissolved-nitrate concentrations increased moderately (+ 0.045 to + 0.090 mg/L/yr) during 1980−90 at sites in the stream reach downstream of Atlanta, including sites at Fairburn (location 17), near Whitesburg (location 19), and at Franklin (location 20; fig. 38). Although, trends in total-phosphorus concentration for the period 1980−90 in the Chattahoochee River either were increasing or insignificant, the beginning of the decrease in total-phosphorus concentrations in the late 1980's was apparent on the Chattahoochee River downstream of Atlanta near Fairburn (location 17), at Franklin (location 20), and at the LaGrange Water Intake (location 21; fig. 39).

Time-series plots of dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations, LOWESS lines, and results of trend tests are shown in figures 40−42 for eight river and reservoir sites in the Flint and Apalachicola River basins. The largest rates of change in 1980−90 concentrations for all nutrient constituent groups occurred in the Upper Flint River subbasin, because of the removal of municipal-wastewater outfalls from the Upper Flint River basin in the early- to mid-1980's. For example, at Flint River near Fayetteville (location 33) dissolved-ammonia concentrations decreased an average of −0.068 (concentration) and −0.096 (flow adjusted) mg/L/yr (fig. 40), and total-phosphorus concentrations decreased an average of −0.094 (concentration) and −0.089 (flow adjusted) mg/L/yr (fig. 42). Upstream at Flint River near Jonesboro (location 32), dissolved-nitrate concentrations decreased an average of −0.139 (concentration) and −0.145 (flow adjusted) mg/L/yr (table 15). Trends in dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations were slightly increasing at Flint River at Montezuma (location 37) and Lake Blackshear (location 38, table 15, figs. 40−42). The patterns of

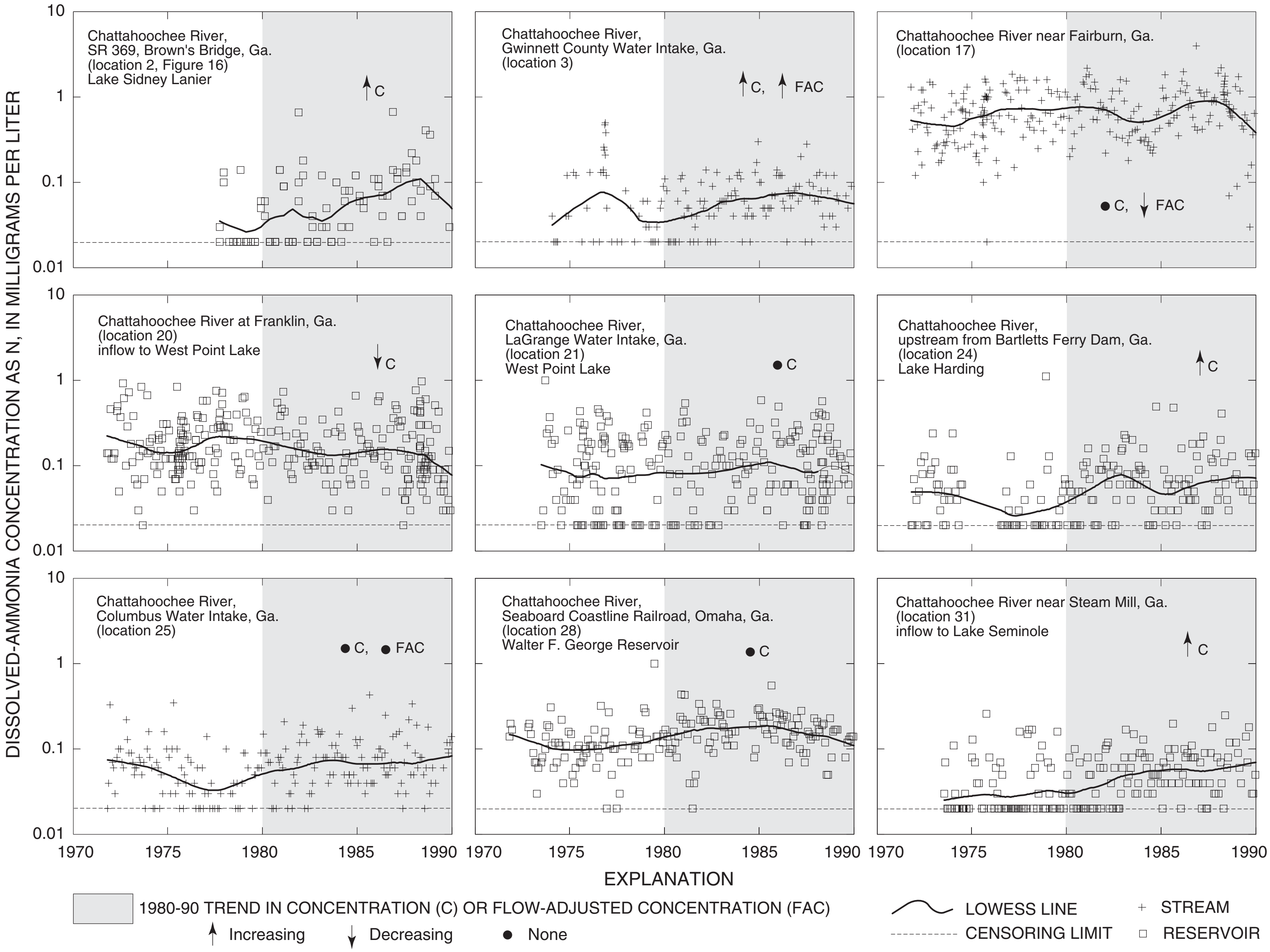


Figure 37. Temporal variation in dissolved-ammonia concentrations for selected streams and reservoirs and 1980-90 trend, Chattahoochee River,1972–90 water years. (See table 15 for more information on trends.)

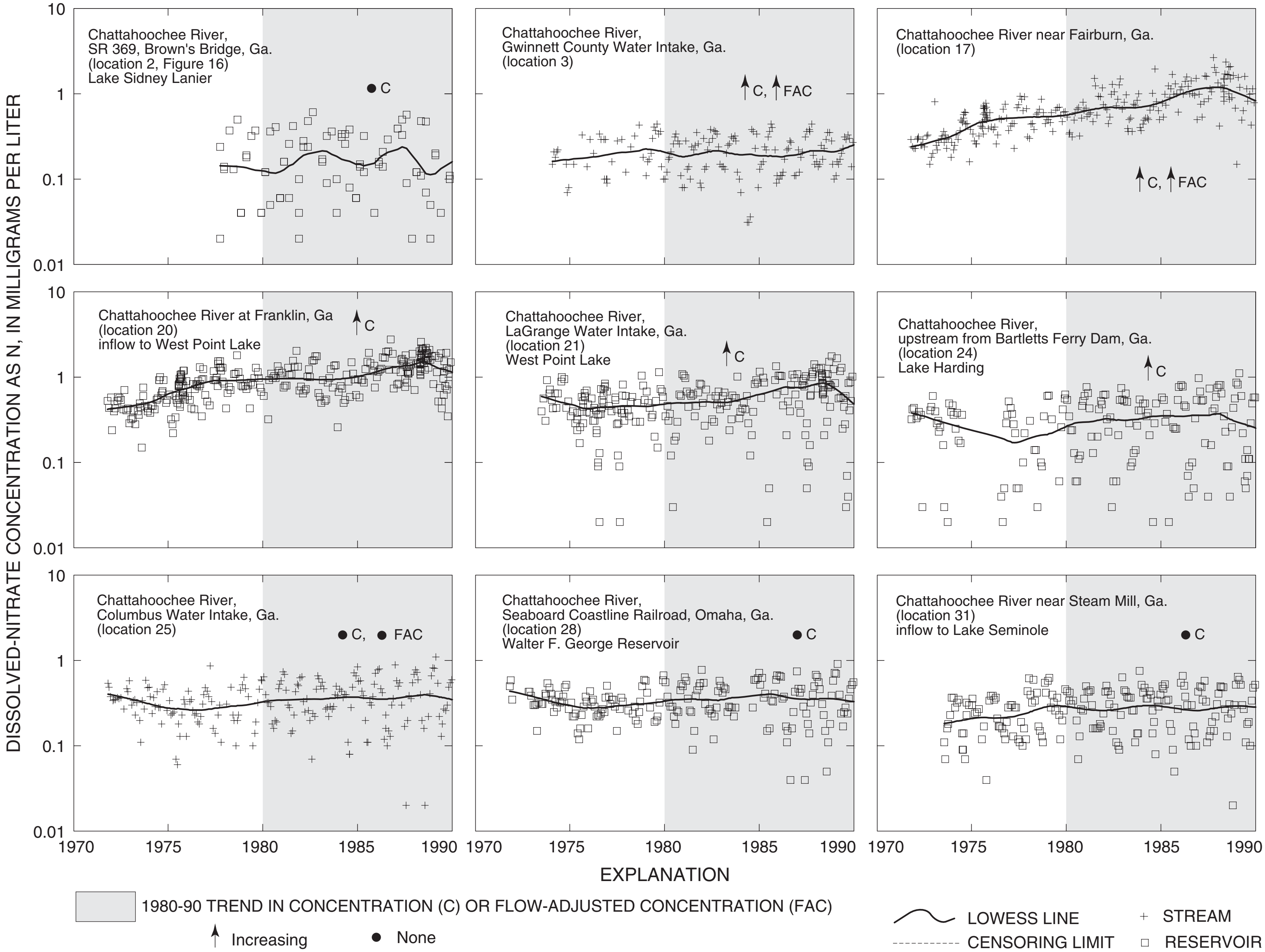


Figure 38. Temporal variation in dissolved-nitrate concentrations for selected streams and reservoirs and 1980-90 trend, Chattahoochee River, 1972–90 water years. (See table 15 for more information on trends.)

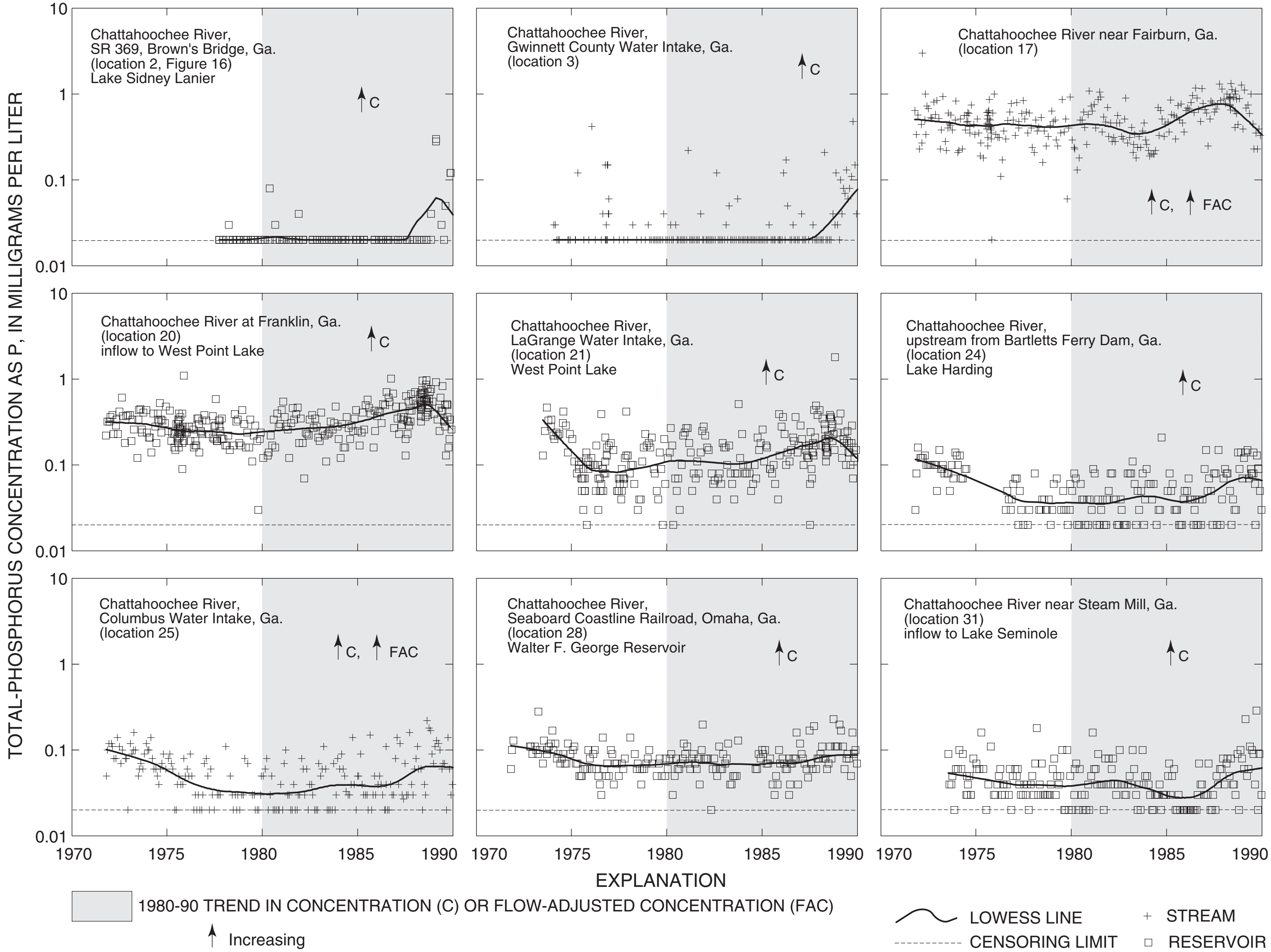


Figure 39. Temporal variation in total-phosphorus concentrations for selected streams and reservoirs and 1980-90 trend, Chattahoochee River, 1972–90 water years. (See table 15 for more information on trends.)

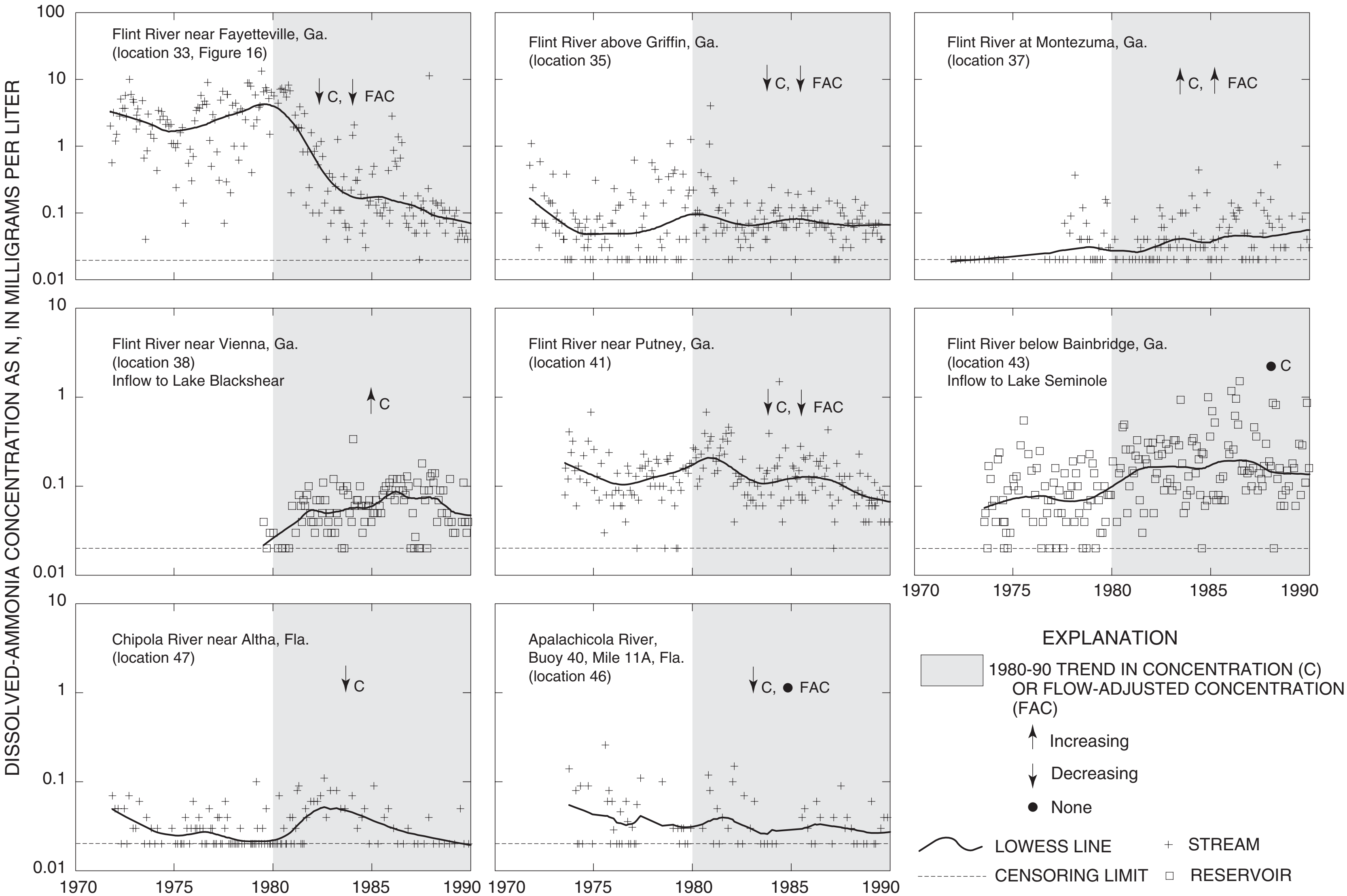


Figure 40. Temporal variation in dissolved-ammonia concentrations for selected streams and reservoirs and 1980-90 trend, Flint, Chipola, and Apalachicola Rivers, 1972–90 water years. (Locations 33, 35, and 37 are plotted with 4-log cycle scales. See table 15 for more information on trends.)

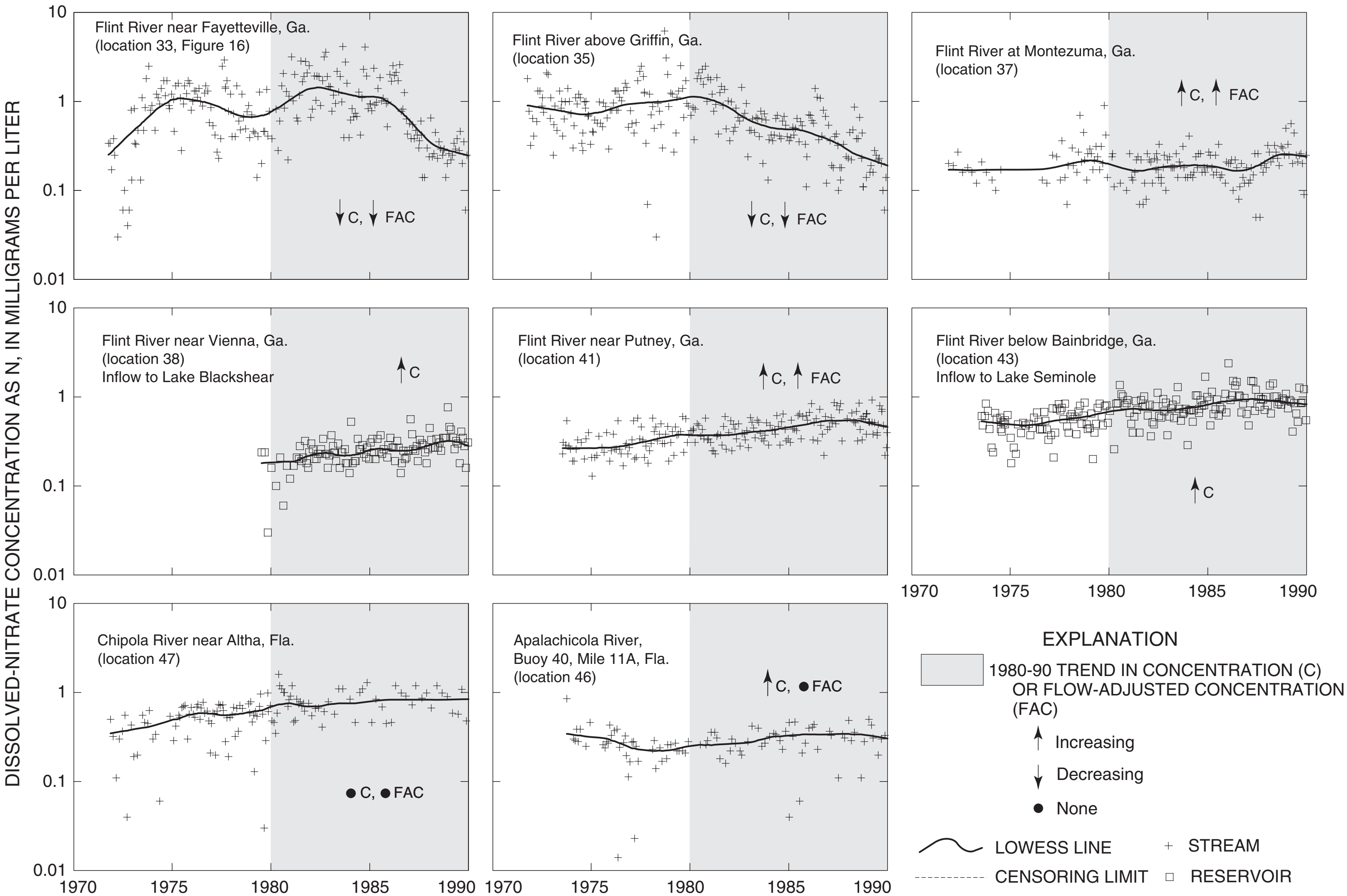


Figure 41. Temporal variation in dissolved-nitrate concentrations for selected streams and reservoirs and 1980-90 trend, Flint, Chipola, and Apalachicola Rivers, 1972–90 water years. (See table 15 for more information on trends.)

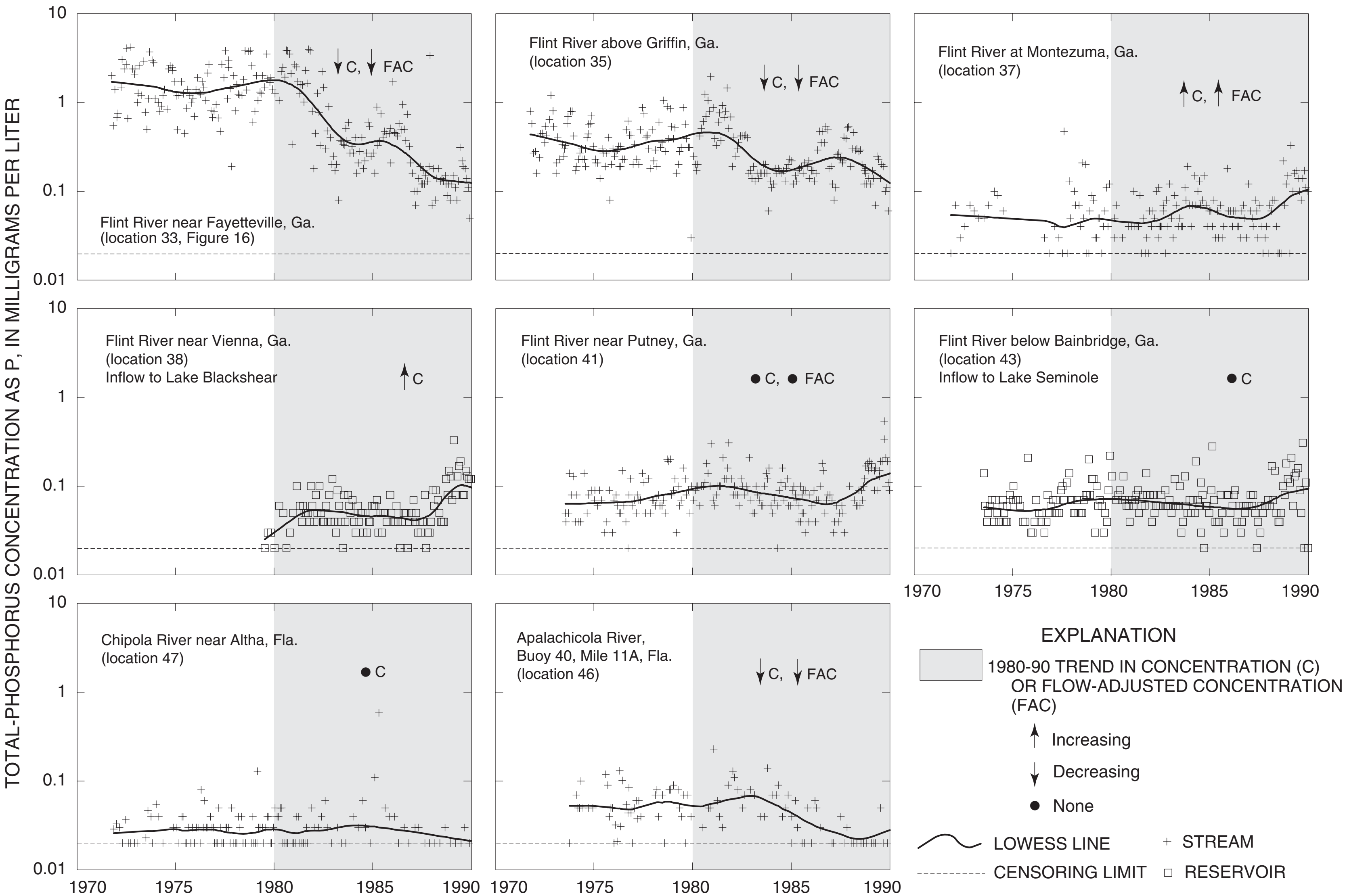


Figure 42. Temporal variation in total-phosphorus concentrations for selected streams and reservoirs and 1980-90 trend, Flint, Chipola, and Apalachicola Rivers, 1972–90 water years. (See table 15 for more information on trends.)

decreasing trend in dissolved-ammonia concentrations and increasing trend in dissolved-nitrate concentrations downstream of Albany (Flint River at Putney, location 41; figs. 40, 41) are similar to patterns downstream of Atlanta (Chattahoochee River near Fairburn and at Franklin, locations 17 and 20; figs. 37, 38). Trends in nutrient concentrations in the Apalachicola and Chipola Rivers either were slight or not significant at the 90-percent confidence level (table 15, figs. 40–42).

Annual loads and mean annual yields

Annual loads were estimated for 1972–90 water years for total nitrogen, total-inorganic nitrogen, total-organic nitrogen, dissolved ammonia, dissolved nitrate, total phosphorus, and dissolved orthophosphate at sites on the Apalachicola, Chattahoochee, and Flint Rivers, and at a few tributary sites where sufficient data were available (table 16, at end of report). Loads generally increase with increasing drainage area because of a positive relation between drainage area and discharge. Load estimates are not used when the standard error of the load estimate is greater than 30 percent of the load estimate for a given year. The period of record for load estimates is longer than the period of record for nutrient-concentration data when discharge data for one to three years are similar to discharge data for years with water-quality data and the standard error of the load estimates based on simulated nutrient-concentration data are less than 30 percent of the load estimates. Loads for Apalachicola River, Buoy 40 (location 46), for 1972–76 are based on synthesized-flow data from a time lag of flow data collected at Apalachicola River near Blountstown (78 mi upstream from the mouth of the Apalachicola River) and at Chipola River near Altha (Marvin Franklin, U.S. Geological Survey, written commun., 1994). Loads determined at sites downstream of West Point Lake on the Chattahoochee River since 1975 show the effects of the reservoir, which began filling in October 1974.

Annual load estimates were calculated using various relations among time (to compensate for long-term trends), logarithm of discharge, and sine and cosine of time (to compensate for seasonal variations). Instantaneous nutrient loads are calculated by multiplying the nutrient concentration by the stream discharge at the time of sample collection. Annual loads are more difficult to accurately estimate because concentration data are limited (often monthly or quarterly), and because nutrient concentrations are highly variable as a result of a wide variety of physical, chemical, and biological factors. For data sets without censored observations, the Minimum Variance Unbiased Estimator (Cohn and others, 1989; Gilroy and others, 1990) method was used to estimate annual loads, and for data sets with censored observations, the Adjusted Maximum Likelihood Estimator (Cohn, 1988) method was used. Accuracy of the constituent transport models and estimated loads depend on how much of the variance in nutrient concentrations can be explained by discharge and time, and how representative samples are of the range of hydrologic conditions at each site. Many factors that influence or control nutrient cycling (particularly for nitrogen) and transport were not accounted for in models used to estimate nutrient loads in this report. Concentration data collected during high-flow conditions are particularly important because the timing, amount, and distance of transport of many constituents is strongly influenced by high-flow conditions. Errors in individual estimates of nutrient load generally are less than differences: (1) among nutrient loads at each site among years with different hydrologic conditions (wet, normal, dry years); (2) among nutrient loads among sites along a flow system for a given period of time or hydrologic condition; and (3) between the amount of nutrients exported from a basin compared to estimated sources of nutrients. Load estimates are also useful in determining the proportion of nitrogen load in organic and inorganic form.

Estimated annual loads of dissolved ammonia, dissolved nitrate, and total phosphorus and mean annual discharge for eight surface-water sites are shown in figure 43 for 1972–90 water years. Estimated annual loads of dissolved nitrate tend to parallel year-to-year fluctuations in mean annual discharge more closely than dissolved ammonia or total phosphorus. An exception to this included a large increase in annual load of dissolved nitrate at the Chipola River (location 47). This increase may be the result of increases in irrigated agricultural land and fertilizer applications in the Chipola River watershed. The Floridan aquifer system underlies the Chipola River watershed, is karstic, and has relatively fast recharge rates and high transmissivities. These hydraulic characteristics may allow nutrients from land-surface sources to rapidly leach to the aquifer and discharge to the Chipola River. Another exception is Flint River above Griffin (location 35), which had significant decreases in concentrations and loads in dissolved nitrate and total phosphorus as a result of removal of several municipal wastewater-treatment discharges from the Upper Flint River in the early- to

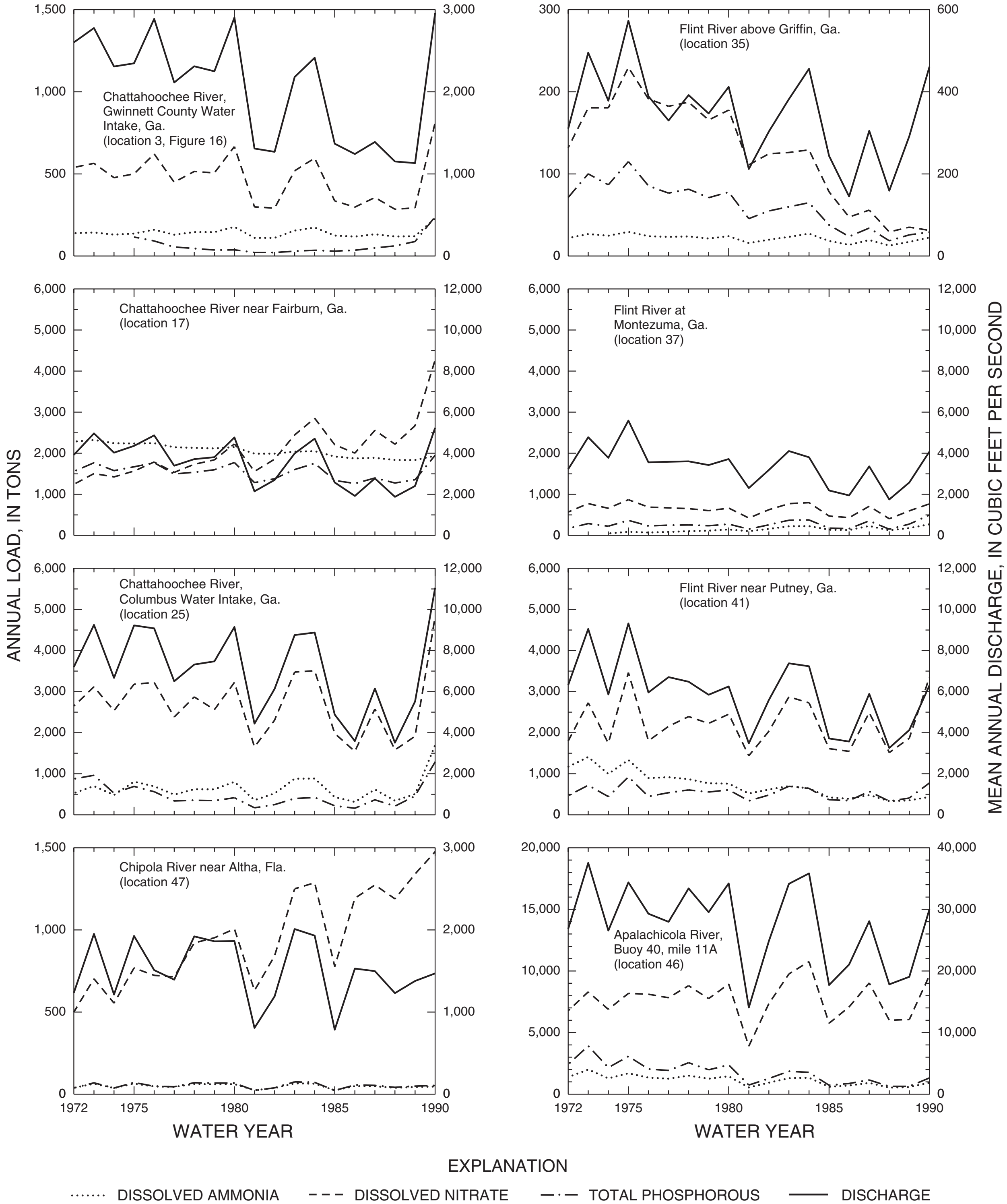


Figure 43. Annual loads of dissolved ammonia, dissolved nitrate, and total phosphorus and mean annual discharge for eight stream-sampling sites, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years.

mid-1980's. During the period 1972–80, Chattahoochee River near Fairburn (location 17; fig. 43) and Chattahoochee River at I-285 and near Whitesburg (locations 15 and 19, not shown in fig. 43) had larger estimated annual dissolved-ammonia loads than dissolved-nitrate loads. Estimated dissolved-ammonia loads declined steadily in the river reach downstream of Atlanta from 1972–90 (location 17, fig. 43), in spite of population growth and increases in the volume of treated effluent discharged from WWTF during this same time period. Estimated ammonia loads, that were larger than nitrate loads in the 1970's, are an indication of the relatively low level of treatment that municipal-wastewater effluent in the Metropolitan Atlanta area received during the 1970's. The conversion from larger ammonia loads to larger nitrate loads in the 1980's indicates the effectiveness of major improvements to WWTF in reducing ammonia loads, and subsequently reducing the threat of toxicity to fish by decreasing oxygen demand and ammonia toxicity of the effluent. The conversion also helps decrease the potential for eutrophication downstream of WWTF because dissolved nitrate in rivers is more readily denitrified (nitrogen gas released to the atmosphere) than dissolved ammonia.

Annual loads of total inorganic and organic nitrogen at mainstem sites are shown in figure 44 for 1989–a year of moderate flow; and for 1990–a year that included a several-week period of extremely high flows on the Chattahoochee River. The mouths of the Chattahoochee and Flint Rivers join in Lake Seminole to form the headwaters of the Apalachicola River. To help visually compare values in a downstream direction, data from the Apalachicola River are shown with data from the Chattahoochee River and the Flint River. At 10 sites where organic-nitrogen load could be estimated, organic nitrogen ranged from 27 to 77 percent of the total-nitrogen load in the ACF River basin. Because a large percent of total nitrogen is organic in form, future monitoring programs that intend to estimate total-nitrogen load should include organic nitrogen. Nitrogen loads in the Chattahoochee and Flint Rivers increased at a moderate rate downstream as drainage areas increased. Large increases in nitrogen loads occurred at sites in the Chattahoochee River downstream of Atlanta. In 1990, higher flows in the Chattahoochee and Apalachicola Rivers resulted in proportionately higher loads compared to loads in 1989.

Annual loads of total phosphorus at mainstem sites in 1989 and 1990 are shown on figure 45. Increases in phosphorus loads at sites downstream of Atlanta and Albany were proportionately larger than increases in nitrogen loads because municipal wastewater was the primary source of phosphorus in the rivers. A large decrease in phosphorus load occurred downstream of West Point Lake because much of the phosphorus was adsorbed onto sediments that were deposited in the reservoir. Proportionately more of the phosphorus load was deposited in West Point Lake in 1989 than 1990 because higher flows in 1990 reduced residence time in the reservoir. Extreme high flows such as occurred in the Chattahoochee River in 1990 cause greater turbulence in reservoirs which keeps more sediment in suspension and reduces the time available for settling of sediment and phosphorous uptake by aquatic organisms. Annual phosphorus loads were similar near the headwaters and the mouth of the Apalachicola River in 1989. In 1990, loads in the Apalachicola River were nearly three times greater than in 1989 and, similar to nitrogen loads, estimated phosphorus loads decreased downstream. However, because of the variance in the estimates, it can only be stated that the Apalachicola River system and its floodplain were probably a sink for phosphorus in 1990.

The floodplain ecosystem of the Apalachicola River either is a source or a sink for nutrients depending on the season, flow conditions, and location (Mattraw and Elder, 1984, p. C33–C37). Comparisons of ranges of annual load estimates (mean-annual load estimate for each year plus or minus the standard error of the estimate for that year) between sites can provide some indication if the stream reach between sites was a source or a sink for a constituent. Comparisons of ranges of annual load estimates for Apalachicola River at Chattahoochee (location 45) and Apalachicola River, Buoy 40, mile 11a (location 46) indicate that the Apalachicola River and its floodplain were a source for total phosphorus for 17 years (1972–88) and could have been either a source or a sink (estimates of loads plus or minus the standard error of the estimate overlap) in 1989–90. Based on ranges of annual load estimates for dissolved nitrate, the Apalachicola River and its floodplain were a source for 7 years, a sink for 2 years, and had an unknown role for 10 years. Ranges of estimated annual dissolved-ammonia loads at these two sites overlapped for all 19 years.

Estimated nitrogen and phosphorus loads flowing from the Apalachicola River into Apalachicola Bay were relatively small compared to nutrient sources estimated in this report to the ACF River basin from animal manure, fertilizer, atmospheric deposition, and municipal-wastewater effluent (fig. 46). Load estimates for 1990 water year for Apalachicola River,

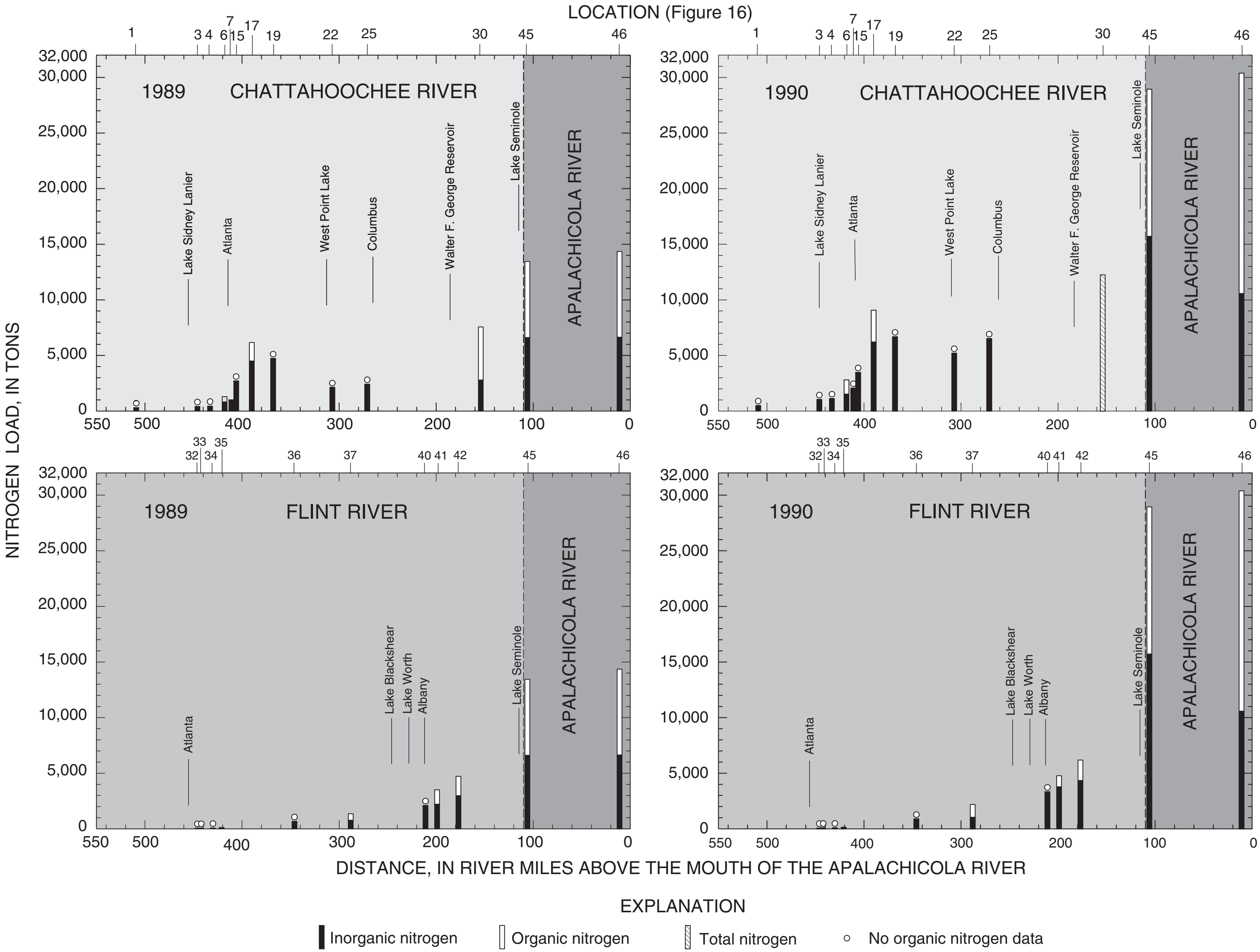


Figure 44. Nitrogen loads at selected sites along the Apalachicola, Chattahoochee, and Flint Rivers, 1989 and 1990 water years.

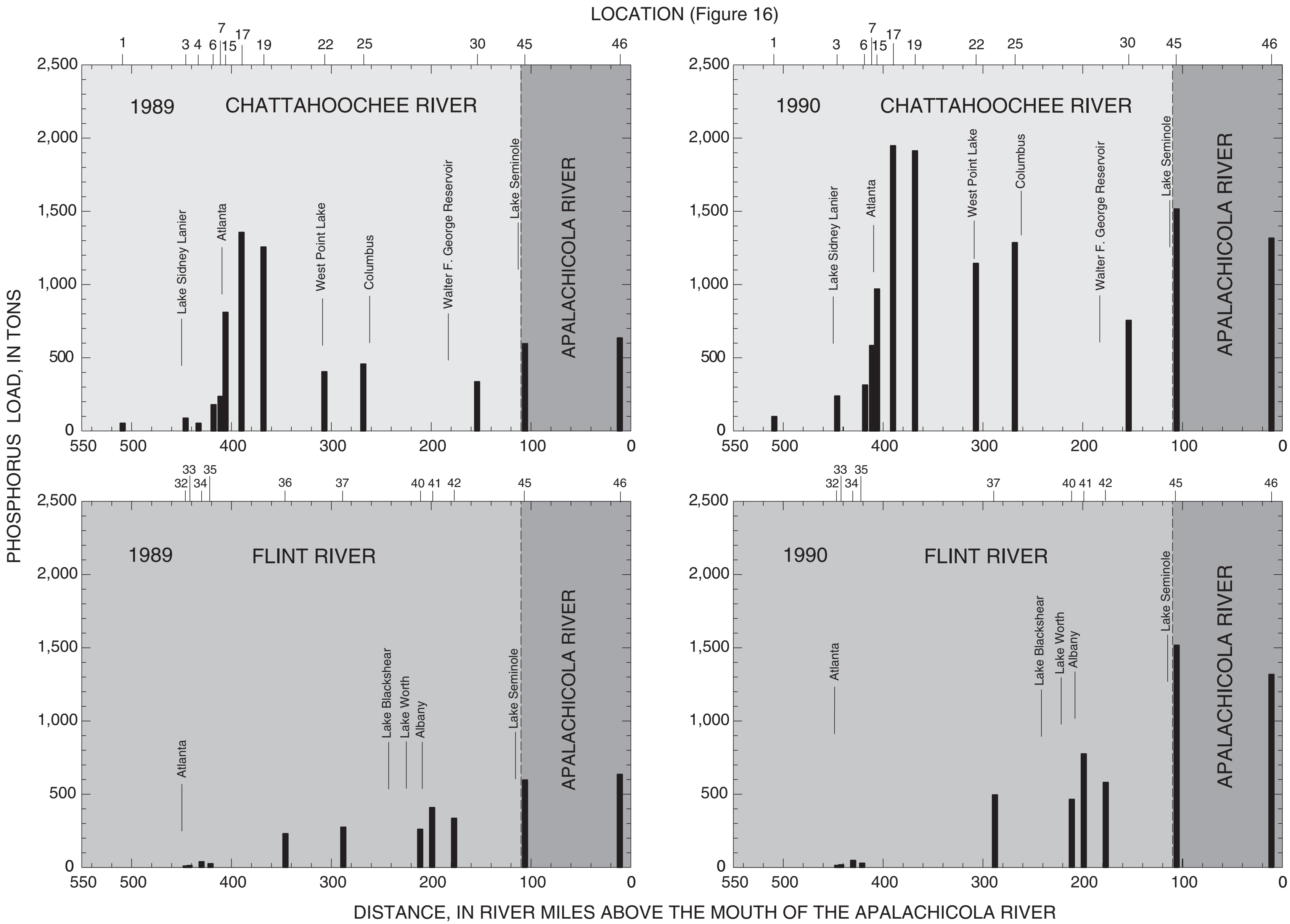


Figure 45. Total-phosphorus loads at selected sites along the Apalachicola, Chattahoochee, and Flint Rivers, 1989 and 1990 water years.

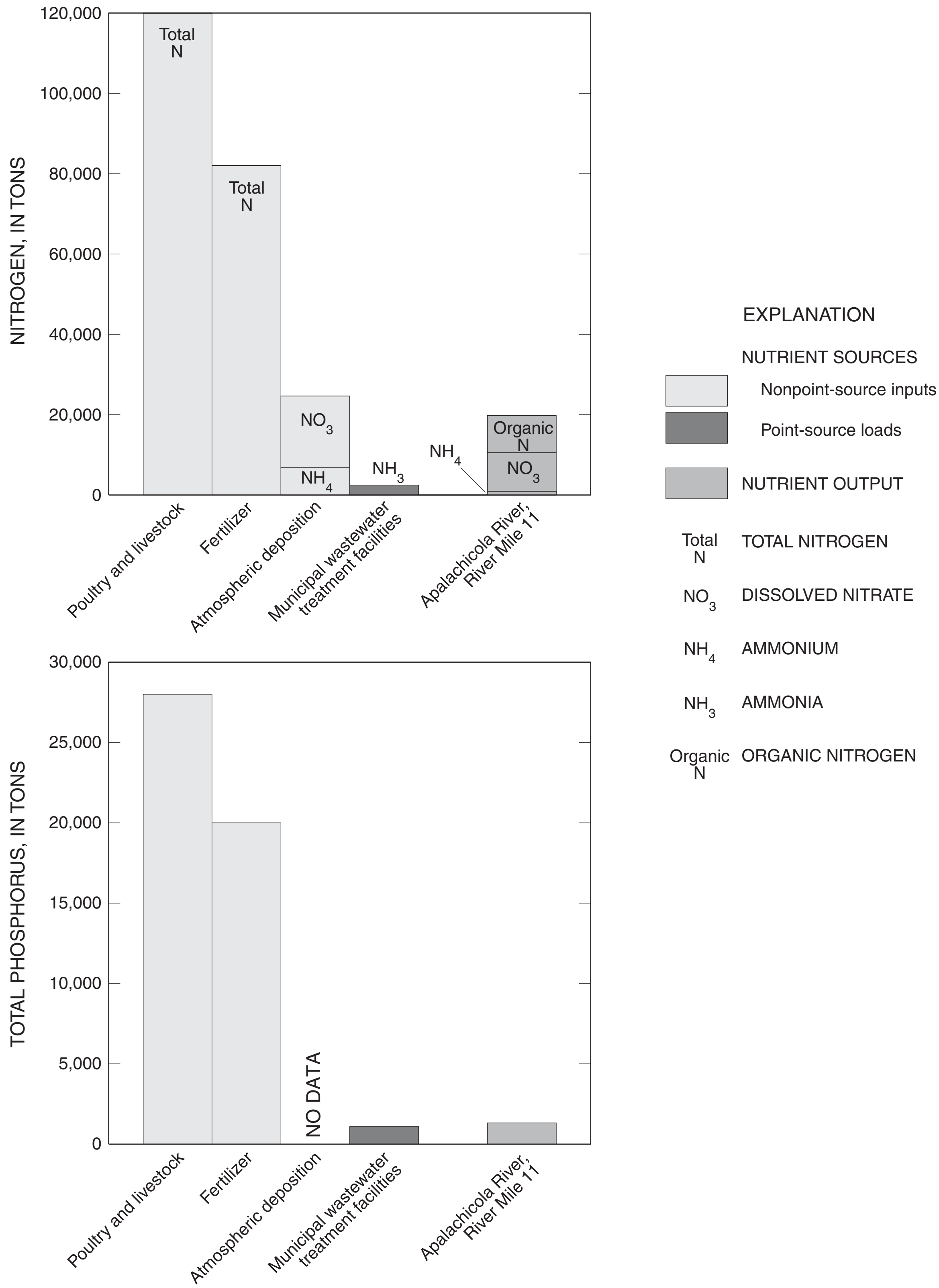


Figure 46. Nitrogen and total-phosphorus sources to and output from the Apalachicola-Chattahoochee-Flint River basin, 1990.

Buoy 40, mile 11A (location 46) were 13 percent (30,400 tons) of estimated nitrogen sources and three percent (1,320 tons) of estimated phosphorus sources to the ACF River basin. Mean discharge for 1990 water year near the mouth of the Apalachicola River was 15 percent higher than average discharge from 1977–1990 (Meadows and others, 1991, p. 92). Much of the year-to-year variation in estimates of nutrient loads flowing into Apalachicola Bay is controlled by year-to-year variation in quantity of water flowing into the bay. Load estimates (accounting for standard errors) for Apalachicola River, Buoy 40, mile 11A ranged from 9,180 to 33,900 tons/yr of nitrogen and from 660 to 3,500 tons/yr of total phosphorus for 1974–90 water years. These estimates were calculated with nutrient-concentration data from 1974–90 water years (river mile 11) and synthesized-flow data from 1974–77 and actual-flow data for 1978–90 water years (river mile 20.6). By comparison, Mattraw and Elder (1984, p. C1 and C55) estimated loads of 24,000 tons of nitrogen and 1,900 tons of total phosphorus for the one-year period from June 3, 1979, to June 2, 1980, and Frick and others (1993, p. 39) estimated 18,900 tons of nitrogen and 860 tons of total phosphorus for 1990 calendar year.

Yields (load divided by drainage area) are a way to normalize load estimates and facilitate comparisons among watersheds of different sizes. Estimated mean-annual yields ranged from 0.72 to 2.9 tons/mi^2 for total nitrogen, 0.27 to 2.0 tons/mi^2 for total-inorganic nitrogen, 0.27 to 0.74 tons/mi^2 for total-organic nitrogen, 0.02 to 1.1 tons/mi^2 for dissolved ammonia, 0.22 to 1.2 tons/mi^2 for dissolved nitrate, 0.05 to 0.75 tons/mi^2 for total phosphorus, and 0.02 to 0.03 tons/mi^2 (range based on only three sites) for dissolved orthophosphate (table 16). Yields could not be calculated for dissolved-organic nitrogen.

In unmodified watersheds, yields generally remain relatively constant as drainage area increases. Mean-annual yields of most nutrients increased in the Chattahoochee and Flint Rivers in and downstream of Atlanta. The Chattahoochee River downstream of Atlanta (locations 15, 17, or 19) had the highest mean-annual yields estimated in the ACF River basin for total nitrogen, total-inorganic nitrogen, dissolved ammonia, and total phosphorus, and the second highest mean-annual yield estimates in the basin for dissolved nitrate. Yields of total-inorganic nitrogen, dissolved ammonia, dissolved nitrate, and total phosphorus decreased substantially in the Chattahoochee River at the site downstream of West Point Lake (location 22) and continued to decrease downstream. This indicates that West Point Lake probably acts as a sink for these nutrient species. Yields of total-inorganic nitrogen, dissolved ammonia, dissolved nitrate, and total phosphorus decreased between sites upstream and downstream of all four reservoirs (Lake Sidney Lanier, locations 1 to 3; West Point Lake, locations 19 to 22; Lake Harding, locations 22 to 25; and Walter F. George Reservoir, locations 25 to 30) on the Chattahoochee River with available nutrient data. The only exception was that the yield of dissolved ammonia increased slightly downstream of Lake Sidney Lanier. For the time period 1972–90, nutrient yields in the Flint River were relatively high upstream of Griffin because of WWTF effluent discharged to the headwaters of the Flint River. Chipola River near Altha (location 47) had the highest estimated mean-annual yields for total-organic nitrogen and dissolved nitrate. Relatively high yields of dissolved nitrate (1.2 tons/mi^2) and low yields of dissolved ammonia (0.06 tons/mi^2) and total phosphorus (0.07 tons/mi^2) in the Chipola River suggests an agricultural nonpoint source of nutrient, rather than a point source, that probably enters the Chipola River as ground-water discharge rather than overland flow.

Nutrients in Ground Water

Nitrate is the nutrient of primary concern in ground water in most areas because elevated concentrations of nitrate in drinking-water supplies pose a possible health risk, and nitrate is the only major nutrient for which a MCL (10 mg/L as nitrogen) has been established by USEPA for drinking water. Data are more abundant for nitrate concentrations in ground water than for other nitrogen and phosphorus compounds. Natural sources of nitrate in ground water primarily include dissolution from nitrogen-bearing minerals in aquifer materials and leaching of nitrogen from natural soils. A partial list of anthropogenic sources of nitrate in ground water includes leaching of fertilizer and animal manure, infiltration of sewage from septic tanks, land application of treated effluent, and atmospheric deposition.

Dissolved ammonia has not been considered important in ground water because it is readily adsorbed and rapidly oxidized in aerobic environments. Dissolved ammonia can be produced in an aquifer by anoxic decomposition of organic material or by reduction of nitrate or can be derived directly from the surface application of nitrogen fertilizer in the form of anhydrous ammonia (Burkart and Kolpin, 1993, p. 651).

Within the ACF River basin, concentrations of dissolved nitrate in ground water (fig. 47) were higher and much more varied than in surface water (fig. 15). Concentrations of organic nitrogen, dissolved ammonia, and dissolved orthophosphate in ground water were very low. Nutrient data for springs are limited to 16 springs (fig. 47b).

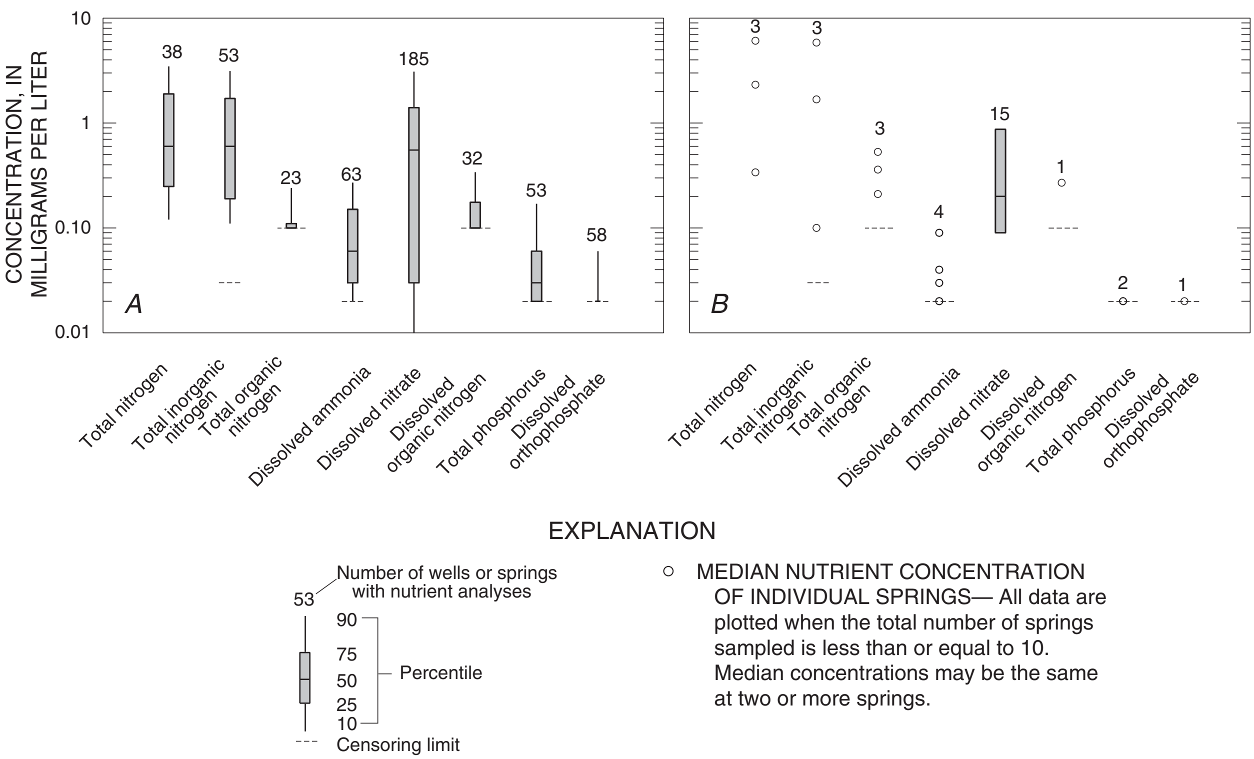


Figure 47. Distribution of nutrient concentrations in (*A*) wells and (*B*) springs by nutrient-constituent groups, Apalachicola-Chattahoochee-Flint River basin, 1972–90 water years.

Nitrate concentrations

In a nationwide evaluation of the occurrence of nitrate in ground water based on more than 87,000 wells, Madison and Brunett (1985, p. 95) defined the following four ranges of nitrate concentrations:

- less than 0.2 mg/L—assumed to represent natural background concentrations;
- 0.21 to 3.0 mg/L—transitional concentrations that may or may not represent human influence;
- 3.1 to 10 mg/L—probably indicates elevated concentrations resulting from human activities; and
- more than 10 mg/L—exceeds MCL for drinking-water supplies set by the USEPA.

Using the same ranges as Madison and Brunett (1985), the distribution of nitrate concentrations based on analyses from 185 wells and 15 springs in the ACF River basin for 1972–90 water years was:

- 70 wells (38 percent) and 9 springs (60 percent) with concentrations representative of natural background;
- 94 wells (51 percent) and 5 springs (33 percent) with concentrations that may or may not be influenced by humans;
- 19 wells (10 percent) and 1 spring (6 percent) with concentrations that probably have elevated nitrate concentrations, and
- 2 wells (1 percent) with median nitrate concentrations exceeding the MCL of 10 mg/L.

The maximum concentration of dissolved nitrate measured within the ACF River basin was 36.9 mg/L in USGS test well 13, Albany, Ga., 178-ft deep in the Floridan aquifer system.

In a national review of over 200,000 nitrate analyses, Spalding and Exner (1993) stated that "aquifers in highly agricultural areas of the southeastern USA reportedly are not contaminated." Some reasons for the lack of widespread nitrate contamination in Southeast, in spite of extensive fertilizer use on row crops (Kellogg and others, 1992), include vegetative uptake and denitrification in a warm, wet carbon-rich environment (Spalding and Exner, 1993). Forested riparian buffer strips, which are common in the Coastal Plain of the ACF River basin, are effective in reducing nutrients in streamflow (Lowrance and Pionke, 1989; Hubbard and Sheridan, 1989). Hubbard and others (1984) reported that nitrate concentrations beneath forested areas ranged from less than 0.1 to 1.1 mg/L in shallow ground water, compared with concentrations from less than 1 to 113 mg/L beneath a center pivot site using sprinkler-applied fertilizer and intense multiple cropping systems.

Buffer strips between fields and within agricultural fields are becoming more common in the study area, and may act as filters for nutrients and sediment and may be another reason for relatively low nitrate concentrations in ground water near agricultural areas of the ACF River basin. This is in contrast to regions of the United States such as the midwest where large areas of well-drained soils are in irrigated cropland areas and as many as 29 percent of samples exceed 3 mg/L of nitrate and 6 percent exceed 10 mg/L of nitrate (Burkart and Kolpin, 1993; Spalding and Exner, 1993; Hamilton and Helsel, 1995).

There were too few nitrate analyses in ground water from 1972–90 in the northern part of the ACF River basin, where poultry production was highest, to determine if nitrate concentrations were elevated near intensive poultry production and litter application areas. In a recent study in the White and Mossy Creek watersheds (north of Lake Sidney Lanier) by Peck and Garrett (1994), six out of 24 wells sampled in 1992–93 had nitrate concentrations higher than 3 mg/L and two wells exceeded the USEPA drinking-water standard of 10 mg/L nitrate.

Three studies to determine the distribution and occurrence of nitrate concentrations in shallow ground water in Georgia were conducted between 1989 and 1994. Although the nutrient data are not included in this report; the studies deserve to be mentioned because of the large number and thorough spatial distribution of samples collected. From 1990 through 1994, the Georgia Geologic Survey (GGS) sampled about 4,800 domestic drinking-water wells that were less than 250 feet deep to evaluate nonpoint sources of nitrate in the State's ground water. Nitrate concentrations exceeded the MCL of 10 mg/L in less than 2 percent of 2,588 domestic wells sampled in south Georgia (Stuart and others, 1995; Georgia Department of Natural Resources, 1992). In another study, the University of Georgia Cooperative Extension Service determined nitrate concentrations in water samples collected from 1989 through 1993 from 3,419 domestic wells. The MCL for nitrate was exceeded in 3.8 percent of wells having depths less than 100 feet and 0.9 percent of wells having depths more than 100 feet (Tyson and others, 1995). In 1994, the University of Georgia Cooperative Extension Service reported that the MCL for nitrate was exceeded in samples from 5.1 percent of 823 wells located on farms in counties with large livestock and poultry production. The MCL for nitrate was exceeded in 7.5 percent of the subset of those wells used specifically for livestock and poultry (Tyson and others, 1995).

Nutrient distributions by aquifer and well depth

Ground-water sampling sites for nutrients within the ACF River basin appear to be reasonably well distributed areally and among aquifers (fig. 48); however, several gaps in available data are apparent in figure 49. For example, measurements are not available from 1972–90 for dissolved ammonia or total phosphorus in the crystalline-rock aquifers, which means the occurrence and distribution of these nutrients are unknown for the northern one-third of the study area. Sample sizes smaller than 10 are too small to compare statistically. Sample sizes larger than 30 are preferred, because larger sample sizes are more likely to be representative of the population of interest. The Floridan aquifer system was the only aquifer having more than 10-sampling sites with dissolved-ammonia or total-phosphorus concentration data within the ACF River basin. Kruskal-Wallis test (followed by Mann-Whiney tests) for dissolved nitrate, indicate that dissolved-nitrate concentrations were significantly higher in the Floridan aquifer system and the crystalline-rock aquifers than in the Providence aquifer (fig. 49; Inman and Conover, 1983, p. 418–19). Probable reasons for higher nitrate concentrations in water from the Floridan aquifer system include:

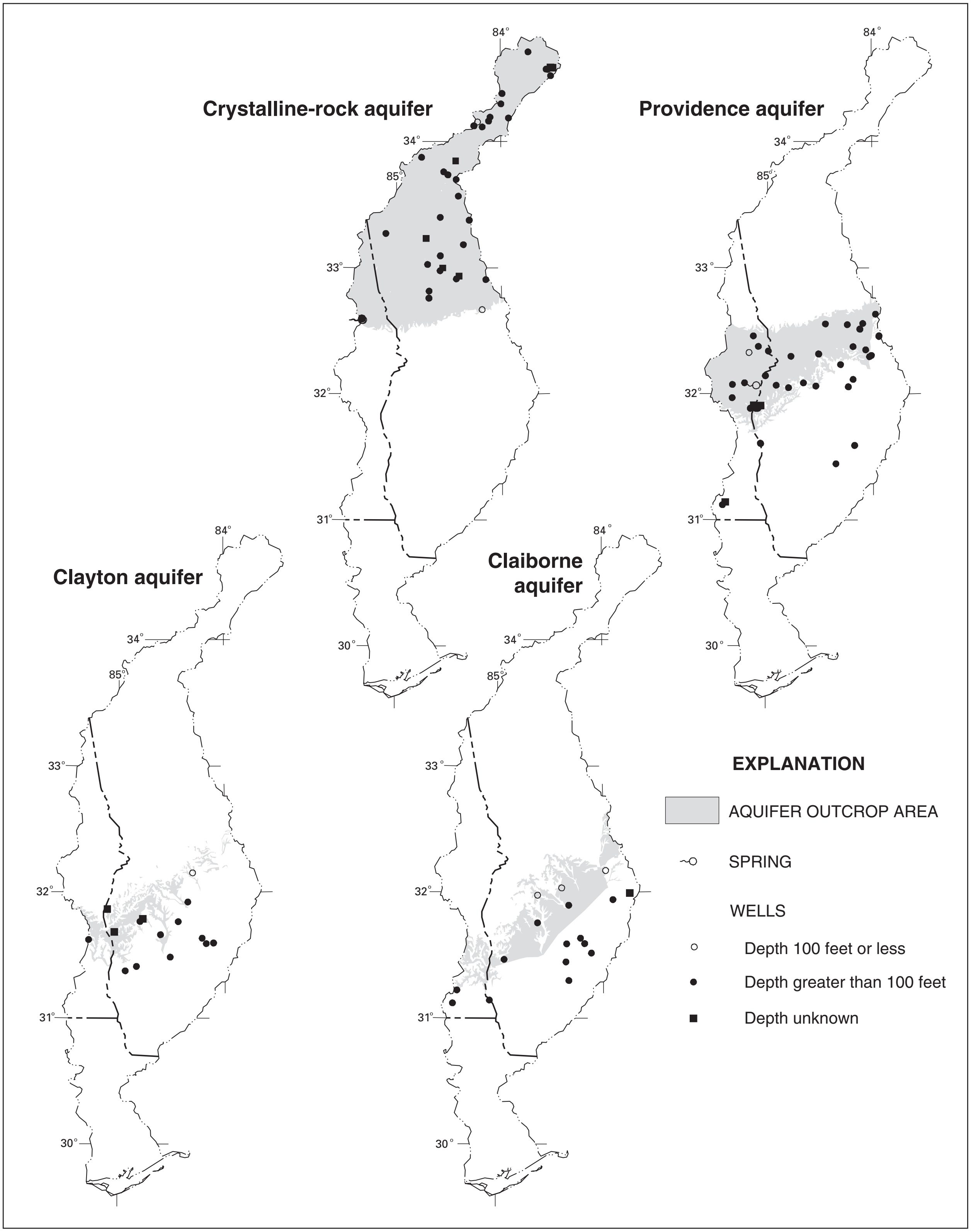
- a prevalence of row-crop agricultural land-use overlying the Floridan aquifer system,
- samples collected from a high percentage of shallow wells in the Upper Floridan aquifer, and
- relatively high aquifer transmissivities within the Upper Floridan aquifer.

Probable reasons for higher nitrate concentrations in water from the crystalline-rock aquifers include:

- a prevalence of poultry agricultural land-use overlying the crystalline-rock aquifers, and
- wells often are large-diameter shallow-bored wells in the regolith which may be more susceptible to contamination than drilled wells.

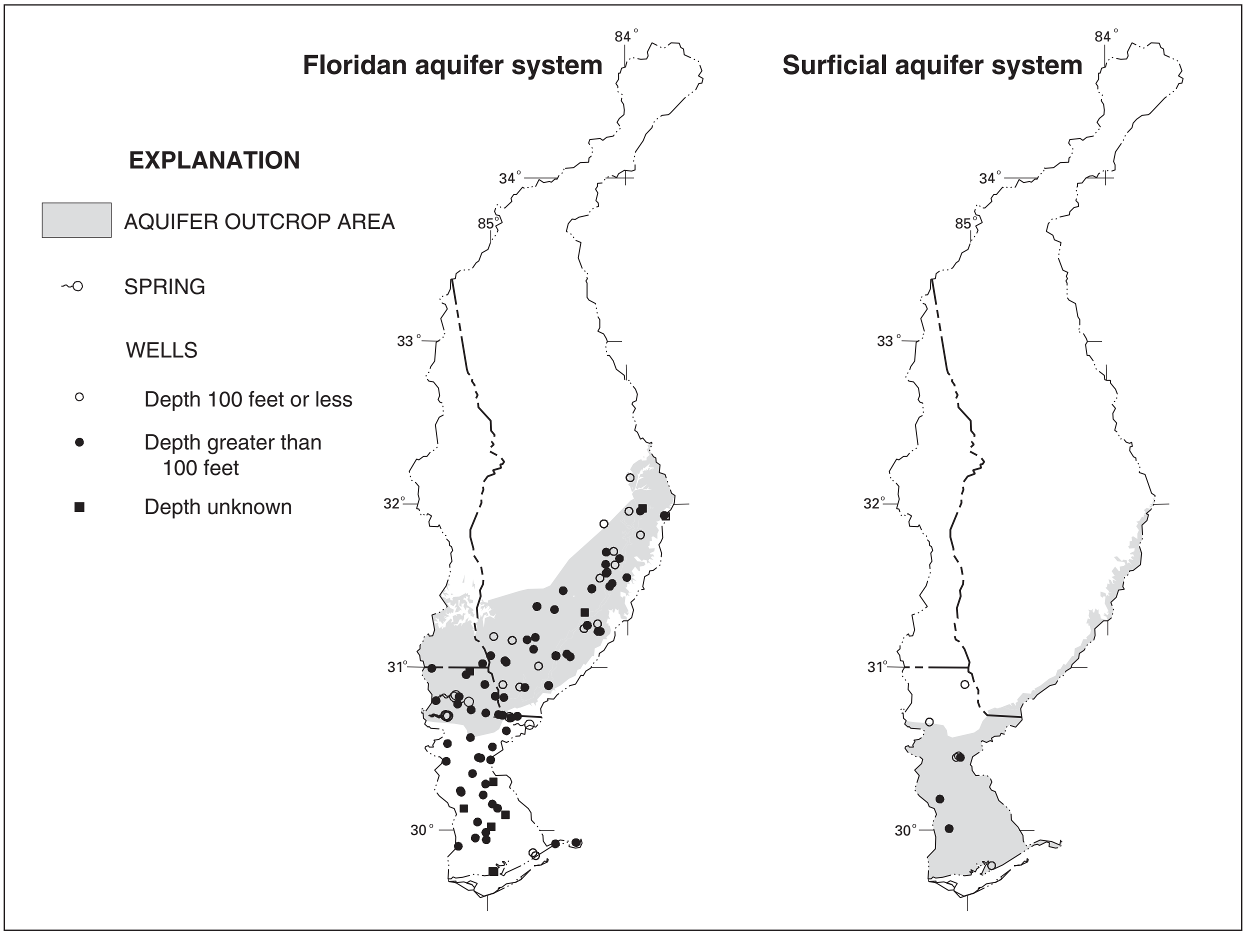
There are no statistically significant differences among nitrate concentrations among other aquifers (fig. 49). The lack of significant differences may be the result of relatively small sample sizes rather than actual lack of differences.

Some studies have reported inverse relations between well depths in shallow aquifers (generally for well depths less than 50 to 100 ft) and nitrate concentrations (Madison and Brunett, 1985, p. 95; Burkart and Kolpin, 1993, p. 654; Hamilton and others, 1989, p. 47). Because most nitrate sources either are at land surface or in the soil column, shallow aquifers probably are more susceptible to nitrate contamination than deeper aquifers (Madison and Brunett, 1985, p. 97). Older water, deep in an aquifer, is less likely to be affected by human activities. Nitrate concentrations in shallow ground water (less than 100 feet deep) could not be compared with deeper ground water in the ACF because, with the exception of the Floridan aquifer system, very few shallow wells had nitrate-concentration data available for 1972–90 water years (fig. 48). The relation between depth of water below land surface and nitrate concentration could not be tested, because many water-quality data analyses from 1972–90 in the ACF River basin (particularly analyses stored in STORET) do not include ground-water-level data.



Base from U.S. Geological Survey digital files

Figure 48. Location of ground-water-sampling sites with nutrient data, by aquifer and well depth, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years.



Base from U.S. Geological Survey digital files

Figure 48. Location of ground-water-sampling sites with nutrient data, by aquifer and well depth, Apalachicola-Chattahoochee-Flint River basin, 1972-90 water years—Continued.

Nutrient distributions by water-use category

Distributions of dissolved ammonia, dissolved nitrate, and total phosphorus by water-use category are shown in figure 50. Dissolved-nitrate concentrations in public-supply wells were significantly lower than in domestic and unused wells. Public-supply wells tend to be deeper and are initially drilled in locations expected to have low nitrate concentrations. Most public-supply wells that have high nitrate concentrations either are abandoned or their water is mixed with water from another source to reduce nitrate concentrations to meet USEPA drinking-water standards. Domestic wells tend to be shallower, may have less stringent well construction and sanitary seal requirements, and are often drilled in close proximity to sources of nitrate contamination such as septic fields, agricultural fields, or animal-feeding areas. The water-use category "unused" was assigned to water-quality-monitoring wells, test-wells (often drilled to test hydraulic properties of an aquifer), and abandoned wells. Wells used for other water-use categories (irrigation, commercial, industrial, or recreation) were not compared because of sample sizes less than 10.

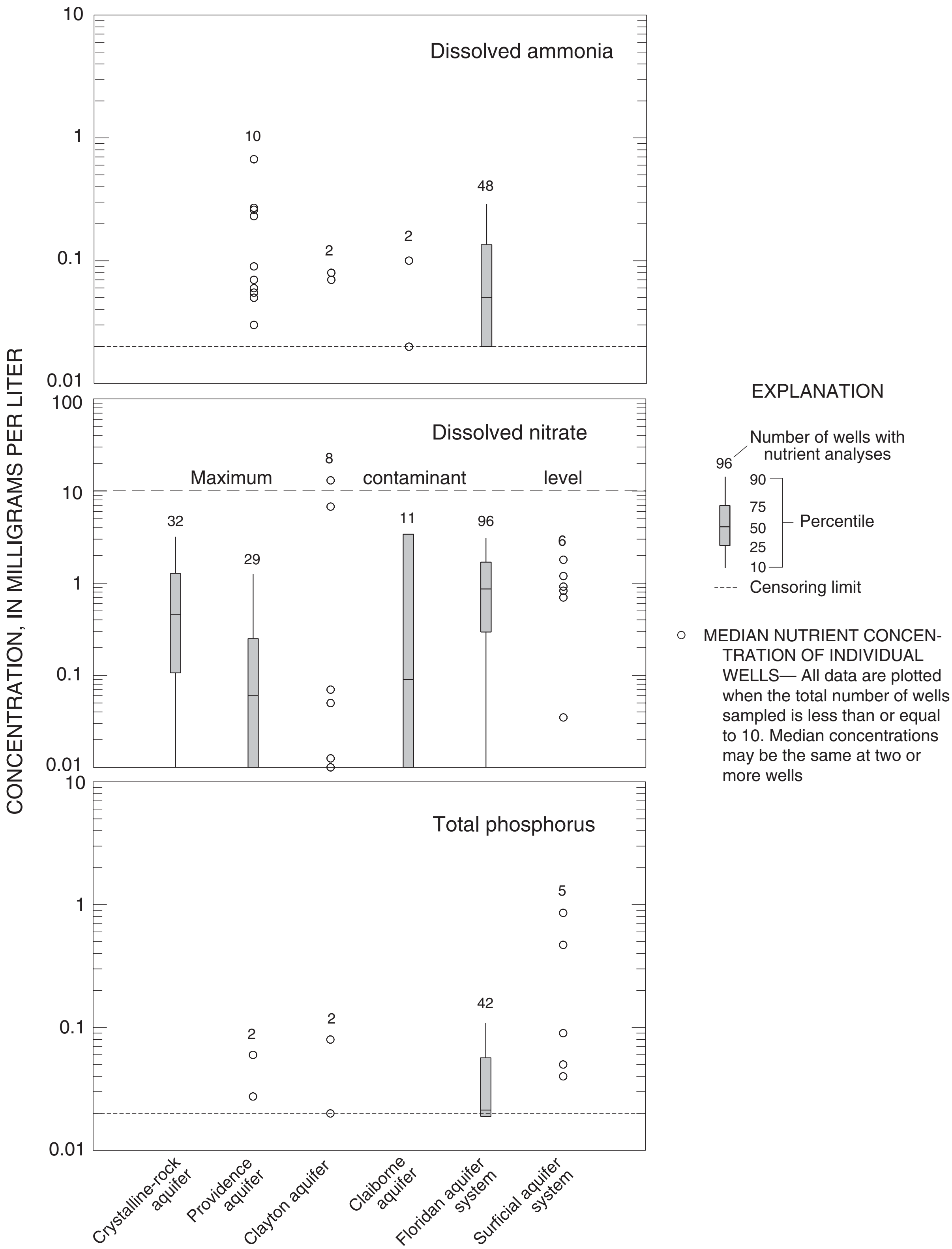


Figure 49. Distribution by aquifer of dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations in wells, Apalachicola-Chattahoochee-Flint River basin, 1972–90 water years.

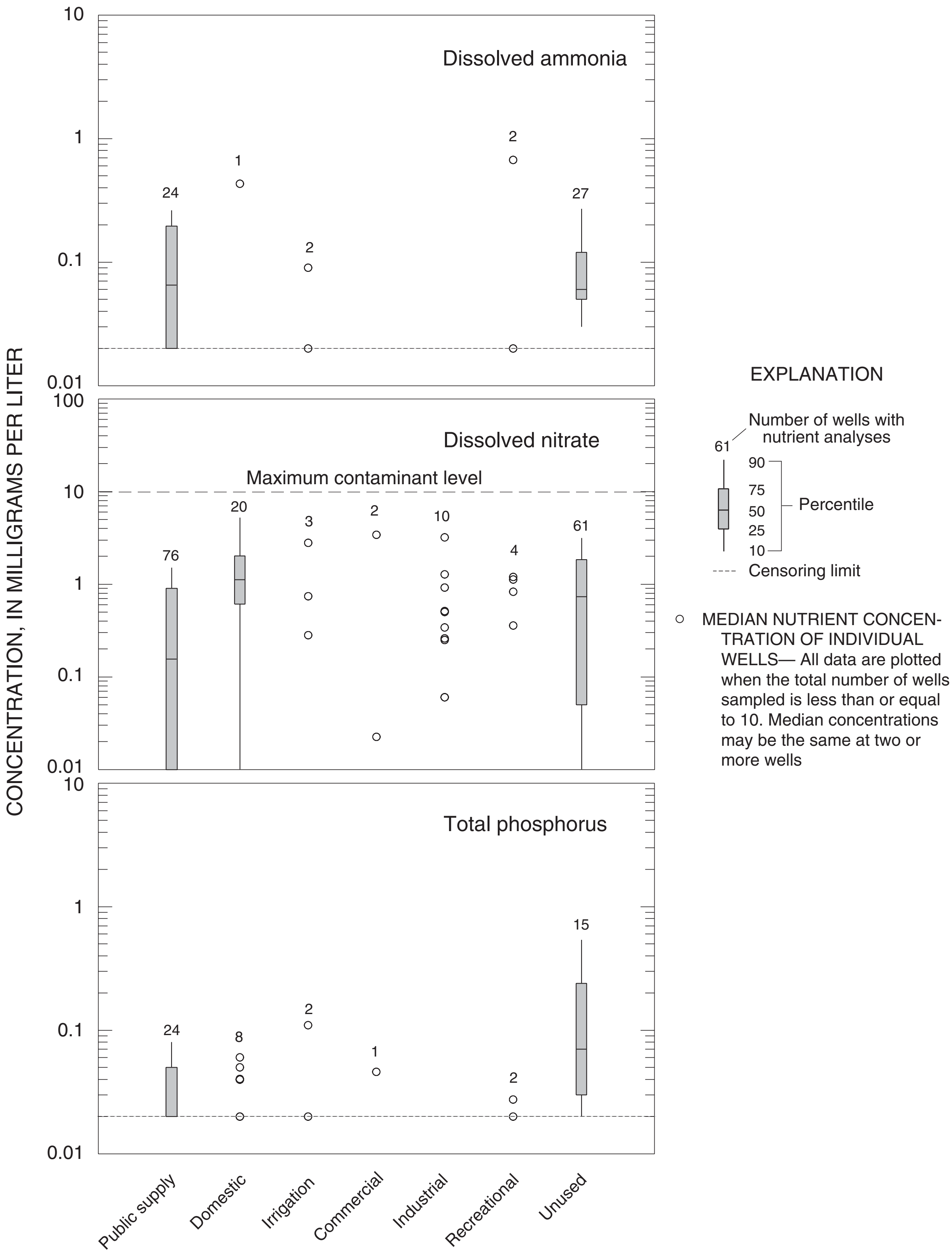


Figure 50. Distribution by water-use category of dissolved-ammonia, dissolved-nitrate, and total-phosphorus concentrations in wells, Apalachicola-Chattahoochee-Flint River basin, 1972–90 water years.

SUMMARY

In 1991, the U.S. Geological Survey (USGS) began full-scale implementation of the National Water-Quality Assessment (NAWQA) program. One of the initial tasks of the NAWQA program is to compile and evaluate existing data from individual study units. This report estimates nutrient sources to the ACF River basin and describes the presence, distribution, and transport of nutrients in surface and ground waters based on available and accessible nutrient data collected during the period 1972–90 water years. Where possible, variations in nutrient water quality are related to hydrologic, environmental, and anthropogenic factors.

Nutrient sources to the ACF River basin from municipal wastewater-treatment facilities (WWTF), animal manure, fertilizer, and atmospheric deposition for 1990 were estimated and compared with nutrient outputs. Estimates of nutrient input to the ACF River basin were not made for natural sources and for the following anthropogenic sources: industrial-wastewater effluent; storm drains; sanitary and combined sewer overflows; and runoff from agricultural, urban, and suburban areas. Point-source loads from WWTF effluent were about 2,500 tons of nitrogen and 1,100 tons of phosphorus. Unlike point-source loads, an unknown percentage of nonpoint-source inputs (manure, fertilizer, and atmospheric deposition) enter the hydrologic system. Manure generated by chickens, cows, and pigs in the ACF River basin contained about 120,000 tons of nitrogen and 28,000 tons of phosphorus. Poultry production was concentrated in a 5-county area in the headwaters of the Chattahoochee River and accounted for 89 percent of the nutrient input from manure. About 82,000 tons of nitrogen and 20,000 tons of phosphorus were applied as fertilizer to lands in the ACF River basin. The lower part of the basin, predominantly the row-crop agricultural areas of the Middle and Lower Flint River subbasins, received the greatest input of nitrogen and phosphorus from commercial fertilizer. Information on nitrogen and phosphorus inputs from fertilizer applied to urban and suburban areas are unavailable for most of the ACF River basin; however, conservative estimates would increase the estimates of total nutrient inputs from fertilizer to the ACF River basin by about 10 percent. Atmospheric deposition of nitrogen was about 24,000 tons in 1990 calendar year. Nutrient outflow into Apalachicola Bay from Apalachicola River was about 13 percent of estimated nitrogen sources and about three percent of estimated total phosphorus sources for 1990 in the ACF River basin.

Changes in nutrient concentrations, loads, and yields in river reaches from upstream to downstream of metropolitan areas provide indications of the combined affects of large point sources and urban nonpoint sources. The metropolitan areas of Atlanta, Ga.; Columbus, Ga. and Phenix City, Ala.; and Albany, Ga.; contained all municipal discharges larger than 10 Mgal/d in 1990 within the ACF River basin. These large municipal discharges contributed to significant increases in concentrations of total-inorganic nitrogen, dissolved ammonia, dissolved nitrate, and total phosphorus from upstream to downstream of the metropolitan areas of Atlanta, Columbus and Phenix City, and Albany. There were also significant increases in concentrations of total nitrogen, total-organic nitrogen, and dissolved orthophosphate from upstream to downstream of Atlanta and of total nitrogen and dissolved orthophosphate from upstream to downstream of Albany. Concentrations of dissolved ammonia, dissolved nitrate, and total phosphorus at Chattahoochee River near Fairburn (downstream of Atlanta) decrease as flow increases indicating that point sources account for much of the load. The same relation occurs between dissolved nitrate and discharge at Flint River near Putney (downstream from Albany); however, the cause could be from the dilution of baseflow and(or) the dilution of point-source loads. In addition to increases in concentrations, large increases in nitrogen and phosphorus loads and yields occurred from upstream to downstream of Atlanta, Columbus and Phenix City, and Albany. Increases in phosphorus loads from upstream to downstream of urban centers were proportionately larger than increases in nitrogen loads because municipal wastewater was the primary source of phosphorus in the rivers from 1972–90. The Chattahoochee River downstream of Atlanta had the highest mean-annual yields estimated in the ACF River basin for total nitrogen, total-inorganic nitrogen, dissolved ammonia, and total phosphorus, and the second highest mean-annual yield estimates in the basin for dissolved nitrate.

Many improvements to the water quality of the Chattahoochee and Flint Rivers in the 1980's and early 1990's can be directly attributed to improvements in wastewater-treatment facilities, legislation directed at decreasing point-source loads of phosphorus, and changes in wastewater-treatment outfall locations. Three examples are:

- From 1972–80, the Chattahoochee River downstream of Atlanta had annual dissolved-ammonia loads larger than dissolved-nitrate loads because of the relatively low level of treatment of municipal-wastewater effluent in the Metropolitan Atlanta area during the 1970's. The reversal to larger nitrate loads than ammonia loads in the 1980's is an indication of positive effects from major improvements made to WWTFs in the 1980's. Decreasing trends in dissolved-ammonia concentration and increasing trends in dissolved-nitrate concentration in the Chattahoochee and Flint Rivers at sites downstream of Atlanta and Albany were the result of improved wastewater treatment at WWTF in these urban areas. The conversion from larger ammonia loads to larger nitrate loads in the 1980's indicates the effectiveness of major improvements to WWTF in reducing ammonia loads, and subsequently reducing the threat of toxicity to fish by decreasing oxygen demand and ammonia toxicity of the effluent. The conversion also helps decrease the potential for eutrophication downstream of WWTF because dissolved nitrate in rivers is more readily denitrified than dissolved ammonia.
- Increasing trends in total-phosphorus concentrations throughout most of the Chattahoochee River are an accurate representation of data for the period 1980–90. However, legislated restrictions on the use of phosphate detergents and improvements of WWTF beginning in the late 1980's resulted in substantial reductions in concentrations of phosphorus in wastewater influent and effluent in the 1990's. Point-source loads of phosphorus from the 13 major WWTF that discharge into the Chattahoochee River between Buford Dam and West Point Lake decreased from a high of 1,670 tons in 1988 to 298 tons in 1993. Total-phosphorus loads in the Chattahoochee River upstream of Metropolitan Atlanta continued to increase from 47 tons in 1988 to 200 tons in 1993, because of increases in nonpoint-source inputs. Although volume of effluent discharged increased, total-phosphorus loads in the Chattahoochee River downstream from Atlanta decreased from 1,190 tons in 1988 to 550 tons in 1993, primarily because of large decreases in point-source loads.
- The Upper Flint River (downstream of Atlanta) and Long Cane Creek (downstream of effluent discharged from LaGrange, Ga.) had high concentrations and yields of total-inorganic nitrogen, dissolved ammonia, dissolved nitrate, and total phosphorus during the period 1972–90, because of municipal effluent discharged into relatively small streams with low waste-assimilation capacities. Long Cane Creek also had strong negative relations between dissolved-ammonia and total-phosphorus concentrations and discharge during 1972–90. As a result of removal of municipal-wastewater outfalls from the Upper Flint River basin in the early- to mid-1980's, all significant trends in nutrient concentrations in the Upper Flint decreased for 1980–90 and the rates of decreases were larger in the Upper Flint than rates of change for any other surface-water-quality site within the study area for the 1980–90 period. The discharge location of effluent from the city of LaGrange was moved from Long Cane Creek to the Chattahoochee River in 1993. Concentrations of nutrients most commonly in effluent were about an order-of-magnitude less in 1994 in the Upper Flint River and in Long Cane Creek than concentrations shown for 1972–90 water years.

Reservoirs affect transport of nutrients because of uptake by phytoplankton and aquatic plants, denitrification, and accumulation of phosphorus associated with sediment in reservoirs. Total-phosphorus concentrations significantly decreased from sampling sites in and downstream of Lake Sidney Lanier, West Point Lake, Lake Harding, and the Flint River arm of Lake Seminole. Four nutrient species significantly decreased downstream of Walter F. George Reservoir and six nutrient species significantly decreased downstream of the Flint River arm of Lake Seminole. Total-inorganic nitrogen and dissolved nitrate in Lake Sidney Lanier were the only constituents in any reservoir in the study area that had a significant increase in nutrient concentrations from a reservoir sampling site to a downstream sampling site during 1972–90. Yields of total-inorganic nitrogen, dissolved ammonia, dissolved nitrate, and total phosphorus decreased between sampling sites upstream and downstream of all four reservoirs on the Chattahoochee River with available nutrient data. The only exception was the yield of dissolved ammonia increased slightly from upstream to downstream of Lake Sidney Lanier. In general, nitrogen loads and yields decreased downstream of West Point Lake. Large decreases in phosphorus loads occurred downstream of West Point Lake, because much of the phosphorus is associated with sediments that are deposited in the reservoir. Much of the nutrient load in the Chattahoochee River downstream of Atlanta is utilized by algae or settles out primarily in West Point Lake, and to a lesser extent, in Lake Harding and Walter F. George Reservoir. In general, the Flint River arm of Lake Seminole had significantly higher concentrations of nutrients than the Chattahoochee River arm of Lake Seminole, which may be the result of the large percentage of the Middle and Lower Chattahoochee River in backwater from reservoirs, the absence of reservoirs on the Flint River downstream of Albany until Lake Seminole, and nonpoint-source inputs of nutrients from intensively farmed areas in the Lower Flint River basin.

Seasonal variations in nutrient concentrations in the Chattahoochee River are strongly influenced by the 13 reservoirs on the river, particularly from West Point Lake to Lake Seminole. Dissolved-nitrogen concentrations are generally lower in the warm, summer months near the inflow of West Point Lake to Lake Seminole for ammonia and near the center of West Point Lake to Lake Seminole for nitrate. Total-phosphorus concentrations also seem to be lower in the summer and early fall in the Middle and Lower Chattahoochee River, although the pattern is not as pronounced as for dissolved ammonia and dissolved nitrate. Summer decreases in concentrations of nutrients in reservoirs, and stream sites directly affected by reservoirs, are related to the seasonality of phytoplankton production in reservoirs. In contrast to the Chattahoochee River, seasonal patterns in nutrient concentrations in the Flint, Chipola, and Apalachicola Rivers either are not present or are less apparent.

In addition to changes in nutrients in surface-water as a result of urban point and nonpoint sources, municipal-wastewater effluent, reservoirs, and seasonal variations, several miscellaneous observations about nutrients in surface waters of the ACF include:

- No noticeable changes in nutrient concentrations occurred in mainstem rivers in the ACF River basin downstream of confluences of eight tributary streams with sufficient available nutrient-concentration data. In general, tributaries in the ACF River basin have small discharges relative to the discharge of the mainstem rivers they flow into.
- Concerns about accelerated eutrophication were warranted throughout much of the ACF River basin based on total-phosphorus concentrations from 1972–90. Concerns about toxicity to fish were intermittently warranted based on dissolved-ammonia concentrations downstream of wastewater-treatment outfalls for the Metropolitan Atlanta area in the Chattahoochee and Flint Rivers and downstream of the wastewater-treatment outfall for LaGrange in Long Cane Creek.
- In river reaches downstream of all major point-source loads from Atlanta, Columbus, and Phenix City, and Albany metropolitan areas, total-phosphorus and dissolved-ammonia concentrations significantly decreased from sampling sites near WWTFs to sampling sites further downstream. Significant decreases in total-phosphorus concentrations were probably the result of biological uptake, decomposition, and settling out of phosphorus associated with suspended sediment. Significant decreases in dissolved-ammonia and increases in dissolved-nitrate concentrations in these river reaches downstream of Atlanta and Albany occurred because of nitrification of ammonia to nitrate.
- Compared to other surface-water sampling sites within the ACF River basin, Chipola River near Altha, Fla. had moderate-to-high dissolved-nitrate concentrations and the highest yields estimated in the basin for dissolved nitrate. Chipola River near Altha had decreasing relations between dissolved nitrate and discharge, which often are indicative of a nonpoint source of nitrate. Estimated loads of dissolved nitrate in the Chipola River increased fairly steadily from about 500 tons/yr in

1972 to about 1,500 tons/yr in 1990, unlike most other load estimates which more closely paralleled changes in flow conditions from year to year. Large increases in estimates of mean-annual load of dissolved nitrate to the Chipola River are probably the result of elevated dissolved-nitrate concentrations in ground-water discharge (baseflow) from increased irrigated agriculture and fertilizer applications in the Chipola River watershed.

Analyses of nutrients in ground water within the ACF River basin for 1972–90 water years were restricted because of limited available data. A cursory description of distribution of nutrient concentrations in wells and springs; and for wells, differences in dissolved-nitrate concentrations by aquifer, by well depth, and by water-use category are presented. The distribution of nitrate concentrations for 1972–90 water years include 38 percent of wells and 60 percent of springs with concentrations representative of natural background (less than 0.2 mg/L); 51 percent of wells and 33 percent of springs with concentrations that may or may not be influenced by humans (0.21 to 3.0 mg/L); 10 percent of wells and 6 percent of springs with concentrations that probably have elevated nitrate concentrations (3.1 to 10 mg/L), and 1 percent of wells with median nitrate concentrations exceeding the USEPA maximum contaminant level of 10 mg/L. Dissolved-nitrate concentrations in wells used for public supply were significantly lower than in wells used for domestic use and unused wells. Dissolved-nitrate concentrations were significantly lower in the Providence aquifer than in the Floridan aquifer system and the crystalline-rock aquifers. Statistically significant differences in nitrate concentrations were not identified among other aquifers possibly because of relatively small sample sizes rather than actual lack of differences. Nitrate concentrations in ground water less than 100 feet deep could not be compared with deeper ground water because, with the exception of the Floridan aquifer system, very few shallow wells had nitrate-concentration data available for 1972–90 water years.

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Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years
[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations: Less than censoring limit	Number of nutrient observations: Greater than or equal to censoring limit	Mean annual load (tons)	Range of annual load (tons) (water years in parentheses)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
		Total nitrogen (0.12 mg/L = censoring limit)							
6	03130001	Chattahoochee River - Cobb County Water Intake, Ga.[G]	[5/]1972–90	0	72	1,290	880–2,800 (1981; 1990)	58.9–436	0.94
17	03130002	Chattahoochee River near Fairburn, Ga.[U]	[5/]1972–90	0	152	6,010	4,950–9,060 (1981; 1990)	169–641	2.9
30	03130003	Chattahoochee River near Columbia, Ala.[U]	1983–90	0	41	8,960	5,610–12,400 (1988; 1984)	595–2,250	1.1
35	03130005	Flint River above Griffin, Ga.[U]	[5/]1974–90	0	148	335	75.3–889 (1988; 1975)	4.6–199	1.7
37	03130006	Flint River at Montezuma, Ga.[U]	[5/]1972–90	0	47	2,080	772–4,170 (1988; 1975)	64.9–804	.72
41	03130008	Flint River near Putney, Ga.[U]	[5/]1972–90	0	68	4,430	2,740–6,580 (1988; 1975)	117–710	.83
42	03130008	Flint River at Newton, Ga.[U]	[5/]1981–90	0	47	5,750	1,980–8,920 (1981; 1984)	301–889	1.0
45	03130011	Apalachicola River at Chattahoochee, Fla.[U]	[5/]1972–90	0	136	17,200	9,150–28,900 (1981; 1990)	267–2,650	1.0
47	03130012	Chipola River near Altha, Fla.[U]	[5/]1972–90	0	114	1,510	903–2,020 (1981; 1983, 84)	28.5–121	1.9
46	03130011	Apalachicola River, Buoy 40, mile 11A, Fla.[F]	[6/]1974–90	0	63	20,400	9,820–30,400 (1981; 1990)	560–3,560	1.1
		Total-inorganic nitrogen (0.04 mg/L = censoring limit)							
1	03130001	Chattahoochee River near Cornelia, Ga.[U]	1972–90	1	93	212	102–500 (1981; 1990)	[7/]3.1–37.6	.67
3	03130001	Chattahoochee River - Gwinnett County Water Intake, Ga.[G]	[5/]1972–90	1	154	612	402–1,040 (1982; 1990)	[7/]17.1–90.5	.56
4	03130001	Chattahoochee River - DeKalb County Water Intake, Ga.[G]	[5/]1972–90	0	165	661	407–1,120 (1981; 1990)	[7/]17.3–89.3	.55
5	03130001	Big Creek - Roswell Water Intake, Ga.[G]	[5,8/]1972–89	0	117	106	37.2–404 (1981; 1984)	[7/]1.6–110	1.0
6	03130001	Chattahoochee River - Cobb County Water Intake, Ga.[G]	[5/]1972–90	0	185	827	621–1,530 (1981; 1990)	[7/]21.4–104	.60
7	03130001	Chattahoochee River - Atlanta Water Intake, Ga.[G]	1972–90	0	204	1,040	669–2,060 (1981; 1990)	[7/]27.4–152	.66

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
<u>*Stream station name sources*</u>: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations: Less than censoring limit	Number of nutrient observations: Greater than or equal to censoring limit	Mean annual load (tons)	Range of annual load (tons) (water years in parentheses)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
12	03130001	Peachtree Creek at Atlanta, Ga.[U]	[5/]1972–90	0	191	87.6	44.0–131 (1981; 1984)	[7/]1.6–9.6	1.0
15	03130002	Chattahoochee River at I-285, at Atlanta, Ga.[U]	1981–90	0	124	2,920	1,780–3,510 (1981; 1984)	[7/]135–242	1.8
16	03130002	Sweetwater Creek near Austell, Ga.[U]	[8/]1972–89	1	170	135	44.7–226 (1988; 1975)	[7/]1.9–42.4	.55
17	03130002	Chattahoochee River near Fairburn, Ga.[U]	[5/]1972–90	0	258	4,140	3,530–6,210 (1972; 1990)	[7/]91.2–273	2.0
19	03130002	Chattahoochee River near Whitesburg, Ga.[U]	[5/]1972–90	0	327	4,090	3,320–6,680 (1981; 1990)	[7/]66.8–287	1.7
22	03130002	Chattahoochee River at West Point, Ga.[U]	[9/]1972–90	0	204	2,810	1,490–5,210 (1988; 1990)	[7/]70.3–576	.79
25	03130002	Chattahoochee River - Columbus Water Intake, Ga.[G]	[9/]1972–90	1	211	3,340	1,860–6,520 (1986; 1990)	[7/]61.7–556	.72
30	03130003	Chattahoochee River near Columbia, Ala.[U]	[5/]1979–89	1	35	4,610	1,710–8,740 (1988; 1980)	[7/]163–2,080	.56
32	03130004	Flint River near Jonesboro, Ga.[U]	1985–90	0	71	38.4	12.4–69.4 (1985; 1990)	[7/]1.1–6.1	.98
33	03130005	Flint River near Fayetteville, Ga.[U]	1985–90	0	69	45.1	16.5–77.5 (1985; 1990)	[7/]1.8–7.7	.92
34	03130005	Flint River near Inman, Ga.[U]	1985–90	0	69	82.2	50.6–128 (1985; 1987)	[7/]5.4–19.6	.52
35	03130005	Flint River above Griffin, Ga.[U]	[5/]1972–90	0	228	148	42.1–259 (1988; 1975)	[7/]2.4–14.2	.76
36	03130005	Flint River near Culloden, Ga.[U]	1972–79, 1990	0	57	492	329–882 (1972; 1990)	[7/]26.2–216	.27
37	03130006	Flint River at Montezuma, Ga.[U]	[5/]1972–90	0	154	772	526–1,040 (1981; 1990)	[7/]21.4–93.2	.27
40	03130008	Flint River at Albany, Ga.[U]	1972–90	0	71	2,320	1,420–3,320 (1981; 1990)	[7/]84–530	.44
41	03130008	Flint River near Putney, Ga.[U]	[5/]1972–90	0	198	2,960	1,850–4,800 (1988; 1975)	[7/]46.9–282	.55

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations		Mean annual load (tons)	Range of annual load (tons)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
				Less than censoring limit	Greater than or equal to censoring limit		(water years in parentheses)		
42	03130008	Flint River at Newton, Ga.[U]	[5/]1972–90	0	52	3,420	2,070–4,550 (1981; 1984)	[7/]118–547	.60
45	03130011	Apalachicola River at Chattahoochee, Fla.[U]	[5/]1972–90	0	153	8,730	3,880–15,700 (1981; 1990)	[7/]156–1,750	.51
47	03130012	Chipola River near Altha, Fla.[U]	[5/]1972–90	0	134	1,000	539–1,520 (1972; 1990)	[7/]36.7–160	1.3
46	03130011	Apalachicola River, Buoy 40, mile 11A, Fla.[F]	[6/]1974–90	0	83	8,830	4,440–12,100 (1981; 1984)	[7/]290–1,180	.46
		Total-organic nitrogen (0.1 mg/L = censoring limit)							
6	03130001	Chattahoochee River - Cobb County Water Intake, Ga.[G]	1979–89	25	43	559	259–754 (1981; 1984)	[10/]65.2–182	.41
17	03130002	Chattahoochee River near Fairburn, Ga.[U]	[5/]1973–90	15	136	1,400	1,400–2,850 (1981; 1990)	[10/]199–697	.68
30	03130003	Chattahoochee River near Columbia, Ala.[U]	1985–89	0	30	4,690	3,890–6,270 (1988; 1987)	[10/]617–1,450	.57
35	03130005	Flint River above Griffin, Ga.[U]	1976–90	8	134	142	31.0–368 (1986; 1976)	[10/]5.2–104	.73
37	03130006	Flint River at Montezuma, Ga.[U]	1972–88	10	37	1,360	243–3,220 (1988; 1975)	[10/]68.8–808	.47
41	03130008	Flint River near Putney, Ga.[U]	[8/]1974–89	8	64	1,440	829–2,050 (1981; 1984)	[10/]129–430	.27
42	03130008	Flint River at Newton, Ga.[U]	1983–89	0	43	3,010	1,740–4,460 (1989; 1987)	[10/]329–937	.52
45	03130011	Apalachicola River at Chattahoochee, Fla.[U]	[5/]1972–90	1	135	8,430	4,760–14,800 (1986; 1975)	[10/]309–3,180	.49
47	03130012	Chipola River near Altha, Fla.[U]	[5,8/]1972–86	14	84	577	248–938 (1981; 1975)	[10/]46.5–130	.74
46	03130011	Apalachicola River, Buoy 40, mile 11A, Fla.[F]	[6/]1974–90	4	55	11,600	5,380–19,800 (1981; 1990)	[10/]709–3,750	.60

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations		Mean annual load (tons)	Range of annual load (tons)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
				Less than censoring limit	Greater than or equal to censoring limit		(water years in parentheses)		
		Dissolved ammonia (0.02 mg/L = censoring limit)							
1	03130001	Chattahoochee River near Cornelia, Ga.[U]	1972–90	26	68	39.3	13.2–125 (1972; 1990)	1.8–26.2	.12
3	03130001	Chattahoochee River - Gwinnett County Water Intake, Ga.[G]	[5/]1972–90	24	138	142	110–230 (1981,82; 1990)	9.4–38.9	.13
4	03130001	Chattahoochee River - DeKalb County Water Intake, Ga.[G]	[5/]1972–90	27	147	151	106–250 (1981; 1990)	9.6–42.0	.12
5	03130001	Big Creek - Roswell Water Intake, Ga.[G]	[5,8/]1973–89	1	57	11.2	4.7–22.3 (1986; 1973)	0.4–6.4	.11
6	03130001	Chattahoochee River - Cobb County Water Intake, Ga.[G]	[5/]1972–90	18	179	205	162–363 (1981; 1990)	10.4–50.5	.15
7	03130001	Chattahoochee River - Atlanta Water Intake, Ga.[G]	1972v90	32	174	180	103–416 (1981; 1990)	9.5–71.5	.11
12	03130001	Peachtree Creek at Atlanta, Ga.[U]	[5/]1972–90	3	188	20.3	10.5–35.1 (1981; 1990)	0.8–5.7	.23
15	03130002	Chattahoochee River at I-285, at Atlanta, Ga.[U]	1981–90	0	124	1,740	1,280–2,140 (1981; 1982)	130–237	1.1
16	03130002	Sweetwater Creek near Austell, Ga.[U]	[8/]1973–89	14	121	38.6	11.6–79.5 (1986; 1976)	1.1–22.2	.16
17	03130002	Chattahoochee River near Fairburn, Ga.[U]	[5/]1972–90	1	256	2,070	1,830–2,320 (1989; 1973)	79.2–149	1.0
19	03130002	Chattahoochee River near Whitesburg, Ga.[U]	[5/]1972–90	0	329	1,320	960–1,750 (1989; 1973)	44.0–93.7	.54
22	03130002	Chattahoochee River at West Point, Ga.[U]	[9/]1972–90	7	197	608	365–1,260 (1988; 1990)	22.2–172	.17
25	03130002	Chattahoochee River - Columbus Water Intake, Ga.[G]	[9/]1972–90	25	187	647	313–1,700 (1986; 1990)	23.5–337	.14
30	03130003	Chattahoochee River near Columbia, Ala.[U]	[5/]1981–89	3	39	822	312–1,590 (1988; 1983)	36.1–396	.10
32	03130004	Flint River near Jonesboro, Ga.[U]	1985–90	0	71	15.1	5.2–26.1 (1985; 1990)	0.8–3.9	.39
33	03130005	Flint River near Fayetteville, Ga.[U]	1985–90	1	68	13.8	7.5–21.0 (1985; 1987)	1.4–3.9	.28

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations: Less than censoring limit	Number of nutrient observations: Greater than or equal to censoring limit	Mean annual load (tons)	Range of annual load (tons) (water years in parentheses)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
34	03130005	Flint River near Inman, Ga.[U]	[8/]1985–89	0	47	18.5	10.0–27.5 (1985; 1989)	2.0–8.1	0.12
35	03130005	Flint River above Griffin, Ga.[U]	[5/]1972–90	19	209	21.6	12.7–29.5 (1988; 1975)	1.3–3.7	.11
36	03130005	Flint River near Culloden, Ga.[U]	1972–79	38	17	37.9	23.9–47.0 (1972; 1975)	5.0–11.2	.02
37	03130006	Flint River at Montezuma, Ga.[U]	[5/]1974–90	38	108	143	46.5–270 (1974; 1990)	12.8–71.0	.05
40	03130008	Flint River at Albany, Ga.[U]	[8/]1972–89	14	52	581	284–1,050 (1981; 1984)	56.8–278	.11
41	03130008	Flint River near Putney, Ga.[U]	[5/]1972–90	4	198	737	333–1,410 (1988; 1973)	22.8–147	.14
42	03130008	Flint River at Newton, Ga.[U]	[5/]1974–90	5	45	497	247–923 (1988; 1975)	33.7–256	.09
45	03130011	Apalachicola River at Chattahoochee, Fla.[U]	[5/]1972–90	22	131	1,110	538–2,020 (1988; 1975)	36.8–239	.06
47	03130012	Chipola River near Altha, Fla.[U]	[5/]1972–90	33	101	48.5	23.4–66.1 (1985; 1983)	1.6–5.9	.06
46	03130011	Apalachicola River, Buoy 40, mile 11A, Fla.[F]	[6/]1974–90	28	56	1,070	534–1,760 (1988; 1975)	77.6–381	.06
		Dissolved nitrate (0.01 mg/L = censoring limit)							
1	03130001	Chattahoochee River near Cornelia, Ga.[U]	1972–90	0	100	172	83.3–375 (1981; 1990)	2.5–27.0	.55
3	03130001	Chattahoochee River - Gwinnett County Water Intake, Ga.[G]	[5/]1972–90	0	165	470	285–812 (1988; 1990)	14.2–81.7	.43
4	03130001	Chattahoochee River - DeKalb County Water Intake, Ga.[G]	[5/]1972–90	0	176	510	292–869 (1988; 1990)	14.3–78.8	.42
5	03130001	Big Creek - Roswell Water Intake, Ga.[G]	[5,8/]1972–89	0	121	74.0	30.8–248 (1972; 1984)	1.5–62.6	.72
6	03130001	Chattahoochee River - Cobb County Water Intake, Ga.[G]	[5/]1972–90	0	196	622	459–1,160 (1981; 1990)	18.5–90.4	.45
7	03130001	Chattahoochee River - Atlanta Water Intake, Ga.[G]	1972–90	0	213	860	566–1,650 (1981; 1990)	25.7–135	.54

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations		Mean annual load (tons)	Range of annual load (tons)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
				Less than censoring limit	Greater than or equal to censoring limit		(water years in parentheses)		
12	03130001	Peachtree Creek at Atlanta, Ga.[U]	[5/]1972–90	0	192	67.3	33.5–100 (1981; 1984)	1.4–7.7	0.78
15	03130002	Chattahoochee River at I-285, at Atlanta, Ga.[U]	1981–90	0	125	1,180	498–2,000 (1981; 1990)	26.7–127	.74
16	03130002	Sweetwater Creek near Austell, Ga.[U]	1972–90	0	184	84.8	32.0–130 (1988; 1984)	1.5–10.5	.34
17	03130002	Chattahoochee River near Fairburn, Ga.[U]	[5/]1972–90	0	258	2,080	1,240–4,270 (1972; 1990)	41.6–229	1.0
19	03130002	Chattahoochee River near Whitesburg, Ga.[U]	[5/]1972–90	0	326	2,770	1,600–5,570 (1972; 1990)	46.2–274	1.1
22	03130002	Chattahoochee River at West Point, Ga.[U]	[9/]1972–90	0	199	2,200	1,120–3,950 (1988; 1990)	66.7–550	.62
25	03130002	Chattahoochee River - Columbus Water Intake, Ga.[G]	[9/]1972–90	0	217	2,690	1,540–4,820 (1986; 1990)	56.8–443	.58
30	03130003	Chattahoochee River near Columbia, Ala.[U]	[5/]1980–90	0	37	3,460	1,400–6,310 (1988; 1980)	159–1,870	.42
32	03130004	Flint River near Jonesboro, Ga.[U]	1985–90	0	74	23.3	7.2–43.3 (1985; 1990)	0.8–4.6	.59
33	03130005	Flint River near Fayetteville, Ga.[U]	1985–90	0	75	31.3	9.0–60.6 (1985; 1990)	1.0–6.9	.64
34	03130005	Flint River near Inman, Ga.[U]	1985–90	0	73	57.2	40.7–93 (1985; 1987)	4.0–13.9	.36
35	03130005	Flint River above Griffin, Ga.[U]	[5/]1972–90	0	236	126	29.3–230 (1988; 1975)	1.8–13.7	.65
36	03130005	Flint River near Culloden, Ga.[U]	1972–79, 1990	0	59	445	305–761 (1972; 1990)	25.7–206	.24
37	03130006	Flint River at Montezuma, Ga.[U]	[5/]1972–90	0	168	640	405–869 (1988; 1975)	17.1–70.4	.22
40	03130008	Flint River at Albany, Ga.[U]	1972–90	0	76	1,700	1,140–2,260 (1981; 1975)	61.9–221	.32
41	03130008	Flint River near Putney, Ga.[U]	[5/]1972–90	0	205	2,220	1,440–3,460 (1981; 1975)	39.6–246	.42

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations		Mean annual load (tons)	Range of annual load (tons)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
				Less than censoring limit	Greater than or equal to censoring limit		(water years in parentheses)		
42	03130008	Flint River at Newton, Ga.[U]	[5/]1972–90	0	53	2,900	1,820–3,880 (1981; 1984)	112–471	0.50
45	03130011	Apalachicola River at Chattahoochee, Fla.[U]	[5/]1972–90	0	153	7,620	3,280–14,400 (1981; 1990)	152–1,740	.44
47	03130012	Chipola River near Altha, Fla.[U]	[5/]1972–90	0	134	953	500–1,480 (1972; 1990)	36.6–160	1.2
46	03130011	Apalachicola River, Buoy 40, mile 11A, Fla.[F]	[6/]1974–90	0	98	7,760	3,900–10,800 (1981; 1984)	278–1,160	.40
		Total phosphorous (0.02 mg/L = censoring limit)							
1	03130001	Chattahoochee River near Cornelia, Ga.[U]	1972–90	24	76	39.7	13.3–99.3 (1981; 1990)	1.5–22.9	.13
3	03130001	Chattahoochee River - Gwinnett County Water Intake, Ga.[G]	1975–90	104	64	62.2	21.2–239 (1982; 1990)	3.6–70.8	.06
4	03130001	Chattahoochee River - DeKalb County Water Intake, Ga.[G]	[5/]1972–89	104	72	69.5	38.6–114 (1981; 1984)	5.4–19.9	.06
5	03130001	Big Creek - Roswell Water Intake, Ga.[G]	[5,8/]1973–89	3	77	15.9	4.6–28.0 (1986; 1978)	0.4–7.3	.15
6	03130001	Chattahoochee River - Cobb County Water Intake, Ga.[G]	[5/]1972–90	32	185	169	131–314 (1981; 1990)	9.6–51.2	.12
7	03130001	Chattahoochee River - Atlanta Water Intake, Ga.[G]	1972–90	12	204	202	96.6–584 (1981; 1990)	6.6–74.7	.13
12	03130001	Peachtree Creek at Atlanta, Ga.[U]	[5/]1972–90	1	191	25.9	9.9–46.4 (1981; 1990)	0.8–7.3	.30
15	03130002	Chattahoochee River at I-285, at Atlanta, Ga.[U]	1981–90	0	125	809	513–970 (1981; 1990)	41.9–106	.51
16	03130002	Sweetwater Creek near Austell, Ga.[U]	1972–90	20	169	41.9	7.4–111 (1986; 1973)	0.5–18.3	.17
17	03130002	Chattahoochee River near Fairburn, Ga.[U]	[5/]1972–90	0	260	1,540	1,260–1,950 (1986; 1990)	42.2–136	.75
19	03130002	Chattahoochee River near Whitesburg, Ga.[U]	[5/]1972–90	0	328	1,380	1,090–1,910 (1981; 1990)	27.2–114	.57
22	03130002	Chattahoochee River at West Point, Ga.[U]	[9/]1972–90	15	188	477	146–1,240 (1981; 1972)	10.6-189	.13

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations: Less than censoring limit	Number of nutrient observations: Greater than or equal to censoring limit	Mean annual load (tons)	Range of annual load (tons) (water years in parentheses)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
25	03130002	Chattahoochee River - Columbus Water Intake, Ga.[G]	[9/]1972–90	14	206	474	161–1,290 (1986; 1990)	8.9–159	0.10
30	03130003	Chattahoochee River near Columbia, Ala.[U]	[5/]1978–90	7	41	440	203–756 (1988; 1990)	16.8–179	.05
32	03130004	Flint River near Jonesboro, Ga.[U]	1985–90	1	73	8.2	3.1–13.5 (1985; 1990)	0.3–1.4	.21
33	03130005	Flint River near Fayetteville, Ga.[U]	1985–90	0	75	12.8	6.0–18.5 (1985; 1987)	0.6–1.8	.26
34	03130005	Flint River near Inman, Ga.[U]	1985–90	0	75	45.6	27.4–74.9 (1985; 1987)	2.2–6.1	.29
35	03130005	Flint River above Griffin, Ga.[U]	[5/]1972–90	0	239	61.1	18.6–115 (1988; 1975)	1.1–7.5	.31
36	03130005	Flint River near Culloden, Ga.[U]	1972–79	1	56	176	107–271 (1972; 1975)	13.1–33.7	.10
37	03130006	Flint River at Montezuma, Ga.[U]	[5/]1972–90	8	160	267	149–496 (1988; 1990)	10.4–79.0	.09
40	03130008	Flint River at Albany, Ga.[U]	1972–90	6	71	541	201–1,070 (1988; 1975)	33.5–215	.10
41	03130008	Flint River near Putney, Ga.[U]	[5/]1972–90	1	208	540	331–923 (1988; 1975)	13.4v93.1	.10
42	03130008	Flint River at Newton, Ga.[U]	[5/]1972–90	2	52	473	291–665 (1981; 1975)	24.7–132	.08
45	03130011	Apalachicola River at Chattahoochee, Fla.[U]	[5/]1972–90	4	149	1,140	456–2,180 (1988; 1975)	16.8–159	.07
47	03130012	Chipola River near Altha, Fla.[U]	[5/]1972–90	12	120	52.6	22.2–75.2 (1985; 1983)	1.2–6.1	.07
46	03130011	Apalachicola River, Buoy 40, mile 11A, Fla.[F]	[6/]1974–90	18	83	1,590	634–3,070 (1988; 1975)	60.4–431	.08
		Dissolved orthophosphate (0.02 mg/L = censoring limit)							
30	03130003	Chattahoochee River near Columbia, Ala.[U]	1983–90	42	6	[11/]	[11/]	[11/]	[11/]
42	03130008	Flint River at Newton, Ga.[U]	[5/]1981–90	13	36	191	149–247 (1988; 1983, 84)	18.5–51.2	.03

Table 16. Mean annual loads[1/] and yields for nutrients for selected surface-water sampling sites, by nutrient constituent group[2/], Apalachicola–Chattahoochee–Flint River basin, 1972–90 water years—Continued

[mg/L, milligrams per liter;
Stream station name sources: F, Florida Department of Environmental Regulation; G, Georgia Environmental Protection Division; U, U.S. Geological Survey]

Location number (figure 16)	Hydrologic unit code	Stream station name	Period of record for nutrient load estimates	Number of nutrient observations: Less than censoring limit	Number of nutrient observations: Greater than or equal to censoring limit	Mean annual load (tons)	Range of annual load (tons) (water years in parentheses)	Range of standard errors[3/] of annual load estimates	Mean annual yield[4/] (tons per square mile of drainage area)
45	03130011	Apalachicola River at Chattahoochee, Fla.[U]	[5/]1972–90	85	20	358	126–733 (1988; 1973)	17.6–147	0.02
47	03130012	Chipola River near Altha, Fla.[U]	1975–90	52	31	25.9	12.9–37.6 (1985; 1983)	1.4–9.4	.03

[1/] Annual loads were only included for years where the variance in the estimate was less than or equal to 30 percent.
[2/] Data were not available to calculate loads for dissolved-organic nitrogen at any sites within the Apalachicola–Chattahoochee–Flint River basin.

[3/] $$Standard\ error = \frac{Standard\ deviation}{\sqrt{Sample\ size}} = \frac{\sigma}{\sqrt{n}}$$

[4/] Mean annual yield = mean annual load ÷ drainage area.
[5/] The period of record for load estimates is longer than the period of record for nutrient-concentration data when discharge data for one to three years are similar to discharge data for years with water-quality data and the standard error of the load estimates based on simulated nutrient-concentration data are less than 30 percent of the load estimates.
[6/] Load estimates for the Apalachicola River, Buoy 40, mile 11A (31010022) for 1974 to 1977 water years are based on synthesized flow data from a time lag of flow data collected at the Apalachicola River near Blountstown (02358700) and the Chipola River near Altha (02359000) (Marvin Franklin, U.S. Geological Survey, oral commun., 1994).

[7/] $$Standard\ error_{total\ inorganic\ nitrogen} = \sqrt{(Standard\ error_{dissolved\ ammonia})^2 + (Standard\ error_{dissolved\ nitrate})^2}.$$

[8/] Load estimates are not used for one or more years with nutrient-concentration data, because the standard error of the load estimates are greater than 30 percent of the load estimates.
[9/] Storage in West Point Lake began October 16, 1974, and the reservoir reached maximum power pool June 10, 1975. Load estimates for 1972–74 at the Chattahoochee River at West Point and the Chattahoochee River - Columbus Water Intake are representative of pre-reservoir conditions.

[10/] $$Standard\ error_{total\ organic\ nitrogen} = \sqrt{(Standard\ error_{total\ nitrogen})^2 + (Standard\ error_{total\ inorganic\ nitrogen})^2}.$$

[11/] Annual loads could not be estimated, because less than 20 percent of concentration data were greater than or equal to the censoring limit (Baier, G., Cohn, T., and Gilroy, E., U.S. Geological Survey, written commun., 1993).

Frick, E.A., Buell, G.R., and Hopkins, E.H.—NUTRIENT SOURCES AND ANALYSIS OF NUTRIENT WATER-QUALITY DATA, APALACHICOLA-CHATTAHOOCHEE-FLINT RIVER BASIN, GEORGIA, ALABAMA, AND FLORIDA, 1972-90—
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