NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

WATER-QUALITY ASSESSMENT OF THE ALBEMARLE-PAMLICO DRAINAGE BASIN, NORTH CAROLINA AND VIRGINIA— Characterization of Suspended Sediment, Nutrients, And Pesticides

By Douglas A. Harned, Gerard McMahon, Timothy B. Spruill, and Michael D. Woodside

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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch
Chief Hydrologist

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FIGURES (Continued)

FIGURES (Continued)

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CONVERSION FACTORS, VERTICAL DATUM, TEMPERATURE, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
ton, short (2,000 lb)	907.2	kilogram
	0.9072	megagram
ton per square mile (ton/mi^2)	0.3503	megagram per square kilometer
ton per square mile per year [(ton/mi^2)/yr]	0.3503	megagram per square kilometer per year
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Application rate	
pound per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year
	Specific conductance	
microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C)	1.000	micromhos per centimeter at 25 degree Celsius

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

Temperature: In this report temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\,(°C) + 32$$

Abbreviations used in this report in addition to those shown above:

lbs/yr, pound per year
mg/L, milligram per liter
µg/L, microgram per liter

Definition used in this report:

Water Year—The period October 1 through September 30, determined by the calendar year in which it ends.

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

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By Douglas A. Harned, Gerard McMahon, Timothy B. Spruill, *and* Michael D. Woodside

ABSTRACT

The 28,000-square-mile Albemarle-Pamlico drainage basin includes the Roanoke, Dan, Chowan, Tar, and Neuse Rivers. The basin extends through four physiographic provinces in North Carolina and Virginia—Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain. About 50 percent of the area is forested, more than 30 percent is agricultural, 15 percent is wetlands, and about 5 percent is developed. The basin population is approximately 3 million.

The spatial and temporal trends in ground-water and riverine water quality in the study area were characterized by using readily available data sources. The primary data sources that were used included the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) database, the U.S. Environmental Protection Agency's Storage and Retrieval System (STORET) database, and results of a few investigations of pesticide occurrence. The principal water-quality constituents examined were suspended sediment, nutrients, and pesticides. The data examined generally spanned the period from 1950 to 1993.

The distribution of available data is uneven. No suitable stations are located in large areas of the Coastal Plain and the upper reaches of the Blackwater, Nottoway, Meherrin, Hyco, Otter, Pigg, and Dan River Basins. There is, however, better coverage of the major trunks of the Roanoke, Dan, and Neuse Rivers.

Suspended-sediment concentrations for the National Stream Quality Accounting Network (NASQAN) stations generally were less than 50 milligrams per liter except for the Dan River at Paces, Va. Kerr and Gaston Lakes serve as effective traps for sediment from the upper Roanoke River Basin, as does Falls Lake for the Neuse River. Agricultural land use, particularly corn and tobacco farming when highly erosive standard land-management practices are used, and the high slopes of the Piedmont promote high sediment concentrations similar to those measured at the Dan River site.

Total nitrogen concentrations at most of the larger stream sites generally are greater than 0.3 milligram per liter, a level associated with potential nuisance growth of algae. Contentnea Creek at Hookerton, N.C., has the highest total nitrogen concentrations, followed by the Neuse River at Kinston, N.C., Tar River at Tarboro, N.C., Dan River at Paces, Va., Blackwater River near Franklin, Va., the other Chowan River tributaries in Virginia, and the Roanoke River at Roanoke Rapids, N.C. In general, the most developed basins and those with the most intensive agriculture have the highest nitrogen concentrations. Nitrogen concentrations generally decrease downstream in the Roanoke River, and increase downstream in the Tar River. The decrease in nitrogen concentrations in the Roanoke River reflects the influence of the lakes downstream from major inputs of nutrients to the basin in the area around Roanoke, Va. The increase in nitrogen concentrations

in the Tar River probably reflects the intensity of farming in the basin. Nitrogen concentrations in the Neuse River peak near the Smithfield station and decrease downstream.

Total phosphorus concentrations are relatively uniform in the Dan River, with median concentrations between 0.1 and 0.2 milligram per liter; increase downstream in the Tar River, with median concentrations ranging from just below 0.1 milligram per liter to just above 0.1 milligram per liter; and peak in the Neuse River near Smithfield in a manner similar to the pattern observed for other constituents. The concentrations of phosphorus in the Neuse River are some of the highest values of any in the Albemarle-Pamlico drainage study subbasins, showing median concentrations between 0.1 and 0.4 milligram per liter. Median concentrations of total phosphorus generally were below 0.1 milligram per liter in the Chowan River, and ranged between 0.1 and 0.4 milligram per liter in the Roanoke River. Concentrations of total phosphorus less than 0.1 milligram per liter generally are needed to prevent algal blooms in streams. The highest phosphorus concentrations occurred in Coastal Plain basins that have considerable agriculture and poorly drained soils. Developed basins also had high phosphorus concentrations.

The most commonly detected pesticides in surface water in the STORET database were atrazine and aldrin. The pesticide groups most frequently detected in the WATSTORE data set were the chloroacetnalilide herbicides and triazine herbicides and their metabolites.

Intensive organonitrogen herbicide sampling of Chicod Creek in 1992 showed seasonal variations in pesticide concentration. The most commonly detected herbicides were atrazine, alachlor, metolachlor, prometon, and metribuzin. No relation between streamflow and pesticide concentration was evident. Concentrations of atrazine were highest in late May and early June and decreased gradually until September.

Median concentrations of nitrate in ground water in four of seven hydrogeologic zones in the study area were less than 0.5 milligram per liter. Median concentrations were largest and variability greatest in fractured carbonate aquifers of the Valley and Ridge and granitic rocks of the Piedmont. Nitrate concentrations and variability are greater in shallow (less than 100 feet deep) wells than in deeper wells. Median concentrations of nitrate are lowest in the Coastal Plain. The highest median concentration (0.25 milligram per liter) and the largest variability in total phosphorus occurred in the Coastal Plain, probably as a result of the presence of natural phosphorites in Coastal Plain sediments.

In a 1992 study, alachlor and atrazine were detected in 16 percent of the 139 shallow wells sampled in eastern North Carolina. In a 1991 study for Duplin County, also in eastern North Carolina, approximately one-third of the 189 private wells sampled for atrazine, alachlor, metalaxyl, and aldicarb had detectable concentrations, and 5 percent of the sampled wells had concentrations greater than 1 microgram per liter for at least one of these pesticides.

The only significant trends in suspended sediment were detected at three Chowan River tributary sites which showed long-term decreases. Suspended- and total-solids concentrations have decreased throughout the Albemarle-Pamlico drainage basin. The decreases are probably a result of (1) construction of new lakes and ponds in the basin, which trap solids, (2) improved agricultural soil management, and (3) improved wastewater treatment.

Total nitrogen trends show a cluster of increases in the tributaries at the upstream end of Kerr Lake and a cluster of decreases in the Neuse River Basin. Trends observed for total ammonia plus organic nitrogen and for nitrate nitrogen were similar to those observed for total nitrogen.

In general, increasing trends in total phosphorus concentrations were observed for the stations in Virginia, and decreasing trends were observed for the riverine stations in North Carolina. Decreases in phosphorus concentrations as a result of the 1988 phosphorus ban in both States is evident at several stations. All eight Virginia stations having total organic carbon data showed decreasing concentrations during 1980-89. Generalized decreases in organic carbon are consistent with decreases in solids concentrations as part of improved wastewater treatment. Increasing trends in potassium were detected in seven of the eight NASQAN stations.

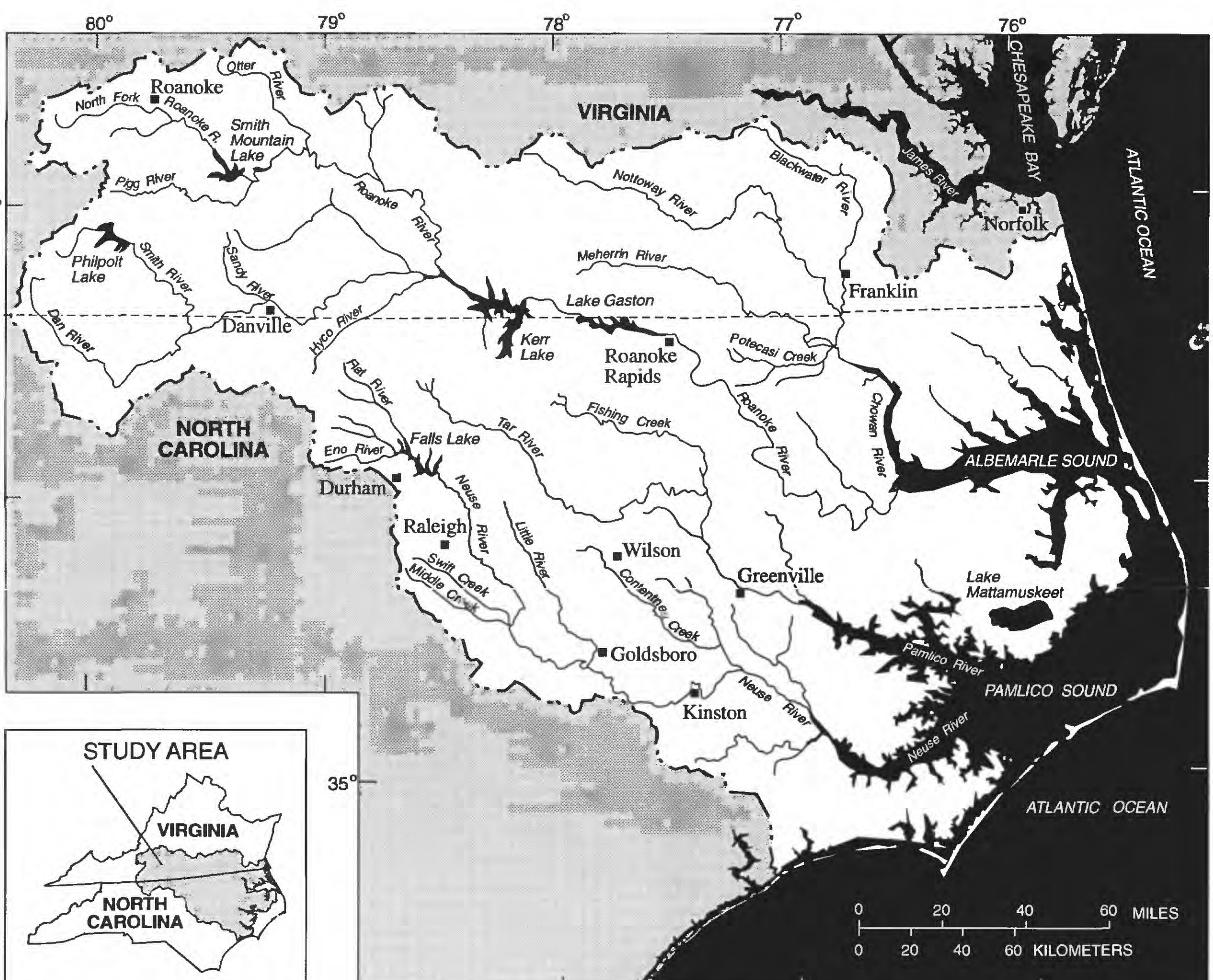
Nutrient point sources are much less than nonpoint nutrient sources at the eight NASQAN basins examined for nutrient loads. The greatest nitrogen inputs are associated with crop fertilizer and biological nitrogen fixation by soybeans and peanuts, whereas atmospheric and animal-related nitrogen inputs are comparable in magnitude. The largest phosphorus inputs are associated with animal wastes.

Nitrogen loads at the NASQAN stations generally are directly related to the size of the nitrogen inputs. Phosphorus and sediment loads are generally greater than loads reported for 14 national water-resource regions. Sediment yields are greatest in basins characterized by relatively steep slopes, erodible soils, and predominantly urban and agricultural land uses. Sediment yields at the basin outlet are mitigated by upstream reservoirs.

INTRODUCTION

The 28,000-square-mile (mi^2) Albemarle-Pamlico drainage basin (fig. 1) is undergoing significant environmental changes. Increasing population, urban and industrial development, and changing agricultural practices are all reflected in water-quality changes. An ongoing characterization of (1) the status of water-quality conditions in the basin, (2) trends in water quality, and (3) the causes of those water-quality changes is necessary for effective scientific understanding and management of water resources in the basin.

The Albemarle-Pamlico drainage basin consists primarily of four major stream systems—the Roanoke River (8,900 mi^2), the Chowan River (5,000 mi^2), the Tar River (3,100 mi^2), and the Neuse River (4,500 mi^2); the remaining drainage area consists of smaller basins located around the estuaries. The



EXPLANATION

— · · — **Drainage area boundary**

Figure 1. Albemarle-Pamlico drainage basin, North Carolina and Virginia.

combined mean annual flows into the estuaries from the four major subbasins total over 22,000 cubic feet per second (ft^3/s). The basin extends through four physiographic provinces—Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain. About 50 percent of the area is forested, more than 30 percent is agricultural, about 15 percent is wetlands, and about 5 percent is developed. The basin population is estimated to be 3 million. Surface water provides about 60 percent of municipal and domestic water supply, and ground water provides the remaining amount. Surface water provides 80 percent of the water supply for industrial and agricultural uses. A detailed description of the basin environmental setting, including natural, cultural, and hydrologic characteristics, is given in an earlier report in this series (McMahon and Lloyd, 1995).

During the 1980's, the estuarine area of the Albemarle-Pamlico drainage basin has been the focus of a comprehensive assessment by the State of North Carolina, Federal water-resources agencies, university researchers, and local interest groups. This assessment is being conducted as part of the National Estuary Program authorized by the Clean Water Bill Amendments of 1987 (Rader, 1988). The goal of this effort is to develop and implement regional management plans. Whereas the comprehensive study of the basin under the National Estuary Program focuses on the estuarine area of the Albemarle-Pamlico drainage basin, the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program is concerned primarily with the riverine areas of the basin. In spite of this distinction, it is difficult operationally to separate the two areas. Because environmental concerns for the estuarine system are largely a function of what occurs upstream, the estuarine concerns have influenced the current design of study for the Albemarle-Pamlico drainage area NAWQA Program. A complete discussion of the NAWQA Program and the general approach of study of the Albemarle-Pamlico drainage basin as part of that Program is provided in the first report of this series (McMahon and Lloyd, 1995).

The Albemarle-Pamlico drainage basin has been the focus of recent attention because of public and scientific concerns about perceived and reported environmental changes. These concerns include pronounced changes in water quality resulting in noxious algal blooms in the Chowan and Neuse Rivers; outbreaks of fish disease, large sediment loads, and low dissolved-oxygen concentrations in the Tar-Pamlico system; declines in submerged macrophyte populations in the Pamlico River; and declines in fish stocks and changes in salinity regimes throughout the system (North Carolina Department of Natural Resources and Community Development 1987; North Carolina Department of Environment, Health, and Natural Resources, 1993b).

Purpose and Scope

The primary purpose of this report is to characterize spatial and temporal patterns in ground-water and riverine water quality in the Albemarle-Pamlico drainage basin by using readily available data sources. In addition, this report can (1) provide a foundation for investigation of relations between basin characteristics and water quality, (2) identify areas with little existing data, and (3) document findings for future study cycles of the NAWQA Program in the Albemarle-Pamlico drainage basin.

The data examined included water-quality data collected at 66 stations by the North Carolina Department of Environment, Health, and Natural Resources (DEHNR); the Virginia Department of Environmental Quality (VADEQ); and the USGS. These water-quality data were collected from 1950 through 1993. The U.S. Environmental Protection agency (USEPA) Storage and Retrieval (STORET) database contains much of the ambient network data collected by DEHNR and VADEQ. The USGS National Water Data Storage and Retrieval System (WATSTORE) database contains much of the data collected by the USGS.

The study area was subdivided into areas, termed "strata," based on basin characteristics which included land use, physiographic province, and soil drainage properties (McMahon and Lloyd, 1995). The strata categories examined included Forest/Coastal Plain; Forest/Granitic; Agriculture/Coastal Plain/Poorly Drained; Agriculture/Coastal Plain/Well Drained; Agriculture/Granitic/Well Drained; Agriculture and Forest/Slate Belt; and Developed. These categories were derived by grouping data from the stations with the highest land-area percentages of the given strata.

Records of water-quality properties and inorganic constituents examined included specific conductance, suspended sediment, dissolved solids, total fixed solids, total volatile solids, total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, total ammonia nitrogen, total phosphorus, and dissolved phosphorus.

Results from previous studies, including some studies from outside the Albemarle-Pamlico drainage basin study area, were summarized. Pesticide data for surface water, ground water, and bed sediment were examined.

Analysis of the data involved graphic summaries using box plots and nonparametric tests of comparison. The seasonal Kendall trend test along with locally weighted smoothed scatter plots (LOWESS) were used for trend analyses for 1980 through 1990 (Helsel, 1993). Regressions and residual analysis and the minimum-variance unbiased estimation technique (Cohn and others, 1989) were used to estimate sediment and nutrient loads and trends in loads.

Recent Water-Quality Studies

A series of USGS reports provides water-quality and hydrologic data for the estuarine system. Giese and others (1985) provide a general overview of the hydrology of the estuaries. Garrett and Bales (1991) and Garrett (1992 and 1994) provide water-quality data for salinity, water temperature, and dissolved oxygen for 1989-92 in the Pamlico and Neuse River estuaries. Garrett (1993) provides similar data for 1989-91 in Albemarle Sound. Bales and others (1993) describe the hydrology of the lower Roanoke River and the hydrology and water quality, including salinity, temperature, and dissolved-oxygen concentration, of Albemarle Sound. Treece and Bales (1992) and Treece (1993) provide hydrologic and water-quality data from six agricultural drainages in tidally affected areas in eastern North Carolina. Treece collected data from 1988 to 1992 for water-quality parameters, suspended sediment, and a suite of nutrient constituents.

An extensive bibliography (Bales and Nelson, 1988) lists more than 1,000 references for investigations conducted in or near the estuarine part of the basin. In addition, much research has been published as part of the National Estuary Program's Albemarle-Pamlico study (see publication list in North Carolina Department of Environment, Health, and Natural Resources, 1993b). Several investigations merit particular mention for their generalized analysis of water quality in parts of the basin.

Rader and others (1987) provide a detailed review of water quality of the Tar-Pamlico system. Decreases in salinity (Sholar, 1980) in the Pamlico Sound area are reported to be associated with decreases in populations of oysters and other freshwater-intolerant species (Phillips, 1982). However, analysis by Stanley (1988) does not support a decrease in salinity. Nitrogen and phosphorus concentrations in the Tar-Pamlico system are large enough to support noxious algal growth (Stanley, 1988). A nutrient budget of nutrient sources (1980-85) for the Tar-Pamlico system indicates that 66 percent of the total phosphorus inputs were from point sources, such as municipal and industrial discharges (Rader and others, 1987). In contrast, 78 percent of the total nitrogen inputs were determined to be from nonpoint sources, such as runoff from agricultural lands. Increased numbers of fish kills in the Pamlico River from 1965 to 1984 are also reported (North Carolina Department of Natural Resources and Community Development, 1987).

A report series by researchers of the Research Triangle Institute included calculation of annual nutrient budgets (Dodd and others, 1992), summaries of ground-water quality, toxic analysis, subbasin profiles of basin characteristics (Dodd and others, 1993), and nutrient mass balances for the Albemarle-Pamlico estuarine system. A nutrient budget for 1987-90 (Dodd and others, 1992) indicated that 51 percent of the phosphorus inputs and 56 percent of the nitrogen inputs resulted from nonpoint sources, and 29 percent of the phosphorus inputs and 6 percent of the nitrogen inputs resulted from point sources. An additional 15 percent of the phosphorus inputs and 29 percent of the nitrogen inputs were estimated to result from direct atmospheric deposition. Five percent of the phosphorus inputs and 9 percent of the nitrogen inputs were from reservoir releases. Subbasin profiles by Dodd and others (1993) identify the Neuse and Pamlico River estuaries as areas with intense development activity and environmental stress.

Screening studies by the National Oceanic and Atmospheric Administration (NOAA) identified the Albemarle and Pamlico Sounds as areas with particularly high pesticide use. Of 78 estuarine drainage areas examined in the United States, Pait and others (1989) ranked the Albemarle Sound first and the Pamlico Sound fourth highest in use of selected agricultural pesticides normalized by relative toxicity. However, NOAA monitoring has not detected high levels of metals or selected pesticides in mussel tissue in these estuaries (O'Conner, 1990).

A 1991 report by DEHNR details the effect of phosphorus detergent restrictions (North Carolina Department of Environment, Health, and Natural Resources, 1991). A 26-percent reduction for the Neuse River and a 12-percent reduction for the Tar River were observed in phosphorus point-source loading beginning in 1988.

For the Pamlico River, Stanley (1988 and 1993) detected trends of decreasing pH, decreasing concentrations of nitrate nitrogen (in the upstream half of the river), and decreasing concentrations of ammonia nitrogen between 1967 and 1986. According to Stanley (1988), phosphorus concentrations have increased considerably in the middle and downstream parts of the Pamlico River estuary. Stanley also observed that chlorophyll *a* concentrations have increased in the upstream and middle zones of the Pamlico River. In comparing the chemical water quality of different estuaries, Stanley inferred that the water quality of the Pamlico estuary is similar to that of the Neuse, except that the Pamlico estuary has greater concentrations of phosphorus. Indeed, phosphorus concentrations in the Pamlico River estuary were among the largest measured nationally (Nixon, 1983). Stanley concluded that nitrogen is the primary nutrient that limits algal growth in the Pamlico River. Stanley (1989) expanded his investigation to include aspects of some of the other estuarine systems in the Albemarle-Pamlico drainage basin. The 1989 investigation included nutrient production in the drainage basin, estuarine water quality, and fisheries. Stanley estimated that cropland supplied 30 percent of the total nitrogen in the basin; animals, urban runoff, and point sources contributed about 17 percent. The remainder of the total nitrogen was supplied primarily by atmospheric and forest inputs.

Harned and Davenport (1990) reviewed available data for the estuarine part of the Albemarle-Pamlico drainage basin to identify trends in water quality and correlate changes in water quality to basin characteristics. This study identified increasing pH and dissolved oxygen and decreasing nutrient trends that are probably related to the effects of increased production of plant biomass in the estuary system and to agricultural practices. A generalized decrease in suspended-solids concentrations at many stations throughout the region was noted probably to be an effect of reservoir and pond construction, as well as improved sediment-runoff controls.

An extensive reference on the Albemarle-Pamlico estuarine system was edited by Steel (1991). This report represents the input of many of the principal university and governmental researchers working in the basin at that time and includes information on basin characteristics, environmental concerns, probable causes of environmental changes, status and trends of environmental resources, and an evaluation of water quality. The study reports that the growth of algae in the estuaries is limited by the supply of nitrogen and that nutrient loads have increased rapidly with population growth and waste input. Decreases in nutrient concentrations likely are a result of increases in algal abundance.

Paerl (1987) reported symptoms of accelerated eutrophication in the lower Neuse River. In describing the dynamics of blue-green algal blooms in the Neuse River, he noted the importance of the complex interplay of causal factors, including water discharge, temperature, and nutrient loading. Paerl determined that nitrogen is the limiting nutrient for algal growth and that phosphorus is generally available at levels exceeding the need for phytoplankton growth demands. In a more recent analysis, Paerl and others (1990) reported seasonality in the nutrients limiting phytoplankton productivity in the Albemarle-Pamlico estuarine system. Paerl reported that nitrogen was the limiting nutrient during summer and fall and that nitrogen and phosphorus were co-limiting nutrients during the winter and spring.

Riggs and others (1989, 1990, and 1993) examined heavy metals in sediment from the Pamlico River, Albemarle Sound, and the Neuse River estuary. Areas with bottom sediment having trace-element concentrations higher than the trimmed mean value were delineated for all three estuary areas. Anthropogenic sources are principally responsible for the enriched metals concentrations in these areas.

Wells (1989) discussed sediment in the estuaries of the Albemarle-Pamlico drainage basin, and Wells and Kim (1991) examined the movement of fine-grained sediment within the Neuse and Pamlico estuary systems. Wells and Kim (1991) identified two accumulation sites within the system—the axis of the Neuse River estuary and the central basin of Pamlico Sound. Very little sediment transported into the estuarine system ever reaches the ocean.

Publications by DEHNR which focus on the estuarine area of the Albemarle-Pamlico drainage basin include management plans and supporting documents (North Carolina Department of Environment, Health, and Natural Resources, 1993d) as well as water-quality data analyses (North Carolina Department of Environment, Health, and Natural Resources, 1990a and b, 1992a and b, and 1993a). The water-quality analysis included physical parameters, nutrient constituents, metals, and measures of phytoplankton, chlorophyll *a*, and fecal coliform bacteria for stations in the ambient water-quality network during 1988-92. Some of the upstream DEHNR stations also are included in the analysis for the current (1991-96) USGS NAWQA study.

Citizens' advisory committees for the National Estuary Program's Albemarle-Pamlico Estuarine Study implemented a citizens' water-quality monitoring program and produced several publications, including management recommendations (Armingeon, 1990; McNaught, 1991), public interest reports (Gale, 1989), and data summaries (Blinkoff and Orbach, 1991). The citizens' water-quality monitoring program involved 100 volunteers who collected data from 85 sites during 1988-91. Water-quality data collected included temperature, pH, salinity, dissolved-oxygen concentration, and secchi disk depth.

The literature available for riverine areas of the Albemarle-Pamlico drainage basin is less extensive than that for the estuarine areas. The principal organizations that have sponsored research in the rivers include DEHNR, VADEQ, Water Resources Research Institute (WRRI), and the USGS.

Every 2 years, DEHNR and VADEQ compile statewide assessments of programs for improving water quality as part of the requirements of section 305(b) of the Clean Water Act. The North Carolina Department of Environment, Health, and Natural Resources 305(b) report (1992b) indicates that 88 percent of the estuarine area is fully supporting its classified uses; 4.4 percent is threatened; and 7.8 percent is partially supporting its classified uses. For the freshwater streams, 18 percent of the stream mileage meets its classified use; 32 percent is threatened; and 34 percent partially supports its classified uses. Freshwater that only partially supports its classified uses has been degraded by high sediment concentrations in 33 percent of the area, by low dissolved-oxygen concentrations in 10 percent of the area, and by nutrients, metals, or other constituents in the remaining area. Degradation was caused by nonpoint sources in 76 percent of the impaired stream miles. Fifty-nine percent of the nonpoint sources for these areas was from agriculture and forestry, and 12 percent was from urban runoff and development. Details of nonpoint-source stream degradation for specific stream segments are given by the North Carolina Department of Natural Resources and Community Development (1988).

In 1992, DEHNR implemented a basinwide approach to water-quality management to integrate and coordinate the many different agency water-quality activities. Some of the objectives of the approach are similar to NAWQA Program objectives, including reporting water-quality status and trends. The Neuse River Management Plan and the Tar River Plan (North Carolina Department of Environment, Health, and Natural Resources, 1993d and 1994) are major sources of information about basin characteristics, water quality, and management strategies. The Neuse River Basin report (North Carolina Department of Environment, Health, and Natural Resources, 1993d) notes low dissolved-oxygen concentrations in the lower Neuse Basin and a lack of nutrient assimilative capacity in the Neuse River estuary in 13 major lakes within the basin, including Falls Lake, and in six lakes within the Contentnea Creek tributary basin. With the implementation in 1988 of a phosphorus ban and with improvement in wastewater treatment, point-source nutrient loading in the Neuse Basin has been halved between 1986 and 1990. The Contentnea Creek Basin has been given high priority by DEHNR for improved nonpoint-nutrient control through use of more conservation land-management practices.

Publications of VADEQ provide information for the upper Roanoke, Dan, Meherrin, Nottoway, and Blackwater Rivers. The Virginia Water Assessment 305(b) report (Virginia Water Control Board, 1992) contains a discussion on compliance or noncompliance with water-quality standards for every major river basin in Virginia. Further discussions on causes and solutions to water-quality problems are included for river segments not in compliance with water-quality standards or other water criteria. The Virginia priority water bodies catalogue (Virginia Water Control Board, 1991) identifies stream segments having specific water-quality problems, describes the cause of the problems, and lists recommendations and corrective actions.

Alling (1990 and 1991) recommended that Kerr Reservoir and sections of the Roanoke and Dan Rivers above Kerr Reservoir be classified as Nutrient Enriched Waters. Rivers that exceed certain dissolved-oxygen and total phosphorus concentrations can be classified as nutrient enriched, thereby affecting point-source discharge limits to these rivers. Woodside (1994) examined the water quality of a Lake Gaston segment proposed for use as a water-supply source for the city of Virginia Beach. Woodside reported no relations between lake water quality and local land-use patterns but identified a relation to flow zones within the lake. Tilger and others (1990) reviewed concentrations of arsenic, beryllium, mercury, lead, cadmium, copper, aldrin, dieldrin, chlordane, DDT, and polychlorinated biphenyls in bed-sediment, fish tissue, and water-column data collected from 1979 to 1990 throughout Virginia. The report summarizes background concentrations, identifies contaminated areas, and recommends future monitoring activities.

In 1982, Virginia and North Carolina developed a management strategy for addressing eutrophication problems in the Chowan River. Nutrient-reduction control measures enacted between 1981 and 1989 are discussed in Virginia Water Control Board (1992). The Virginia Division of Soil and Water identified the Chowan Basin as seriously affected by nonpoint sources. As a result of the nonpoint sources, the Chowan Basin was the first area in Virginia to receive cost-share assistance for initiating conservation land-management practices in agricultural areas. Estimates indicate that erosion of more than 5 million tons of soil per year has been prevented as a result of the initiation of these conservation practices.

The Roanoke River corridor study was an assessment of the river upstream from Smith Mountain Lake, including the segment that flows through the city of Roanoke, Va. (Fifth Planning District Commission, 1990a and b). As a result of this study, basin characteristics were identified, water quality and point sources of pollution were reviewed, and management recommendations were made.

Riverine studies by the USGS in the Albemarle-Pamlico drainage area include general summaries of stream water quality for North Carolina and Virginia (Barnes and Davenport, 1993; Belval, 1993). The summaries provide a comparison of water quality for major USGS monitoring stations and an evaluation of trends for these stations from 1980 through 1989. Increasing trends in dissolved ammonia concentrations in the Tar and Neuse Rivers and in total ammonia plus organic nitrogen concentrations in the Neuse River Basin were noted. Increasing trends in dissolved sulfate in the Dan River and decreasing trends in dissolved oxygen and dissolved solids in the Blackwater River were noted for Virginia. The time period for trend testing in this report was limited to 1980-89 to match the period for earlier investigations.

Harned (1982) examined water-quality trends for the Neuse River at Kinston, which is upstream from the Neuse River estuary, and reported increases in dissolved-solids, potassium, and sulfate concentrations from 1956 to 1980. Statistically significant trends in nutrient concentrations were not detected.

Lakes play an important role in riverine water quality, and much research has focused on them. The 305(b) reports (North Carolina Department of Environment, Health, and Natural Resources, 1992b; Virginia Water Control Board, 1992) list and categorize the major lakes within the basin. These lakes include Kerr Lake (mesotrophic to eutrophic), Falls Lake (eutrophic), Lake Gaston (mesotrophic), Smith Mountain Lake (eutrophic to mesotrophic), and Philpott Reservoir (oligotrophic). A lake-by-lake survey in North Carolina is given by North Carolina Department of Environment, Health, and Natural Resources (1992c) and includes results of ambient lake monitoring from 1981 to 1987 for temperature, conductivity, dissolved-oxygen concentration, secchi depth, fecal bacteria, metals, nutrients, and chlorophyll *a*.

Seasonal lake sampling, storm-event runoff sampling, and land-use characteristics were investigated by the Virginia Water Control Board (1980) to assess the effect of nonpoint sources on water quality in Smith Mountain Lake in the upper Roanoke River Basin. Enhancements to wastewater-treatment plants upstream from the lake led investigators to predict an increase in lake water quality. Based on small watershed monitoring, pasture lands produced the highest nutrient loads in the Smith Mountain Lake drainage basin.

Johnson and Thomas (1990) and Thomas and Johnson (1991 and 1992) described water-quality conditions in Smith Mountain Lake by using data collected as part of a citizens' monitoring program. A decline in water quality was observed in the upper lake areas where sediment and nutrients are deposited as stream velocities are reduced upon entering the lake. The program included monitoring of total phosphorus, chlorophyll *a*, and secchi disk depth at 99 sites in the reservoir during 1987-92. Johnson and Thomas report that the lake is considered eutrophic.

A great deal of water-quality research has been done on Falls Lake. A post-impoundment study (Water and Air Research, Inc., 1985, 1986, 1987, and 1988) reported findings of water-quality monitoring for physical characteristics, nutrients, metals, fecal bacteria, and phytoplankton. The study noted high iron and manganese levels, and nutrient concentrations at eutrophic to hypereutrophic conditions, and thermal stratification of the reservoir during spring through fall with mixing through the winter.

A review of available information on toxic substances in Falls Lake (North Carolina Department of Natural Resources and Community Development, 1985) identified possible sources and summarized water-quality conditions. The review noted that no detectable synthetic organic chemicals occurred in the lake.

Garrett (1990) compared inflow to outflow water quality in Falls Lake during 1982-87. In this study, six inflow sites were compared to the outflow site below the dam. The water-quality data included physical characteristics, major dissolved constituents, nutrients, metals, and suspended sediment. Inflow concentrations were considerably greater than those for outflow for suspended sediment, nitrogen, and phosphorus. Inflow nutrient yields ranged from 3 to 41 pounds per acre per year [(lbs/acre)/yr] for nitrogen and 0.2 to 9 (lbs/acre)/yr for phosphorus, compared to outflows of 3 (lbs/acre)/yr for nitrogen and 0.2 (lb/acre)/yr for phosphorus.

The WRRI of the University of North Carolina has sponsored research by individual investigators on a wide range of topics. Estuarine research by Witherspoon and others (1979); Kuenzler and others (1982 and 1984); Paerl (1982, 1983, and 1987); Water Resources Research Institute (1982); and Stanley (1983), which involved studies of nutrient and algal dynamics of the estuaries, set the stage for later study as part of the National Estuary Program for the Albemarle-Pamlico area.

A study of stable isotope tracers of nitrogen in the Neuse River was used to distinguish between point and nonpoint inputs to the river. Point sources dominated during the low-flow summer months, whereas nonpoint sources dominated during the high-flow winter months (Showers and others, 1990). Nutrient loading during March and April of each year is critical to the establishment of algal blooms in May and June in the lower Neuse River.

Several reports include information on nutrients in ground water in the Albemarle-Pamlico drainage basin. Cederstrom (1946) described ground-water quality of the Coastal Plain in the Virginia part of the study area. More recently, water quality of principal aquifers of the Coastal Plain of Virginia are presented in Focazio and others (1993). Summaries of ground-water quality, which include parts of the Albemarle-Pamlico study area, are presented for Virginia in Powell and Hamilton (1986) and for North Carolina in Giese and others (1986).

Nutrient concentrations in North Carolina ground water generally are low. Jennings and others (1991) reported that the incidence of nitrate contamination in more than 9,000 supply wells, located in agricultural areas throughout the State, was only 3.2 percent. Jacobs and Gilliam (1985) noted that even though the use of nitrogen fertilizers had increased 400 percent since 1945, nitrate concentrations in streams had not increased. Gilliam (1991) concluded that nitrate is not a problem in ground water downgradient from properly fertilized fields. Although nitrate concentrations may be 15 to 20 milligrams per liter (mg/L) in shallow ground water directly beneath fertilized cornfields in the North Carolina Coastal Plain, concentrations this high were not observed in water at depths below 4 meters (m). Gilliam (1991) reasoned that sufficient organic matter is present in ground water of the Coastal Plain to allow microbial reduction of nitrate. Other researchers have hypothesized that denitrification is responsible for most of the loss of nitrate from ground water (Daniels and others, 1975; Gambrell and others, 1975; Jacobs and Gilliam, 1985). Similar phenomena were observed in the Piedmont, where Daniels and Gilliam (1990) hypothesized that low stream concentrations of nitrate were due to reduction of nitrate moving to shallow alluvial fills from the B and C soil horizons, or hillslope sediment. Although nitrate nitrogen concentrations are generally low in ground water in the Albemarle-

Pamlico study area, Duda and Finan (1983) compared low-flow data from 12 watersheds having different land uses and noted that the highest nutrient concentrations (which included nitrate, ammonia, and phosphorus) occurred in streams draining watersheds that sustained high populations of livestock. Agricultural watersheds having extensive swamps adjoining the stream and forested, minimally affected watersheds had the lowest concentrations of nutrients.

Only a few studies have focused on determining the effects of pesticides on ground-water quality. Sheets and others (1972), Maas and others (1992), and Jennings and others (1991) constitute the primary published literature on pesticide research in North Carolina. These findings will be discussed later in this report.

Recently (1994), the Division of Environmental Management, DEHNR, in cooperation with the North Carolina Department of Agriculture, implemented an interagency study of the effect of pesticide use on ground water in North Carolina (Interagency Pesticide Ground Water Study Work Group, 1993). In Phase I of the study, 56 ambient monitoring network wells (various water-supply wells representing major drinking-water aquifers of the State) were sampled and analyzed for more than 152 pesticides. The primary targeted pesticides in the study included 31 pesticides identified by the USEPA as "primary leachers." Phase II of the study involved installation and sampling of more than 100 wells in 39 counties across the State (Interagency Pesticide Ground Water Study Work Group, 1993). By March 1993, 69 wells had been sampled (56 ambient supply wells and 13 installed wells), and only two pesticides, DDD and malathion, had been detected in one ambient well and one installed monitoring well. The malathion detected in the ambient well resulted from spraying the well house with the insecticide. The cause of the DDD detection was unknown. Sampling of the 100 shallow monitoring wells began in March 1993 and was expected to be completed by the end of 1994.

Acknowledgments

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COMPILATION AND SCREENING OF AVAILABLE DATA

Three principal sources of available surface-water quality data were used in this study. The USEPA Storage and Retrieval (STORET) database contains much of the ambient network data collected by DEHNR and VADEQ. The USGS National Water Data Storage and Retrieval System (WATSTORE) database contains much of the data collected by the USGS. Additional sources of data include information collected by individual investigators associated with universities, private firms, or public interest groups. However, data analysis for this study has been limited to information from the two major public databases—STORET and WATSTORE.

The STORET and WATSTORE databases were screened to obtain an appropriate subset of surface-water stations for further analysis. A retrieval of STORET data for 1955-93, with estuary areas excluded, produced an initial data set for approximately 9,000 stations. The STORET stations with the greatest number of nutrient analyses were identified and ranked by number of samples. This procedure produced a subset of 130 sites that generally had 100 or more nutrient samples. Stations were removed from the data set if they duplicated information provided by other stations. The resultant subset consisted of 53 sites.

The WATSTORE database initially was screened for stations which had 6 or more years of nutrient analyses and greater than 30 observations, which resulted in a list of 15 sites. Nine additional stations which had shorter periods of record or fewer nutrient samples were added.

The resultant list of surface-water stations consists of a subset of 77 sites compiled from STORET and WATSTORE. Eleven sites have information from STORET and WATSTORE; therefore, 66 different sites are represented in the data set (table 1). The locations of these sites are shown in figure 2. As a convention, if a STORET site is co-located with a WATSTORE site, the USGS map location number is appended with an "x." For example, in the map location for the station on the Roanoke River at Roanoke Rapids, "r15" signifies STORET data, and "r15x" signifies WATSTORE data.

Table 1. Surface-water stations in the Albemarle-Pamlico drainage study area

[STORET, U.S. Environmental Protection Agency Storage and Retrieval System; USGS, U.S. Geological Survey; mi^2, square mile; --, not available; WATSTORE, USGS National Water Data Storage and Retrieval System; SR, secondary road; NC, North Carolina State Highway]

Map location (fig. 2)	Station name	STORET station number	USGS downstream order identification number	Data source	Drainage area (mi^2)
	Roanoke River Basin (r)				
r1	North Fork Roanoke River at Route 603, Va.	371111080210901	--	STORET	60
r2	South Fork Roanoke River at Ellison, Va.	371330080140001	--	STORET	134
r3	Roanoke River at LaFayette, Va.	371413080123301	02054500	STORET	254
r4	Roanoke River at Roanoke, Va.	371530079562001	02055000	WATSTORE	385
r5	Roanoke River 14th Street Bridge at Roanoke, Va.	371552079545501	--	STORET	390
r6	Tinker Creek at Glebe Mills, Va.	371631079542801	--	STORET	102
r7	Roanoke River at Route 634 at Hardy, Va.	371310079475601	02056670	STORET	580
r8	Smith Mountain Lake at Hardy's Ford, Va.	371312079475601	--	STORET	580
r9	Pigg River near Sandy Level, Va.	365655079310501	02058400	STORET	350
r10	Roanoke River at Altavista, Va.	370616079174401	02060500	WATSTORE	1,781
r11	Big Otter Creek at Route 712, Va.	370824079143601	--	STORET	393
r12	Roanoke River at Randolph, Va.	365454078442801	02066000	WATSTORE	2,979
r13	Roanoke River at Route 360, Va.	365017078400601	02067000	STORET	3,250
r14	Nutbush Creek near Henderson, N.C.	362210078243101	0207926400	STORET	3
r15, r15x	Roanoke River at Roanoke Rapids, N.C.	362737077380401	02080500	STORET, WATSTORE	8,474
	Dan River Basin (d)				
d1	Smith River at Route 609, Va.	364204079555901	--	STORET	331
d2	Smith River at Route 622, Va.	363331079444601	--	STORET	545
d3	Dan River near Mayfield, Va.	363229079362101	02074218	STORET	1,779
d4	Dan River at Robertson Bridge at Danville, Va.	363443079255501	--	STORET	2,024
d5	Dan River at Paces, Va.	363832079052301	02075500	WATSTORE	2,587
d6	Dan River at Route 501 Bridge, Va.	364138078540201	02076005	STORET	2,756
d7	Bannister River at Terry's Bridge, Va.	364444078503101	02077050	STORET	580
d8	Hyco River at Route 58, Va.	364003078452001	--	STORET	416
	Chowan River Basin (c)				
c1	Meherrin River at Emporia, Va.	364124077322701	02052000	WATSTORE	745
c2	Nottoway River near Sebrell, Va.	364613077095901	02047000	WATSTORE	1,441
c3	Spring Branch at U.S. Highway 460 near Waverly, Va.	370312077070101	--	STORET	4
c4, c4x	Blackwater River near Franklin, Va.	364545076535501	02049500	STORET, WATSTORE	610
c6	Chowan River near Riddicksville, N.C.	363154076551701	0205011000	STORET	2,476
c7	Chowan River tributary near Riddicksville, N.C.	363027076565801	0205017000	STORET	1
c8	Bells Branch at SR 1167 near Mapleton, N.C.	362320077024101	0205320500	STORET	.7
c9	Potecasi Creek near Union, N.C.	362214077013601	02053200	STORET	222
c10	Cutawhiskie Creek tributary near Menola, N.C.	361848077083401	0205317160	STORET	4

Table 1. Surface-water stations in the Albemarle-Pamlico drainage study area—Continued

[STORET, U.S. Environmental Protection Agency Storage and Retrieval System; USGS, U.S. Geological Survey; mi^2, square mile; --, not available; WATSTORE, USGS National Water Data Storage and Retrieval System; SR, secondary road; NC, North Carolina State Highway]

Map location (fig. 2)	Station name	STORET station number	USGS downstream order identification number	Data source	Drainage area (mi^2)
	Chowan River Basin (c)—Continued				
c11	Panther's Branch at SR 1164 near Murfreesboro, N.C.	362321077075701	0205316300	STORET	12
c12	Cypress Creek at SR 1324 near Seaboard, N.C.	363110077270301	0205305000	STORET	6
	Tar River Basin (t)				
t1	Tar River at Louisburg, N.C.	360534078174801	02081747	STORET	433
t2	Tar River below Tar River Reservoir, N.C.	355358077515701	02082506	STORET	787
t3	Tar River at NC 97 at Rocky Mount, N.C.	355715077471501	02082585	STORET	929
t4	Devil's Cradle Creek near Alert, N.C.	361203078141901	02082731	WATSTORE	14
t5	Swift Creek near Hilliardston, N.C.	360642077551601	02082770	STORET	166
t6	Little Fishing Creek near White Oak, N.C.	361108077523401	02082950	STORET	177
t7	Fishing Creek near Enfield, N.C.	360903077413501	02083000	STORET	525
t8, t8x	Tar River at Tarboro, N.C.	355338077320001	02083500	STORET, WATSTORE	2,222
t9	Conetoe Creek near Bethel, N.C.	354633077274501	02083800	STORET	69
t10	Juniper Branch at SR 1766 near Simpson, N.C.	353355077144301	02084164	WATSTORE	7
t11	Cow Swamp near Grimesland, N.C.	353200077133001	02084158	WATSTORE	14
t12	Chicod Creek at SR 1565 near Grimesland, N.C.	353157077111301	02084148	WATSTORE	15
t13, t13x	Chicod Creek at SR 1760 near Simpson, N.C.	353347077134301	02084160	STORET, WATSTORE	39
	Neuse River Basin (n)				
n1	Flat River near Quail Roost, N.C.	361200078531201	0208547700	STORET	150
n2	Flat River at Bahama, N.C.	361057078524401	02085500	WATSTORE	552
n3, n3x	Little River at SR 1461 near Orange Factory, N.C.	360830078551001	0208521324	STORET, WATSTORE	88
n4	Eno River near Durham, N.C.	360420078543001	02085070	STORET	133
n5	Ellerbe Creek at SR 1709 at Durham, N.C.	360118078521501	0208679920	STORET	7
n6, n6x	Neuse River near Falls, N.C.	355624078343201	02087183	STORET, WATSTORE	773
n7	Neuse River near Clayton, N.C.	353850078242201	02087500	WATSTORE	1,160
n8, n8x	Neuse River at Smithfield, N.C.	353046078210001	02087570	STORET, WATSTORE	1,216
n9	Swift Creek at Holly Springs Road, N.C.	354300078450001	02087580	STORET	21
n10	Middle Creek near Clayton, N.C.	353412078353001	02088000	STORET	83
n11	Neuse River at Richardson Bridge, N.C.	352227078114701	02088119	WATSTORE	1,730
n12	Little River near Princeton, N.C.	353040078093601	02088500	STORET	232
n13	Neuse River near Goldsboro, N.C.	352014077595101	02089000	STORET	2,409
n14, n14x	Neuse River at Kinston, N.C.	351529077350901	02089500	STORET, WATSTORE	2,712

Table 1. Surface-water stations in the Albemarle-Pamlico drainage study area—Continued

[STORET, U.S. Environmental Protection Agency Storage and Retrieval System; USGS, U.S. Geological Survey; mi^2, square mile; --, not available; WATSTORE, USGS National Water Data Storage and Retrieval System; SR, secondary road; NC, North Carolina State Highway]

Map location (fig. 2)	Station name	STORET station number	USGS downstream order identification number	Data source	Drainage area (mi^2)
Neuse River Basin (n)—Continued					
n15, n15x	Trent River near Trenton, N.C.	350354077272401	02092500	STORET, WATSTORE	166
n16	Contentnea Creek near Lucama, N.C.	354129078063801	02090380	STORET	157
n17	Nahunta Swamp near Shine, N.C.	352920077482201	02091000	STORET	80
n18, n18x	Contentnea Creek at Hookerton, N.C.	352544077345901	02091500	STORET, WATSTORE	737
n19, n19x	Creeping Swamp near Vanceboro, N.C.	352330077134601	02091970	STORET, WATSTORE	30

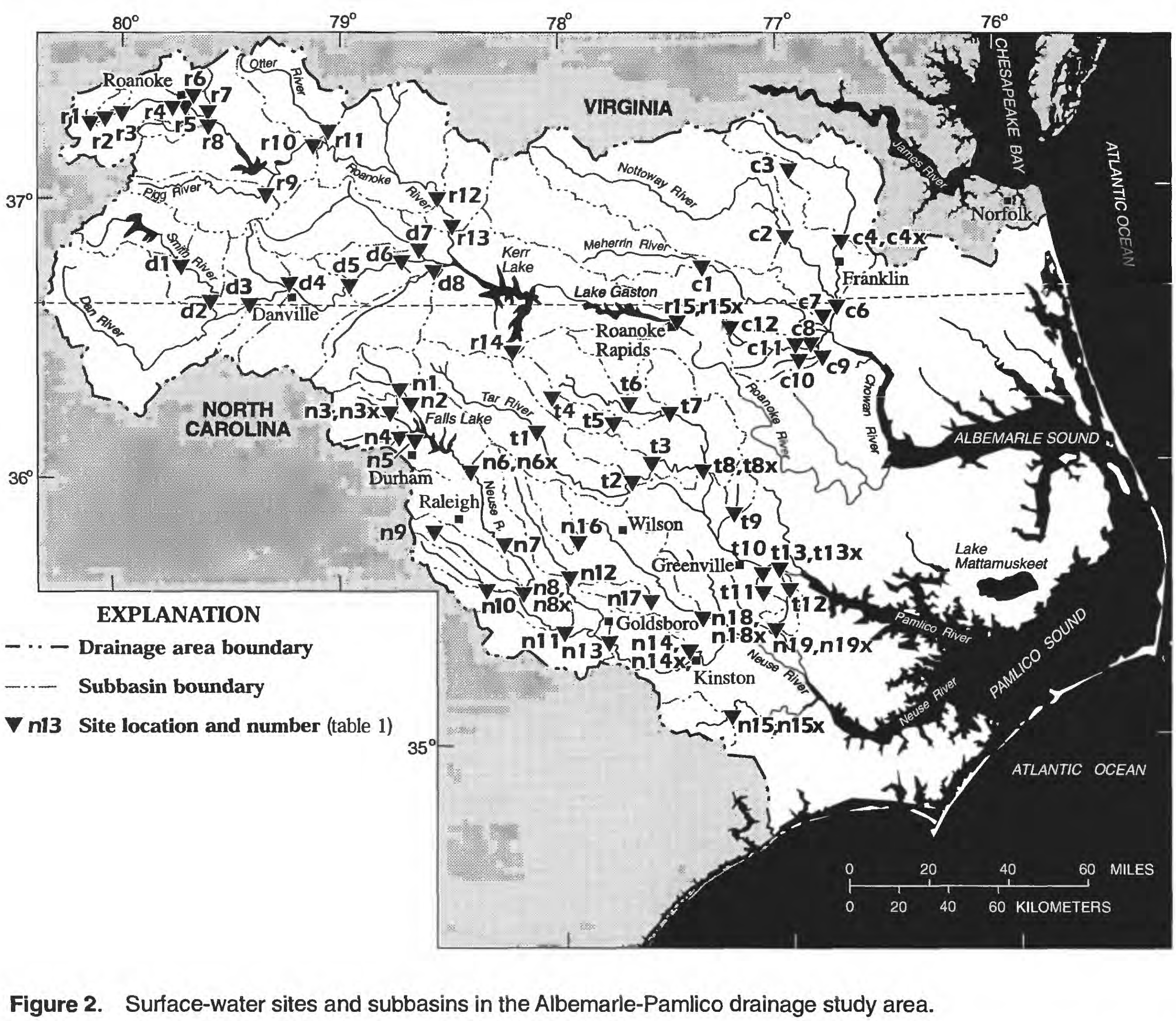


Figure 2. Surface-water sites and subbasins in the Albemarle-Pamlico drainage study area.

Data from 10 co-located sites were compared statistically to determine the appropriateness of grouping the data together. Results of the Wilcoxon ranked sum test for the paired stations (table 2) indicate significant differences (alpha = 0.05) between the STORET data and the WATSTORE data in 60 percent of the comparisons. Significant differences occurred for every station except Chicod Creek near Simpson. Differences in period of record (table 2), flows at times of sampling, sampling methods, and laboratory techniques might have contributed to the observed differences in the data distributions. The sampling objectives of the USGS, DEHNR, and VADEQ are different, and these differences are reflected in the data collected by the agencies. In subsequent analyses of available data for this report, results for co-located stations are shown independently.

Data were retrieved from STORET and WATSTORE for the period 1950-90 for wells less than 2,000 feet (ft) deep. Wells not having well-depth information were excluded. Ground-water sites (wells) in the Albemarle-Pamlico study area are shown in figures 3 and 4. Total well-depth information was available for more than 2,400 well sites, and data from 82 percent of the sites (1,948) were stored in STORET. Data from approximately 500 well sites having depth information were available in the WATSTORE database. Depth distribution of these wells in each of seven hydrogeologic zones (fig. 5) indicates that the deepest wells are in the Coastal Plain carbonates zone and the shallowest wells are in the Outer Coastal Plain deposits zone (fig. 6).

Relatively few ground-water quality data were stored in WATSTORE or STORET databases after 1980, indicating a need to computerize data that may exist in paper files of major State agencies and a need to establish ground-water quality monitoring networks for adequately assessing spatial and temporal water-quality characteristics. Locations of wells having water-quality data collected before 1980 are shown in figure 7. Most sites are in the Inner and Outer Coastal Plain deposits zones, but a few sites are in the Valley and Ridge carbonates and granitic rocks zones. Locations of wells having water-quality data collected during and after 1980 and having depth data are shown in figure 8. These sites are primarily in Virginia, mostly in the Coastal Plain deposits or the Valley and Ridge carbonates zones. Water-quality data were available for only a few North Carolina sites.

For this report, wells having water-quality information were selected for statistical analysis based on the availability of water analyses, which contained

Table 2. Probabilities for the Wilcoxon rank sum test for comparisons of nutrient data from U.S. Geological Survey stations, North Carolina Department of Environment, Health, and Natural Resources stations, and Virginia Department of Environmental Quality stations

[STORET, U.S. Environmental Protection Agency Storage and Retrieval System; WATSTORE, U.S. Geological Survey National Water Data Storage and Retrieval System; SR, secondary road]

Station name	Map location (fig. 2)	Rank-sum probabilities			Type of data source and period of record	
		Total nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	STORET	WATSTORE
Roanoke River at Roanoke Rapids, N.C.	r15, r15x	0.261	0.307	0.001	1968-92	1957-93
Blackwater River near Franklin, Va.	c4, c4x	.0001	.875	.001	1968-92	1951-93
Tar River at Tarboro, N.C.	t8, t8x	.027	.0001	.0021	1976-92	1957-93
Chicod Creek at SR 1760 near Simpson, N.C.	t13, t13x	.175	.934	.114	1985-91	1975-93
Little River at SR 1461 near Orange Factory, N.C.	n3, n3x	.005	.0001	.628	1988-92	1988-92
Neuse River near Falls, N.C.	n6, n6x	.0001	.0001	.426	1969-92	1969-92
Neuse River at Smithfield, N.C.	n8, n8x	.0004	.0001	.0001	1968-92	1972-93
Neuse River at Kinston, N.C.	n14, n14x	.365	.001	.055	1973-92	1955-93
Trent River near Trenton, N.C.	n15, n15x	.26	.022	.003	1969-92	1955-81
Creeping Swamp near Vanceboro, N.C.	n19, n19x	.009	.0011	.895	1985-92	1972-87

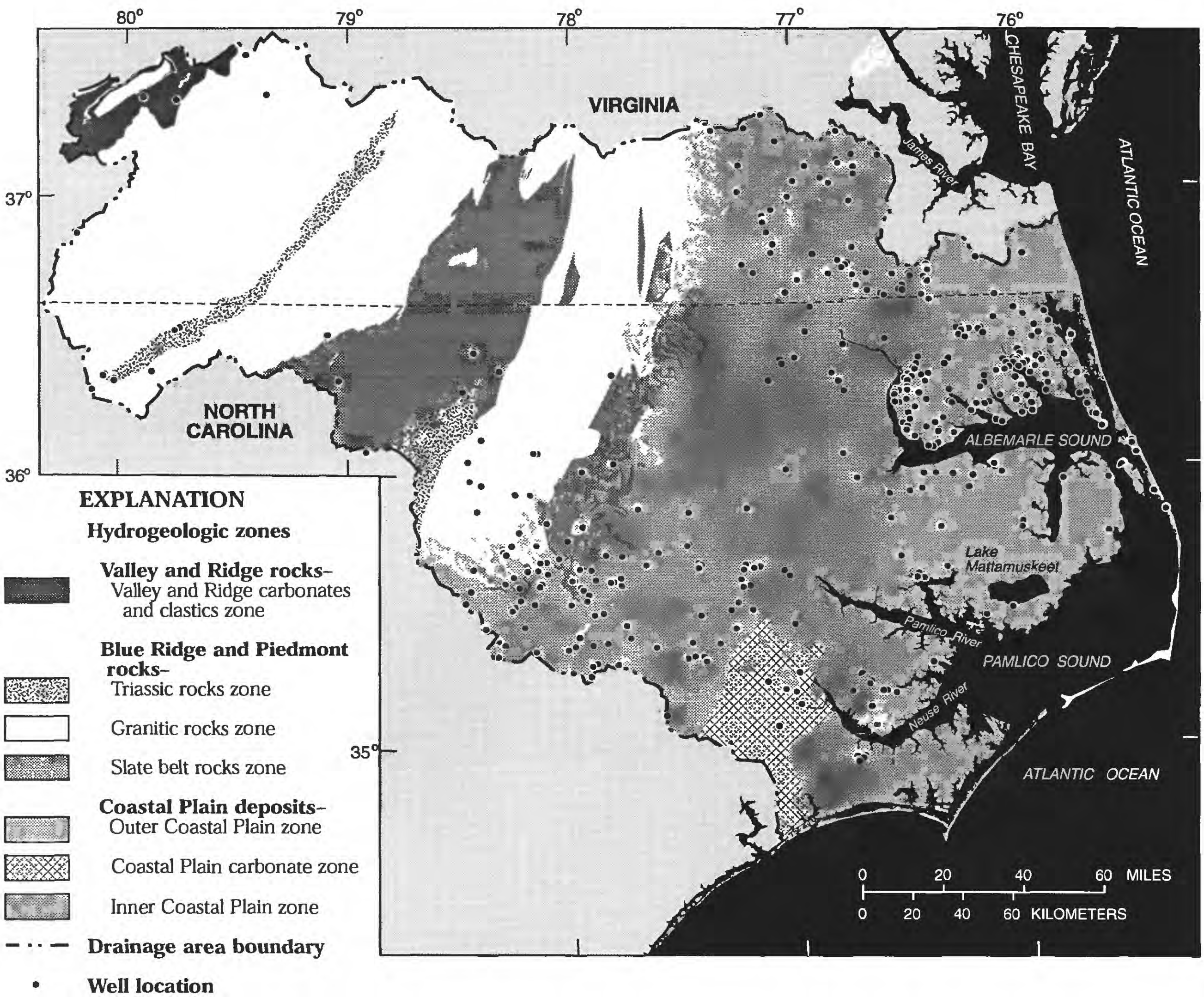


Figure 3. Locations of ground-water sites having depth data in the WATSTORE database for the Albemarle-Pamlico drainage study area, 1950-90.

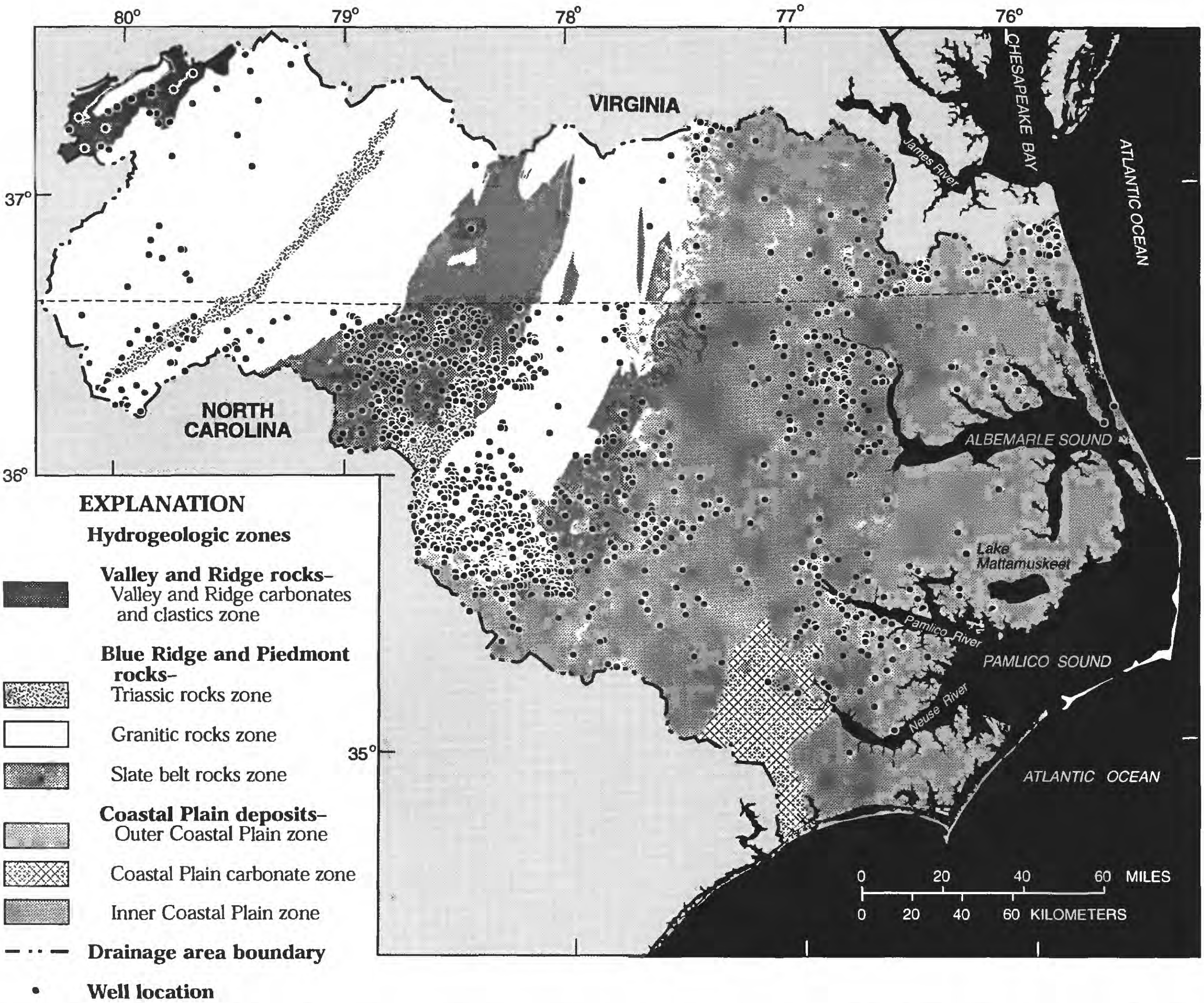


Figure 4. Locations of ground-water sites having depth data in the STORET database for the Albemarle-Pamlico drainage study area, 1950-90.

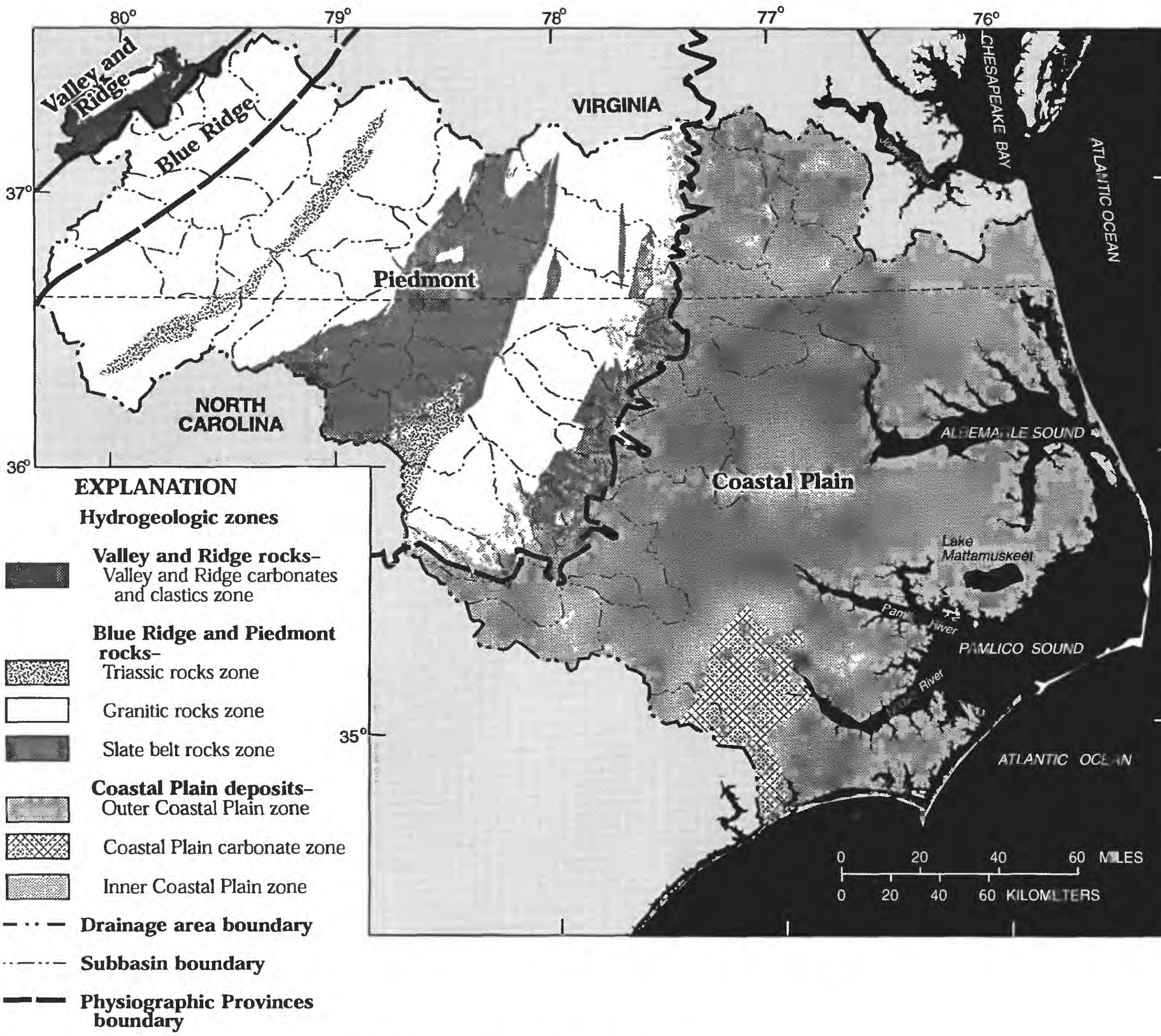


Figure 5. Hydrogeologic zones of the Albemarle-Pamlico drainage basin.

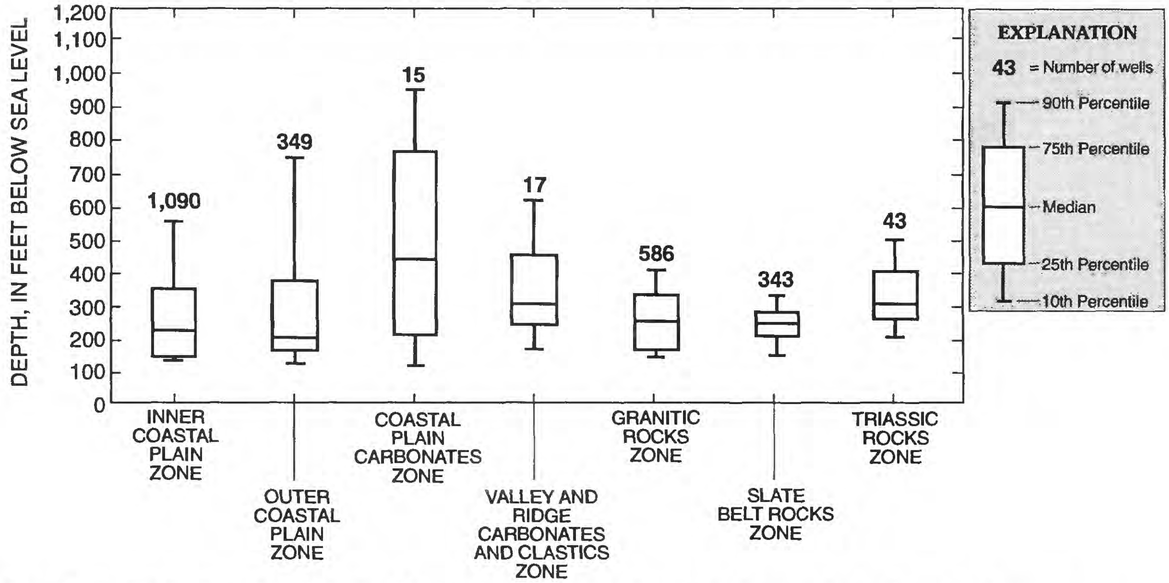


Figure 6. Depth distribution of wells in the Albemarle-Pamlico drainage study area, by hydrogeologic zone.

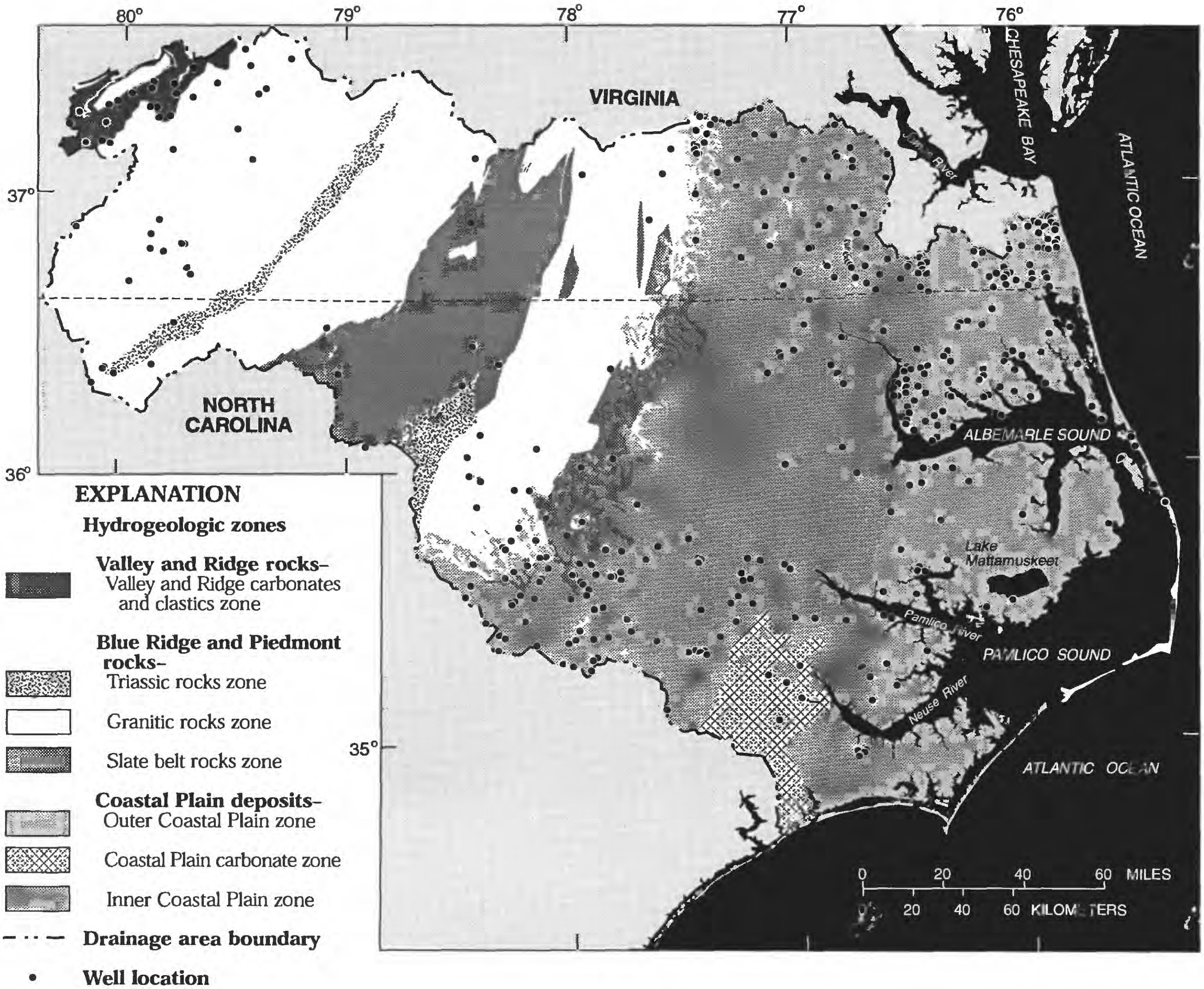


Figure 7. Locations of wells having water-quality and depth data before 1980 in the Albemarle-Pamlico drainage study area, 1950-80.

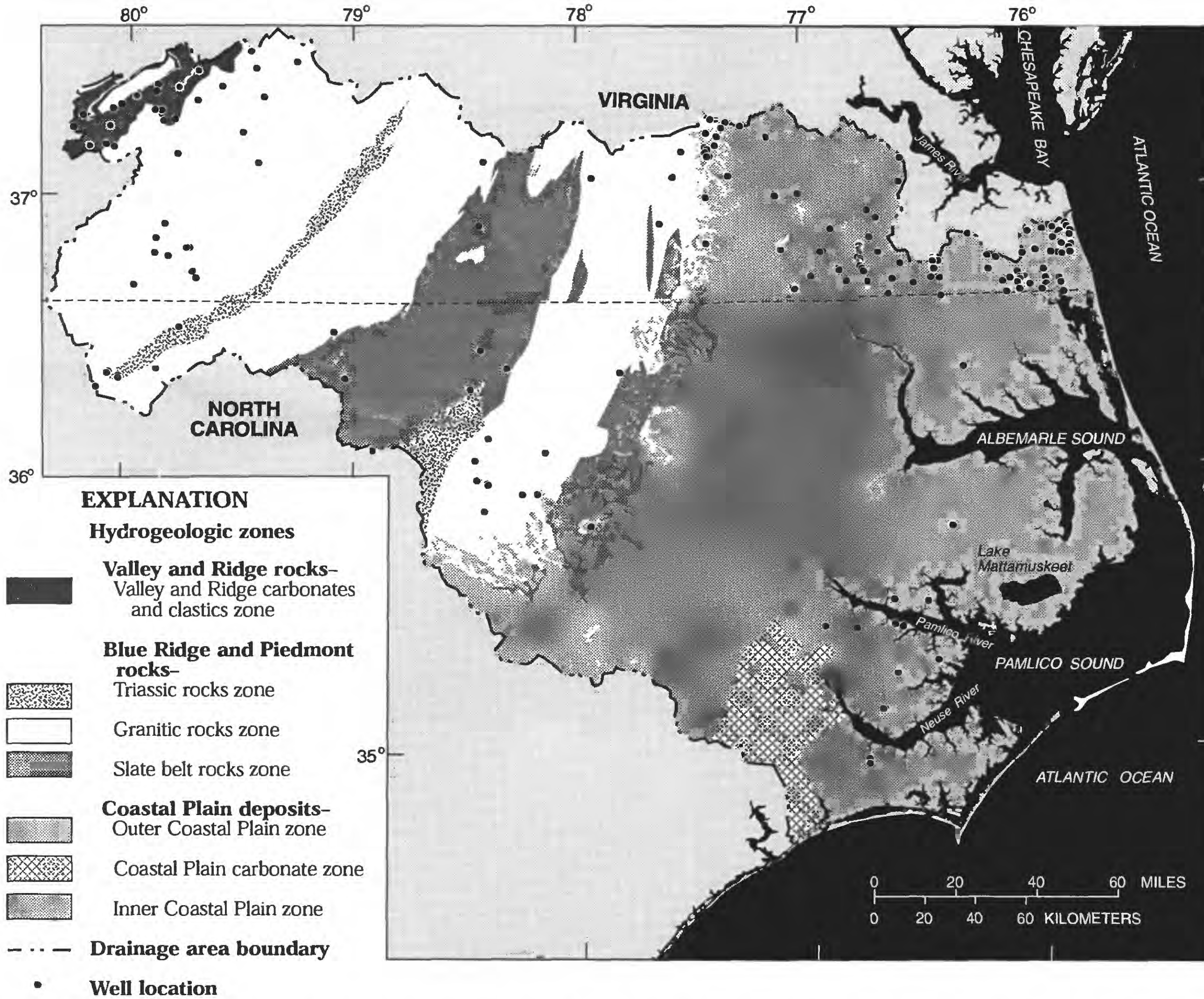


Figure 8. Locations of wells having water-quality and depth data in the Albemarle-Pamlico drainage study area, 1980-90.

specific conductance and major ion data (analyses for calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate) and dissolved nitrate as nitrogen (nitrite plus nitrate is shown as nitrate nitrogen because nitrite is assumed to be negligible) or total phosphorus data. Total phosphorus data represent chemical analyses of unfiltered samples and were generally available for most of the period of record. Because phosphorus can sorb onto fine particles, water analyses used in this report reflect the amount of phosphorus dissolved plus the amount sorbed on fine particles that might have passed through the well screen. Most of this phosphorus should be in the dissolved form, because ground water passing into a supply well is filtered by the sand pack around the well. Nitrate as nitrogen or total phosphorus data for 757 well sites for 1954-90 are in the STORET and WATSTORE databases. Data for these wells are summarized in table 3.

SPATIAL AND TEMPORAL COVERAGE OF SURFACE-WATER DATA

Station characteristics, including discharge, period of record, and location were reviewed to examine the geographic extent of the surface-water data set. This review highlights particular areas that lack available data and provides a basis for understanding spatial water-quality trends.

The spatial distribution of surface-water stations is uneven (fig. 2). There are no stations in large areas of the Coastal Plain and the upper reaches of the

Table 3. Number of nitrogen and phosphorus analyses, by data source

[STORET, U.S. Environmental Protection Agency Storage and Retrieval System; WATSTORE, U.S. Geological Survey National Water Data Storage and Retrieval System]

Source of data	Number of sites with depth	Dissolved nitrate			Total phosphorus		
		Period of record	Number of analyses	Number of well sites	Period of record	Number of analyses	Number of well sites
STORET	1,948	1966-90	602	180	1974-90	558	195
WATSTORE	502	1954-89	404	319	1954-89	140	63
Total	2,450	1966-90	1,006	499	1954-90	698	258

Blackwater, Nottoway, Meherrin, Hyco, Tar, Otter, Pigg, and Dan River Basins. There is more even distribution of stations on the main stems of the Roanoke, Dan, and Neuse Rivers.

The drainage areas of the basins (fig. 9) range from the 8,474-mi^2 Roanoke River Basin at Roanoke Rapids (r15) to the 0.7-mi^2 Bells Branch Basin (c8). The median drainage basin size is 340 mi^2.

The set of study sites includes eight National Stream Quality Accounting Network (NASQAN) stations of the USGS (fig. 9). A precursor to the NAWQA Program, NASQAN was established to provide nationally consistent measurements for documenting water quality of major rivers of the Nation (Ficke and Hawkinson, 1975). These stations generally are located on the downstream-most nontidal

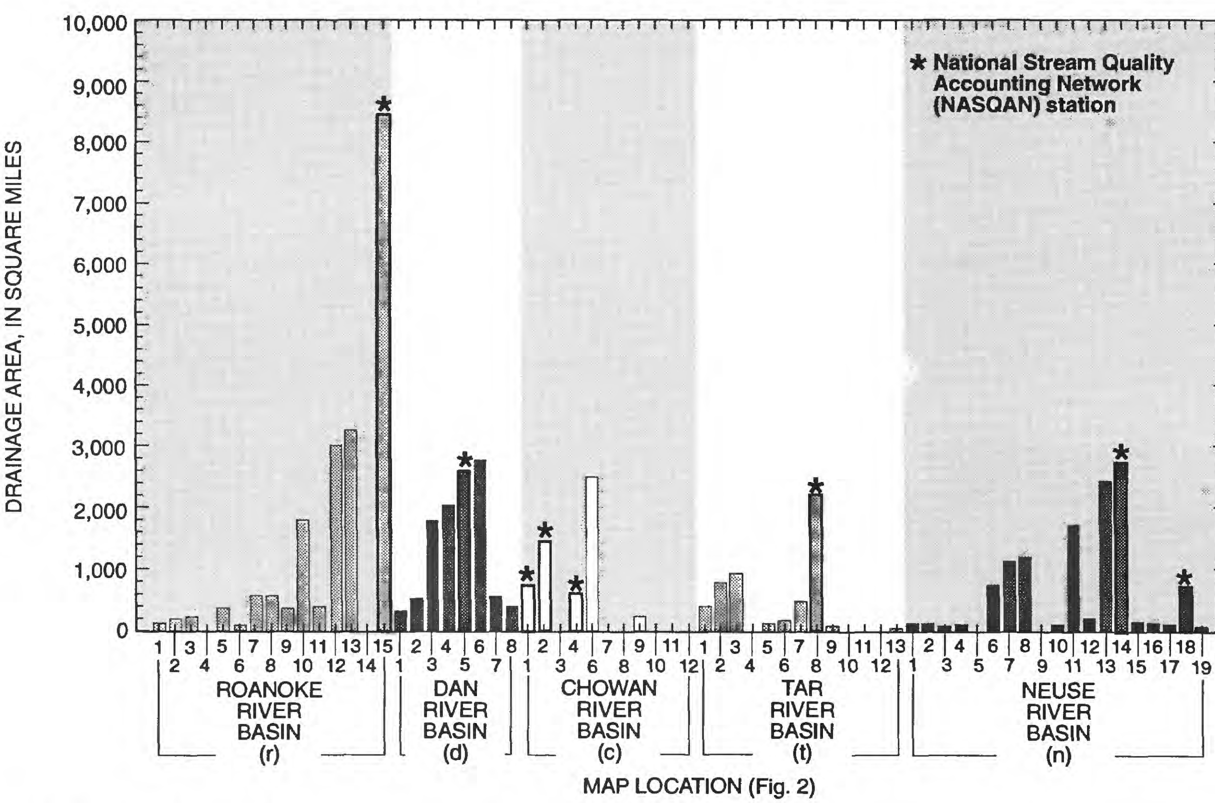


Figure 9. Drainage areas of the Albemarle-Pamlico drainage study area.

points of major rivers and tributaries. The NASQAN stations in the study area have long periods of discharge record and have been monitored for a variety of water-quality measures. Drainage areas of the NASQAN basins range in size from 610 to 8,474 mi^2, and each of the five major drainages of the study area has at least one station. Because of the length and consistency of water-quality and discharge record at the NASQAN sites, these sites are the most suitable for quantitative analysis, including trend testing and load estimation.

Variation in streamflow at the USGS NASQAN stations is illustrative of streamflow variation within the Albemarle-Pamlico drainage area. Annual mean discharges from 1950 to 1989 for these stations range from 12,900 ft^3/s at the Roanoke River at Roanoke Rapids, N.C., site (r15) to less than 100 ft^3/s at the Blackwater River near Franklin, Va., site (c4) (fig. 10). The driest years include 1951, 1966, 1967, 1977, 1981, 1985-86, and 1988. Some of the wettest years include 1953, 1960, 1965, 1973, 1984, and 1989. Discharge generally peaks in February or March and is least in July, August, and September (fig. 11). Seasonality is more evident in the larger streams that primarily drain the Piedmont, and less so in the basins that drain large areas of the Coastal Plain.

Land Use Data Analysis (LUDA) maps produced by the USGS (Anderson and others, 1976) provide historical data on a regional scale (1:250,000) for general land-use categories in the study area. More recent land-use classification data are available for much of the study area (North Carolina Center for Geographic Information and Analysis, 1990). These data are based on 1992 LANDSAT aerial photographs and exclude the Roanoke River Basin upstream from Roanoke Rapids, N.C. A comparison of the LUDA and LANDSAT data is reported by Holman (1993). LUDA data were used in the NAWQA analysis for national consistency.

A median of 31 percent of the land for all the subbasins combined is agricultural land. In general, the Roanoke and Dan River Basins have less agricultural land use than the Chowan, Tar, and Neuse River Basins (fig. 12), illustrating a land-use pattern of more intensive agriculture in the Coastal Plain than in the Piedmont. The percentages of total developed basin area (fig. 13) indicate the highest urbanization in the Roanoke and Neuse River Basins. A median of 4.6 percent of the area for the subbasins is developed land. The basin at the Ellerbe Creek site (n5) is completely developed. In general, the remainder of the land area not in agriculture or in developed land is forested.

The 1990 basin population data reflect the developed land-use patterns. The greatest number of people live in the Roanoke, Neuse, and Dan River Basins (fig. 14). The highest population is in the Roanoke River Basin at Roanoke Rapids, which is the largest subbasin and combines the upstream population of the upper Roanoke and Dan River Basins. The pattern of population density for the subbasins (fig. 15) closely matches the pattern of developed land use (fig. 13). Ellerbe Creek subbasin (n5) has a population density of 2,588 persons per square mile. Nutbush Creek subbasin (r14) has a population density of 1,107 persons per square mile. The median population density for all the subbasins is 96 people per square mile.

Wastewater discharge is an important source of water-quality constituents in streams. A comparison of total reported wastewater discharge for the subbasins (North Carolina Department of Environment, Health, and Natural Resources, written commun., 1990, and Virginia Water Control Board, written commun., 1990) (fig. 16) shows the greatest total volume of discharge in the Roanoke, Dan, and Neuse River Basins and relatively little point-source discharge in the Chowan and Tar River Basins. When these total discharges are shown as discharge per square mile (fig. 17), the subbasins having relatively large point-source discharge per drainage area are highlighted. Nutbush Creek (r14) and Spring Branch (c3) subbasins have particularly high point-source discharge per square mile. These wastewater discharges do not include land application of wastewater.

Station locations and distributions of sample-collection dates over the period of record of water quality, streamflow at time of sample collection, and specific conductance for the NASQAN stations and for selected sites along the Roanoke, Dan, Chowan, Tar, and Neuse Rivers are shown in figures 18-23. All but the illustration for the NASQAN stations (fig. 18) and the Chowan River Basin (fig. 21) show subbasins in downstream order.

In general, most of the water-quality sampling for the NASQAN stations began in the 1970's. The Tar River (t8x) and Neuse River (n14x) stations have particularly long periods of water-quality record, beginning in or before 1960. The period of record of the DEHNR stations on the Tar (t8) and the Neuse (n14) Rivers is shorter, but has a greater sampling frequency than the NASQAN stations.

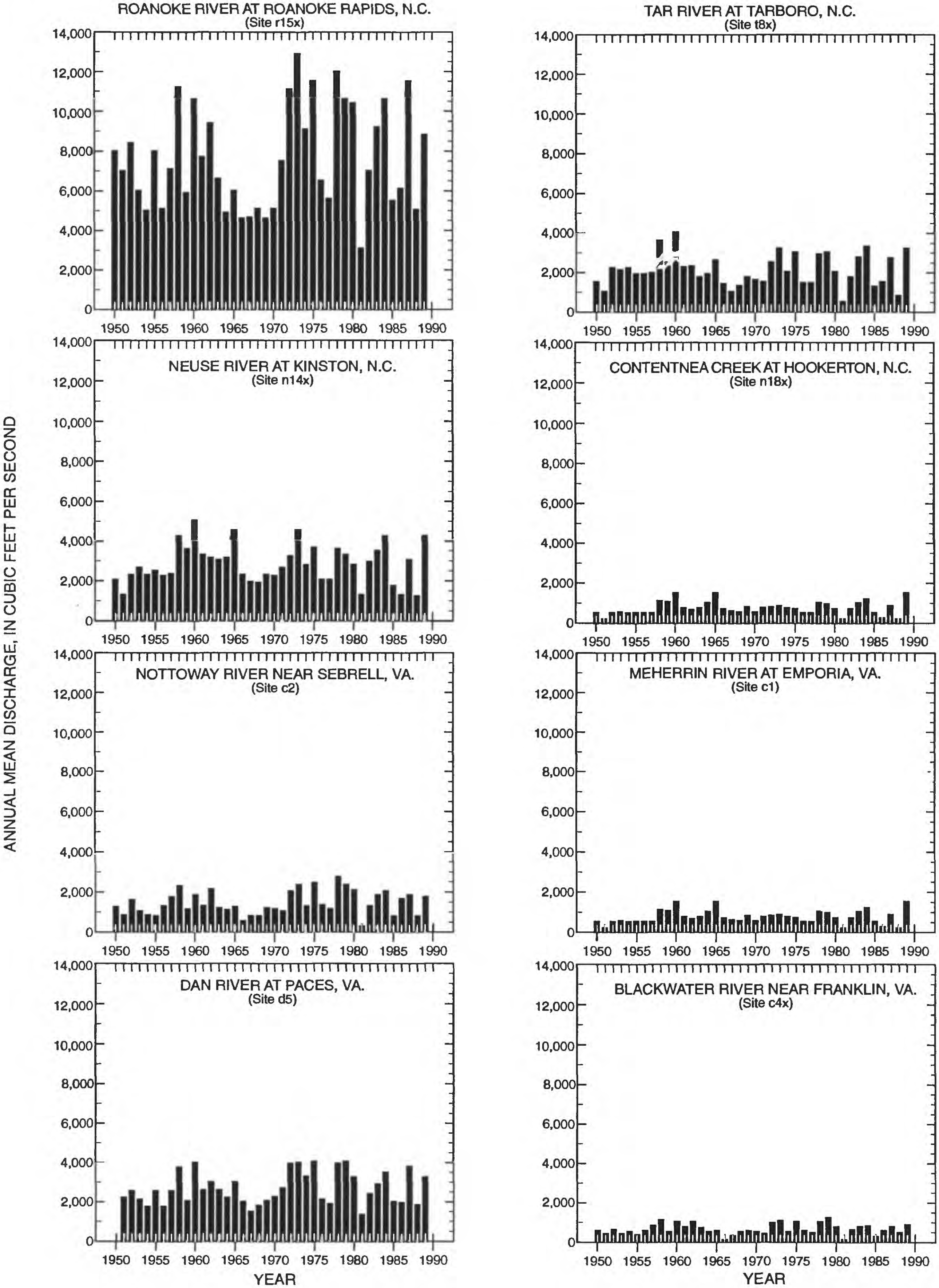


Figure 10. Annual mean discharge for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area, 1950-89. (Site locations shown in figure 2.)

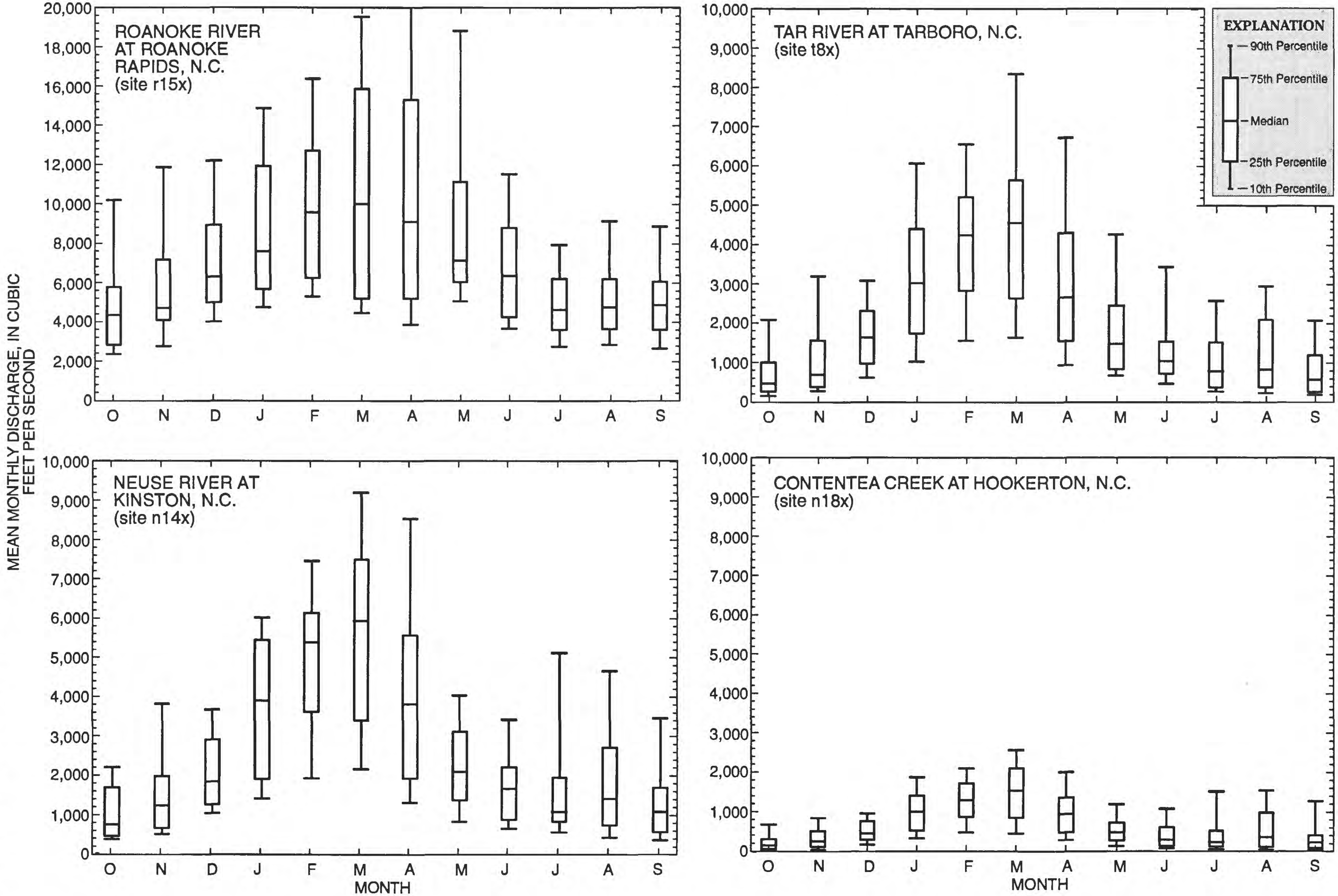


Figure 11. Mean monthly discharge for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area, 1950-89. (Site locations shown in figure 2.)

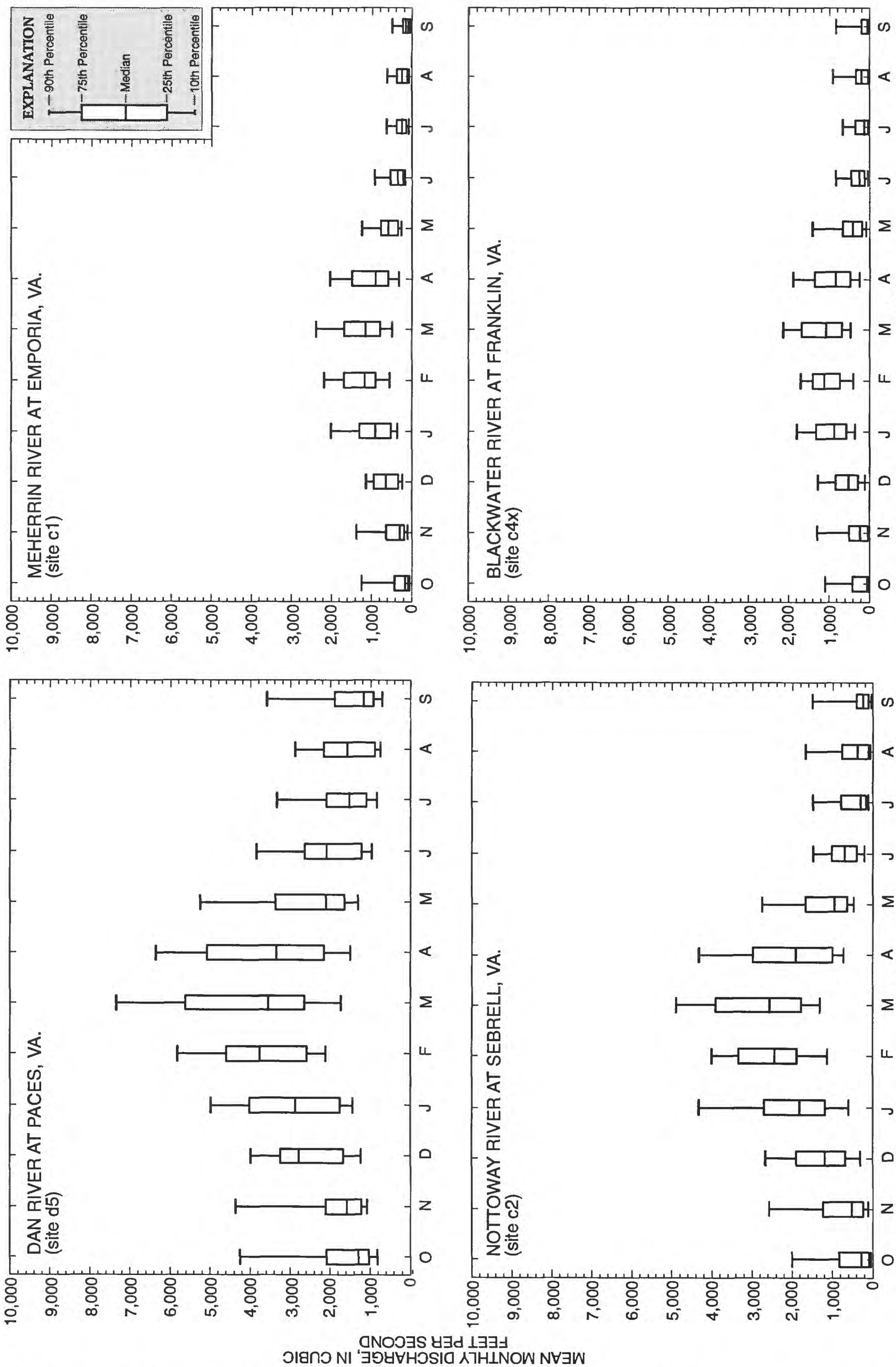


Figure 11. (continued) Mean monthly discharge for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area, 1950-89. (Site locations shown in figure 2.)

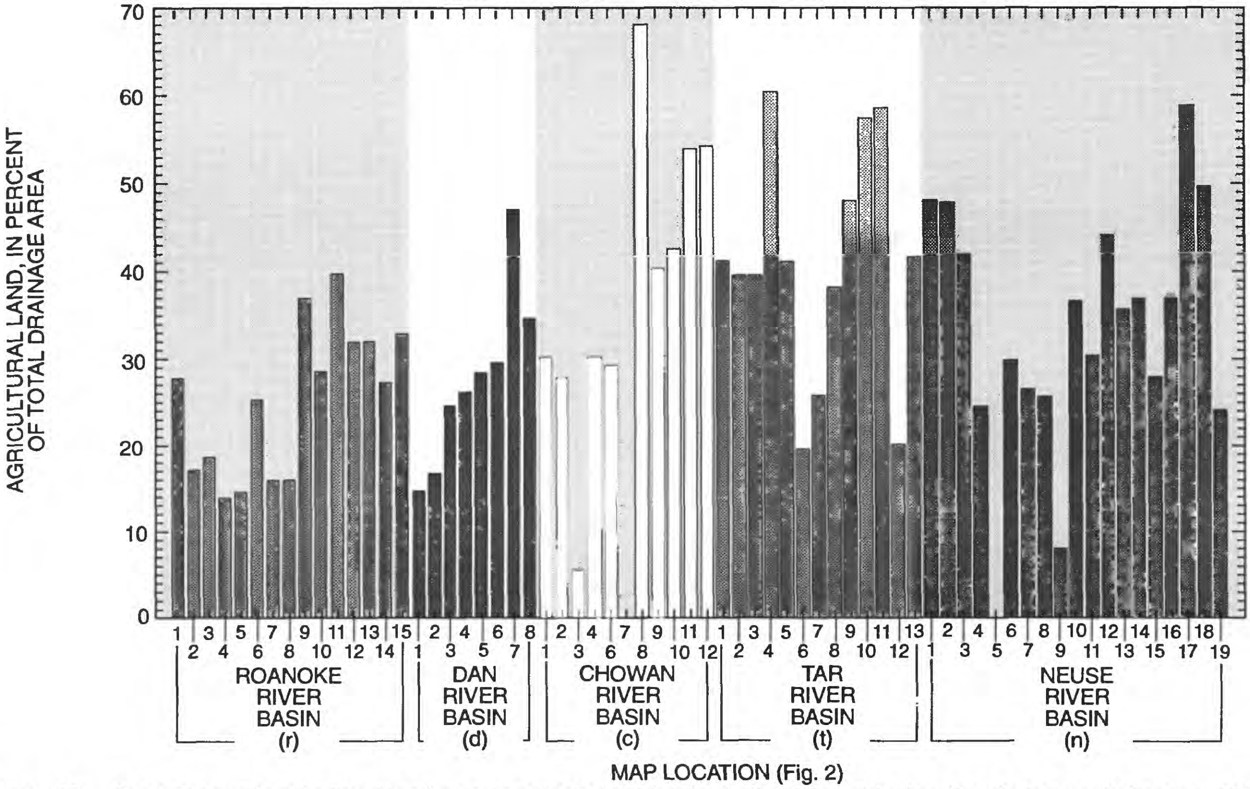


Figure 12. Percentage of agricultural land area in selected subbasins in the Albemarle-Pamlico drainage study area, 1975.

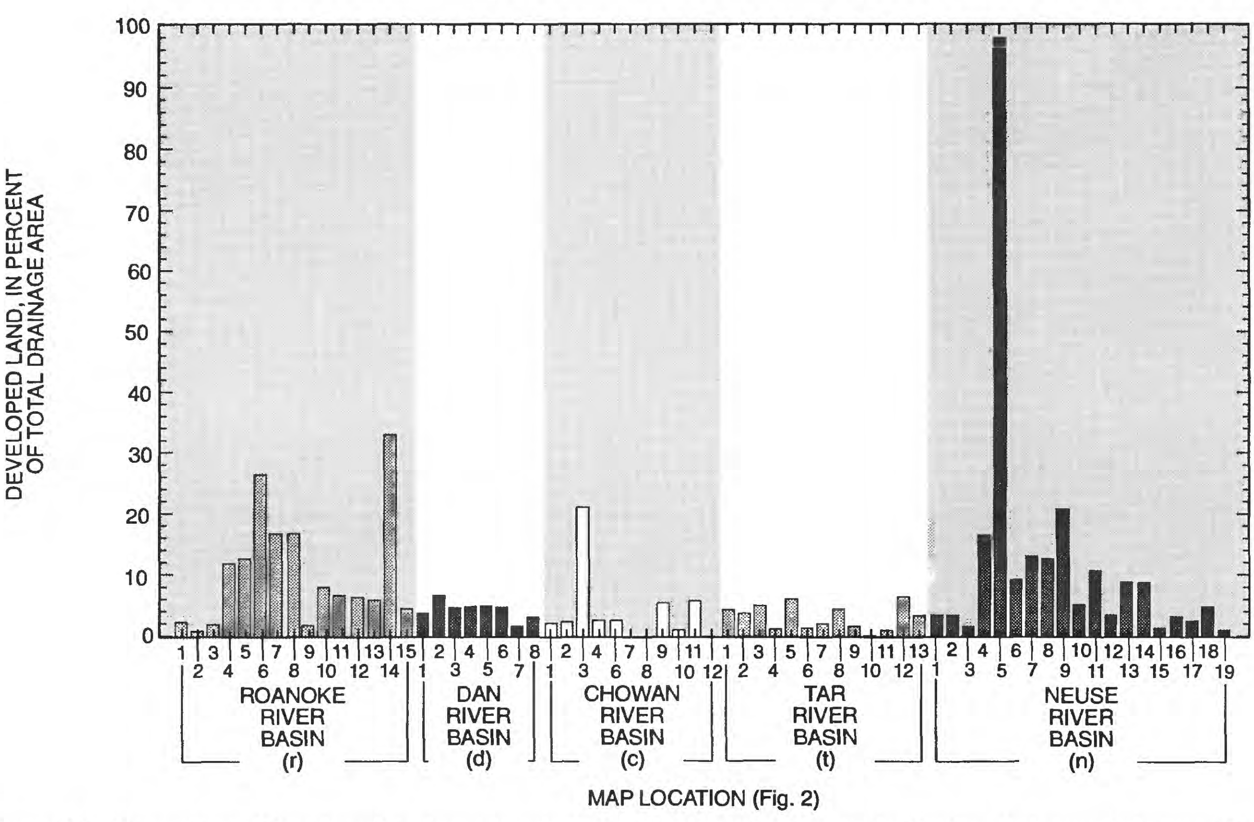


Figure 13. Percentage of developed land area in selected subbasins in the Albemarle-Pamlico drainage study area, 1975.

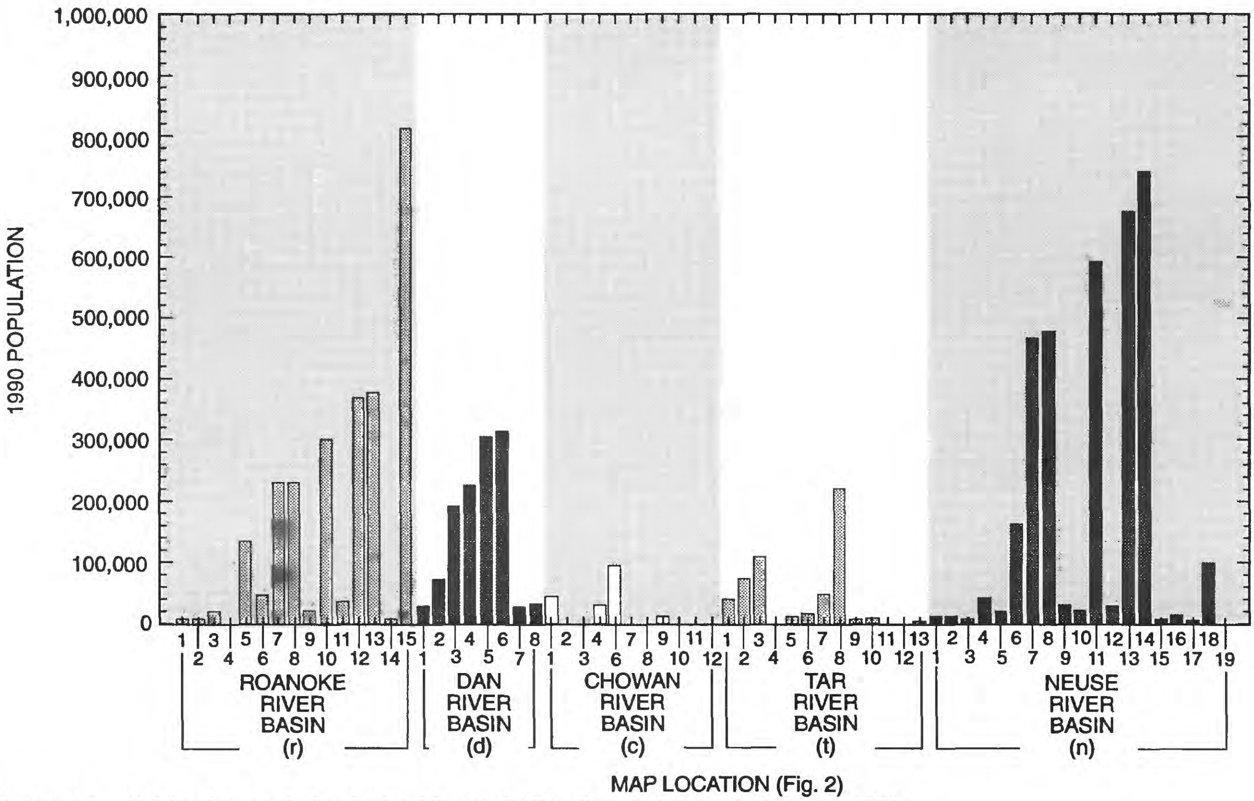


Figure 14. Subbasin population in the Albemarle-Pamlico drainage study area, 1990.

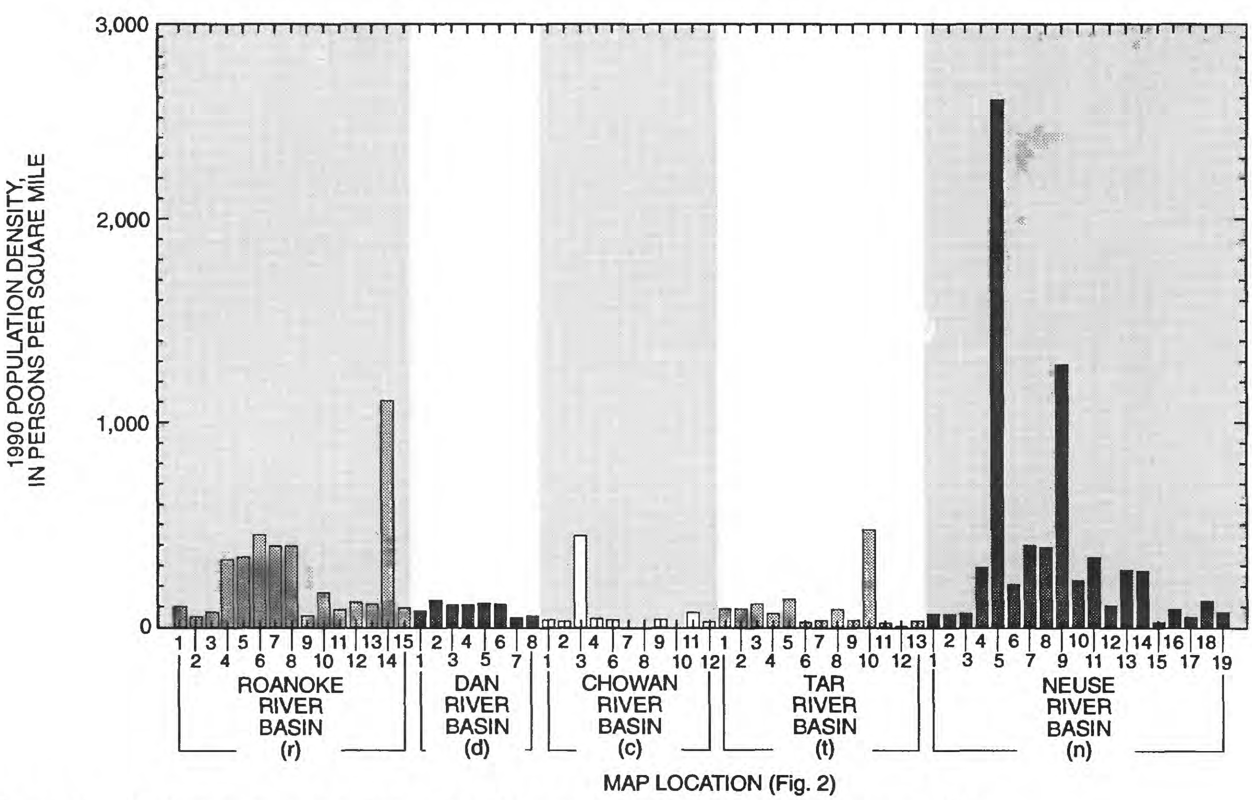


Figure 15. Subbasin population density of the Albemarle-Pamlico drainage study area, 1990.

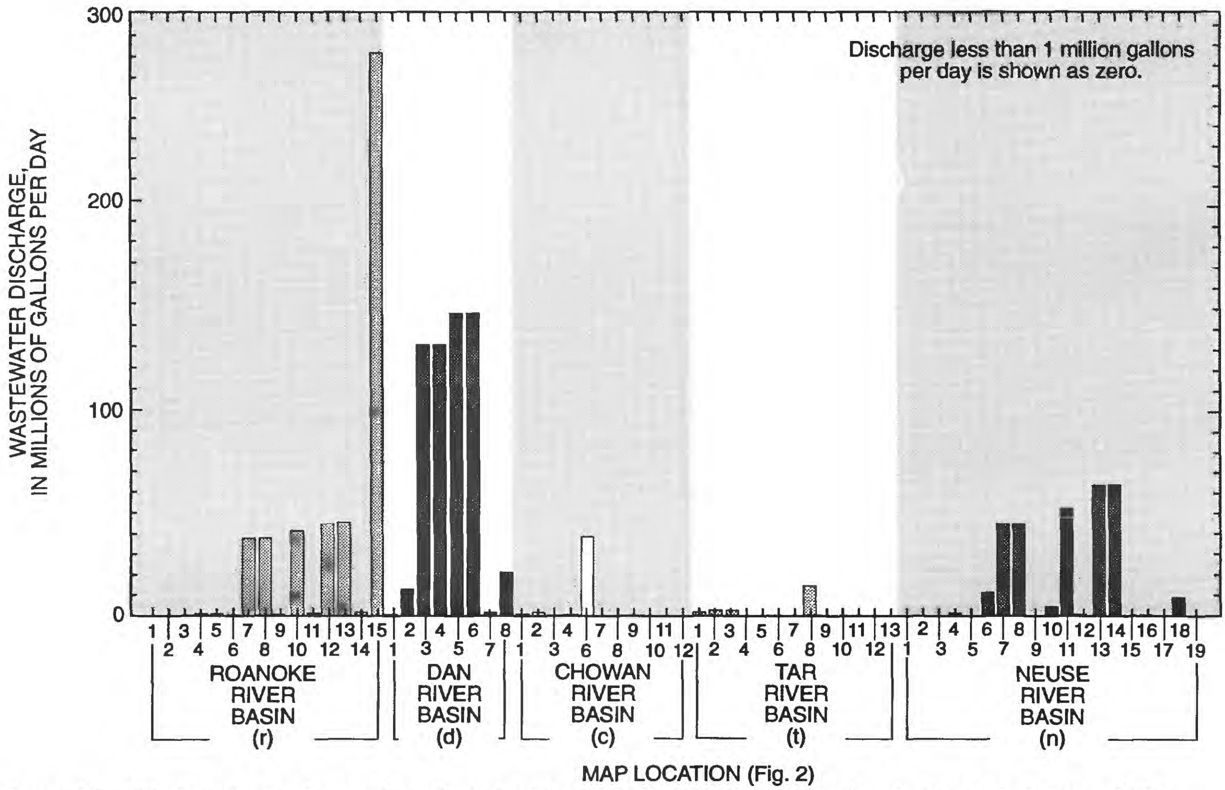


Figure 16. Wastewater discharge, by selected subbasin, in the Albemarle-Pamlico drainage study area, 1990.

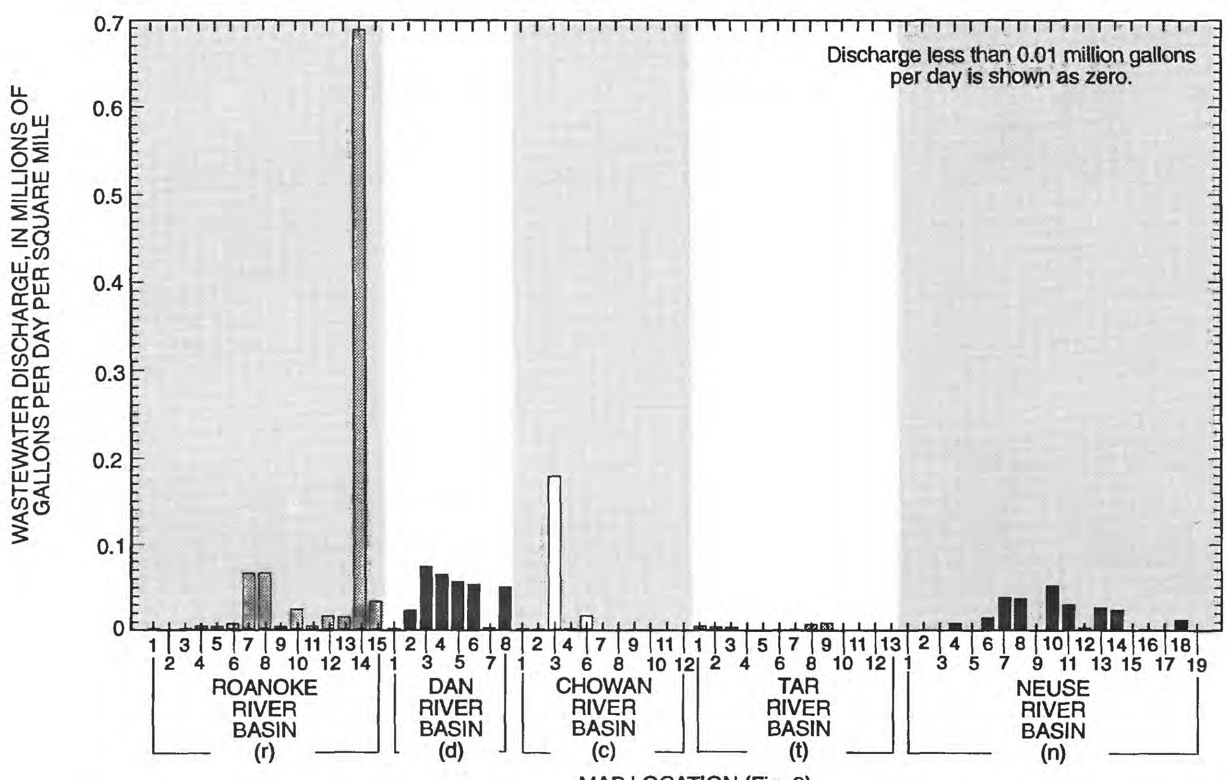


Figure 17. Wastewater discharge per square mile, by selected subbasin, in the Albemarle-Pamlico drainage study area, 1990.

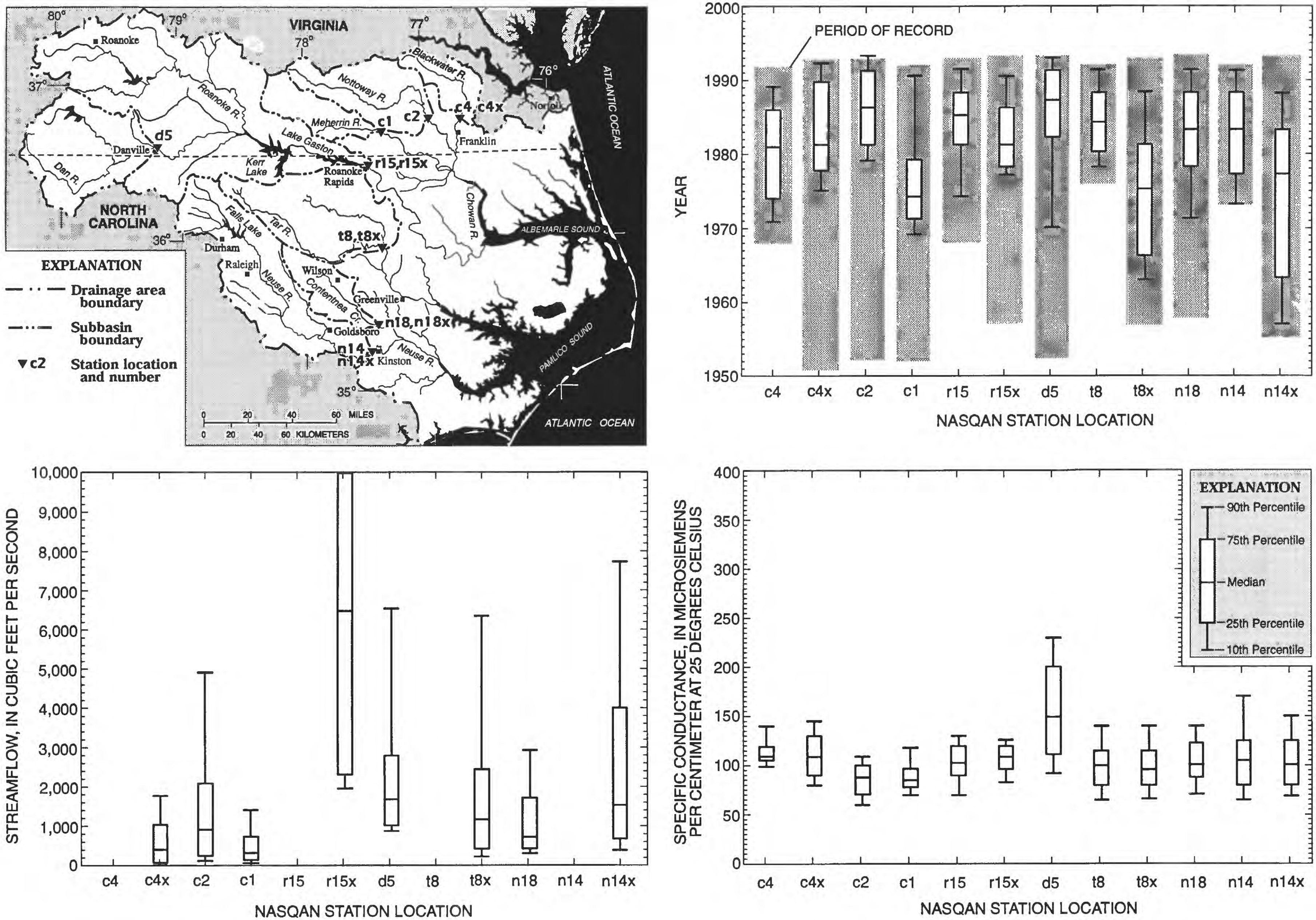


Figure 18. Locations of stations and subbasins for the National Stream Quality Accounting Network (NASQAN), and box plots of sample collection frequency within period of record, streamflow, and specific conductance. Locations without box plots have no data.

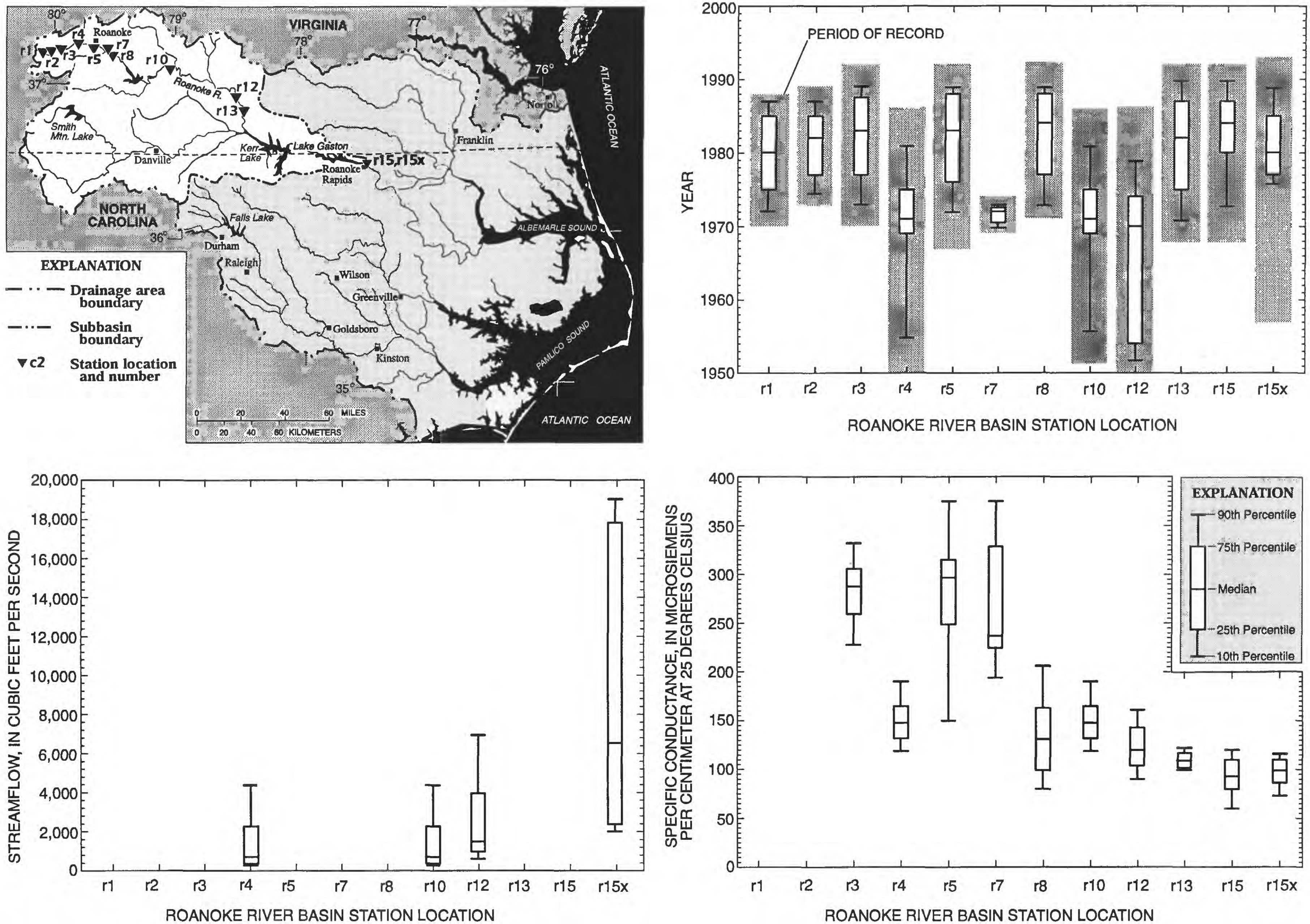


Figure 19. Locations of stations and subbasin for the Roanoke River, and box plots of sample collection frequency within period of record, streamflow, and specific conductance. Locations without box plots have no data.

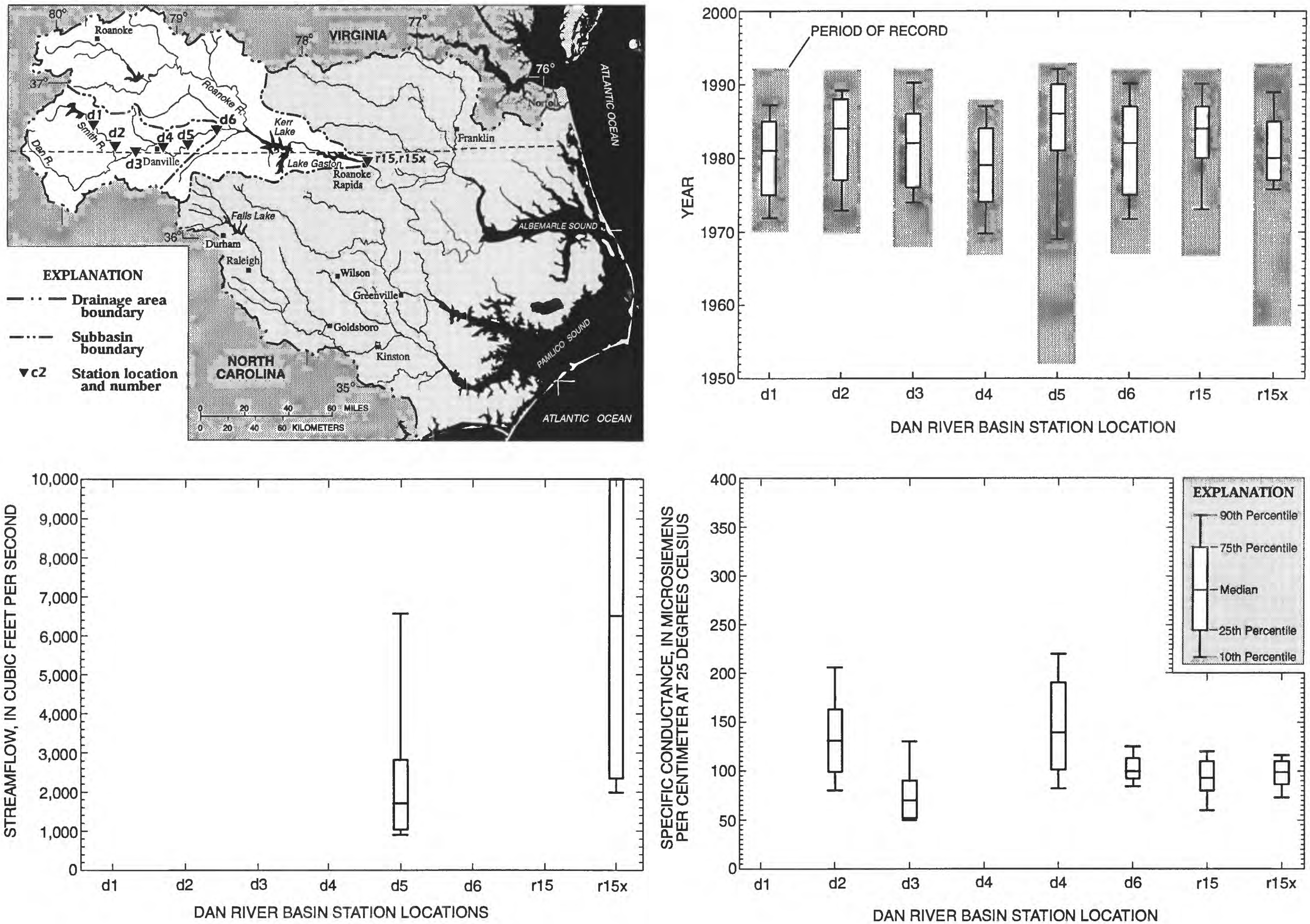


Figure 20. Locations of stations and subbasins for the Dan River, and box plots of sample collection frequency within period of record, streamflow, and specific conductance. Locations without box plots have no data.

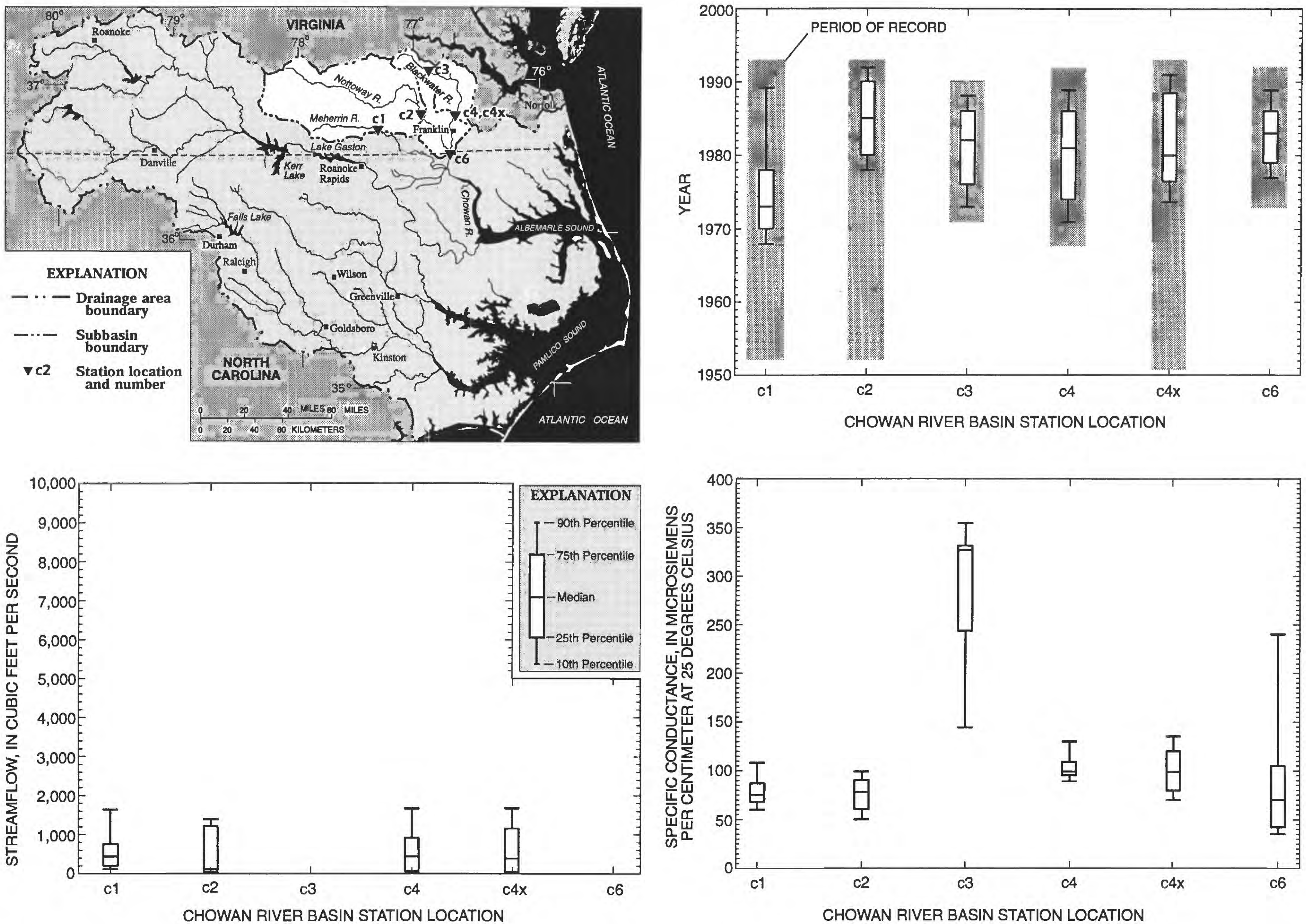


Figure 21. Locations of stations and subbasins for the Chowan River, and box plots of sample collection frequency within period of record, streamflow, and specific conductance. Locations without box plots have no data.

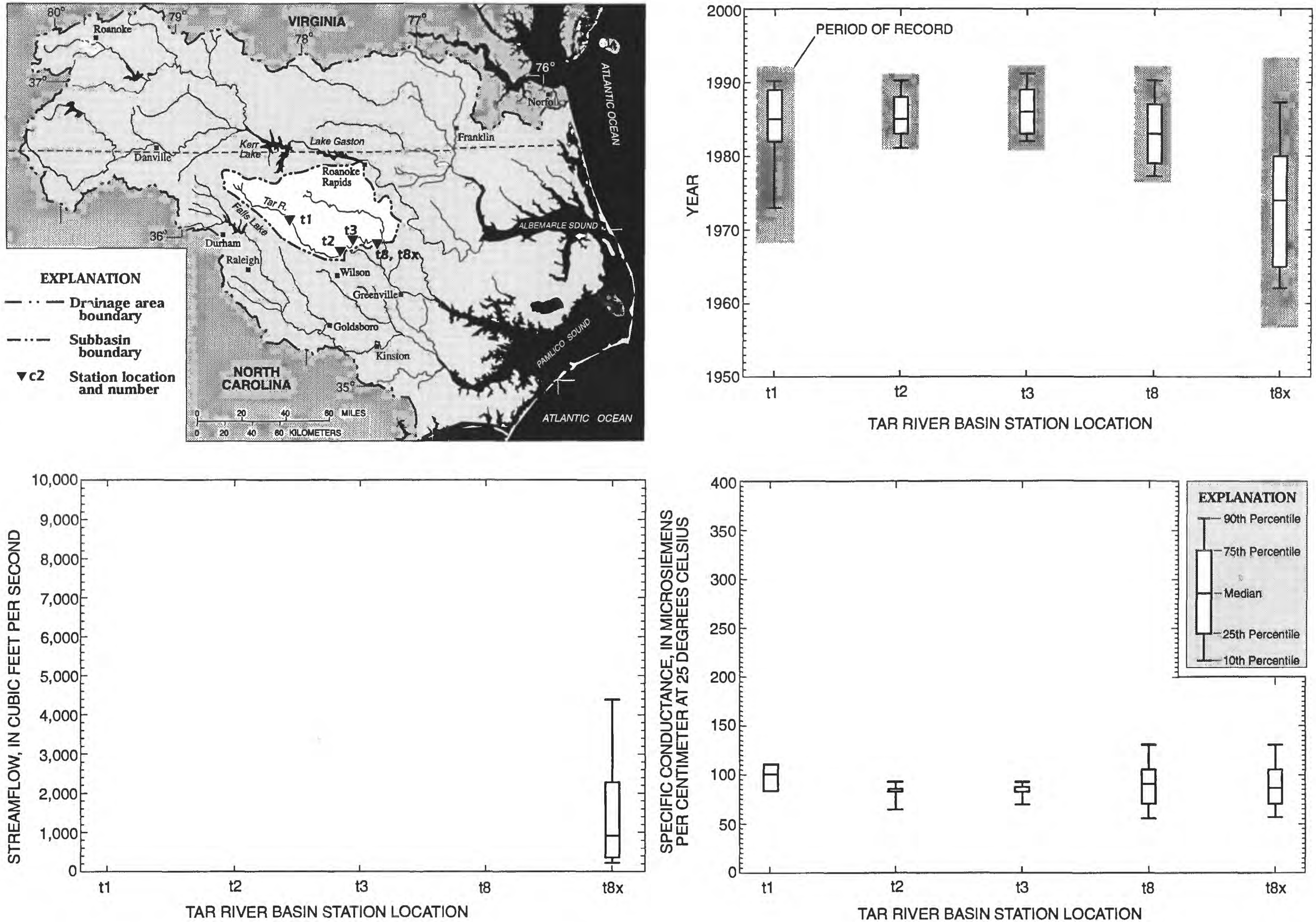


Figure 22. Locations of stations and subbasin for the Tar River, and box plots of sample collection frequency within period of record, streamflow, and specific conductance. Locations without box plots have no data.

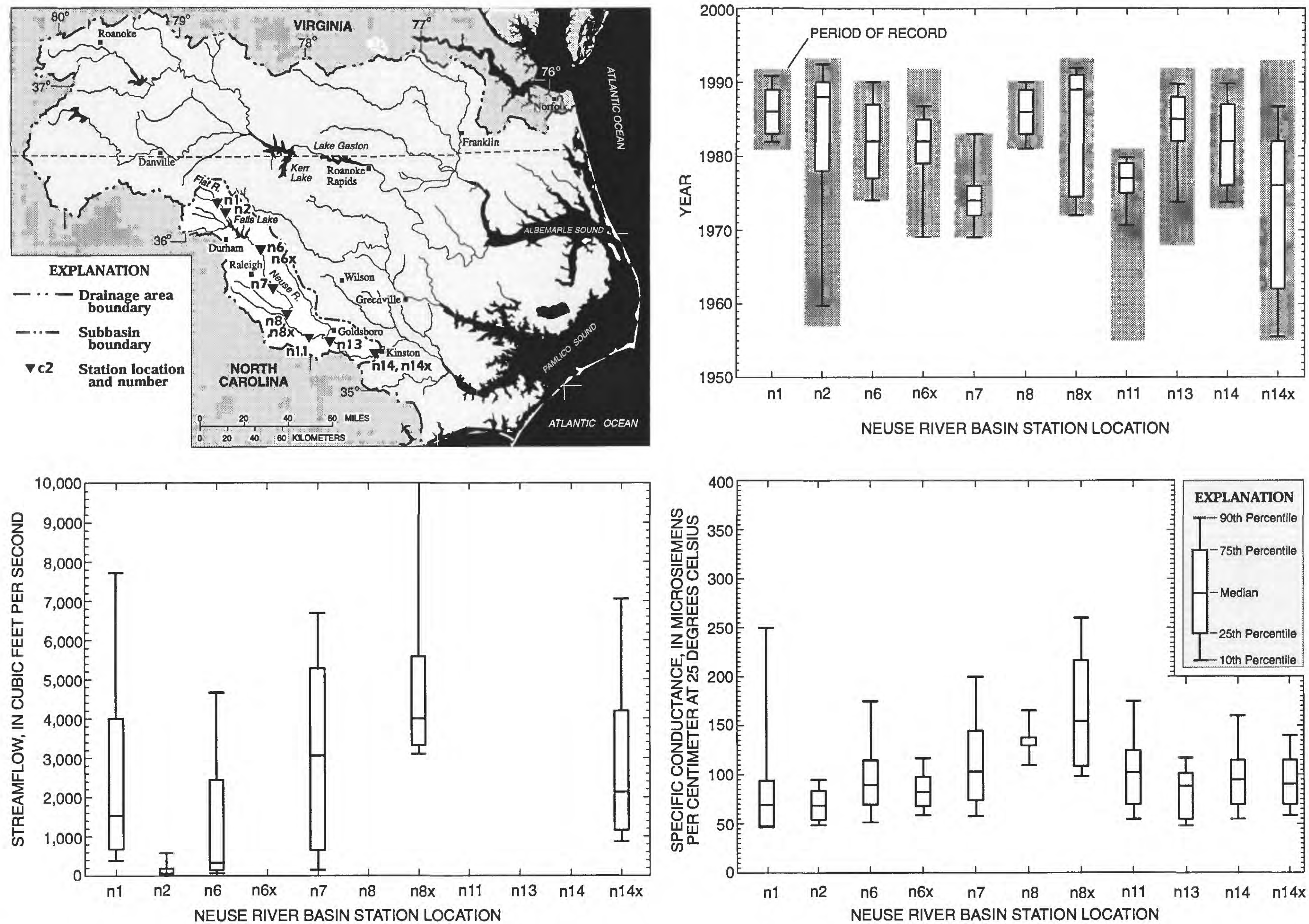


Figure 23. Locations of stations and subbasin for the Neuse River, and box plots of sample collection frequency within period of record, streamflow, and specific conductance. Locations without box plots have no data.

Discharge data are available for all the NASQAN stations. The larger drainage basins, including the Roanoke (r15, r15x), Neuse (n14, n14x), Dan (d5), and Tar Rivers (t8x), have the greatest and most variable streamflows, whereas the smaller basins, including the Meherrin (c1), Nottoway (c2), and Blackwater Rivers (c4x), and Contentnea Creek (n18), have smaller and less variable flow. The annual mean discharge for the period of record ranged from 7,841 ft^3/s at the Roanoke River site (r15x) to 136 ft^3/s at the Nottoway River site (c2).

Specific conductance, a measure of the ability of water to conduct electric current, is dependent upon the number and types of ions dissolved in the water and is useful as an indirect measure of the relative amounts of chemical ions in solution. The NASQAN sites have very similar specific conductance values, ranging generally between 50 and 150 microsiemens per centimeter at 25 degrees Celsius (µS/cm), except for the Dan River site, which frequently has values of 200 µS/cm or more. The higher specific conductance measured at the Dan River site could be due to wastewater inflows, which indicate greater discharge per square mile for the Dan River Basin than for the other NASQAN sites (fig. 17).

The Roanoke River sites (fig. 19) include the North Fork of the Roanoke River at Route 603, Va. (r1), the South Fork of the Roanoke River at Ellison, Va. (r2), the Roanoke River at Lafayette, Va. (r3), the Roanoke River at Roanoke, Va. (r4), the Roanoke River at the 14th Street Bridge at Roanoke, Va. (r5), the Roanoke River at Route 634 at Hardy, Va. (r7), Smith Mountain Lake at Hardy's Ford, Va. (r8), the Roanoke River at Altavista, Va. (r10), the Roanoke River at Randolph, Va. (r12), the Roanoke River at Route 360, Va. (r13), and the Roanoke River at Roanoke Rapids, N.C. (r15, r15x). The r4 and r5 sites are located in the city of Roanoke and are separated by only 3 river miles. The r7 and r8 sites are located on a bridge spanning the upper reach of Smith Mountain Lake. The period of record for the r5 site is more current than that for the r4 site, and the record for site r8 is more current than that for site r7, which only covers several years in the early 1970's. Sites r10 and r12 were discontinued about 1980. The Roanoke River at Roanoke Rapids station (r15, r15x) is located downstream from Kerr Lake and Lake Gaston.

Only four of the Roanoke River stations (r4, r10, r12, and r15x) have streamflow record (fig. 19). Streamflow at the Roanoke Rapids station is regulated by the upstream lakes. Annual mean discharge for the period of record ranged from 836 ft^3/s at the Roanoke River at Roanoke site (r4) to 7,841 ft^3/s at the Roanoke River at Roanoke Rapids site (r15x).

Specific conductance for the Roanoke River decreased downstream. The headwater streams of the Roanoke drain the Valley and Ridge Province, which is underlain by carbonate rocks resulting in higher dissolved constituent concentrations in area streams. Dissolved constituents from urban runoff and wastewater can elevate specific conductance as the river passes through the city of Roanoke. A significant reduction in specific conductance occurs in Smith Mountain Lake where suspended constituents settle out, leaving less opportunity for dissolution, and dissolved nutrients are used by algae. These processes also occur in Kerr Lake and Lake Gaston, as suggested by the continued decline in specific conductance below the lake at the Roanoke Rapids station (r15, r15x).

The Dan River is a major tributary to the Roanoke River, primarily in Virginia. The Dan River Basin sites (fig. 20) include Smith River at Route 609 (d1), Smith River at Route 622 (d2), Dan River near Mayfield (d3), Dan River at Robertson Bridge at Danville (d4), Dan River at Paces (d5), and Dan River at Route 501 Bridge (d6). Also included in figure 20 for comparison with the Dan River sites is the Roanoke River at the Roanoke Rapids site (r15, r15x). In general, the period of water-quality record for the Dan River stations (fig. 20) begins in the early 1970's and does not show a great degree of variation between stations.

The only Dan River station with discharge record is at Paces (d5). Median streamflow at Paces is approximately one third of that measured at the Roanoke River at Roanoke Rapids.

Specific conductance values for the Dan River stations show some spatial variation; however, the relation between station-to-station differences and upstream basin characteristics is not clear. Specific conductance values at sites d2 and d5 tend to be higher than at sites d3, d6, r15, and r15x.

The Chowan River Basin (fig. 21) stations include Meherrin River at Emporia (c1), Nottoway River near Sebrell (c2), and Blackwater River near Franklin (c4, c4x), all of which are major tributaries to the Chowan River; Spring Branch near Waverly (c3), which is a small, developed tributary to the Blackwater River; and Chowan River near Riddicksville (c6). The period of record for site c1 is the longest, beginning in

1968, and records for the other stations begin in the 1970's.

Streamflow records are available for sites c1, c2, c4, and c4x. The annual mean discharge for the period of record ranged from 631 ft^3/s at Blackwater River (c4, c4x) to 136 ft^3/s at Nottoway River (c2).

Specific conductance values for the three major Chowan River tributaries (c1, c2, c4, and c4x) are similar, commonly ranging from 50 to 175 µS/cm. However, the specific conductance at Spring Branch near Waverly (c3) is higher and more variable, probably because of upstream development and wastewater discharge. Specific conductance for the Chowan River site (c6) is considerably more variable than for its tributaries, perhaps reflecting the influence of point sources.

Tar River Basin sites (fig. 22) include Tar River at Louisburg (t1); Tar River below Tar River Reservoir (t2), a small reservoir that supplies water for Rocky Mount; Tar River at NC 97 at Rocky Mount (t3); and Tar River at Tarboro (t8, t8x). The period of water-quality record for the USGS station at Tar River at Tarboro (t8x) is more than 10 years longer than for the other stations, which generally have been monitored most intensely since around 1980.

Streamflow record is only available for the Tar River at Tarboro station (t8x). The mean annual flow at this site for the period of record is 2,220 ft^3/s.

The specific conductance distributions for the Tar River range from approximately 50 to 140 µS/cm and show little spatial variation. The distribution at the Tar River at Tarboro station shows greater variation than at the other sites, perhaps reflecting the influences of upstream development or a longer period of record.

Neuse River sites (fig. 23) include the Flat River near Quail Roost (n1) and at Bahama (n2), which are only 2 river miles apart. Further downstream are the following stations: Neuse River near Falls (n6, n6x), just downstream from Falls Lake; Neuse River near Clayton (n7); Neuse River at Smithfield (n8, n8x); Neuse River at Richardson Bridge (n11), 20 river miles upstream from Goldsboro; Neuse River near Goldsboro (n13); and Neuse River at Kinston (n14, n14x). The water-quality data records for the Flat River at Bahama (n2) and the Neuse River at Kinston (n14, n14x) are available starting from the late 1950's. Records for the remaining stations began in the 1970's or early 1980's. The record for the Neuse River near Clayton (n7) and the Neuse River at Richardson Bridge (n11) ended about 1980.

Streamflow record is available for Neuse River stations n1, n2, n6, n7, n8x, and n14x. The larger range of discharges for site n7 relative to downstream site n8x is probably a result of an abbreviated period of record for site n7, which included some years with unusually high flow. The annual mean discharge for the period of record ranged from 142 ft^3/s at the Flat River at Bahama site (n2) to 4,216 ft^3/s at the Neuse River at Kinston site (n14).

Specific conductance values for Neuse River sites generally increase from a median value of 70 µS/cm at the Flat River near Quail Roost site (n1) downstream until the Neuse River at Smithfield site (n8, n8x) (median 155 µS/cm), and then decrease downstream. This spatial variation probably reflects the influences of runoff from developed areas and wastewater discharges from sources upstream from Smithfield, including municipal discharge from the Raleigh area. The dissolved-ion concentration is diluted by relatively unaffected water downstream from the developed areas.

CHARACTERIZATION OF BASIN WATER QUALITY

Water quality for the Albemarle-Pamlico drainage area varies spatially as a function of land use, geology, soil types, contaminant inputs, and instream conditions. Available data can be used to support a generalized comparison of water quality based on some of these factors. A graphic presentation of the water quality in the main channels of major streams in the basin provides an overview of patterns of spatial variation in water quality and a basis for comparisons to be made between basins.

Surface Water

In the following section, a generalized description of basinwide water quality is presented for the NASQAN stations and for the Roanoke, Dan, Chowan, Tar, and Neuse River Basins. A comparison of sites grouped by land use and geology illustrates the effect that basin character has on water quality. Box plots of constituent concentration frequency distributions, arranged side-by-side, allow comparisons of sediment and nutrient concentrations in different basins. Analyses of dissolved- and total-solids concentrations are shown to supplement the sediment analysis, because available suspended-sediment data are limited and solids data can be used to suggest probable patterns in suspended-sediment concentrations. Analysis of nutrient data was limited to nitrogen and phosphorus constituents.

A series of map overlays of basin characteristics, including land use, geology, and soil type, was used to subdivide the Albemarle-Pamlico drainage area into 12 major groupings by basin characteristics, termed "strata" (McMahon and Lloyd, 1995). The study subbasins were then subdivided by strata, and the subbasins with the highest percentages of each strata were identified. Only 8 of the 12 strata derived by McMahon and Lloyd (1995) are adequately represented by available water-quality data. The strata Agriculture/Slate Belt and Forest/Slate Belt shared too many subbasins with the stratum Forest/Slate Belt to support any meaningful distinction between the two strata; therefore, they were grouped together into a combined Agriculture and Forest/Slate Belt stratum (table 4). Smaller drainage sizes generally were used in the strata analysis (table 4) because they are more likely to have a larger percentage of land area in a single stratum than are larger basins.

Table 4. Sites used in the basin strata comparison, Albemarle-Pamlico drainage study area

[SR, secondary road]

Map location (fig. 2)	Station name		Percentage of area in basin strata
	Agriculture/Coastal Plain/Poorly Drained		
t9	Conetoe Creek near Bethel, N.C.		0.25
t10	Juniper Branch at SR 1766 near Simpson, N.C.		.27
t13	Chicod Creek at SR 1760 near Simpson, N.C.		.27
c10	Cutawhiskie Creek tributary near Menola, N.C.		38
t11	Cow Swamp near Grimesland, N.C.		55
	Agriculture/Coastal Plain/Well Drained		
c12	Cypress Creek at SR 1324 near Seaboard, N.C.		20
n18	Contentnea Creek at Hookerton, N.C.		21
c11	Panther's Branch at SR 1164 near Murfreesboro, N.C.		35
n17	Nahunta Swamp near Shine, N.C.		45
c8	Bells Branch at SR 1167 near Mapleton, N.C.		68
	Agriculture/Granitic/Well Drained		
r9	Pigg River near Sandy Level, Va.		26
r11	Big Otter Creek at Route 712, Va.		29
t5	Swift Creek near Hilliardston, N.C.		29
d7	Bannister River at Terry's Bridge, Va.		31
t4	Devil's Cradle Creek near Alert, N.C.		51
		Agriculture/Slate	**Forest/Slate**
t1	Tar River at Louisburg, N.C.	19	14
d8	Hyco River at Route 58, Va.	20	27
n3	Little River at SR 1461 near Orange Factory, N.C.	35	44
n2	Flat River at Bahama, N.C.	35	30
n1	Flat River near Quail Roost, N.C.	36	30
n9	Swift Creek at Holly Springs Road, N.C.	0	25
n16	Contentnea Creek near Lucama, N.C.	6	27
	Forest/Granitic		
d4	Dan River at Robertson Bridge at Danville, Va.		51
r9	Pigg River near Sandy Level, Va.		53
d3	Dan River near Mayfield, Va.		53
d2	Smith River at Route 622, Va.		64
d1	Smith River at Route 609, Va.		70
	Forest/Coastal Plain		
t12	Chicod Creek at SR 1565 near Grimesland, N.C.		39
n19	Creeping Swamp near Vanceboro, N.C.		44
n15	Trent River near Trenton, N.C.		49
c7	Chowan River tributary near Riddicksville, N.C.		98
c4	Blackwater River near Franklin, Va.		38
	Developed		
n4	Eno River near Durham, N.C.		6
r7	Roanoke River at Route 634 at Hardy, Va.		6
r6	Tinker Creek at Glebe Mills, Va.		9
r14	Nutbush Creek near Henderson, N.C.		16
n5	Ellerbe Creek at SR 1709 at Durham, N.C.		53

Strata comparisons were made on the basis of the nonparametric Kruskall-Wallis analysis of variance test to establish whether a difference exists among the data distributions (Helsel and Hirsh, 1992). When there was a significant difference, a Tukey multiple-comparison test (alpha = 0.05) was used to group strata together that are not significantly different from each other. The results of the Tukey test are shown along with box plots of water-quality constituents. A letter is assigned to each box; boxes with the same letter are not significantly different.

The subbasins used in the strata analysis include 36 sites (fig. 24; table 4). The periods of record for the strata (fig. 25) show, in general, that most of the

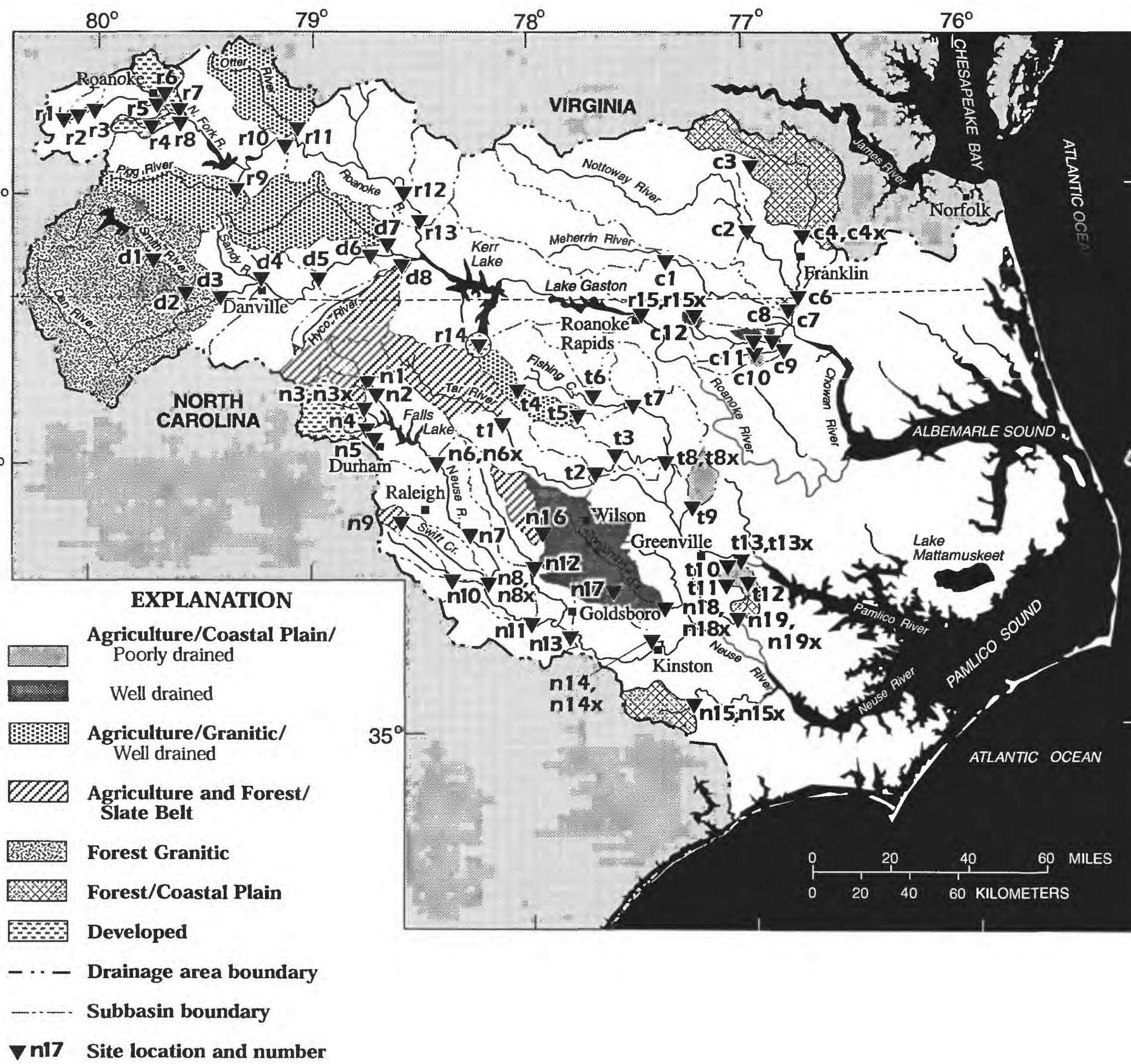


Figure 24. Locations of sites and subbasins for the basin strata in the Albemarle-Pamlico drainage study area.

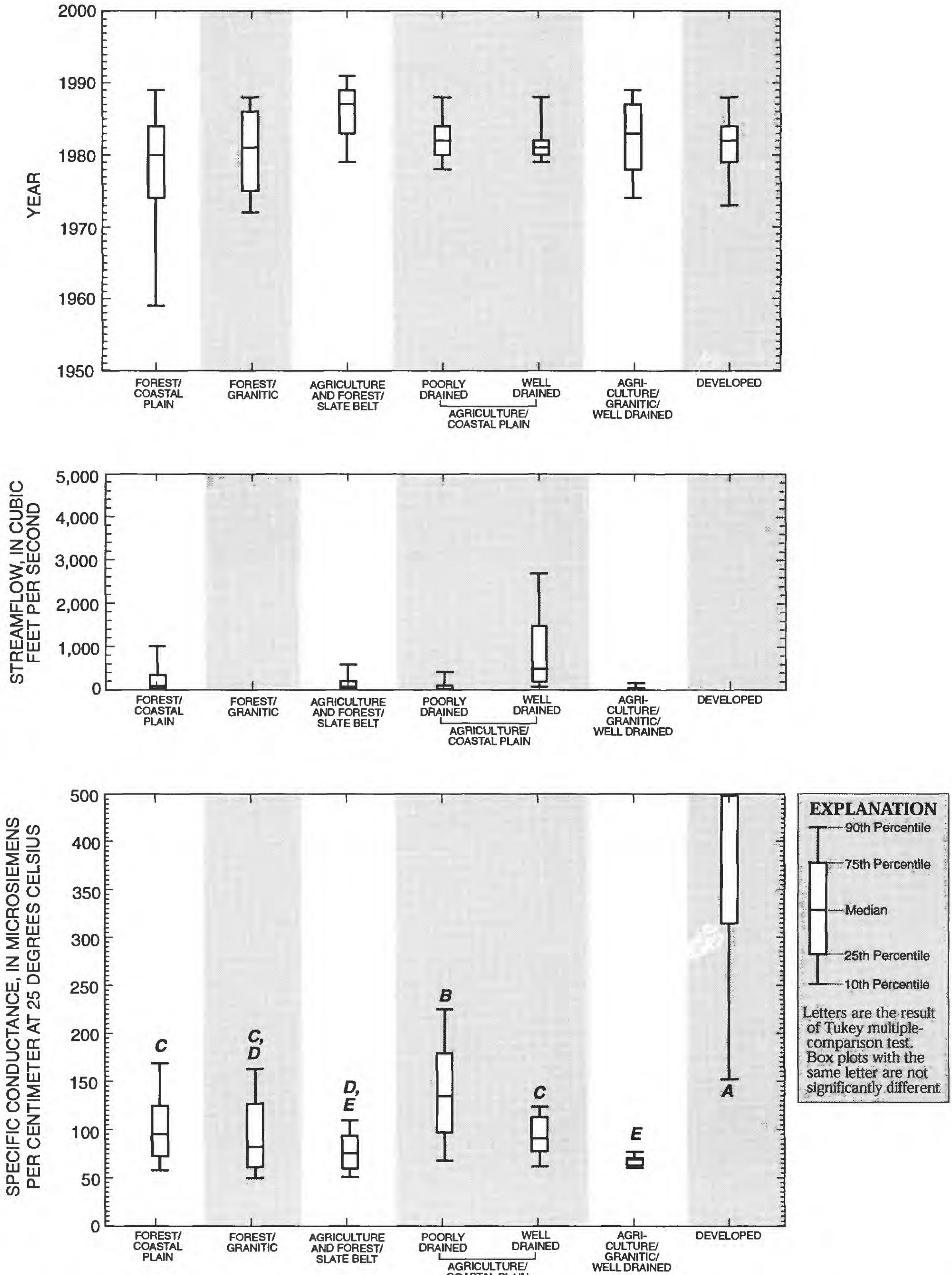


Figure 25. Periods of record, streamflow, and specific conductance for the different basin strata for subbasins in the Albemarle-Pamlico drainage study area.

samples were collected in the early 1980's. Collection of some samples for the Forest/Coastal Plain stratum began in the late 1950's.

Streamflow at the strata analysis sites (fig. 25) is generally below 1,000 ft^3/s for all but the Agriculture/Coastal Plain/Well Drained stratum. The relatively low streamflows are due to the small size of the strata basins compared to the other subbasins.

The specific conductance distribution for the Developed stratum subbasins was significantly different from the other strata (fig. 25). The Agriculture/Coastal Plain/Poorly Drained stratum showed a higher median than all but the Developed stratum. The two Forest strata and the Agriculture/Coastal Plain/Well Drained stratum were grouped together. The Forest/Granitic and Agriculture and Forest/Slate Belt were grouped together as were the Agriculture and Forest/Slate Belt and the Agriculture/Granitic/Well Drained strata. Overall, these differences among groups suggest that the greatest effect of basin factors on specific conductance occurs in developed areas and in the Coastal Plain in poorly drained agricultural areas. The differences in specific conductance distributions for the other forest and agriculture strata are generally not as significant.

Suspended-Sediment and Solids Concentrations

Sediment is the solid material transported in streamflow, either in suspension or along the stream bottom. It consists primarily of fragmented material that originates from weathering of rocks and includes soil debris. Many nutrients, trace metals, and pesticides are readily sorbed and transported by sediment particles.

A limited amount of sediment data, generally for the suspended component of fluvial sediment, is available for the study area. To supplement these data, several means of measuring solids, including dissolved solids, total fixed solids, and total volatile solids, also were examined. Considerably more data were available for measuring solids than for suspended sediment. In general, the material left as residue upon evaporation of an unfiltered water sample at 103 to 105 degrees Celsius (°C) is referred to as solids. The material left upon evaporation consists primarily of suspended sediment and dissolved inorganic salts. Dissolved solids, which is primarily inorganic salts, is the residue remaining upon evaporation of a filtered water sample and is a general indication, like specific conductance, of dissolved inorganic material. Total fixed solids is a measure of the inorganic material, including dissolved matter and suspended sediment. Total volatile solids is a measure of the organic material present in a water sample. Organic material is an important component of sediment.

Sediment concentrations in 25 North Carolina streams in forested basins ranged from 0 to 383 mg/L (Simmons and Heath, 1982; Simmons, 1993). These studies were specifically designed to characterize water quality for undeveloped or natural conditions.

Distributions of suspended-sediment, dissolved-solids, total fixed-solids, and total volatile-solids concentrations for the NASQAN stations (fig. 26) and for selected sites along the Roanoke, Dan, Chowan, Tar, and Neuse Rivers are shown in figures 27-31. The locations of the sites shown in these illustrations are given in figures 2 and 18-23.

Suspended-sediment data are available for all of the NASQAN stations (fig. 26). In general, most suspended-sediment concentrations for these stations are less than 50 mg/L except for Dan River at Paces (d5). The Dan River Basin is in an area of the Piedmont that has generally steeper slopes and more erodible soils than the Coastal Plain or the area of the Piedmont upstream from the other NASQAN stations.

Of the NASQAN stations, median dissolved-solids concentrations are greatest at the Blackwater (c4x) and Dan River (d5) sites. For the four sites having data, the fixed-solids concentrations are slightly greater than the volatile-solids concentrations, indicating a greater percentage of inorganic than organic material in the sediment.

In the Roanoke River Basin (fig. 27), suspended-sediment data were available only at the Roanoke River at Randolph (r12) and the Roanoke River at Roanoke Rapids (r15x) sites. Suspended-sediment concentrations are much greater at the Randolph site than at Roanoke Rapids. Kerr Lake and Lake Gaston lie between these two sites and serve as effective traps for sediment from the upper Roanoke River and Dan River Basins.

Solids concentrations decline downstream in the Roanoke River. The greatest median total fixed- and volatile-solids concentrations occurred at the North Fork of the Roanoke River (r1). The high values and variation in the upstream station reflect high suspended-sediment yields from Valley and Ridge, Blue Ridge, and Piedmont areas. Some influence of wastewater input is suggested by the greater dissolved-

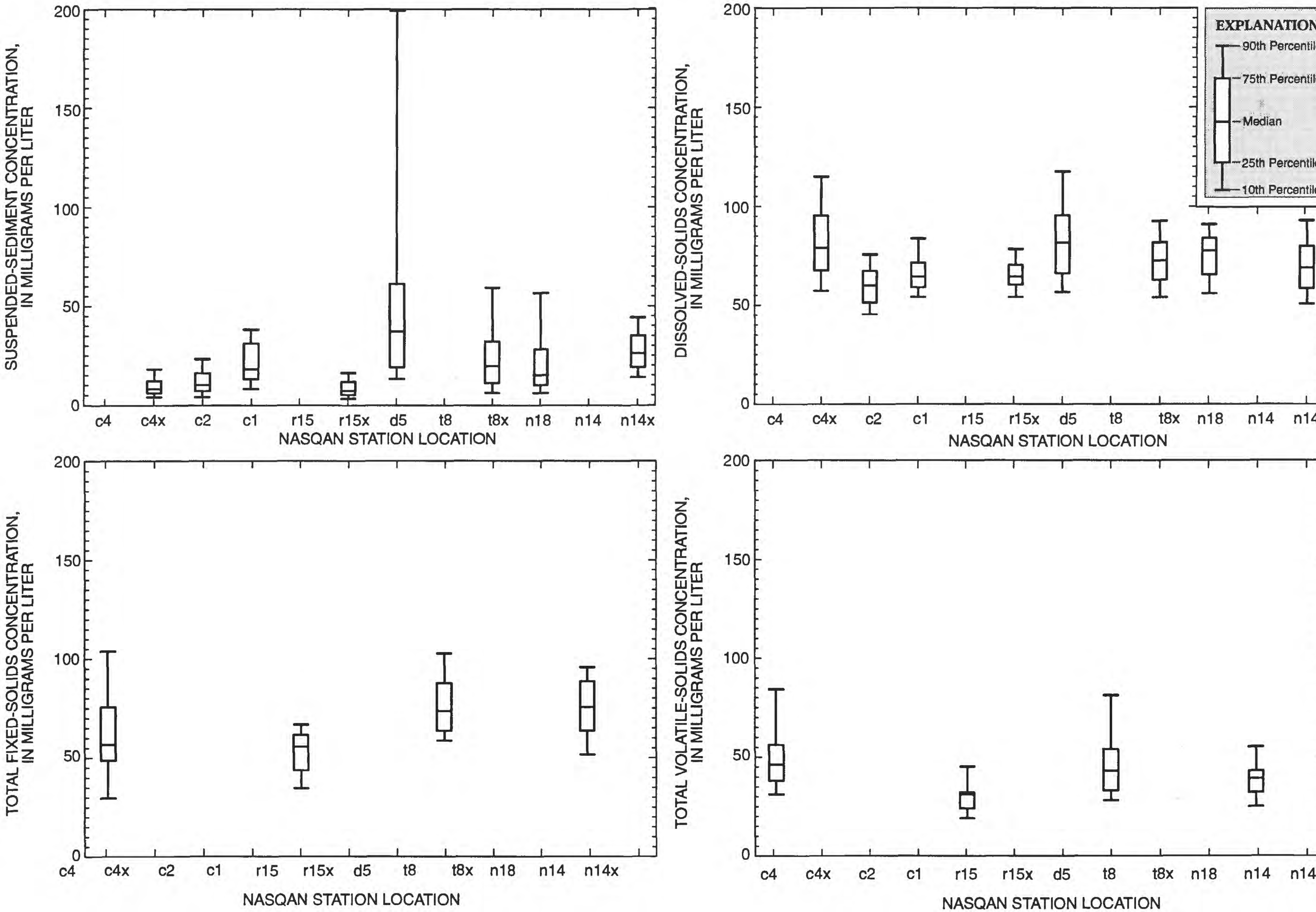


Figure 26. Suspended-sediment, dissolved-solids, total fixed-solids, and total volatile-solids concentrations for sites in the National Stream Quality Accounting Network (NASQAN). Locations without box plots have no data. (Site locations shown in figure 18.)

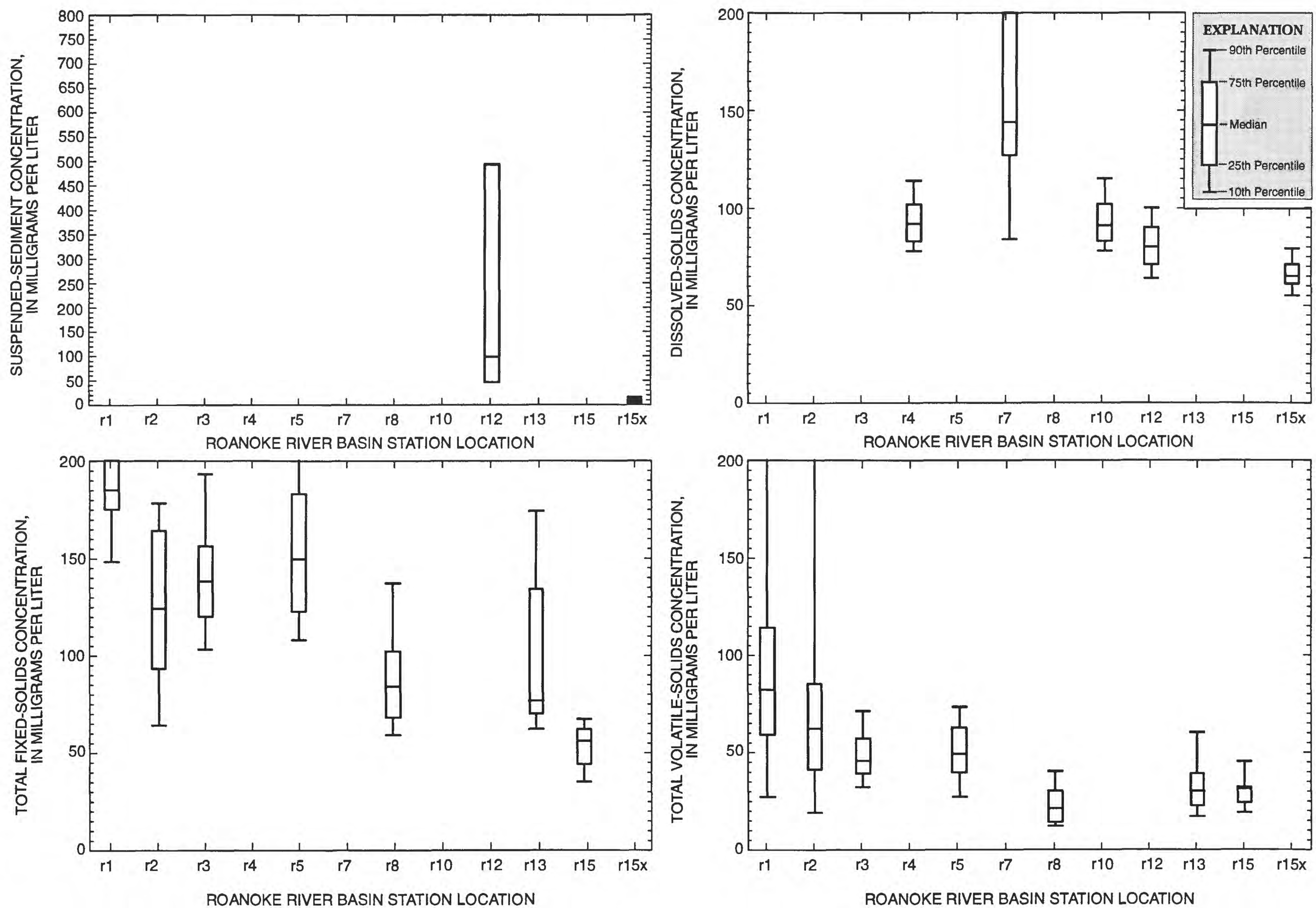


Figure 27. Suspended-sediment, dissolved-solids, total fixed-solids, and total volatile-solids concentrations for sites in the Roanoke River Basin. Locations without box plots have no data. (Site locations shown in figure 19.)

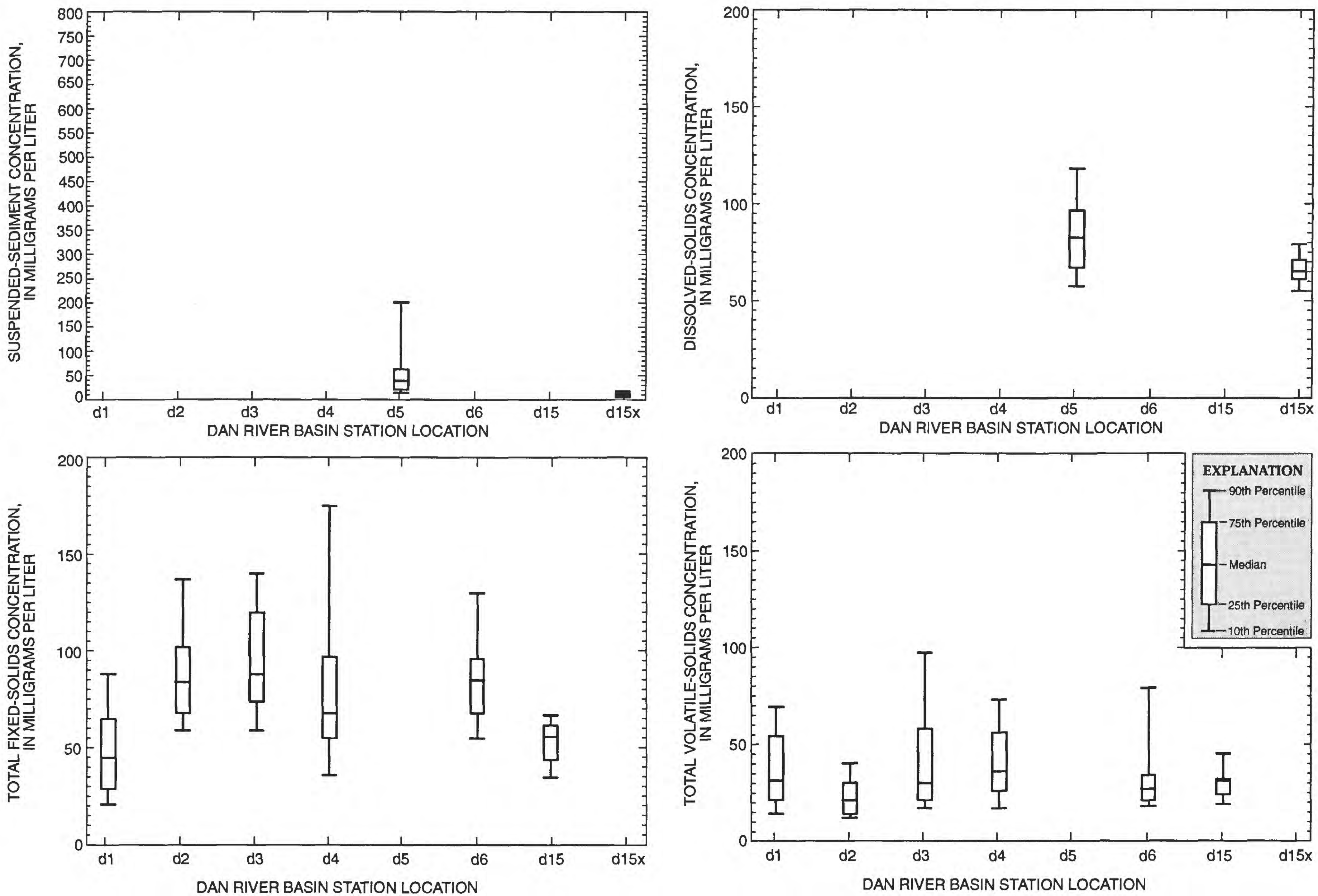


Figure 28. Suspended-sediment, dissolved-solids, total fixed-solids, and total volatile-solids concentrations for sites in the Dan River Basin. Locations without box plots have no data. (Site locations shown in figure 20.)

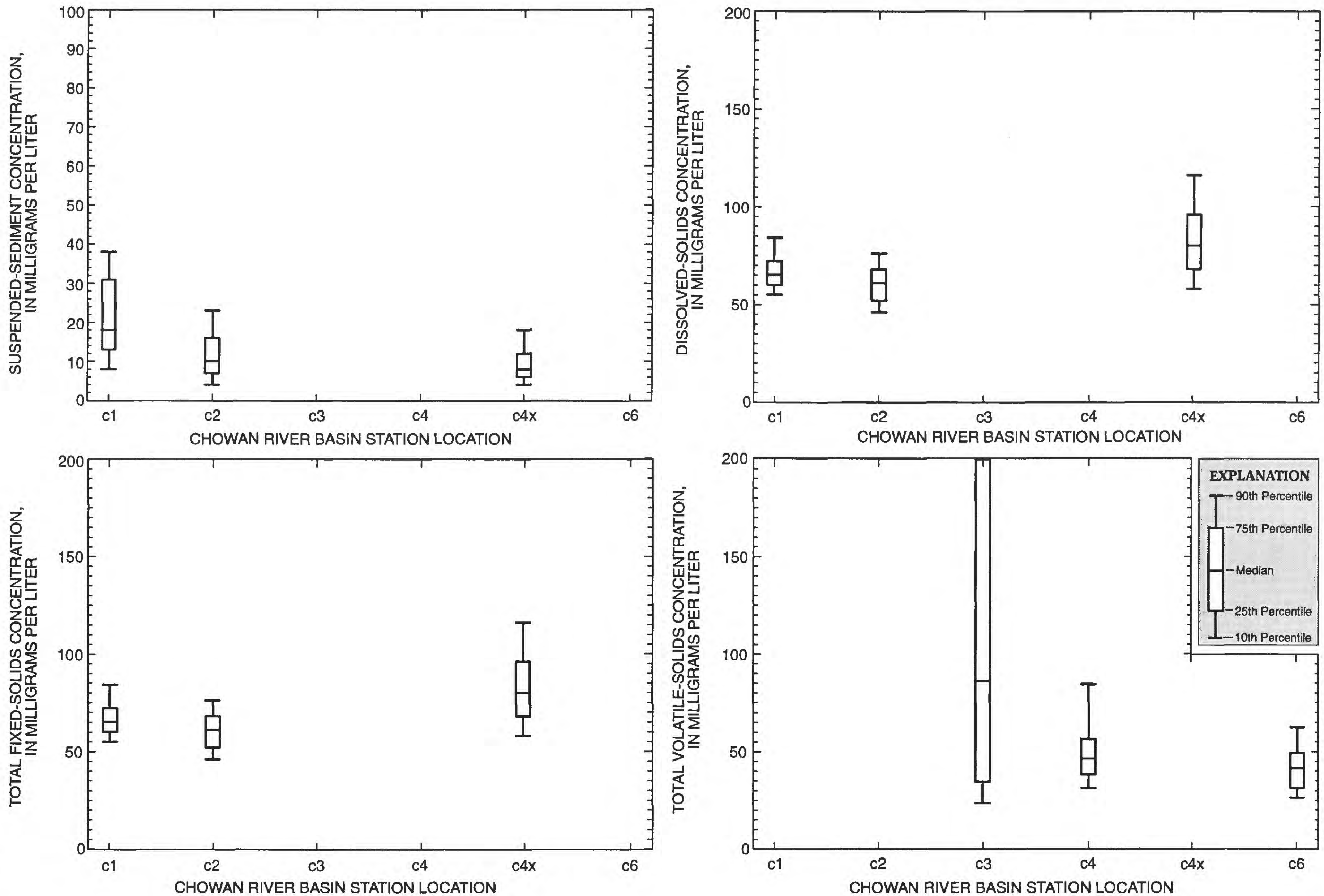


Figure 29. Suspended-sediment, dissolved-solids, total fixed-solids, and total volatile-solids concentrations for sites in the Chowan River Basin. Locations without box plots have no data. (Site locations shown in figure 21.)

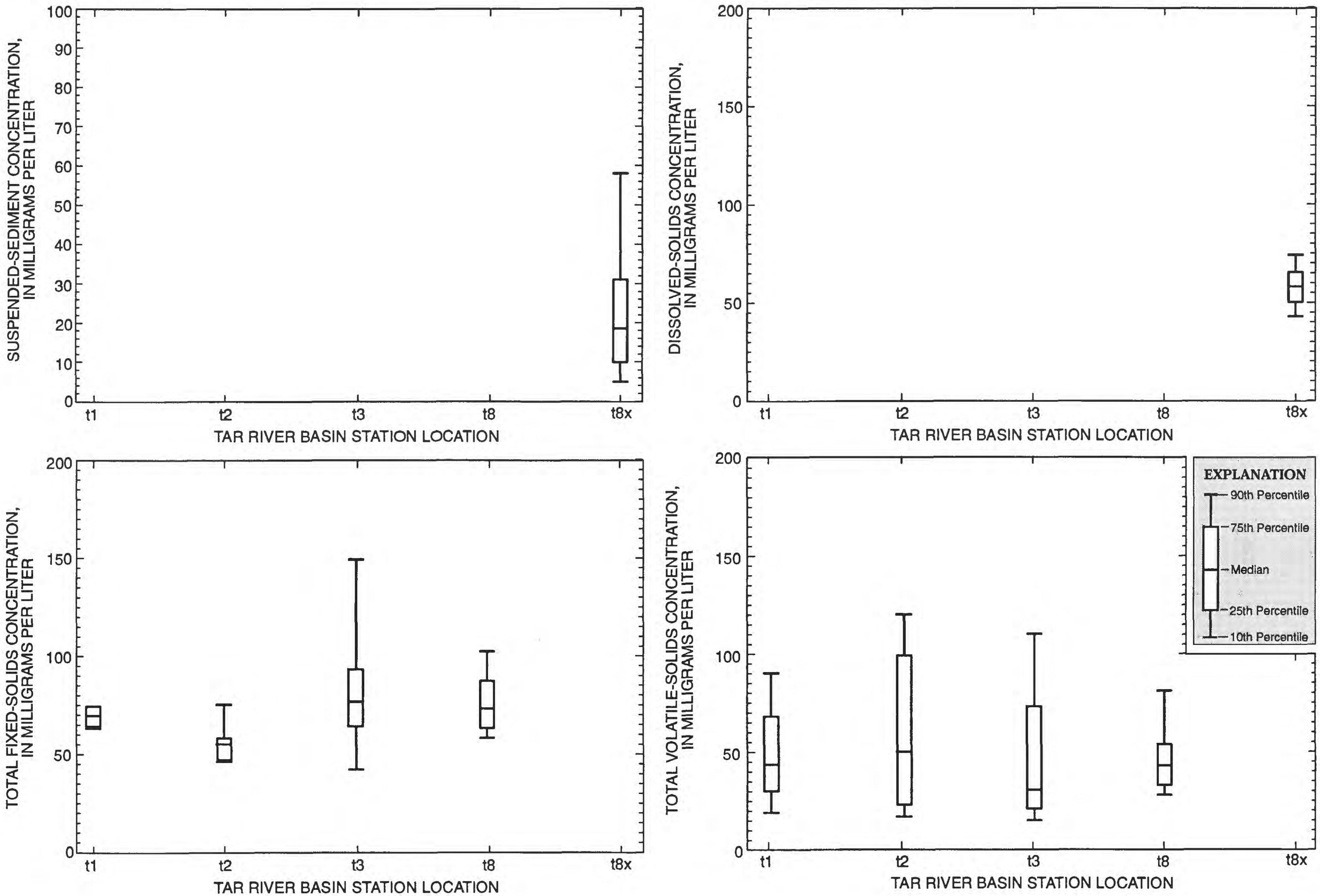


Figure 30. Suspended-sediment, dissolved-solids, total fixed-solids, and total volatile-solids concentrations for sites in the Tar River Basin. Locations without box plots have no data. (Site locations shown in figure 22.)

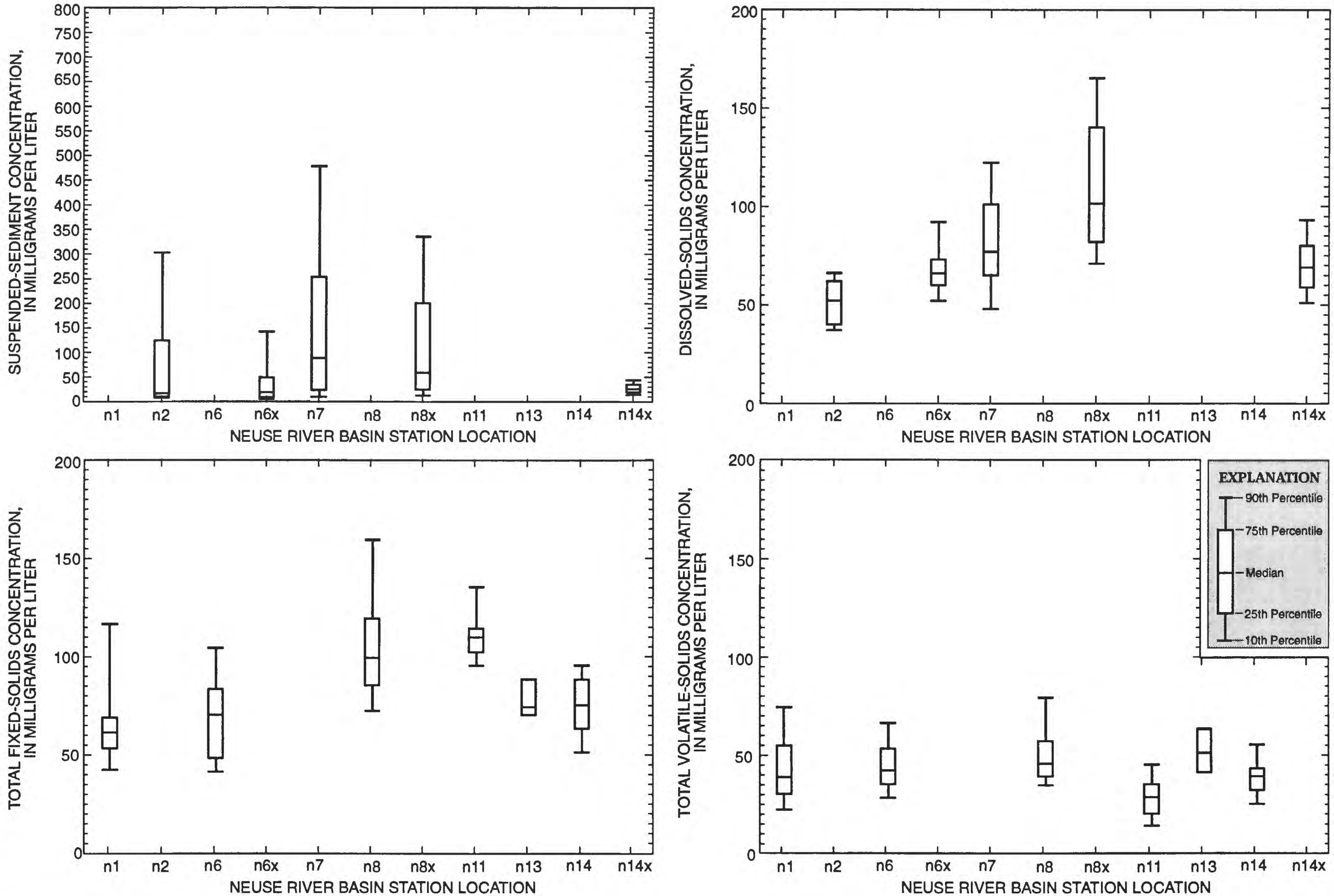


Figure 31. Suspended-sediment, dissolved-solids, total fixed-solids, and total-volatile solids concentrations for sites in the Neuse River Basin. Locations without box plots have no data. (Site locations shown in figure 23.)

solids concentrations at site r7. The lowest values for dissolved solids were observed at site r15x, and fixed solids were observed at site r15 downstream from Lake Gaston; whereas the volatile organic fraction of solids was lowest at site r8, at the upstream end of Smith Mountain Lake, and at site r15.

In the Dan River Basin (fig. 28), suspended-sediment data were available for the Dan River at Paces site (d5). The suspended-sediment concentrations at this site are generally greater than those observed at the downstream Roanoke River at Roanoke Rapids site (r15x). This reduction mirrors the decrease observed for the Roanoke River. The relatively high suspended-sediment concentrations of the Piedmont segment of the stream are reduced significantly downstream as sediment settles out in Kerr and Gaston Lakes.

Solids concentrations for the Dan River indicate a less distinct downstream decrease than those observed for the Roanoke River. Again, a comparison between sites d5 and r15x shows a decrease in dissolved solids by the lake system. This decrease is also evident in the inorganic fixed fraction of the solids. However, the Smith River site (d1) has considerably lower values than all of the other downstream sites except r15. This is likely due to the effect of Philpott Reservoir, which is 8 river miles upstream from site d1. Although there is considerable variation in fixed-solids concentrations, particularly at site d4, sites d2, d3, d4, and d6 show similar concentrations—about 50 mg/L higher than the lake-affected sites d1 and r15. Volatile-solids concentrations do not indicate a spatial pattern.

In the Chowan River Basin (fig. 29), suspended-sediment data were available for stations on the Meherrin (c1), Nottoway (c2), and Blackwater (c4x) Rivers. These three sites are NASQAN stations (fig. 18), which are on the three major tributaries to the Chowan River (c6). However, no suspended-sediment data for the Chowan River station are available. The suspended-sediment concentrations for these three tributaries are low (median concentrations less than 20 mg/L) compared with the other NASQAN stations (fig. 26), and very low compared with suspended-sediment concentrations for the Dan (d5) and upper Roanoke Rivers. This is due to the low slopes of the basins for the three Chowan tributaries, which lie in the eastern Piedmont and Coastal Plain. The steeper slopes of the western Piedmont are more conducive to greater erosion and sediment transport than the gentler slopes of the Chowan tributary basins.

Fixed- and volatile-solids concentrations generally do not differ between the Blackwater River site (c4) and the Chowan River site (c6). However, concentrations of fixed and volatile solids at Spring Branch (c3) are considerably greater than those observed for the Chowan River. Spring Branch, a small (3.7 mi^2) tributary to the Blackwater River, drains a developed area that has a wastewater-treatment plant. The effects of development and wastewater discharge on water quality in Spring Branch are evident in the distributions of fixed- and volatile-solids concentrations. The concentration of dissolved solids in the Blackwater River is greater than concentrations in the Meherrin and Nottoway Rivers, possibly because of wastewater discharge into the Blackwater River from upstream in Spring Branch.

In the Tar River Basin (fig. 30), suspended-sediment data were available only for the NASQAN station on the Tar River at Tarboro (t8x). The distribution of suspended-sediment concentrations at this site is characteristic of a stream draining parts of the eastern Piedmont and Coastal Plain. Suspended-sediment concentrations for the Tar River at Tarboro are similar to, but greater and more variable than, those measured for the Chowan River tributaries (fig. 29).

Concentrations of solids indicate that the sediment variability at Tarboro is a result of relatively localized influences. Although fixed-solids concentrations for the Tar River at Louisburg (t1) and downstream from Tar Reservoir (t2) are low, considerable variation and greater concentrations are evident at the station at Rocky Mount (t3). This variation could be partly a result of development around Rocky Mount. Volatile-solids concentrations vary considerably at sites t2 and t3, indicating input of organic material in the downstream segment from Rocky Mount. Dissolved-solids data were available only for the Tar River at Tarboro (t8x). Dissolved-solids concentrations at Tarboro are similar to those observed for the other NASQAN sites (fig. 26).

In the Neuse River Basin (fig. 31), suspended-sediment data were available for the Flat River at Bahama (n2), Neuse River near Falls (n6x), Neuse River near Clayton (n7), Neuse River at Smithfield (n8x), and Neuse River at Kinston (n14x). Suspended-sediment concentrations for sites n2, n7, and n8x are among the highest in the study area. Sediment concentrations at the station just downstream from Falls Lake (n6x) are considerably less than those measured upstream from the lake on the Flat River (n2), indicating that Falls Lake functions as a trap for sediment eroded from the Upper Neuse River Basin. Sediment concentrations increase downstream from

Falls Lake at the Neuse River near Clayton and near Smithfield. Because sediment-data record for the Neuse River near Clayton was discontinued in 1978, the distribution shown in figure 31 does not show the effect of Falls Lake, which was filled in 1983. Suspended-sediment concentrations decrease downstream at the Neuse River at Kinston site (n14x), probably as a result of the settling of suspended sediment on the stream bottom where the stream slope flattens in the Coastal Plain.

A similar spatial pattern to that observed for specific conductance is evident for dissolved-solids and fixed-solids concentrations in the Neuse River. Dissolved- and fixed-solids concentrations for the Neuse River generally increase downstream from the Falls site (n6) to Smithfield (n8 and n8x), and then decrease downstream from Smithfield. This spatial variation probably reflects the influences of wastewater discharges, including discharges from the Raleigh area. The downstream increases result primarily from inorganic material, as indicated by the lack of change in volatile-solids concentrations downstream.

Grouping the subbasins by strata (fig. 32) illustrates relations between basin characteristics and water quality. The Agriculture/Granitic/Well Drained stratum had the greatest suspended-sediment concentrations. Agricultural activities, particularly traditional, highly erosive corn and tobacco farming, combined with the steep slopes of the Piedmont, promote high sediment yields. The pattern of strata grouping for dissolved-solids concentrations is similar to the pattern observed for specific conductance (fig. 25). Concentrations of dissolved solids were significantly greater for the Developed stratum than for all other strata except the Agricultural/Coastal Plain/Poorly Drained. The Developed stratum also had the greatest median concentration value for fixed solids, but this value was not significantly greater than that of any other stratum except the Agriculture/Coastal Plain/Well Drained. The pattern for fixed-solids concentrations is more similar to that of suspended sediment than to the specific conductance pattern. No significant differences were detected among the distributions of volatile-solids concentrations for the identified strata.

Nutrients

Nutrients are chemical elements required by plants for growth. Eutrophication, the enrichment of a body of water with nutrients, is normally associated with increases in algal populations. The accumulation of organic matter caused by growth and decomposition of algae in turn provides habitats and ample food supplies for bacteria and other aquatic organisms. These effects are usually most pronounced in lakes and estuaries where accumulation of nutrients can result in particularly large concentrations of algae.

This section provides a generalized description of nitrogen and phosphorus concentrations for the NASQAN stations, and for selected sites along the Roanoke, Dan, Chowan, Tar, and Neuse Rivers. A comparison of stations grouped by strata is provided to illustrate relations of water quality and basin characteristics.

Nitrogen

Nitrogen is critical in the growth of algae in the Albemarle-Pamlico drainage system. According to Stanley (1988), nitrogen is the limiting nutrient in the Pamlico River, and Paerl (1987) reported nitrogen as a limiting nutrient in the Neuse River. Total nitrogen concentrations greater than 0.3 mg/L indicate potential for nuisance algal growth (Sawyer, 1947; Sakamoto, 1966; Vollenweider, 1971).

The oxidation of reduced forms of nitrogen (ammonia plus organic nitrogen) in surface waters is readily accomplished by aerobic aquatic biota that produce nitrite and nitrate nitrogen. Because these processes oxidize reduced nitrogen, concentrations of reduced nitrogen are transient in surface water. Weiss and others (1973) considered concentrations of total ammonia nitrogen greater than 0.5 mg/L in lakes indicative of animal or human contamination.

Distributions of total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate, and total ammonia nitrogen concentrations for the NASQAN stations (fig. 33) and for selected sites along the Roanoke, Dan, Chowan, Tar, and Neuse Rivers are shown in figures 34-38. The locations of the sites shown in these illustrations are given in figures 2 and 18-23.

Total nitrogen concentrations at all NASQAN stations (fig. 33) are generally greater than the 0.3 mg/L concentration indicative of potential for nuisance algal growth. The highest values were at Contentnea Creek (n18) followed by, in descending order, Neuse River at Kinston (n14, n14x), Tar River at Tarboro (t8, t8x), Dan River at Paces (d5), Blackwater River (c4, c4x), the other Chowan tributaries (c2, c1), and Roanoke River

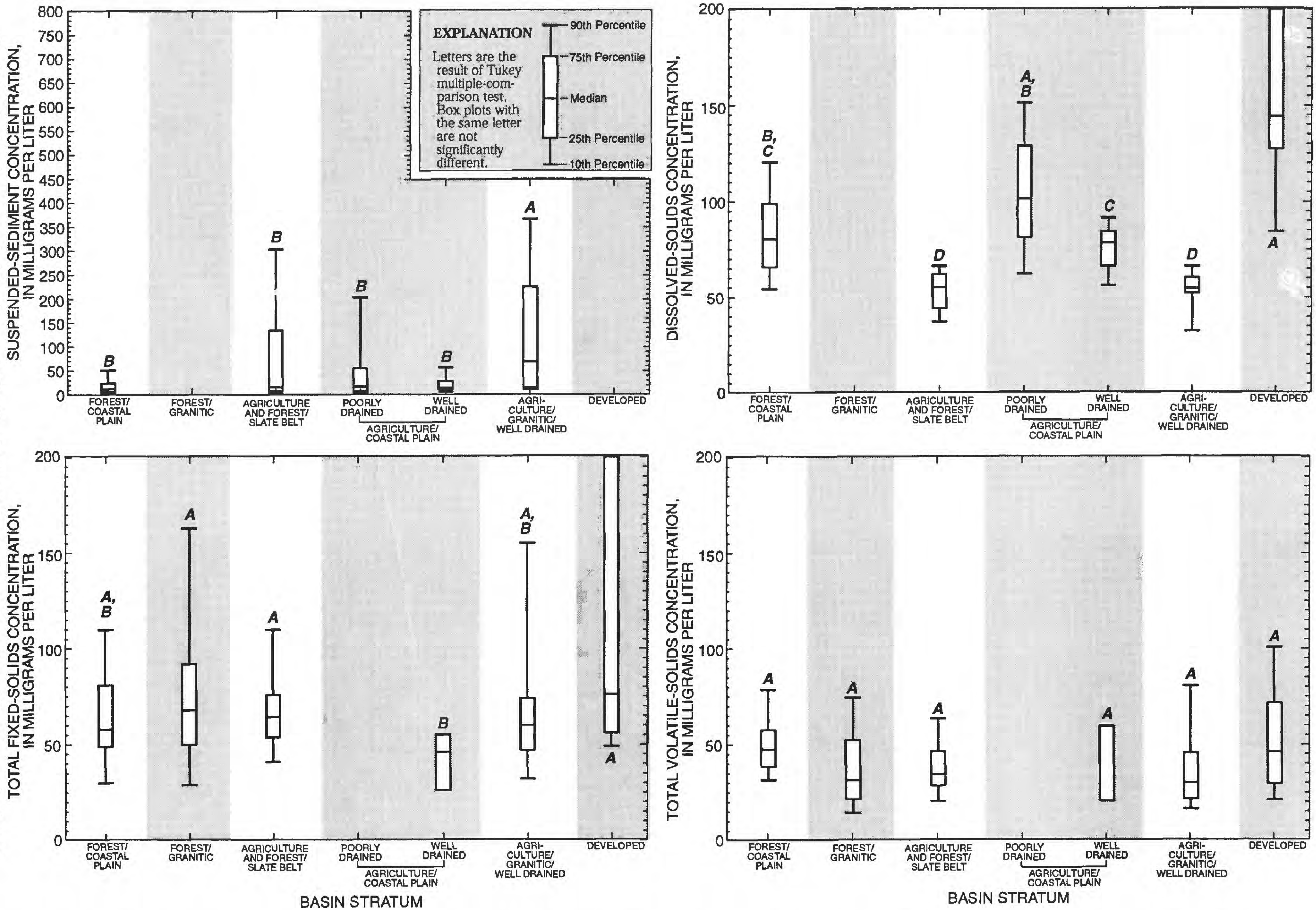


Figure 32. Suspended-sediment, dissolved-solids, total fixed-solids, and total volatile-solids concentrations for the different basin strata in the Albemarle-Pamlico drainage study area. Locations without box plots have no data.

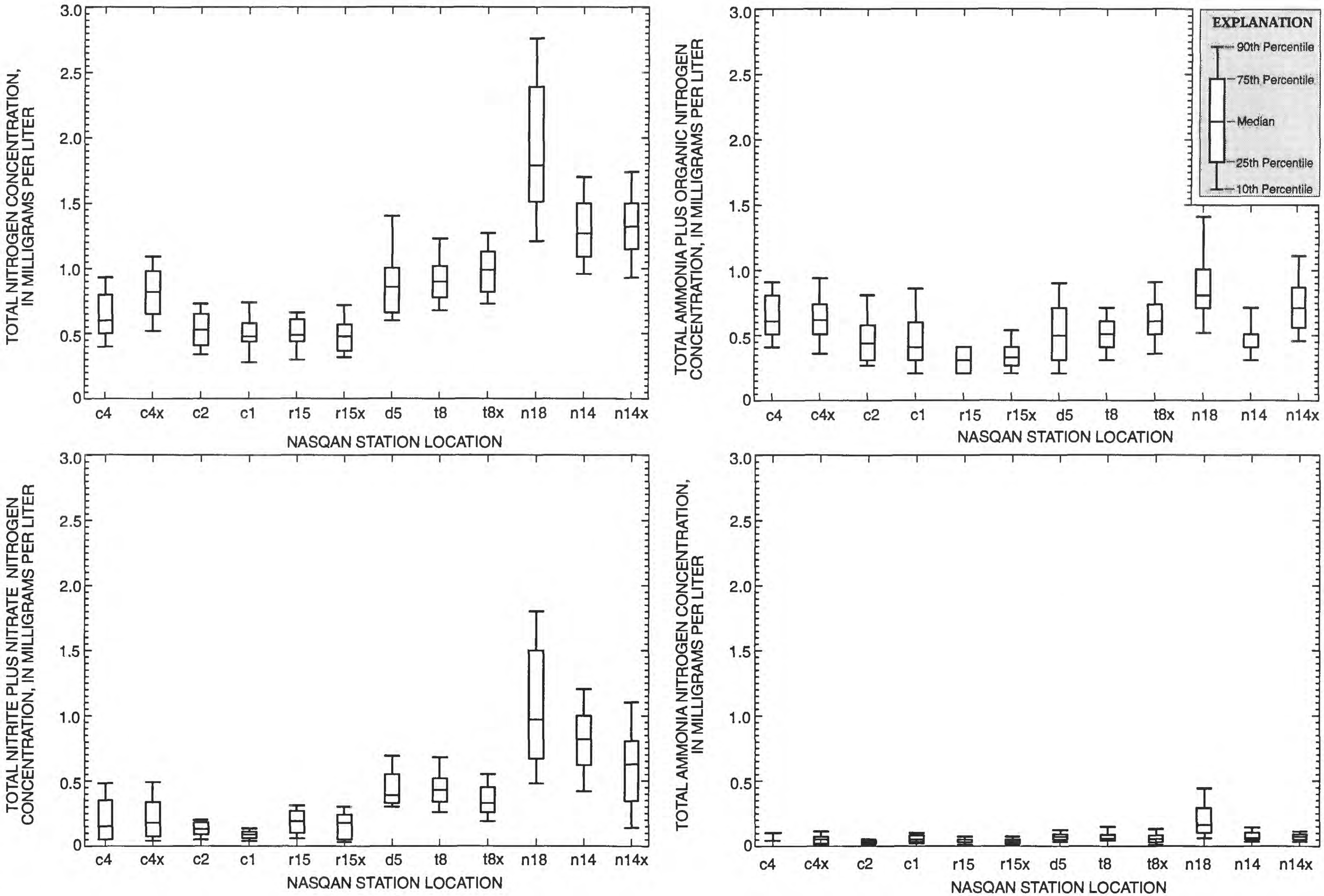


Figure 33. Total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total ammonia nitrogen concentrations for sites in the National Stream Quality Accounting Network (NASQAN). Locations without box plots have no data. (Site locations shown in figure 18.)

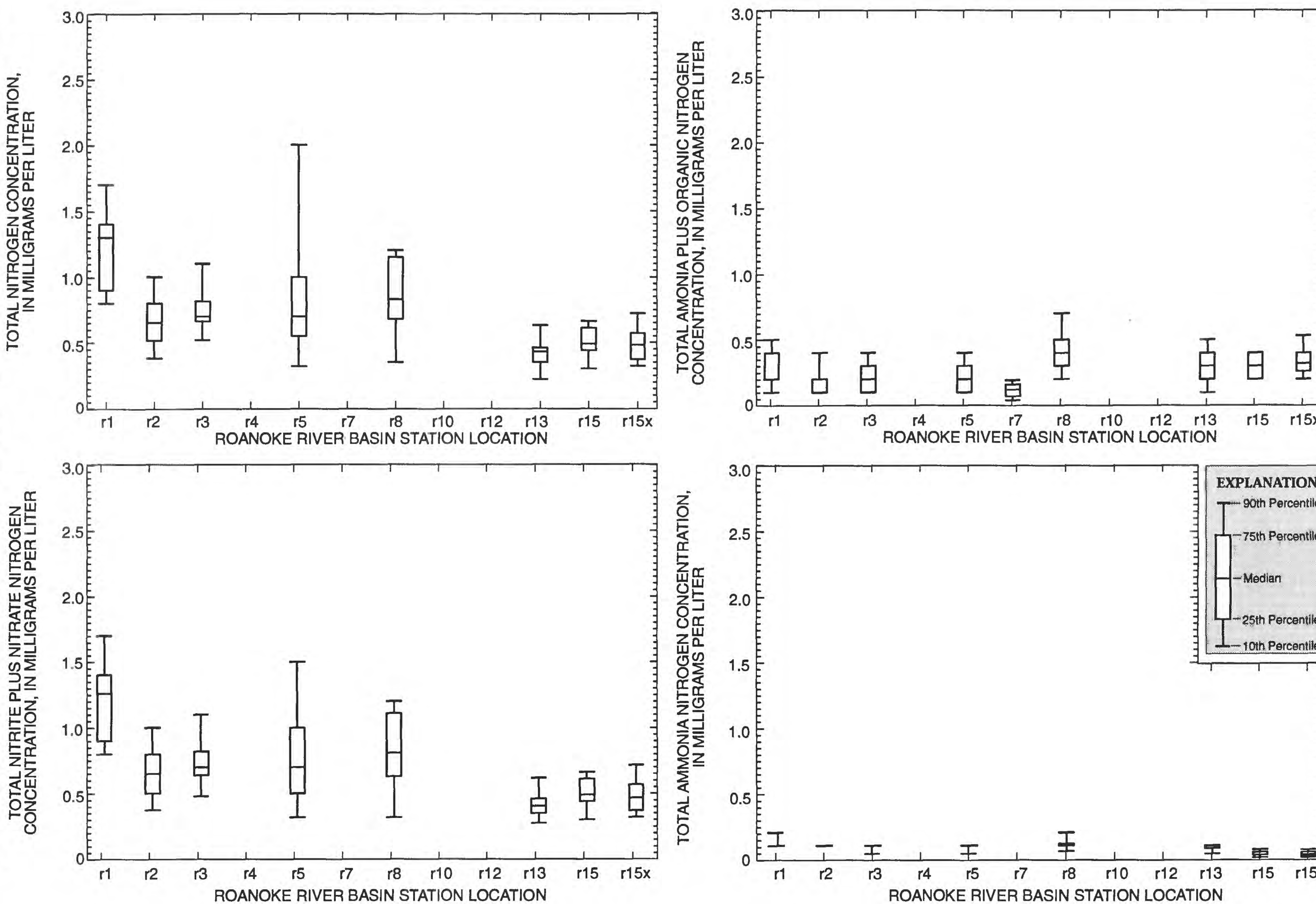


Figure 34. Total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total ammonia nitrogen concentrations for sites in the Roanoke River Basin. Locations without box plots have no data. (Site locations shown in figure 19.)

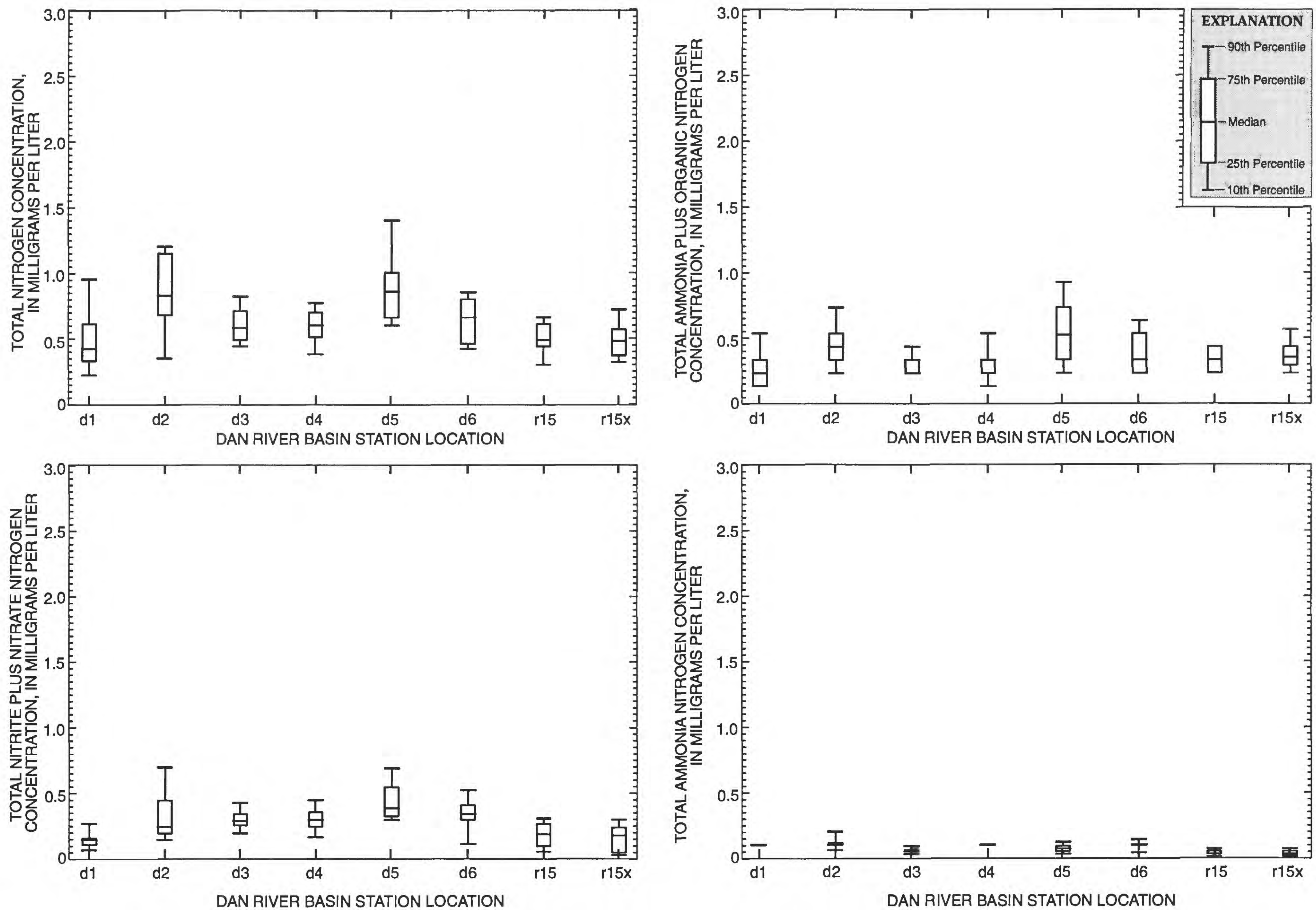


Figure 35. Total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total ammonia nitrogen concentrations for sites in the Dan River Basin. (Site locations shown in figure 20.)

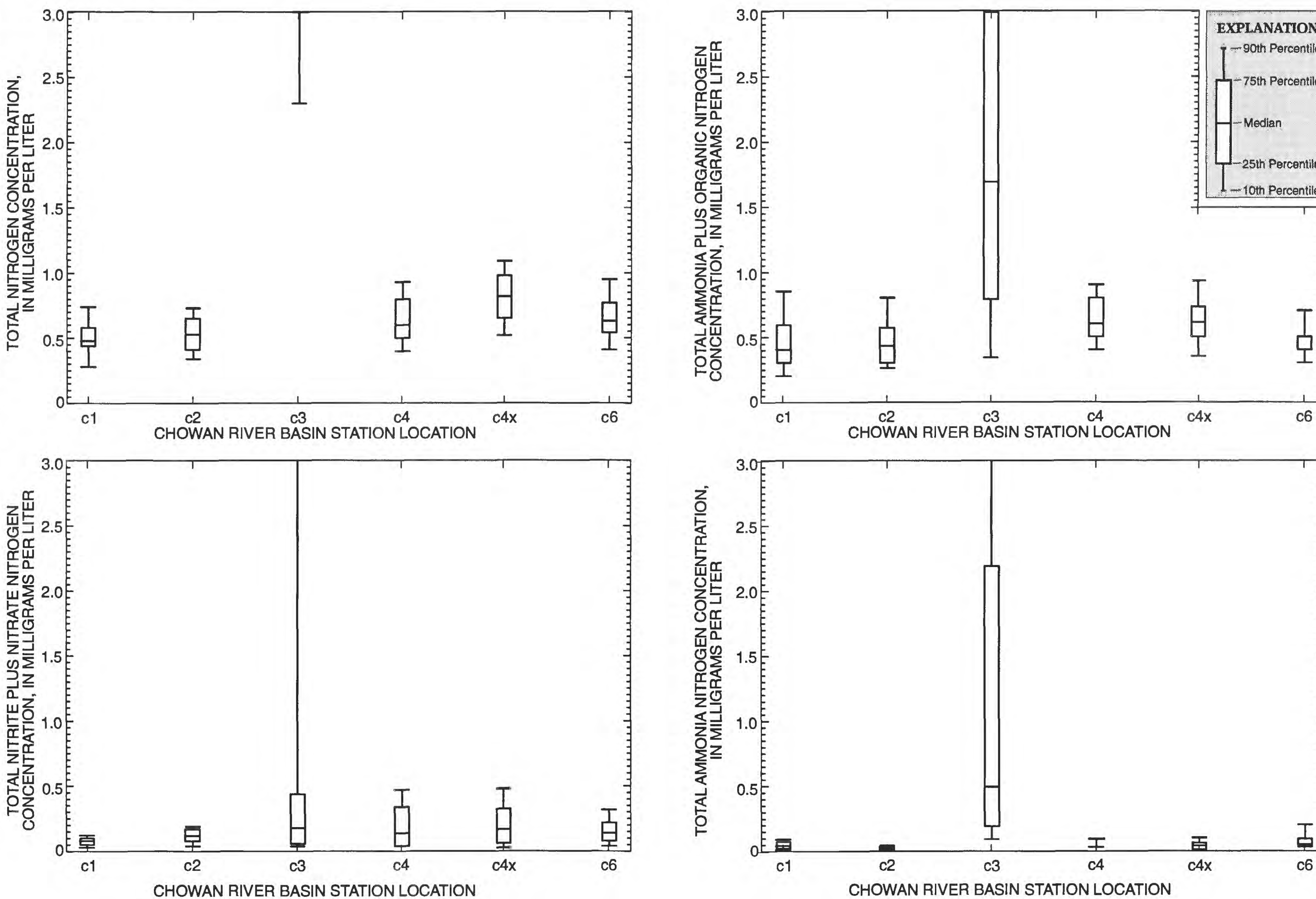


Figure 36. Total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total ammonia nitrogen concentrations for sites in the Chowan River Basin. Locations without box plots have no data. (Site locations shown in figure 21.)

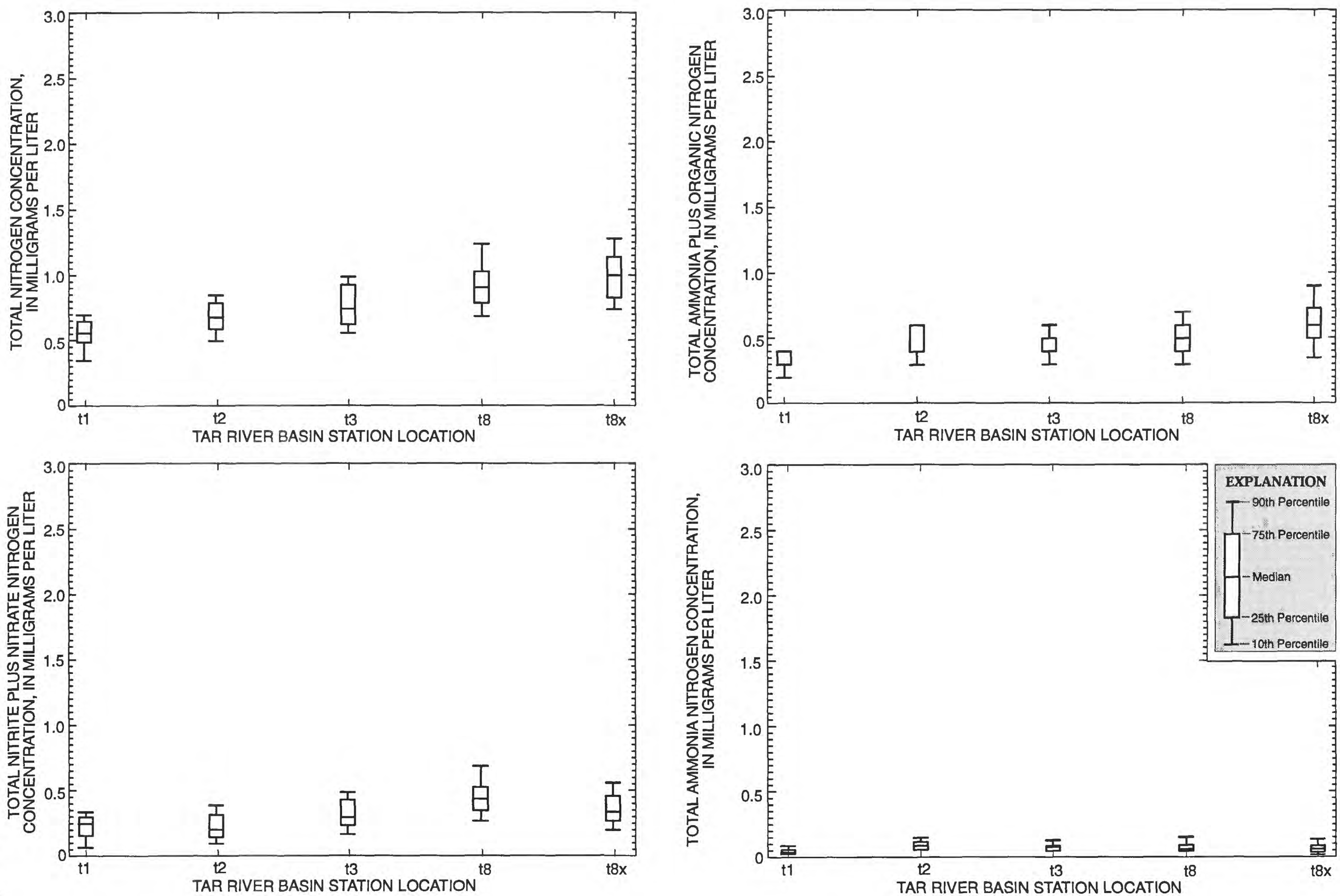


Figure 37. Total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total ammonia nitrogen concentrations for sites in the Tar River Basin. (Site locations shown in figure 22.)

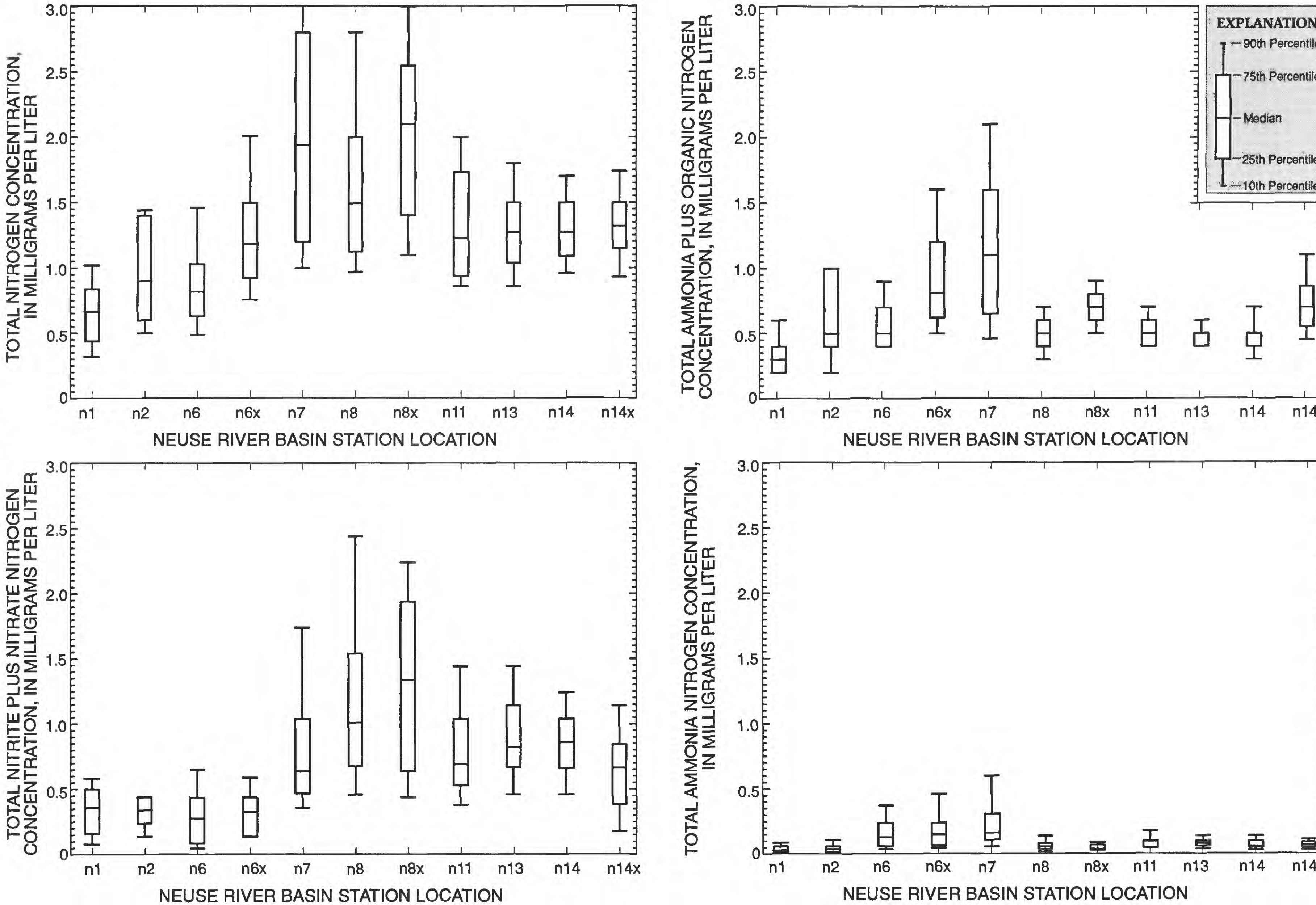


Figure 38. Total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total ammonia nitrogen concentrations for sites in the Neuse River Basin. (Site locations shown in figure 23.)

at Roanoke Rapids (r15, r15x). This ranking generally mirrors the ranking of the NASQAN stations by the relative intensity of urban and agricultural development. The most developed basins, including the Neuse, Tar, and Dan River Basins, had the highest total nitrogen values. The Contentnea, Neuse, and Tar River Basins also are areas having the most intensive agriculture. The Contentnea Creek Basin, in particular, includes a large percentage of agricultural land and many farm-animal operations. Agriculture and urban development are linked to downstream nitrogen levels. The exception to this pattern is Roanoke River at Roanoke Rapids, which has low total nitrogen concentrations but considerable upstream development. The reason for this is the effective trapping of nitrogen in Kerr and Gaston Lakes through sedimentation, assimilation in algal biomass, or denitrification.

The pattern observed for total nitrogen concentrations also is apparent for total ammonia plus organic nitrogen, and total nitrite plus nitrate. Most of the total nitrogen at the Chowan River tributary sites is organic nitrogen, indicating the relatively high concentrations of organic matter commonly found in Coastal Plain streams. Total ammonia nitrogen concentrations are generally low except at Contentnea Creek (n18), perhaps as a result of upstream sources of farm-animal wastes in this heavily cultivated basin.

Total nitrogen concentrations for the Roanoke River generally decrease downstream (fig. 34). The high values measured for the North Fork of the Roanoke River (r1) are predominantly nitrite plus nitrate, which can originate as agricultural fertilizer in this highly erodible, moderately agricultural basin (fig. 12). The high total nitrogen concentrations and variability evident at Roanoke River site r5 could result from point- and nonpoint-source effects of development around the city of Roanoke. Total nitrogen concentrations for the sites upstream from Gaston, Kerr, and Smith Mountain Lakes are commonly greater than the 0.3 mg/L cited to indicate potential for nuisance algal growth. These lakes are reported to be phosphorus limited because of the relative abundance of nitrogen. The lower total nitrogen values downstream at Roanoke River at Route 360 (r13) and Roanoke River at Roanoke Rapids probably reflect nutrient assimilation in the upstream lakes.

Total nitrite plus nitrate nitrogen concentrations also show a general decline downstream in the Roanoke River. This pattern is not apparent in total ammonia plus organic nitrogen or total ammonia nitrogen concentrations.

Total nitrogen concentrations for the Dan River show no clear spatial pattern (fig. 35). Total nitrogen concentrations are greatest at Smith River at Route 622 (d2) and Dan River at Paces (d5), but are generally less than concentrations in the upper Roanoke River (fig. 34). Total nitrogen concentrations are commonly greater than the 0.3 mg/L level cited as sufficient for supporting nuisance algal growth.

No spatial pattern is evident in either total ammonia plus organic nitrogen or total nitrite plus nitrate concentrations in the Dan River. Total ammonia nitrogen concentrations for the Dan River stations are usually less than 0.2 mg/L.

Total nitrogen concentrations for the Chowan River sites (fig. 36) indicate extremely high concentrations (greater than 2.0 mg/L) at Spring Branch (c3) and slightly greater concentrations at the Blackwater River site (c4, c4x) compared with the Meherrin (c1) and Nottoway (c2) Rivers. Wastewater discharges and runoff from developed land are the sources of nitrogen for Spring Branch which, as a tributary to the Blackwater River, also contributes to increased nitrogen concentrations at that site.

Total ammonia plus organic nitrogen concentrations for the Chowan River sites are commonly greater than concentrations measured for the Roanoke and Dan River sites. This increase could be a result of the greater population of farm animals near the Coastal Plain sites, as well as the greater amount of organic material and, therefore, organic nitrogen commonly found in slow moving Coastal Plain streams. The extremely high total ammonia plus organic nitrogen, total nitrite plus nitrate, and total ammonia concentrations observed at Spring Branch (c3) are due primarily to wastewater discharge and basin development.

Total nitrogen concentrations for the Tar River (fig. 37) generally increase downstream. The values measured for the Tar River at Louisburg (t1) are commonly greater than the 0.3 mg/L cited as sufficient for supporting nuisance algal growth.

A pattern of downstream increase is also apparent in total ammonia plus organic nitrogen and total nitrite plus nitrate concentrations. This gradual increase in nitrogen concentration is primarily an effect of upstream agriculture. The Tar River Basin as a whole is the most intensively farmed basin in the study area (fig. 12), and point-source wastewater inputs into the basin are comparatively low (fig. 17). Total ammonia nitrogen concentrations do not indicate a distinct increase downstream and are much less than the 0.5 mg/L level that would indicate contamination from human or animal waste (Weiss and others, 1973).

Total nitrogen concentrations in the Neuse River Basin (fig. 38) increase downstream and peak near Clayton (n7) and Smithfield (n8, n8x). This pattern is similar to the one observed for specific conductance, sediment, dissolved-solids, and total fixed-solids concentrations (figs. 23 and 31). The total nitrogen concentrations recorded for the Neuse River were frequently the highest measured in any of the rivers of the Albemarle-Pamlico drainage basin. Median total nitrogen concentrations were greater than 1.0 mg/L at all but the Flat River (n1, n2) and Falls (n6) sites, and were greater than 1.5 mg/L at Clayton (n7) and Smithfield (n8, n8x). The pattern of increase and high nitrogen concentrations reflects the effect of nitrogen in runoff from developed areas and wastewater discharge from point sources near Raleigh.

A similar pattern of downstream increase and peak near Clayton and Smithfield is apparent for total ammonia plus organic nitrogen and total nitrite plus nitrate concentrations. Total ammonia nitrogen concentrations are also higher at the Neuse River near Falls (n6, n6x) and Neuse River near Clayton (n7) sites, indicating contamination from human or animal waste. Total nitrogen at the Falls (n6, n6x) and Clayton (n7) sites is largely ammonia plus organic nitrogen but changes to nitrite and nitrate nitrogen downstream at the Smithfield site indicating oxidation of nitrogen as it moves downstream.

Grouping the subbasins by strata (fig. 39) emphasizes the importance of agricultural and urban effects on nitrogen concentrations in the streams. Distributions of total nitrogen, total ammonia plus organic nitrogen, and total nitrite plus nitrate nitrogen concentrations for the Agriculture/Coastal Plain/Poorly Drained stratum are significantly different from those of the other strata, with higher median concentration values than all the other strata. The Agriculture/Coastal Plain/Well Drained and Developed strata were grouped together to show the second highest median concentrations of total nitrogen of all strata. The Agriculture/Coastal Plain/Well Drained stratum ranked second, and the Developed stratum ranked third for total ammonia plus organic nitrogen concentrations. The Agriculture/Coastal Plain/Well Drained stratum ranked third, and the Developed stratum ranked second for nitrite plus nitrate nitrogen concentrations. The Agriculture/Coastal Plain/Poorly Drained and Developed strata also were among the strata with the highest median total ammonia nitrogen concentrations.

Phosphorus

Phosphorus is a nutrient essential to algal growth. The National Technical Advisory Committee (1968) recommends 0.05 mg/L total phosphorus (as P) as the maximum concentration limit for waters entering impoundments. Other sources (Sawyer, 1947; Sakamoto, 1966; and Vollenweider, 1971) note that total phosphorus concentrations greater than 0.01 mg/L in lakes promote undesirable algal growth. Concentrations less than 0.1 mg/L are recommended by Mackenthum (1969) to prevent algal blooms in streams.

Distributions of total and dissolved phosphorus concentrations for the NASQAN stations (fig. 40), and for selected sites along the Roanoke, Dan, Chowan, Tar, and Neuse Rivers are shown in figures 41-45. Sufficient data were not available to generate box plots for dissolved phosphorus for the Roanoke and Tar Rivers. Locations of the sites shown in these illustrations are given in figures 2 and 18-23.

The ranking of phosphorus concentrations for the NASQAN sites (fig. 40) is almost identical to the ranking observed for nitrogen concentrations. Contentnea Creek (n18) has the highest values, followed in descending order by Neuse River at Kinston (n14, n14x), Tar River at Tarboro (t8, t8x), and Dan River at Paces (d5), which show similar values, the Chowan tributaries (c1, c2, c4x, c4), and Roanoke River at Roanoke Rapids (r15, r15x). This ranking reflects the ranking of the NASQAN stations by land use. The basins having the greatest urban development and most intensive agriculture, including the Contentnea, Neuse, Tar, and Dan River Basins, show the highest total and dissolved phosphorus concentrations. Roanoke River at Roanoke Rapids (r15, r15x) is an exception to this pattern because of the influence of Kerr and Gaston Lakes. Phosphorus effectively sorbs to sediment, which is trapped by the lake system, and is taken up by algae growing in the lakes. Phosphorus concentrations are commonly greater than 0.1 mg/L in all but the Chowan River tributaries and Roanoke River at Roanoke Rapids, thus

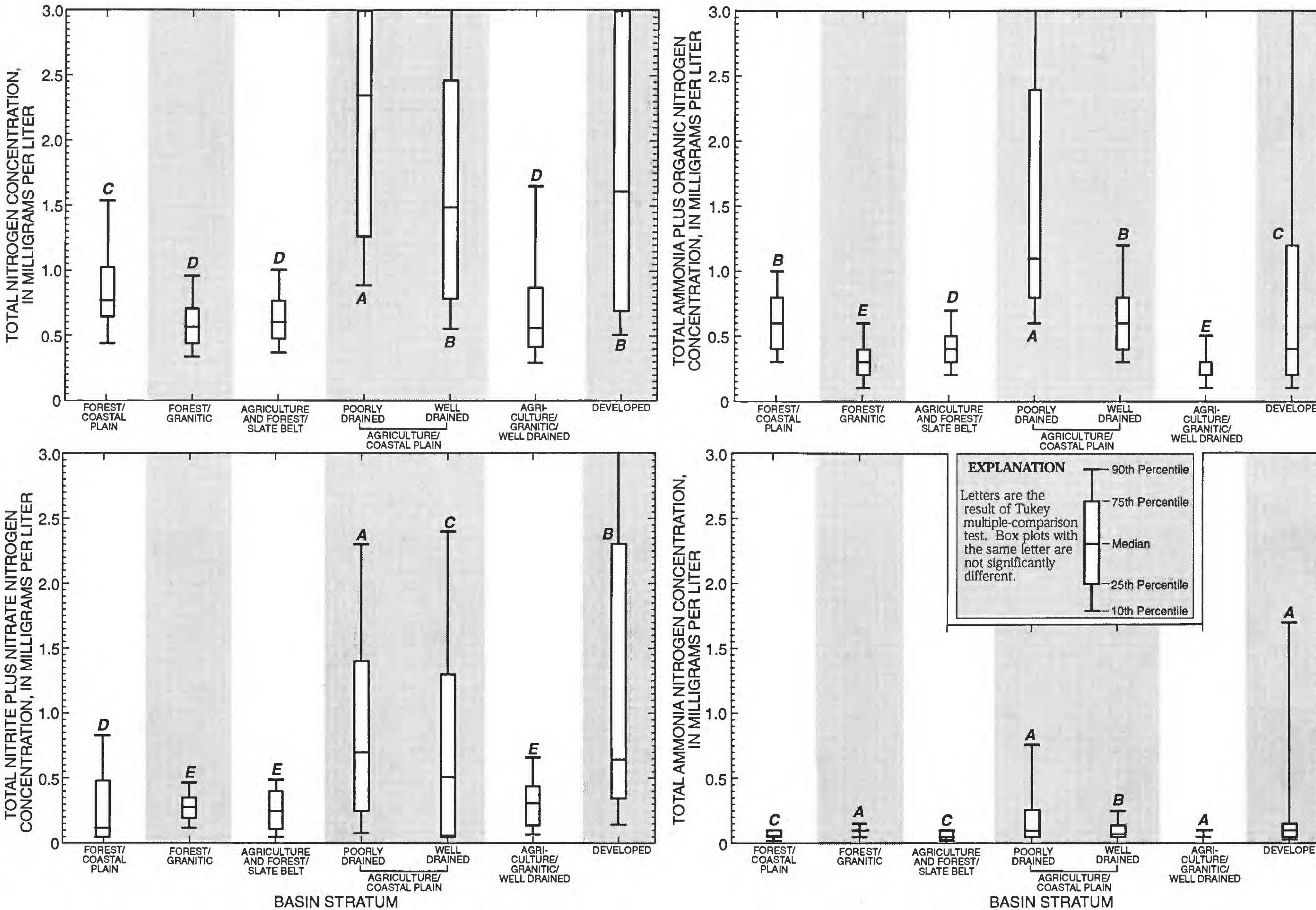


Figure 39. Total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total anmonia nitrogen concentrations for the different basin strata in the Albemarle-Pamlico drainage study area.

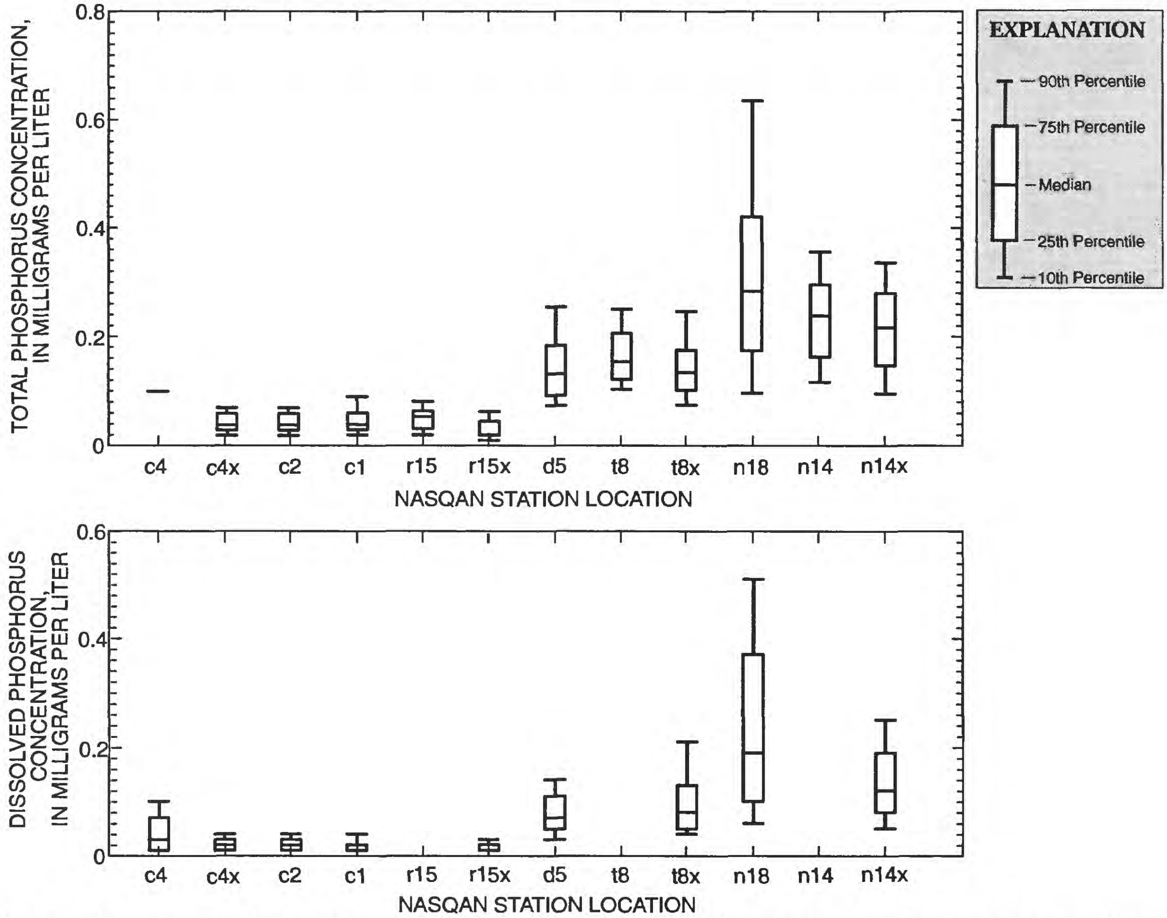


Figure 40. Total and dissolved phosphorus concentrations for sites in the National Stream Quality Accounting Network (NASQAN). Locations without box plots have no data. (Site locations shown in figure 18.)

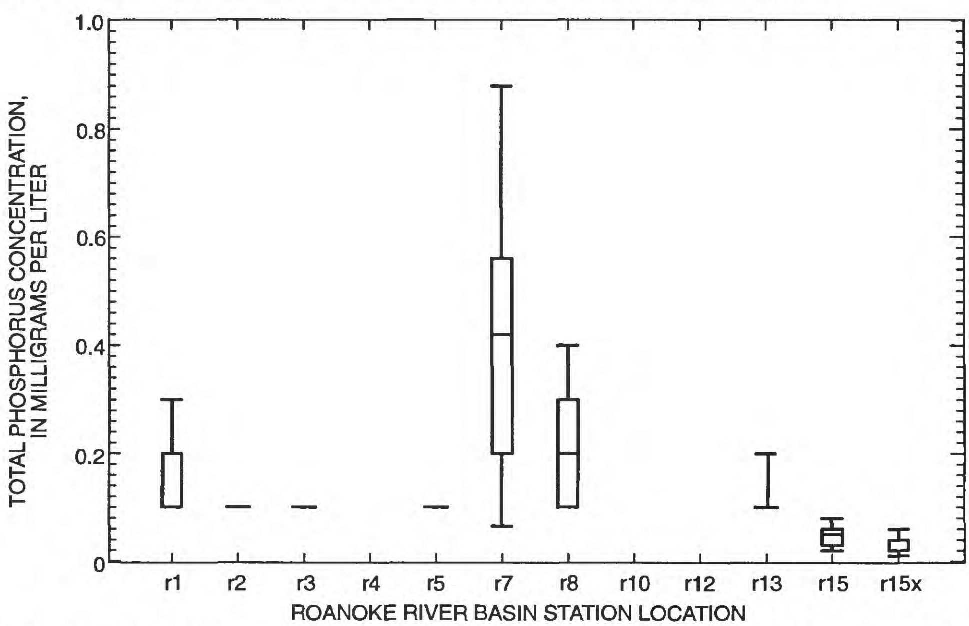


Figure 41. Total phosphorus concentrations for sites in the Roanoke River Basin. Locations without box plots have no data. (Site locations shown in figure 19.)

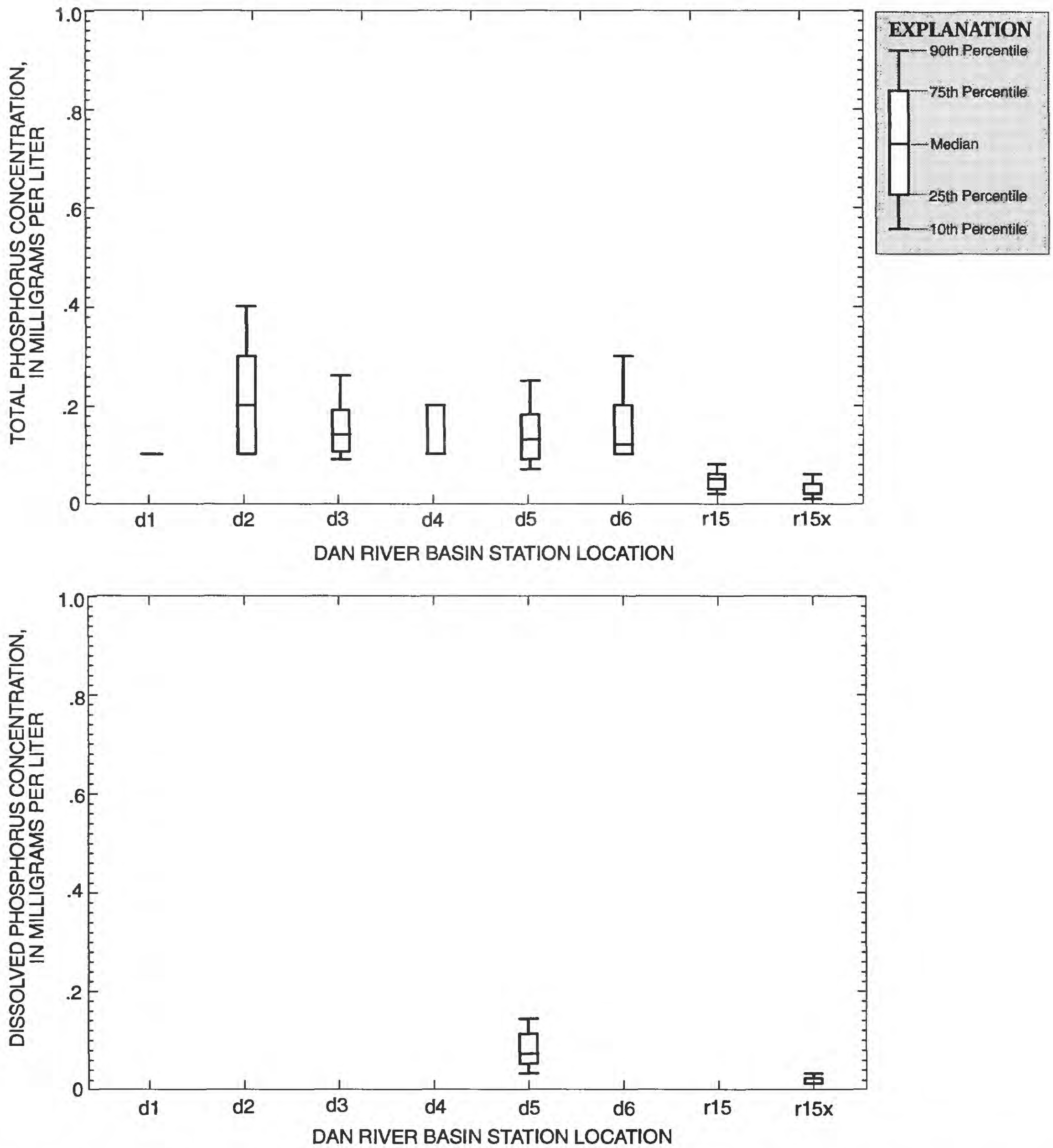


Figure 42. Total and dissolved phosphorus concentrations for sites in the Dan River Basin. Locations without box plots have no data. (Site locations shown in figure 20.)

providing an ample supply of the nutrient for instream algal growth.

Limited total phosphorus data are available for the Roanoke River stations (fig. 41). The available data indicate moderate values of total phosphorus in the North Fork of the Roanoke River (r1), high values at the stations on the upper end of Smith Mountain Lake (r7, r8), and low values at Roanoke Rapids (r15, r15x). The high concentrations for the r7 site are for a very limited period of record in the early 1970's; thus, the data may not be representative of current (1994) conditions. The relatively high median total phosphorus measured at site r8, which is located near site r7, is probably a result of point- and nonpoint-source effects of development around the city of Roanoke. The low concentrations of total phosphorus at Roanoke Rapids (r15, r15x) are a result of phosphorus settling with sediment in Kerr and Gaston Lakes, and assimilation of soluble phosphorus

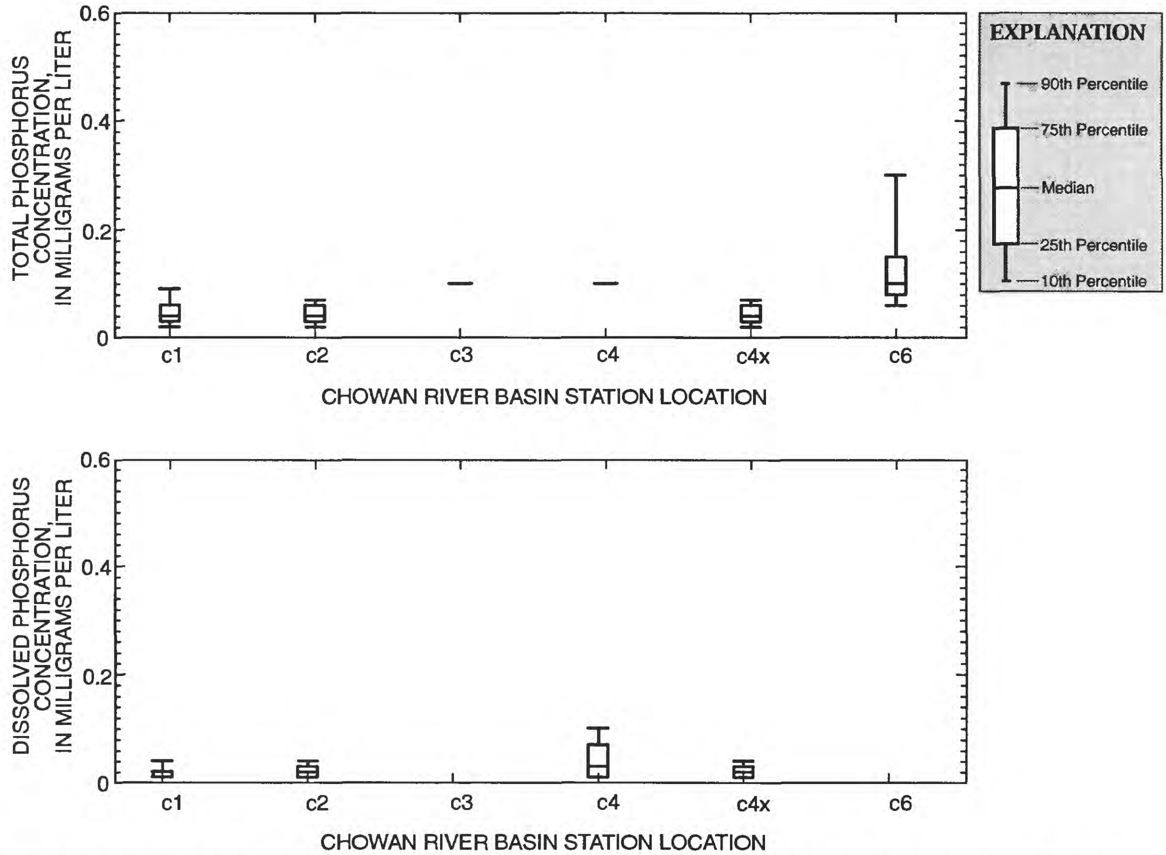


Figure 43. Total and dissolved phosphorus concentrations for sites in the Chowan River Basin. Locations without box plots have no data. (Site locations shown in figure 21.)

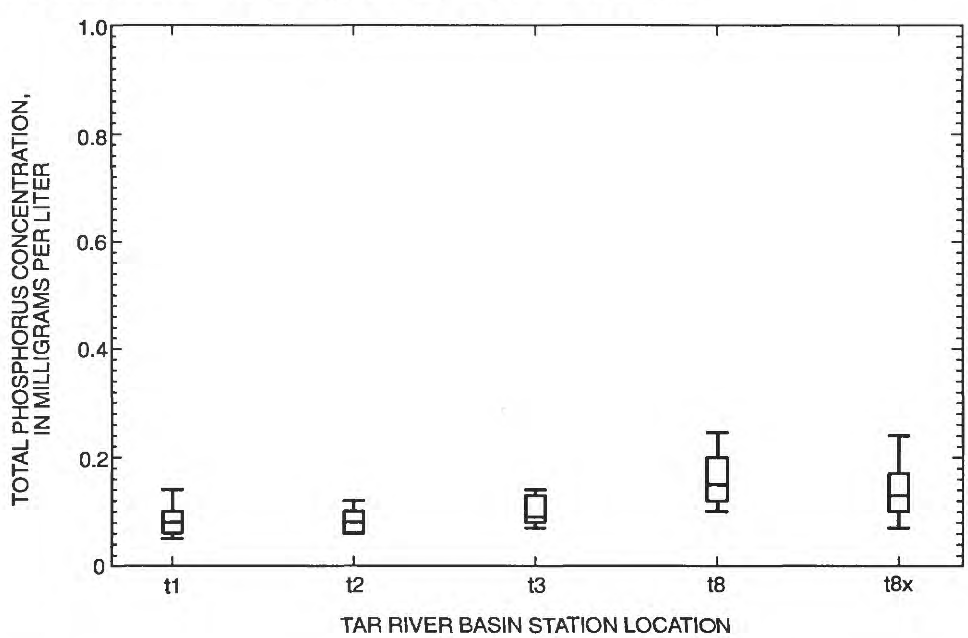


Figure 44. Total phosphorus concentrations for sites in the Tar River Basin. (Site locations shown in figure 22.)

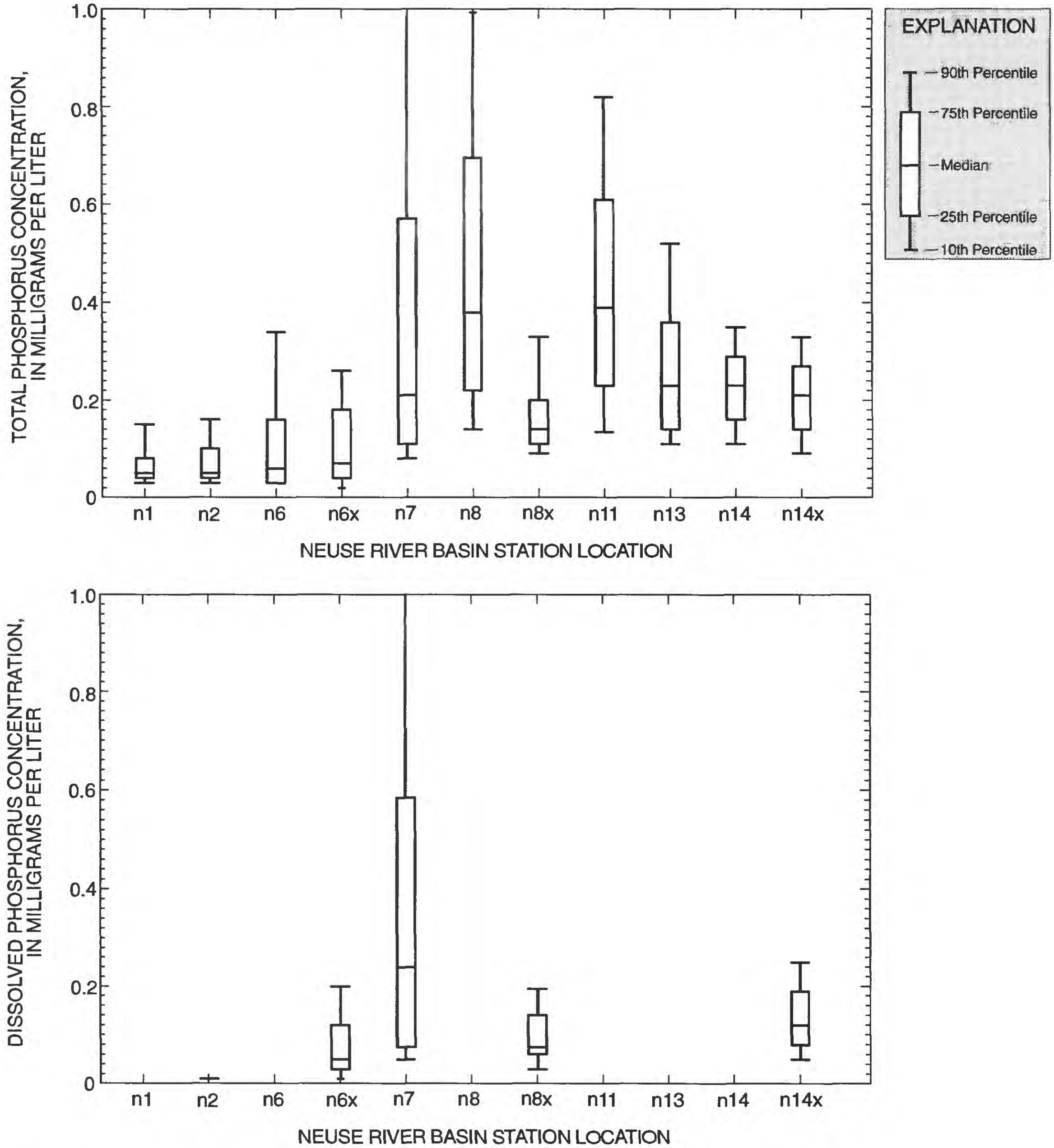


Figure 45. Total and dissolved phosphorus concentrations for sites in the Neuse River Basin. Locations without box plots have no data. (Site locations shown in figure 23.)

by algae in the lakes. Phosphorus concentrations at sites r1, r7, and r8 are frequently greater than the 0.1 mg/L level cited as sufficient to support undesirable algal growth.

Total phosphorus concentrations for the Dan River generally are uniform (fig. 42). Concentrations of total phosphorus are greater at Smith River at Route 622 (d2) than at the downstream stations Dan River near Mayfield (d3), Dan River at Robertson Bridge (d4), Dan River at Paces (d5), and Dan River at Route 501 Bridge (d6). There is a distinct decrease in total phosphorus concentrations between the Dan River stations (d2-d6) and those at Roanoke River at Roanoke Rapids (r15, r15x), and in dissolved phosphorus concentrations between Dan River at Paces (d5) and the Roanoke Rapids site (r15x). This reduction in phosphorus is a result of the trapping of phosphorus by the lake system upstream from Roanoke Rapids. Total phosphorus concentrations for the Dan River sites generally are greater than the 0.1 mg/L level suggested as sufficient to promote nuisance algal growth in streams. These high phosphorus concentrations probably are largely a result of wastewater inputs, because the Dan River has moderately high wastewater discharge per unit of basin area (fig. 17). Nonpoint agricultural sources are important; however, as the high suspended-sediment concentrations observed at Dan River at Paces (d5; fig. 26) indicate, the basin soils are highly erodible. Eroded soil carrying fertilizer from farms could be an important source of phosphorus to the Dan River.

Phosphorus concentrations for the Chowan River tributaries (fig. 43) were among the lowest of any of the study area subbasins, possibly as a result of the low erosion rates of the Coastal Plain soils in much of the basin and management programs for nutrient control implemented in the early 1980's (North Carolina Department of Environment, Health, and Natural Resources, 1990). Concentrations of total and dissolved phosphorus generally were less than 0.1 mg/L, except total phosphorus for the Chowan River site near Riddicksville (c6). The greater total phosphorus concentrations at site c6 are probably a result of industrial wastewater inputs upstream near Franklin, Va.

Total phosphorus concentrations increased downstream in the Tar River (fig. 44). This increase is similar to the pattern of increasing concentrations noted for nitrogen. The increase is most apparent between the Rocky Mount (t3) and Tarboro (t8, t8x) sites. Much of the development in the basin is upstream from the Rocky Mount site; thus, the increased phosphorus concentration at Tarboro is likely a result of agricultural sources, particularly from several large tributaries which enter the river between Rocky Mount and Tarboro. Total phosphorus concentrations at all the Tar River sites commonly are greater than the 0.1 mg/L concentration sufficient to support nuisance algal growth in streams.

Phosphorus concentrations in the Neuse River Basin (fig. 45) increase downstream between Clayton (n7) and Richardson Bridge (n11) and decrease to more moderate concentrations at the Neuse River near Goldsboro (n13). It is unclear exactly where the peak occurs, because the period of record for sites n7 and n8 ended in 1978 resulting in data distribution that is probably not representative of current (1994) conditions. The distributions of total phosphorus concentrations at sites n8 and n8x are considerably different, probably as a result of the differing periods of record. This pattern of downstream increase and then decrease is similar to the patterns noted for specific conductance (fig. 23), suspended-sediment and solids concentrations (fig. 31), and nitrogen concentrations (fig. 38). In addition, the concentrations of phosphorus in the Neuse River are some of the highest values of any of the Albemarle-Pamlico drainage study subbasins. All but the Flat River sites (n1 and n2) commonly have concentrations of total phosphorus greater than 0.1 mg/L. The high phosphorus concentrations and the peaking of concentrations downstream from Raleigh suggest that principal sources of phosphorus are runoff and point sources from developed areas.

A comparison of phosphorus concentration distributions by strata (fig. 46) indicates a pattern similar to that observed for specific conductance, dissolved-solids, total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate nitrogen, and total ammonia nitrogen concentrations. Generally, the greatest water-quality effects are in agricultural and developed areas. The Agriculture/Coastal Plain/Poorly Drained stratum has a distribution of total phosphorus that is significantly different in that it has a higher median value than all of the other strata. The Developed stratum has the second highest median total phosphorus concentration. The Agriculture/Coastal Plain/Poorly Drained stratum and the Agriculture/Coastal Plain/Well Drained stratum grouped together have higher median dissolved phosphorus concentrations than the other strata. No dissolved phosphorus data were available, however, for the Developed and Forest/Granitic strata.

Pesticides

In the last 50 years, pesticides have become an integral part of the agricultural industry in the United States. The use of pesticides has coincided with a significant increase in agricultural productivity. World population growth increases pressure on the agricultural industry to continue to develop new pesticides at a rapid pace. The large number of pesticides and the variety of pesticide classes make pesticide monitoring expensive; thus, the amount of available pesticide data is limited.

Because pesticides are toxic by design, there is a natural concern about the potential acute and chronic effects of pesticides on nontarget organisms. The fate of pesticides in surface water is a function of transformation, sorption, and transport processes. Water-soluble pesticides, such as atrazine, tend to be transported into surface waters by way of runoff or by infiltrating into shallow ground-water systems. Hydrophobic pesticides, such as DDT, tend to sorb onto soil particles and are transported in the bed sediments of rivers and lakes. Water-soluble pesticides tend to be less persistent in the environment compared to hydrophobic pesticides.

Pesticides are used extensively in North Carolina for controlling weeds, insects, fungi, and pathogens that can destroy or severely damage crops. Of all pesticides used in Virginia and North Carolina, atrazine and alachlor are the most commonly used (McMahon and Lloyd, 1995). Alachlor is an acetanilide herbicide used on corn and soybeans. Atrazine, one of the triazine herbicides, is used almost exclusively on corn and, in 1987, was estimated by the

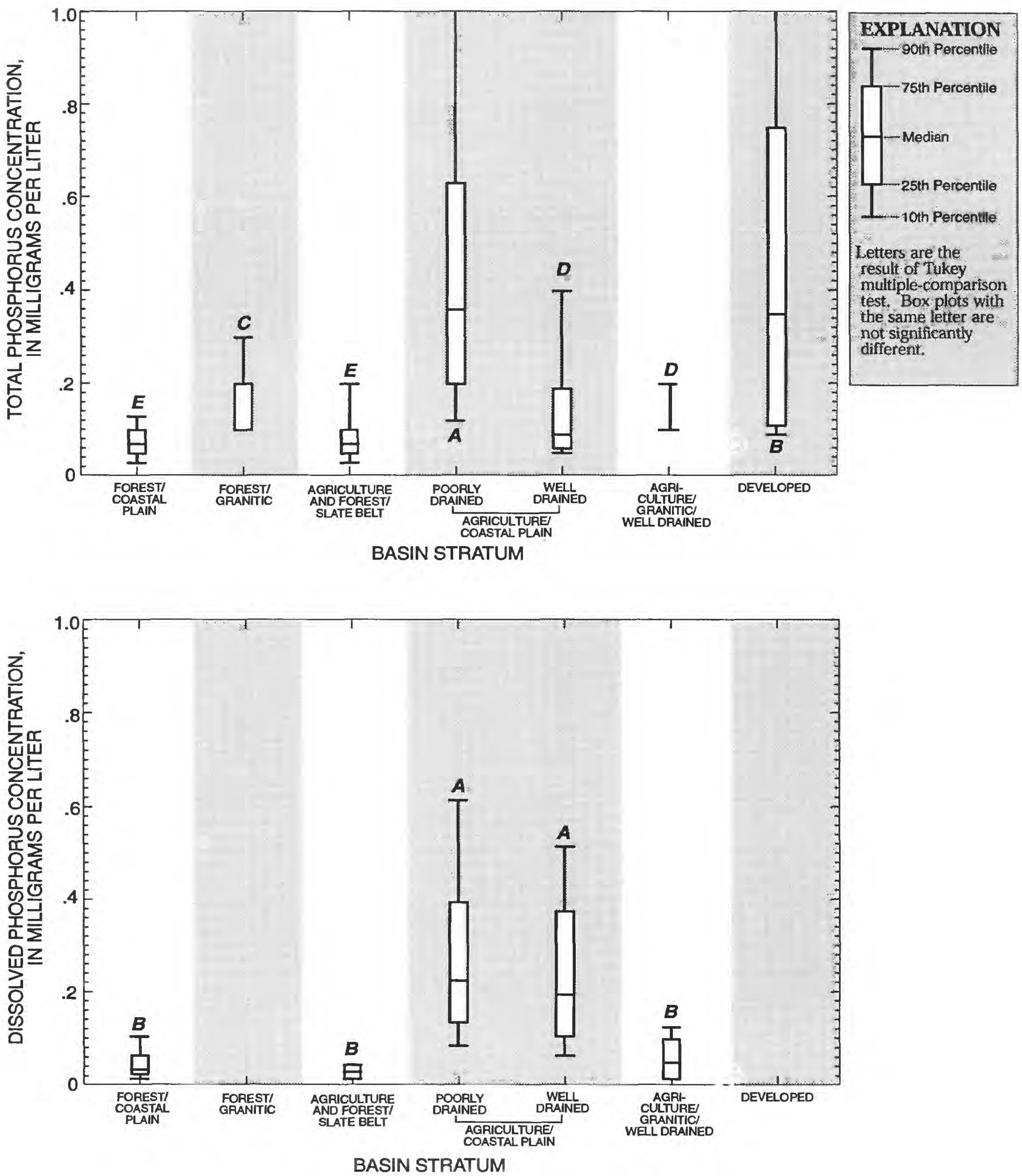


Figure 46. Total and dissolved phosphorus concentrations for the different basin strata in the Albemarle-Pamlico drainage study area. Locations without box plots have no data.

USEPA to be the most heavily used pesticide in the United States (Ware, 1989). Based on data for the entire Albemarle-Pamlico study area (McMahon and Lloyd, 1995), six herbicides (alachlor, atrazine, butylate, EPTC, metolachlor, and pendimethalin) and three insecticides (carbaryl, carbofuran, and ethoprop) were used in quantities of more than 100,000 pounds per year (lbs/yr) (fig. 47).

Pesticide data collected at meteorological, lake, or stream stations in the Albemarle-Pamlico drainage basin were retrieved from the WATSTORE and STORET databases for use in evaluating the spatial and temporal occurrences and distributions of the data. The WATSTORE database contains data for 332 water samples that have been analyzed for 1 to 74 pesticides at 34 stations for water years 1970-92 (table 5; fig. 48). The WATSTORE database also contains data for 18 stations with pesticide data for bed sediments (table 5). The STORET database contains data for 291 water samples that have been analyzed for 1 to 28 pesticides at 95 stations for water years 1970-90 (table 5; fig. 49). STORET also contains pesticide data for bed sediments at 96 stations (table 5).

STORET pesticide data are summarized for water years 1970-90 (table 6). All of the concentrations for 10 of the 28 pesticides analyzed were either less than reporting limits or were reported as nondetected. The most commonly detected pesticides were atrazine and aldrin. The reporting limits for many pesticides have been lowered as a result of new laboratory methods and instruments; consequently, a pesticide data set commonly contains multiple reporting limits for a single pesticide. Therefore, when interpreting data with multiple reporting limits, caution must be exercised. The number of detections or nondetections can be a function of the multiple reporting limits.

WATSTORE pesticide data are summarized for water years 1970-92 (table 7). All of the concentrations for 36 of the 74 pesticides analyzed were less than reporting limits. Approximately 75 percent of the pesticides analyzed had less than 5 detections per pesticide. The pesticide groups most frequently detected in water samples in the Albemarle-Pamlico drainage basin were the chloroacetnalilide herbicides and the triazine herbicides and their metabolites. The majority of pesticide data retrieved from the USGS database has been collected for four projects—the National Pesticide Monitoring Program (Gilliom and others, 1985); the Chicod Creek Channelization Project (Mason and others, 1990); the Chicod Creek Prototype Pesticide Project (Manning and others, 1994); and the Triangle Area Water-Supply Monitoring Project (Garrett and others, 1994).

The purpose of the National Pesticide Monitoring Program was to assess general levels of pesticides in runoff and bed sediments in the Nation's rivers. Collection and analysis methods and a summary of the national results are described by Gilliom and others (1985). Pesticide samples were collected by the USGS and analyzed by the USEPA. Samples were analyzed for selected organochlorine insecticides, organophosphate insecticides, and triazine and chlorophenoxy herbicides.

As part of the National Pesticide Monitoring Program, pesticide samples were collected at three stations in the Albemarle-Pamlico Basin—Roanoke

Table 5. Summary of pesticide water-quality and bed-sediment data collected in the Albemarle-Pamlico drainage study area, by source

[Data are from the U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) and the U.S. Environmental Protection Agency Storage and Retrieval System (STORET)]

Samples analyzed for pesticides	Source of data					
	WATSTORE			STORET		
	Number of stations	Number of water-quality records	Water years of record from 1970-92	Number of stations	Number of water-quality records	Water years of record from 1970-90
Water samples	34	332	1970-92	95	291	1970-90
Bed-material samples	18	96	1975-90	96	155	1981-90

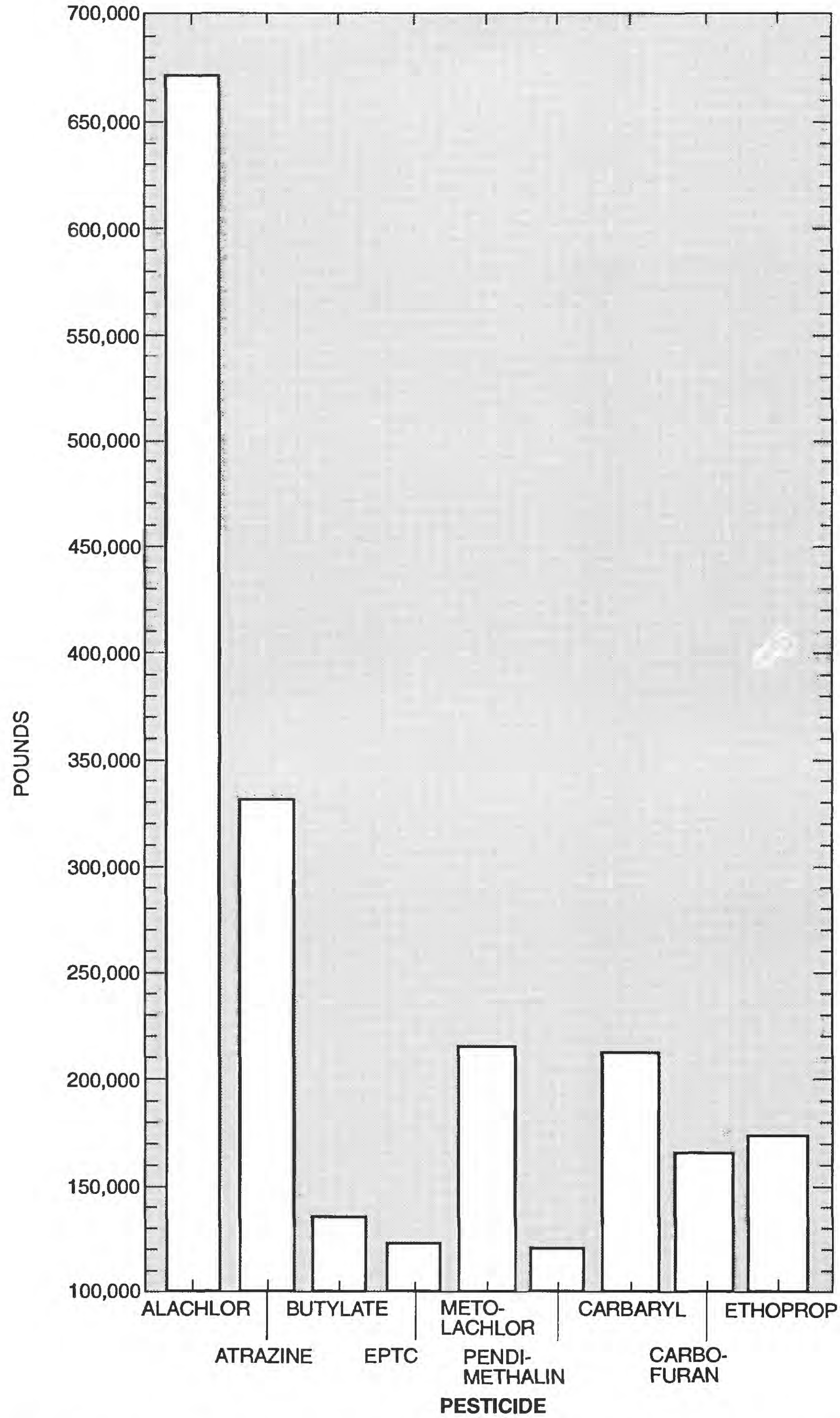


Figure 47. Pesticides used in quantities of more than 100,000 pounds in the Albemarle-Pamlico drainage study area, 1988-91.

River at Roanoke Rapids (r15), Neuse River at Kinston (n14), and Blackwater River near Franklin (c4). Pesticide concentrations in water samples collected from these three stations generally were less than the reporting limits for greater than 90 percent of the data. Hydrophobic insecticides were the most commonly detected pesticides in bed-sediment samples.

Water samples and bed sediments were analyzed for organochlorine insecticides as part of the Chicod Creek Channelization Project. The purpose of this

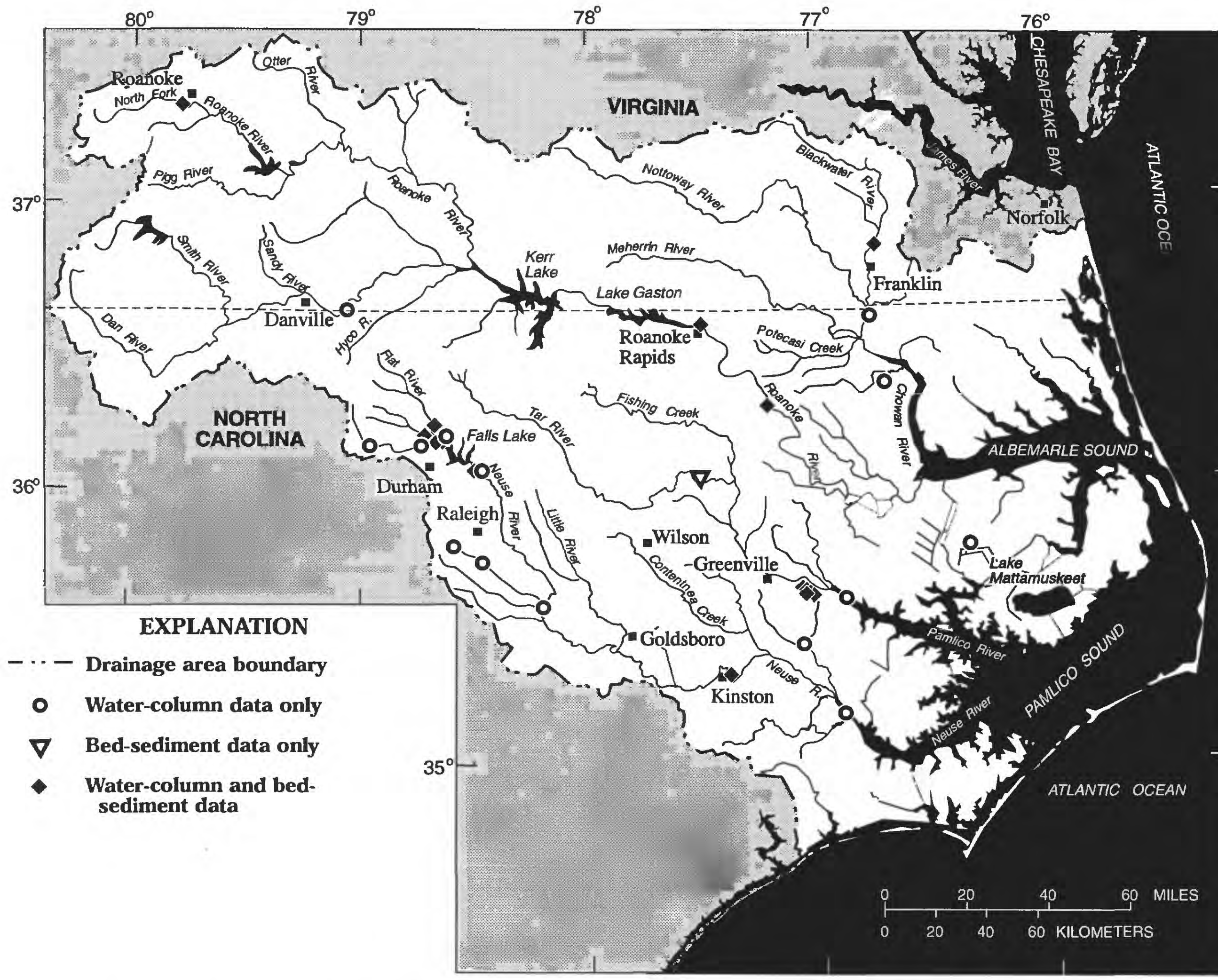


Figure 48. Locations of U. S. Geological Survey WATSTORE pesticide data-sampling sites in the Albemarle-Pamlico drainage study area.

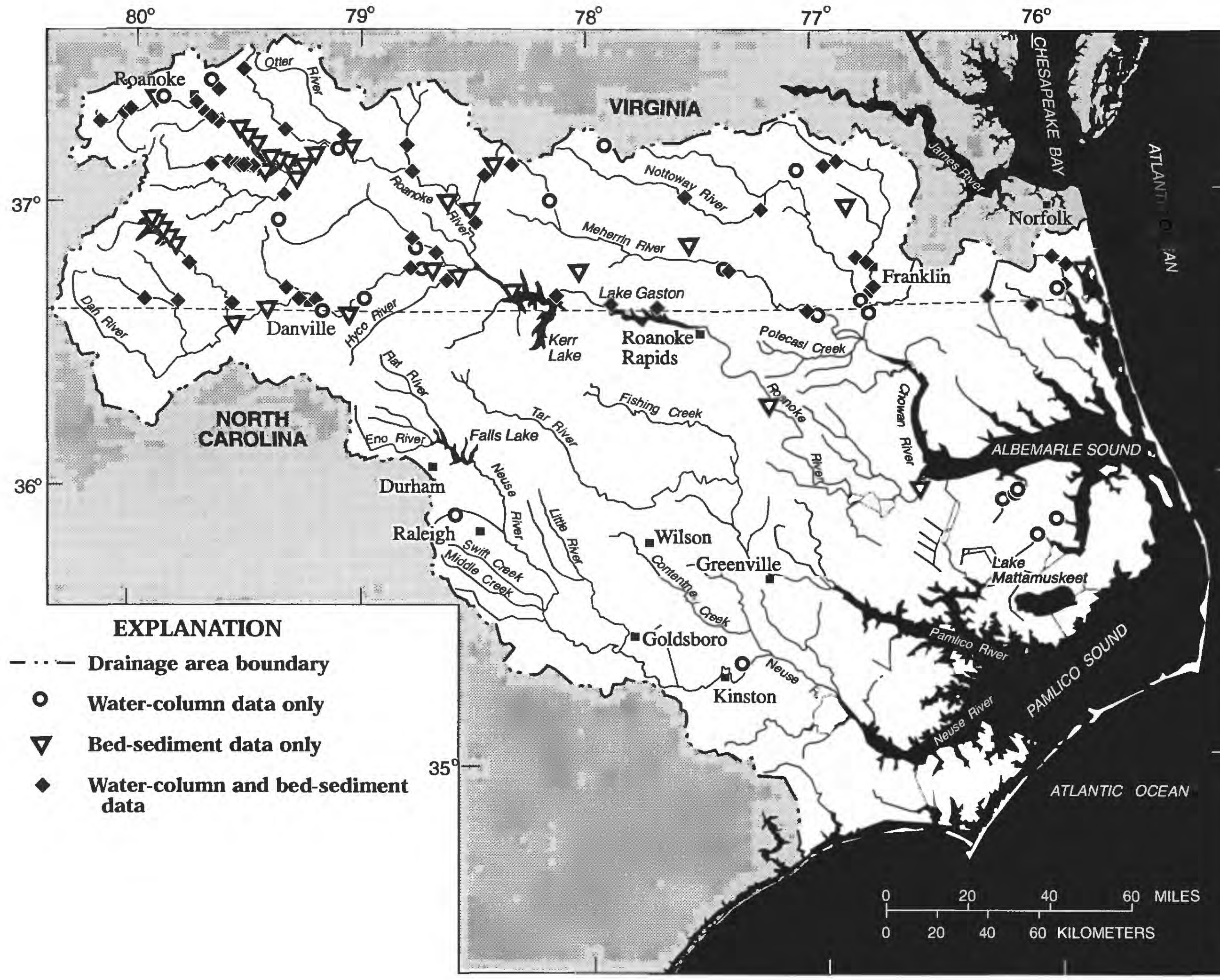


Figure 49. Locations of U.S. Environmental Protection agency STORET pesticide data-sampling sites in the Albemarle-Pamlico drainage study area.

Table 6. Summary of surface water-quality pesticide data from the U.S. Environmental Protection Agency Storage and Retrieval System (STORET) database, water years 1970-90

[µg/L, microgram per liter; ND, not detected; <, less than; --, no value]

Parameter code	Common pesticide name	Water years	Number of observations	Range of concentrations (µg/L)	Minimum reporting limit (µg/L)	Number (and percent) of observations above the reporting limit
			Substituted aromatic fungicide			
39700	Hexachlorobenzene, total	1979-82	102	ND - <10	<10	0 (0)
			Chloroacetnalilide herbicides			
39161	Alachlor, total	1987	3	<0.02 - 0.02	<0.02	1 (33)
39415	Metolachlor, dissolved	1987	4	ND	--	--
			Benzoic or alphiphatic acid herbicide			
38442	Dicamba (banvel), dissolved	1984-87	86	<0.1 - <0.2	<0.1	0 (0)
			Phenoxy acid herbicide			
38451	Dichloroprop, suspended	1984-88	86	<0.1 - <0.2	<0.1	0 (0)
39730	2,4-D, total	1984-87	86	<0.1 - <0.2	<0.1	0 (0)
39740	2,4,5-T, total	1984-87	86	<0.1 - <0.2	<0.1	0 (0)
38745	2,4-DB, total	1984-87	86	<0.1 - <0.2	<0.1	0 (0)
39760	Silvex, total	1984-87	86	<0.1 - <0.2	<0.1	0 (0)
			Triazine herbicides			
39025	Simazine, total	1987	4	0.02 - 0.11	0.02	3 (75)
39630	Atrazine, total	1978-86	59	ND - 2.0	0.1	26 (44)
39632	Atrazine, dissolved	1987	4	0.02 - 0.07	0.02	3 (75)
			Carbamate insecticide			
39750	Carbaryl, dissolved	1975	11	<5 - 50	<5	3 (27)
			Organochlorine insecticides and their metabolites			
39300	P,P' DDT, total	1980-90	197	ND - <0.02	<0.01	0 (0)
39305	O,P' DDT, total	1979-82	101	ND	--	--
39310	P,P' DDD, total	1979-90	197	ND - <0.02	<0.01	0 (0)
39315	O,P' DDD, total	1979-82	101	ND	--	--
39320	P,P' DDE, total	1980-90	197	ND - <0.2	<0.01	0 (0)
39327	O,P' DDE, total	1979-90	101	ND	--	--
39330	Aldrin, total	1970-90	271	ND - <0.6	<0.01	23 (9)
39340	Lindane, total	1979-90	96	<0.01 - <0.2	<0.01	0 (0)
39380	Dieldrin, total	1970-90	210	ND - <0.3	<0.01	8 (4)
39390	Endrin, total	1970-90	202	ND - <0.2	<0.01	0 (0)
39400	Toxaphene, total	1970-90	99	ND - <1.0	<0.1	0 (0)
39410	Heptachlor, total	1970-90	101	<0.01 - <0.20	<0.01	0 (0)
39420	Heptachlor epoxide, total	1970-90	101	<0.01 - <0.20	<0.01	1 (1)
39480	Methoxychlor, total	1970-82	105	ND - <0.6	<0.2	1 (1)
34696	Naphthalene, total	1980-87	8	<10	<10	0 (0)

Table 7. Summary of surface water-quality pesticide data from the U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) database, water years 1970-92

[µg/L, microgram per liter; <, less than; ND, not detected; --, no value; 2,4,5-T, 2,4,5-trichlorophenoxyacetic acid; DCPA, dacthal,chlorthal-dimethyl; EPTC, S-Ethyl dipropylthiocarbamate; DDE, dichlorodiphenyldroethylene; DDD, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane; DDT, dichlorodichloroethylene]

Parameter code	Common pesticide name	Water years	Number of observations	Range of concentrations (µg/L)	Minimum reporting limit (µg/L)	Number (and percent) of observations above the reporting limit
			Organophosphorus defoliant			
39040	Tribufos, total	1989 - 1992	106	<0.01	<0.01	0 (0)
			Chloroacetnalilide herbicides			
04024	Propachlor, dissolved	1992	39	ND	--	--
39415	Metolachlor, dissolved	1992	45	0.01 - 0.87	0.01	39 (87)
46342	Alachlor, dissolved	1992	45	0.01 - 3.2	0.01	40 (89
			Amide or substituted amide herbicides			
82676	Pronamide, dissolved	1992	39	ND - 0.02	<0.01	3(8)
82679	Propanil, dissolved	1992	39	ND	--	--
82684	Napropamide, dissolved	1992	39	ND - 0.04	<0.01	29 (74)
			Chlorophenoxy-acid herbicides			
39740	2, 4, 5-T, total	1976 - 1992	54	ND-<0.01	<0.01	0 (0)
39760	Silvex, total	1976 - 1988	54	ND-<0.01	<0.01	0 (0)
			Dinitroaniline or nitroaniline herbicides			
82661	Trifluralin, dissolved	1992	39	ND - 0.03	0.01	1 (3)
82663	Ethalfluralin, dissolved	1992	39	ND-<0.01	<0.01	1 (3)
82683	Benefluralin, dissolved	1992	39	ND - 0.01	0.01	0 (0)
82683	Pendimethalin, dissolved	1992	39	ND-<0.04	<0.01	4 (10)
			Phenylureas or substituted urea herbicides			
82666	Linuron, dissolved	1992	39	<0.01 - 0.05	<0.01	7 (18)
82670	Tebuthiuron, dissolved	1992	39	ND-<0.18	<0.01	19 (49)
			Phthalic acid herbicide			
82682	DCPA, dissolved	1992	39	ND-<0.05	<0.01	0 (0)
			Thiocarbamate herbicides			
04028	Butylate, dissolved	1992	39	ND - 0.02	0.01	1 (3)
82668	EPTC, dissolved	1992	39	ND - 0.02	0.01	1 (3)
82669	Pebulate, dissolved	1992	39	ND - 0.01	<0.01	1 (3)
82671	Molinate, dissolved	1992	39	ND	--	--
82861	Thiobencarb, dissolved	1992	39	ND - 0.01	<0.01	0 (0)
			Triazine herbicides and their metabolites			
39025	Simazine, total	1992	29	ND	--	--
04035	Simazine, dissolved	1992	45	ND - 0.46	<0.01	24 (62)
04036	Prometryn, dissolved	1992	6	<0.05	<0.05	0 (0)
04037	Prometon, dissolved	1992	45	0.01 - 0.68	0.01	38 (84)
04038	Deisopropylatrazine, dissolved	1992	6	<0.05	<0.05	0 (0)
04040	Desethylatrazine, dissolved	1992	45	<0.02 - 0.05	<0.02	4 (9)
39630	Atrazine, total	1976 - 1978	40	ND - 0.6	0.6	0 (0)
39632	Atrazine, dissolved	1992	45	0.01 - 1.8	0.01	39 (82)
04041	Cyanazine, dissolved	1992	45	ND-<0.02	<0.01	12 (26)

Table 7. Summary of surface water-quality pesticide data from the U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) database, water years 1970-92—Continued

[µg/L, microgram per liter; <, less than; ND, not detected; --, no value; 2,4,5-T, 2,4,5-trichlorophenoxyacetic acid; DCPA, dacthal,chlorthal-dimethyl; EPTC, S-Ethyl dipropylthiocarbamate; DDE, dichlorodiphenyldroethylene; DDD, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane; DDT, dichlorodichloroethylene]

Parameter code	Common pesticide name	Water years	Number of observations	Range of concentrations (µg/L)	Minimum reporting limit (µg/L)	Number (and percent) of observations above the reporting limit
	Triazine herbicides and their metabolites—Continued					
38401	Ametryn, dissolved	1992	6	<0.05	<0.05	0 (0)
38535	Propazine, dissolved	1992	6	<0.05	<0.05	0 (0)
82630	Metribuzin, dissolved	1992	45	ND - <1.0	<1.0	34 (76)
	Uracil and substitute uracil herbicide					
82665	Terbacil, dissolved	1992	39	<0.01 - 0.01	<0.01	1 (3)
	Carbamate insecticides					
82680	Carbaryl, dissolved	1992	39	ND - 0.03	<0.01	15 (38)
82674	Carbofuran, dissolved	1992	39	ND - 0.02	<0.01	3 (8)
	Organochlorine insecticides and their metabolites					
39330	Aldrin, total	1970 -1992	302	ND-<0.01	<0.001	0 (0)
39340	Lindane, total	1970 - 1992	302	ND-<0.01	<0.001	16 (5)
39341	Lindane, dissolved	1992	39	ND - 0.08	<0.01	8 (20)
39350	Chlordane, total	1970 - 1992	302	ND - <0.1	<0.1	0 (0)
39365	DDE, total	1970 - 1992	302	ND-<0.01	<0.001	0 (0)
34653	P,P' DDE, dissolved	1992	39	ND - 0.01	<0.01	1 (3)
39034	Perthane, total	1970 - 1992	198	ND - <0.1	<0.1	0 (0)
39360	DDD, total	1970 - 1992	302	ND-<0.01	<0.001	0 (0)
39370	DDT, total	1970 - 1992	302	ND-<0.01	<0.001	3 (1)
39380	Dieldrin, total	1970 - 1992	301	ND - 0.08	<0.001	22 (7)
39381	Dieldrin, dissolved	1992	39	<0.02 - 0.2	<0.02	2 (5.1)
39388	Endosulfan I, total	1970 - 1992	204	ND -<0.01	<0.001	0 (0)
39390	Endrin, total	1970 - 1992	301	ND - 0.01	<0.01	1 (<1)
39398	Ethion, total	1970 - 1992	284	ND - <1.0	ND - <1.0	0 (0)
39400	Toxaphene, total	1970 - 1992	302	ND - <1.0	<0.1	0 (0)
39410	Heptachlor, total	1970 - 1992	302	ND -<0.01	<0.001	0 (0)
39420	Heptachlor epoxide, total	1970 - 1992	302	ND -<0.01	<0.001	3 (1)
39480	Methoxychlor, total	1970 - 1992	296	ND-<0.02	<0.01	0 (0)
39755	Mirex, total	1978 - 1992	203	ND-<0.01	<0.01	0 (0)
82662	Dimethoate, dissolved	1992	39	<0.02-<0.05	<0.02	1 (3)
	Organophosphate insecticides					
39011	Disulfoton, dissolved	1989 - 1992	106	<0.01	<0.01	0 (0)
39023	Phorate, total	1989 - 1992	106	<0.01	<0.01	0 (0)
38932	Chlorpyrifos, total	1990 - 1991	59	<0.01 - 0.01	<0.01	5 (11)
38933	Chlorpyrifos, dissolved	1989 - 1992	39	ND - 0.01	<0.01	4 (10)
39530	Malathion, total	1973 - 1990	284	ND - 0.01	<0.01	0 (0)
39532	Malathion, dissolved	1992	86	ND - 0.01	<0.01	2 (2)
39540	Parathion, total	1973 - 1992	284	ND-<0.01	<0.01	0 (0)
39542	Parathion, dissolved	1992	39	ND-<0.01	<0.01	0 (0)
39570	Diazinon, total	1973 - 1992	284	ND - 0.25	<0.01	20 (7)

Table 7. Summary of surface water-quality pesticide data from the U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) database, water years 1970-92—Continued

[µg/L, microgram per liter; <, less than; ND, not detected; --, no value; 2,4,5-T, 2,4,5-trichlorophenoxyacetic acid; DCPA, dacthal,chlorthal-dimethyl; EPTC, S-Ethyl dipropylthiocarbamate; DDE, dichlorodiphenyldroethylene; DDD, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane; DDT, dichlorodichloroethylene]

Parameter code	Common pesticide name	Water years	Number of observations	Range of concentrations (µg/L)	Minimum reporting limit (µg/L)	Number (and percent) of observations above the reporting limit
			Organophosphate insecticides—Continued			
39572	Diazinon, dissolved	1992	39	ND - 0.03	<0.01	7 (18)
39786	Ethyl trithion, total	1973 - 1992	284	ND - <0.01	<0.01	0 (0)
39790	Methyl trithion, total	1973 - 1991	268	ND - <0.01	<0.01	0 (0)
82614	Fonofos, dissolved	1990 - 1992	59	<0.01	<0.01	0 (0)
82664	Phorate, dissolved	1992	39	<0.02 - <0.06	<0.02	1 (3)
82672	Ethoprop, dissolved	1992	39	ND - 0.01	0.01	0 (0)
82675	Terbufos, dissolved	1992	39	<0.01 - <0.05	<0.01	0 (0)
82667	Methyl parathion, dissolved	1992	39	<0.05 - 0.1	<0.05	1 (3)
			Organosulfur insecticide			
82685	Propargite, dissolved	1992	39	<0.01 - <0.02	<0.01	1 (3)
			Pyrethroid insecticide			
82687	Permethrin, dissolved	1992	39	ND - <0.01	<0.01	1 (3)

project was to assess the effects of stream channelization on the hydrology and water quality in the Chicod Creek Basin (sites t10, t11, t12, and t13). Six to nine pesticide water samples were collected from 1976 to 1981 at each of four stations in the Chicod Creek Basin. The majority of the pesticides monitored were at or less than reporting limits. Mason and others (1990) reported that dieldrin, DDT, DDE, and DDD were the most commonly detected compounds in bed-sediment samples.

In 1992, the Chicod Creek Basin, a tributary to the Tar River, was selected as a field-test site for solid-phase extraction procedures for organonitrogen herbicides. Pesticide water samples were collected either weekly or three times a week at one station in the Chicod Creek Basin from May to September 1992. Sampling methods are discussed by Manning and others (1994). The most commonly detected herbicides were atrazine, alachlor, metolachlor, prometon, and metribuzin. No relation between streamflow and pesticide concentrations was noted (M.D. Woodside, U.S. Geological Survey, written commun., 1994). Concentrations of atrazine increased in late May and early June and decreased gradually until September. During the study period, no pattern was observed for concentrations of alachlor, metolachlor, prometon, and metribuzin.

During water years 1988-92, water-quality samples were collected for organochlorine and organophosphorus pesticides at various frequencies at 18 stations in the Raleigh-Durham and Chapel Hill, N.C., area as part of the Triangle Area Water-Supply Monitoring Project (Garrett and others, 1994). Surface water serves as the primary drinking-water source for approximately 30 municipalities in the Research Triangle area. The rapid urban and industrial growth in the area has the potential of affecting the quality of the surface-water drinking supplies. Over 2,000 permitted discharges are upstream from two of the major drinking-water supplies in the Research Triangle area. Most of the organochlorine and organophosphorus pesticide concentrations were less than the reporting limits.

Sheets and others (1970) proposed a monitoring program for pesticides in North Carolina. The monitoring program was based on water samples collected from August 1967 to October 1968 at 13 estuarine stations in the lower Neuse and White Oak River Basins and at 9 stations in the Tar River Basin. Dieldrin; p,p'-DDE; o,p'-DDT; p,p'-DDD; p,p'-DDT;

and total DDT were selected for testing the proposed monitoring program. Of the 162 water samples collected in the Tar River Basin, 34 (21 percent) had concentrations of total DDT greater than 0.040 microgram per liter (μg/L). Concentrations of total DDT ranged from less than 0.040 to 65 μg/L. Six percent of the water samples collected in the Tar River Basin had concentrations of dieldrin greater than 0.010 μg/L, and concentrations ranged from less than 0.01 to 0.10 μg/L. The Tar River at Louisburg station had the greatest frequency of insecticide detections; 10 of 23 samples (43 percent) had concentrations greater than the reporting limit for one or more insecticides. Sheets and others (1970) also reported that the peak concentrations of monitored insecticides usually occurred in the spring and late summer.

Sheets and others (1972) studied the movement of trifluralin, DDT, toxaphene, and methyl parathion in surface runoff and in one farm pond draining test plots of cotton at two locations in the inner Coastal Plain. They reported that high percentages of the compounds studied were associated with sediment fraction in the surface-water runoff (DDT, 96 percent; trifluralin, 84 percent; toxaphene, 75 percent; and methyl parathion, 12 percent). Nevertheless, the range of dissolved pesticide concentrations was large, and concentrations exceeded acute toxicity levels on occasion.

Harned (1994) monitored selected pesticides commonly used in tobacco cultivation in four small Piedmont basins in Guilford County, N.C., from 1985 to 1990. Three insecticides (acephate, ethoprop, and fenamiphos), two herbicides (diphenamid and napropamide), a fungicide (metalaxyl), and a growth regulator (flumetralin) were monitored in runoff, soil, and ground water. Pesticides were applied beginning in March, peaking in July, and ending in September. The greatest number of detections of the selected pesticides was in soil and runoff from the tobacco fields; fewer detections were noted in a larger, mixed land-use basin, and no detections were noted in a forested basin.

Ground Water

Considerably less nutrient and pesticide data are available for ground water than for surface water. Most available data on nitrogen in ground water are for nitrate, the oxidized form of nitrogen commonly monitored for public health concerns. (Nitrate can cause methemoglobinemia in babies.) Dissolved nitrate data were collected from wells shown in figure 50. The database source of more than 60 percent of the nitrate data used in this analysis is STORET. These data were collected from wells between 1966 and 1990 (table 3). The remaining nitrate data were obtained from the USGS WATSTORE database. However, paper copies of some analyses from the North Carolina Piedmont were obtained from the North Carolina Division of Environmental Management (DEM) and used as part of the USGS Appalachian-Piedmont Regional Aquifer System Analysis (APRASA) program (Harned, 1989). In general, nitrate data were available for many areas of the Inner and Outer Coastal Plain hydrogeologic zones and the Valley and Ridge carbonates and clastics zone, but few data were available for other zones (fig. 50). Most data referred to in this report were collected before 1980 (compare fig. 7 with fig. 50), and most of the more recent data (after 1980) and better areal coverages are for Virginia (fig. 8).

Phosphorus data are generally reported as total phosphorus, although most of the phosphorus in ground water is assumed to be in the dissolved form. Total phosphorus data were collected at wells shown in figure 51. Most phosphorus data are for areas in the Coastal Plain hydrogeologic zones of Virginia, Blue Ridge and Piedmont granitic and slate belt rocks zones of North Carolina, and Valley and Ridge carbonates and clastics zone of Virginia. Only a few scattered sites have phosphorus data for the Coastal Plain zones of North Carolina. As with nitrate data, more phosphorus data are available for years prior to 1980; most data available during and after 1980 are for Virginia (figs. 7, 8, and 51). Available pesticide data are sparse and are limited to the results of a few studies conducted since 1972. The following discussion of nutrients and pesticides data for the Albemarle-Pamlico study area is based on data collected during the entire period of record.

Nitrate

Sources of nitrate in ground water are varied. Natural sources of nitrate are derived from the atmosphere, plant and animal matter, and geologic deposits. Anthropogenic sources of nitrate are nitrogen fertilizers, waste materials, and industrial processes of various kinds. Prevalent geochemical conditions determine the form that nitrogen takes in ground water. Generally, in shallow ground water having low

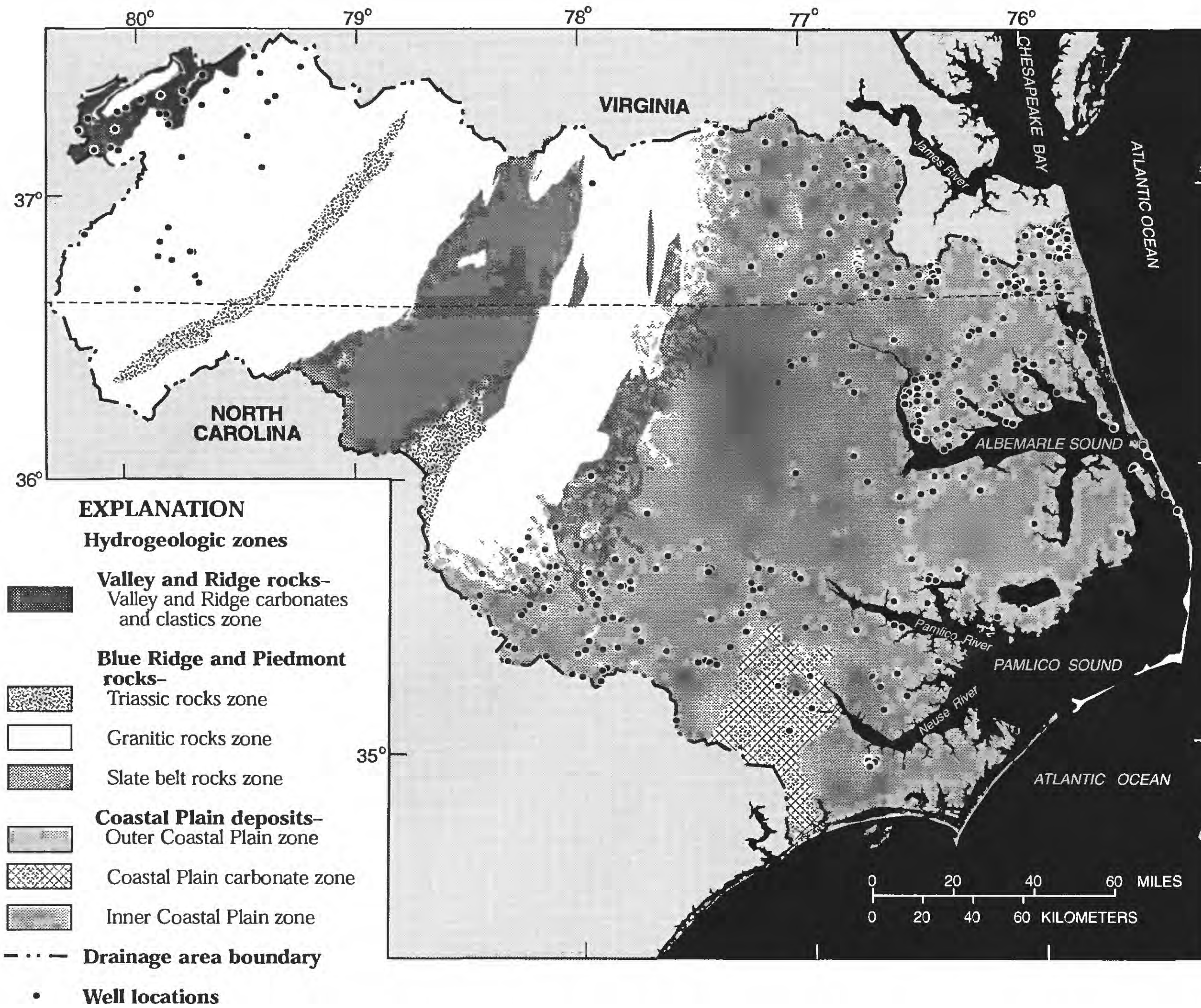


Figure 50. Locations of wells where dissolved nitrate nitrogen data were collected, Albemarle-Pamlico drainage study area, 1950-90.

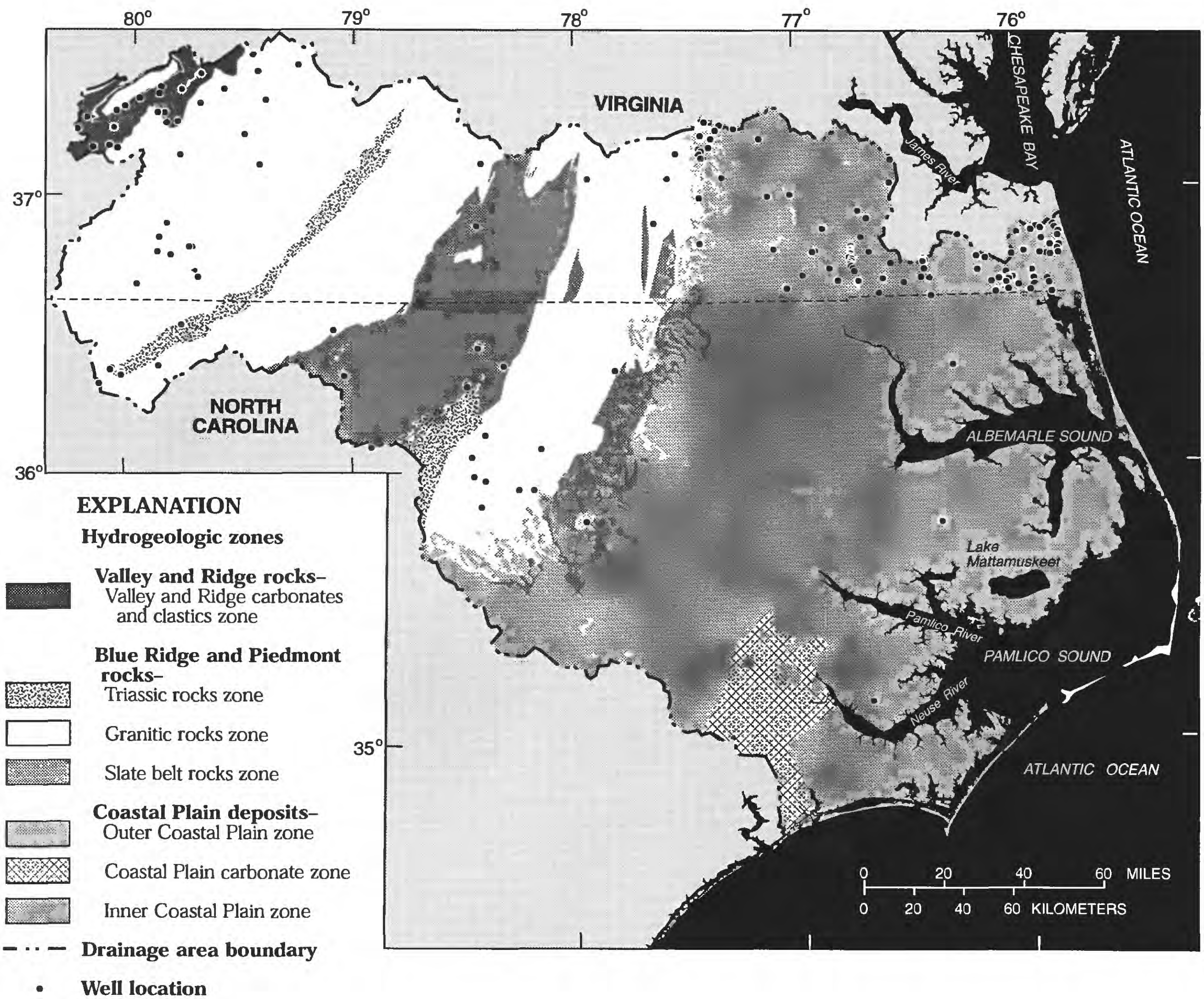


Figure 51. Locations of wells where dissolved phosphorus data were collected, Albemarle-Pamlico drainage study area, 1950-90.

concentrations of organic carbon and rapid water movement, nitrogen occurs as dissolved nitrate. In slow moving ground water having large concentrations of organic carbon and low oxygen content, and in confined aquifers with low oxygen content, nitrogen occurs in reduced forms, such as ammonia. Nitrate concentrations in these conditions tend to be relatively low. Most ground water, which is affected by human activities, usually contains less than 3 mg/L of nitrate as nitrogen (Madison and Brunette, 1985). The current (1994) USEPA maximum contaminant level (MCL) for nitrate nitrogen has been set at 10 mg/L. Other environmental hazards relate to increased nitrate concentrations in surface water derived from base flow, which in turn drains to the coastal sounds. Increased nitrate is considered to be limiting to the growth of some macrophytes in the sounds, while simultaneously encouraging algal growth, thereby causing oxygen depletion in the sounds as algae die off.

Median concentrations of nitrate in ground water in four of the seven hydrogeologic zones in the Albemarle-Pamlico study area were less than 0.5 mg/L (fig. 52). Adequate data (more than 10 observations) were available in only four of the zones. In each of these zones, 90th-percentile concentrations of nitrate in water samples collected from wells ranged from 0.75 mg/L in the Outer Coastal Plain zone to more than 4 mg/L in water samples from wells in the granitic rocks zone of the Piedmont. Median concentrations were largest and variability was greatest in fractured rock aquifers of the Valley and Ridge carbonates and clastics and granitic rocks zones.

If nitrate is derived from surficial sources, concentrations would be expected to be greater in shallow wells than in deep wells. This phenomenon is apparent in figure 53, which shows that shallow wells (less than 100 ft deep) had the greatest concentrations and variability, and deep wells (more than 100 ft deep) had the least concentrations and variability. These data indicate that, in general, nitrate is derived from surficial sources.

The occurrence of greatest concentrations and variability of nitrate in fractured rock environments suggests that surficial contamination potential is greatest in these types of environments. Water can move very rapidly in fractures, as compared with unconsolidated media, and little filtering or biological uptake or denitrification occurs in such environments.

Median concentrations of nitrate nitrogen are lowest in the Inner and Outer Coastal Plain hydrogeologic zones and are generally less than 0.5 mg/L (fig. 52). In general, nitrate concentrations in the Outer Coastal Plain zone are lower than those in the

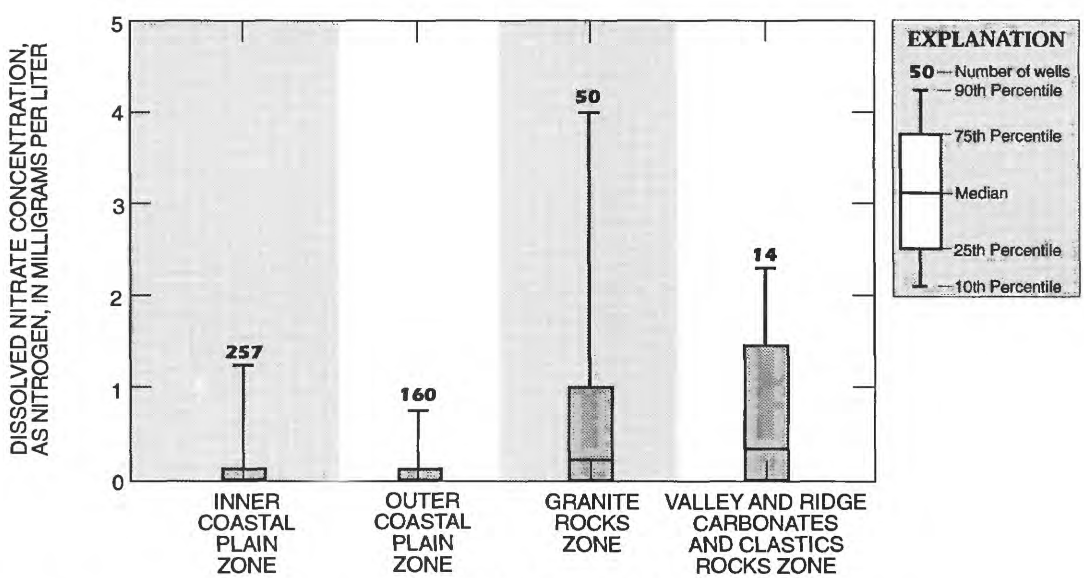


Figure 52. Dissolved nitrate concentrations in ground water, in selected hydrogeologic zones, in the Albemarle-Pamlico drainage study area, 1950-90.

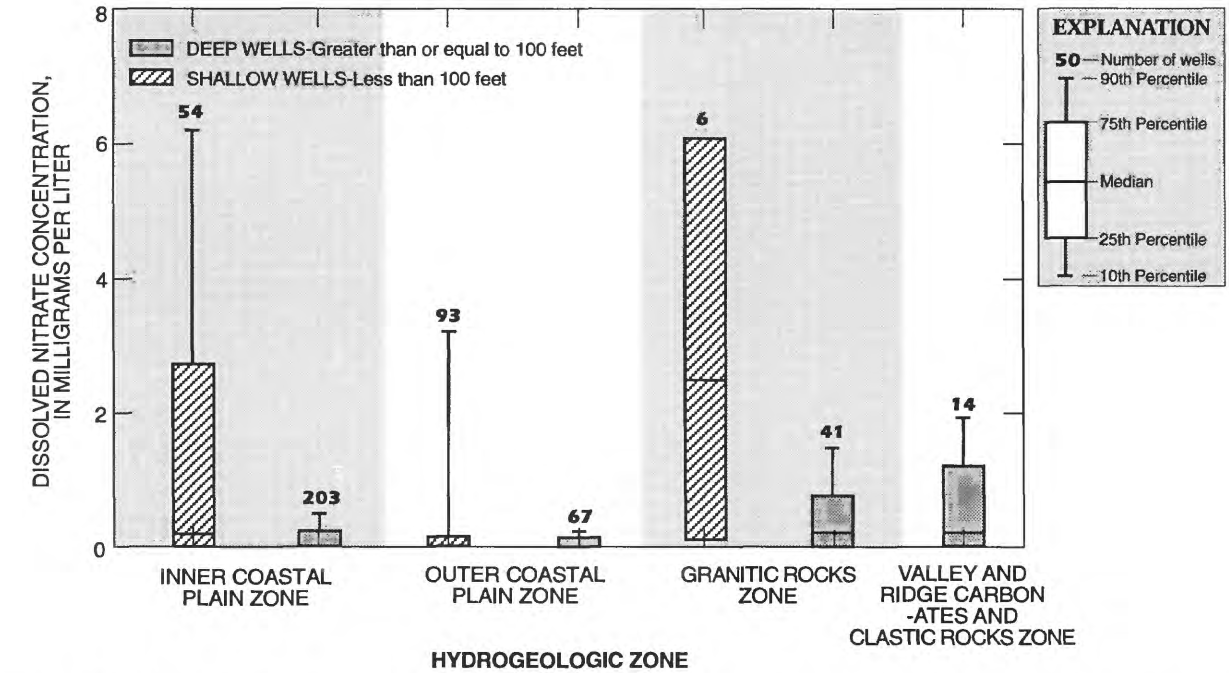


Figure 53. Dissolved nitrate concentrations in ground water, by depth, in selected hydrogeologic zones in the Albemarle-Pamlico drainage study area, 1950-90.

Inner Coastal Plain zone (fig. 53), probably because of vast Coastal Plain swamps, flat terrain with fine-grained, poorly transmissive sediments, and low hydraulic gradients. Dissolved-oxygen concentrations are relatively low (less than 1 mg/L), and organic carbon concentrations are high (greater than 2 mg/L) in ground water in these geologic environments. Geochemically, ground water in these environments is characterized as reducing and would be conducive to denitrification. Also, plant uptake is possibly more efficient in the Outer Coastal Plain zone because water tables tend to be shallower than in the Inner Coastal Plain zone, and roots of crops and native plants can actively take up nitrogen.

Nitrate concentrations can be affected by factors other than predominant hydrogeology. Nitrate can originate from several anthropogenic sources. Leakage from septic tanks, feedlots, and fertilizer applications in rural areas can be sources of nitrate to ground water. Effects of land use on nitrate concentrations could be evaluated for only a few land-use categories (fig. 54). A Kruskal-Wallis test (Conover, 1980) was applied to the data using categories shown in figure 54. Significant differences were detected between nitrate nitrogen concentrations at the 99-percent confidence level ($p = 0.007$) for categories shown in figure 54. The largest concentrations and maximum variability of nitrate concentrations occurred in the agricultural and residential categories. These data suggest that activities associated with agriculture can affect nitrate concentrations in ground water. However, more recent and comparable ground-water quality data are needed, particularly in North Carolina, to properly evaluate effects of land use and to evaluate long-term trends.

Phosphorus

Sources of phosphorus in ground water have a variety of natural and anthropogenic origins (Hem, 1985). Phosphorus is a common element of igneous rocks but also can be abundant in sediments. Although phosphorus can occur in several oxidation states, the fully oxidized form (phosphate) is the most important in most natural water systems. The most common mineral form, apatite, or calcium phosphate, can occur in many types of rocks. An important mineral form in sedimentary rocks is phosphorite, an impure form of calcium phosphate. Phosphorites are important sources of commercial phosphorus for fertilizer production and are mined on the southern bank of the Pamlico River in North Carolina. Anthropogenic sources of phosphorus include animal wastes, which are a principal water

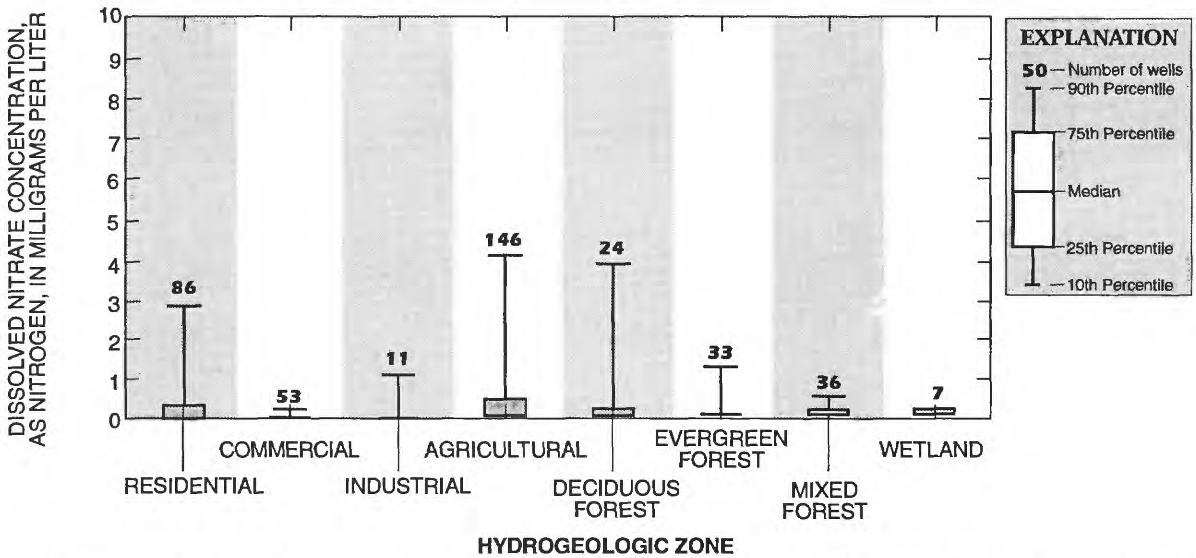


Figure 54. Dissolved nitrate concentrations in ground water, by land use, in the Albemarle-Pamlico drainage study area, 1950-90.

contaminant released from untreated sewage, and agricultural fertilizers. Phosphorus also was used for many years in detergents and was a major source of phosphorus to surface-water discharge from sewer lines and septic systems.

Phosphorus in water includes dissolved and particulate forms. In general, total phosphorus includes particulate (various mineral forms) and dissolved (primarily orthophosphate forms).

For hydrogeologic zone categories with sample sizes greater than 10 in the Albemarle-Pamlico study area, 90 percent of phosphorus concentrations in ground water are less than 1 mg/L (fig. 55). Comparison of total phosphorus concentrations in ground water from four hydrogeologic zones depicted in figure 55 indicates that the greatest variability and median concentrations are in water from the Inner (0.25 mg/L) and Outer (0.2 mg/L) Coastal Plain hydrogeologic zones. Median concentrations from the granitic rocks zone and Valley and Ridge carbonates and clastic zones are less than 0.2 mg/L. The least concentrations and variability occurred in ground water from the granitic rocks zone.

Analyses of phosphorus concentrations by depth categories (shallow equals less than 100 ft deep; deep equals more than 100 ft deep) (fig. 56) indicate that the largest concentrations are in the Inner and Outer Coastal Plain hydrogeologic zones. Reasons for differences in phosphorus concentrations relate to the occurrence of natural phosphorites in the deeper Coastal Plain sediments. Deep formations of the Coastal Plain, primarily pre-Miocene-age deposits, contain deposits of phosphorites which are commercially mined in Beaufort County, N.C. These concentrations are well above those observed in the other hydrogeologic zones represented in figure 56. These data imply that concentrations of phosphorus in shallow ground water are below or at the detection limit of 0.010 mg/L and are typically not affected by agricultural fertilizers and other anthropogenic sources. Because phosphate has a propensity to be incorporated into plant tissues or to be sorbed onto particular soils (Hem, 1985), it does not easily leach from land surface into ground water. Phosphorus typically tends to be a greater problem in surface water because it is transported on sediment eroded from hillsides and fields.

According to the available data set, land use had no apparent effect on phosphorus concentrations. A Kruskal-Wallis test was applied to the data by using land-use categories shown in figure 57. No significant differences were detected at the 95-percent confidence level ($p = 0.07$). These data also suggest that anthropogenic activities do not appear to significantly affect phosphorus concentrations in ground water. However, because of the long time period included in the data set (1950-90), these findings may not reflect current (1994) land-use conditions. The data also are geographically limited and may not represent the entire Albemarle-Pamlico study area.

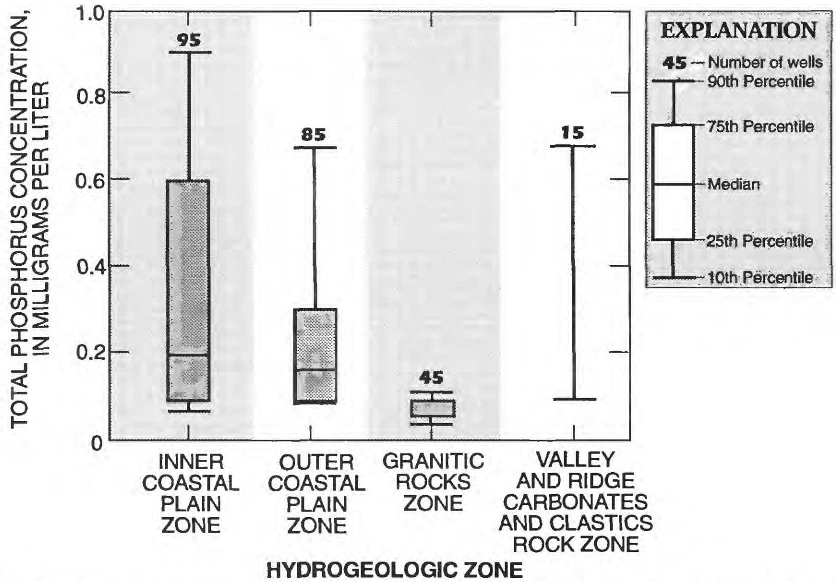


Figure 55. Total phosphorus concentrations in ground water in selected hydrogeologic zones in the Albemarle-Pamlico drainage study area, 1950-90.

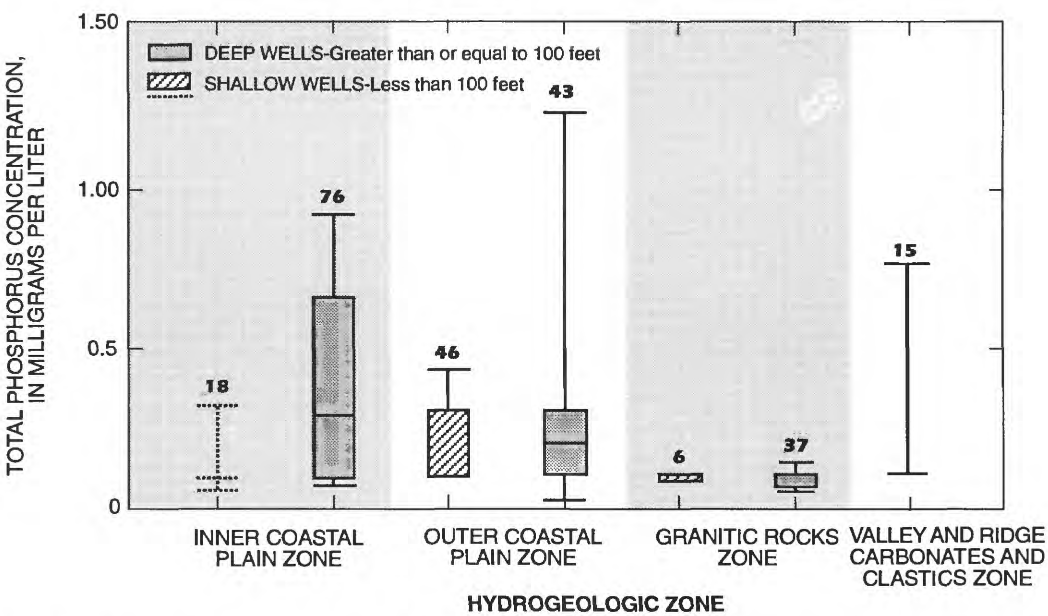


Figure 56. Total phosphorus concentrations in ground water, by depth, in selected hydrogeologic zones in the Albemarle-Pamlico drainage study area, 1950-90.

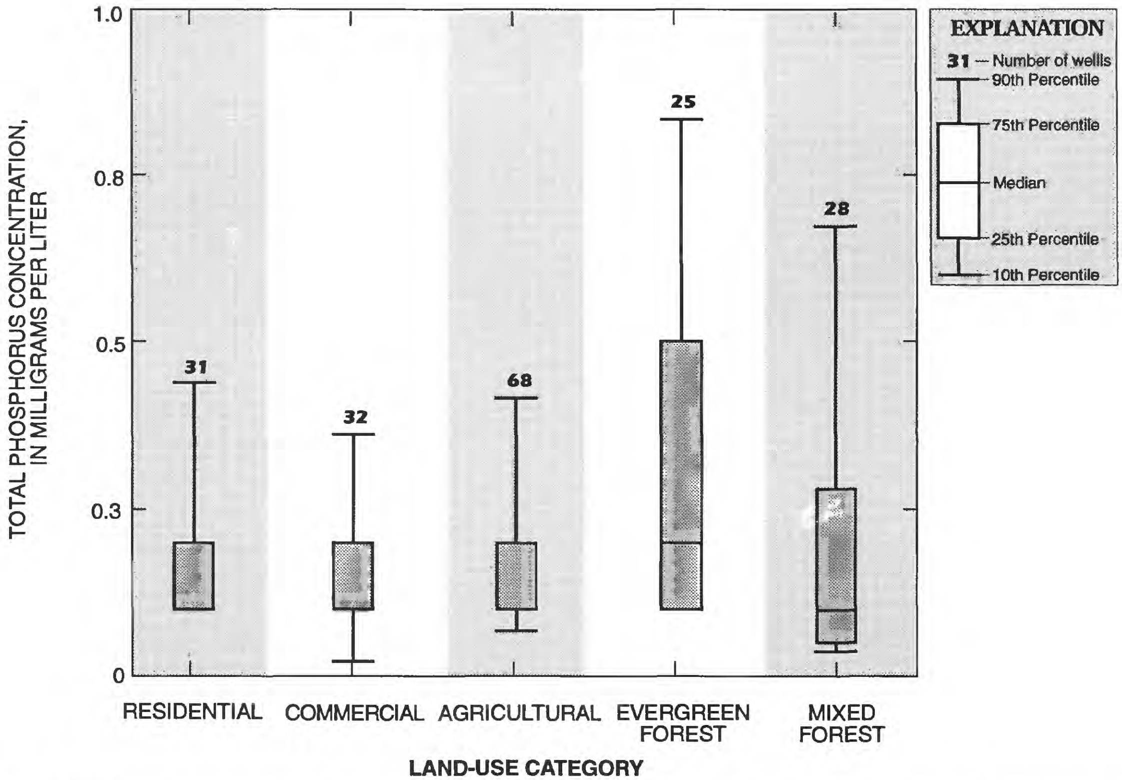


Figure 57. Total phosphorus concentrations in ground water, by land use, in the Albemarle-Pamlico drainage study area, 1950-90.

Pesticides

Neither STORET nor WATSTORE contained data on pesticides in ground water within the study area. Published information on the occurrence of pesticides in ground water in the study area is generally sparse. Only a few studies investigating pesticides in North Carolina ground water have been conducted since about 1970. These studies include Sheets and others (1972), Jennings and others (1991), and Maas and others (1992). A study was conducted by the Sussex County Health Department in 1979 in the Virginia part of the Albemarle-Pamlico study area. The study addressed ground-water contamination by dibromochloropropane (DBCP) (U.S. Environmental Protection Agency, 1992). DBCP was detected in water from the well at a newly constructed home and was attributed to contamination from the plumbing. Following is a summary of findings in current literature on pesticides in ground water in the study area.

The earliest study (Sheets and others, 1972) did not detect methyl parathion (detection limit = 1 µg/L); trifluralin (detection limit = 0.05 µg/L); or toxaphene (detection limit = 1 µg/L) in water from five wells. The wells were in cotton fields treated with these pesticides and DDT, and were located in Lewiston and Rocky Mount, N.C. The wells ranged from 4 to 12 ft deep and were sampled in March, July, August, September, and December 1970. These insecticides, detected primarily in surface runoff and pond water, are relatively insoluble and do not easily leach into ground water.

A study of 104 wells in eastern North Carolina during 1982-83 by the North Carolina Department of Agriculture detected concentrations of aldicarb in several wells (U.S. Environmental Protection Agency, 1992). For this study, 164 samples were collected from 104 domestic-supply wells in Cumberland, Edgecombe, Gates, Halifax, Northampton, Martin, Pitt, and Scotland Counties. Aldicarb was detected in 12 samples from 8 of these wells. Most wells were located within 600 ft of aldicarb-treated areas. Detectable aldicarb was in water samples from wells that were located between 30 and 276 ft from cotton fields and ranged in depth from 20 to 50 ft (Interagency Working Committee on Groundwater Monitoring for the North Carolina Pesticide Board, written commun., October 26, 1988).

Harned (1994) compared selected pesticide concentrations in ground water from a Piedmont tobacco field where conservation land-management practices were used to a field where standard land-management practices were used during 1985-90. Detection of eight different pesticides commonly used for tobacco cultivation generally occurred in less than 10 percent of the ground-water samples, except for fenamiphos, an organophosphate insecticide, which was detected in about 20 percent of the ground-water samples. No statistical difference was observed in ground-water concentrations of pesticides for the two fields where different land-management strategies were used. The greatest numbers of pesticide detections were observed in the top 9 inches (in.) of soil, compared to soil at greater depths and ground water.

A recent pesticide study in North Carolina within the Albemarle-Pamlico study area was reported by Maas and others (1992). Objectives of the study were to (1) provide an estimate of the prevalence of pesticides in well water in eastern North Carolina; (2) determine relations between distances from wells to nearest crop, percentages of surrounding land with pesticide application, depths of wells, and distance to pesticide and loading areas from the wells; (3) determine relations between nitrate and pesticides, depths of wells, and distance to pesticide loading and mixing areas; and (4) observe variability of pesticide concentrations through time. Samples were generally collected in June and July. Samples were collected in 1-liter brown glass bottles with Teflon-lined caps, and preserved with mercuric chloride. Water samples were collected from exterior home spigots following a 60-second purge.

Based on results from Maas and others (1992), alachlor and atrazine were detected in the largest percentage of wells. Of the five pesticides detected in eastern North Carolina well water, 16.5 percent, or 23 of the 139 wells, had one or more of the five detected pesticides. Study results also indicated that no statistically significant relation (alpha = 0.05) was found between distance from well to loading and pesticide storage areas for either alachlor or atrazine. A significant relation was observed between distance from the well to the nearest crop and alachlor concentrations in well water, but not between distance to the nearest crop and atrazine concentrations.

In addition to evaluating the areal occurrence of detectable concentrations in ground water, Maas and others (1992) investigated the persistence of pesticides in ground water. Eight wells having detectable concentrations of pesticides in June 1991 were resampled in October 1991 and January 1992. Although the data set was small and no discernible seasonal pattern was evident in the eight wells sampled, small concentrations of atrazine and aldicarb were detected throughout the sampling period.

The Interagency Pesticide Ground (IPG) Water Study Work Group (1993) reported the most recent results pertaining to their study of pesticides in ground water. Of 56 wells sampled between 1991 and 1993 during phase I of the study (composed of ambient monitoring wells jointly constructed and managed by the USGS and DEHNR), 14 had pesticide applications within the last 5 years and 3 of these 14 had one sample that tested positive for pesticides other than those applied. Pesticides were detected in six other ambient wells, yet pesticide applications had not occurred within 300 ft of these wells over the last 5 years. The same analyte was detected twice in one well. In 35 wells, none of the 152 pesticides analyzed were detected, and none of these pesticides had been applied within 300 ft of the wells for the last 5 years. One or more organic compounds was detected in 10 of the 56 wells. In locations where wells had positive detections in the study area, 2,4,5-T, DDT, metribuzin, and hexazinone were the only compounds used for crop applications. Although they are industrial organic compounds, pentachlorophenol (a wood preservative) and arochlor 1260 (a PCB compound) were detected in three wells. The IPG data for wells in the Albemarle-Pamlico study area are summarized in table 8. During phase II of the study, sampling is being conducted in 100 wells installed in areas of specific land uses. DDT and a breakdown product, DDD, occurred in water from three wells installed during phase II in the study area. These compounds (as well as 2,4,5-T in the ambient monitoring well) have very low solubility in water and probably occur in the sample as sediment from the well (because the samples are not filtered).

Because of potential effects of pesticides on human and environmental health, the need for pesticide research in the Albemarle-Pamlico study area is substantial. Too few samples over too small of an area exist to statistically evaluate the occurrence of pesticides in ground water in the Albemarle-Pamlico study area. Additional data on pesticides in the study area are needed in order to assess potential problems and to determine appropriate management procedures. Without knowledge of the occurrence of pesticides in ground water in the Albemarle-Pamlico drainage basin, anticipation or remediation of potential problems will not be possible.

Table 8. Compounds detected in water samples from wells in the Albemarle-Pamlico drainage study area during phase I of the Interagency Pesticide Ground Water Study (1993)
[µg/L, microgram per liter; est, estimated value; *, concentration less than lower quantification limit]

North Carolina county	Well number	Well depth (feet)	Compound detected	Concentration (µg/L)
Pitt	G28	132	2,4,5-T	est 0.02*
Jones	G35	15	DDT	est 0.02*
Carteret	G12	191	metribuzin	4.5
Gates	G13	565	pentachlorophenol	est 0.012*
Lenoir	G34	490	pentachlorophenol, 2,4,5-T	est 0.07, 0.10*
Hertford	G41	570	arochlor 1260	0.61

TRENDS IN SURFACE-WATER QUALITY

An objective of this report is to summarize temporal trends in riverine water quality in the Albemarle-Pamlico drainage basin. Available data for the study basins (table 1) were evaluated for monotonically increasing or decreasing trends for selected water properties and constituents, including suspended sediment, solids, and nutrients. The period of analysis of available data for trends was limited to 1980-89 to match the trend evaluations by Barnes and Davenport (1993) and by Belval (1993) as part of a coordinated national effort to summarize water quality in major rivers of the United States (U.S. Geological Survey, 1993).

The statistical test used for trend analysis was the seasonal Kendall test as described by Hirsch and others (1982) and Helsel (1993). The seasonal Kendall test is a nonparametric, or distribution free, procedure designed to detect monotonically (one direction) increasing or decreasing trends over time in water-quality data that show seasonality. The test compensates for seasonal water-quality variation, and only stations with sufficient seasonal data coverage were evaluated. Variation in water quality as a result of variation in streamflow also was accounted for in the cases where streamflow data were available. In general, only the USGS stations had available streamflow data (table 1). The method used for streamflow adjustment involved using residual values about a smoothed data curve of the water-quality constituent related to streamflow (Helsel, 1993). The method of curve smoothing used in streamflow adjustment and in presentation of data scatter-plot smoothing is Locally Weighted Scatter-Plot Smoothing (LOWESS) (Helsel, 1993). Although adjustments for streamflow for many of the stations tested for trends were not possible, variation in streamflow in the Albemarle-Pamlico drainage study area is strongly seasonal; therefore, the seasonal compensation used in the seasonal Kendall trend test at least accounts for the seasonal component in the variation of streamflow.

Results of trend analysis by Harned and Davenport (1990) of estuarine water quality for selected constituents provide a picture of generalized trends in the estuaries of the Albemarle-Pamlico drainage area. The results represent a different time period (1970-88) and different methods of data screening and grouping from the current (1994) study and, therefore, are only qualitatively comparable.

Results of the evaluation of water-quality trends during 1980-89 for the study basins are summarized in table 9. In the seasonal Kendall test used for this analysis, a significance level (alpha) of 0.05 was considered to show statistical significance of the trend test. Trend evaluation was possible using data for a limited number of stations with sediment data, and for solids and nutrients at most stations. There were not sufficient data to evaluate trends in pesticide concentrations.

LOWESS curves also are used to illustrate the character of the concentration trends. The seasonal Kendall trend test gives a statistical measure of the monotonic trend, but looking at scatter plots and the LOWESS curve through the data points allows visual identification of nonmonotonic changes. Values that are less than the detection limit (censored values) are shown on the scatter plots as open triangles.

Specific Conductance

Specific conductance values are a useful indirect measure of the relative amounts of chemical ions in solution. Increases in specific conductance in a stream would imply an increase in concentration of one or more of the major cations in the water including calcium, magnesium, sodium, and potassium, or of the major anions including bicarbonate, sulfate, chloride, or nitrate.

Table 9. Seasonal Kendall trend analyses for selected water-quality constituents in the Albemarle-Pamlico drainage study area, 1980-89

[0 indicates no monotonic trend detected; --, inadequate data for trend analysis; - indicates a monotonically decreasing trend; + indicates a monotonically increasing trend. STORET, U.S. Environmental Protection Agency Storage and Retrieval System; WATSTORE, U.S. Geological Survey National Water Data Storage and Retrieval System; NC, North Carolina State Highway]

Station name	Map location number (fig. 2)	Constituent															
		Specific conductance	Total solids	Suspended solids	Total nitrogen	Dissolved ammonia	Total ammonia	Total nitrite	Total nitrate	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Dissolved orthophosphorus	Total organic carbon	Dissolved potassium	Suspended sediment
Roanoke River Basin (r)																	
North Fork Roanoke River at Route 603, Va.	r1	0	--	0	0	--	-	0	0	0	--	0	--	-	--	--	--
South Fork Roanoke River at Ellison, Va.	r2	0	--	0	0	--	0	0	0	0	--	0	--	0	--	--	--
Roanoke River at LaFayette, Va.	r3	0	--	0	+	--	0	+	0	+	--	+	--	0	-	--	--
Roanoke River 14th Street Bridge at Roanoke, Va.	r5	-	--	0	+	--	0	+	+	+	--	+	--	0	-	--	--
Tinker Creek at Glebe Mills, Va.	r6	0	--	0	0	--	0	0	+	0	--	0	--	0	--	--	--
Smith Mountain Lake at Hardy's Ford, Va.	r8	-	--	-	0	--	0	0	0	0	--	0	--	0	-	--	--
Pigg River near Sandy Level, Va.	r9	0	--	0	0	--	0	0	+	0	--	0	--	+	--	--	--
Big Otter Creek at Route 712, Va.	r11	0	--	0	0		0	0	0	0	--	0	--	0	--	--	--
Roanoke River at Route 360, Va.	r13	0	--	0	+	--	0	+	+	+	--	+	--	+	-	--	--
Nutbush Creek near Henderson, N.C.	r14	+	0	-	0	--	-	--	+	-	+	-	--	--	--	--	--
Roanoke River at Roanoke Rapids, N.C. (STORET)	r15	0	-	-	--	--	--	--	--	--	--	--	--	--	--	--	--
Roanoke River at Roanoke Rapids, N.C. (WATSTORE)	r15x	0	--	--	--	0	--	--	--	+	0	-	0	--	--	0	0
Dan River Basin (d)																	
Smith River at Route 609, Va.	d1	-	--	0	0	--	0	0	0	0	--	0	--	0	--	--	--
Dan River near Mayfield, Va.	d3	0	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--
Dan River at Robertson Bridge at Danville, Va.	d4	0	--	0	0	--	0	0	0	0	--	+	--	0	--	--	--
Dan River at Paces, Va.	d5	+	--	--	--	0	0	--	--	0	0	-	-	0	--	+	0
Dan River at Route 501 Bridge, Va.	d6	0	--	0	+	--	0	0	0	+	--	0	--	-	-	--	--
Bannister River at Terry's Bridge, Va.	d7	0	--	0	+	--	0	0	+	+	--	+	--	0	-	--	--
Hyco River at Route 58, Va.	d8	0	--	-	+	--	0	0	0	+	--	0	--	0	-	--	--

Table 9. Seasonal Kendall trend analyses for selected water-quality constituents in the Albemarle-Pamlico drainage study area, 1980-89—Continued

[0 indicates no monotonic trend detected; --, inadequate data for trend analysis; - indicates a monotonically decreasing trend; + indicates a monotonically increasing trend. STORET, U.S. Environmental Protection Agency Storage and Retrieval System; WATSTORE, U.S. Geological Survey National Water Data Storage and Retrieval System; NC, North Carolina State Highway]

Station name	Map location number (fig. 2)	Constituent: Specific conductance	Total solids	Suspended solids	Total nitrogen	Dissolved ammonia	Total ammonia	Total nitrite	Total nitrate	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Dissolved orthophosphorus	Total organic carbon	Dissolved potassium	Suspended sediment
Chowan River Basin (c)																	
Meherrin River at Emporia, Va.	c1	0	--	--	--	0	0	--	--	0	0	0	0	0	--	+	-
Nottoway River near Sebrell, Va.	c2	0	--	--	--	0	0	--	--	0	0	+	0	0	--	+	-
Spring Branch at U.S. Highway 460 near Waverly, Va.	c3	0	--	0	-	--	0	0	-	-	--	0	--	0	-	--	--
Blackwater River near Franklin, Va. (STORET)	c4	-	--	0	+	--	0	+	0	+	--	+	--	+	-	--	--
Blackwater River near Franklin, Va. (WATSTORE)	c4x	0	--	--	--	0	0	--	--	0	0	0	0	0	--	+	-
Chowan River near Riddicksville, N.C.	c6	--	--	--	0	--	0	--	+	0	+	-	--	--	--	--	--
Potecasi Creek near Union, N.C.	c9	0	-	0	0	--	0	--	0	0	0	0	--	--	--	--	--
Tar River Basin (t)																	
Tar River at Louisburg, N.C.	t1	0	-	0	0	--	0	--	0	0	0	0	--	--	--	--	--
Tar River below Tar River Reservoir, N.C.	t2	+	0	0	0	--	0	--	+	0	+	0	--	--	--	--	--
Tar River at NC 97 at Rocky Mount, N.C.	t3	0	0	0	0	--	0	--	0	0	0	0	--	--	--	--	--
Swift Creek near Hilliardston, N.C.	t5	0	0	0	+	--	0	--	+	0	+	0	--	--	--	--	--
Little Fishing Creek near White Oak, N.C.	t6	0	-	0	--	--	--	--	--	--	--	--	--	--	--	--	--
Fishing Creek near Enfield, N.C.	t7	0	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--
Tar River at Tarboro, N.C. (STORET)	t8	+	-	-	--	--	--	--	--	--	--	--	--	--	--	--	--
Tar River at Tarboro, N.C. (WATSTORE)	t8x	0	--	--	--	0	--	--	--	0	0	0	0	--	--	+	0

Table 9. Seasonal Kendall trend analyses for selected water-quality constituents in the Albemarle-Pamlico drainage study area, 1980-89—Continued

[0 indicates no monotonic trend detected; --, inadequate data for trend analysis; - indicates a monotonically decreasing trend; + indicates a monotonically increasing trend. STORET, U.S. Environmental Protection Agency Storage and Retrieval System; WATSTORE, U.S. Geological Survey National Water Data Storage and Retrieval System; NC, North Carolina State Highway]

Station name	Map location number (fig. 2)	Constituent															
		Specific conductance	Total solids	Suspended solids	Total nitrogen	Dissolved ammonia	Total ammonia	Total nitrite	Total nitrate	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Dissolved orthophosphorus	Total organic carbon	Dissolved potassium	Suspended sediment
Neuse River Basin (n)																	
Flat River near Quail Roost, N.C.	n1	0	0	0	0	--	0	--	--	-	0	0	--	--	--	--	--
Eno River near Durham, N.C.	n4	+	0	0	0	--	0	--	0	0	0	0	--	--	--	--	--
Neuse River near Falls, N.C. (STORET)	n6	0	-	-	-	--	0	--	-	-	-	-	--	--	--	--	--
Neuse River near Falls, N.C. (WATSTORE)	n6x	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Neuse River at Smithfield, N.C. (STORET)	n8	0	0	+	0	--	0	--	0	-	0	-	--	--	--	--	--
Middle Creek near Clayton, N.C.	n10	+	0	0	+	--	0	--	+	0	+	0	--	--	--	--	--
Neuse River at Richardson Bridge, N.C.	n11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Little River near Princeton, N.C.	n12	0	0	0	-	--	0	--	0	-	0	-	--	--	--	--	--
Neuse River near Goldsboro, N.C.	n13	+	-	0	0	--	0	--	0	0	0	-	--	--	--	--	--
Neuse River at Kinston, N.C. (WATSTORE)	n14x	+	--	--	--	0	--	--	--	+	0	-	0	--	--	+	0
Trent River near Trenton, N.C. (STORET)	n15	+	0	0	0	--	+	--	0	0	0	+	--	--	--	--	--
Contentnea Creek near Lucama, N.C.	n16	0	-	-	0	--	+	--	0	0	+	0	--	--	--	--	--
Nahunta Swamp near Shine, N.C.	n17	+	-	0	-	--	0	--	0	0	0	-	--	--	-	--	--
Contentnea Creek at Hookerton, N.C. (STORET)	n18	0	-	-	-	--	0	--	-	-	-	0	--	--	--	--	--
Contentnea Creek at Hookerton, N.C. (WATSTORE)	n18x	0	--	--	-	0	--	--	--	0	-	0	0	--	--	+	0

Data from several stations indicated statistically significant trends in specific conductance values (fig. 58). The stations showing increases include several stations in the lower Neuse River Basin (n10, n13, n14x, n15, and n17); two in the lower Tar River Basin (t2, t8); and one each in the Eno River (n4), Dan River (d5), and Roanoke River (r14) Basins. Scatter plots with LOWESS curves of these trends are shown in figure 59. The smoothed-trend curve for several stations (n13, n14x, n17, t2, and t8) shows a slight rise around 1988, which was a low-flow year. Other stations (n4, n10, n15, and d5) show a steady increase that started around 1985. These increases probably reflect a mixture of causes, including increased wastewater discharges and the effects of development. Effects of point sources and development are particularly likely at the Eno River (n4), Middle Creek (n10), and Nutbush Creek (r14) sites. Harned and Davenport (1990) reported an increasing trend in specific conductance in atmospheric deposition from 1979 to 1987 for the National Acid Deposition Program (NADP) station at Lewiston, N.C. This trend in atmospheric deposition was not reflected in concentrations of major dissolved substances in precipitation.

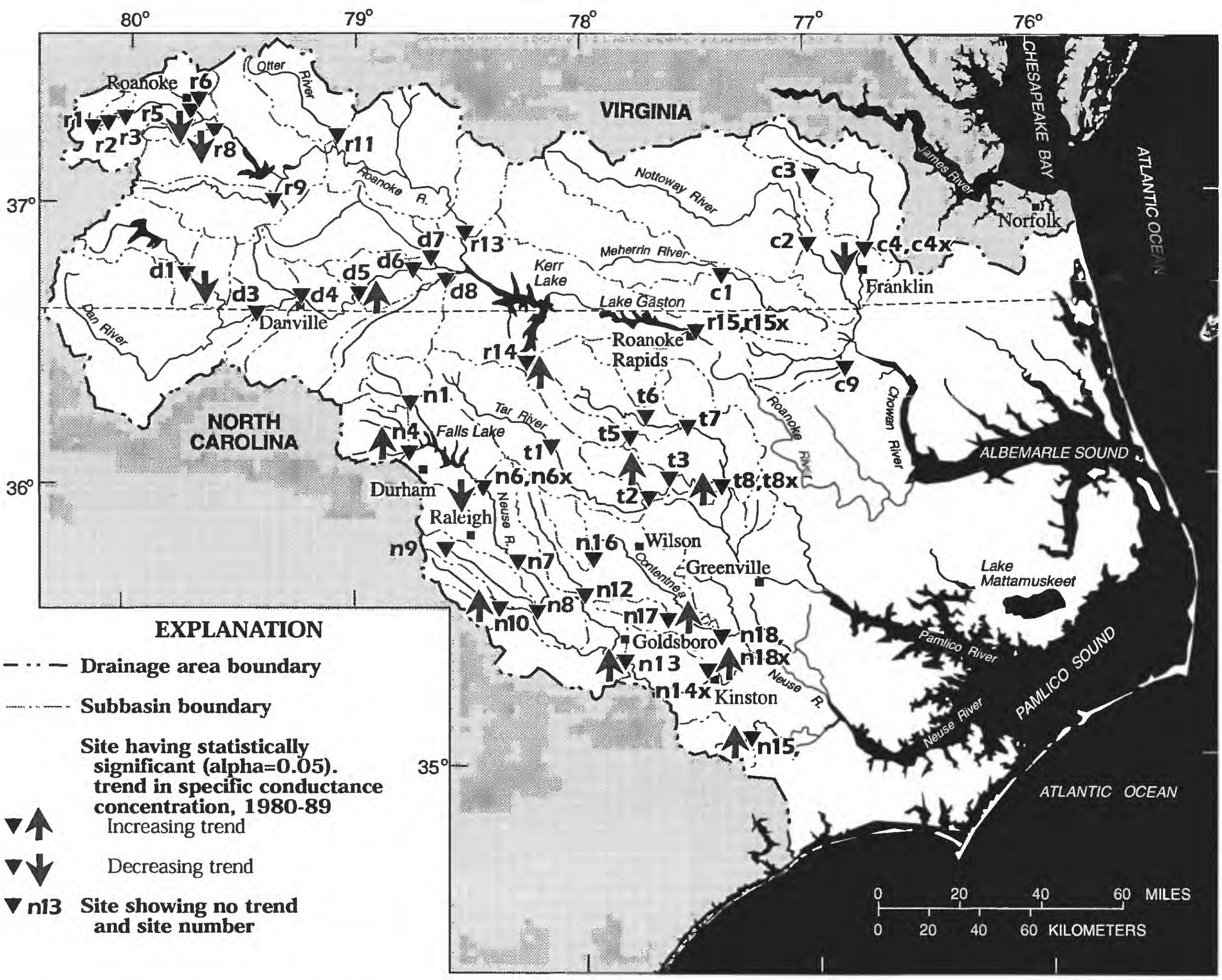
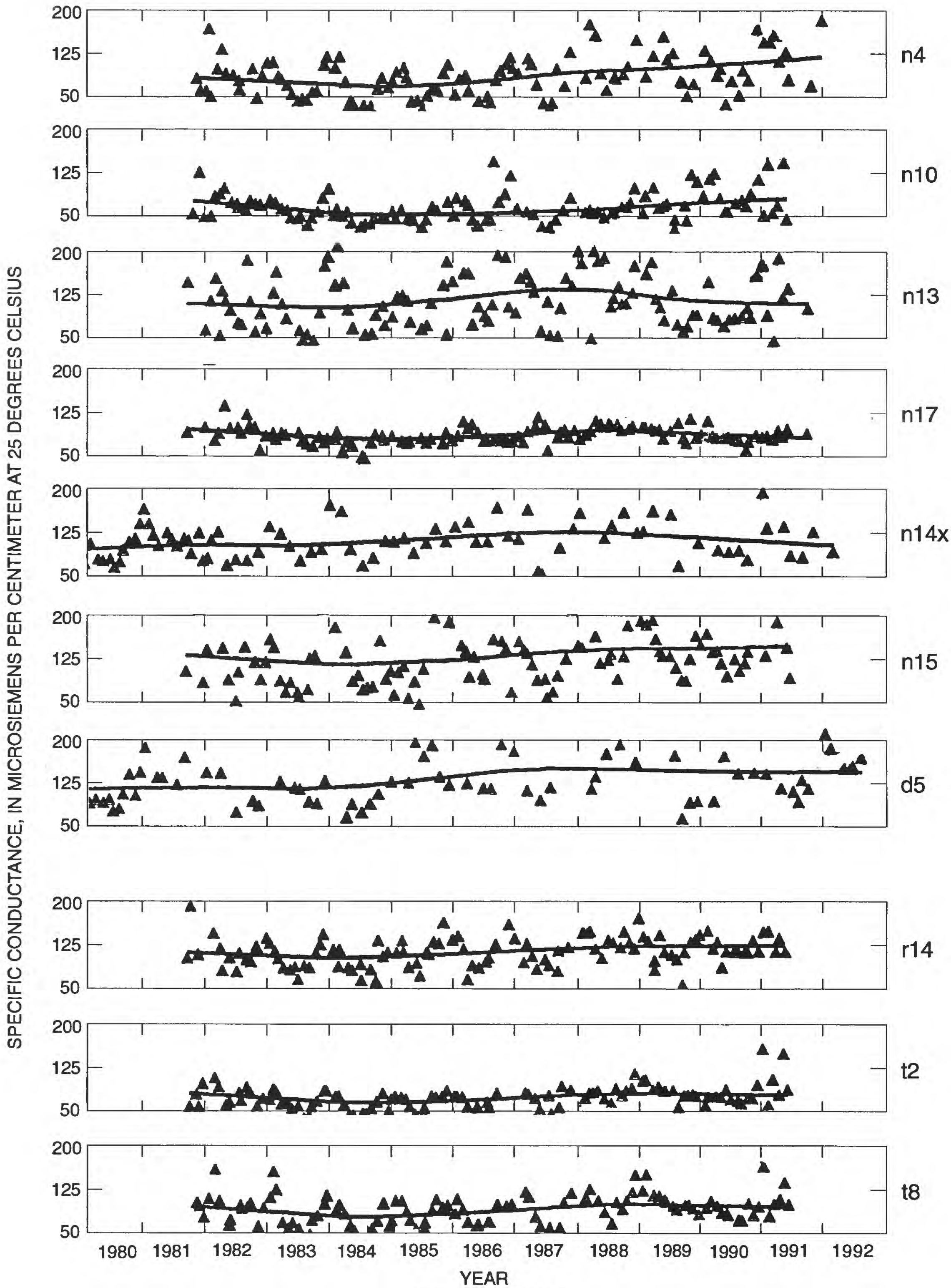


Figure 58. Locations of sites having statistically significant increasing or decreasing trends in specific conductance, 1980-89.



EXPLANATION

Concentration trend **Detected value** t8 **Surface-water site number (see fig. 58)**

Figure 59. Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing increasing trends in specific conductance.

Seasonality in specific conductance values is apparent from the annual variation in values from low in the winter to high in the summer (fig. 59). The seasonality in concentration matches the seasonality in streamflow (fig. 11). Low streamflows correspond to high specific conductance, and high streamflows are often associated with low specific conductance.

Several stations in the upper Roanoke and Dan River Basins (r5, r8, and d1), the Neuse River near Falls (n6), and the Blackwater River (c4x) showed decreasing trends in specific conductance (fig. 58). The decreases at all but the Falls site could reflect improvements in wastewater-treatment processes. The decreasing trend noted at Neuse River near Falls is probably the result of the upstream effect of Falls Lake, which was impounded in 1983, and possibly conservation agricultural land-management practices implemented in 1983 around the new lake.

Suspended Sediment and Solids

Suspended-sediment data were available only for the NASQAN stations. Scatter plots of suspended sediment with time are shown for eight sites (fig. 60). The only significant trends detected were for the three Chowan River tributary sites (c1, c2, and c4x), which showed long-term decreases. These decreases probably are a result of changes in agricultural land-management practices, which have resulted in less erosion of farmland during the last decade in the Chowan River Basin (North Carolina Department of Environment, Health, and Natural Resources, 1990).

Suspended- and total-solids concentrations have decreased throughout the Albemarle-Pamlico drainage basin (table 9; fig. 61). Decreases in suspended- and total-solids concentrations were detected for every site showing a statistically significant trend, except for site n8, which showed an increase in suspended solids. A pattern of decreasing trends in suspended-solids concentrations also was reported for estuarine stations (fig. 61) by Harned and Davenport (1990). An examination of scatter plots for suspended-solids concentrations with time shows that the long-term decreasing trend is gradual for all the sites except for Neuse River near Falls (n6; fig. 62). At this site, an abrupt decrease in concentration occurred in 1983. This change occurred when Falls Lake, just upstream from n6, was impounded. The generalized decrease in solids concentrations is probably a result of construction of new lakes and ponds in the basin which trap solids, improved agricultural soil management, and improved wastewater treatment.

Nutrients

Trend test results for plant nutrients (table 9), including nitrogen, phosphorus, carbon, and potassium, reveal distinct areas in the basin that show long-term changes in nutrient concentrations.

Nitrogen

Total nitrogen trends show a cluster of increases in the tributaries at the upper end of Kerr Lake (fig. 63; d6, d7, d8, and r13) and a cluster of decreases in the Neuse River Basin (n6, n12, n17, and n18). The increases detected for the Kerr Lake tributaries are similar in character; all show a gradual long-term increase (fig. 64) until 1989, and then a slight decline. These increases possibly reflect changes in atmospheric inputs from the cogeneration powerplants that have been constructed in the area. Decreasing trends in total nitrogen at the Neuse River Basin sites are dissimilar, suggesting differing causes of the decreases (fig. 65). The decrease detected at the Neuse River near Falls site (n6) is probably related to the 1983 impoundment of Falls Lake upstream, whereas the decreases at the other sites could indicate changes in agricultural practices. Increasing trends in total nitrogen concentrations detected at the Middle Creek site (n10) and at the Roanoke River at 14th Street Bridge site (r5) (fig. 63) are probably a result of runoff from increasing development around the city of Roanoke, Va.; increases detected at Roanoke River at LaFayette (r3) and Swift Creek near Hilliardston (t5) are likely related to changes in agricultural practices. The decreasing trend in total nitrogen concentration detected at Spring Branch near Waverly (c3) probably is a result of improved wastewater treatment.

Trends in total ammonia plus organic nitrogen concentrations have similar increasing and decreasing patterns to those observed for total nitrogen (fig. 66). A cluster of sites on tributaries at the upstream end of Kerr Lake (fig. 67) have increasing trends in total ammonia plus organic nitrogen concentrations (d6, d7, d8, and r13). The stations downstream from Kerr and Gaston Lakes also had increasing total ammonia plus organic nitrogen concentrations, reflecting the increases upstream. Total ammonia plus organic nitrogen concentrations increased from 1980 to 1990

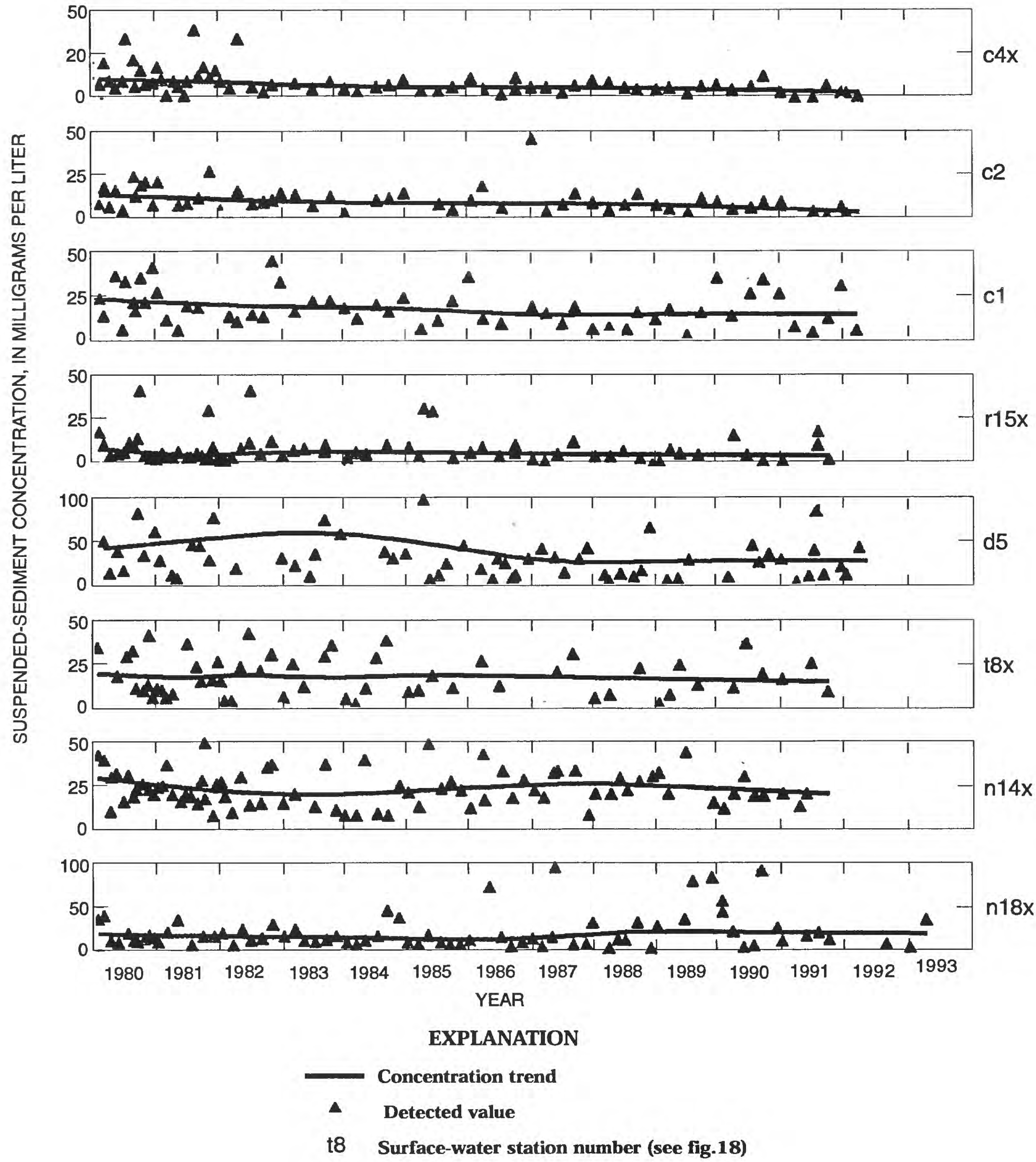


Figure 60. Stacked scatter plots showing variations in suspended-sediment concentrations at National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area.

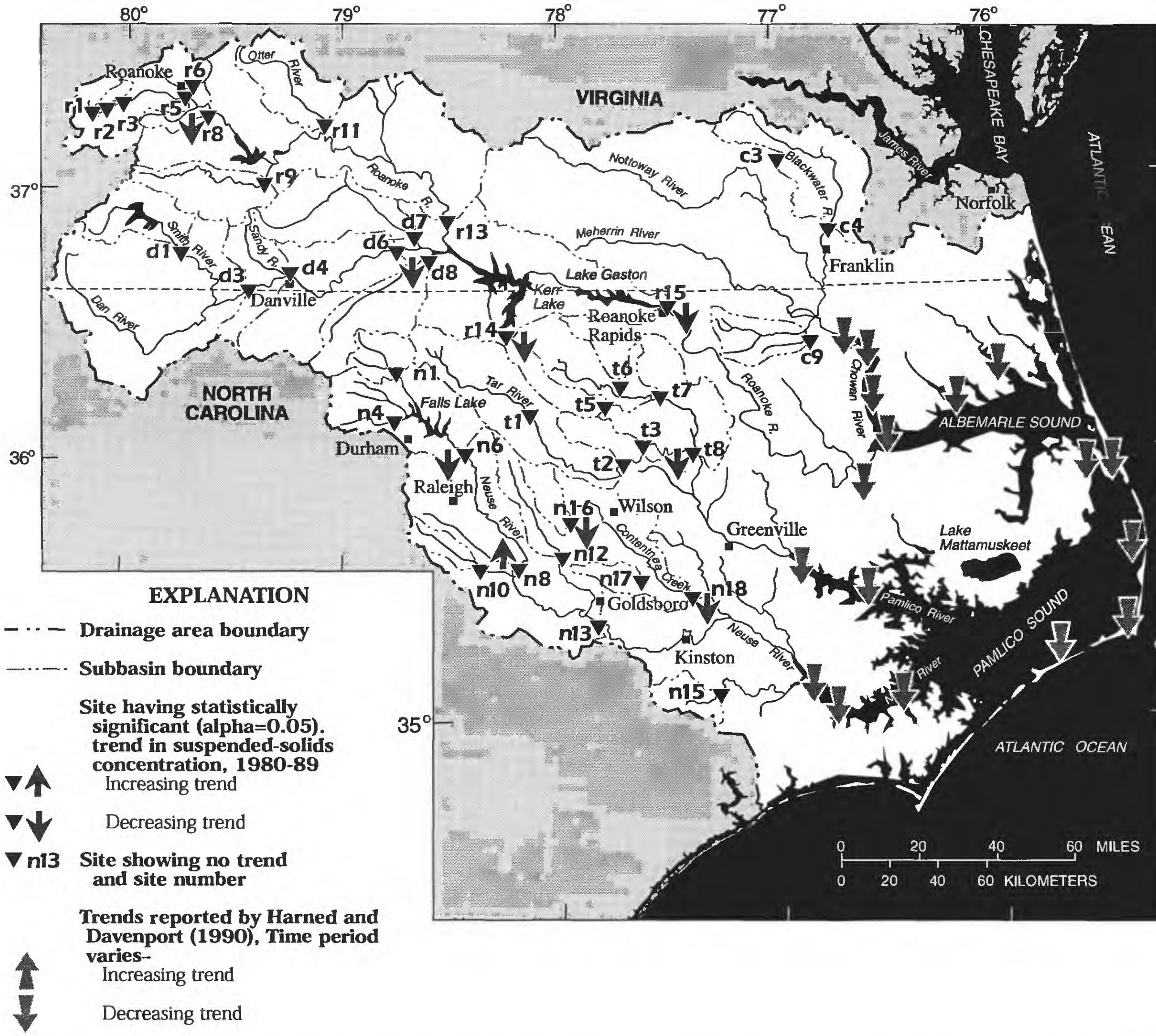


Figure 61. Locations of sites having statistically significant decreasing trends in suspended-solids concentrations, 1980-89.

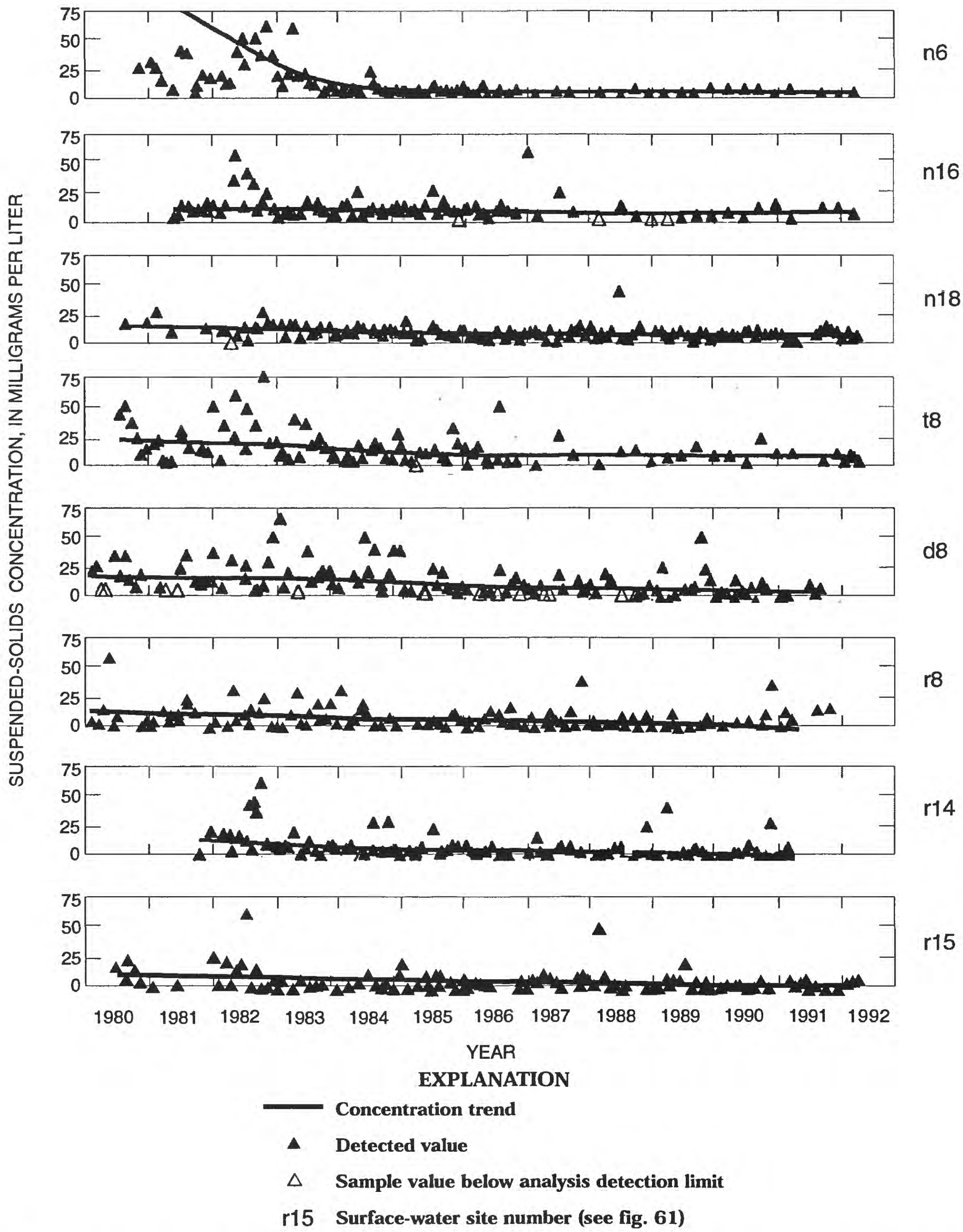


Figure 62. Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing decreasing trends in suspended-solids concentrations.

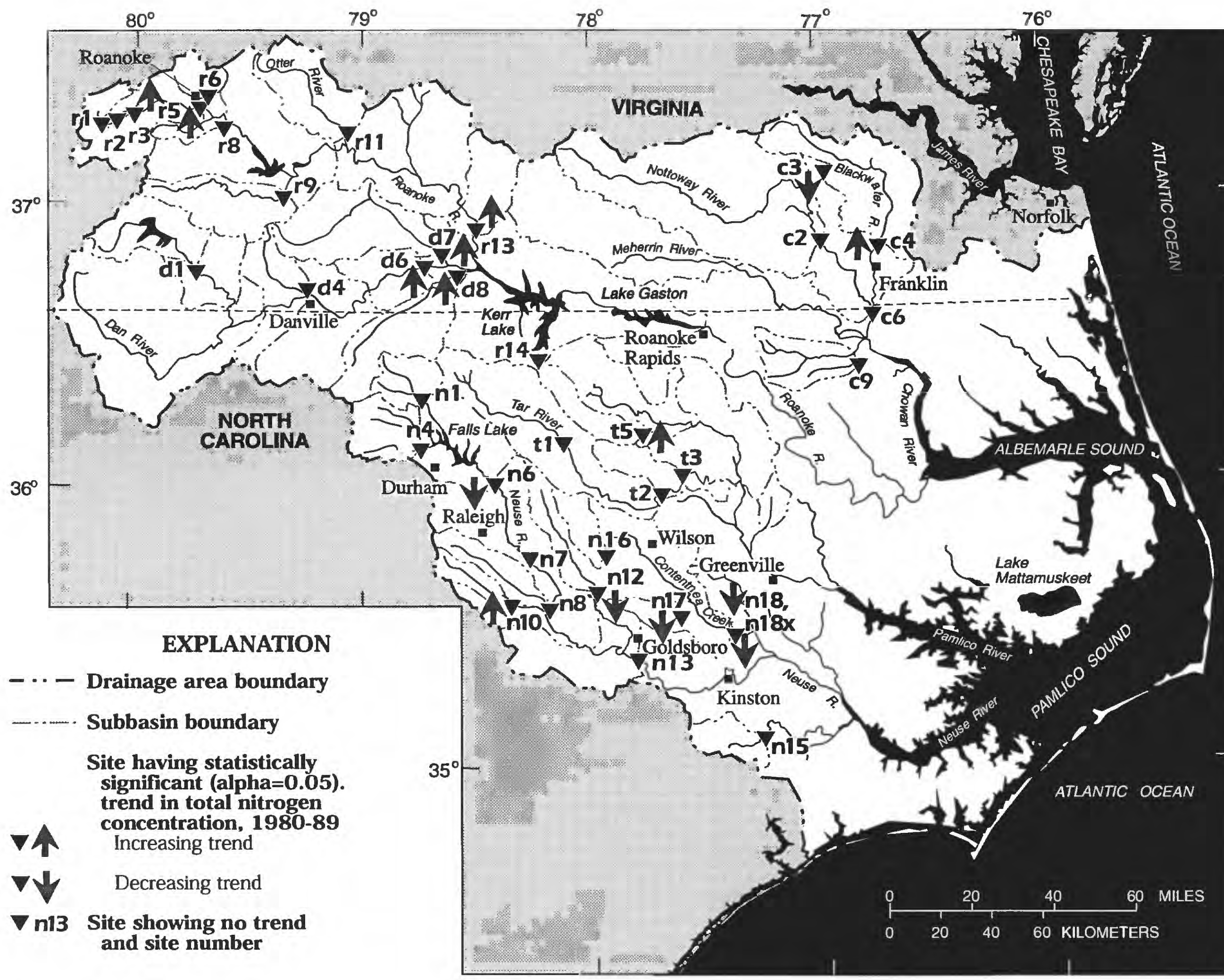


Figure 63. Locations of sites having statistically significant increasing or decreasing trends in total nitrogen concentrations, 1980-89.

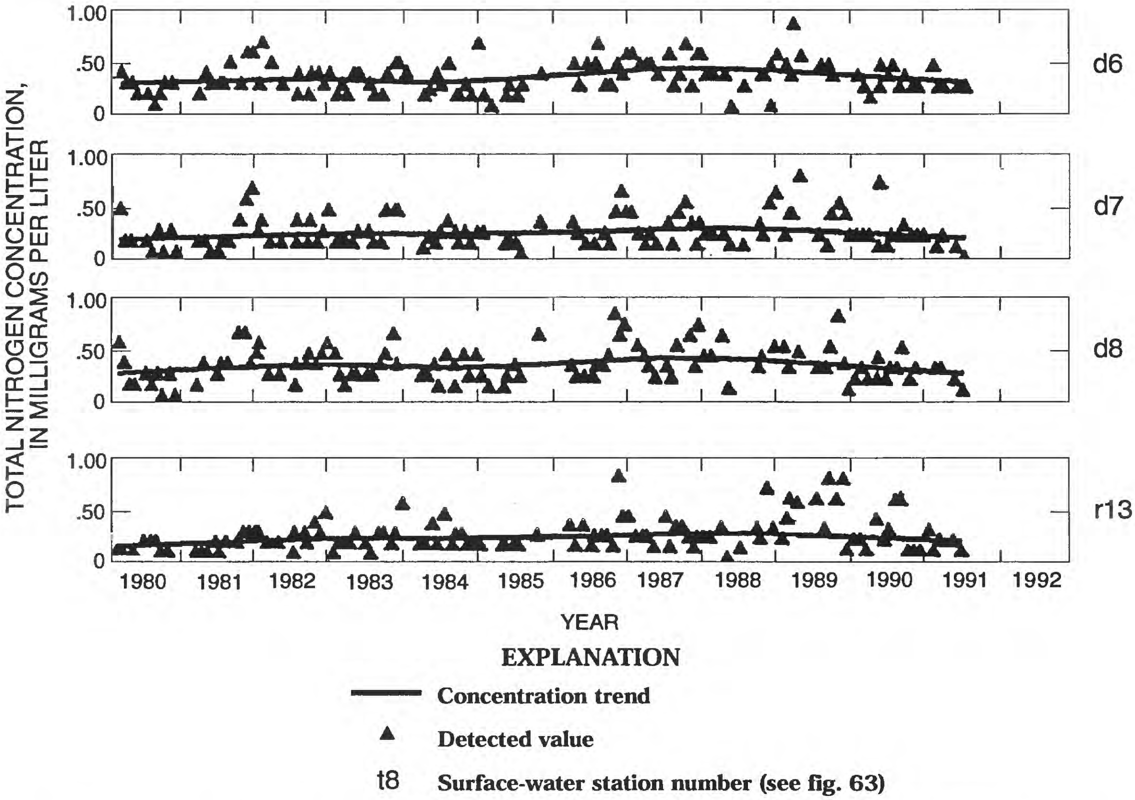


Figure 64–Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing increasing trends in total nitrogen concentrations.

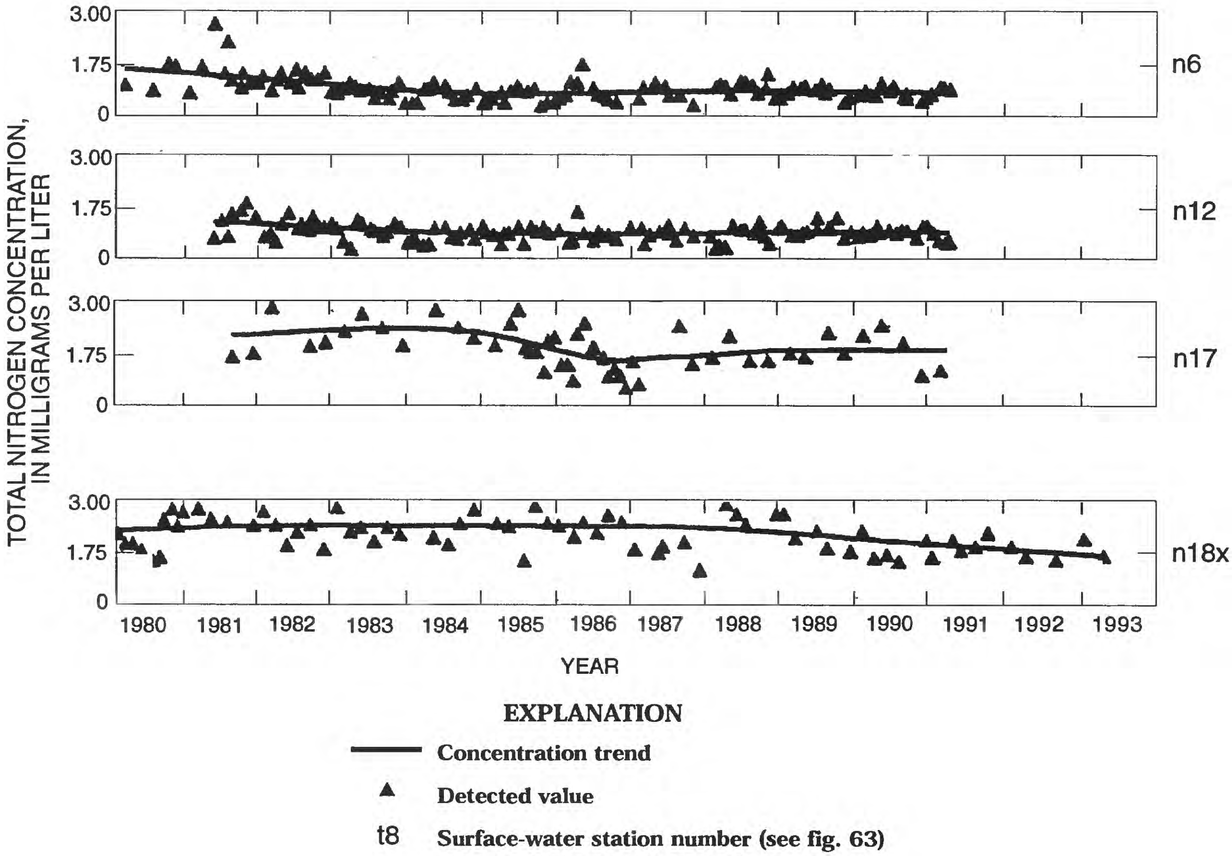


Figure 65. Stacked scatter plots for the Neuse River Basin sites showing decreasing trends in total nitrogen concentrations.

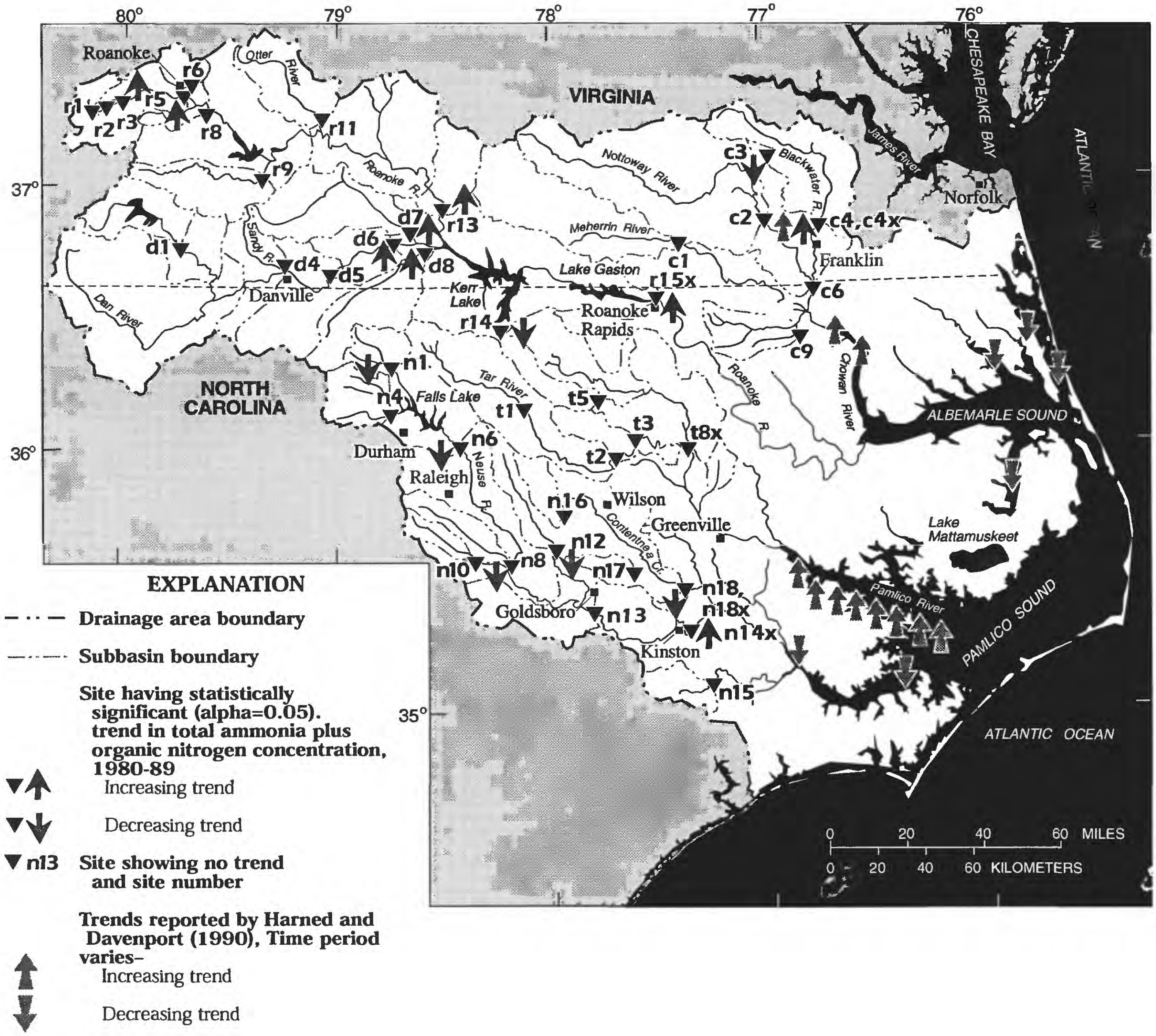


Figure 66. Locations of sites having statistically significant increasing or decreasing trends in total ammonia plus organic nitrogen concentrations, 1980-89.

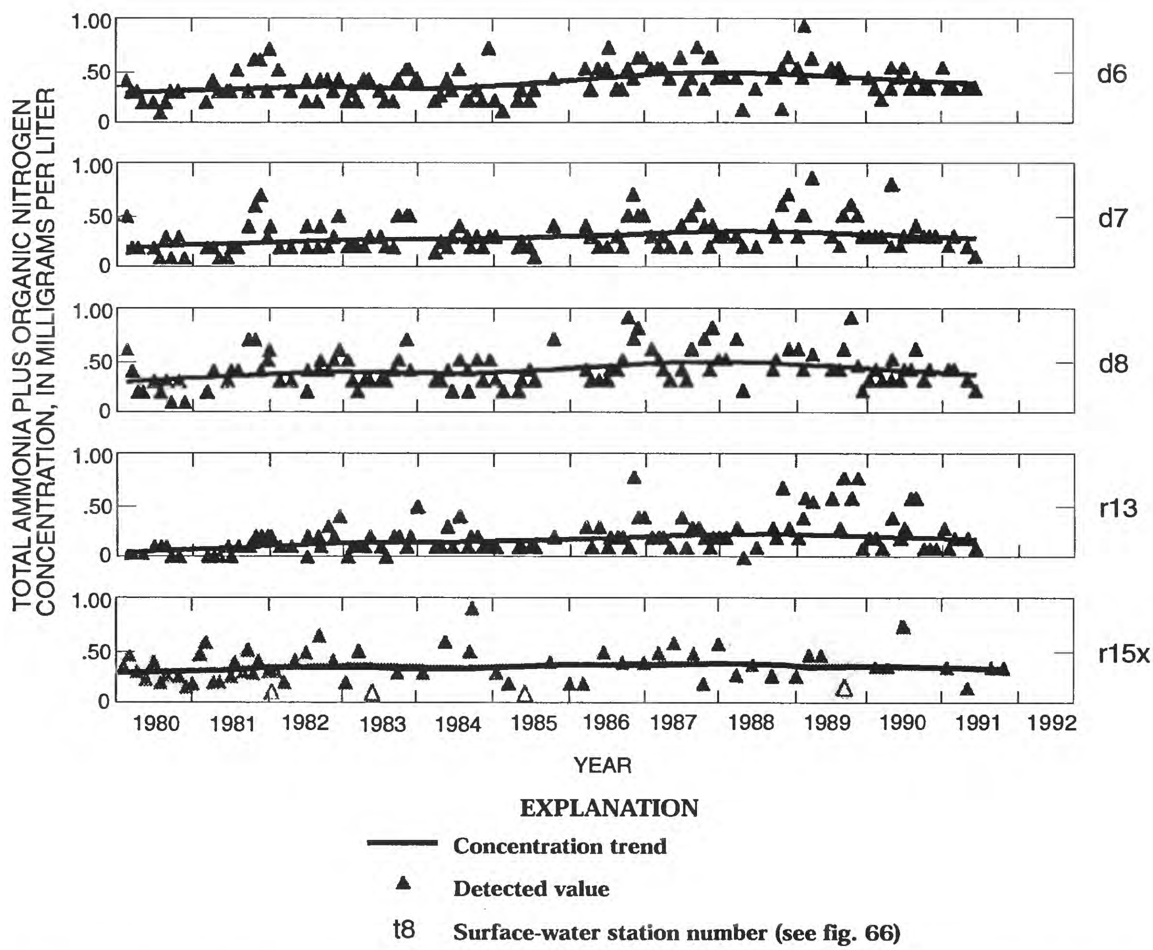


Figure 67. Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing increasing trends in total ammonia plus organic nitrogen concentrations.

and then declined in a pattern similar to that of the total nitrogen concentrations. This pattern is repeated at the Neuse River at Kinston (n14x) site (fig. 66). The increases are probably a result of changing agricultural practices. Increasing trends in total ammonia plus organic nitrogen concentrations also were detected for sites r3 and r5, which had increasing trends in total nitrogen concentrations.

Decreasing trends in total ammonia plus organic nitrogen concentrations also were detected at a cluster of Neuse River Basin stations (fig. 68), including two sites that had significantly decreasing trends in total nitrogen concentrations (n6, n12). Three additional Neuse River Basin sites—Flat River near Quail Roost (n1), Neuse River at Smithfield (n8), and Contentnea Creek at Hookerton (n18)—had decreasing total ammonia plus organic nitrogen concentrations. A generalized reduction in nitrogen concentrations in the Neuse River Basin during 1980-90 is suggested from the data; however, the increase in concentrations at the Neuse River at Kinston site (n14x) for the same period indicated that local basin effects can reverse the upstream trend (fig. 66).

A markedly decreasing trend in total organic nitrogen was observed at Nutbush Creek (r14), which flows into Kerr Lake. This decrease was likely a result of reduction in input of total ammonia plus organic nitrogen from wastewater.

Trends in total ammonia plus organic nitrogen in the estuarine areas (Harned and Davenport, 1990) indicated increases in the Chowan River and the Pamlico River estuaries, but decreases in the Neuse

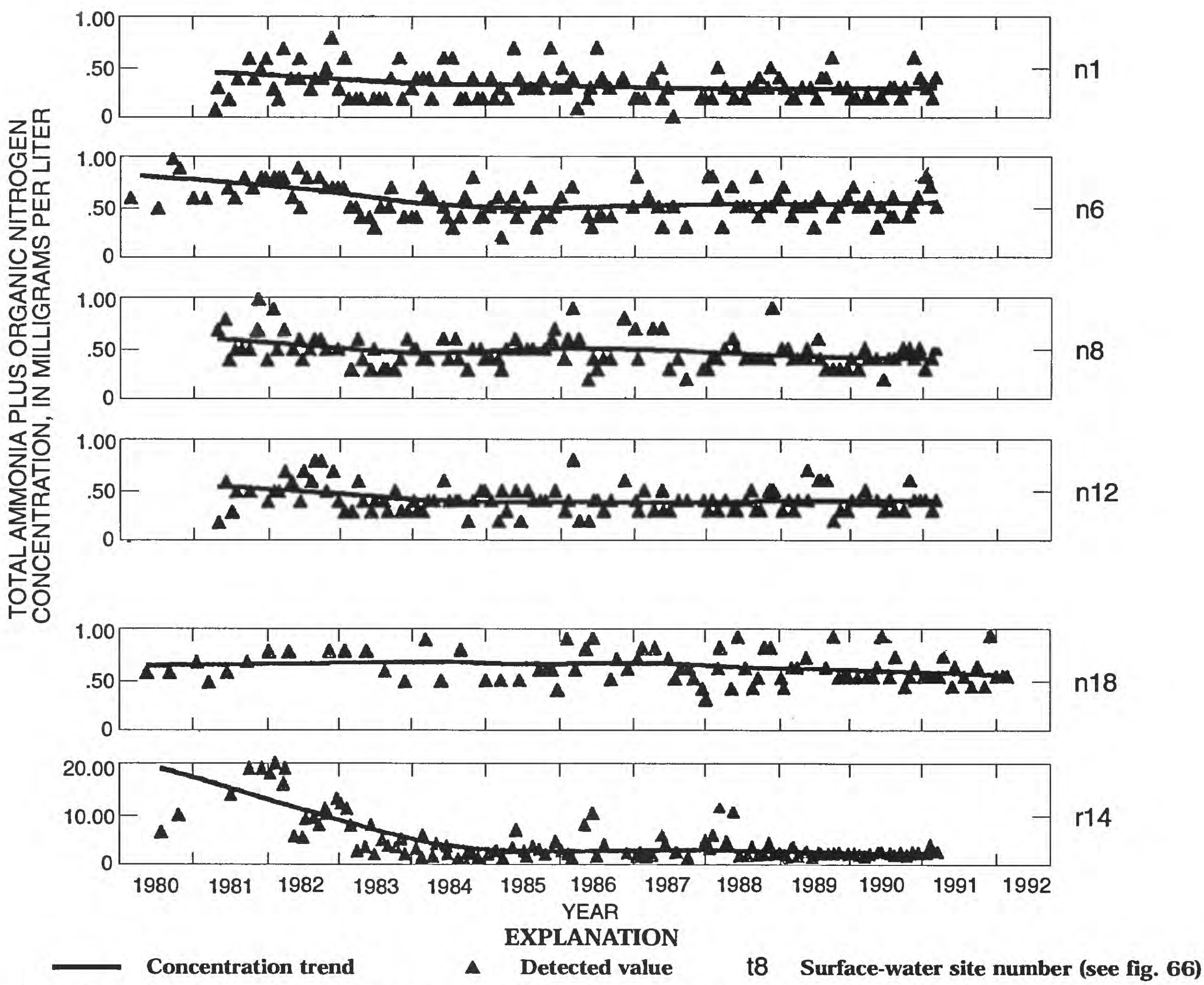


Figure 68. Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing decreasing trends in total ammonia plus organic nitrogen concentrations.

River estuary. These trends were correlated to Coastal Plain agricultural basin characteristics, including tobacco and soybean acreages, numbers of chickens, total and mixed fertilizer materials sold, and total mileage of secondary unpaved roads. Increases in total ammonia plus organic nitrogen were detected in the Pamlico River, but not upstream in the Tar River, probably as a result of a local point source of nitrogen on the Pamlico River.

Ammonia plus organic nitrogen is readily converted by bacteria to nitrate nitrogen. Water contaminated by domestic wastewater commonly contains high concentrations of ammonia plus organic nitrogen. As the contaminated water moves downstream from the point sources, oxidation converts the ammonia plus organic nitrogen to nitrite and nitrate nitrogen. Therefore, high levels of nitrate nitrogen may indicate a wastewater source upstream. However, fertilizer also is a common source of nitrate.

Statistically significant trends in nitrate concentrations were evident in the study basin (fig. 69). Several stations in the upper Roanoke and Dan River Basins (r5, r6, r13, and d7) (fig. 70) had increasing trends in nitrate, total nitrogen, and total ammonia plus organic nitrogen concentrations. The Tinker Creek (r6) and Pigg River (r9) stations also had increasing trends that are probably a result of agricultural nonpoint sources. A gradual increase in nitrate concentrations in the Chowan River near Riddicksville (c6) parallels the reported increase in total ammonia plus organic nitrogen in the estuary (fig. 66) (Harned and Davenport, 1990). Substantial increases in nitrate concentrations occurred at the Nutbush Creek (r14) and Middle Creek (n10) stations (fig. 70). The increasing trend at Nutbush Creek (r14) corresponds to a decrease in total ammonia plus organic nitrogen concentrations (fig. 68) and probably represents a change in nitrogen treatment of wastewater entering the creek. The increasing trend at the Middle Creek (n10) station corresponds to the rapid development that has occurred in the basin since 1980. Increasing trends in the Tar River Basin (t5, t2) are probably a result of changes in agricultural practices.

Decreasing concentrations in nitrate during 1980-90 were detected at the Spring Branch (c3), Contentnea Creek (n18), and Neuse River near Falls (n6) stations (figs. 69 and 71). The decrease in nitrate concentrations at Spring Branch probably is a result of changing upstream wastewater-treatment practices. The decline in nitrate concentrations at Contentnea Creek was gradual (fig. 71) and probably is a result of changing agricultural practices in the basin. The decrease at Falls is explained by the impoundment of Falls Lake in 1983. The strongly seasonal character of nitrate concentrations is particularly evident after 1983. Nitrate concentrations are highest around May and lowest around October within a range of about 0.01 to 0.5 mg/L. This seasonal variation corresponds directly to seasonal variation in streamflow and in algal productivity. Seasonal high flows wash off nitrogen fertilizer applied in the spring, causing nitrogen concentrations to peak. The peak declines through the summer as runoff decreases and the nitrate is used by algae. This seasonal pattern could be particularly evident at the Falls site because the upstream lake dampens the effect of high flow on nitrate concentrations, but not the seasonal effect on concentrations.

Phosphorus

In general, total phosphorus concentrations indicated increasing trends for the stations in Virginia and decreasing trends for the stations in North Carolina (fig. 72). The exceptions to this pattern were the increasing trend detected for the Trent River (n15) and decreasing trend detected for Dan River at Paces (d5). Increasing trends in total phosphorus concentrations in the Pamlico River estuary were reported by Harned and Davenport (1990).

North Carolina and Virginia initiated bans on phosphate detergents in 1988, which could be a cause for the observed decreasing phosphorus trends in North Carolina. This change is evident at several stations (fig. 73), including Neuse River at Kinston (n14x) and Contentnea Creek at Hookerton (n18).

Total phosphorus is strongly associated with sediment; therefore, locations having high sediment concentrations generally have high phosphorus concentrations. The upper Roanoke and Dan River Basins are in the hilly, highly erodible terrain of the Piedmont, Blue Ridge, and Valley and Ridge Provinces. Erosion of sediment laden with fertilizer from agriculture could be a cause for the increasing trends in total phosphorus concentrations in the Roanoke and Dan River Basins. The generally decreasing trends in suspended-solids concentrations observed predominately at North Carolina sites (fig. 61) corroborates the supposition that decreasing phosphorus concentrations are associated with decreasing suspended-sediment concentrations.

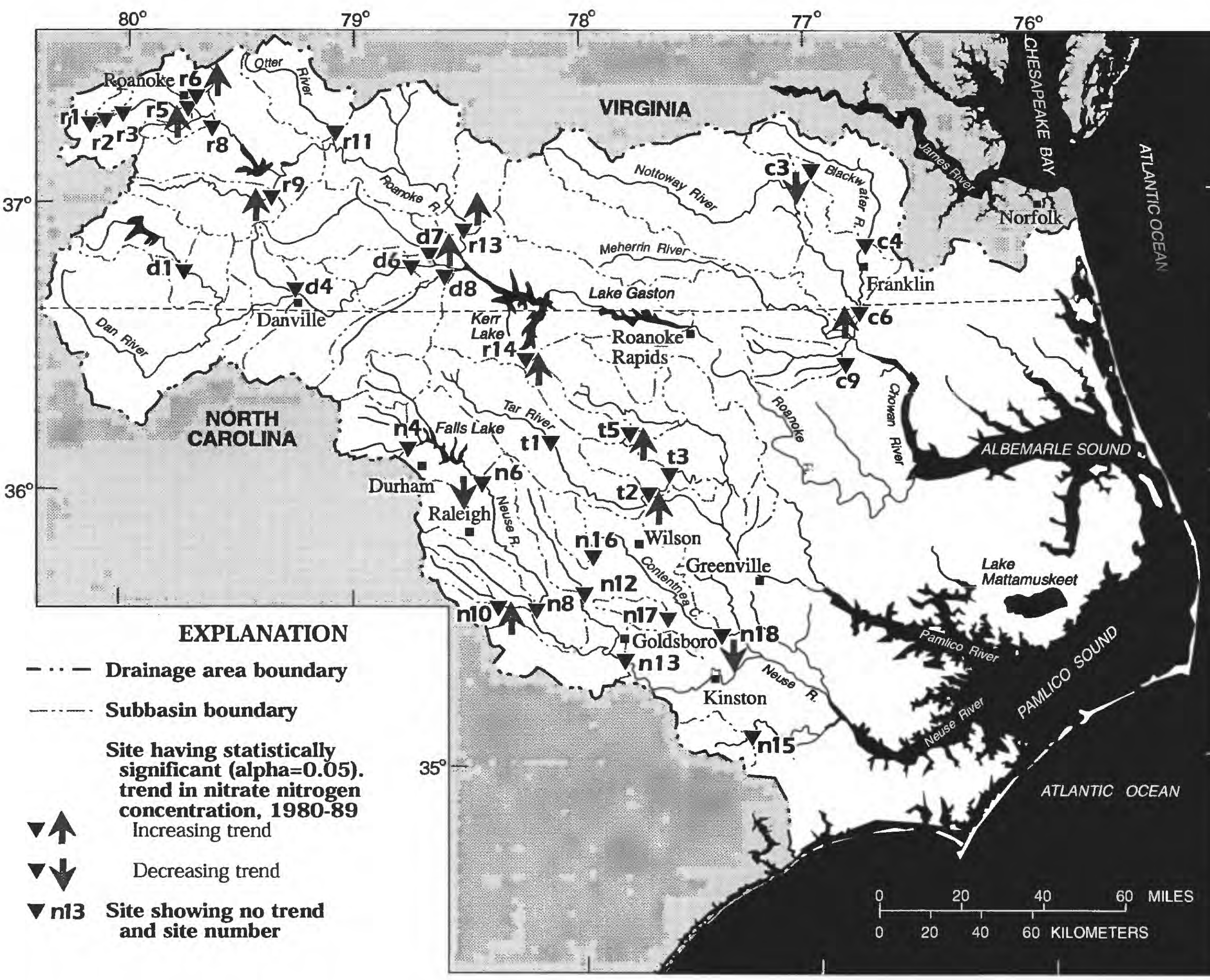


Figure 69. Locations of sites having statistically significant increasing or decreasing trends in nitrate nitrogen concentrations, 1980-89.

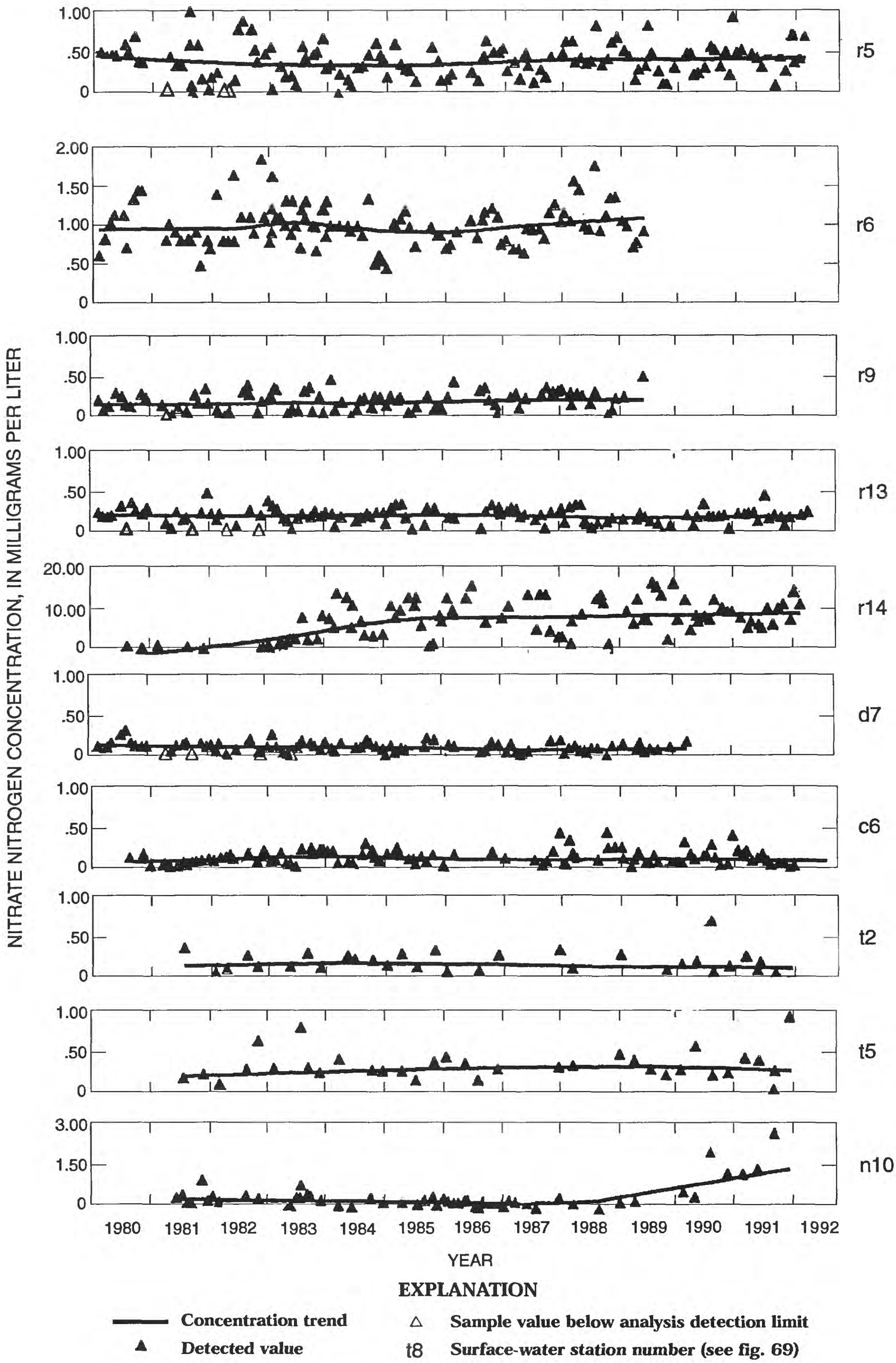


Figure 70. Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing increasing trends in nitrate nitrogen concentrations.

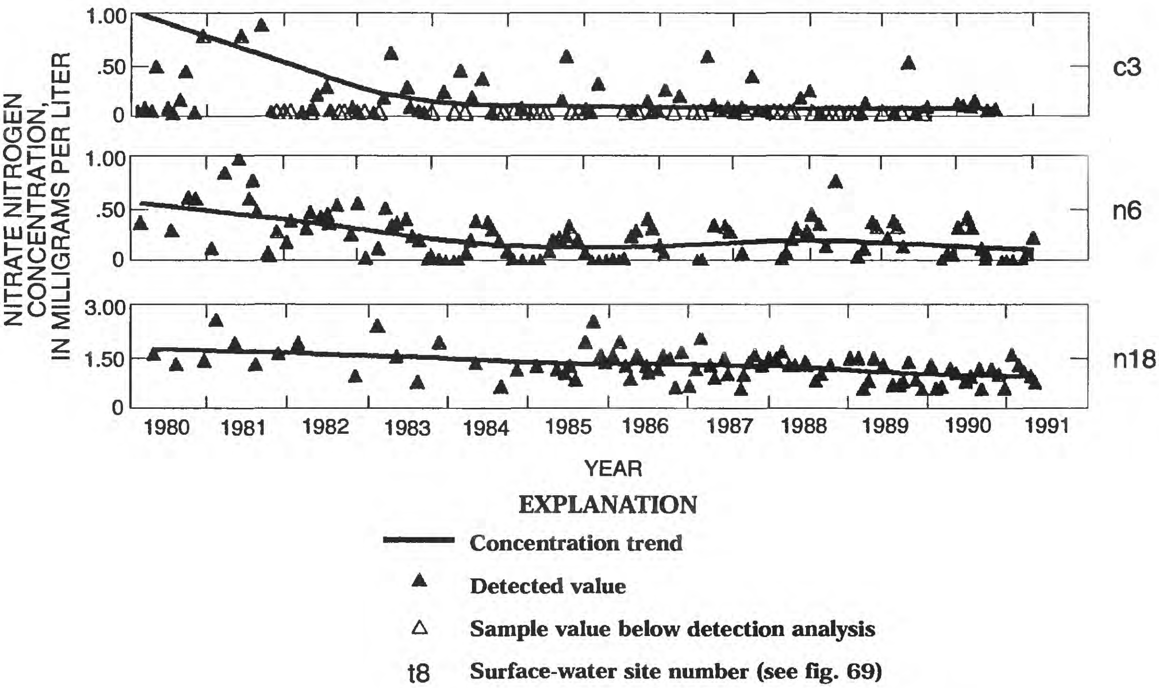


Figure 71. Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing decreasing trends in nitrate nitrogen concentrations.

Several Coastal Plain sites showed increasing total phosphorus trends, including Trent River near Trenton (n15), Nottoway River near Sebrell (c2), and Blackwater River near Franklin (c4) (fig. 72). The increase for the Nottoway River station probably reflects influences of upstream industrial wastewater discharges. The increase in trends for the Blackwater and Trent Rivers may be due to increases in agricultural sources of phosphorus.

The reported increases in total phosphorus concentrations in the Pamlico River estuary (Harned and Davenport, 1990) are probably associated with the extensive phosphate mining operation in Beaufort County, N.C. Decreases elsewhere in the estuary system could actually reflect increases in algal growth. Soluble nutrient concentrations, including dissolved phosphorus, are a net result of the effects of biological uptake, solution and dissolution of nutrients available in sediment, and new nutrient inputs. Biomass increases over time could result in decreases in soluble nutrients.

Carbon

Total organic carbon data were available for eight stations in Virginia, including Roanoke River at Lafayette (r3), Roanoke River at the 14th Street Bridge at Roanoke (r5), Smith Mountain Lake at Hardy's Ford (r8), Roanoke River at Route 360 (r13), Bannister River (d7), Hyco River (d8), Spring Branch (c3), and Blackwater River (c4). All stations showed decreasing trends in organic carbon from 1980 to 1989 (fig. 74). Similar gradual, long-term declines are evident at the Roanoke and Dan River sites. The most rapid decline occurred in the early 1980's, and the decrease flattened in the late 1980's. These declines are most likely a result of decreasing upstream inputs of wastewater sources of organic carbon. Generalized decreases in organic carbon are consistent with decreases in solids concentration as part of improved wastewater treatment. A notable example of this change is the reduction in total organic carbon at Spring Branch (c3). The decreased trend at the Blackwater River station (c4), which is downstream from Spring Branch, could be a result of the upstream wastewater organic carbon reductions at Spring Branch and elsewhere.

Potassium

Potassium is an abundant element commonly occurring in silicate-mineral rocks or in clay. Potassium is depleted from agricultural soil with crop

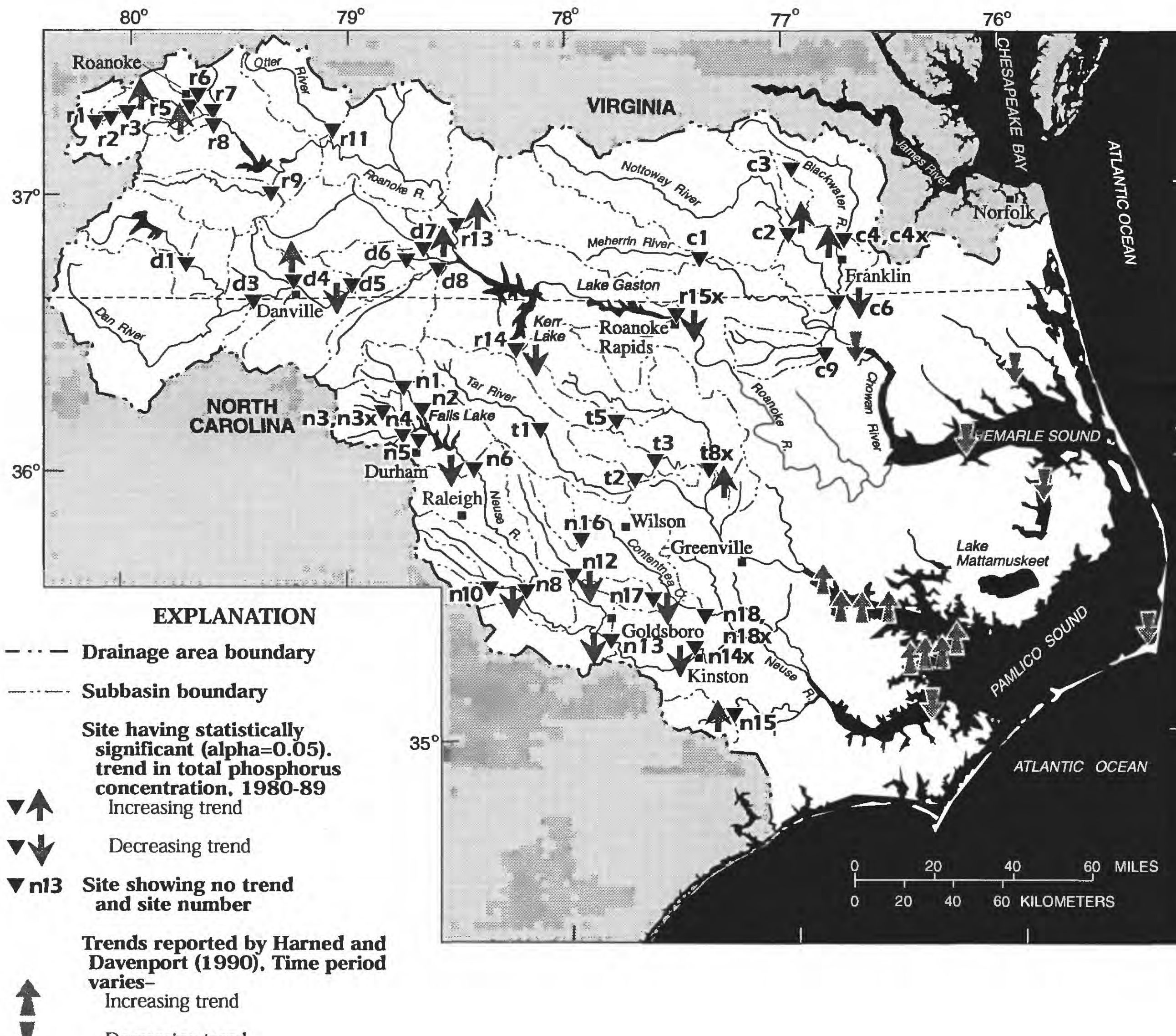


Figure 72. Locations of sites having statistically significant increasing or decreasing trends in total phosphorus concentrations, 1980-89.

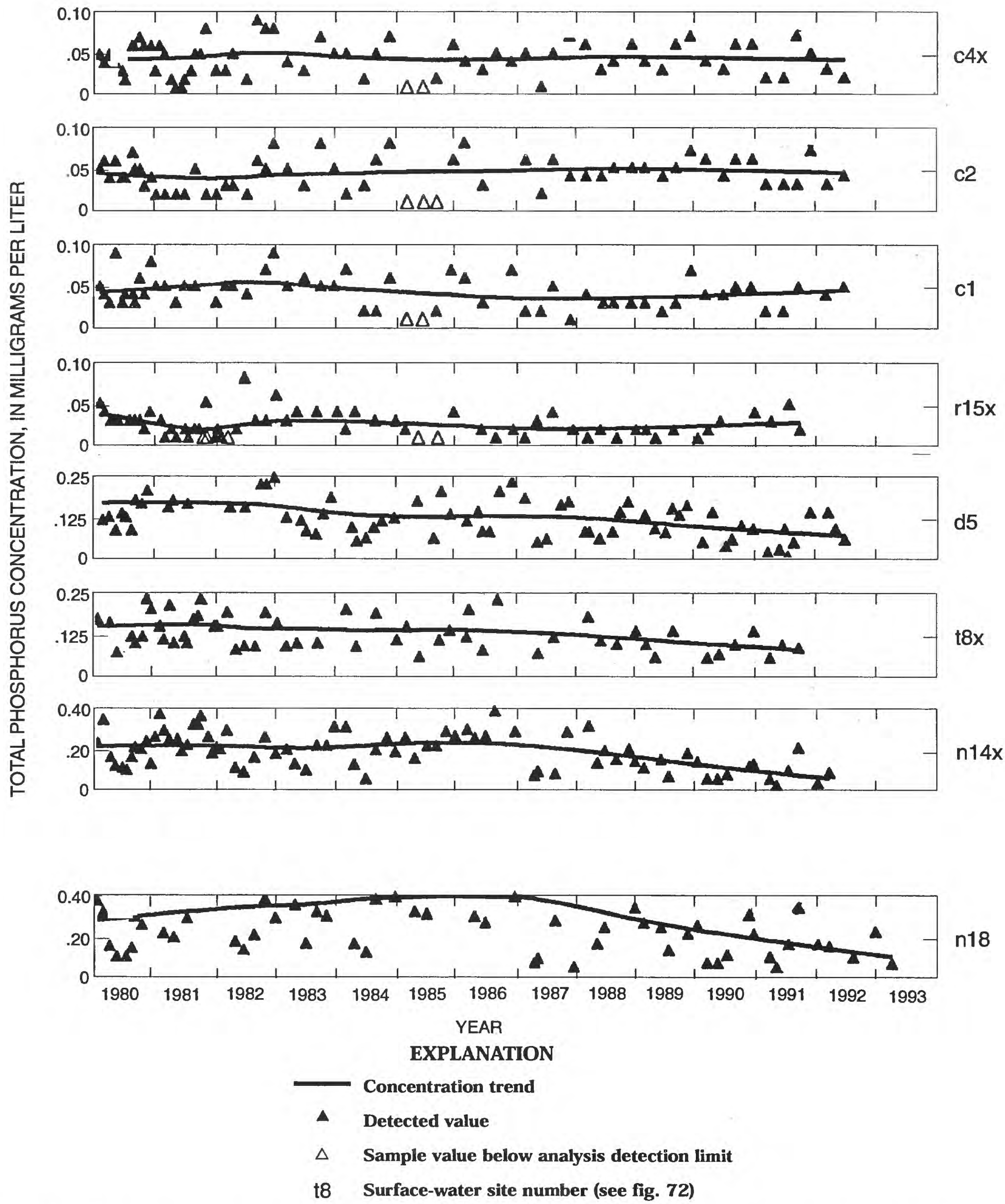


Figure 73. Stacked scatter plots showing variations in total phosphorus concentrations for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area.

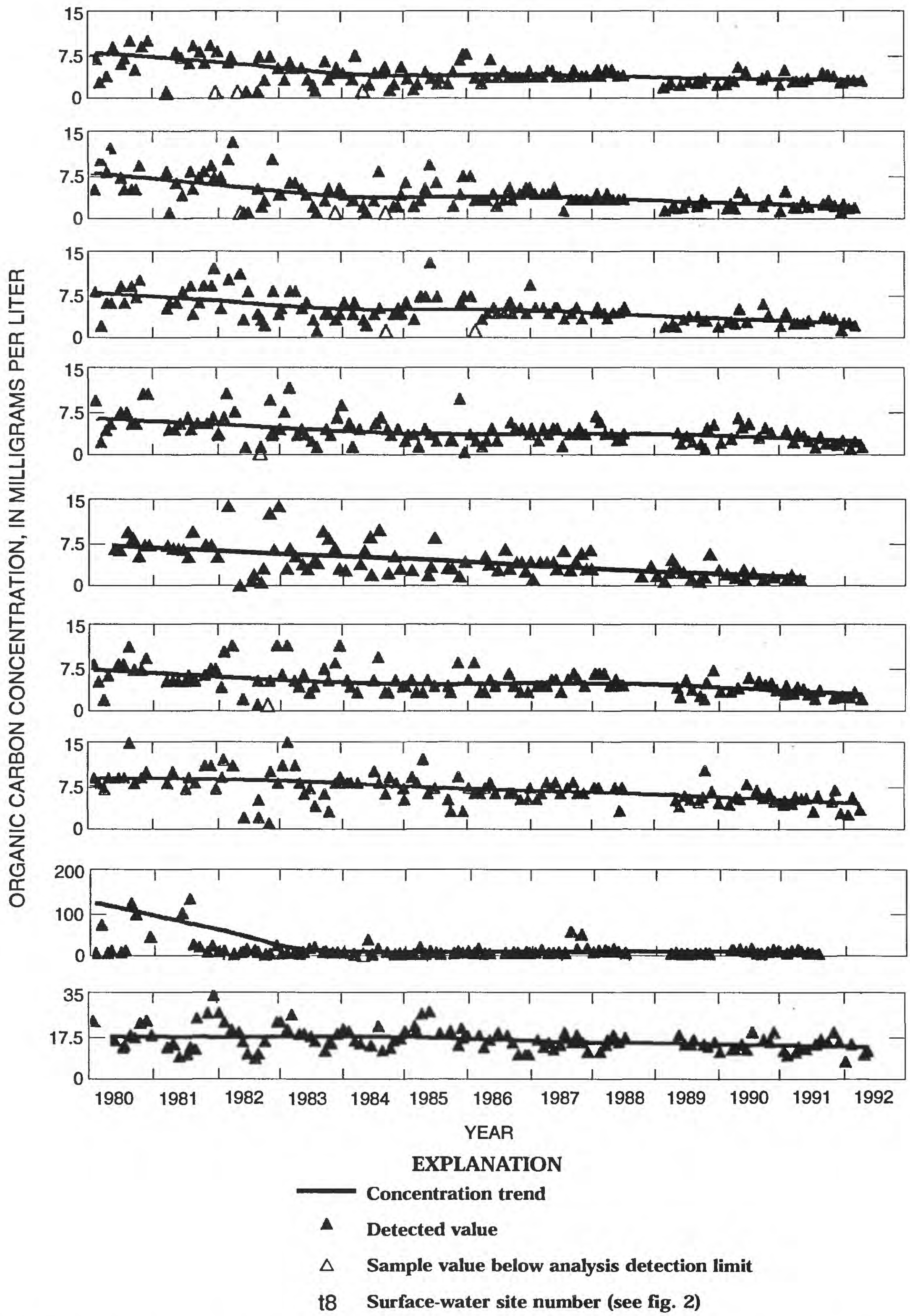


Figure 74. Stacked scatter plots for sites in the Albemarle-Pamlico drainage study area showing decreasing trends in total organic carbon concentrations.

removal and overland runoff; therefore, it is an essential component of common fertilizers.

Dissolved-potassium concentration data were only available for the eight NASQAN stations. Gradually increasing trends in dissolved-potassium concentrations were detected in all but the Roanoke River at Roanoke Rapids (r15x) station from 1980 to 1990 (fig. 75). A strong seasonal component to potassium concentration is evident, particularly in the early 1980's. Seasonality in concentrations corresponds to seasonality in streamflow. Low streamflows correspond to high concentrations, and high streamflows are associated with low concentrations. This seasonal pattern is similar to that observed for specific conductance and is the inverse of the pattern observed for nitrogen. The nature of this seasonality implies that the source of the long-term increase in potassium concentrations is not a result of increased usage of fertilizer, which would enter streams during storm runoff, but rather to wastewater discharge, which generally influences low-flow concentrations. The observed increasing trend in potassium concentration in the Neuse River is a continuation of a trend that began at least as early as 1955 (Harned, 1982).

CHARACTERIZATION OF NUTRIENT INPUT LOADS AND SEDIMENT AND NUTRIENT OUTPUT LOADS

The sources and transport of nutrients into the Albemarle-Pamlico estuarine system are an important regional water-quality concern. In the past decade, efforts have been made at the national and State levels to identify nutrient and sediment sources and to estimate the amount of these constituents entering the estuarine system (Stanley, 1989; Dodd and others, 1992; North Carolina Department of Environment, Health, and Natural Resources, 1992b, 1993b and c; Smith and others, 1993; Research Triangle Institute, 1994).

A systematic attempt to estimate nutrient input mass and sediment and nutrient output flux for major river basins, however, has not been completed previously for the Albemarle-Pamlico drainage system. This section of the report provides estimates of the magnitude of nutrient inputs for the eight Albemarle-Pamlico NASQAN basins. In addition, information on the flux, or annual load, of sediments and nutrients is provided for the NASQAN stations.

Streamflow and water-quality data for the NASQAN stations were examined for suspended-sediment, total nitrogen, and total phosphorus input and output loads. The NASQAN stations and associated drainage areas, dominant land uses, and population densities are listed in table 10.

The NASQAN basins have more area devoted to urban land uses, with a range of 2.3 to 8.9 percent of basin land area classified as developed (table 10), compared with a national median of 1.8 percent for 2,000 similarly sized basins (Smith and others, 1993). The study area basins also have more land classified as agricultural (a range of 28 to nearly 51 percent of basin land area, compared with a national median of 15.3 percent) and forested (a range of about 37 to 67 percent of basin land area, compared with a national median of 17.4 percent).

The NASQAN basins can be classified as one of three basin types—agriculture, agriculture/urban, and agriculture/forest (table 10). This classification can be used for comparing study area load estimates with national estimates, and for understanding differences among the stations. This land-use classification system is derived from a system presented in Smith and others (1993) and is different from the strata classification used in the "Characterization of Basin Water Quality" section of this report. The agricultural class is directly derived from the Smith classification system, whereas the other two categories combine several Smith categories. Two NASQAN basins, Tar River at Tarboro (t8) and Roanoke River at Roanoke Rapids (r15), have land-use and population characteristics that could qualify them for placement in either the agriculture/urban or agriculture/forest categories. The final classification assignment was based on local knowledge of these basins.

Characterization of nutrient inputs in the NASQAN basins also included examination of the percentages of major crops harvested within the basins and the dominant animal categories (table 11). Nutrients associated with animal wastes compose 20 percent or more of the total estimated basin nutrient inputs in five basins, and corn and soybeans are grown in 50 percent or more of the agricultural acreage in five of the basins. Acreage for one or more crops exceeds 15 percent of agricultural land use in all basins (table 11).

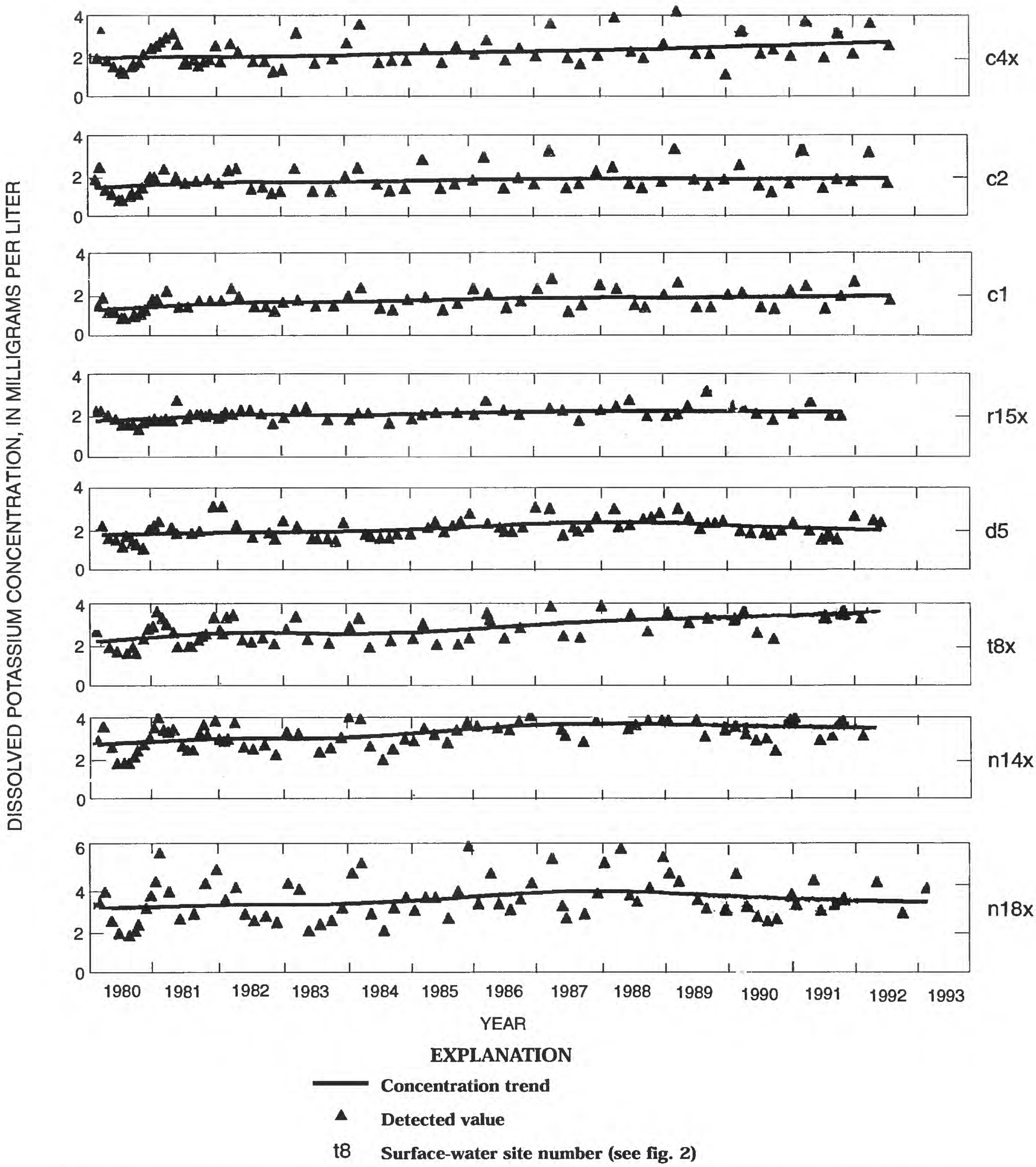


Figure 75. Stacked scatter plots showing trends in dissolved potassium concentrations for National Stream Quality Accounting Network sites in the Albemarle-Pamlico drainage study area.

Table 10. Summary of agriculture, agriculture/urban, and agriculture/forest land-use information for the National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area

Basin types: Agriculture: greater than 40 percent agricultural land use, less than 40 percent forested, less than 10 percent developed; Agriculture/Urban: greater than 25 percent agricultural, population density greater than 100 people per square mile; Agriculture/Forest: greater than 50 percent forested, less than 40 percent agricultural, less than 10 percent developed; USGS, U.S. Geological Survey; mi^2, square mile; people/mi^2, people per square mile]

Station name	Map location (fig. 2)	USGS downstream order identification number	Drainage area (mi^2)	Major land-use types, as a percent of basin drainage area				1990 estimated population density (people/mi^2)
				Developed	Agricultural	Forested	Wetlands	
Agriculture								
Contentnea Creek at Hookerton, N.C.	n18x	02091500	737	4.9	50.6	37.4	7.1	129
Agriculture/Urban								
Dan River at Paces, Va.	d5	02075500	2,587	4.9	28.0	65.0	1.0	119
Neuse River at Kinston, N.C.	n14x	02089500	2,712	8.9	37.7	50.5	1.8	275
Tar River at Tarboro, N.C.	t8x	02083500	2,222	4.5	39.1	51.1	6.4	91
Agriculture/Forest								
Blackwater River near Franklin, Va.	c4x	02049500	610	2.8	29.8	59.3	5.3	44
Meherrin River at Emporia, Va.	c1	02052000	745	2.3	30.2	67.1	.1	37
Nottoway River near Sebrell, Va.	c2	02047000	1,441	2.5	28.3	66.2	3.5	30
Roanoke River at Roanoke Rapids, N.C.	r15x	02080500	8,474	4.7	33.3	60.2	.2	97

Table 11. Percentages of acres harvested, by individual crop, and major livestock categories for the National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area, 1990

[Numbers in parentheses are site numbers in figure 2; <, less than; NA, not available]

	Blackwater River near Franklin, Va. (c4x)	Nottoway River near Sebrell, Va. (c2)	Meherrin River at Emporia, Va. (c1)	Roanoke River at Roanoke Rapids, N.C. (r15x)	Dan River at Paces, Va. (d5)	Tar River at Tarboro, N.C. (t8x)	Neuse River at Kinston, N.C. (n14x)	Contentnea Creek at Hookerton, N.C. (n18x)
Corn and soybeans	59	58	59	42	35	46	61	64
Grains[1]	<1	13	14	27	30	15	19	17
Cotton	<1	2	1	1	0	12	3	5
Peanuts	29	22	2	1	0	12	<1	1
Tobacco	<1	4	23	28	35	12	13	12
Potatoes	0	0	0	<1	<1	3	3	2
Livestock[2]	NA	NA	cattle, hogs	cattle	cattle	NA	cattle, hogs	hogs, chickens

[1] Grains include wheat, sorghum, barley, and oats.

[2] Dominant livestock types are reported where livestock-related waste nutrients compose more than 20 percent of total station nutrient inputs (see table 13).

Nutrient Input Loads

Total nitrogen and total phosphorus inputs, including atmospheric sources, fertilizer and nutrients related to animal wastes, and point-source inputs, were estimated for each of the eight drainage areas. Fertilizer use associated with urban land uses, such as lawn fertilization and other nonpoint nutrient inputs associated with development, are not included in these estimates. The methods used for developing these estimates are described in McMahon and Lloyd (1995).

Nutrient input estimates for the NASQAN basins indicate that nonpoint nutrient sources make up a larger proportion of total input nutrients than do point sources (tables 12 and 13; fig. 76). Point sources of total nitrogen and total phosphorus averaged 2.6 and 3.3 percent, respectively, of total nutrient inputs in the eight basins.

Atmospheric Deposition

Atmospheric loads of nitrogen were calculated by using water year 1990 data from four National Atmospheric Deposition Program (NADP) sites located in or adjoining the Albemarle-Pamlico study area (National Atmospheric Deposition Program (NRSP-3)/National Trends Network, 1993). The total nitrogen contribution from atmospheric deposition was calculated as the sum of wet deposition nitrate nitrogen and ammonium nitrogen, nitrate nitrogen dry deposition, nitrate nitrogen droplet deposition, and nitrate nitrogen urban wet deposition. Deposition in each of these categories was calculated by multiplying an associated deposition rate—measured as mass of nutrient per land area per year—by the corresponding area of the drainage basin. The total phosphorus component of atmospheric nutrient loads was based on a literature-derived value of 0.18 ton of total phosphorus deposited per square mile of drainage basin (Dodd and others, 1992).

Examined in terms of total nutrient input percentages (table 13), atmospheric sources of nitrogen range from nearly 11 to 44 percent and, on average, make up slightly more than 25 percent of total nitrogen inputs in the eight basins. Atmospheric phosphorus

Table 12. Summary of total nitrogen and total phosphorus inputs and outputs, in tons per square mile of basin drainage area, for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area, 1990
[Numbers in parentheses are site numbers in figure 2; N, total nitrogen; P, total phosphorus]

Category	Blackwater River near Franklin, Va. (c4x)		Nottoway River near Sebrell, Va. (c2)		Meherrin River at Emporia, Va. (c1)		Roanoke River at Roanoke Rapids, N.C. (r15x)		Dan River at Paces, Va. (d5)		Tar River at Tarboro, N.C. (t8x)		Neuse River at Kinston, N.C. (n14x)		Contentnea Creek at Hookerton, N.C. (n18x)	
	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P
Inputs																
Atmospheric deposition	1.831	0.186	1.816	0.186	1.799	0.186	1.941	0.186	1.980	0.186	1.949	0.186	2.160	0.186	1.958	0.186
Commercial fertilizer	3.258	.413	1.633	.204	.624	.067	.825	.063	.802	.055	2.994	.307	3.614	.407	7.872	.894
Nitrogen fixation	4.125	.000	2.502	.000	0.711	.000	0.317	.000	0.231	.000	2.364	.000	2.129	.000	3.977	.000
Animal waste	.989	.284	1.144	.310	1.349	.349	1.774	.450	1.145	.290	2.045	.582	1.978	.600	3.977	1.262
Point sources	.023	.003	.023	.011	.034	.007	.243	.029	.347	.071	.133	.025	0.464	.054	.205	.020
Total inputs	10.226	.886	7.118	.711	4.517	.609	5.100	.728	4.505	0.602	9.485	1.100	10.345	1.247	17.989	2.362
Outputs																
Crop harvest	6.524	0.729	3.403	0.362	1.060	0.114	0.745	0.096	0.668	0.086	3.406	0.392	3.358	0.427	7.374	0.948
Instream load	1.037	.041	.627	.054	.631	.054	.734	.036	1.368	.154	1.368	.133	1.620	.121	1.828	.211
Retention and storage	2.665	.116	3.088	.295	2.826	.441	3.621	.596	2.469	.362	4.711	.575	5.367	.699	8.787	1.203

Table 13. Summary of total nitrogen and total phosphorus inputs and outputs, as a percent of total station nutrient inputs, for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area, 1990

Numbers in parentheses are site numbers in figure 2; N, total nitrogen; P, total phosphorus; --, not applicable

Category	Blackwater River near Franklin, Va. (c4x)		Nottoway River near Sebrell, Va. (c2)		Meherrin River at Emporia, Va. (c1)		Roanoke River at Roanoke Rapids, N.C. (r15x)		Dan River at Paces, Va. (d5)		Tar River at Tarboro, N.C. (t8x)		Neuse River at Kinston, N.C. (n14x)		Contentnea Creek at Hookerton, N.C. (n18x)	
	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P
Inputs																
Atmospheric deposition	17.9	21.0	25.5	26.1	39.8	30.5	38.1	25.5	44.0	30.9	20.6	16.9	20.9	14.9	10.9	7.9
Commercial fertilizer	31.9	46.6	22.9	28.7	13.8	11.0	16.2	8.6	17.8	9.1	31.6	27.9	34.9	32.6	43.8	37.8
Nitrogen fixation	40.3	--	35.2	--	15.8	--	6.2	--	5.1	--	24.9	--	20.6	--	22.1	--
Animal waste	9.7	32.0	16.1	43.6	29.9	57.4	34.8	61.9	25.4	48.3	21.5	52.9	19.1	48.1	22.1	53.4
Point sources	.2	.4	.3	1.6	.7	1.1	4.7	4.0	7.7	11.7	1.4	2.3	4.5	4.4	1.1	.9
Outputs																
Crop harvest	63.8	82.3	47.8	51.0	23.5	18.8	14.6	13.2	14.8	14.3	35.9	35.8	32.5	34.4	41.0	40.1
Instream load	10.1	4.6	8.8	7.4	14.0	8.8	14.4	4.8	30.4	25.4	14.4	12.1	15.7	9.9	10.2	9.0
Retention and storage	26.1	13.1	43.4	41.6	62.5	72.4	71.0	82.0	54.8	60.3	49.7	52.1	51.8	55.7	48.8	50.9

inputs, as a percent of total phosphorus inputs from all categories, range from about 8 to 31 percent and average about 20 percent of phosphorus inputs for the eight basins. Because of the estimation methodology, atmospheric total phosphorus inputs, on a tons per square mile basis, are constant. On an areal basis, atmospheric phosphorus inputs are less than fertilizer inputs and comparable to animal-waste inputs.

On a tons-per-square-mile basis (table 12), the rate of nitrogen deposition is relatively constant; the higher rates reflect the increased deposition associated with urban areas or higher elevations. Atmospheric total nitrogen inputs average 1.93 tons per square mile (tons/mi^2), and total phosphorus inputs average about 0.19 tons/mi^2 across the eight basins. Except for Contentnea Creek (n18), the atmospheric nitrogen deposition rate is comparable to the area-weighted animal-waste nitrogen input rate (fig. 76). In the Roanoke, Dan, and Meherrin River Basins, atmospheric nitrogen represented the largest nonpoint nitrogen source on a tons-per-square-mile basis. The generally higher deposition rates in the northwestern part of the study area reflect the positive effect of high elevation on deposition rates, and also can reflect relative proximity to sources of atmospheric nitrogen in the Ohio Valley.

Atmospheric input rates, measured in tons of nitrogen or phosphorus per square mile of drainage basin area, have been estimated for the Neuse, Tar-Pamlico, and Chowan River Basins (Dodd and others, 1992); the entire Albemarle-Pamlico drainage basin (Stanley, 1989); the Chowan River Basin (Kuenzler and Craig, 1986); the upper Potomac River Basin above Washington, D.C. (Jaworski and others, 1992); and the entire Chesapeake Bay drainage area (Fisher and Oppenheimer, 1991). Atmospheric total nitrogen input rates in these studies were 3.5 tons/mi^2 for the Neuse, Tar-Pamlico, and Chowan River Basins; 2.5 tons/mi^2 for the Chowan River Basin; 4.08 tons/mi^2 for the entire Chesapeake Bay drainage area; and 3.8 tons/mi^2 for the upper Potomac River Basin above Washington, D.C. The nitrogen deposition rates are higher than the average deposition rate for the eight NASQAN basins, reflecting the fact that the monitoring stations used to estimate the deposition rates in these studies had higher deposition rates. Atmospheric total phosphorus input rates were 0.19 ton/mi^2 for the Chowan River Basin, 0.11 ton/mi^2 for the entire Albemarle-Pamlico drainage basin, and 0.22 ton/mi^2 for the upper Potomac River Basin above Washington, D.C.

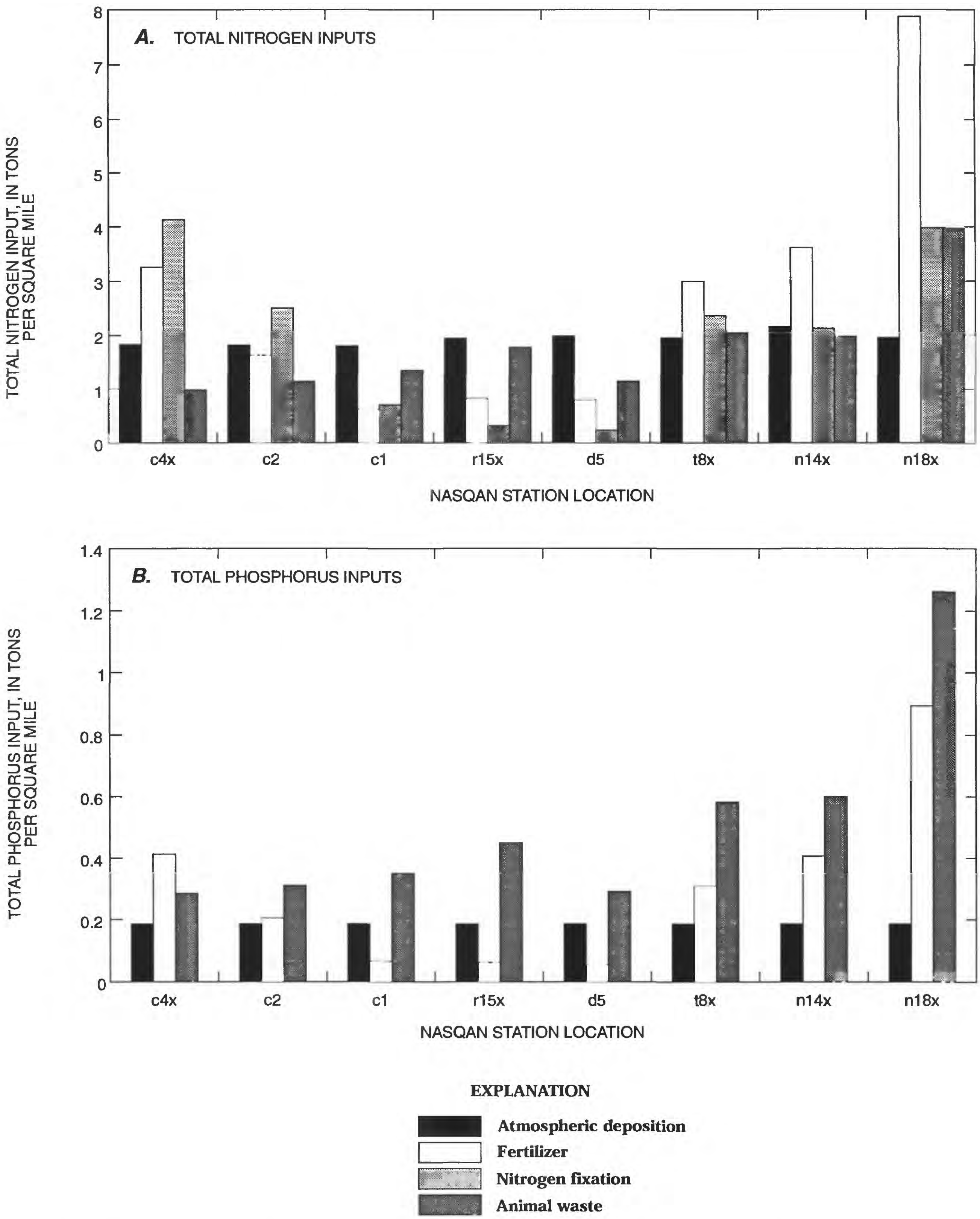


Figure 76. Nonpoint-source (***A***) total nitrogen and (***B***) total phosphorus inputs, measured in tons per square mile of basin drainage area, for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area,1990.

Crop-Related Nutrients

Estimates of the 1990 total nitrogen and total phosphorus inputs to the NASQAN stations from major agricultural crops were made by using (1) crop acreages for major crops within a basin; (2) recommended fertilizer application rates for various major crops, including corn, cotton, tobacco, barley, oats, wheat, Irish potatoes, and sweet potatoes (College of Agriculture and Life Sciences, 1991); and (3) estimates of biologically mediated nitrogen fixation associated with soybeans and peanuts (McMahon and Lloyd, 1995). Crop acreages were based on 1990 crop statistics for harvested acreage reported by county in North Carolina and Virginia. County harvested acreage data were apportioned among the major drainage basins according to the proportion of each county's agricultural land within the associated drainage basin. Once the number of harvested acres for each of the 10 major crops was determined for each drainage area, estimates of fertilizer use were made by multiplying recommended application rates by harvested acres per crop, and then summing all crop types. Estimates of biologically fixed nitrogen inputs were made by multiplying harvested acres of soybeans and peanuts by a nitrogen fixation constant.

The use of harvested, rather than planted, acres produces a conservative estimate of fertilizer use, because generally there are fewer harvested acres than planted acres on which fertilizer originally was applied. Using recommended application rates also results in lower fertilizer-use estimates than those obtained by using county fertilizer sales data. Estimates of fertilizer use based on area-weighted apportioning of county fertilizer sales data were much higher than estimates based on application rates (table 14). Application rates were used in this study because of the uncertainty associated with apportioning county-level fertilizer sales data to fertilizer use in a particular county.

Estimates of crop fertilizer nutrients ranged from about 14 to 44 percent of total basin nitrogen inputs and represented, on average, 27 percent of total nitrogen inputs. Nitrogen fixation inputs ranged from about 5 to 40 percent of total basin nitrogen inputs, and averaged 21 percent for the eight basins (table 13).

Crop-related nitrogen fertilizer and nitrogen fixation are the most important sources of nitrogen in the eight basins (table 13). On a tons-per-square-mile basis, the highest nitrogen fertilizer input rates were in the Blackwater (c4x, 3.3 tons/mi^2), Kinston (n14x, 3.6 tons/mi^2), and Contentnea (n18x, 7.9 tons/mi^2) Basins. At least 60 percent of the Contentnea Basin's crop acreage is devoted to corn and nitrogen-fixing soybeans and peanuts (table 11). Across the eight basins, the average 1990 input rates for nitrogen and phosphorus were 2.7 and 0.30 tons/mi^2, respectively. The highest areal rates of biological nitrogen fixation are in the Kinston (n14x, 9.3 tons/mi^2), Tar River at Tarboro (t8x, 8.4 tons/mi^2), and Nottoway (c2, 5.8 tons/mi^2) Basins. On a tons-per-square-mile basis, fertilizer-related inputs were

Table 14. Two methods of estimating fertilizer nutrient inputs at National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area

[Comparison of estimates are from recommended fertilizer application rates and county-based fertilizer sales information (College of Agriculture and Life Sciences, 1991). Estimates are presented in tons of elemental nitrogen (N) or phosphorus (P]

Station name and map location (fig. 2)	Fertilizer application rate method [A]		Fertilizer sales method [B]		Difference in estimated nutrient inputs (in percent) [(B-A)/A]	
	N	P	N	P	N	P
Blackwater River near Franklin, Va., c4x	2,010	255	2,705	778	34.6	205.2
Contentnea Creek at Hookerton, N.C., n18x	5,770	655	9,075	1,836	57.3	180.3
Meherrin River at Emporia, Va., c1	465	50	1,435	413	208.6	725.6
Neuse River at Kinston, N.C., n14x	9,730	1,095	19,075	3,857	96.0	252.2
Nottoway River near Sebrell, Va., c2	2,320	290	3,885	1,118	67.5	285.5
Roanoke River at Roanoke Rapids, N.C., r15x	6,920	525	22,170	5,708	220.4	987.3
Tar River at Tarboro, N.C., t8x	6,535	670	13,274	2,684	103.1	300.7

generally greater than those from atmospheric sources and less than those related to animal waste (table 12; fig. 76). Phosphorus from commercial fertilizer ranged from about 8 to 47 percent of total phosphorus inputs, and averaged about 25 percent of total inputs (table 13).

Crop fertilization input rates, measured in tons per square mile of drainage basin area, also have been estimated for the Neuse, Tar-Pamlico, and Chowan River Basins (Dodd and others, 1992); the entire Albemarle-Pamlico drainage basin (Stanley, 1989); the Chowan River Basin, including biological fixation by soybeans and peanuts (Kuenzler and Craig, 1986); the upper Potomac River Basin above Washington, D.C. (Jaworski and others, 1992); and the entire Chesapeake Bay drainage area (Fisher and Oppenheimer, 1991). Fertilizer total nitrogen input rates in these studies were 2.8 tons/mi^2 for the Neuse, Tar-Pamlico, and Chowan River Basins; 3.7 tons/mi^2 for the entire Albemarle-Pamlico drainage basin; 4.1 tons/mi^2 for the Chowan River Basin; 2.7 tons/mi^2 for the entire Chesapeake Bay drainage area; and 2.2 tons/mi^2 for the upper Potomac River Basin above Washington, D.C. These rates are comparable to the average nitrogen fertilization rate for the eight NASQAN basins. Fertilizer total phosphorus input rates in these studies were 0.28 ton/mi^2 for the Neuse, Tar-Pamlico, and Chowan River Basins; 0.88 ton/mi^2 for the entire Albemarle-Pamlico drainage basin; 1.3 tons/mi^2 for the Chowan River Basin; and 0.81 ton/mi^2 for the upper Potomac River Basin above Washington, D.C.

Animal Waste

County livestock inventories for chickens, cattle, hogs, and turkeys were obtained from the 1987 U.S. Department of Agriculture's Census of Agriculture, the most recent year for which data are available for all study-area counties. County livestock inventories were allocated to major drainage areas by using a method similar to that described for crop allocation. Resulting inventories of each livestock type were multiplied by estimates of annual per-animal waste nutrient content (Barker, 1991), and waste nutrient loads were summed for all livestock types in a drainage basin to estimate total livestock-related nutrient generation.

Animal-related nitrogen inputs ranged from about 10 to 35 percent of total nitrogen inputs, and averaged slightly more than 20 percent for the eight drainage areas (table 13). On a tons-per-square-mile basis, nitrogen inputs related to animal-waste generally were comparable to atmospheric nitrogen loads averaging 1.8 tons/mi^2 (table 12).

Phosphorus loads from animal waste ranged from 32 to nearly 62 percent of total phosphorus inputs, and averaged almost 50 percent for the eight basins (table 13). These data indicate that phosphorus derived from animal waste was the largest source among the four phosphorus input categories. This dominance is also evident for phosphorus inputs on a tons-per-square-mile basis (table 12; fig. 76). Animal-waste phosphorus inputs averaged 0.52 tons/mi^2.

Animal-waste nutrient input rates, measured in tons per square mile of basin drainage area, also have been estimated for the entire Albemarle-Pamlico drainage basin (Stanley, 1989) and for the upper Potomac River Basin above Washington, D.C. (Jaworski and others, 1992). Animal-waste total nitrogen input rates in these studies were 2.91 and 5.8 tons/mi^2, respectively. The higher rates reflect the inclusion of areas with greater animal inventories. Animal-waste total phosphorus input rates in these studies were 0.82 (Stanley, 1989) and 1.7 tons/mi^2 (Jaworski and others, 1992).

Point Sources

Because of differences in available data, different methods were used to estimate the 1990 total nitrogen and total phosphorus loads generated by point-source dischargers in Virginia and North Carolina. The Virginia Water Control Board supplied daily discharge data for 106 point-source dischargers in the Virginia NASQAN drainage basins, along with Standard Industrial Codes (SIC) describing the type of activity, such as a municipal wastewater-treatment plant, associated with each permit (Robert McEarren, Virginia Water Control Board, written and oral commun., April 1993). These facilities discharge approximately 170 million gallons per day (Mgal/d) of waste effluent. The number of discharge measurements reported by each discharger ranged from 2 to 48 during 1990. Annual nutrient load estimates were obtained by (1) calculating the median value of the daily discharge values, (2) multiplying the median value by a total nitrogen and total phosphorus concentration value based on the SIC to estimate daily nutrient loads, and then (3) multiplying the product obtained in step 2 by 365 (days).

The North Carolina Division of Environmental Management, DEHNR, supplied 1990 monthly average discharge and nutrient concentration data for 172 point-source dischargers in the North Carolina NASQAN drainage basins. These facilities discharge approximately 280 Mgal/d. Most dischargers had monthly average flow and concentration data for all 12 months of 1990. For these dischargers, monthly load estimates were calculated by multiplying the average daily discharge for a given month by the average total nitrogen and total phosphorus concentration values for the same month. Monthly load estimates for each discharger having a 12-month data set were summed over the entire year. For dischargers having less than 12 months of 1990 data, annual nutrient loads were calculated in the same manner as those for Virginia dischargers. The median of all reported daily discharge data for a discharger was multiplied by the median of total nitrogen and phosphorus concentration data for the same discharger to estimate daily loads, and these loads were summed to produce an annual estimate.

Point-source contributions of nitrogen ranged from 0.2 percent of total nitrogen inputs at the Blackwater River near Franklin (c4x) to 7.7 percent at the Dan River at Paces (d5), and averaged 2.6 percent; whereas, point-source phosphorus contributions at the same stations ranged from 0.4 percent of total phosphorus inputs to 11.7 percent, and averaged 3.3 percent (table 13). The station with the highest total input for phosphorus was Dan River at Paces (d5). Point-source contributions averaged 0.18 and 0.03 ton/mi^2 for nitrogen and phosphorus, respectively.

Point-source nutrient input rates, measured in tons per square mile of drainage basin area, also have been estimated for the entire Albemarle-Pamlico drainage basin (Stanley, 1989); the upper Potomac River Basin above Washington, D.C. (Jaworski and others, 1992); and the entire Chesapeake Bay drainage area (Fisher and Oppenheimer, 1991). Point-source total nitrogen input rates in these studies were 0.12 ton/mi^2 (Stanley, 1989), 0.71 ton/mi^2 (Fisher and Oppenheimer, 1991), and 0.29 ton/mi^2 (Jaworski and others, 1992). The higher rates in Fisher and Oppenheimer (1991) reflect the inclusion of the Washington, D.C., point-source discharges. Point-source total phosphorus input rates in these studies were 0.04 (Stanley, 1989) and 0.09 tons/mi^2 (Jaworski and others, 1992).

Annual Output Loads

This section provides information on sediment and nutrients removed from the NASQAN station streams. Instream loads for any NASQAN station represent the total mass of suspended sediment, total nitrogen, and total phosphorus transported by a stream past that station. Estimates also are presented for nutrients removed from each basin through the 1990 crop harvest. Finally, a nutrient-retention/storage estimate is made by subtracting nutrients removed from the basin (by stream transport or by crop harvest in 1990) from the total 1990 estimated nutrient inputs.

Relation of Loads to Streamflow

The total mass of a constituent transported by a stream is often correlated with streamflow, so that the greatest nutrient loads for any period will tend to be associated with the highest discharge rates. When calculating loads, it is desirable to have samples that represent all parts of a stream's flow regime, especially the less frequently occurring high-flow periods when a high proportion of annual sediment and nutrient load can be transported by a stream. Loads were estimated using discharge and concentration data from water years 1980-92. This period included a wide range of annual-mean discharges (fig. 77). The lowest annual-mean discharges at all eight stations for the period of record occurred during water years 1980-92. At least one of the highest 10 annual-mean discharges was recorded at each of the eight stations during 1980-92. Although low and high annual-mean discharges were recorded during the load estimation period, the duration curve for 1980-92 is similar to the duration curve for the period of record at each of the eight stations.

Because the discharge record during the time period for a load analysis adequately represents extreme flow regimes, the accuracy of load calculations depends on the availability of constituent samples that are distributed throughout low, medium, and high streamflows. The distribution of total phosphorus samples by the corresponding percentage of the streamflow duration is shown in figure 78. High discharge corresponds to low percentages, and low discharge corresponds to high percentages. The percentage of total phosphorus samples collected during high streamflows (flows of less than 10-percent duration of the daily mean discharge) ranged from 6 to

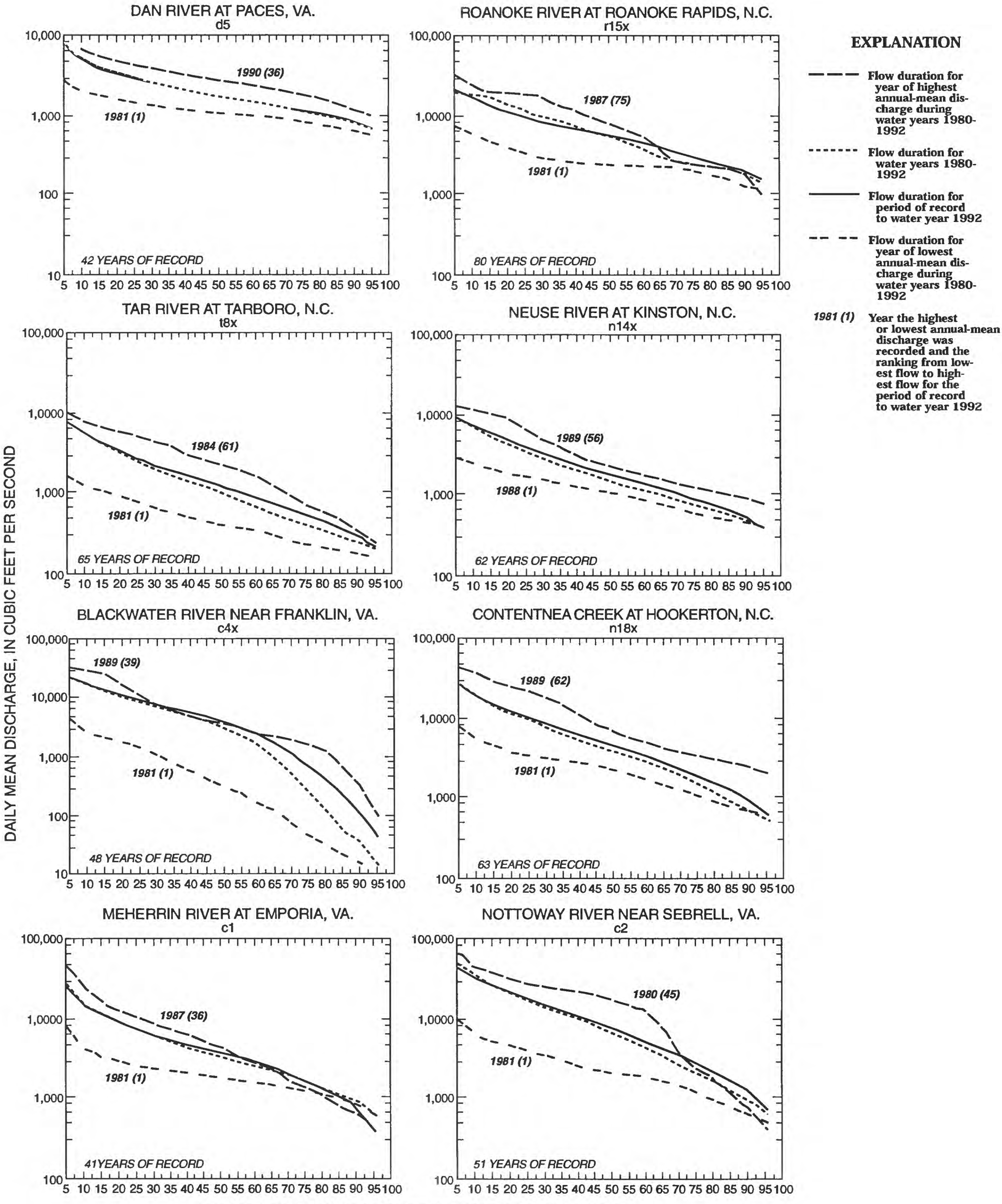


Figure 77. Flow-duration curves for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area.

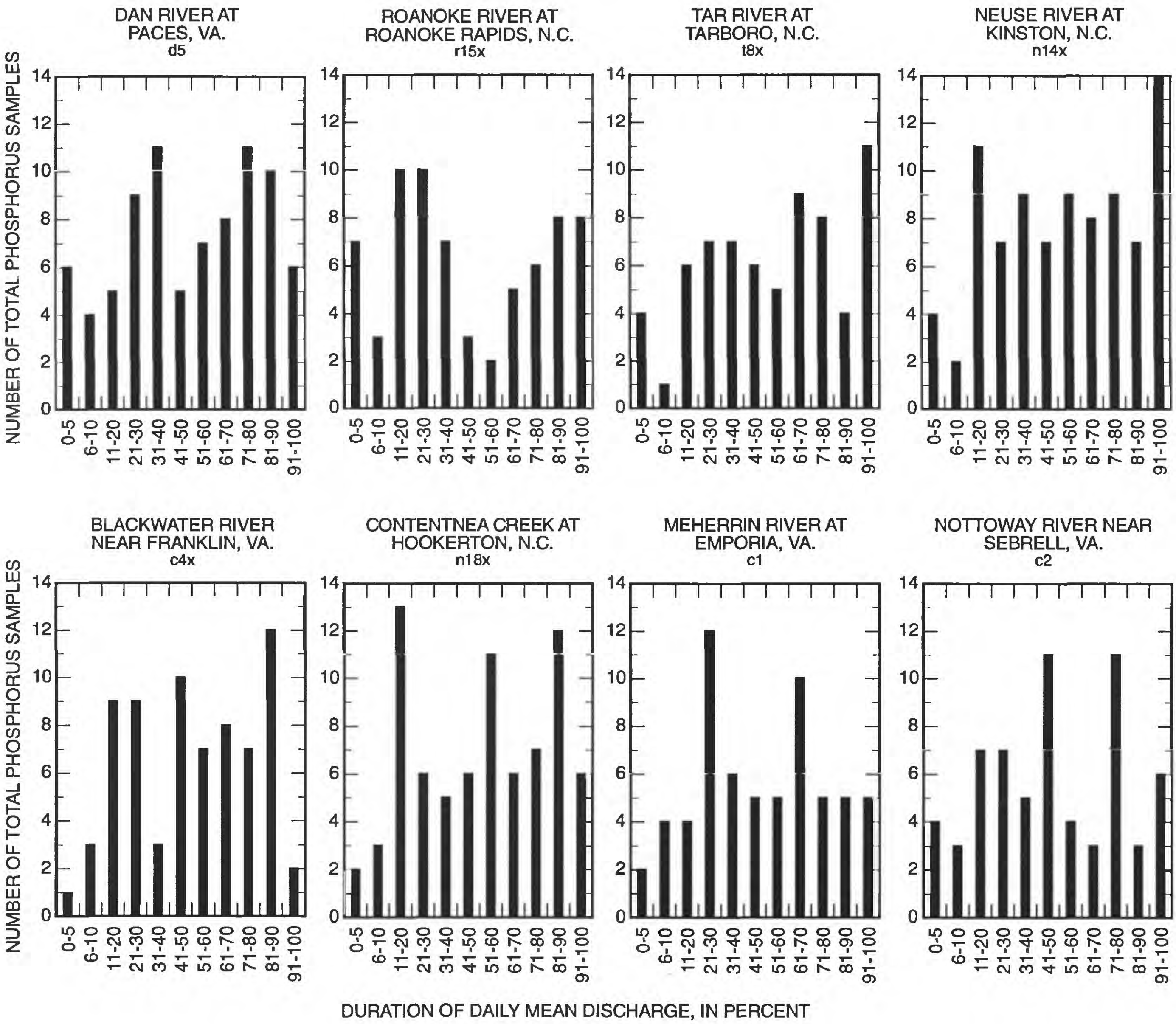


Figure 78. Number of total phosphorus samples corresponding to the duration of daily mean discharge for National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area.

14 percent of the total number of samples collected at each of the NASQAN stations during water years 1980-92. The percentage of total phosphorus samples collected during low streamflows (flows of greater than 89-percent duration of the daily mean discharge) ranged from 2 to 16 percent of the total number of samples collected. Adequate samples of suspended sediment, total nitrogen, and total phosphorus were collected during high-flow regimes to support load calculations.

Annual loads of suspended sediment, total nitrogen, and total phosphorus were calculated for the NASQAN stations by using data for water years 1980-92 and a log-linear regression model producing minimum-variance unbiased estimates (MVUE) of seven parameters (Cohn and others, 1992). Coefficients used in the model for estimating instream sediment and nutrient loads are reported in table 15. The dependent variable in the model is constituent load, and parameters include a constant, two flow-dependent parameters, two parameters for time trends, and two parameters for seasonal effects. These loads represent the mass of a constituent moving past a NASQAN station during a given period of time. In this report, loads are reported on an annual basis and either in absolute terms, such as tons, or as an areal rate (tons per square mile of drainage area).

Sediment Loads

Suspended-sediment loads were estimated at the NASQAN stations for 1980-92 and for 1990 (fig. 79;

Table 15. Regression model parameters used to estimate annual instream loads of total nitrogen, total phosphorus, and suspended-sediment concentrations at National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area

[ln(C*Q)=l+a(ln(Q)+b(lnQ^2)+c(TIME) +d(TIME^2) + e(sine(2*pi*TIME)) + f(consine(2*pi*TIME)), where ln is the natural logarithm; C is the constituent concentration in milligrams per liter; Q is the streamflow in cubic feet per second; l is the regression intercept; a, b, c, d, e, and f are the regression coefficients; TIME is the date in decimal years; pi is 3.141592. A bold number indicates a coefficient significantly different from zero. All available data from October 1979 to September 1992 were used to calibrate the models shown in the table]

Station name and map location (fig. 2)	Constituent	Regression model parameters						
		l	a	b	c	d	e	f
Blackwater River near Franklin, Va., c4x	Total nitrogen	**4.7822**	**1.0646**	0.0142	-0.0015	-.0023	0.0134	**-0.2572**
	Total phosphorus	**1.8636**	**1.043**	-.0117	-.0176	-.0002	**-.2017**	**-.5232**
	Sediment	**6.7515**	**1.05**	.0105	**-.0771**	.0006	.1033	**-.2938**
Nottoway River near Sebrell, Va., c2	Total nitrogen	**6.7815**	**1.109**	.003	.0032	**-.0084**	-.0311	**-.4196**
	Total phosphorus	**4.006**	**1.2232**	-.014	.0008	-.0034	**-.2976**	**-.3694**
	Sediment	**9.4336**	**1.3024**	-.0153	**-.0404**	**-.0086**	-.0894	**-.6383**
Meherrin River at Emporia, Va., c1	Total nitrogen	**6.1422**	**1.234**	.0031	.0017	-.0031	-.1359	**-.35**
	Total phosphorus	**3.5271**	**1.2836**	.019	-.0364	.0059	**-.33**	**-.301**
	Sediment	**9.6317**	**1.5219**	-.0314	**-.0427**	-.0029	**-.2667**	**-.6562**
Roanoke River at Roanoke Rapids, N.C., r15x	Total nitrogen	**8.723**	**1.104**	**.179**	.0091	-.0053	**.1767**	**.243**
	Total phosphorus	**5.5895**	**1.3467**	.03	**-.056**	.0037	-.1942	.066
	Sediment	**11.5843**	**1.3886**	.0115	-.0131	-.0017	.1685	**.2737**
Dan River at Paces, Va., d5	Total nitrogen	**9.0359**	**1.0102**	**.0755**	-.0063	-.0042	-.0753	**-.176**
	Total phosphorus	**6.966**	**1.0086**	**.18**	**-.0617**	-.0041	**-.2183**	**-.1898**
	Sediment	**13.325**	**2.1993**	-.0384	**-.0714**	-.0012	**-.5441**	**-.0616**
Tar River at Tarboro, N.C., t8x	Total nitrogen	**8.0041**	**1.0112**	.0095	.0061	-.0006	-.0672	**-.1103**
	Total phosphorus	**5.8702**	**.096**	**.0899**	**-.0294**	-.0045	-.1319	**-.2295**
	Sediment	**11.3037**	**1.5706**	**-.1016**	**-.071**	.0024	-.1179	**-.3092**
Neuse River at Kinston, N.C., n14x	Total nitrogen	**8.8582**	**.865**	**-.0735**	.0158	**-.0061**	.0405	.0406
	Total phosphorus	**6.0396**	**.7297**	**-.077**	**-.0537**	**-.0123**	-.0463	-.0801
	Sediment	**11.8132**	**1.1562**	-.0996	**.0407**	-.0057	.0417	-.0255
Contentnea Creek at Hookerton, N.C., n18x	Total nitrogen	**7.5347**	**.8612**	.0021	**-.0334**	**-.0069**	-.0225	.0095
	Total phosphorus	**5.802**	**.785**	**-.0684**	**-.0393**	**-.0162**	**-.1537**	**-.1845**
	Sediment	**9.3383**	**1.3536**	-.0005	.0174	.0062	**-.3512**	.2124

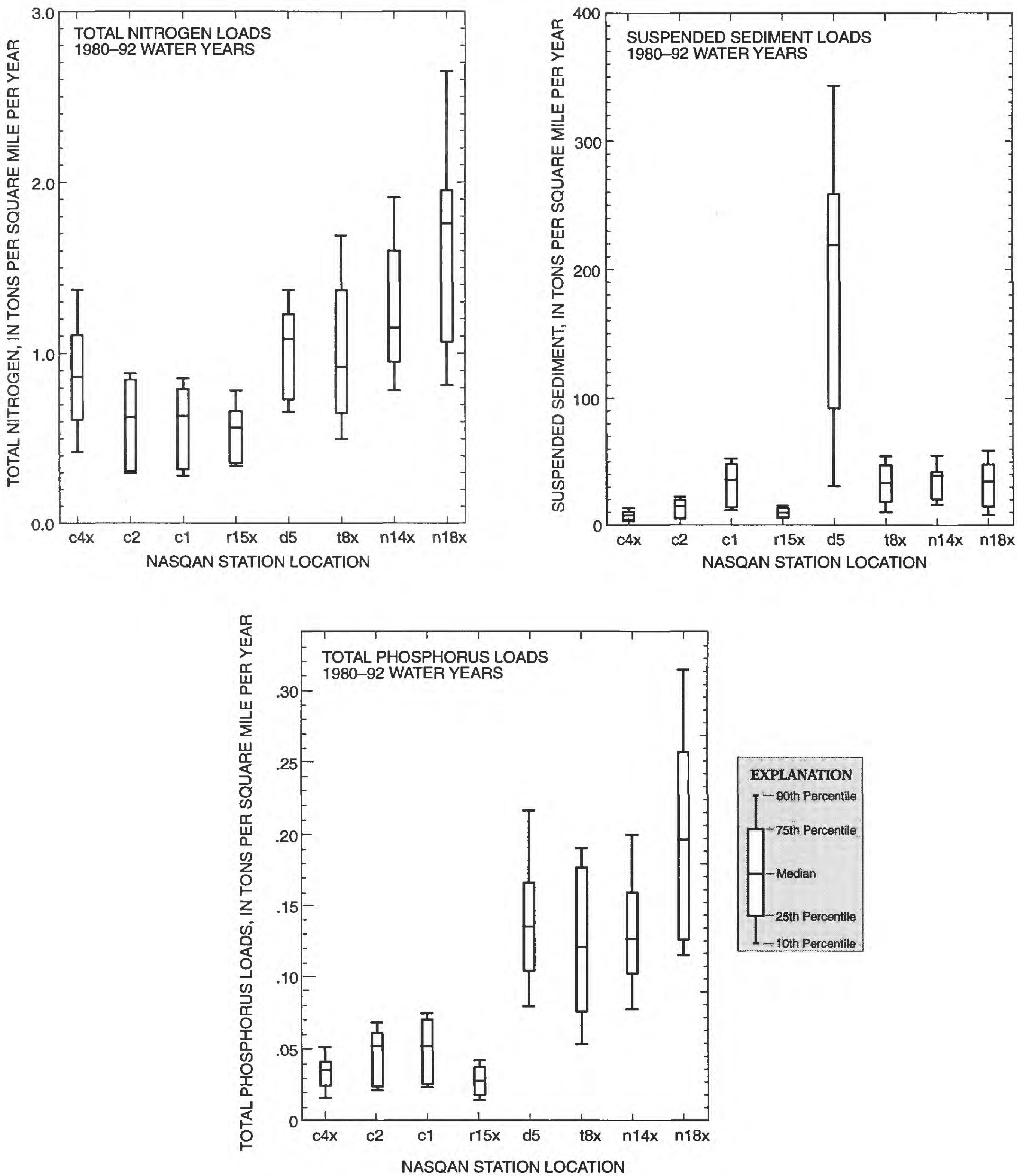


Figure 79. Instream loads of suspended sediment, total nitrogen, and total phosphorus concentrations at the National Stream Quality Accounting Network (NASQAN) stations in the Albemarle-Pamlico drainage study area for water years 1980-92.

table 16). The highest sediment loads during 1980-92, by almost an order of magnitude, were estimated for the Dan River (d5) Basin. Intermediate-level sediment loads were indicated for the Contentnea (n18x), Neuse (n14x), Tar (t8x), and Meherrin (c1) River Basins, and the lowest sediment loads were estimated for the Blackwater (c4x), Nottoway (c2), and Roanoke River (r15x) Basins. Estimated 1990 loads, measured in tons of suspended sediment per square mile of drainage basin, ranged from about 7 tons per square mile per year [(tons/mi^2)/yr] at the Blackwater station (c4) to nearly 269 (tons/mi^2)/yr at the Dan River station (d5); a mean sediment load of 64 (tons/mi^2)/yr of basin area was estimated for the eight basins (table 16).

Nitrogen Loads

Annual total nitrogen loads were estimated for the NASQAN stations for water years 1980-92 (fig. 79; table 16). For all stations except the Neuse River at Kinston (n14), the lowest loads during this period corresponded with the year of lowest annual mean discharge. However, the highest load value at each station does not necessarily occur in the same year as the highest annual mean discharge.

Instream nitrogen loads for 1990 ranged from 0.62 ton/mi^2 at the Nottoway (c2) station, to 1.8 tons/mi^2 at the Contentnea (n18x) station, and averaged 1.1 tons/mi^2 in water year 1990 (table 12). Instream nitrogen loads, measured in tons per square mile of drainage basin area, for the upper Potomac River Basin above Washington, D.C. (Jaworski and others, 1992), and for the Tar River Basin (Research Triangle Institute, 1994) were 2.4 and 0.85 (tons/mi^2)/yr, respectively. Nitrogen loads for 1980-92 and water year 1990 can be distinguished according to basin land use (table 16). The highest loads occur at the agricultural basin (n18); intermediate loads occur at the agricultural/urban sites (d5, n14x, and t8x); and the lowest loads occur at the agricultural/forested sites (c4x, c1, c2, and r15x). Instream nitrogen loads, as a percent of total nitrogen inputs, ranged from 8.8 percent at the Nottoway (c2) station to about 30 percent at the Dan River (d5) station, and averaged 15 percent of total nitrogen inputs (table 13). This average is close

Table 16. Annual instream loads of suspended-sediment, total nitrogen, and total phosphorus concentrations at National Stream Quality Accounting Network stations in the Albemarle-Pamlico drainage study area

[Basin types: Agriculture: greater than 40 percent agricultural land use, less than 40 percent forested, less than 10 percent developed; Agriculture/Urban: greater than 25 percent agricultural, population density greater than 100 people per square mile; Agriculture/Forest: greater than 50 percent forested, less than 40 percent agricultural, less than 10 percent developed. tons/mi^2, tons per square mile]

Station name	Map location (fig. 2)	Sediment loads (tons/mi^2)		Nitrogen loads (tons/mi^2)		Phosphorus loads (tons/mi^2)	
		1980-92 mean annual load[1]	1990 load	1980-92 mean annual load[1]	1990 load	1980-92 mean annual load[1]	1990 load
Agriculture							
Contentnea Creek at Hookerton, N.C.	n18x	33.83	48.11	1.6	1.8	0.21	0.21
Agriculture/Urban							
Dan River at Paces, Va.	d5	204.68	268.87	1.02	1.37	.14	.15
Neuse River at Kinston, N.C.	n14x	36.19	54.96	1.26	1.62	.13	.12
Tar River at Tarboro, N.C.	t8x	32.09	33.34	1.00	1.37	.12	.13
Agriculture/Forest							
Blackwater River near Franklin, Va.	c4x	7.81	7.05	.86	1.04	.03	.04
Meherrin River at Emporia, Va.	c1	32.99	30.12	.57	.63	.05	.05
Nottoway River near Sebrell, Va.	c2	13.81	12.38	.58	.62	.04	.05
Roanoke River at Roanoke Rapids, N.C.	r15x	9.87	13.41	.53	.73	.03	.04

[1]Annual loads are calculated on a water-year basis.

to the 17-percent river export figure reported by Jaworski and others (1992) for the upper Potomac River Basin.

Phosphorus Loads

Estimated annual total phosphorus loads at NASQAN stations for water years 1980-92 ranged from 0.03 to 0.21 ton/mi^2 (fig. 79; table 16). Instream total phosphorus loads in 1990 ranged from 0.04 ton/mi^2 at the Roanoke and Blackwater stations to 0.21 ton/mi^2 at the Contentnea station, and averaged 0.1 ton/mi^2 in 1990 (tables 12 and 16). Instream phosphorus loads, measured in tons per square mile of drainage basin area, for the upper Potomac River Basin above Washington, D.C. (Jaworski and others, 1992), and for the Tar River Basin (Research Triangle Institute, 1994) were 0.23 and 0.11 (ton/mi^2)/yr, respectively. These loads, when examined by land-use category, followed a pattern similar to that of nitrogen loads. Instream total phosphorus loads, as a percent of total phosphorus inputs, ranged from 4.6 percent at the Blackwater (c4x) station to more than 25 percent at the Dan River (d5) station (table 13). The high instream total phosphorus loads at the Dan River (d5) station can be related to the high suspended-sediment loads at this station for the same period. Instream fluxes at the NASQAN stations averaged 10 percent of the total estimated 1990 phosphorus inputs (table 13), an amount comparable to the 8 percent reported by Jaworski and others (1992).

Other Nutrient Outputs

Other important nonpoint-source nutrient outputs are associated with crop harvest and basin retention and storage (fig. 80). Crop harvest removes, on average, slightly more than one-third of agricultural nitrogen and phosphorus inputs (crop fertilizer, nitrogen fixation, and animal waste), a somewhat larger proportion of total nutrient inputs than the crop harvest proportion of nutrient inputs reported for the upper Potomac Basin. Crop harvest removes only a part of the agricultural nutrient inputs associated with fertilizer, biological fixation, and animal waste (Zublena and Barker, 1991). Agricultural-related nutrient inputs contribute more than two-thirds of overall point and nonpoint nutrient inputs, whereas crop harvest removes only a third of these same total nutrient inputs.

Basin retention and storage is calculated as the difference between total nutrient inputs and the sum of instream load and crop harvest categories. This category represents nutrients that otherwise cannot be accounted for because of a lack of knowledge about terrestrial and aquatic nutrient cycling associated with processes such as denitrification, retention in forest ecosystems, and uptake by stream biota. The magnitude of the retention category, averaging approximately 50 percent of total inputs for nitrogen and phosphorus for the NASQAN stations, is lower than the approximately two-thirds proportion reported for the retention and storage category in the Potomac Basin by Jaworski and others (1992) and for four small basins in the Coastal Plain of Georgia (Lowrance and Leonard, 1988). Retention estimates (measured in tons per square mile) are highest in the basin with the most intense agricultural activity, measured by fertilizer inputs, biological fixation, and animal waste.

Input and Output Discussion

A number of factors influence the transport and fate of sediment, nitrogen, and phosphorus in the Albemarle-Pamlico NASQAN drainage basins. Land use, soil type, and physiography are especially important.

Sediment

The average sediment yield of 20 tons/mi^2 for the South Atlantic region basin area (Smith and others, 1993) was exceeded during 1980-92 by five of the eight NASQAN stations (table 16). When national sediment information was examined by land use, the national average sediment yields from land planted in corn and soybeans (100 tons/mi^2) and from mixed agricultural land uses (79 tons/mi^2) were generally higher than sediment yields from comparable basins in the Albemarle-Pamlico drainage area (Smith and others, 1993).

The Dan River Basin station (d5) differs from the other NASQAN stations in the magnitude of annual sediment loads during 1980-92; this station has an average annual sediment load of about 200 tons/mi^2. This load is higher than the loads from 14 national water-resource regions described by Smith and others (1993), where the highest average annual sediment load (111 tons/mi^2) was reported for the lower Mississippi River region.

Three factors—slope, general soil erodibility, and land use—can explain these high sediment yields

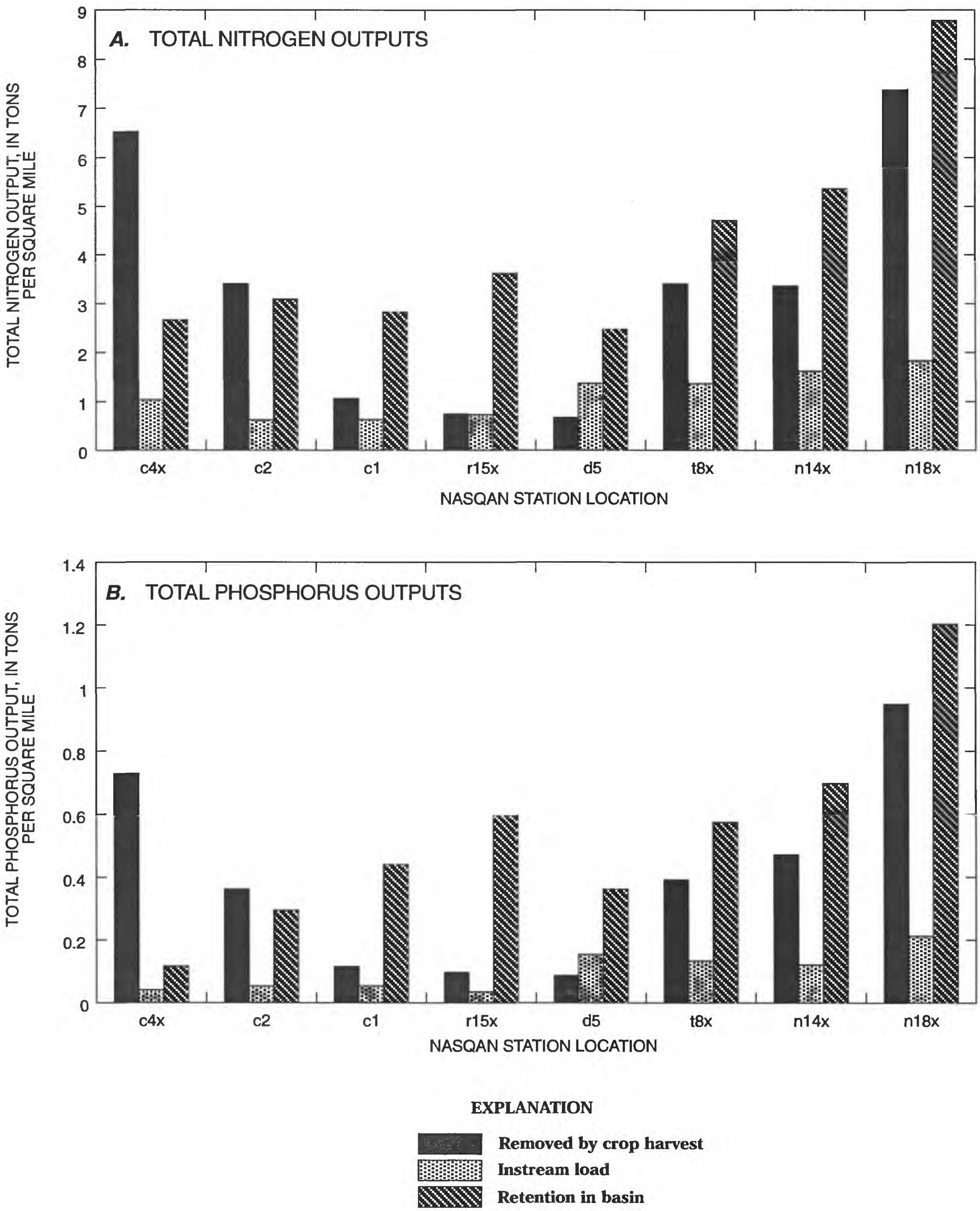


Figure 80. Nonpoint source (*A*) total nitrogen and (*B*) total phosphorus outputs, measured in tons per square mile of basin drainage area, for National Stream Quality Accounting Network (NASQAN) stations in the Albemarle-Pamlico drainage study area, 1990.

in the Dan River Basin. The highest elevations and the steepest slopes in the Albemarle-Pamlico drainage study area are in the upper Roanoke and Dan River Basins (McMahon and Lloyd, 1995). The soil erodibility factor—the *k*-factor of the Universal Soil Loss Equation—is also relatively high for the soil associations in the Dan and upper Roanoke River Basins, compared with other areas in the study unit (McMahon and Lloyd, 1995). Finally, the Dan River and upper Roanoke River Basins have a number of urban areas, the largest cattle inventories of the NASQAN basins, and large acreages in tobacco, a crop requiring a great deal of cultivation (Lilly, 1990; McMahon and Lloyd, 1995). All of these land-use factors can contribute to relatively high sediment loads in the Dan and upper Roanoke River Basins.

Similarities in factors contributing to erosion, shared by the Dan River and the remainder of the upper Roanoke, are not reflected in the actual instream loads measured at the outlet of these two basins. Sediment yields at the Roanoke River station (r15, which includes the Dan River Basin) are less than those at the Dan River station (d5), in absolute terms as well as on a tons-per-square-mile basis. This discrepancy is due to the series of large reservoirs upstream from the Roanoke station that act as effective sediment traps.

Nitrogen

The previous discussion of nitrogen concentrations showed an apparent relation between developed land uses and nitrogen concentrations. This relation suggests that although the load of nitrogen from point sources is smaller than the load from nonpoint sources, these point sources are important in determining instream nitrogen loads. This relation also could reflect effects of nonpoint urban runoff of nitrogen, or sources, such as septic tank effluent, which were not included in the input nitrogen estimates.

Several generalizations are possible regarding nitrogen input categories. Nitrogen inputs associated with atmospheric sources and animal waste are comparable for the NASQAN basins. Fertilizer nitrogen inputs are somewhat larger, except in basins in the northwestern part of the study area where atmospheric nitrogen sources are dominant. Point sources of nitrogen compose the smallest percentage of nitrogen inputs.

Nitrogen loads appear to vary directly with the intensity of agricultural and urban land-use activity. The highest nitrogen loads are reported at Contentnea Creek (n18x), a predominantly agricultural basin. Next in magnitude are the Neuse (n14x), Dan (d5), and Tar (t8x) River Basins, agricultural basins that have relatively high population densities as well as similar basin sizes and flow regimes. The Neuse and Tar River Basins have high nitrogen input rates compared with the Dan River Basin. The relatively high instream nitrogen loads at the Dan River station could be related to the relative importance of point sources among the river's nitrogen input sources.

Agricultural nitrogen-input rates for the entire Albemarle-Pamlico drainage areas, including the land area adjoining the estuaries (Stanley, 1989) are even higher than the input rate at the NASQAN stations. The high level of agricultural activity in these areas near the estuaries could exert a greater influence on estuary water quality than nitrogen originating in upstream areas.

The Blackwater River station (c4x) data indicated evidence of relatively low instream nitrogen loads, despite having the second highest nitrogen input rate among the NASQAN stations. The Blackwater River is a low-gradient Coastal Plain stream, and the relatively large area of riparian wetlands could enhance nitrogen processing by denitrification, providing opportunities for uptake by riparian vegetation.

Nitrogen storage and retention estimates could indicate an excess availability of nitrogen associated with fertilizer, biological fixation, and animal waste compared with nitrogen removed in crop harvest. This excess could, in fact, be underestimated because of the use of harvested, rather than planted, acres for calculating fertilizer use, and the use of fertilizer application rates rather than sales data. The large amount of nitrogen in the retention and storage category also could indicate the high rates (70 to 90 percent) of nitrogen retention reported for forested ecosystems (Jaworski and others, 1992). This process could be especially important, given the significance of atmospheric nitrogen inputs and the large areas of the NASQAN basins in forested land cover.

Relatively few studies have been conducted concerning the transport and fate of nutrients related to animal waste in watersheds. Robbins and others (1972) suggest that between 5 and 10 percent of the total nutrients associated with animal waste actually reach nearby streams. Removing the remaining 90 percent of nutrients from the mass balance-type nutrient accounting system would decrease the size of the retention and storage category. Results reported by Robbins and others (1972) also reinforce the importance of point-source nutrient inputs because all point-source nutrients are delivered directly to the stream. New North Carolina legislation regulating animal-waste disposal is designed to reduce the amounts of animal-waste related nutrients reaching waterways (Ann Coan, North Carolina Farm Bureau, oral commun., 1994).

Phosphorus

Phosphorus input categories, whether measured in tons per square mile of basin area or as a proportion of total inputs, are dominated by animal-related sources in all NASQAN basins except the Blackwater River Basin. This dominance indicates the magnitude of commercial livestock operations in the study area, as well as the small amount of atmospheric phosphorus and the relatively small amount of phosphorus fertilizers required for the mineral soils present in many agricultural areas (J. Zublena, North Carolina State University, oral commun., 1993).

Less phosphorus than nitrogen was present in instream loads at the basin outlets, in terms of loads per unit of basin area and as a percent of total inputs. The Contentnea Basin (n18), which had the highest phosphorus input rate, also had the highest rate of phosphorus loading (table 16). Intermediate-level instream phosphorus loads occurred at the Dan (d5), Neuse (n14x), and Tar (t8x) River stations, although the Dan River station had a relatively low phosphorus input rate. Instream phosphorus loads at the Dan River station could be influenced positively by the large suspended-sediment loads at this same station. Lowest total phosphorus loads occurred at the Blackwater (c4x), Meherrin (c1), Nottoway (c2), and Roanoke River (r15x) stations. Low instream loads at the Roanoke and Meherrin sites could be related to the presence of reservoirs immediately upstream from the sampling sites for these stations, which would lower sediment-attached phosphorus loads at downstream sampling sites.

Phosphorus load estimates from four of the eight Albemarle-Pamlico NASQAN stations are high compared to regional instream total phosphorus load estimates prepared by Smith and others (1993). In that study, the continental United States was divided into 14 regions, and instream phosphorus loads were calculated for each region during a similar time period to this study by using the same load estimation technique. For the South Atlantic Region, Smith and others (1993) reported a mean total phosphorus load of 0.092 ton/mi^2. This amount is less than the instream phosphorus loads estimated for agricultural and agricultural/urban basins in the Albemarle-Pamlico drainage area but greater than the loads reported in the agricultural/forested basins. At a national level, the highest instream total phosphorus load, reported in the Upper Mississippi Region, was 0.157 ton/mi^2, a rate lower than the 0.211 ton/mi^2 estimated for the Contentnea Creek (n18) Basin.

Smith and others (1993) also reported loads for basins having different predominant land uses and different predominant crop types. In this national study, agricultural basins having a predominance of corn and soybeans (over 50 percent of the cropped area per basin) had the highest total phosphorus loads (0.163 ton/mi^2) followed by urban basins (0.119 ton/mi^2). The Albemarle-Pamlico NASQAN stations located where corn and soybeans compose more than 50 percent of total crop acreage (table 11) (Contentnea (n18x), 64 percent; Neuse (n14x), 61 percent; Meherrin (c1), 59 percent; and Nottoway (c2), 58 percent) had instream phosphorus loads less than the national load estimate, except for Contentnea Creek (n18x) where half the drainage area is devoted to agriculture. The relatively low phosphorus loads at the Meherrin and Nottoway River stations could be explained by the high proportion of forested land in each basin and the heterogeneous landscape pattern characteristic of the Piedmont (McMahon and Lloyd, 1995). An intermixed pattern of agricultural fields and forested land can mitigate phosphorus movement associated with sediment transport.

SUMMARY

This report is the second in a series of reports summarizing data pertinent to the quality of surface- and ground-water resources in the large river basins of the Albemarle-Pamlico drainage basin. This report is intended to be used in concert with an earlier report, which describes the environmental setting of the study basin.

The 28,000-mi^2 Albemarle-Pamlico drainage basin includes the Roanoke, Dan, Chowan, Tar, and Neuse Rivers. The basin extends through four physiographic provinces—Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain. About 50 percent of the area is forested, more than 30 percent is agricultural, 15 percent is wetlands, and about 5 percent is developed. The basin population is about 3 million.

The study basin has recently been the focus of a comprehensive assessment by the North Carolina State Government, Federal water-resources agencies, university researchers, and local interest groups. This assessment was conducted as part of the National Estuary Program authorized by the Clean Water Act Amendments of 1987. An extensive body of literature, primarily on the estuarine areas, is available.

The purpose of this report was to summarize the spatial and temporal patterns in riverine water quality in the study area, using readily available data sources. The primary data sources included the USGS WATSTORE database, the USEPA STORET database, and results of a few investigations of pesticide occurrence. The principal water-quality constituents examined were suspended sediment, nutrients, and pesticides. The data examined were generally for the period from 1950 to 1993.

The available surface-water data were screened for sites having the longest period of record and the most nutrient samples. Sixty-six separate locations, including 10 with two sets of data collected by different agencies, were used in the analysis. A statistical test of the sites having data from two different agencies indicated that the data should not be grouped together, so each data set for these sites was examined separately.

The distribution of surface-water stations is uneven. There are no stations in large areas of the Coastal Plain and the upper reaches of the Blackwater, Nottoway, Meherrin, Hyco, Otter, Pigg, and Dan River Basins. However, the major trunks of the Roanoke, Dan, and Neuse Rivers have better surface-water station coverage.

Ground-water nutrient data were obtained from three principal sources—the WATSTORE and STORET databases were combined with APRASA data. Most of the ground-water data were collected from 1960 to 1990.

Streamflow data were available only for the WATSTORE stations and were most extensive at the eight NASQAN sites. Discharge generally peaks in February or March and is least in July, August, and September. Seasonality of discharge is more evident in the larger streams of the Piedmont, and less so in the basins that drain large areas of the Coastal Plain.

Specific conductance reflects the relative amounts of chemical ions in solution. The NASQAN sites had similar specific conductance distributions; values ranged between 50 and 150 μS/cm. Specific conductance showed a progressive downstream decrease in the Roanoke River, in particular as a result of effects of Smith Mountain, Kerr, and Gaston Lakes. Specific conductance for the Dan, Chowan, and Tar Rivers indicated little spatial variation. Specific conductance in the Neuse River generally increased downstream until the Smithfield site and then decreased downstream. This spatial variation probably reflects the influences of point and nonpoint sources in and around Raleigh, N.C.

A series of map overlays of basin characteristics, including land use, geology, and soil type, was used to subdivide the study area into 12 major logical groupings by basin characteristics, termed “strata.” Eight of the 12 strata were adequately represented by available water-quality data, and two of those eight were grouped together after further analysis. These strata categories included Agriculture/Coastal Plain/Poorly Drained; Agriculture/Coastal Plain/Well Drained; Agriculture/Granitic/Well Drained; Agriculture and Forest/Slate Belt; Forest/Granitic; Forest/Coastal Plain; and Developed.

The specific conductance distribution for the Developed stratum subbasins was significantly different, with a higher median value than the distributions for the Agriculture and Forest strata. These differences between groups suggest that the greatest effect on dissolved ion concentrations in the streams occurs in developed areas and in the Coastal Plain agricultural areas having poorly drained soils.

Suspended-sediment concentrations for the NASQAN stations generally are less than 50 mg/L except for the Dan River at Paces. Suspended-sediment concentrations in Piedmont streams tend to be greater than those in Coastal Plain streams because of steeper slopes and highly erodible soils. Kerr and Gaston Lakes are effective traps for sediment from the upper Roanoke River Basin, as is Falls Lake for the Neuse River. Substantial reductions in suspended-sediment concentrations are evident as the Neuse River flows out of the Piedmont into the Coastal Plain. Strata comparisons indicated that the Agriculture/Granitic/Well Drained category has the highest suspended-sediment concentrations. Agricultural activities, particularly highly erosive corn and tobacco farming, combined with the steep slopes of the Piedmont promote high sediment yields.

Of the NASQAN stations, median dissolved-solids concentrations are greatest at the Blackwater and Dan River sites. At four NASQAN stations, a greater fraction of inorganic than organic material made up the total solids. Solids concentrations decreased downstream in the Roanoke River, as the river flows out of the developed, highly erodible Piedmont into lakes in the middle of the basin. The downstream decrease is less distinctive in the Dan River, but this indicates the effects of the lakes on solids concentrations. Little variation in solids concentrations is evident in the Chowan Basin, except for Spring Branch, a small tributary affected by point-source inputs. Relatively localized influences on solids concentrations occurred in the Tar River as a result of development around Rocky Mount, N.C. Solids concentrations in the Neuse River reflect the pattern noted with specific conductance—concentrations increase downstream, peak near the Smithfield station, and then decrease further downstream. This pattern for the Neuse River probably is the result of the effects of wastewater discharges. Comparison of dissolved-solids concentrations by strata indicated a pattern similar to that for specific conductance, and the pattern for fixed solids was similar to that observed for suspended sediment.

The measures of nitrogen examined included total nitrogen, total ammonia plus organic nitrogen, total nitrite plus nitrate, and total ammonia nitrogen. Total nitrogen concentrations at most of the larger stream sites generally are greater than the 0.3 mg/L level cited to indicate potential for nuisance algal growth. Contentnea Creek has the highest total nitrogen values, followed by the Neuse River at Kinston, Tar River at Tarboro, Dan River at Paces, Blackwater River, the other Chowan tributaries, and the Roanoke River at Roanoke Rapids. This ranking mirrors the ranking of these sites by relative intensity of urban and agricultural development. In general, the most developed basins and those with the most intensive agriculture have the highest nitrogen values. However, the Roanoke River station at Roanoke Rapids has low total nitrogen concentrations because of upstream sedimentation and assimilation of nitrogen in algal biomass.

Nitrogen concentrations generally decrease downstream in the Roanoke River, and increase downstream in the Tar River. The decrease in the Roanoke reflects the influence of the lakes downstream from the major inputs of nutrients to the basin in the area around Roanoke, Va. The increase in the Tar River probably reflects the intensity of farming in the basin. The spatial pattern for nitrogen concentration in the Neuse is similar to that observed for specific conductance, sediment, and solids concentrations—concentrations peak near the Smithfield station and then decline downstream. Nitrogen at the Falls and Clayton Neuse River stations is largely ammonia plus organic nitrogen but changes to nitrite and nitrate nitrogen downstream at the Smithfield station. The Agriculture/Coastal Plain/Poorly Drained stratum had the highest nitrogen values, followed by the Agriculture/Coastal Plain/Well Drained and Developed strata.

The ranking of phosphorus concentrations for the NASQAN stations was similar to the ranking observed for nitrogen concentrations. The basins with the most development and most intensive agriculture showed the highest phosphorus concentrations. Phosphorus concentrations were frequently above 0.1 mg/L in all but the Chowan River and the Roanoke River at Roanoke Rapids, providing an ample supply of the nutrient for algal growth. Low concentrations of phosphorus at Roanoke Rapids are due to settling of phosphorus with sediment in Kerr and Gaston Lakes, and assimilation in the lake of soluble phosphorus by algae.

Total phosphorus concentrations are relatively uniform in the Dan River, increase downstream in the Tar River, peak in the Tar River, and peak in the Neuse River near Smithfield in a manner similar to the pattern observed for other constituents. The concentrations of phosphorus in the Neuse River are some of the highest values of any of the Albemarle-Pamlico drainage study subbasins. The stratum having the highest phosphorus concentrations was the Agriculture/Coastal Plain/Poorly Drained category. The Developed strata had the second highest median total phosphorus concentration. This pattern is similar to that observed for specific conductance, dissolved solids, and nitrogen.

The large number of pesticides and variety of pesticide classes make pesticide monitoring expensive; thus, the amount of available pesticide data is limited. Surface-water pesticide data for this report were obtained primarily from the WATSTORE and STORET databases. The WATSTORE database contains information for multiple samples at a few stations, whereas the STORET database contains data for a few samples at multiple stations.

All of the concentrations for 10 of the 28 pesticides analyzed from the STORET database for 1970-90 were either less than reporting limits or were reported as nondetected. The most commonly detected pesticides were atrazine and aldrin. The WATSTORE pesticide data for 1970-92 indicated that all of the concentrations for 36 of the 74 pesticides analyzed were less than reporting limits. The pesticide groups most frequently detected in water samples were the chloroacetnalilide herbicides and triazine herbicides and their metabolites.

Intensive organonitrogen herbicide sampling of Chicod Creek in 1992 indicated seasonal variation in pesticide concentrations. The most commonly detected herbicides were atrazine, alachlor, metolachlor, prometon, and metribuzin. No relation between streamflow and pesticide concentrations was noted. Concentrations of atrazine increased in late May and early June and decreased gradually until September.

Considerably less nutrient and pesticide data are available for ground water than for surface water. Median concentrations of nitrate in ground water in four of seven hydrogeologic zones in the study area were less than 0.5 mg/L. Median concentrations were largest and variability greatest in water from wells completed in fractured-rock aquifers of the Valley and Ridge carbonates and Piedmont granitic rocks. Nitrate concentrations and variability are greatest in shallow wells (less than 100 ft deep), compared to deeper wells. Median concentrations of nitrate are lowest in the Coastal Plain.

Comparison of total phosphorus concentrations in ground water from four hydrogeologic zones in the study area indicates that the highest median concentration (0.25 mg/L) and the largest variability are in the Coastal Plain zones. Median concentrations from granitic rocks of the Piedmont and carbonate rocks of the Valley and Ridge Provinces are less than 0.2 mg/L. Phosphorus concentrations in the Coastal Plain zones are high probably as a result of the natural phosphorites in some Coastal Plain sediments.

Only a few studies investigating pesticides in North Carolina ground water have been conducted since about 1970. Alachlor and atrazine were detected in the largest percentage of shallow domestic wells in eastern North Carolina. Only 16.5 percent of the 139 tested wells had one or more of the five detected pesticides. In Duplin County, a Coastal Plain county just south of the study area, approximately one-third of the 189 private wells sampled for atrazine, alachlor, metalaxyl, and aldicarb had detectable concentrations, and 5 percent of the sampled wells had at least one of these pesticides in concentrations greater than 1 µg/L.

Trends in surface-water quality were examined for available data during 1980-89 with the seasonal Kendall test for trends, using residuals from LOWESS-smoothed curves to adjust for streamflow. Trend evaluation was possible using available data for a limited number of stations for sediment, and for solids and nutrients at most stations. Sufficient data were not available to evaluate trends in pesticide concentrations in ground-water quality.

Increases in specific conductance were detected for stations in the lower Neuse River Basin, in the lower Tar River Basin, and in the Eno, Dan, and Roanoke Rivers. These increases probably result from increased wastewater discharges and the effects of development. Decreases in specific conductance in the upper Roanoke, Dan, and Blackwater Rivers possibly reflect improvements in waste-treatment processes. A decreasing trend noted at the Neuse River near Falls is probably a result of the upstream effect of Falls Lake.

Suspended-sediment data were available only for the NASQAN stations. The only significant trends detected were for the three Chowan River tributary sites, which showed long-term decreases. These decreases probably result from changes in agricultural land-management practices in the Chowan River Basin during the last decade.

Suspended- and total-solids concentrations have decreased throughout the Albemarle-Pamlico drainage basin. The decrease is probably a result of (1) construction of new lakes and ponds in the basin, which trap solids; (2) improved agricultural soil management; and (3) improved wastewater treatment.

Total nitrogen trends indicate a cluster of increases in the tributaries at the upper end of Kerr Lake, and a cluster of decreases in the Neuse River Basin. The increases in nitrogen concentrations upstream from Kerr Lake possibly reflect changes in atmospheric inputs of nitrogen. Decreases in nitrogen concentrations in the Neuse River Basin are dissimilar, suggesting differing causes of the decreases. Trends observed for total ammonia plus organic nitrogen were similar to those observed for total nitrogen and nitrate nitrogen. Increasing trends in nitrate also were detected for two sites in the Tar River Basin, and probably are due to changes in agricultural practices. A gradual increase in nitrate concentrations in the Chowan River near Riddicksville was detected.

In general, total phosphorus concentrations showed increasing trends for the stations in Virginia and decreasing trends for the riverine stations in North Carolina. The effect of the 1988 phosphate detergent ban in both states is evident at several stations, including Nottoway River near Sebrell, Neuse River at Kinston, and Contentnea Creek at Hookerton. Total phosphorus is strongly associated with sediment; therefore, locations having high sediment concentrations, such as those in the upper Roanoke and Dan River Basins, generally have high phosphorus concentrations.

The eight Virginia stations having total organic carbon data showed decreasing concentrations from 1980 to 1989. These decreases are most likely a result of decreasing upstream inputs of wastewater sources of organic carbon. Generalized decreases in organic carbon are consistent with decreases in solids concentrations as part of improved wastewater treatment.

Data on potassium, a common component of fertilizer, were available only for the NASQAN stations. Increasing trends were detected in seven of the eight stations. The nature of the seasonality of potassium concentration implies that the source of the long-term increase in potassium concentration results from waste discharges.

Generally, nutrient point sources are much smaller than nonpoint nutrient input sources at the NASQAN basins examined for nutrient loads. The highest nitrogen inputs are associated with crop fertilizer and biological nitrogen fixation by soybeans and peanuts, whereas atmospheric and animal-related nitrogen inputs are comparable in magnitude. The largest phosphorus inputs are associated with animal wastes.

Generally, nitrogen loads at the NASQAN stations are directly related to the size of the nitrogen inputs, although loads at the Dan River station are higher and loads at the Blackwater River station are lower than would be expected on the basis of the size of nitrogen inputs. This can be attributed to the influence of point sources, as in the case of the Dan River, and to the mitigating influence of wetlands, as in the case of the Blackwater River. Phosphorus and sediment loads are generally higher than loads reported for 14 national water-resource regions. The higher loads could represent the averaging of loads over larger areas in the national study, but also could reflect the positive effect of land use and environmental factors on constituent loads in the Albemarle-Pamlico basins. Sediment yields are highest in basins characterized by relatively steep slopes, erodible soils, and predominantly urban and agricultural land uses. Sediment yields, at the basin outlet, appear to be mitigated by upstream reservoirs.

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