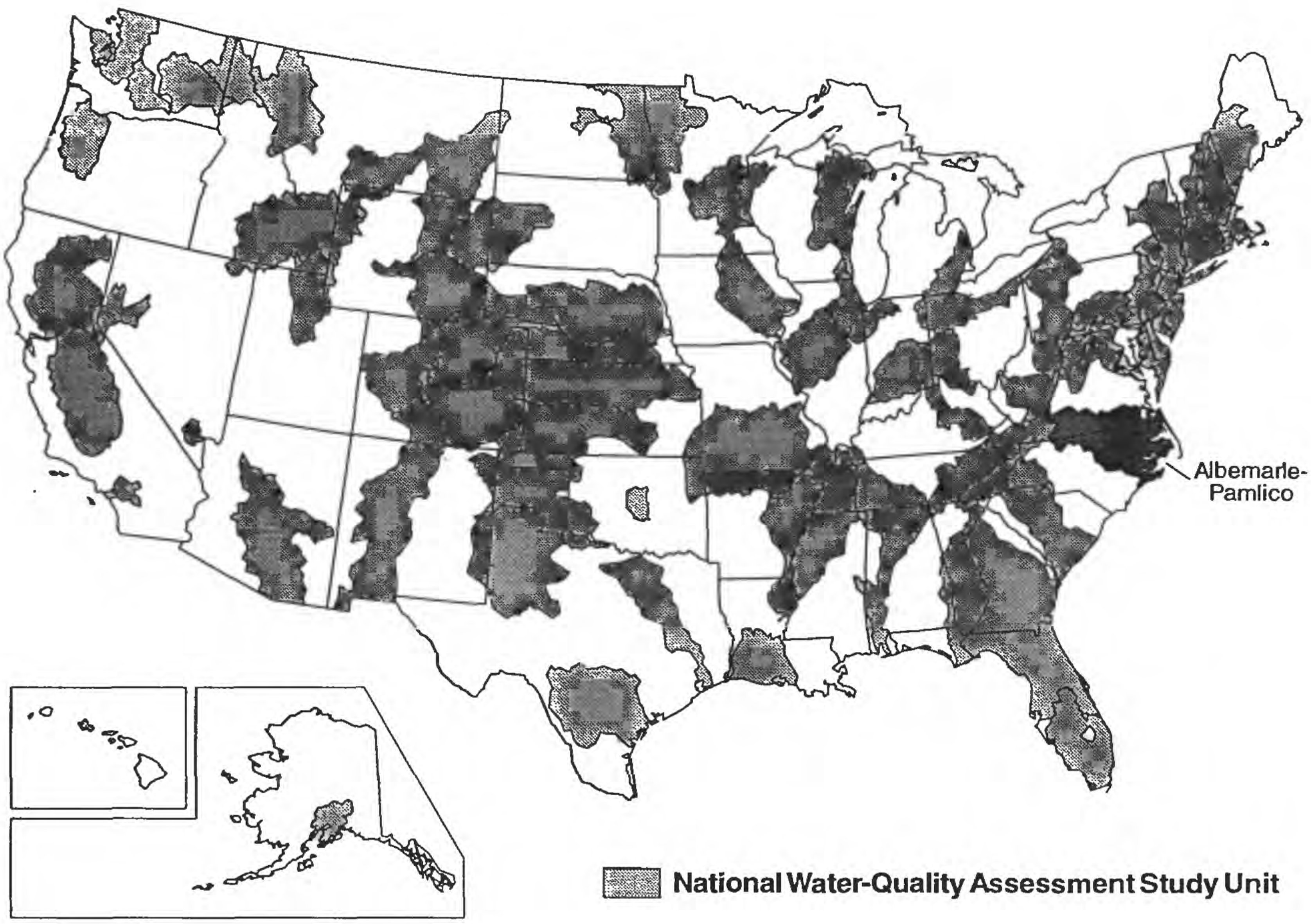
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

WATER-QUALITY ASSESSMENT OF THE ALBEMARLE-PAMLICO DRAINAGE BASIN, NORTH CAROLINA AND VIRGINIA-- Environmental Setting and Water-Quality Issues

U.S. GEOLOGICAL SURVEY
Open-File Report 95-136



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By Gerard McMahon and Orville B. Lloyd, Jr.

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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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WATER-QUALITY ASSESSMENT OF THE ALBEMARLE-PAMLICO DRAINAGE BASIN, NORTH CAROLINA AND VIRGINIA--Environmental Setting and Water-Quality Issues

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ABSTRACT

The Albemarle-Pamlico drainage study unit is one of 60 units of the U.S. Geological Survey's National Water-Quality Assessment Program, and includes the large river basins which drain into the Albemarle and Pamlico Sounds—the Chowan, Roanoke, Tar-Pamlico, and Neuse River Basins. The study unit includes about 28,000 square miles and has an interrelated set of environmental characteristics which strongly influence water quality. The chemical and physical nature of these characteristics are the dominant controls on baseline water quality in the study area. About 50 percent of the study area is forested, slightly more than 30 percent is agricultural, about 15 percent is wetlands, and less than 5 percent is developed. Three million people live in the study area, and activities related to agriculture and development have caused increased concentrations of constituents such as nutrients, pesticides, and suspended sediment.

About two-thirds of the 36 to 52 inches of precipitation in the area reenters the atmosphere by evapotranspiration. About one-third of the remaining precipitation reaches streams by overland runoff; the remainder recharges the water table aquifer, where much of the water eventually discharges to streams as ground water. Thus, ground-water quality has a substantial influence on surface-water quality, particularly during dry weather.

In 1990, about 152,900 tons of elemental nitrogen and 10,500 tons of elemental phosphorus either were applied to crops as fertilizer or fixed by biological processes, and in 1987, about 43,500 tons of nitrogen and 12,200 tons of phosphorus were produced as animal wastes. In addition, about 1,300 tons of selected herbicides and 400 tons of selected insecticides were applied to crops in 1990. Some 249 permitted point sources discharged 410 million gallons per day, containing an annual load of 5,800 tons of nitrogen and 1,800 tons of phosphorus, to the study area in 1990. Data from 1970-79 indicate that mean annual suspended-sediment yields for selected forested, agricultural, and developed urban basins in North Carolina are 50, 250, and 550 tons per square miles, respectively.

In order to facilitate comparisons, much of the data were compiled by hydrologic unit. Homogeneous areas, or strata, representing the most prevalent combinations of environmental factors, such as land use, soils, and geology, were defined. Future data collection and analyses will be designed to answer objective-related concerns about the relations between important water-quality conditions and these study-unit strata.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began to implement a full-scale National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to (1) provide nationally consistent water-quality descriptions for a large, diverse, and geographically distributed part of the Nation's ground- and surface-water resources; (2) define, where possible, the changes and trends in water quality that have occurred in recent decades; and (3) where data permit, identify and describe the relation of the status and changes in water quality to relevant natural and human factors. In meeting these goals, the program can produce information to be used by policy makers and managers at national, State, and local levels (Leahy and others, 1990). Study-unit investigations constitute a major component of the NAWQA Program, forming the principal building blocks on which national-level assessment activities are based. The 60 study-unit investigations that make up the program are hydrologic systems that include parts of most major river basins and aquifer systems and cut across many political boundaries (fig. 1A; table 1). These study units cover areas of 1,200 to 65,000 square miles (mi^2) and together incorporate 60 to 70 percent of the Nation's population served by public water supply.

Each study-unit investigation will have a 10-year life cycle, including 3 years of continuous and intensive data collection and analysis, and 4 years of intermittent and less intensive water-quality monitoring. Only one-third of the study units are involved in the intensive data-collection activity phase at any given time, but all 60 study units are to have completed one intensive activity phase within 12 years (fig. 1B).

National assessments of important water-quality issues are also a major component of the NAWQA Program. Water-quality issues selected for national assessment include pesticide contamination, suspended sediment, and nutrient loads in surface water, as well as pesticide contamination and nutrients (particularly nitrate) in ground water. Consistent and comparable data collected and analyzed in each of the study units allow regional and national assessments of conditions and trends for these issues.

Albemarle-Pamlico Drainage Study Unit

The Albemarle-Pamlico drainage study unit was among the first 20 units selected for investigation under the full-scale implementation plan of the NAWQA Program in 1991. The study unit area consists of about 28,000 mi^2 and, for operational purposes, excludes the estuarine parts of the rivers, the open waters of the Albemarle, Pamlico, and associated Sounds, and the barrier islands known as the Outer Banks (fig. 2). The quantity and quality of discharge from the study area, however, contribute to the water quality of the biologically sensitive waters of the Albemarle and Pamlico Sounds, and information from this study should benefit agencies managing the estuarine resources of the sounds.

The study area, located in central and eastern North Carolina and southern Virginia, includes four major river basins and covers parts of four physiographic provinces (fig. 2). The major river basins in the study area are the Chowan, Roanoke, Tar-Pamlico, and Neuse Rivers and associated tributaries, as well as the Great Dismal Swamp and associated streams in southeastern Virginia and northeastern North Carolina. Parts of the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain Provinces are in the study area.

The Albemarle-Pamlico drainage study has three basic objectives consistent with the NAWQA Program's national goals: (1) to describe the occurrence and spatial distribution of water-quality conditions associated with nutrients, sediments, and pesticides; (2) to describe temporal trends associated with these constituents; and (3) to assess cause-and-effect relations between environmental factors and water-quality conditions. These objectives, which define the overall scope of the work to be accomplished in the Albemarle-Pamlico study unit, have been developed with guidance from the national NAWQA leadership team and the study unit liaison committee. The liaison committee is composed of representatives from Federal, State, and local agencies; universities; and private business and organizations with interests in water resources in the study area. The concerns listed in the table on page 6 provide a framework for understanding the importance of the research and collection and analysis of new data during the intensive study phase.

Accomplishing the three objectives listed above will require investigators in each study unit to (1) classify and locate areas in the study unit representing important combinations of natural and cultural factors; (2) measure physical, chemical, and biological characteristics of surface and ground water in locations associated with each of the major combination of characteristics; and (3) compare and contrast the temporal and spatial correspondence between environmental factors and water quality.

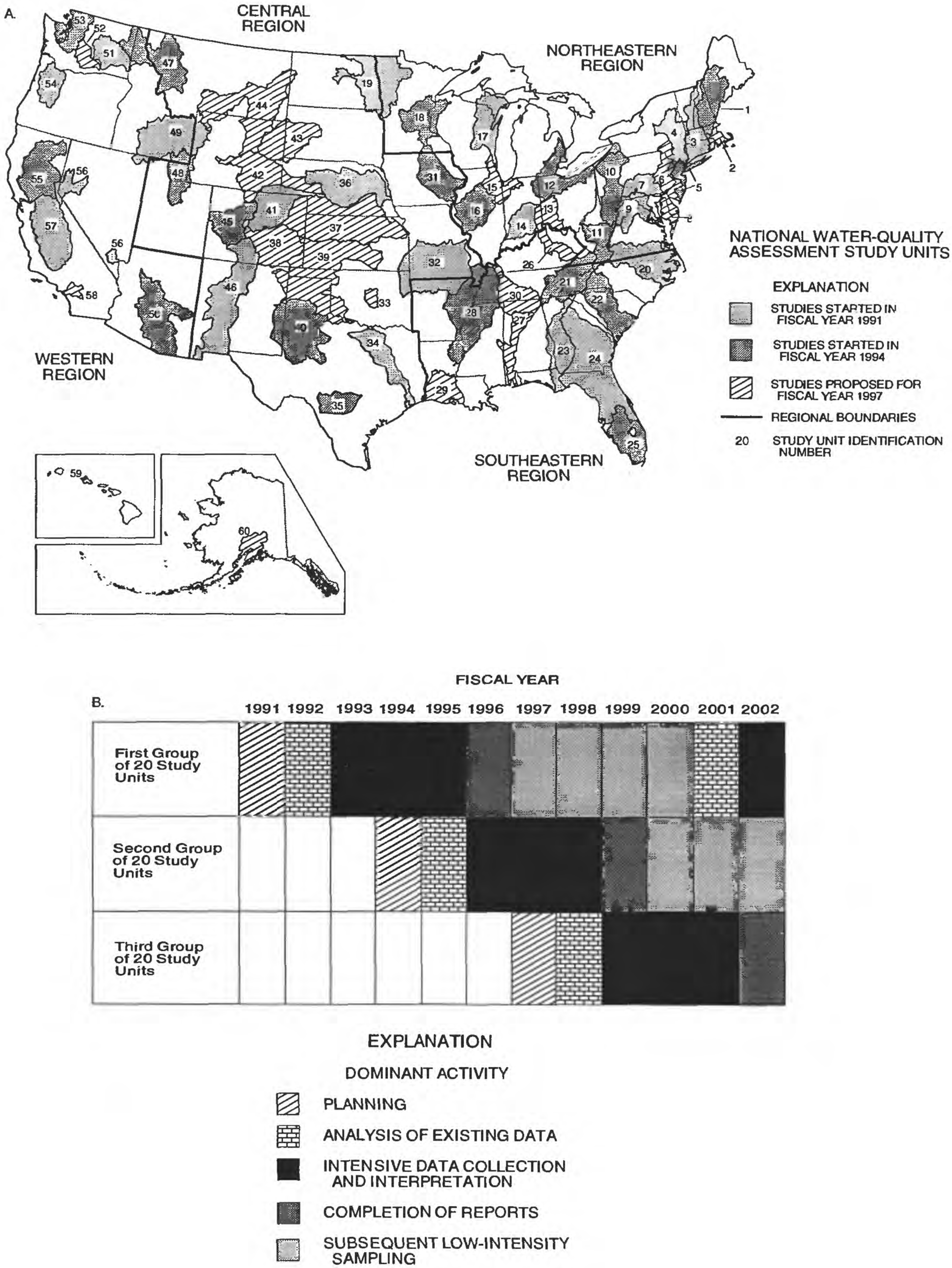
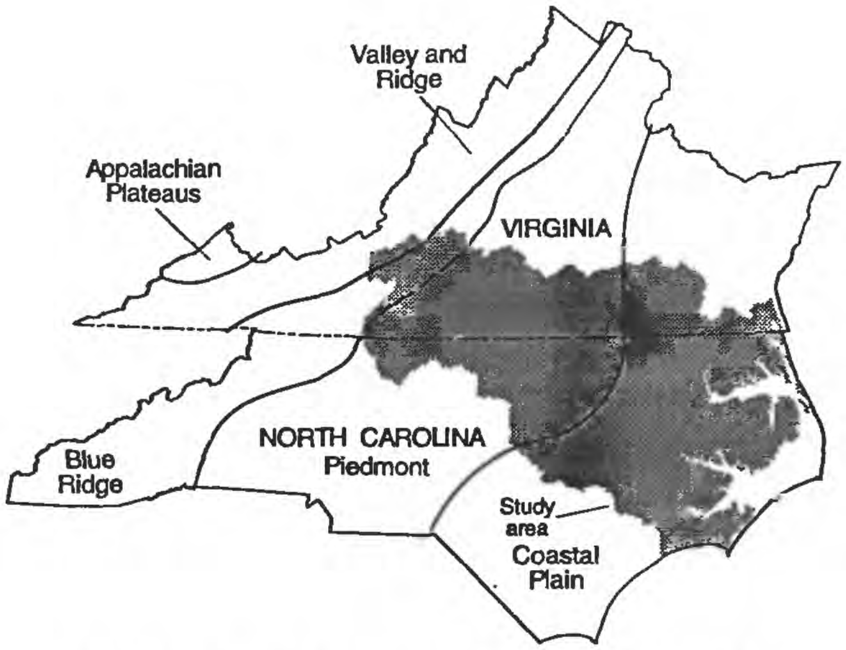


Figure 1. (A) National Water-Quality Assessment Program study units and (B) implementation scheme for program (from Leahy and others, 1990).

Table 1. Study units for the National Water-Quality Assessment Program (from Leahy and others, 1990)

Map no. (fig. 1A)	Study-unit name	State(s) in which units are located	Msp no. (fig. 1A)	Study-unit name	State(s) in which units are located
1	New Hampshire-Southern Maine Basins	Maine, N.H., Mass.	31	Eastern Iowa Basins	Iowa, Minn., Ill.
2	Southeastern New England	Mass., R.I.	32	Ozark Plateaus	Mo., Ark., Okla., Kans.
3	Connecticut, Housatonic, and Thames River Basins	N.H., Vt., Mass., Conn.	33	Central Oklahoma Aquifer	Okla.
4	Hudson River Basin	N.Y., Vt., Mass., Conn., N.J.	34	Trinity River Basin	Tex.
5	Long Island and New Jersey Coastal Plain	N.Y., N.J.	35	Balcones Fault Zone	Tex.
6	Delaware River Basin	N.Y., N.J., Pa., Del.	36	Central Nebraska Basin	Nebr.
7	Lower Susquehanna River Basin	Pa., Md.	37	Kansas River Basin	Kans., Nebr., Colo.
8	Delmarva Peninsula	Del., Md., Va.			
			38	Upper Arkansas River Basin	Colo.
9	Potomac River Basin	W.V., Md., Va.	39	Central High Plains	Kans., Tex., Okla., Colo.
10	Allegheny and Monongahela Basins	N.Y., Pa., W.V.	40	Southern High Plains	Tex., N. Mex.
11	Kanawha Basin	W.V., Va., N.C.	41	South Platte River Basin	Colo., Wyo., Nebr.
12	Lake Erie-Lake Saint Claire Drainage	Mich., Ohio, Ind.	42	North Platte River Basin	Wyo., Colo., Nebr.
13	Great and Little Miami River Basins	Ohio	43	Cheyenne and Belle Fourche Basins	S. Dak., Wyo.
14	White River Basin	Ind.	44	Yellowstone Basin	Mont., Wyo., N. Dak.
15	Upper Illinois River Basin	Ill., Ind., Wis.	45	Upper Colorado Basin	Colo., Utah
16	Lower Illinois River Basin	Ill.	46	Rio Grande Valley	N. Mex., Colo.
17	Western Lake Michigan Drainage	Wis., Mich.	47	Great Salt Lake Basins	Utah, Idaho, Wyo.
18	Minneapolis-St. Paul Basin	Minn.	48	Northern Rockies Intermontane Basins	Mont., Idaho, Wash.
19	Red River of the North	Minn., N. Dak.	49	Upper Snake River Basin	Idaho, Wyo., Nev.
20	Albemarle-Pamlico Drainage	N.C., Va.	50	Southern Arizona	Ariz.
21	Upper Tennessee River Basin	Tenn., N.C., Va.	51	Central Columbia Plateau	Wash.
22	Santee Basin and Coastal Drainage	S.C., N.C., Ga.	52	Yakima River Basin	Wash.
23	Apalachicola-Chattahoochee-Flint River Basin	Ga., Fla., Ala.	53	Puget Sound Drainages	Wash.
24	Georgia-Florida Coastal Plain	Fla., Ga.	54	Willamette Basin	Oreg.
25	Southern Florida	Fla.	55	Sacramento Basin	Calif., Oreg.
26	Kentucky River Basin	Ky.	56	Nevada Basin and Range	Nev., Calif.
27	Mobile River and Tributaries	Ala., Miss.	57	San Joaquin-Tulare Basins	Calif.
28	Mississippi Embayment	Miss., La., Ark., Tenn., Ky., Mo.	58	Santa Ana Basin	Calif.
29	Chicot-Evangeline	La.	59	Oahu	Hawaii
30	Lower Tennessee River Basin	Tenn., Ala., Ky.	60	Cook Inlet Basin	Alaska



LOCATION OF STUDY AREA AND PHYSIOGRAPHIC PROVINCES
IN NORTH CAROLINA AND VIRGINIA
(Modified from Fenneman, 1938)

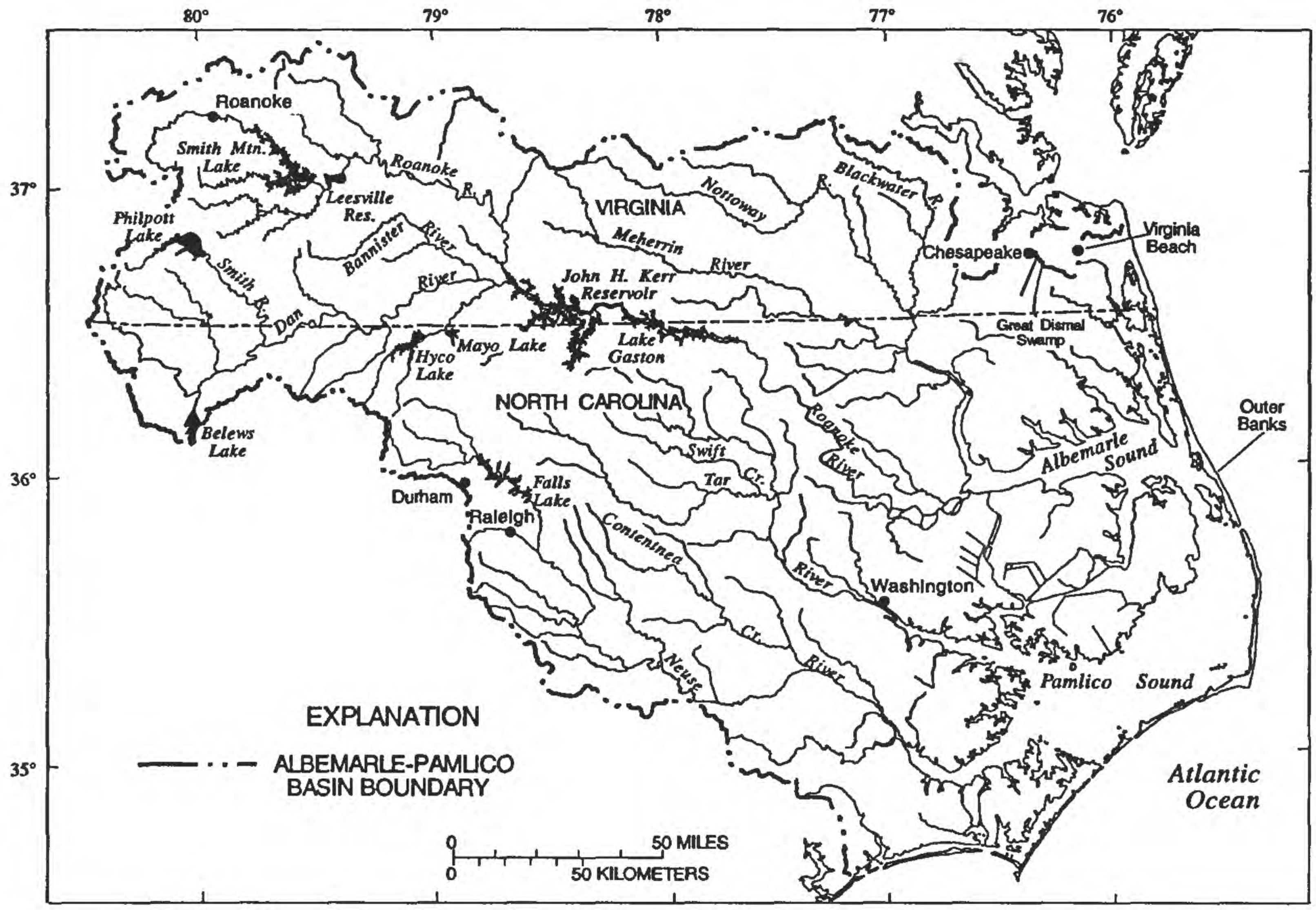


Figure 2. Albemarle-Pamlico drainage study area and physiographic provinces that cross the area.

These efforts will depend on data that exist at the time a NAWQA project begins and on data that are collected after the study begins.

Objectives of NAWQA Program	Water-quality related investigative concerns	Data needed to address concerns	
		Existing	New
To describe water-quality conditions	1. What kind and amount of inorganic and organic constituents occur in the study area?		
	a. Define kind and amount of nutrients, sediments, and pesticides.	X	X
	b. Compare upper- and lower-basin water quality.	X	X
	2. How do these constituents vary spatially?		
	a. Define distribution of nutrients, sediments, and pesticides.	X	X
	b. Provide a basis for comparing ground- and surface-water quality under base-flow conditions.		X
	3. How are these constituents distributed in surface and ground water, in bed sediment, and in organic tissue?		
	a. Define distribution of nutrients and pesticides.	X	
	b. Compare distribution of constituents from shallow and deep wells along flow path.		X
To describe water-quality trends	4. How do these constituents vary in time?		
	a. Define distribution of nutrients, sediments, and pesticides over time.	X	X
	b. Develop data for comparing present and future conditions.		X
To describe cause-and-effect relations	5. What is the relation between physical, chemical, and biological water quality and environmental factors, such as geology, soils, and land use?	X	X

Purpose and Scope

This report is one of two reports on existing data pertinent to the quality of the surface- and ground-water resources in the large river basins (the Chowan, Neuse, Roanoke, and Tar-Pamlico River Basins) of the Albemarle-Pamlico drainage study area. It provides general reference information about the major natural, cultural, and hydrologic factors—the "environmental setting"—of the study area that influence water quality, and describes major water-quality issues in the basins. The report also presents the results of an approach for classifying homogeneous land areas within the study area in terms of environmental-setting characteristics. This classification can be used to examine the spatial and temporal correspondence between environmental factors and water quality. Finally, the report describes methods and assumptions used to compile and analyze the diverse data used in the report (see Appendix). Information reported here is intended to provide a basis for answering the investigative concerns related to pesticides, nutrients, and suspended sediment.

These objectives are addressed in discussions of the study area's environmental setting, including natural (physiography, geology, and soils), cultural (land use, population, water use, and reservoirs), and hydrologic factors (climate, surface water, and ground water), and water-quality issues (nutrients, pesticides, and sediment). Data are drawn from Federal and State agencies, primarily covering the period from the 1970's to 1990. The discussion of water-quality issues is based primarily on 1990 data.

ENVIRONMENTAL SETTING

The environmental setting of the Albemarle-Pamlico study area is composed of a wide variety of natural, cultural, and hydrologic factors that influence the quality of the water resources in the area. It is impossible, in time and space, to completely separate the influences of these factors on the quality of water resources in the study area. For example, the quality of surface and ground water in an area depends, in part, on the quality of precipitation, which is a result of changing kinds and amounts of natural and manmade solids, liquids, and gases that are assimilated and transported by precipitation as it falls to the ground. Water quality is further dependent on the chemical composition, physical nature, and distribution of porosity and permeability of the soil and rock over and through which water flows, as well as human-induced land-use conditions, such as fertilized fields or leaking underground storage tanks. These environmental-setting characteristics provide the conceptual framework for the analysis of water quality in the Albemarle-Pamlico study area.

Physiography, geology, and soils are among the major natural factors that influence water quality. However, human activities in the study area, such as large reservoirs, land use, water use, population distribution, and industrial and agricultural activities, also can directly or indirectly influence the quality and hydrology of surface and ground water. These cultural factors, along with baseline water-quality characteristics, determine long-term trends in water quality. The general nature of these important environmental-setting factors is described in this section.

Many of the environmental-setting factors are illustrated or described with reference to the 22 hydrologic units (Seaber and others, 1987) in the study area (table 2; fig. 3). These units offer a useful spatial frame of reference with which to compare and contrast influences of the different factors on water quality. Where data were available by county, such as county agricultural or population census data, data values were assigned to a hydrologic unit according to the percentage of county area included in that unit. Although not a rigorous approach, the error introduced by this procedure is not considered to be significant for the general purposes of this report.

Natural Factors

The land forms (physiography), rocks (geology), and soils in the Albemarle-Pamlico drainage study area form the container or "matrix" over and through which surface and ground water flows. Many of the minerals that compose the rocks and soils can be dissolved and transported by water and have a significant effect on the quality of freshwater in the study area. Rock distribution and soil porosity and permeability control the amount of time that water is in contact with the rock and soil and, therefore, the amount of mineral matter dissolved in and transported by the water.

Physiography and Ecoregions

The physiographic provinces in the Albemarle-Pamlico drainage study area (fig. 2) have characteristic land-surface and stream elevations, and slopes. Land-surface elevations range from about 3,700 feet (ft) above sea level in the Valley and Ridge, and Blue Ridge parts of the study area to sea level in the eastern Coastal Plain. Corresponding stream elevations along a longitudinal profile of the Roanoke River Basin are about 1,500 ft above sea level in the mountain streams, 800 ft at Smith Mountain Lake, 300 ft at John H. Kerr Reservoir, 200 ft at Lake Gaston, and near sea level where the river flows into Albemarle Sound.

Table 2. Name, code, and area of hydrologic units in the Albemarle-Pamlico drainage study area (Seaber and others, 1987)

Name	Code (fig. 3)	Area (square miles)
Roanoke River Basin		
Upper Roanoke [River]; Virginia	03010101	2,180
Middle Roanoke [River]; North Carolina, Virginia	03010102	1,750
Upper Dan [River]; North Carolina, Virginia	03010103	2,040
Lower Dan [River]; North Carolina, Virginia	03010104	1,240
Banister [River]; Virginia	03010105	590
Roanoke Rapids; North Carolina, Virginia	03010106	590
Lower Roanoke [River]; North Carolina	03010107	1,290
Chowan River Basin		
Nottoway [River]; North Carolina, Virginia	03010201	1,700
Blackwater [River]; North Carolina, Virginia	03010202	744
Chowan [River]; North Carolina, Virginia	03010203	857
Meherrin [River]; North Carolina, Virginia	03010204	1,600
Albemarle Sound; North Carolina, Virginia	03010205	3,750
Tar-Pamlico River Basin		
Upper Tar [River]; North Carolina	03020101	1,280
Fishing [Creek]; North Carolina	03020102	876
Lower Tar [River]; North Carolina	03020103	967
Pamlico [River]; North Carolina	03020104	1,140
Pamlico Sound; North Carolina	03020105	2,060
Bogue and Core Sounds; North Carolina	03020106	1,150
Neuse River Basin		
Upper Neuse [River]; North Carolina	03020201	2,380
Middle Neuse [River]; North Carolina	03020202	1,080
Contentnea [Creek]; North Carolina	03020203	1,010
Lower Neuse [River]; North Carolina	03020204	1,120

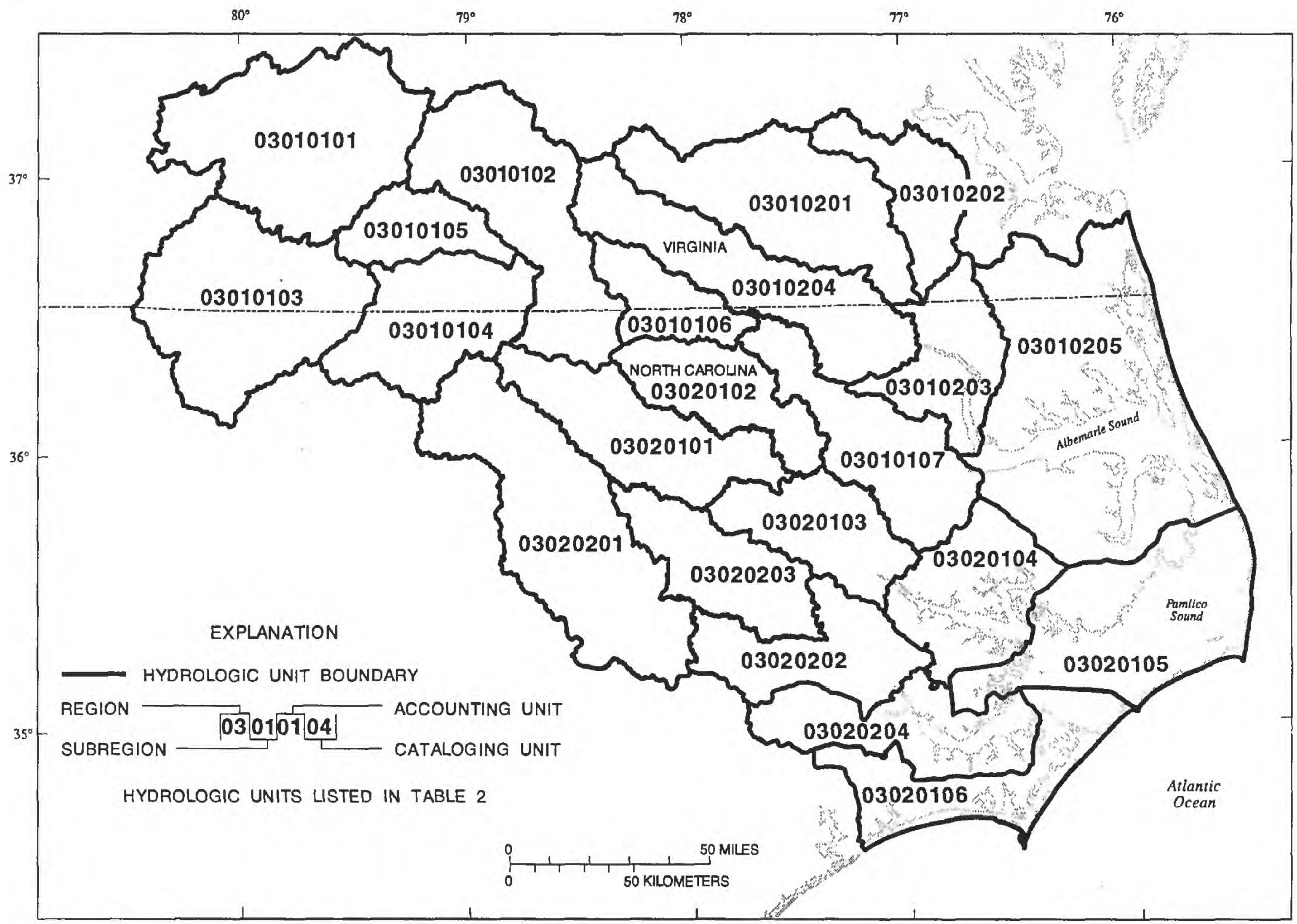


Figure 3. Hydrologic units in the Albemarle-Pamlico drainage study area (from Seaber and others, 1987).

The slope of land surface throughout the area affects the physical, chemical, and biological characteristics of the streams. In the mountainous parts of the area, where slopes are steep, flow velocities are generally swift, which limit opportunities to dissolve mineral matter from the soils and rocks. In the eastern half of the area, where slopes are considerably less steep, flow velocities are generally sluggish, and surface and ground water have a greater opportunity to dissolve mineral matter.

Ecoregions defined by Omernik (1986) generally correspond closely with physiographic provinces of Fenneman (1938) in the study area (fig. 4). The eastern boundary of the Central Appalachian Ridges and Valleys ecoregion generally corresponds to the eastern boundary of the Valley and Ridge physiographic province; the eastern boundary of the Blue Ridge Mountains ecoregion generally corresponds to the eastern boundary of the Blue Ridge Province; the eastern boundary of the Southeastern Plains ecoregion generally corresponds to the eastern boundary of the inner Coastal Plain Province; and the area designated as the Middle Atlantic Coastal Plain ecoregion generally corresponds to the outer Coastal Plain Province, where it is underlain by Quaternary sand, silt, and clay, and Tertiary limestone.

Geology and Soils

Each physiographic province is underlain by a different combination of rock types and, therefore, has different hydrogeologic characteristics (fig. 5). The Valley and Ridge Province is underlain by consolidated limestone, sandstone, and shale. Granite, diabase, gneiss, schist, phyllite, slate, and consolidated sandstone, siltstone, and shale underlie the Piedmont Province. The Coastal Plain Province is underlain by unconsolidated sand, silt, and clay, and consolidated to partly consolidated limestone, sandstone, and shell beds (Virginia Department of Conservation and Economic Development, 1963; Brown, 1985).

Rock type (chemical composition) and the degree and type of rock openings can noticeably influence water quality. For example, water flows through fractures in consolidated rocks and intergranular pore spaces in unconsolidated rocks. All other factors remaining the same, intergranular pore spaces generally expose ground water to greater surface area of the rock than planar fractures, allowing the water more opportunity to dissolve minerals that compose the rock.

Simmons and Heath (1979) divided the North Carolina part of the study area into four distinct geochemical zones on the basis of water quality for unpolluted streams in each zone. They identified two geochemical zones in the Piedmont. One is underlain by relatively insoluble granitic rocks and is drained by streams with the smallest amounts of dissolved mineral matter; the other is underlain by slate, phyllite, and Triassic rocks from which surface water has a larger amount of dissolved mineral matter. Two geochemical zones were identified in the Coastal Plain; both are drained by streams with intermediate—relative to the two Piedmont zones—but distinctive amounts of dissolved mineral matter.

Different soil types in the study area are largely the result of weathering of the underlying rocks. Sandy soils are characteristic of the Coastal Plain and some steep slopes in the Valley and Ridge, and Blue Ridge Provinces; clayey soils have developed on moderate to gentle slopes in the Coastal Plain, Piedmont, Blue Ridge, and limestone valleys of the Valley and Ridge Provinces (Cooper and others, 1975). Relative amounts of sand, silt, and clay strongly influence the infiltration and drainage characteristics of a particular soil. In general, the smaller the silt and clay percentage, the higher the infiltration rate and the better the drainage characteristics.

Most of the poorly drained and well-drained soils of the Albemarle-Pamlico drainage area are in the eastern half of the study area in the Coastal Plain Province, and most of the moderately well-drained soils are in the western half of the study area in the Piedmont and Blue Ridge Provinces. The well-drained, sandy soils are concentrated in hydrologic units along the mid- and southwestern boundary of the Coastal Plain underlain by Cretaceous sands (figs. 5 and 6).

About 93 percent of the area is underlain by moderately well-drained (52 percent) and poorly drained (41 percent) soil groups. The moderately well-drained and well-drained soil groups are generally located in hydrologic units that occur in the Piedmont and western parts of the Coastal Plain, and the poorly drained soil groups occur mostly in the Coastal Plain (table 3; figs. 5 and 6).

The drainage characteristics of the soils provide a general indication of the relative vulnerability of surface and ground water to contamination by human activities. Ground water in an area with sandy, well-drained soil is generally more vulnerable to contamination than in an area with clayey soils. In

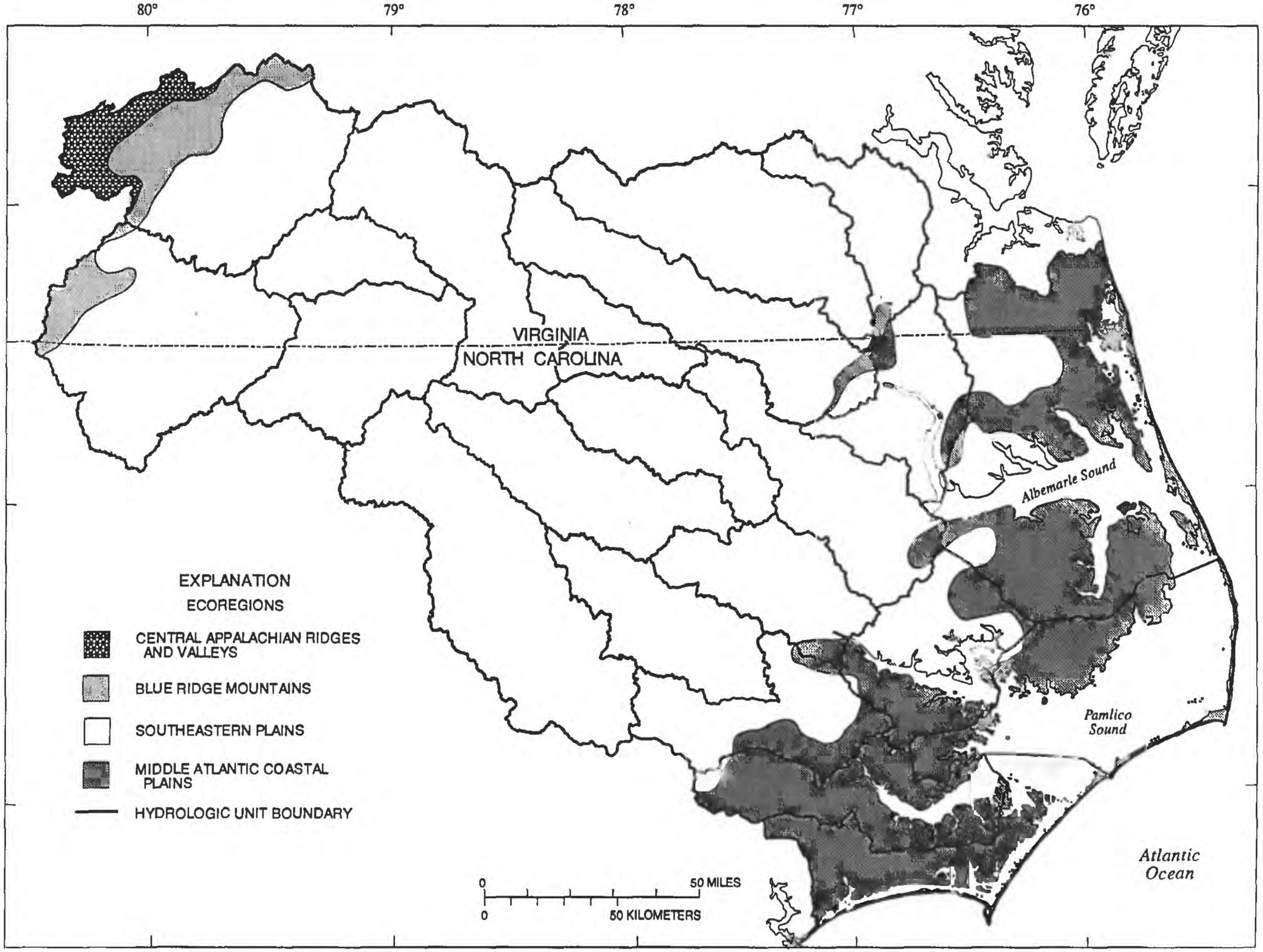


Figure 4. General ecoregions, by hydrologic unit in the Albemarle-Pamlico drainage study area (from Omernik, 1986). (See table 2 and fig. 3 for hydrologic unit names and locations.)

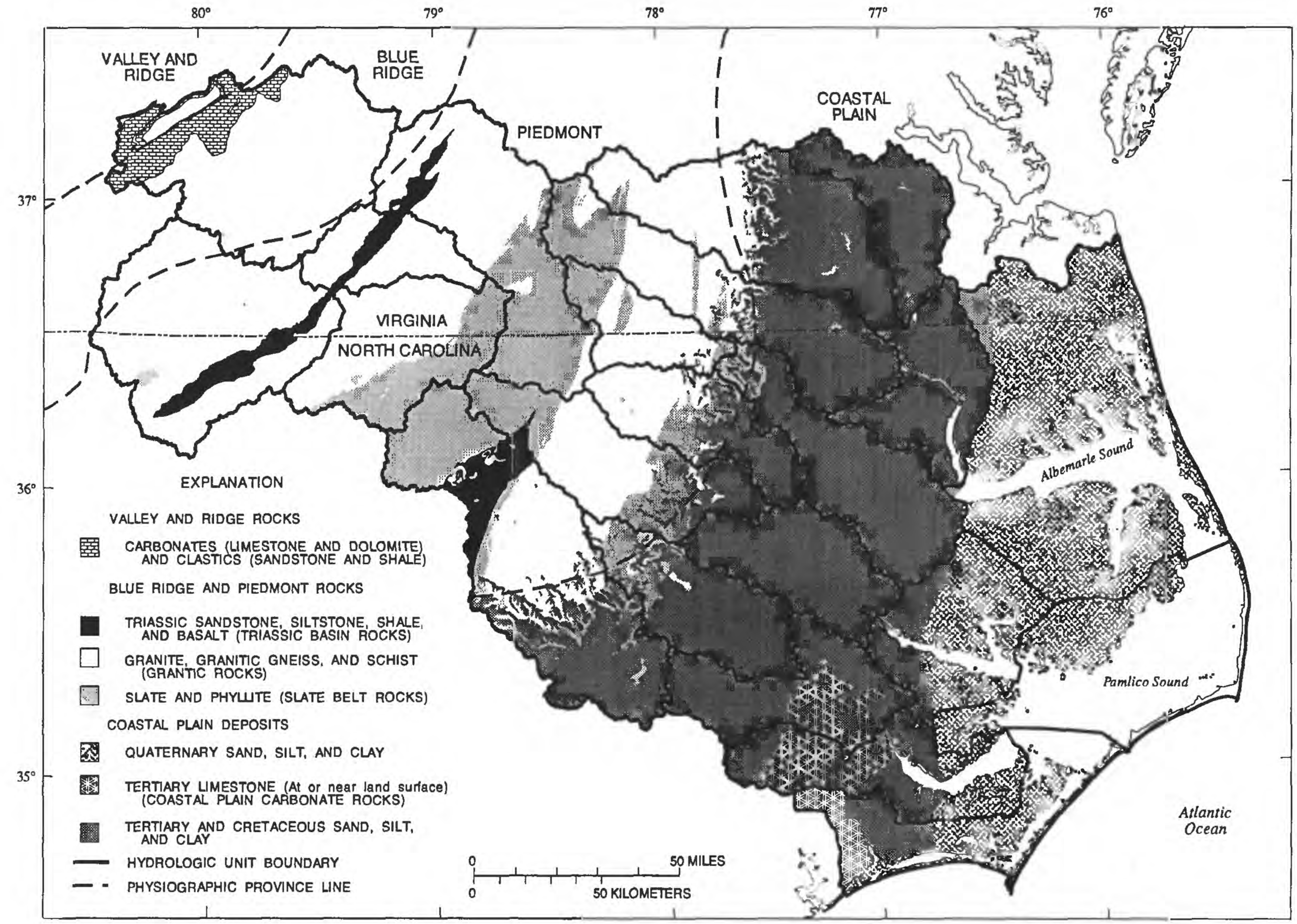
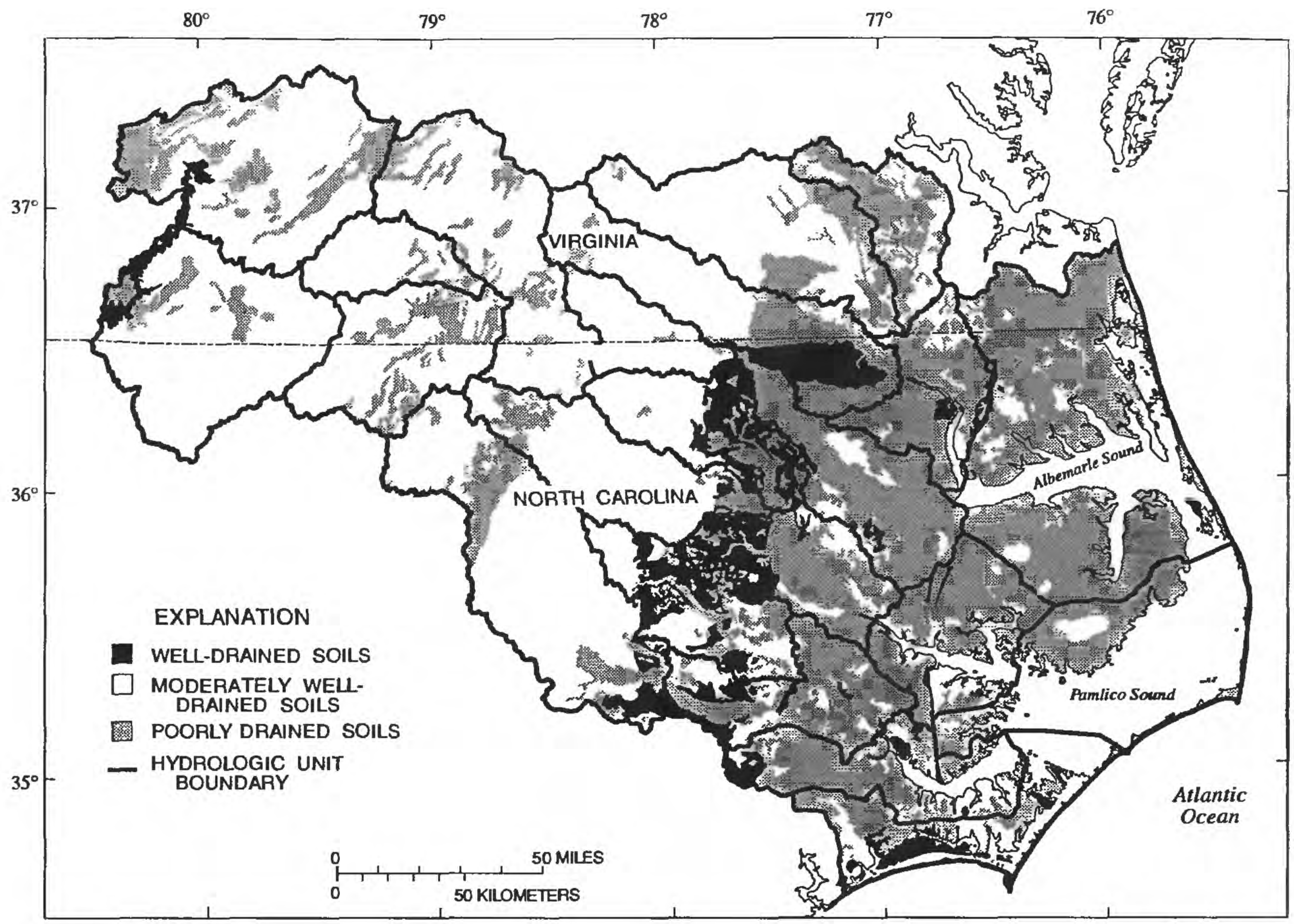


Figure 5. General hydrogeologic zones, by physiographic province and hydrologic unit in the Albemarle-Pamlico drainage study area (from Virginia Department of Conservation and Economic Development, 1963; Brown, 1985).
(See table 2 and fig. 3 for hydrologic unit names and locations.)



Poorly drained[1]		Moderately well drained[1]		Well drained[1]	
Soil group[1]	Area[2] (square miles)	Soil group[1]	Area[2] (square miles)	Soil group[1]	Area[2] (square miles)
A/D	300	B	12,070	A	1,620
B/D	4,240	B/C	1,770	A/B	280
C	1,930	A/C	910		
C/D	860				
D	4,130				

[1]Soil group and drainage characteristics are estimated from a comparison between the table to the right and North Carolina soils (Tant and others, 1974).

[2]Area values in table are rounded to the nearest 10 square miles.

Soil group	Minimum infiltration rate (millimeters per hour)	Soil characteristics
A	8 to 12	Deep sands, deep loesses, aggregated soils.
B	4 to 8	Shallow loess and sandy loam.
C	1 to 4	Many clay loams, shallow sandy loams, soils low in organic matter, and soils high in clay content.
D	0 to 1	Swelling soils, heavy plastic clays, and certain saline soils.

From Musgrave and Holtan (1964).

Figure 6. Soil hydrologic groups, by hydrologic unit in the Albemarle-Pamlico drainage study area. (See table 2 and fig. 3 for hydrologic unit names and locations.)

Table 3. Area and percentage of hydrologic soil groups, by hydrologic unit in the Albemarle-Pamlico drainage study area (from Musgrave and Holtan, 1964)

[Values represent square miles of area over percentage of hydrologic unit in indicated soil group. Combined total area and percentage may not equal the total area of the hydrologic unit because certain minor hydrologic soil groups are not reported. A, soil with infiltration rate of 8-12 millimeters per hour (mm/hr); B, soil with infiltration rate of 4-8 mm/hr; C, soil with infiltration rate of 1-4 mm/hr; D, soil with infiltration rate of 0-1 mm/hr; --, not applicable; <, less than. Two-letter designations have characteristics of both soil groups]

Hydrologic unit (fig. 3)		Hydrologic soil group									
Name	Code	A	B	C	D	A/B	A/C	A/D	B/C	B/D	C/D
					Roanoke River Basin						
Upper Roanoke River	03010101	--	1,427/65	566/27	--	51/2	--	--	112/5	--	12/<1
Middle Roanoke River	03010102	--	1,158/65	146/8	--	--	--	--	270/15	--	124/7
Upper Dan River	03010103	--	1,642/80	179/9	--	94/5	--	--	123/6	--	--
Lower Dan River	03010104	--	493/39	146/12	--	--	--	--	465/37	--	128/10
Banister River	03010105	--	453/76	--	--	--	--	--	98/16	--	47/8
Roanoke Rapids	03010106	5/<1	510/86	--	<1/<1	--	--	--	12/2	9/2	19/3
Lower Roanoke River	03010107	150/12	133/10	--	133/10	--	15/1	--	--	692/53	177/14
					Chowan River Basin						
Nottoway River	03010201	--	1,198/70	304/18	78/5	--	105/6	--	--	5/<1	10/<1
Blackwater River	03010202	--	164/22	310/42	131/18	--	135/18	--	--	4/<1	--
Chowan River	03010203	42/5	38/4	2/<1	120/14	--	107/13	29/3	--	519/60	--
Meherrin River	03010204	224/12	880/55	110/7	151/9	--	--	15/<1	--	185/12	35/2
Albemarle Sound	03010205	33/<1	93/2	29/<1	1,904/51	--	189/5	43/1	--	423/11	--
					Tar-Pamlico River Basin						
Upper Tar River	03020101	55/4	918/71	95/7	--	--	--	--	145/11	60/5	31/2
Fishing Creek	03020102	232/26	420/47	5/<1	--	--	--	--	63/7	157/18	19/2
Lower Tar River	03020103	215/22	169/18	--	49/5	--	2/<1	39/4	--	472/49	18/2
Pamlico River	03020104	11/<1	91/8	--	708/59	13/1	98/8	--	--	100/8	--
Pamlico Sound	03020105	--	--	--	361/17	3/<1	--	30/1	--	149/7	--
Bogue and Core Sounds	03020106	69/6	132/12	--	207/18	78/7	21/2	36/3	15/1	138/12	--
					Neuse River Basin						
Upper Neuse River	03020201	110/5	1,253/52	33/1	--	--	195/8	--	403/17	145/6	219/9
Middle Neuse River	03020202	122/11	236/22	--	114/11	10/<1	--	57/5	--	501/47	23/2
Contentnea Creek	03020203	297/30	415/41	--	15/2	--	--	1/<1	26/3	251/25	--
Lower Neuse River	03020204	51/4	191/17	--	160/14	36/3	40/4	54/5	14/1	427/37	--

areas with clayey soils, however, less water infiltrates land surface and more water runs off directly to nearby streams. Thus, surface water generally is more vulnerable to contamination in areas with clayey soils.

Cultural Factors

Land use and land cover, population density and distribution, water use, and surface-water impoundments are major cultural factors that influence water quality in the study area. The following sections discuss each of these factors.

Land Use and Land Cover

The proportions of land use and land cover in the study area were determined using digital mapped data from the USGS geographic information retrieval and analysis system (GIRAS) (Mitchell and others, 1977; U.S. Geological Survey, 1992). The land-use and land-cover characteristics of the study area are divided into five major categories—forested, agricultural, wetlands, developed, and water. These land-use categories are the "Level I" categories defined by Anderson and others (1976).

In general, the study area is dominated by a patchwork of forested and agricultural land (fig. 7). The individual forested and agricultural areas tend to be smaller in the Piedmont than in the Coastal Plain, resulting in a more complex, heterogeneous landscape pattern in the Piedmont. Wetlands are prominent in the eastern third of the area, and only a small part of the total study area consists of developed land, primarily in and around cities. (Compare figs. 2 and 7.)

Although forested land is usually assumed to have the least effect on water quality, runoff from land used for silvaculture can contain pesticides applied to trees for weed and insect control. Wetlands can act as natural water-treatment plants as they slow water flow, allowing the deposition of suspended sediments with their sorbed compounds. In addition, wetland vegetation uses nutrients dissolved in the water, and wetland soils have significant denitrification capabilities (Johnston, 1991). Agricultural and developed lands generally have the greatest effect on water quality because the use of these lands tends to introduce the largest quantities of nutrients, sediments, and other chemicals into the hydrologic system.

Forested Land

Forested land covers from 6 to 68 percent of each of the hydrologic units in the study area (table 4). The largest percentage of forested land occurs in the Roanoke River Basin hydrologic units, where the average is 57 percent of the land area; the smallest percentage, averaging 35 percent, is in the Tar-Pamlico River Basin hydrologic units.

Agricultural Land

Agricultural land covers between 5 and 50 percent of each of the total area of the hydrologic units in the study area (table 4). When areas of the sounds are excluded from the calculations, the largest percentage of agricultural land occurs in the hydrologic units of the Tar-Pamlico and Neuse River Basins, where averages are 37 and 35 percent, respectively; the smallest is in the Chowan River Basin, which averages 30 percent.

Agricultural land in the study area is used primarily for two major activities—growing crops and raising livestock. In 1990, the primary crops, in order of decreasing acreage, were soybeans, corn, wheat, peanuts, tobacco, and cotton (table 5; fig. 8), with total 1990 acreages ranging from about 938,000 acres of soybeans to about 146,000 acres of cotton. Other important crops included Irish potatoes, sweet potatoes, sorghum, barley, and oats.

The agricultural practices associated with these crops have different effects on water quality in the study area. For example, the kinds and amounts of fertilizers and pesticides used for tobacco cultivation are different from those used on cotton, and different tillage practices, such as no-till and conventional tilling, can influence the amount of sediment transported from a field. The areal and temporal distribution of the various crops, therefore, affect the kinds and amounts of nutrients (nitrogen and phosphorus) and pesticides that can enter ground and surface waters. In general, crop-growing activity is greater in the eastern two-thirds of the study area.

The primary livestock raised in the study area, in order of decreasing numbers for 1987, were chickens, turkeys, hogs, and cattle (table 6; fig. 9). According to Virginia and North Carolina livestock statistics for 1987, 6.8 million chickens, 1.7 million turkeys, about 1.5 million hogs, and 0.4 million cattle were raised in the area (U.S. Bureau of Census, 1990b). As with agricultural practices associated with growing crops, animal-raising and animal-waste disposal practices can

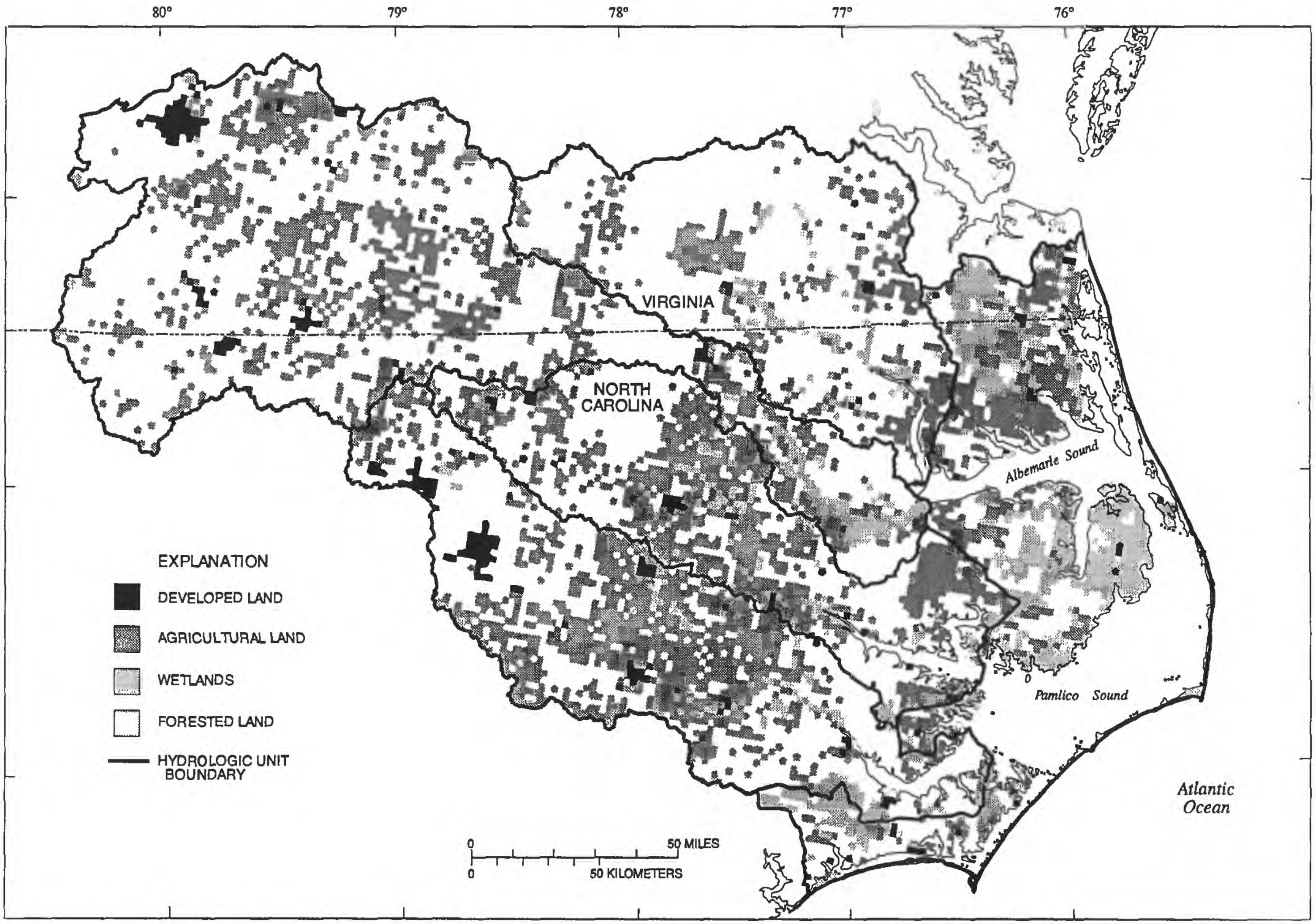


Figure 7. Distribution of generalized land cover and(or) land use, by hydrologic unit in the Albemarle-Pamlico drainage study area for the 1970's (from Anderson and others, 1976; Mitchell and others, 1977). (See table 2 and fig. 3 for hydrologic unit names and locations.)

Table 4. Area and percentage of general land-use categories, by hydrologic unit in the Albemarle-Pamlico drainage study area

[Values represent square miles of area over percentage of hydrologic unit in the indicated land-use category[a]; <, less than]

Hydrologic unit (fig. 3)		Land-use category				
Name	**Code**	**Forested**	**Agricultural**	**Wetlands**	**Developed**	**Water**
			Roanoke River Basin			
Upper Roanoke River	03010101	1,292/59	670/31	0	178/8	36/<2
Middle Roanoke River	03010102	1,014/58	621/35	5/<1	36/2	69/4
Upper Dan River	03010103	1,383/68	540/26	0	98/5	14/<1
Lower Dan River	03010104	703/57	473/38	3/<1	46/4	11/<1
Banister River	03010105	302/51	278/47	<1/<1	8/1	1/<1
Roanoke Rapids	03010106	340/58	187/32	5/<1	20/3	36/6
Lower Roanoke River	03010107	585/45	372/29	275/21	47/4	7/<1
			Chowan River Basin			
Nottoway River	03010201	1,103/65	482/28	70/4	40/2	4/<1
Blackwater River	03010202	432/57	237/32	44/6	28/4	2/<1
Chowan River	03010203	410/48	254/29	106/12	43/5	43/5
Meherrin River	03010204	912/57	520/32	100/6	45/3	2/<1
Albemarle Sound	03010205	686/18	641/17	1,011/27	105/3	714/19
			Tar-Pamlico River Basin			
Upper Tar River	03020101	613/48	523/41	63/5	72/6	3/<1
Fishing Creek	03020102	480/55	300/34	65/7	28/3	2/<1
Lower Tar River	03020103	390/40	420/43	110/11	44/5	2/<1
Pamlico River	03020104	420/37	335/29	176/15	24/2	175/15
Pamlico Sound	03020105	114/6	105/5	331/16	17/<1	1,481/72
Bogue and Core Sounds	03020106	255/22	73/6	302/26	56/5	447/39
			Neuse River Basin			
Upper Neuse River	03020201	1,260/53	862/36	15/<1	214/9	11/<1
Middle Neuse River	03020202	478/44	415/38	127/12	54/5	2/<1
Contentnea Creek	03020203	368/36	505/50	87/9	45/4	2/<1
Lower Neuse River	03020204	543/48	178/16	173/15	42/4	176/16

[a]Land-use categories are "Level I" categories from Anderson and others (1976), and values are calculated from remote sensor data from the mid-1970's. Combined total area and percent may not equal the total area of the hydrologic unit because Barren Land category was omitted as it represents less than 1 percent of the area within each hydrologic unit, except for the Bogue and Core Sounds unit where it represents 2 percent; and Rangeland category was omitted because it represents less than 1 percent of the area within each hydrologic unit. Land areas for land-use categories other than developed have a minimum mapping unit of 40 acres; developed land has a minimum mapping unit of 10 acres.

have considerable influences on water quality in the study area, particularly in areas where large volumes of animal wastes are generated relative to available cropland for application of those wastes (Zublena and Barker, 1991).

Wetlands

The proportion of hydrologic unit land area covered by wetlands ranges from less than 1 percent to as much as 27 percent. The largest areas of wetlands are in the hydrologic units that include the sounds and the lower reaches of the rivers in the eastern part of the study area (table 4; fig. 7).

Developed Land

A relatively small proportion of land is classified as developed (table 4). The percentage ranges from less than 1 percent in the Pamlico Sound hydrologic unit to 9 percent in the Upper Neuse hydrologic unit. The hydrologic units in the Neuse River Basin contain the largest developed land areas, with an average of 5.5 percent. The lowest overall percentage of developed land occurs in the Chowan River Basin, which averages 3.4 percent. The influence of developed land on water quality, however, can be significant, even when the relative area developed is small (Dodd and others, 1992).

Table 5. Acreages of major crops harvested, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1990 (North Carolina Department of Agriculture, 1990; Virginia Department of Agriculture and Consumer Services, 1990)
[Values represent hundreds of acres harvested; --, not applicable; <, less than]

Hydrologic unit (fig. 3)		Major crop										
Name	Code	Soybeans	Corn	Wheat	Peanuts	Tobacco	Cotton	Irish potatoes	Sweet potatoes	Sorghum	Barley	Oats
Roanoke River Basin												
Upper Roanoke River	03010101	26	74	48	--	35	--	--	--	--	8	--
Middle Roanoke River	03010102	141	70	110	--	125	--	--	--	5	11	--
Upper Dan River	03010103	79	66	94	--	143	--	<1	<1	3	6	6
Lower Dan River	03010104	88	65	131	--	140	--	<1	<1	8	4	7
Banister River	03010105	67	34	78	--	71	--	--	--	--	3	--
Roanoke Rapids	03010106	83	30	35	14	41	13	<1	<1	3	6	2
Lower Roanoke River	03010107	309	500	75	431	66	243	2	2	13	2	2
Chowan River Basin												
Nottoway River	03010201	433	257	135	298	34	11	--	--	--	7	--
Blackwater River	03010202	319	272	121	275	100	5	--	--	--	9	--
Chowan River	03010203	258	438	49	307	24	161	<1	3	8	4	<1
Meherrin River	03010204	328	289	92	404	62	203	<1	<1	7	2	<1
Albemarle Sound	03010205	1,959	1,397	716	124	5	99	109	3	24	5	11
Tar-Pamlico River Basin												
Upper Tar River	03020101	460	154	196	59	214	64	--	46	23	8	15
Fishing Creek	03020102	220	192	81	203	67	209	<1	11	10	5	7
Lower Tar River	03020103	637	586	230	169	166	137	<1	15	4	4	7
Pamlico River	03020104	889	785	435	23	46	13	12	2	7	5	7
Pamlico Sound	03020105	279	275	114	--	3	--	13	--	2	2	<1
Bogue and Core Sounds	03020106	172	190	28	<1	16	5	6	<1	2	--	2
Neuse River Basin												
Upper Neuse River	03020201	819	443	381	<1	332	72	1	83	20	21	36
Middle Neuse River	03020202	724	679	201	16	171	80	<1	8	3	3	9
Contentnea Creek	03020203	766	716	324	21	255	101	<1	44	5	4	17
Lower Neuse River	03020204	324	322	85	<1	52	48	12	1	2	<1	2

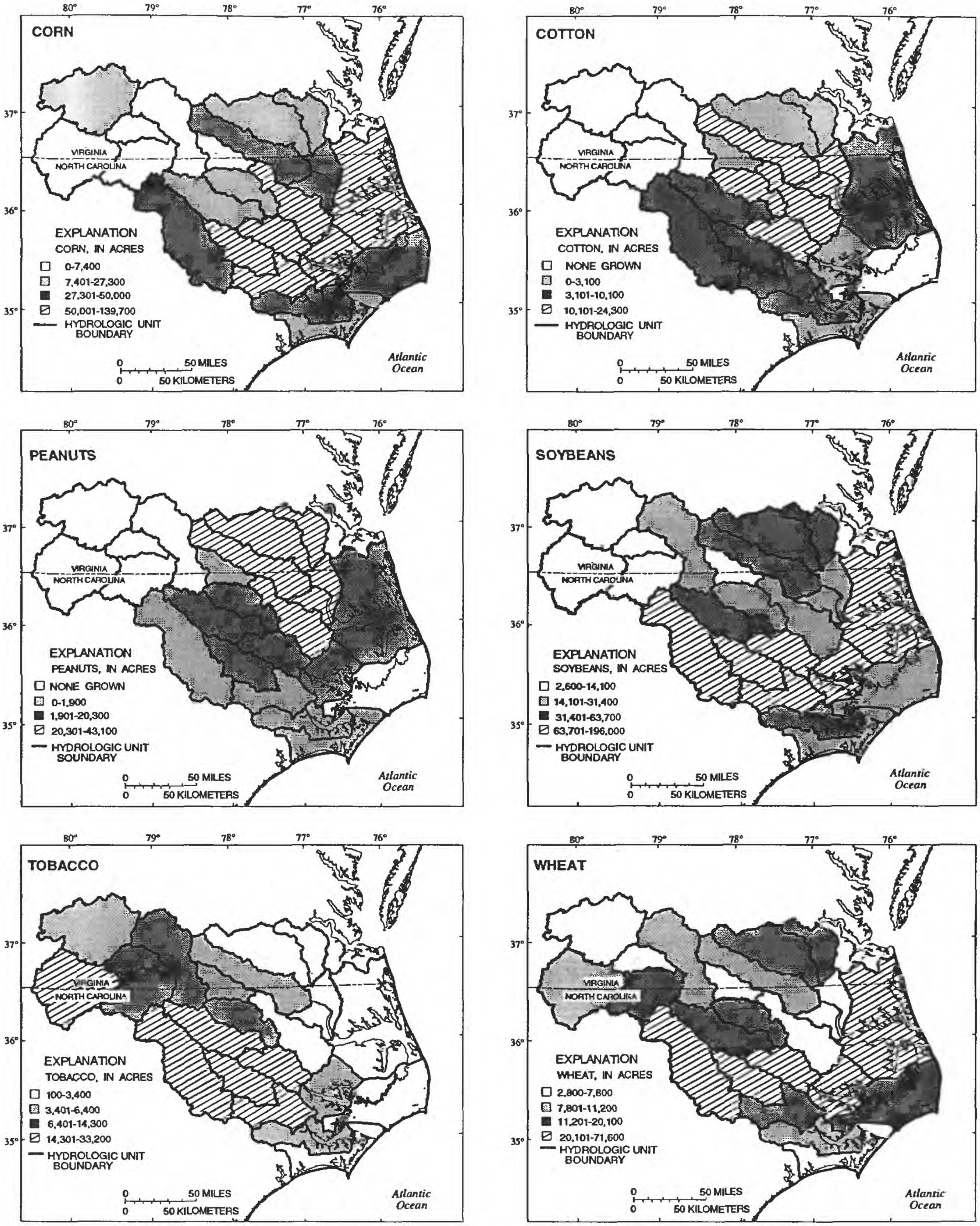


Figure 8. Distribution of dominant crops grown in hydrologic units in the Albemarle-Pamlico drainage study area, 1990. The four divisions shown on each map represent quartiles of harvested acres across the 22 hydrologic units. (See table 2 and fig. 3 for hydrologic unit names and locations.)

Table 6. Numbers of major livestock raised, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1987 (U.S. Bureau of Census, 1990b)

[Values represent livestock in hundreds rounded to the nearest hundred. <, less than; --, not applicable]

Hydrologic unit (fig. 3) Name	Code	Chickens (3 months and older)	Turkeys	Hogs	Cattle and calves
Roanoke River Basin					
Upper Roanoke River	03010101	49	1	53	1,073
Middle Roanoke River	03010102	575	1	93	592
Upper Dan River	03010103	527	<1	66	421
Lower Dan River	03010104	177	<1	145	250
Banister River	03010105	23	<1	36	200
Roanoke Rapids	03010106	514	1	104	153
Lower Roanoke River	03010107	482	<1	757	86
Subtotal		2,347	5	1,254	2,775
Chowan River Basin					
Nottoway River	03010201	1,096	<1	371	215
Blackwater River	03010202	20	--	384	73
Chowan River	03010203	3	--	507	36
Meherrin River	03010204	139	<1	572	226
Albemarle Sound	03010205	16	1	2,208	80
Subtotal		1,274	2	4,042	630
Tar-Pamlico River Basin					
Upper Tar River	03020101	25,460	<1	615	206
Fishing Creek	03020102	4,533	1	644	133
Lower Tar River	03020103	7,926	<1	1,110	57
Pamlico River	03020104	58	--	1,191	28
Pamlico Sound	03020105	<1	--	104	4
Bogue and Core Sounds	03020106	1	1,081	163	5
Subtotal		37,978	1,083	3,827	433
Neuse River Basin					
Upper Neuse River	03020201	5,120	3,972	1,352	390
Middle Neuse River	03020202	6,551	6,478	1,504	61
Contentnea Creek	03020203	14,661	5,066	2,605	84
Lower Neuse River	03020204	522	847	306	19
Subtotal		26,854	16,363	5,767	554
Total		68,453	17,453	14,890	4,392

Population Distribution

Generally, the higher the population, the greater are the effects on water quality. The greatest populations in the study area occur in the Upper Roanoke, Upper Dan, Upper Neuse, Contentnea Creek, and Albemarle Sound hydrologic units (figs. 2 and 10), where some of the largest cities in North Carolina and Virginia are located. Raleigh, N.C., (population 208,000) and Roanoke, Va., (96,000) lie entirely within the study area, and parts of Virginia Beach, Va., (393,000), Chesapeake, Va., (152,000), and Durham, N.C., (136,000) also lie within the area (U.S. Bureau of Census, 1990a). (Compare fig. 10A with fig. 2.)

The total population of the study area increased from about 2.3 million in 1970 to about 3 million in 1990 (table 7). The largest increase in population from 1980 to 1990 occurred in hydrologic units of the Chowan, Tar-Pamlico, and Neuse River Basins. Specifically, increases greater than 10 percent occurred in hydrologic units near the coast—Albemarle Sound (34 percent), Pamlico Sound (32 percent), Bogue and Core Sounds (28 percent)—and in the Upper Neuse (28 percent) and Upper Tar (13 percent) hydrologic units (table 7; fig. 10B).

Water Use

Surface-water use accounts for about two-thirds of the total 1990 water use (excluding thermoelectric use) in the Albemarle-Pamlico drainage study area (fig. 11). The greatest uses of surface water are for public water supplies and for thermoelectric power. (Thermoelectric uses, along with mining, commercial, and industrial water uses, are summarized in the "Other" category in figure 11.) Domestic ground-water use and agricultural surface-water use are comparable in size, and both are slightly less than ground-water use for public water supplies. Total surface-water use in the study area was about 730 million gallons per day (Mgal/d) in 1990, with about 60 percent of this use in North Carolina. Ground-water use was about 370 Mgal/d in 1990, with about 62 percent of this use in the North Carolina part of the study area.

Surface-water use was highest in hydrologic units with large urban populations served by surface-water diversions for public water supplies (fig. 12; for example, the Upper Neuse, 03020201) and in hydrologic units with large commercial, industrial, or mining water users (fig. 12; for example, the Pamlico River, 03020104). Ground-water use was generally highest in the Coastal Plain, although mining, commercial, and industrial uses were also high in the Upper Roanoke hydrologic unit (03010101).

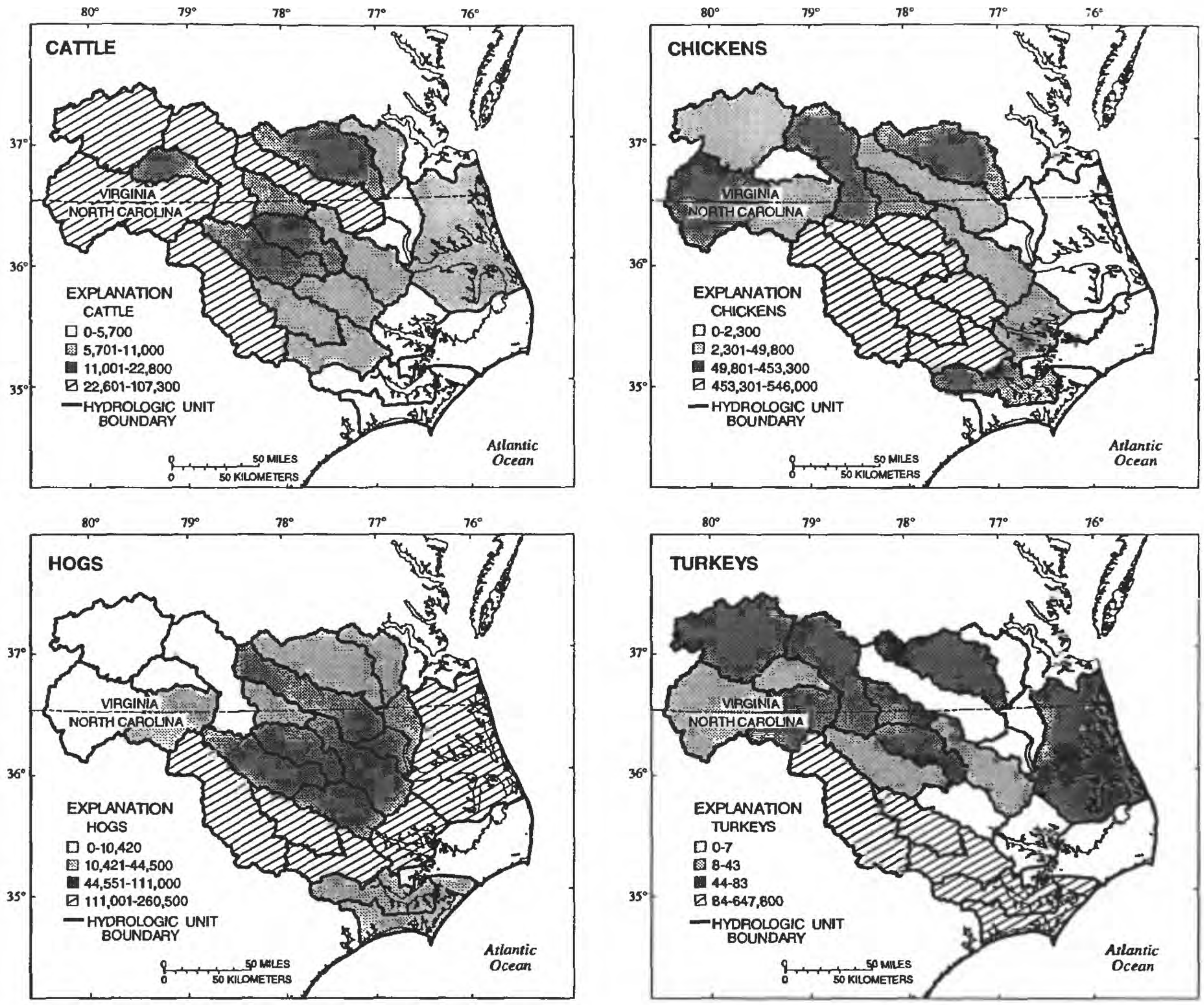


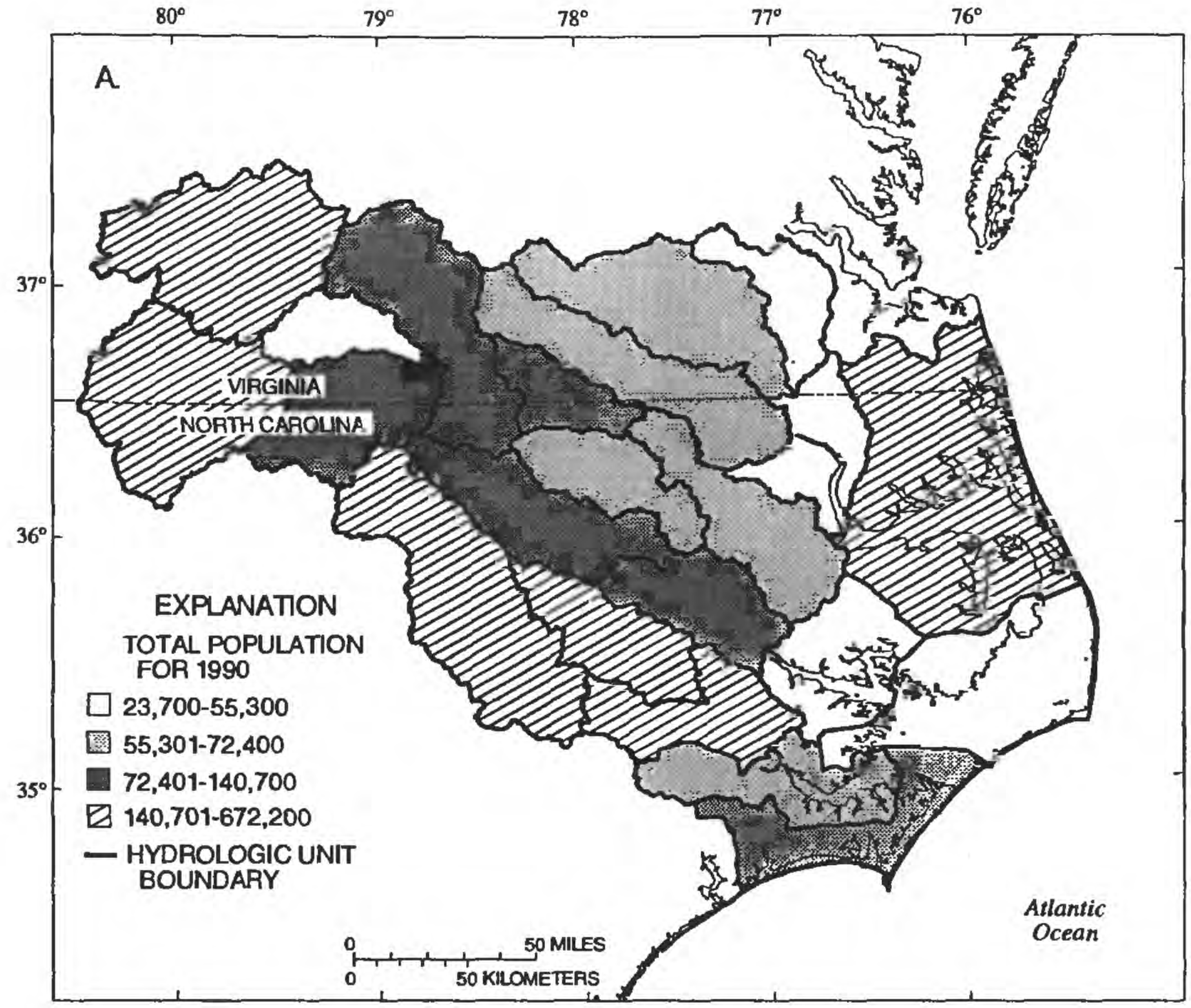
Figure 9. Distribution of dominant livestock raised in hydrologic units in the Albemarle-Pamlico drainage study area, 1987. The four divisions shown on each map represent quartiles of livestock inventories across the 22 hydrologic units. (See table 2 and fig. 3 for hydrologic unit names and locations.)

Water use can affect the quality of surface and ground water. All other factors remaining the same, the larger the percentage of streamflow diverted for anthropogenic uses, the greater the potential is for that use to affect water quality. If water removed from the stream is consumed and not returned to the stream, the reduced volume of water in the stream diminishes the stream's capacity to dilute dissolved substances introduced downstream from the water-removal point. Water returned to the stream generally contains more dissolved substances than before it was removed.

Ground-water pumping can induce nearby saline water or contaminated water to move vertically or horizontally toward the center of pumping and eventually into the pumping well(s). All other factors remaining the same, the larger the amount of water pumped, the greater the distance from which contaminated water can be drawn toward the center of pumping. In addition, pumping large amounts of ground water near a stream can induce some of the stream water to flow toward the center of pumping, thus reducing streamflow and potentially affecting downstream water quality.

Major Surface-Water Reservoirs

There are nine major surface-water reservoirs in the Albemarle-Pamlico drainage study area, primarily in the Piedmont Province (figs. 2 and 13). Eight reservoirs are in the Roanoke River Basin, and Falls



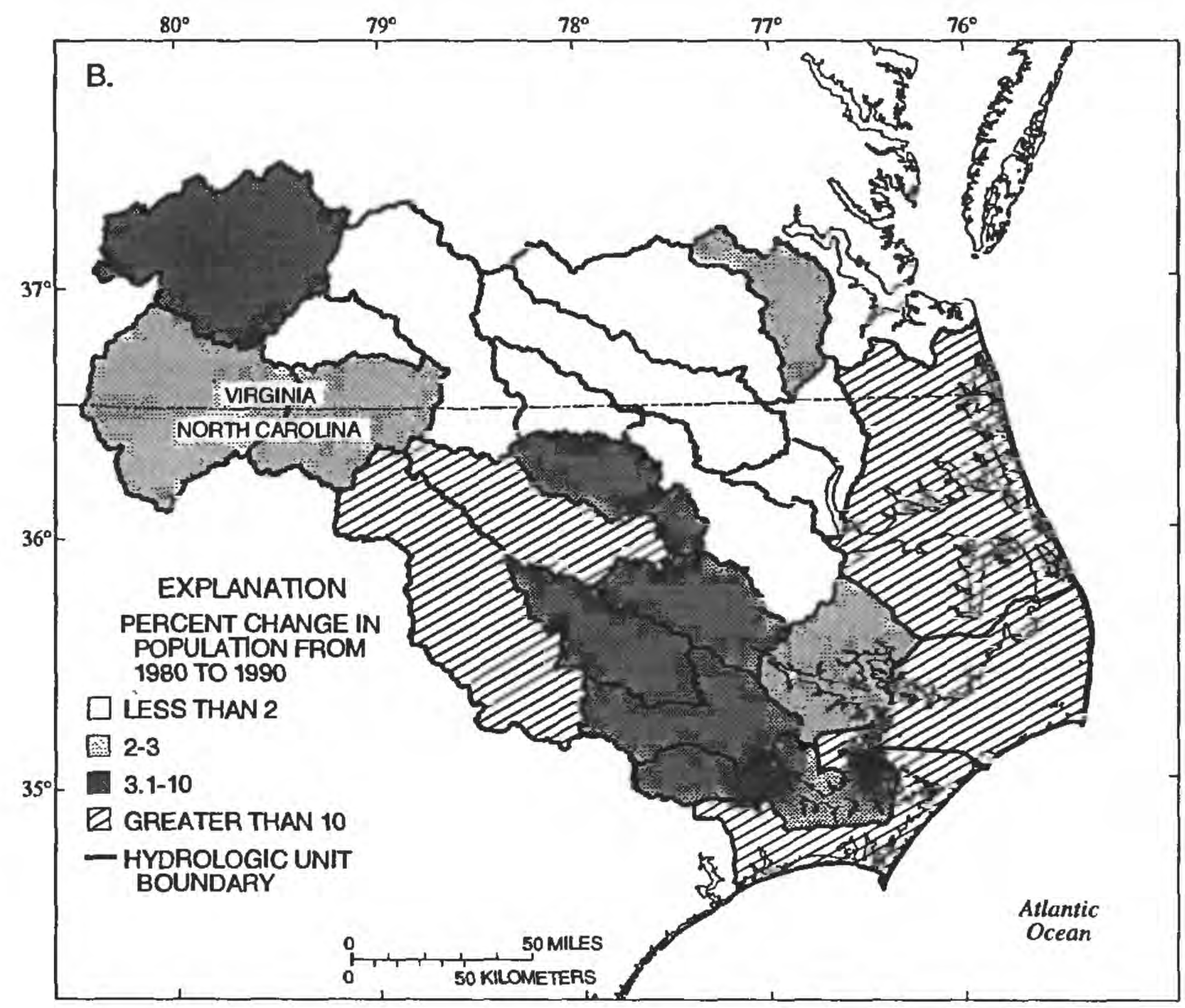


Figure 10. (A) Population distribution for 1990 and (B) percent change in population distribution from 1980 to 1990, by hydrologic unit in the Albemarle-Pamlico drainage study area (U.S. Bureau of Census, 1990a). The four divisions shown on each map represent quartiles of population and population change, respectively, across the 22 hydrologic units. (See table 2 and fig. 3 for hydrologic unit names and locations.)

Table 7. Population, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1970-90
[Population is rounded to the nearest hundred]

Hydrologic unit (fig. 3)		Population (in hundreds)[a]			Percent change
Name	Code	1970	1980	1990	1980-90
Roanoke River Basin					
Upper Roanoke River	03010101	2,771	3,169	3,347	5
Middle Roanoke River	03010102	927	976	996	2
Upper Dan River	03010103	2,386	2,706	2,793	3
Lower Dan River	03010104	1,010	1,071	1,112	3
Banister River	03010105	308	337	290	-13
Roanoke Rapids	03010106	246	249	252	1
Lower Roanoke River	03010107	578	594	577	-2
Subtotal		8,226	9,102	9,367	
Chowan River Basin					
Nottoway River	03010201	620	600	569	-5
Blackwater River	03010202	506	533	553	3
Chowan River	03010203	418	429	440	2
Meherrin River	03010204	630	623	595	-4
Albemarle Sound	03010205	2,198	2,876	3,866	34
Subtotal		4,372	5,061	6,023	
Tar-Pamlico River Basin					
Upper Tar River	03020101	1,067	1,181	1,332	12
Fishing Creek	03020102	599	626	647	3
Lower Tar River	03020103	933	1,069	1,181	10
Pamlico River	03020104	360	405	419	3
Pamlico Sound	03020105	135	180	237	31
Bogue and Core Sounds	03020106	509	608	780	28
Subtotal		3,603	4,069	4,596	
Neuse River Basin					
Upper Neuse River	03020201	4,265	5,241	6,722	28
Middle Neuse River	03020202	1,156	1,306	1,407	7
Contentnea Creek	03020203	1,168	1,319	1,435	8
Lower Neuse River	03020204	537	602	668	10
Subtotal		7,126	8,468	10,232	
Total		23,327	26,700	30,218	

[a]Data adapted from U.S. Bureau of Census (1970, 1980, 1990a) county and city population values. County population was converted to hydrologic unit population in the following manner: City populations were added to the population of the appropriate counties; county population density was then calculated on a people-per-square-mile basis; population densities for the counties located in each hydrologic unit were multiplied by the area of each county in the hydrologic unit and summed to estimate the hydrologic unit population.

Lake is in the Neuse River Basin. In addition to these large reservoirs, hundreds of smaller ponds, lakes, and reservoirs are scattered throughout the study area, particularly in the Piedmont Province. The State of North Carolina is compiling information about water-supply reservoirs as part of the State's water-supply plan to be developed in 1995 (Jessica Miles, North Carolina Department of Environment, Health, and Natural Resources, Division of Water Resources, oral commun., July 1994).

All of these reservoirs have deeper and slower moving water environments than would normally be present along free-flowing stream reaches. The slower moving water allows suspended sediment to settle to the bottoms of the impoundments and aquatic vegetation to remove nutrients dissolved in the water. Even relatively small farm ponds can have positive effects on downstream water quality (Harned, 1994).

Hydrologic Factors

Climate and the associated distribution and routing of surface and ground water are significant hydrologic factors that affect water quality in the Albemarle-Pamlico study area. The following sections describe the general nature of these factors and their relation to one another, some previously described factors, and water quality.

Climate Characteristics

Climatic conditions influence the amount and quality of ground water and surface water in the study area. Air temperature and the amount and distribution of precipitation are limiting factors for the long-term amount of indigenous freshwater available for human use and for chemical weathering and transport of sediment (Selby, 1985). Temperature and precipitation also influence the distribution of flora and fauna, and the kinds and rates of biological processes in an area.

Temperature

Average annual temperatures in the study area during 1961-90 ranged from slightly less than 52 degrees Fahrenheit (°F) in the highest mountains of the Valley and Ridge and Blue Ridge Provinces, to slightly more than 62 °F south and east of Pamlico Sound in the eastern part of the Coastal Plain

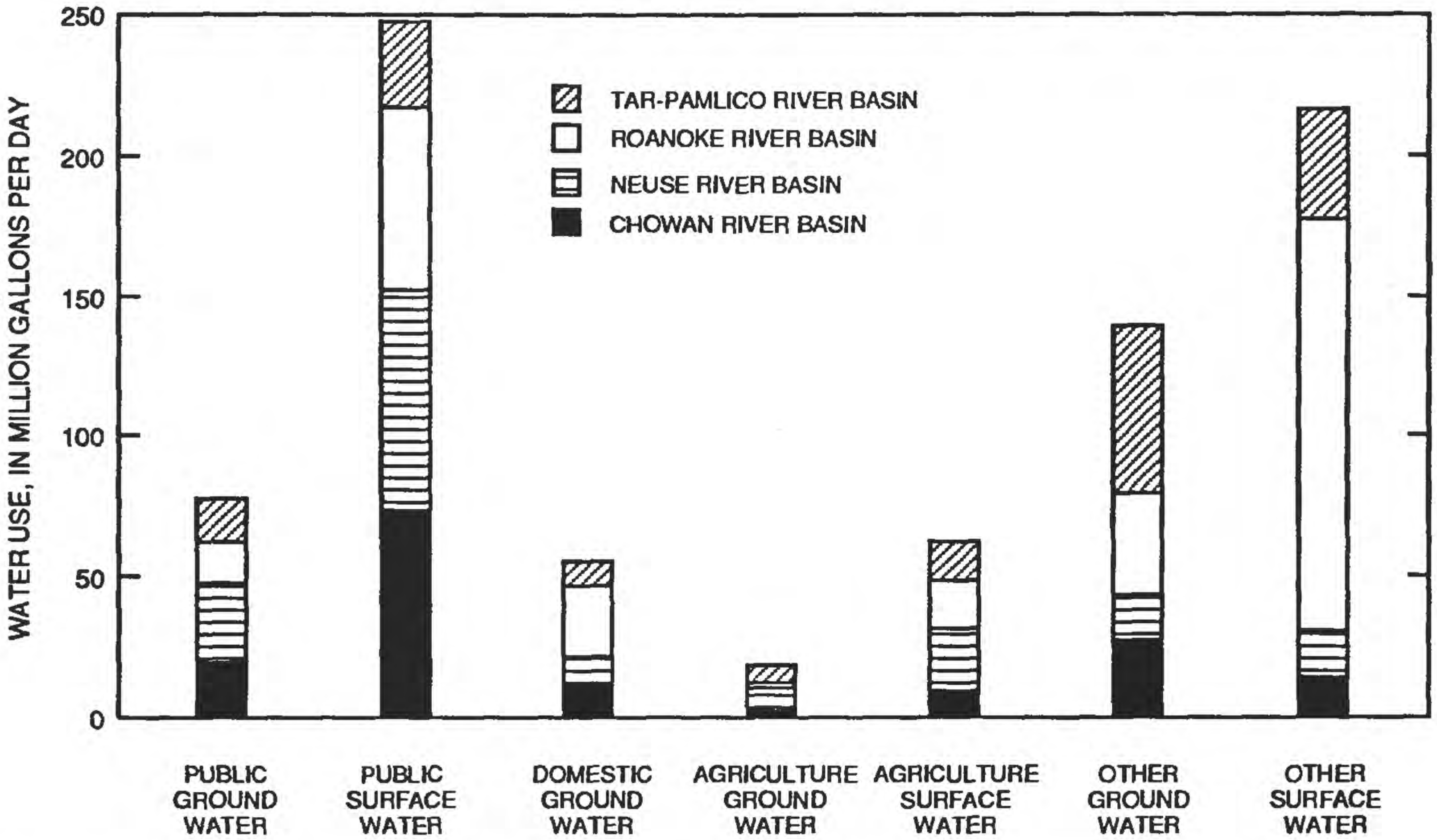


Figure 11. Water use, by withdrawal type in the Albemarle-Pamlico drainage study area, 1990 (from U.S. Geological Survey, 1991a and b). (See table 2 and fig. 3 for hydrologic unit names and locations.)

(U.S. Department of Commerce, 1992). The average annual temperature increases on a fairly even gradient from west to east, except in the mountains where the gradient is about four times that in the rest of the area (fig. 14A).

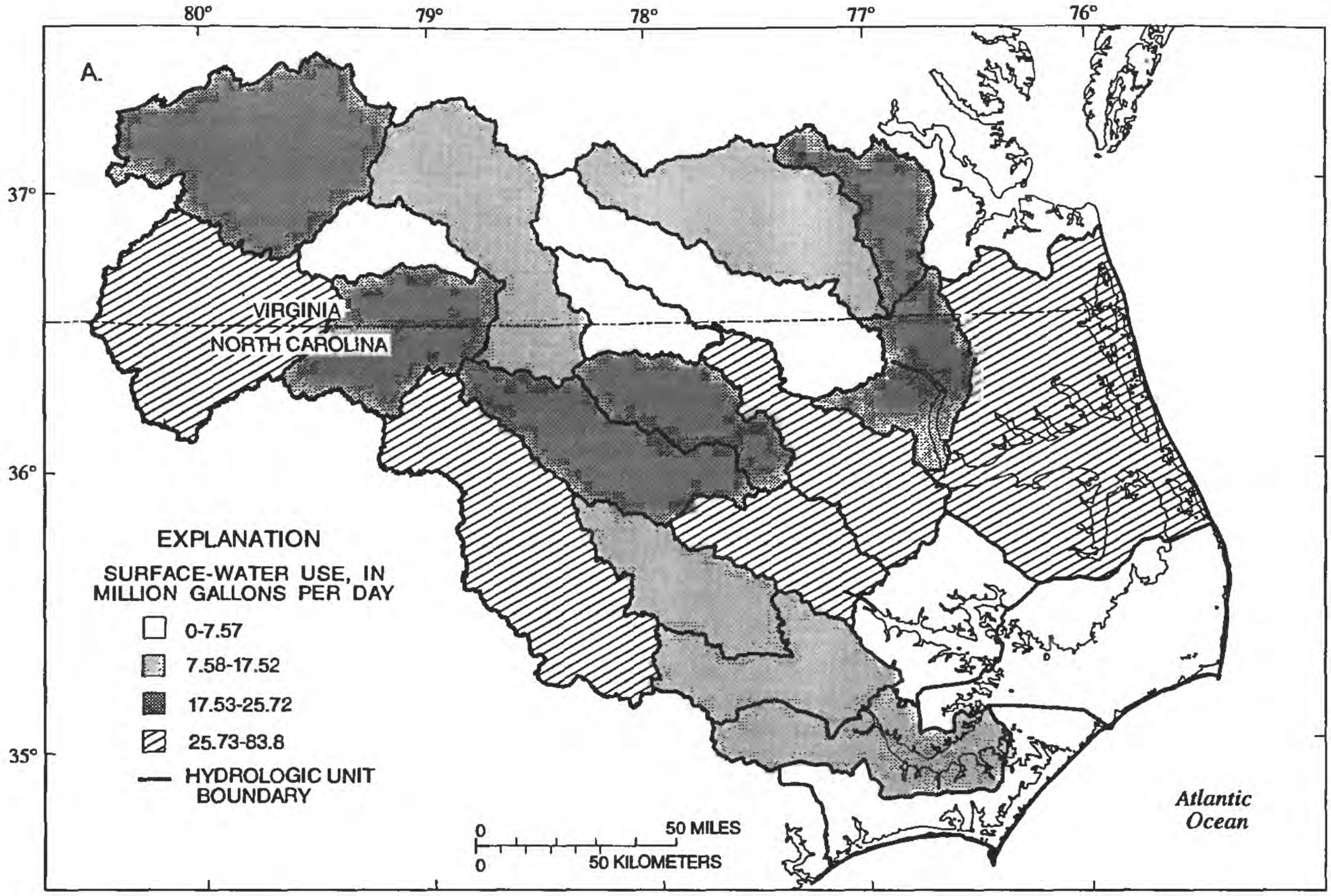
Temperature affects the amount of water evaporated and the amount of water transpired by plants. Generally, the higher the temperature, the higher is the amount of evaporation and transpiration and the lower is the amount of runoff.

Precipitation

Average annual precipitation in the study area ranged from about 36 inches (in.) to more than 52 in. from 1961 to 1990 (fig. 14B). The amount and distribution of precipitation directly influence runoff and chemical and sediment transport in the study area. All other factors remaining the same, the larger the amount of precipitation, the larger is the runoff and total transport of dissolved chemical constituents and suspended-sediment particles. Precipitation chemical characteristics affect chemical reactions with natural and manmade compounds that occur in and on soil and rock in the study area.

Chemical characteristics of precipitation selected for this study include pH units and calcium, chloride, sodium, sulfate, and total nitrogen concentrations (fig. 15). The data are precipitation-weighted average values for 1980, 1985, and 1990, respectively (National Atmospheric Deposition Program/National Trends Network Coordination Office, 1983, 1987, and 1991). Based on these data, pH has remained relatively stable; calcium, chloride, sodium, and sulfate have generally decreased; and total nitrogen has increased for the indicated years for at least three of the four data stations shown in figure 15. The decreasing sulfate and stable pH trends are consistent with national trends between 1980 and 1991 (Baier and Cohn, 1993).

The 1990 data for total nitrogen concentrations (fig. 15) were used to calculate the atmospheric deposition of total nitrogen throughout the hydrologic study units using methods described in the Appendix. The annual atmospheric deposition of total nitrogen varied among hydrologic units in the study area in 1990 and ranged from 1,070 to 7,730 tons per year (fig. 16). Deposition amounts varied directly with total area of the hydrologic unit, the amount of urban area in the hydrologic unit, and land-surface elevation. A



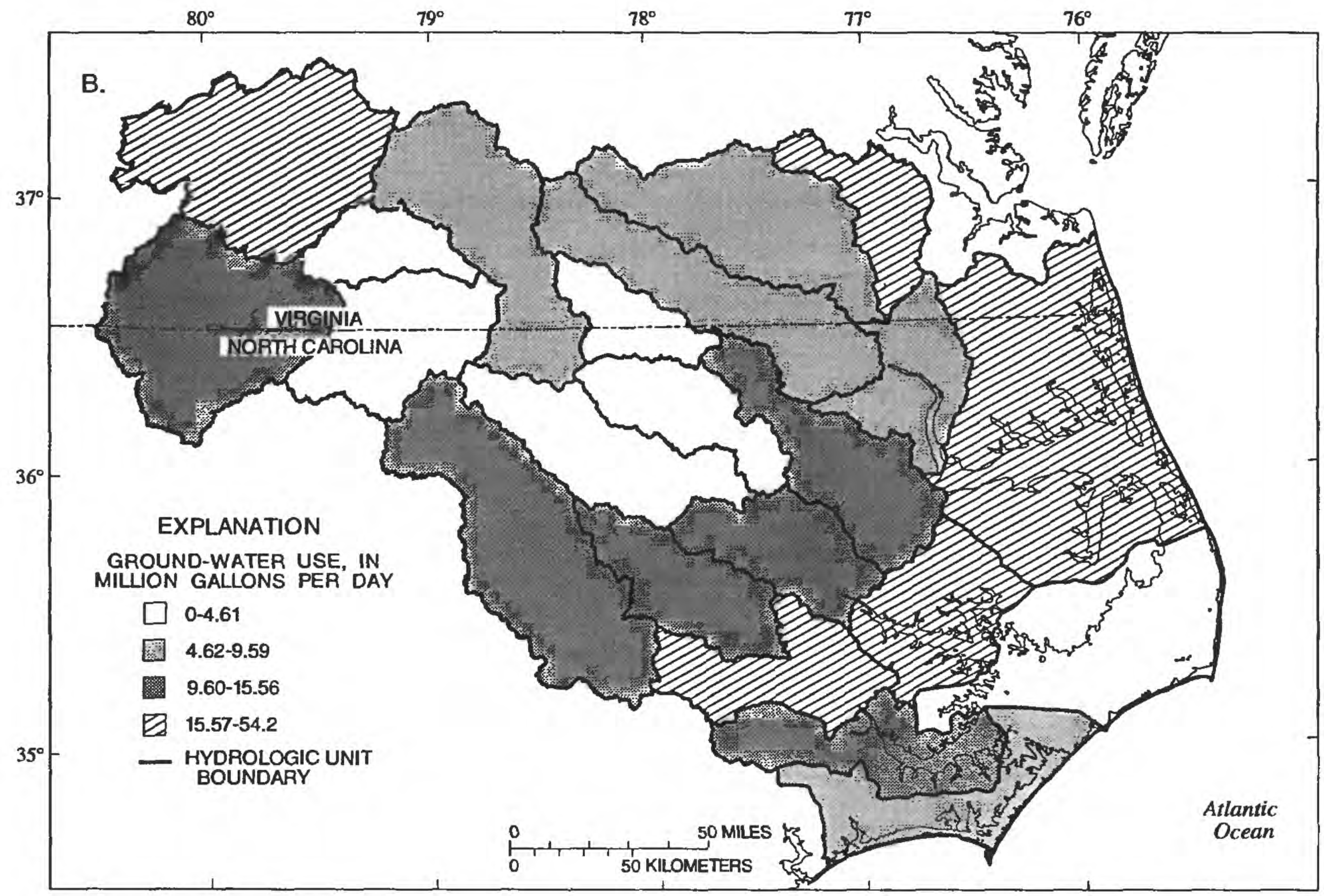
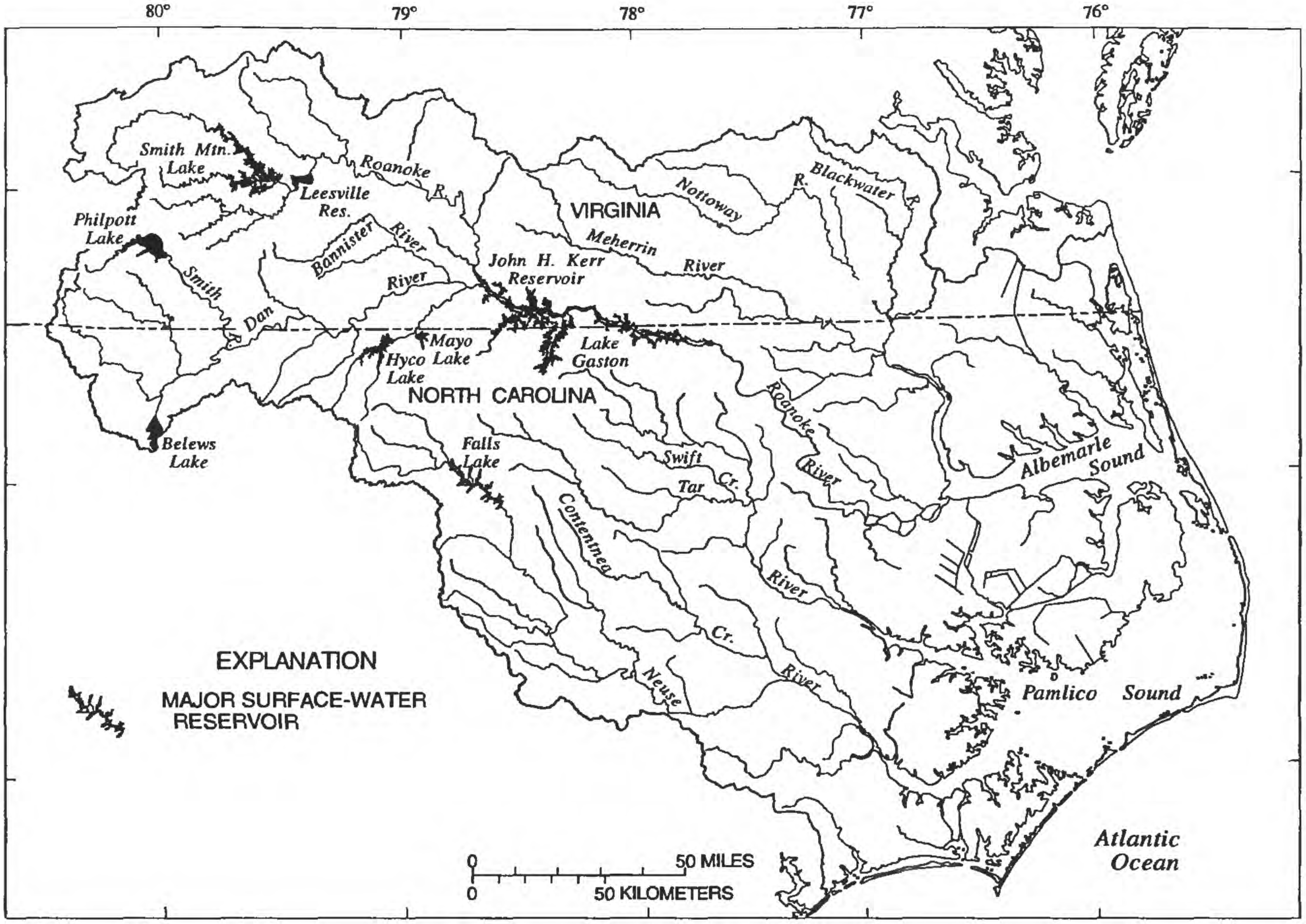


Figure 12. (A) Surface-water and (B) ground-water use, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1990 (U.S. Geological Survey, 1991a and b). The four divisions shown on each map represent quartiles of water use across the 22 hydrologic units. (See table 2 and fig. 3 for hydrologic unit names and locations.)



Reservoir name	Volume (in acre feet)	Drainage area upstream from reservoir (in aquare miles)
John H. Kerr Reservoir	1,576,000	7,780
Smith Mountain Lake	1,142,000	1,024
Gaston Lake	515,000	8,339
Belews Lake	255,200	70
Philpott Lake	167,000	212
Falls Lake	153,700	770
Leesville Reservoir	85,000	1,505
Mayo Lake	85,000	52
Hyco Lake	66,600	189

Figure 13. Major surface-water reservoirs in the Albemarle-Pamlico drainage study area (Hitt, 1990).

comparison of figures 16 and 10 indicates a possible relation between atmospheric deposition of total nitrogen and population distribution in the study area.

The three highest rates of atmospheric total nitrogen deposition in 1990 were in the Upper Neuse (1.80 tons per square mile [tons/mi^2]), the Upper Roanoke (1.71 tons/mi^2), and the Albemarle Sound hydrologic units (1.70 tons/mi^2). The three lowest rates of atmospheric total nitrogen deposition in 1990 were in the Banister, Roanoke Rapids, and Nottoway hydrologic units (1.49 tons/mi^2, respectively).

Evapotranspiration

Temperatures and plant growth in the study area are such that about two-thirds of the average annual

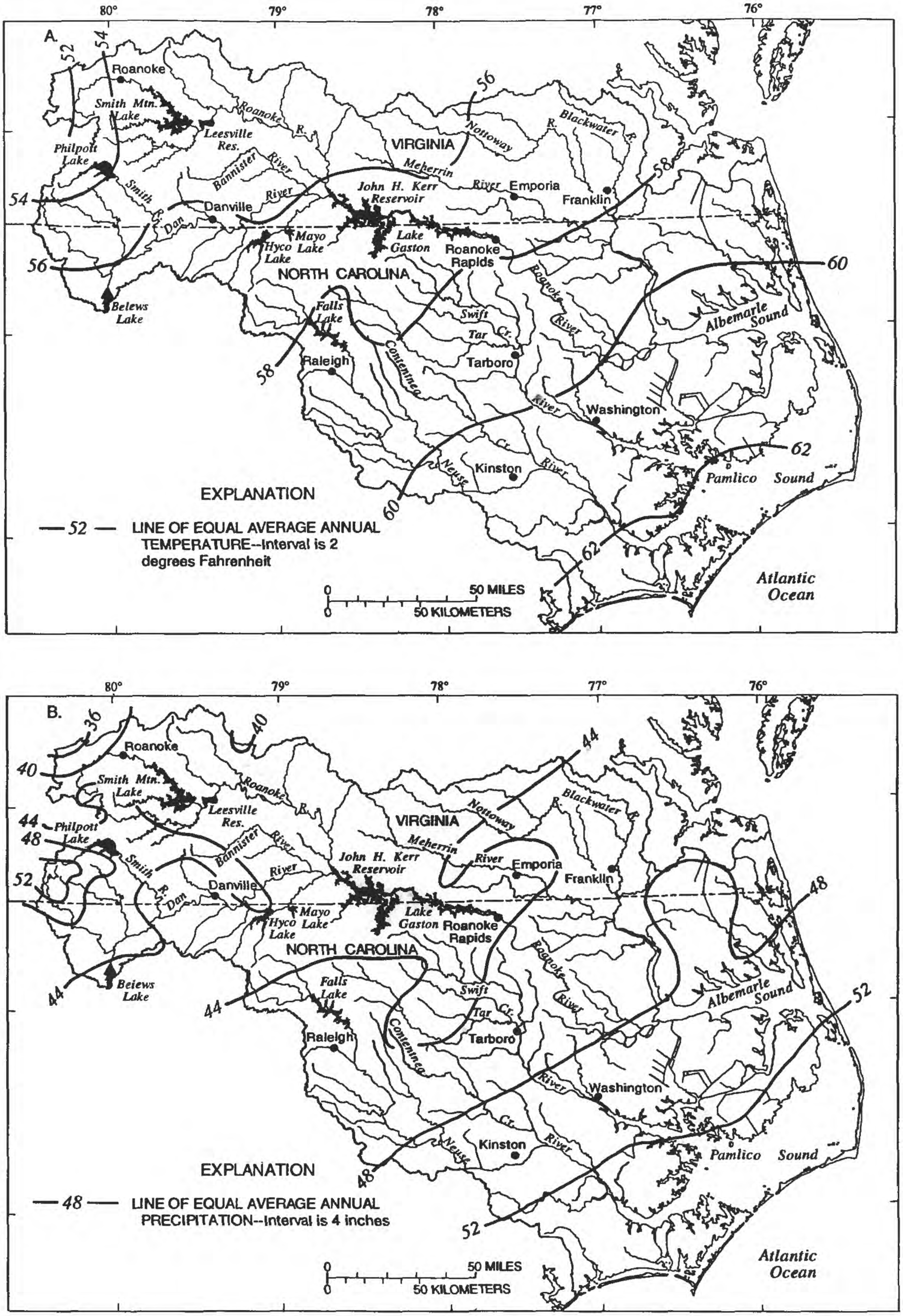
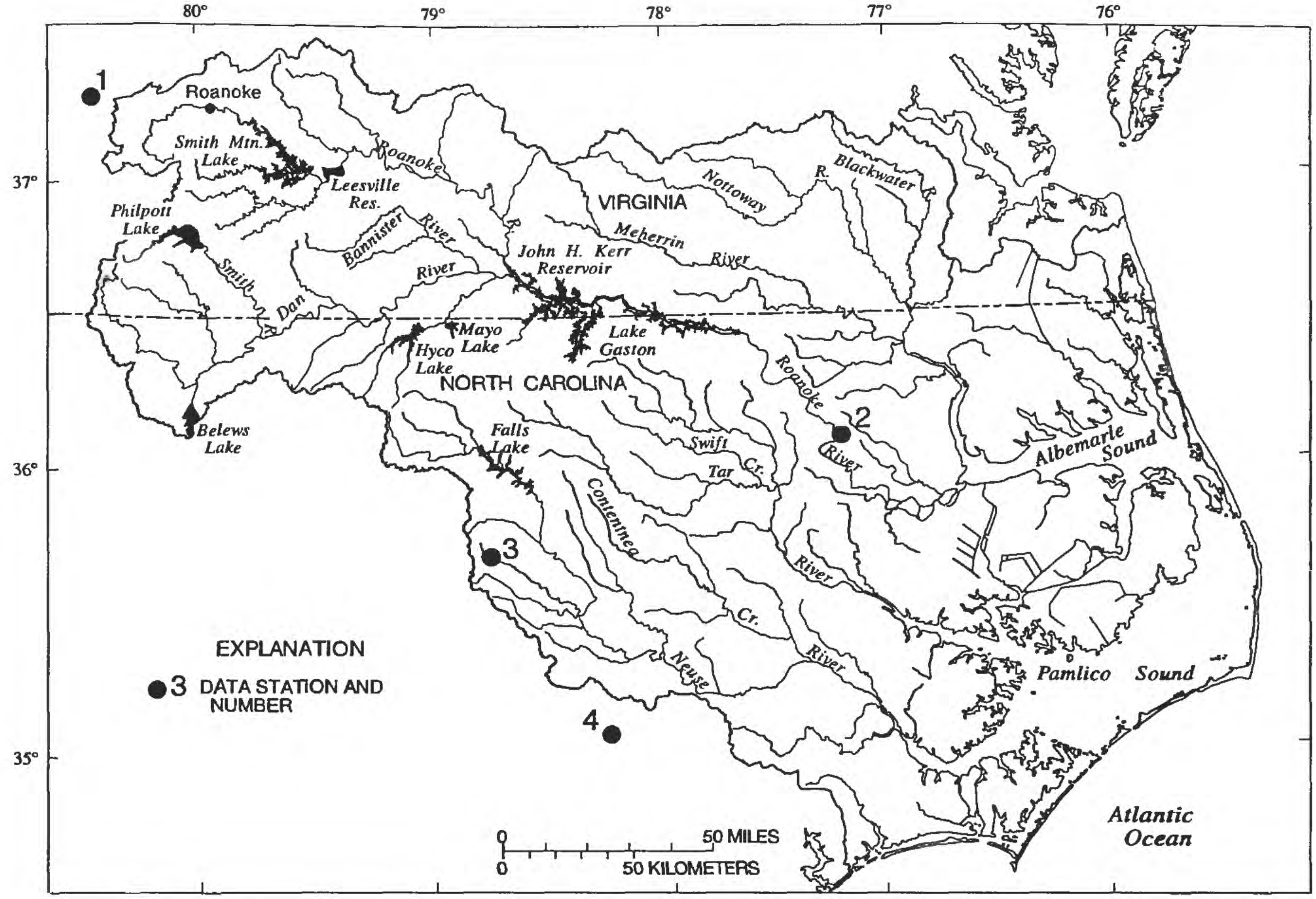


Figure 14. Average annual (A) temperature and (B) precipitation in the Albemarle-Pamlico study area, 1961-90 (U.S. Department of Commerce, 1992).



pH units[1]			
Data station (map number)	1980	1985	1990
1	4.4	4.5	4.5
2	4.5	4.5	4.5
3	4.5	4.6	4.5
4	4.4	4.5	4.5

Calcium concentration[1] (mg/L)			
Data station (map number)	1980	1985	1990
1	0.18	0.11	0.11
2	.13	.10	.10
3	.11	.11	.10
4	.10	.10	.10

Chloride concentration[1] (mg/L)			
Data station (map number)	1980	1985	1990
1	0.23	0.13	0.14
2	.60	.40	.40
3	.34	.31	.30
4	.42	.38	.40

[1]All concentrations are precipitation-weighted averages.

Sodium concentration[1] (mg/L)			
Data station (map number)	1980	1985	1990
1	0.54	0.10	0.10
2	.54	.22	.18
3	.40	.16	.17
4	.37	.21	.22

Sulfate concentration[1] (mg/L)			
Data station (map number)	1980	1985	1990
1	2.7	1.8	1.8
2	2.2	1.6	1.7
3	2.1	1.9	1.9
4	1.9	1.5	2.0

Total nitrogen concentration[1] (mg/L)			
Data station (map number)	1980	1985	1990
1	0.38	0.34	0.44
2	.43	.32	.37
3	.42	.47	.55
4	.36	.35	.49

Figure 15. Precipitation-weighted average of selected chemical characteristics of precipitation in the Albemarle-Pamlico drainage study area, for 1980, 1985, and 1990 (National Atmospheric Deposition Program/National Trends Network Coordination Office, 1983, 1987, and 1991).

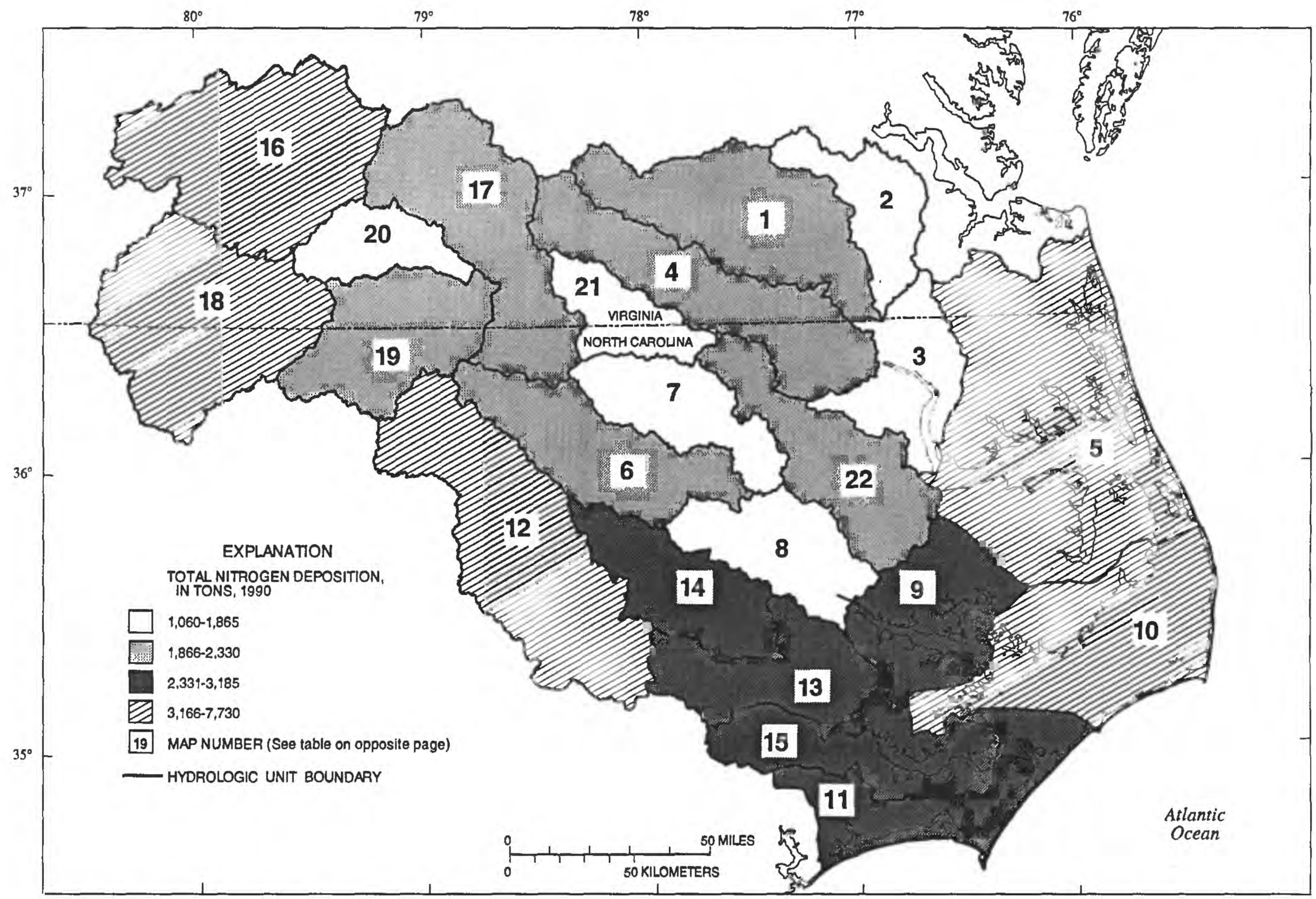


Figure 16. Atmospheric deposition of total nitrogen, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1990 (National Atmospheric Deposition Program/National Trends Network Coordination Office, 1991). The four divisions shown represent quartiles of total nitrogen deposition across the 22 hydrologic units. (See table 2 and fig. 3 for hydrologic unit names and locations.)

Map number	Hydrologic unit (fig. 3) Name	Code	Atmospheric deposition of total nitrogen (in tons)[a]
Chowan River Basin			
1	Nottoway River	03010201	3,070
2	Blackwater River	03010202	1,400
3	Chowan River	03010203	1,660
4	Meherrin River	03010204	2,980
5	Albemarle Sound	03010205	7,730
	Total		16,840
Tar-Pamlico River Basin			
6	Upper Tar River	03020101	2,570
7	Fishing Creek	03020102	1,630
8	Lower Tar River	03020103	1,870
9	Pamlico River	03020104	2,210
10	Pamlico Sound	03020105	3,730
11	Bogue and Core Sounds	03020106	2,160
	Total		14,170
Neuse River Basin			
12	Upper Neuse River	03020201	5,170
13	Middle Neuse River	03020202	2,080
14	Contentnea Creek	03020203	1,940
15	Lower Neuse River	03020204	2,210
	Total		11,400
Roanoke River Basin			
16	Upper Roanoke River	03010101	4,490
17	Middle Roanoke River	03010102	3,180
18	Upper Dan River	03010103	3,930
19	Lower Dan River	03010104	2,450
20	Banister River	03010105	1,070
21	Roanoke Rapids	03010106	1,060
22	Lower Roanoke River	03010107	2,480
	Total		18,660

[a]Area of water bodies were included in calculations to indicate total input to area.

precipitation is returned to the atmosphere by evaporation and transpiration (here combined and called evapotranspiration). Most of the evapotranspiration occurs during the plant-growing season when temperatures are high. Evapotranspiration consumes slightly less than 30 in., or about 55 percent, of the average annual precipitation in the mountains where average annual temperatures are about 50 to 52 °F. It consumes slightly more than 36 in., or about 70 percent, of average annual precipitation in the southeastern part of the study area where temperatures are about 10 °F higher. (Compare figs. 17A and 14.) The remaining 12 to 18 in. of annual precipitation constitutes the surface- and ground-water runoff in the area (fig. 17B).

Surface-Water Characteristics

As previously defined, freshwater streams and impounded lakes and reservoirs compose the surface-water bodies in the study area. The nature of the drainage basins, the physical and chemical nature of the movement and distribution of the surface water, and surface-water use play important roles in defining the environmental setting in the area.

Drainage Basins

The largest river basins in the study area are the Roanoke and the Chowan, and the smallest are the Tar-Pamlico and Neuse (table 2; fig. 3). The basin and streambed slopes of the rivers and creeks in the Chowan River Basin and in the Great Dismal Swamp drainage are the lowest in the study area, producing sluggish flows for long periods and flat, long-lasting flood peaks. Extensive streamflow regulation in the Roanoke River and its major tributaries by means of many large reservoirs decreases streamflow variability, reduces flood peaks, and augments low flow. The Tar River is swift and rocky at its headwaters, but slows and broadens as it nears Washington, N.C., where it becomes the Pamlico River. Several rivers and creeks drain into Falls Lake near Raleigh and Durham, N.C., which serves as the upstream source of the Neuse River. Like the Tar-Pamlico River Basin, the Neuse River Basin and streambed slopes flatten, and the river slows and broadens as it flows eastward across the Coastal Plain (Mason and Jackson, 1986; Prugh and Scott, 1986).

Runoff Amount and Distribution

The rivers in the study area discharge between 12 and 18 in. of average annual runoff to the Albemarle and Pamlico Sounds (fig. 17B). This is equivalent to about 0.9 to 1.3 cubic foot per second per square mile [$(ft^3/s)/mi^2$] of drainage area. The amount and distribution of runoff vary substantially because of seasonal influences and periods of above- and below-average precipitation. The seasonal variation indicates that long-term average monthly stream discharge is fairly independent of long-term average monthly precipitation for the area (fig. 18). This is true for streams in all provinces in the study area. The highest

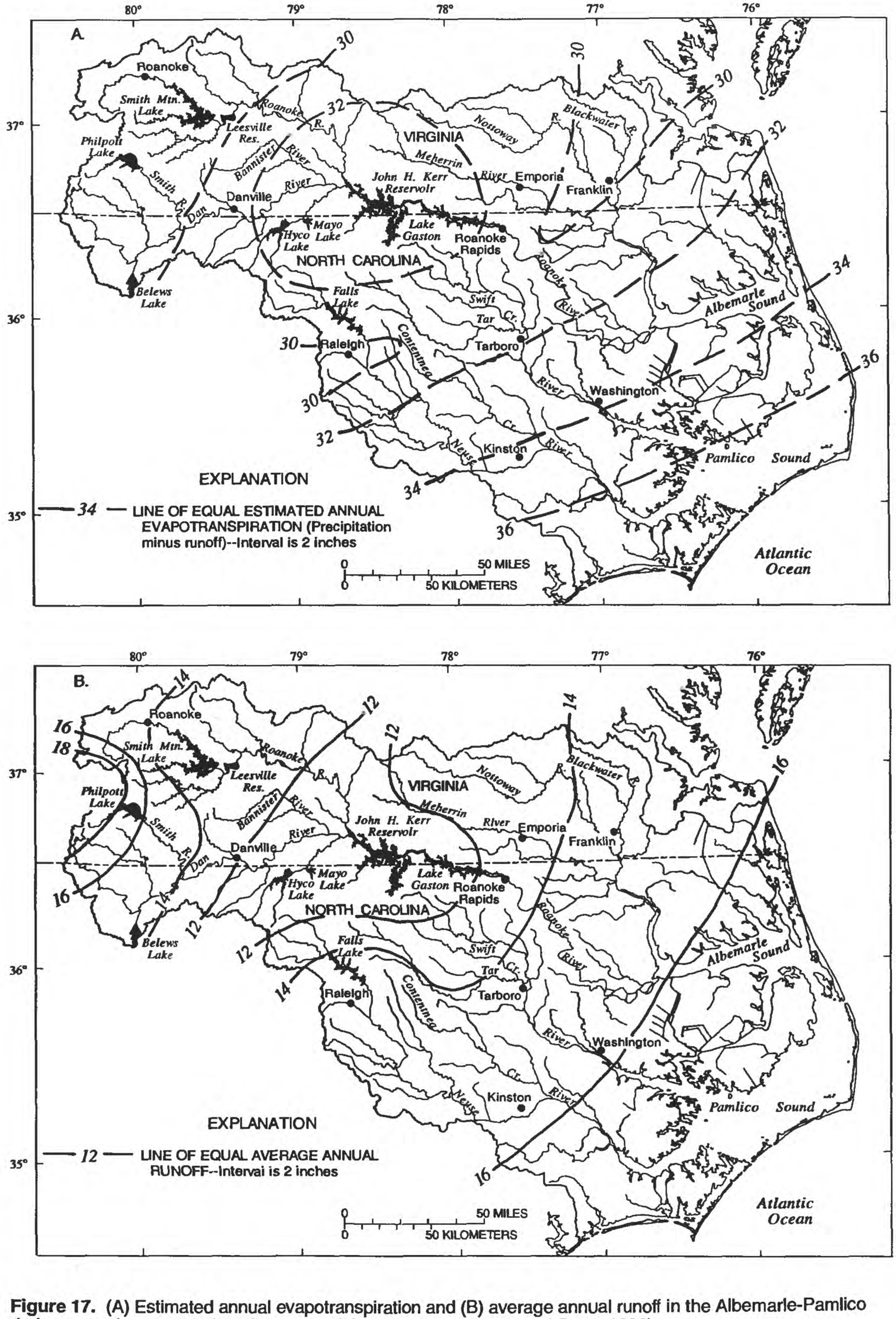


Figure 17. (A) Estimated annual evapotranspiration and (B) average annual runoff in the Albemarle-Pamlico drainage study area, 1951-80 (Mason and Jackson, 1986; Prugh and Scott, 1986).

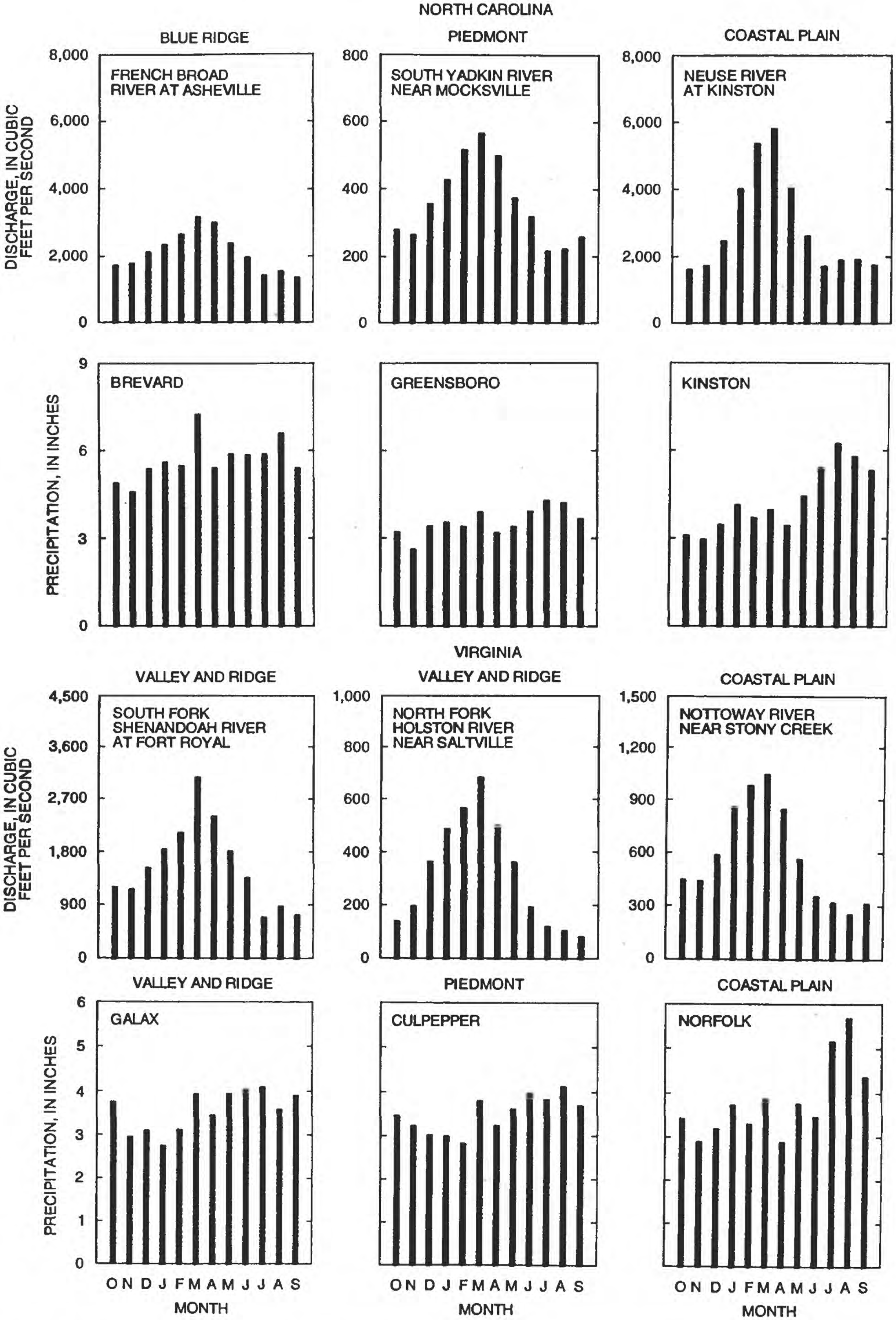


Figure 18. Average monthly stream discharge and precipitation for selected sites in the Blue Ridge, Valley and Ridge, Piedmont, and Coastal Plain Provinces of North Carolina and Virginia, 1951-80 (from Mason and Jackson, 1986; Prugh and Scott, 1986).

average monthly streamflow occurs during the months that include the nongrowing season when temperatures are low and plant activity is minimal (evapotranspiration rates are low). The lowest average monthly streamflow occurs during the growing season when evapotranspiration rates are high.

Long-term streamflow data at selected stations in the study area indicate that small and large basins have wide ranges of annual discharge (fig. 19; table 8). Low-discharge years generally are associated with below-average precipitation, and high-discharge years correlate with above-average precipitation. Lowest and highest water-year discharge for the streams shown in figure 19 differ by a factor that ranges between 4 and 8. This variation in discharge has an effect on water quality. Constituents in stream water generally are more concentrated at low flow than at high flow. However, high flow can initially carry higher concentrations of constituents or compounds that originated from natural weathering or human activities and were stored in or on the soil and rock prior to the heavy rains that caused the high-flow conditions.

Selected Chemical and Physical Characteristics of Runoff

Certain chemical and physical characteristics, such as specific conductance (SC), pH, dissolved oxygen (DO), and concentrations of chloride (CL), total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP), provide a general measure of water-quality conditions in a stream. Specific conductance is a general measure of the amount of ionic substances dissolved in water. pH measures the acidic or basic properties of water. The amount of dissolved oxygen in water is important to the life of aquatic organisms. Concentrations of chloride greater than 250 milligrams per liter (mg/L) limit most uses of water, and high TOC concentrations can cause difficulties in drinking-water treatment. Nutrients, such as nitrogen and phosphorus, can influence important biological characteristics of streams, lakes, and estuaries.

Simmons and Heath (1979) describe natural background levels of dissolved chloride, total nitrogen, and total phosphorus, among other constituents, for streams that are relatively unaffected by human activities (streams with 90- to 100-percent forested basins). They reported the highest concentrations of chloride, total nitrogen, and total phosphorus expected in such streams to be about 5.4, 0.70, and 0.03 mg/L, respectively. Caldwell (1992) reported concentrations of chloride, total nitrogen, and total phosphorus in forested basins as high as 6.8, 1.2, and 0.04 mg/L, respectively.

Some of the chemical and physical characteristics described above are used here to define the general water-quality conditions for selected streams in the Albemarle-Pamlico drainage study area (fig. 20). In general, the specific conductance of these streams was less than 150 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C), suggesting that total dissolved solids were less than about 90 mg/L. An exception occurred at Knap of Reeds Creek, where a large percentage of the discharge was composed of wastewater-treatment effluent with a resultant specific conductance of 346 µS/cm at the sampling site (Mason and Jackson, 1986).

The pH of most streams generally ranged from 6 to 7, except for Van Swamp, where pH ranged from 3 to 4. Dissolved oxygen was generally between 5 and 10 mg/L at all sites. Chloride ranged from about 4 to 44 mg/L and was commonly about twice the concentration expected in baseline streams (Caldwell, 1992). Total nitrogen was between 0.33 and 6.2 mg/L and exceeded 0.70 mg/L in about 78 percent of the samples. Total phosphorus ranged from 0.01 to 2.6 mg/L and exceeded 0.03 mg/L in 89 percent of the samples. Together, these data indicate that water quality in some of the sampled streams shown in figure 20 possibly was influenced by human activities.

Ground-Water Characteristics

Ground water is a significant component of the total water discharged to the Albemarle-Pamlico estuarine system. During dry weather, it is the only component of surface-water discharge in most streams. Consequently, the occurrence, movement, distribution, chemical nature, and use of ground water play important roles in the overall hydrology of the study area. The quality of ground water is dependent on the quality of precipitation, the mineral composition of the soil and rock, the length of time water is in contact with the soil and rock or sediment, and human-introduced compounds applied to the soil that are contacted and dissolved by water.

Major Aquifers

Aquifers are rocks or sediments that can transmit usable quantities of water to wells. Aquifers in the

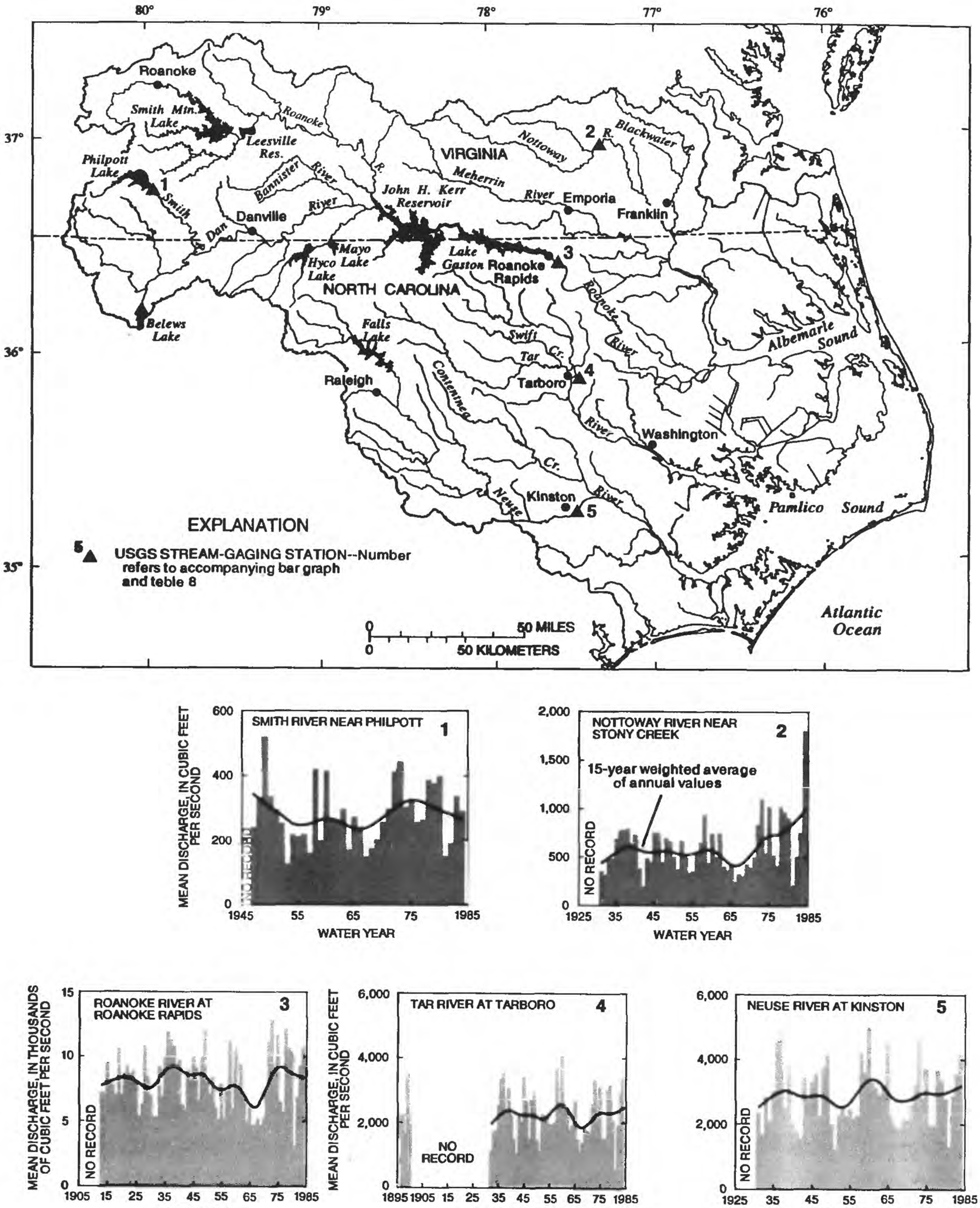


Figure 19. Variations in discharge at selected streamflow stations in the Albemarle-Pamlico drainage study area (Mason and Jackson, 1986; Prugh and Scott, 1986).

Table 8. Streamflow characteristics at selected surface-water gaging stations in the Albemarle-Pamlico drainage study area (Mason and Jackson, 1986; Prugh and Scott, 1986)
[---, insufficient data or not applicable]

Map no. (fig. 19)	Gaging station: Name and USGS number[a]	Gaging station: Drainage area (square miles)	Gaging station: Period of analysis (years)	Streamflow characteristics: 7-day, 10-year low flow[b] (cubic feet per second)	Streamflow characteristics: Average discharge (cubic feet per second)	Streamflow characteristics: 100-year flood[c] (cubic feet per second)	Degree of regulation	Remarks
1	Smith River near Philpott (02072000)	216	1946-50 1951-84	--- 58	354 268	--- ---	Negligible Appreciable	Prior to Philpott Dam. Subsequent to Philpott Dam.
2	Nottoway River near Stony Creek (02045500)	579	1929-84	12.8	564	25,700	Negligible	Major uses include irrigation, fish propagation, and recreation. Typical of southern Piedmont streams.
3	Roanoke River at Roanoke Rapids (02080500)	8,386	1911-49 1950-84	1,010 1,310	8,085 7,700	215,000 66,800	Negligible Appreciable	Flow regulated by John H. Kerr Reservoir since 1950.
4	Tar River at Tarboro (02083500)	2,183	1896-1900 1931-84	90	2,234	45,500	Negligible	---
5	Neuse River at Kinston (02089500)	2,692	1930-81 1981-84	210 ---	2,892 ---	43,100 33,000	Negligible Moderate	Falls Lake partly filled in 1981.

[a]U.S. Geological Survey downstream order identification number.
[b]A low-flow condition lasting at least 7 days, with a 10-percent chance of occurring in any year.
[c]A flood that has a 1-percent probability of occurring in any year.

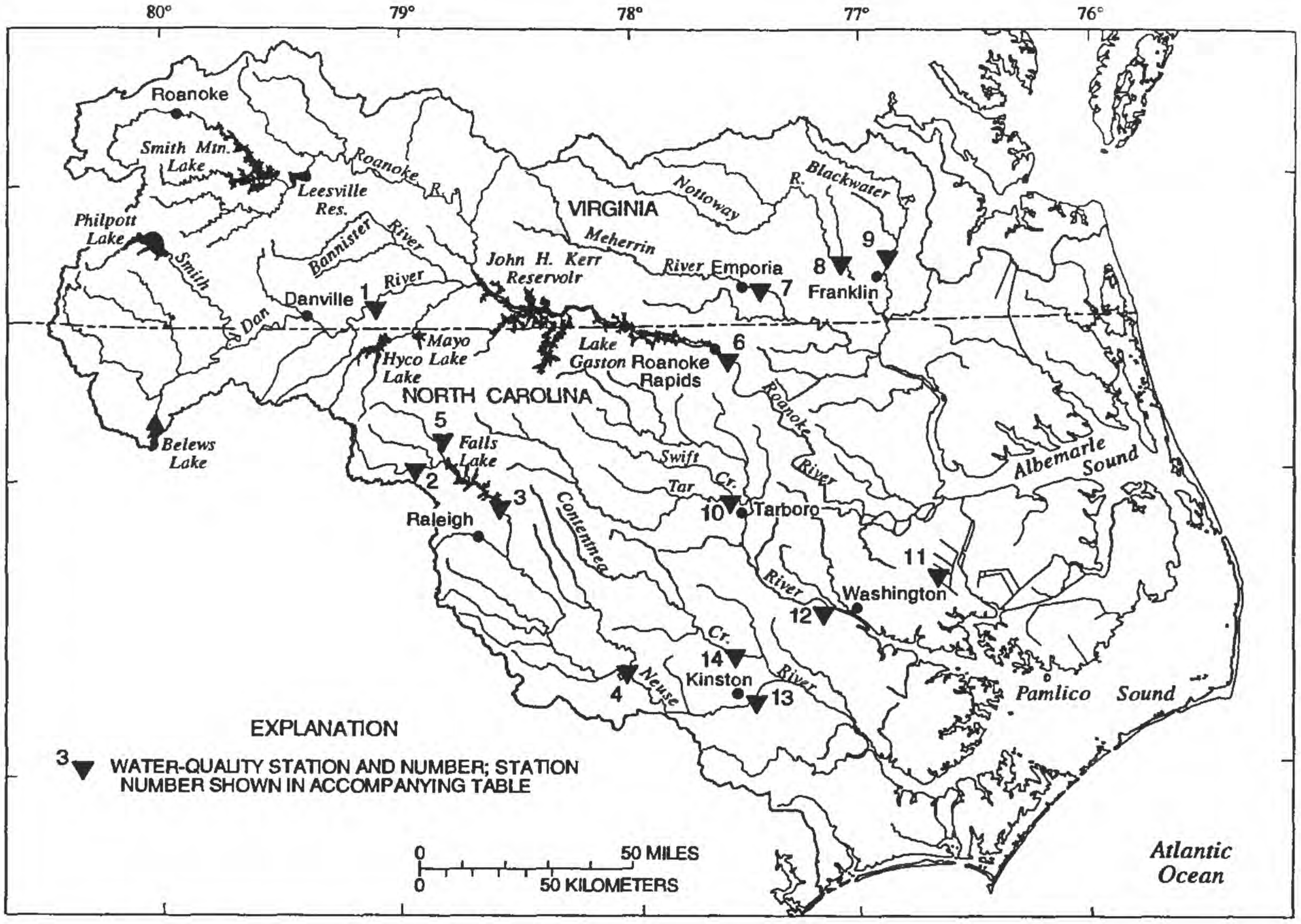
study area are composed of consolidated rocks and unconsolidated sediments. In consolidated rocks, such as granite, ground water occurs in and moves through fractures; in the case of limestone, ground water occurs and moves through fractures and solution openings. In unconsolidated sediments, such as sand, ground water occurs in and moves through pore spaces between the sedimentary particles. The consolidated aquifers in the study area are generally covered with a layer of unconsolidated, weathered rock and soil.

The aquifers in the Valley and Ridge Province are consolidated and fractured limestones and sandstones (fig. 21). Aquifers in the Blue Ridge and Piedmont are consolidated and fractured igneous and metamorphic crystalline rocks (granite, gneiss, schist), and consolidated and fractured Triassic sandstone, siltstone, and mudstone. The Coastal Plain aquifers are unconsolidated sand and shell deposits, and partially consolidated to consolidated sandy limestone and limestone beds (fig. 21).

Most of the natural ground-water circulation occurs at depths of 150 ft or less. However, some freshwater circulates to depths greater than 800 ft below land surface as evidenced by wells producing freshwater at those depths. In the central and western parts of the area, freshwater circulation is restricted by a general decrease in the amount and size of rock fractures with depth. In the eastern part of the study area, freshwater circulation is restricted by hydraulic head and the occurrence of saltwater at depth. From the Valley and Ridge in the west to the Coastal Plain in the east, there is a general decrease in the freshwater head, and in the Coastal Plain deposits, there is a corresponding general decrease in the depth to saltwater toward the sounds and ocean.

Ground-Water Contribution to Surface-Water Discharge

On average, more than half of the water that reaches study area streams first infiltrates the land surface, percolates through the soil to the top of the zone of saturation (the water table), and moves through the unconsolidated sediments and(or) consolidated rocks as ground water before it discharges to streams.



Values are average concentrations of 4 to 12 measurements made during the indicated water year in milligrams per liter; except Van Swamp, where measurements were made only once in 1960. Table numbers correspond to locations on above map. Numbers in parentheses are U.S. Geological Survey downstream order identification numbers.

[WY, water year; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH, power of the hydrogen ion in standard units; DO, dissolved oxygen in milligrams per liter (mg/L); CL, chloride in mg/L; TN, sum of nitrate plus nitrite (total) and ammonia plus organic nitrogen (total) in mg/L as nitrogen; TP, total phosphorus in mg/L as phosphorus; --, no data]

1. Dan River at Paces, Va. (02075500)

WY	SC	pH	DO	CL	TN	TP
1980	109	7.0	8.2	10.7	0.98	0.16
1985	161	7.2	9.5	23.0	1.0	.19
1990	162	7.3	8.6	12.9	.93	.09

2. Eno River near Weaver, N.C. (02085070)

WY	SC	pH	DO	CL	TN	TP
1980	--	--	--	--	--	--
1985	115	6.5	8.8	8.8	1.7	0.54
1990	180	7.1	8.9	15.1	1.7	.07

3. Neuse River near Falls, N.C. (02087183)

WY	SC	pH	DO	CL	TN	TP
1980	--	--	--	--	--	--
1985	121	6.8	9.0	9.4	1.1	0.21
1990	84	6.6	9.7	6.1	1.0	.04

4. Neuse River at Smithfield, N.C. (02087570)

WY	SC	pH	DO	CL	TN	TP
1980	--	--	--	--	--	--
1985	137	7.0	8.5	--	1.6	0.57
1990	148	6.9	9.3	9.9	1.8	.14

5. Knap of Reeds Creek near Butner, N.C. (02086624)

WY	SC	pH	DO	CL	TN	TP
1980	--	--	--	--	--	--
1985	346	6.4	7.2	44	6.2	2.6
1990	--	--	--	--	--	--

6. Roanoke River at Roanoke Rapids, N.C. (02082500)

WY	SC	pH	DO	CL	TN	TP
1980	83	6.9	9.9	5.4	0.44	0.07
1985	104	6.5	9.2	8.3	.33	.04
1990	89	6.6	9.2	6.4	.72	.03

7. Meherrin River at Emporia, Va. (02052000)

WY	SC	pH	DO	CL	TN	TP
1980	73	6.8	9.7	5.3	0.45	0.05
1985	72	7.0	10.8	4.7	.68	.02
1990	70	6.7	8.1	4.1	.64	.05

8. Nottoway River near Sebrell, Va. (02047000)

WY	SC	pH	DO	CL	TN	TP
1980	60	6.5	8.6	4.4	0.53	0.05
1985	82	7.0	9.2	7.1	.67	.02
1990	67	6.7	7.9	5.6	.60	.06

9. Blackwater River near Franklin, Va. (02049500)

WY	SC	pH	DO	CL	TN	TP
1980	90	6.5	7.9	7.9	0.78	0.05
1985	109	6.8	7.6	9.9	.82	.02
1990	86	6.5	6.8	8.3	.92	.05

10. Tar River at Tarboro, N.C. (02083500)

WY	SC	pH	DO	CL	TN	TP
1980	99	6.5	8.7	8.7	1.0	0.16
1985	89	6.2	10.0	7.0	.91	.12
1990	87	7.0	7.0	7.3	1.1	.10

11. Van Swamp near Hoke, N.C. (02084557)

WY	SC	pH	DO	CL	TN	TP
1980	110	3.4	8.6	7.5	1.5	0.01
1985	98	4.7	5.1	--	1.8	.05
1990	--	--	--	--	--	--

12. Chicod Creek near Simpson, N.C. (02084160)

WY	SC	pH	DO	CL	TN	TP
1980	101	6.1	8.5	9.3	3.3	0.38
1985	182	6.2	6.7	12.1	4.4	.53
1990	--	--	--	--	--	--

13. Neuse River at Kinston, N.C. (02089500)

WY	SC	pH	DO	CL	TN	TP
1980	97	7.1	9.8	10.0	1.3	0.20
1985	120	6.2	8.2	11.5	1.5	.25
1990	125	6.5	8.2	9.9	1.3	.11

14. Contentnea Creek at Hookerton, N.C. (02091500)

WY	SC	pH	DO	CL	TN	TP
1980	91	6.0	7.9	10.6	2.2	0.31
1985	110	6.1	7.9	12.8	2.2	.69
1990	89	6.4	7.1	10.0	1.3	.17

Figure 20. Selected chemical and physical characteristics of runoff in the Albemarle-Pamlico drainage study area (U.S. Geological Survey 1981a and b; Hill and others, 1985; Prugh and others, 1986 and 1991; Ragland and others, 1991).

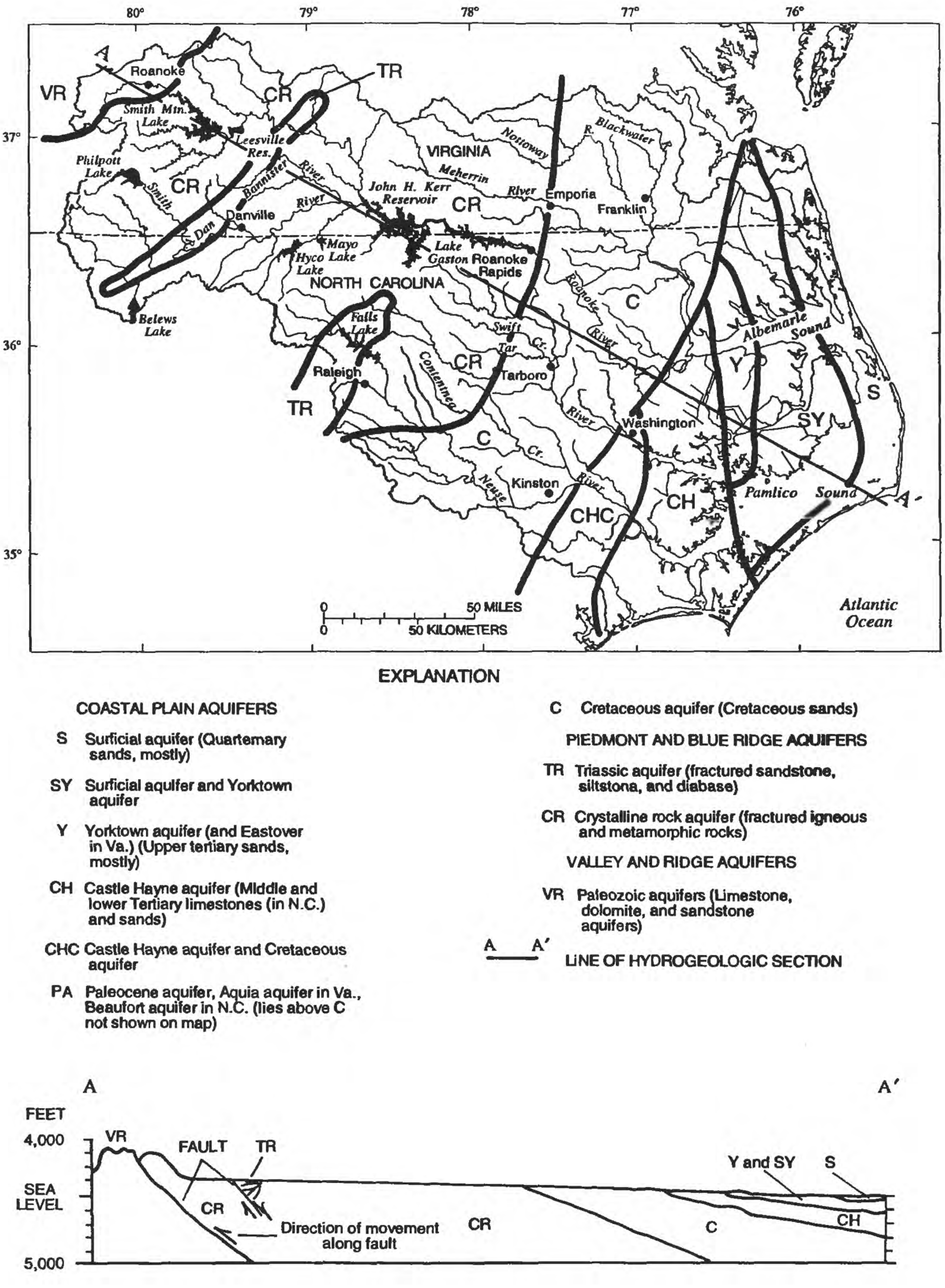


Figure 21. Major aquifers in the Albemarle-Pamlico drainage study area (Coble and others, 1985, p. 329-334; Meng and others, 1985, p. 427-432; Giese and others, 1988, p. 393-400; Powell and Hamilton, 1988, p. 509-514).

Giese and others (1991) estimated that ground water constitutes about 70 percent of streamflow in the North Carolina Coastal Plain (fig. 22).

Estimates of the ground-water contribution to streamflow for streams in the Albemarle-Pamlico drainage area were made by applying hydrograph separation methods (Pettyjohn and Henning, 1979; Rutledge, 1991) to long-term streamflow data from 42 stream-gaging stations located in many of the hydrologic units in the area (table 9). The average ground-water contribution ranged from 61 to 64 percent for stations in the Roanoke River Basin, 48 to 58 percent in the Chowan River Basin, 49 to 57 percent in the Tar-Pamlico River Basin, and 45 to 53 percent for stations in the Neuse River Basin, indicating that ground water has a substantial influence on surface-water quality, particularly during periods of little or no precipitation. The fixed interval and sliding interval hydrograph separation techniques are consistently 8 to 10 percent higher than the local minimum separation technique. This difference is partially attributed to riparian evapotranspiration (Rutledge, 1993; Rutledge and Daniel, 1994).

Selected Chemical and Physical Characteristics of Ground Water

Selected chemical and physical characteristics of ground water sampled throughout North Carolina and Virginia are used here to indicate the kind of water quality that is expected in the aquifers in the Albemarle-Pamlico study area (fig. 23). In general, median concentrations of dissolved solids, iron (except for the surficial aquifer in Virginia), and chloride are below the recommended secondary maximum contaminant levels (MCL's), and nitrate and fluoride are below primary MCL's set by the U.S. Environmental Protection Agency (1986a and b).

Chloride concentrations of 250 mg/L or more occur in ground water at depths ranging from less than 200 ft below sea level to more than 800 ft below sea level in the Coastal Plain (fig. 24). The deepest occurrence of freshwater where chloride concentrations were 250 mg/L or less was in Isle of Wight County and Suffolk, Va., and the shallowest was in Dare County, N.C. In the Piedmont and Blue Ridge Provinces, ground water can be fresh at depths much greater than in the Coastal Plain (LeGrand and Mundorff, 1952; LeGrand, 1954; Daniel, 1989).

WATER-QUALITY ISSUES

Water-quality issues that are being studied during the first cycle of the NAWQA Program in the Albemarle-Pamlico drainage study area are associated with nutrients, pesticides, and suspended sediments. Among the problems addressed are the lack of understanding of the relative importance of point and nonpoint sources of these substances, eutrophication, habitat degradation, and health hazards. These problems have been identified by the North Carolina Division of Environmental Management (North Carolina Department of Natural Resources and Community Development, 1988; North Carolina Department of Environment, Health, and Natural Resources, 1990), the Virginia Water Control Board (1993), the NAWQA National Synthesis Teams, and the NAWQA Albemarle-Pamlico drainage study area liaison committee.

The following sections provide information on the amount and distribution of major sources of nutrients, pesticides, and suspended sediments in the study area. Although not exhaustive, the information can be used to make general comparisons between hydrologic units in the area. More detailed and specific information is required, however, to understand water-quality problems for areas smaller than hydrologic units.

Nutrients

Nitrogen and phosphorus concentrations significantly influence surface- and ground-water quality. Discharges from point sources, such as domestic sewage and industrial wastes; and nonpoint sources, such as atmospheric deposition, dissolution of minerals from soils and rocks, and surface- and ground-water runoff from urban areas, agricultural fields, livestock operations, and managed forests, can contribute to nutrient enrichment and accelerated eutrophication in surface water. Point- and nonpoint-source discharges also can contribute to concentrations of nitrate-nitrogen that exceed the drinking-water standard of 10 mg/L in ground water (U.S. Environmental Protection Agency, 1986a).

Troublesome production rates of aquatic vegetation occur when optimum supplies of all nutrients are available (Hem, 1989). Nitrogen has been reported as the limiting nutrient in the Pamlico River (Stanley, 1988) and the Neuse River (Paerl, 1987), with phosphorus being the limiting nutrient elsewhere in the

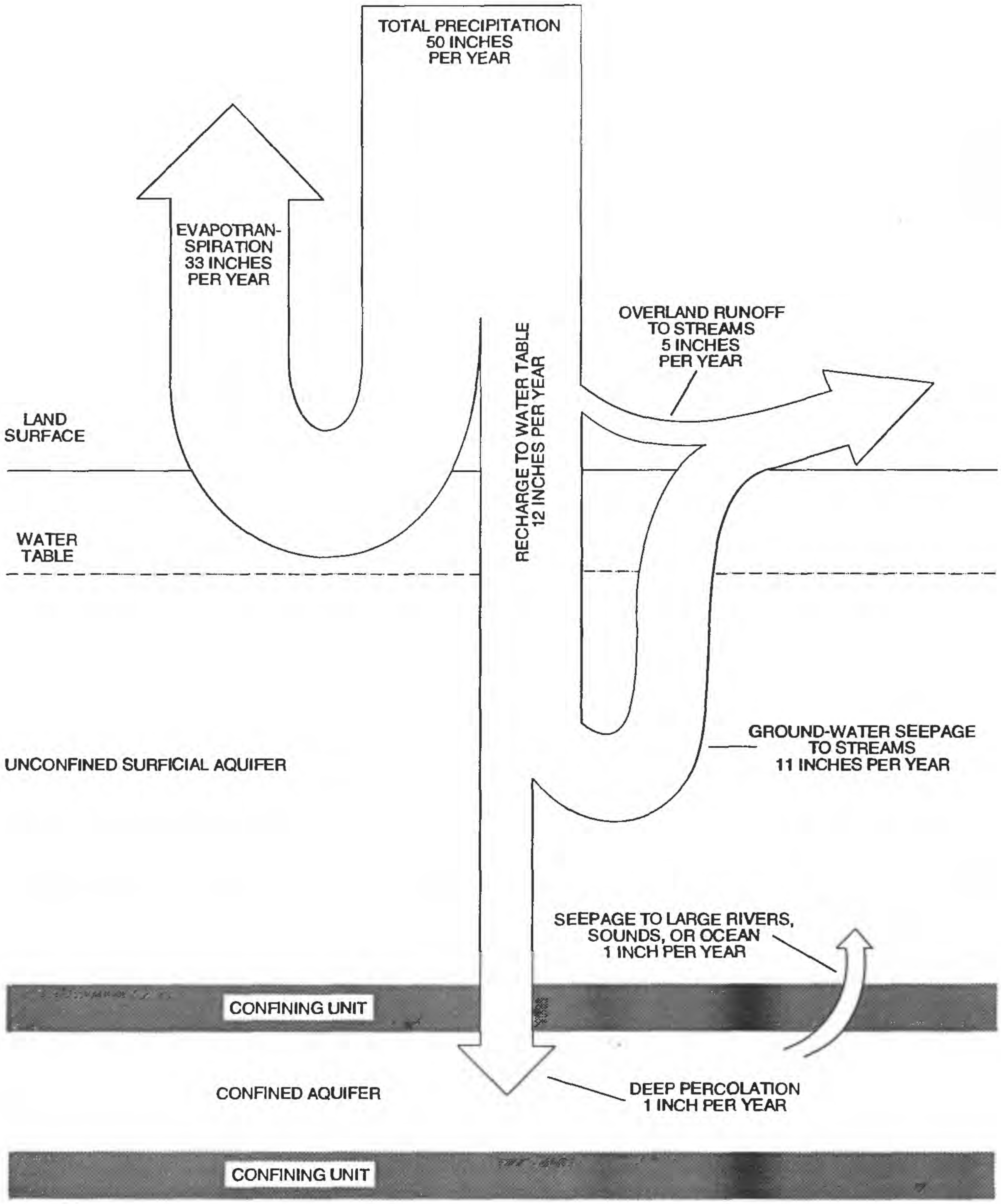


Figure 22. Typical annual water budget for the North Carolina Coastal Plain hydrogeologic system (from Giese and others, 1991).

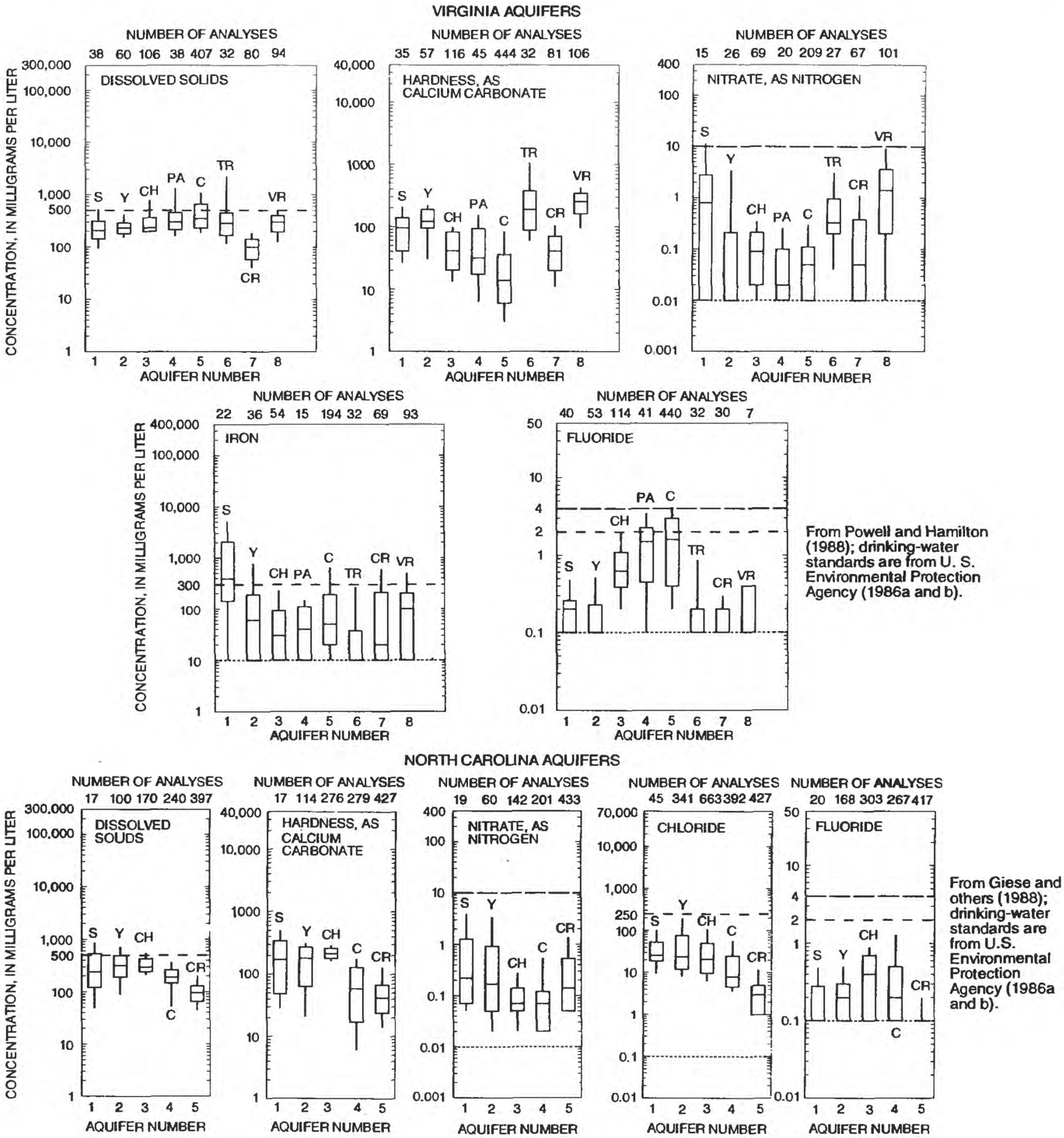
Table 9. Estimated ground-water contribution to runoff for selected streams, by hydrologic unit in the Albemarle-Pamlico drainage study area
[USGS, U.S. Geological Survey; US, U.S. Highway; SR, secondary road]

Hydrologic unit (fig. 3)		USGS stream-gaging station		Drainage area (in square miles)	Percent ground-water contribution to runoff determined by hydrograph separation methods[a]			Period of record used for hydrograph separation (water years[b])
Name	Code	Name	Downstream order number		Fixed interval	Sliding interval	Local minimum	
		Roanoke River Basin						
Upper Roanoke River	03010101	South Fork Roanoke River near Shawsville, Va.	2053800	110	68	68	63	1961-92
Upper Roanoke River	03010101	Tinker Creek near Dalesville, Va.	2055100	11.7	76	75	69	1957-92
Upper Roanoke River	03010101	Back Creek near Dundee, Va.	2056650	56.8	60	60	56	1975-92
Upper Roanoke River	03010101	Blackwater River near Rocky Mount, Va.	2056900	115	66	67	62	1977-92
Upper Roanoke River	03010101	Pigg River near Sandy Level, Va.	2058400	350	63	62	61	1964-92
Upper Roanoke River	03010101	Goose Creek near Huddleston, Va.	2059500	188	64	64	60	1931-92
Upper Roanoke River	03010101	Big Otter River near Evington, Va.	2061500	320	62	61	59	1938-92
Middle Roanoke River	03010102	Cub Creek at Phenix, Va.	2065500	98	66	65	62	1947-92
Upper Dan River	03010103	Dan River near Francisco, N.C.	2068500	129	75	75	73	1925-86
Upper Dan River	03010103	South Mayo River near Nettleridge, Va.	2069700	85	75	75	73	1963-92
Upper Dan River	03010103	North Mayo River near Spencer, Va.	2070000	108	70	70	68	1929-92
Lower Dan River	03010104	Hyco Creek near Leasburg, N.C.	2077200	45.9	41	42	36	1965-91[c]
Banister River	03010105	Georges Creek near Gretna, Va.	2076500	9.24	78	78	75	1950-92
Roanoke Rapids	03010106	Allen Creek near Boydton, Va.	2079640	53.4	39	39	37	1962-92
		Chowan River Basin						
Nottoway River	03010201	Nottoway River near Rawlings, Va.	2044500	309	56	55	54	1951-92
Nottoway River	03010201	Stony Creek near Dinwiddie, Va.	2046000	112	52	53	48	1947-92
Blackwater River	03010202	Blackwater River near Dendron, Va.	2047500	294	69	68	51	1942-92
Chowan River	03010203	Ahoskie Creek at Ahoskie, N.C.	2053500	63.3	47	47	40	1951-91[c]
Meherrin River	03010204	Potecasi Creek near Union, N.C.	2053200	225	66	66	46	1959-91

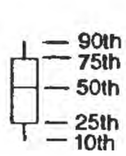
Table 9. Estimated ground-water contribution to runoff for selected streams, by hydrologic unit in the Albemarle-Pamlico drainage study area--Continued
[USGS, U.S. Geological Survey; US, U.S. Highway; SR, secondary road]

Hydrologic unit (fig. 3)		USGS stream-gaging station		Drainage area (in square miles)	Percent ground-water contribution to runoff determined by hydrograph separation methods[a]			Period of record used for hydrograph separation (water years[b])
Name	Code	Name	Downstream order number		Fixed interval	Sliding interval	Local minimum	
		Tar-Pamlico River Basin						
Upper Tar River	03020101	Tar River near Tar River, N.C.	2081500	167	36	36	32	1940-91[c]
Upper Tar River	03020101	Tar River at US 401 near Louisburg, N.C.	2081747	427	44	43	40	1974-91
Fishing Creek	03020102	Swift Creek at Hillardston, N.C.	2082770	166	61	63	57	1964-91[c]
Fishing Creek	03020102	Little Fishing Creek near White Oak, N.C.	2082950	177	54	54	52	1960-91[c]
Fishing Creek	03020102	Fishing Creek near Enfield, N.C.	2083000	526	55	55	51	1927-91
Lower Tar River	03020103	Conetoe Creek near Bethel, N.C.	2083800	78.1	61	61	54	1958-91[c]
Lower Tar River	03020103	Chicod Creek at SR 1760 near Simpson, N.C.	2084160	45	44	44	35	1976-86
Pamlico Sound	03020104	Durham Creek at Edward, N.C.	2084540	26	76	76	52	1966-91[c]
Pamlico Sound	03020104	Van Swamp at Hoke, N.C.	2084557	23	85	86	64	1978-91[c]
		Neuse River Basin						
Upper Neuse River	03020201	Eno River at Hillsborough, N.C.	2085000	66	47	47	44	1928-91[d]
Upper Neuse River	03020201	Eno River near Durham, N.C.	2085070	141	46	46	41	1964-91[c]
Upper Neuse River	03020201	Little River near Orange Factory, N.C.	2085220	80.4	42	42	40	1962-86
Upper Neuse River	03020201	Knap of Reeds Creek near Butner, N.C.	2086624	43	32	32	26	1983-91[c]
Upper Neuse River	03020201	Flat River at Bahama, N.C.	2085500	149	40	40	37	1926-91
Upper Neuse River	03020201	Ellerbe Creek near Gorman, N.C.	2086849	21.9	39	42	36	1983-90[c]
Upper Neuse River	03020201	Middle Creek near Clayton, N.C.	2088000	83.5	55	56	52	1940-91[c]
Upper Neuse River	03020201	Little River near Princeton, N.C.	2088500	232	63	61	50	1931-91[c]
Middle Neuse River	03020202	Swift Creek near Vanceboro, N.C.	2092000	182	64	63	49	1951-90[c]
Contentnea Creek	03020203	Contentnea Creek near Lucama, N.C.	2090380	161	56	57	49	1965-91[c]
Contentnea Creek	03020203	Nahunta Swamp near Shine, N.C.	2091000	80.4	59	59	54	1955-91[c]
Contentnea Creek	03020203	Contentnea Creek at Hookerton, N.C.	2091500	729	70	71	57	1930-91
Contentnea Creek	03020203	Little Contentnea Creek near Farmville, N.C.	2091700	93.3	54	53	42	1957-86
Lower Neuse River	03020204	Trent River near Trenton, N.C.	2092500	168	67	68	48	1952-91

[a]Hydrograph separation methods described in Pettyjohn and Henning (1979).
[b]Water year is the period October 1 to September 30, designated by the year in which it ends.
[c]Record missing for water years 1987 and 1988.
[d]Record missing for water years 1972-84, 1987, and 1988.



EXPLANATION



PERCENTILE--Percentage of analysis equal to or less than indicated values

NATIONAL DRINKING-WATER STANDARDS

— — — Maximum permissible contaminants level (primary)

- - - Maximum recommended contaminant level (secondary)

REPORTING LIMIT

.... Minimum reporting level with analytical method used

COASTAL PLAIN AQUIFERS

S Surficial aquifer (Quarternary sands, mostly)

SY Surficial aquifer and Yorktown aquifer

Y Yorktown aquifer (and Eastover in Va.) (Upper tertiary sands, mostly)

CH Castle Hayne aquifer (Middle and lower Tertiary limestones (in N.C.) and sands)

CHC Castle Hayne aquifer and Cretaceous aquifer

PA Paleocene aquifer, Aquia aquifer in Va., Beaufort aquifer in N.C.

C Cretaceous aquifer (Cretaceous sands)

PIEDMONT AND BLUE RIDGE AQUIFERS

TR Triassic aquifer (fractured sandstone, siltstone, and diabase)

CR Crystalline rock aquifer (fractured igneous and metamorphic rocks)

VALLEY AND RIDGE AQUIFERS

VR Paleozoic aquifers (Limestone, dolomite, and sandstone aquifers)

Figure 23. Selected chemical and physical characteristics of ground water in the Albemarle-Pamlico drainage study area.

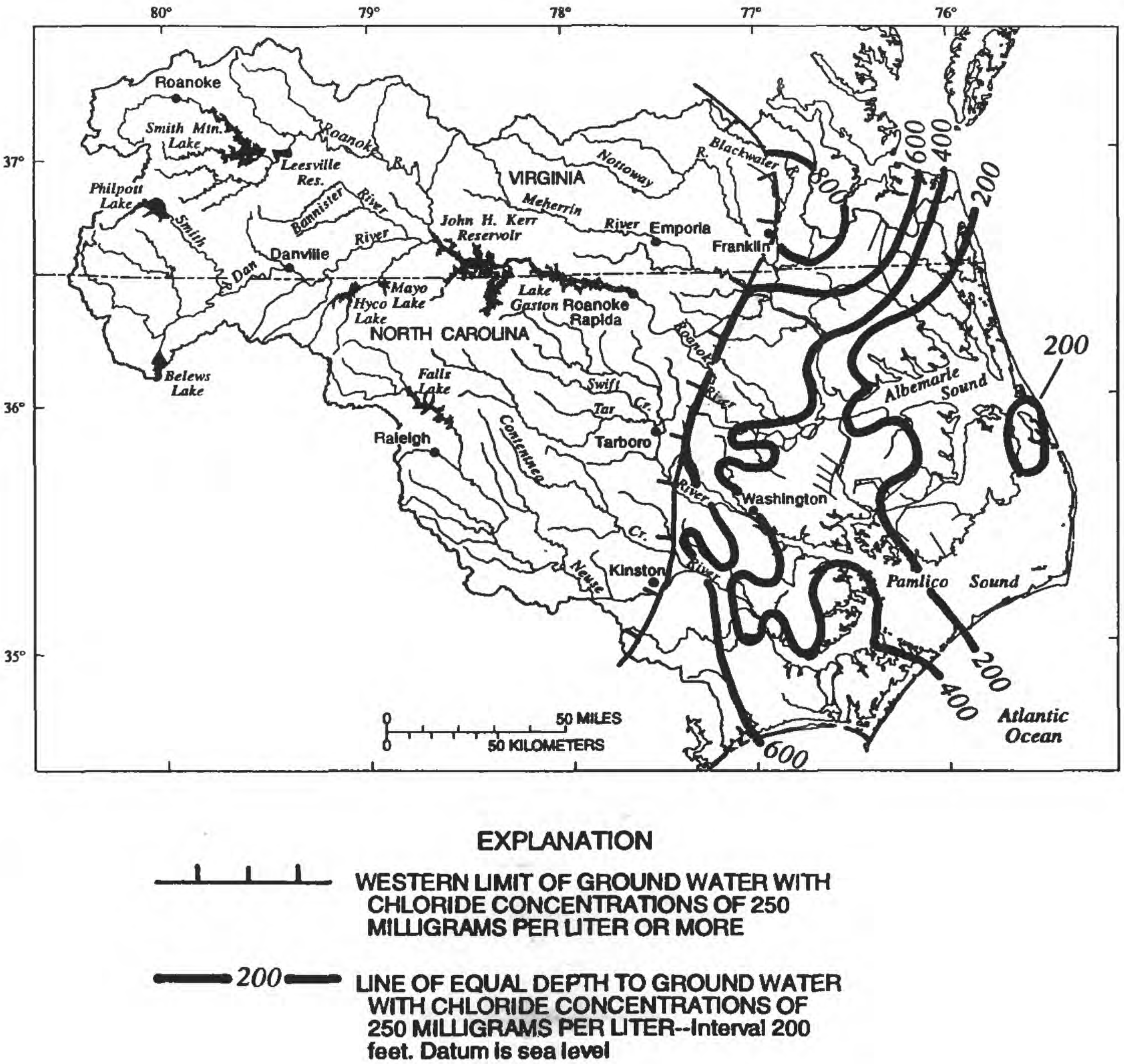


Figure 24. Depth to water containing chloride concentration of 250 milligrams per liter in the Coastal Plain, including the Albemarle-Pamlico drainage study area (from Coble and others, 1985, p. 329-334; Meng and others, 1985, p. 427-432).

Albemarle-Pamlico drainage study area (Harned and Davenport, 1990).

Eutrophication is defined as the "nutrient enrichment of waters which results in stimulation of an array of symptomatic changes among which are included increased production of algae and macrophytes, deterioration of fisheries, deterioration of water quality and other symptomatic changes that are found to be undesirable and interfere with water uses" (Organization for Economic Cooperation and Development, 1982). An increase in algal production increases turbidity, color, and odors creating problems for domestic water supplies. Floating macrophytes and algal mats reduce the suitability of waters for recreational purposes and cause navigational problems. When algae and macrophytes die, their decomposition results in decreased dissolved oxygen, causing the death of fish and other higher aquatic organisms (Connell and Miller, 1984).

The effects of eutrophication are usually more noticeable in water with long residence time—lakes or reservoirs, slow-moving stream reaches, and estuaries. Several areas within the Albemarle-Pamlico drainage study area have experienced symptoms of accelerated eutrophication or nutrient enrichment during the last two decades (fig. 25). As a result, streams in the Neuse and Tar-Pamlico River Basins and the North Carolina part of the Chowan River Basin have been designated as "nutrient sensitive waters." In Virginia, streams tributary to Smith Mountain Lake have been designated as "nutrient enriched" (Virginia Water Control Board, 1992). These designations provide the

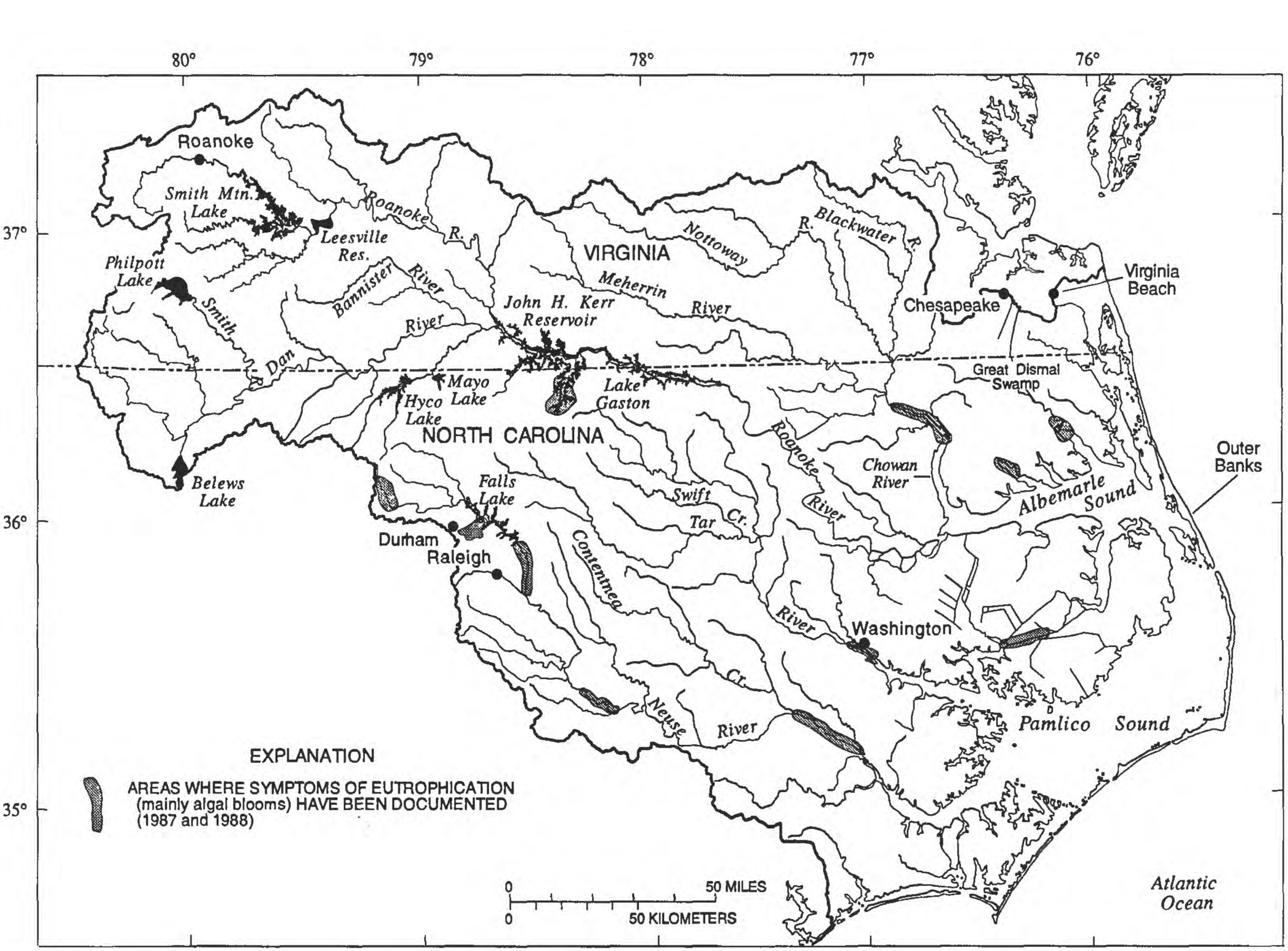


Figure 25. Areas in North Carolina where surface water is prone to eutrophication in the Albemarle-Pamlico drainage study area (North Carolina Department of Natural Resources and Community Development, 1988; North Carolina Department of Environment, Health, and Natural Resources, 1990).

respective States with added authority to limit nutrient contributions from point and nonpoint sources. North Carolina and Virginia implemented phosphate-detergent bans in 1988.

When concentrations of nitrate-nitrogen of 10 mg/L, or more, are ingested and bacterially reduced to nitrite in the intestines of newborn babies, a condition known as methemoglobinemia (commonly called blue-baby syndrome) can result. The death of infants from methemoglobinemia is rare where nitrate-nitrogen concentrations in the ground water are less than 10 mg/L, but the incidence of infant deaths caused by methemoglobinemia increases as nitrate-nitrogen concentrations increase (Walton, 1951). Median nitrate-nitrogen concentrations in ground water in the study area are generally less than 1 mg/L (fig. 23). Concentrations of 3 mg/L or more could indicate human influence (Madison and Brunett, 1985).

Point Sources

Information regarding the location and general size of permitted point-source discharges to surface waters in the hydrologic units of the Albemarle-Pamlico drainage study area is necessary to interpret water-quality conditions in the area (fig. 26; table 10). Discharge permits are issued under the National Pollution Discharge Elimination System (NPDES) program, which was delegated to the North Carolina Division of Environmental Management and the Virginia Water Control Board. In 1990, the permitted point sources in the study area discharged about 410 Mgal/d of treated effluent.

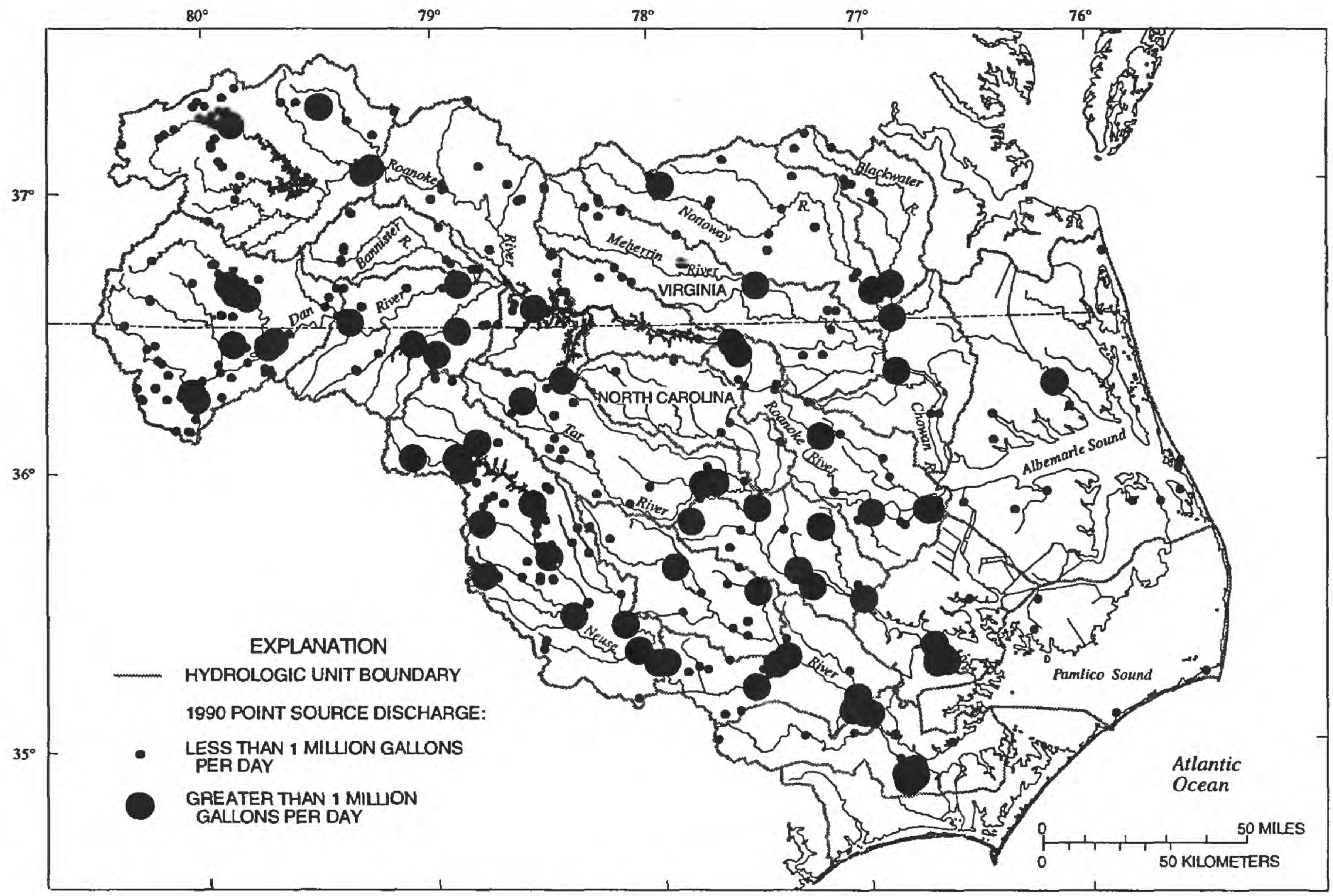


Figure 26. Distribution of point-source discharges to surface waters, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1990 (North Carolina Department of Environment, Health, and Natural Resources, 1992; Virginia Water Control Board, 1993). (See table 2 and fig. 3 for hydrologic unit names and locations.)

Table 10. Point-source discharges and resulting nutrient loads to surface waters, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1990 (North Carolina Department of Environment, Health, and Natural Resources, 1992; Virginia Water Control Board, 1993)

[NPDES, National Pollution Discharge Elimination System; Mgal/d, million gallons per day; >, greater than; <, less than; ---, no data]

Hydrologic unit (fig. 3)		Total NPDES discharge (Mgal/d)	Number of discharges		Nutrient load (tons)	
Name	Code		Total	>1 Mgal/d	Nitrogen	Phosphorus
Roanoke River Basin						
Upper Roanoke River	03010101	44.5	24	4	1,108	128
Middle Roanoke River	03010102	7.1	13	2	117	7
Upper Dan River	03010103	32.7	32	7	460	130
Lower Dan River	03010104	29.3	7	4	505	66
Banister River	03010105	1.5	9	0	57	20
Roanoke Rapids	03010106	.1	2	0	4	<1
Lower Roanoke River	03010107	74.7	17	5	1,012	154
Basin total		190	104	22	3,263	505
Chowan River Basin						
Nottoway River	03010201	4.6	10	2	33	16
Blackwater River	03010202	1.9	6	1	45	5
Chowan River	03010203	33.8	4	2	86	2
Meherrin River	03010204	2.3	18	1	58	7
Albemarle Sound	03010205	2.1	7	1	55	6
Basin total		44.7	45	7	277	36
Tar-Pamlico River Basin						
Upper Tar River	03020101	13.8	7	2	286	52
Fishing Creek	03020102	.4	1	0	5	1
Lower Tar River	03020103	12.1	8	3	227	29
Pamlico River	03020104	59	5	2	46	936
Pamlico Sound	03020105	---	---	---	---	---
Bogue and Core Sounds	03020106	---	---	---	---	---
Basin total		85.3	21	7	564	1,018
Neuse River Basin						
Upper Neuse River	03020201	61.9	42	11	1,227	143
Middle Neuse River	03020202	7.5	11	2	99	27
Contentnea Creek	03020203	11.4	10	3	184	24
Lower Neuse River	03020204	8.2	12	2	137	29
Basin total		89	75	18	1,647	223

Forty-two percent of the point sources are located in the Roanoke River Basin and discharged about 60 percent of the total effluent.

The total estimated 1990 nitrogen load from point-source discharges was about 5,800 tons (see Appendix for load-calculation methods). About 55 percent was from discharges in the Roanoke River Basin, 30 percent from discharges in the Neuse, 10 percent from discharges in the Tar-Pamlico, and 5 percent from discharges in the Chowan River Basin. The hydrologic units receiving the largest nitrogen loads from point-source discharges were the Upper Neuse and the Upper and Lower Roanoke units with loads exceeding 1,000 tons.

The total estimated 1990 phosphorus load from point-source discharges was about 1,800 tons. Approximately 55 percent of this load came from discharges in the Tar-Pamlico River Basin, 30 percent from discharges in the Roanoke, 13 percent from discharges in the Neuse, and 2 percent from discharges in the Chowan River Basin. The Pamlico River hydrologic unit had the largest point-source phosphorus load, which exceeded 900 tons.

Agricultural Sources

Fertilizer used on agricultural land, biologically fixed nitrogen, and nutrients from livestock manure are the major nonpoint-nutrient sources in the study area. Fertilizer-use estimates from the North Carolina Department of Agriculture were used to estimate the amount of elemental nitrogen and phosphorus applied to selected crops (corn, cotton, grains, potatoes, tobacco) and the amount of biologically fixed nitrogen from soybeans and peanuts grown in the area in 1990 (see Appendix for calculation methods). In 1990, a total of 152,900 tons of elemental nitrogen and 10,500 tons of elemental phosphorus were contributed by these nutrient sources (table 11). About 35 percent of the nitrogen and phosphorus inputs were associated with crops in the Chowan River Basin hydrologic units, 27 percent in the Tar-Pamlico, 26 percent in the Neuse, and 12 percent in the Roanoke River Basin.

Agricultural census data (U.S. Bureau of Census, 1990b) were used to estimate the amounts of nitrogen and phosphorus produced by livestock (cattle, chickens, hogs, and turkeys) wastes in the study area in 1987. About 43,500 tons of nitrogen and 12,200 tons of phosphorus were produced as livestock wastes in the hydrologic units throughout the study area in 1987 (table 11). Study-unit wide, about 36 percent of the nitrogen and phosphorus was produced by livestock in the Roanoke River Basin, 28 percent in the Neuse, and 18 percent each in the Tar-Pamlico and Chowan River Basins. The Chowan, Neuse, and Tar-Pamlico River Basins each had about 30 to 40 percent more total nitrogen and phosphorus from livestock wastes and fertilizers than the Roanoke River Basin. The Roanoke had the least nutrient input from fertilizers and the highest amount from livestock wastes.

Combined nutrient input estimates associated with atmospheric deposition (fig. 16), point-source discharges (fig. 26), and agriculture (table 11) may help identify hydrologic units with potential nutrient-related water-quality problems. Nitrogen and phosphorus inputs, by hydrologic unit, are presented on a tons per square mile basis (fig. 27). Nitrogen and phosphorus inputs averaged 8.8 and 0.9 tons, respectively, per square mile of hydrologic unit drainage area. For both nutrients, the highest input levels were in the Contentnea Creek hydrologic unit (03020203).

Pesticides

Approximately 1 billion pounds of pesticides are used annually in the United States or about 4 pounds per person per year (Ware, 1989). The use of pesticides has increased about ten fold in the last 25 years (Ware, 1989). The use of these chemicals has helped increase food production and control insect-borne diseases. However, by design, pesticides are toxic to target organisms and possibly to some nontarget organisms. Younos and Weigmann (1988) estimated that less than 0.1 percent of applied pesticides reaches the targeted pest, leaving large amounts available to enter the environment.

Major pesticide categories include herbicides, insecticides, and fungicides. Herbicides are chemical weed killers and, in many cases, have replaced mechanical methods of controlling weeds in areas where intensive agriculture is practiced. Herbicides, insecticides, and fungicides account for about 60, 25, and 10 percent, respectively, of the total amount of pesticides used in the United States. Other pesticides include rodenticides, fumigants, and molluscicides. Agricultural activities currently account for 75 percent of pesticide use in the United States; corn and soybeans received 82 percent of all agricultural herbicides, and corn, soybeans, and cotton received 82 percent of all agricultural pesticides (Ware, 1989).

The effects of these compounds on the environment are dependent on their chemical properties and the local conditions. Organochlorine pesticides, such as aldrin, DDT, and methoxychlor, sorb to particulate matter in soil, water, and bed sediment, bioaccumulate in organisms, and are relatively persistent in the natural environment (Gilliom and others, 1985). Organophosphate pesticides, such as diazinon and malathion, are highly soluble in water and tend to persist in soils for only a short time after application. The chlorophenoxy and triazine herbicides are generally intermediate in persistence between organochlorine and organophosphate insecticides and are highly soluble in water. Triazine herbicides, such as atrazine, are generally more persistent and less soluble than chlorophenoxy herbicides, such as 2,4-D.

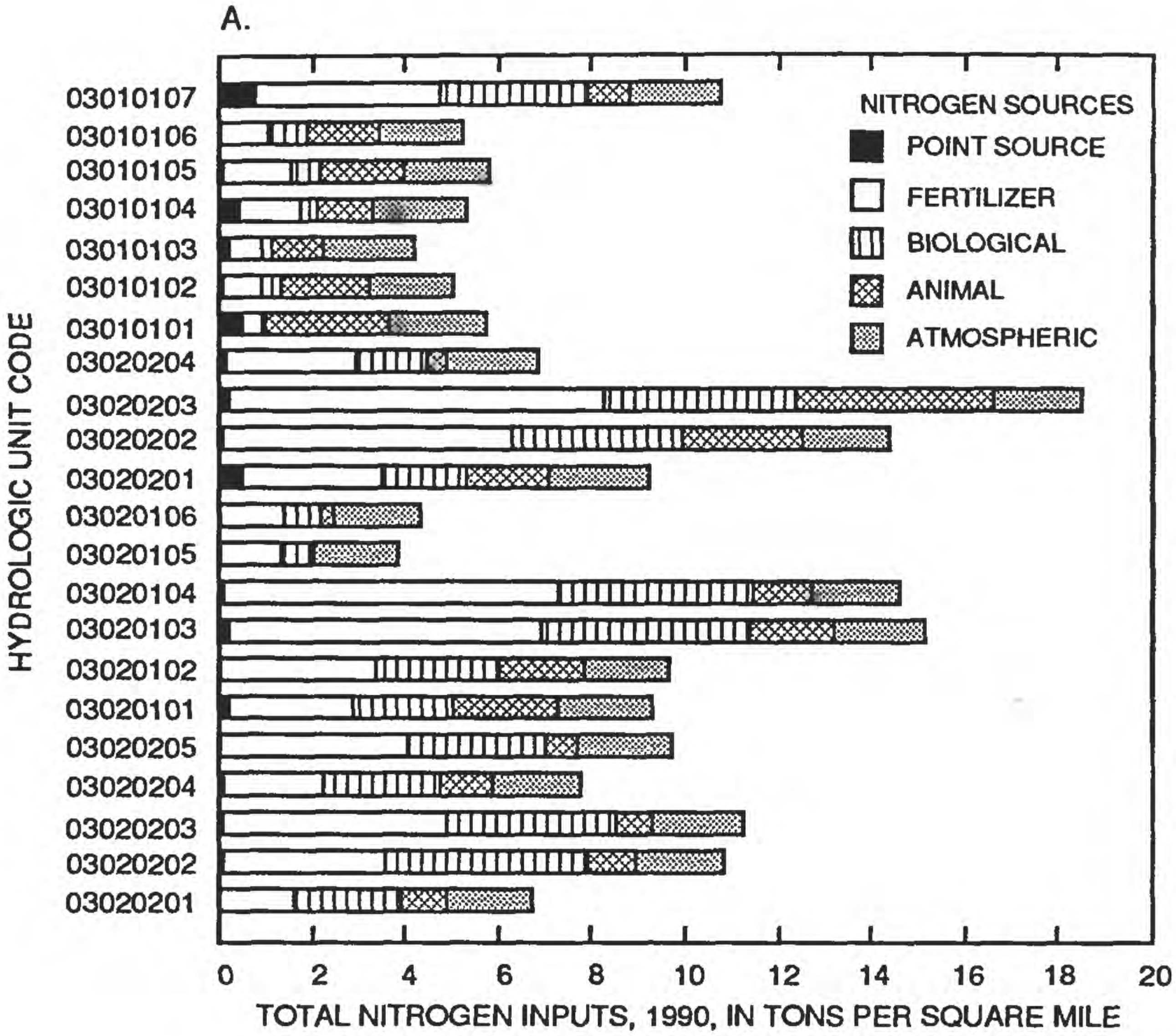
Millions of pounds of pesticides were used in the Albemarle-Pamlico drainage study area in 1990 (table 12). Data from Gianessi and Puffer (1988; 1991) were available to estimate the use of 54 selected pesticides; however, the data do not include pesticides used for non-agricultural purposes. Estimated use for selected herbicides in the study area in 1990 amounted to about 2.6 million pounds of active ingredients, and selected insecticide use was about 0.8 million pounds

Table 11. Elemental nitrogen and phosphorus used or biologically fixed on major crops and produced by livestock, by hydrologic unit in the Albemarle-Pamlico drainage study area in 1990 and 1987, respectively
[Values are elemental nitrogen and phosphorus in hundreds of tons rounded to the nearest hundred; <, less than]

Hydrologic unit (fig. 3)		Fertilizer end nitrogen fixation[a]		Livestock[b]		Total	
Name	Code	Nitrogen	Phos-phorus	Nitrogen	Phos-phorus	Nitrogen	Phos-phorus
Roanoke River Basin							
Upper Roanoke River	03010101	11	1	58	15	69	16
Middle Roanoke River	03010102	22	1	33	8	55	9
Upper Dan River	03010103	18	1	23	6	41	7
Lower Dan River	03010104	21	1	15	4	36	5
Banister River	03010105	12	1	11	3	23	4
Roanoke Rapids	03010106	11	1	9	2	20	3
Lower Roanoke River	03010107	92	6	12	4	104	10
Subtotal		187	12	161	42	348	54
Chowan River Basin							
Nottoway River	03010201	67	3	16	4	83	7
Blackwater River	03010202	58	3	8	2	66	5
Chowan River	03010203	72	5	7	2	79	7
Meherrin River	03010204	75	4	18	5	93	9
Albemarle Sound	03010205	261	20	27	8	288	28
Subtotal		533	35	76	21	609	56
Tar-Pamlico River Basin							
Upper Tar River	03020101	61	4	29	8	90	12
Fishing Creek	03020102	52	3	16	4	68	7
Lower Tar River	03020103	108	7	18	5	126	12
Pamlico River	03020104	130	10	14	4	144	14
Pamlico Sound	03020105	41	3	1	<1	42	3
Bogue and Core Sounds	03020106	25	2	3	1	28	3
Subtotal		417	29	81	22	498	51
Neuse River Basin							
Upper Neuse River	03020201	114	8	41	12	155	20
Middle Neuse River	03020202	106	8	28	9	134	17
Contentnea Creek	03020203	123	9	43	14	166	23
Lower Neuse River	03020204	49	4	5	2	54	6
Subtotal		392	29	117	37	509	66
Total		1,529	105	435	122	1,965	227

[a]Data represent elemental nitrogen and phosphorus applied as fertilizer and nitrogen fixation on major crops (corn, cotton, grains, peanuts, potatoes, soybeans, tobacco) in 1990 (North Carolina Department of Agriculture, 1990; Virginia Department of Agriculture and Consumer Services, 1990).

[b]Data represent elemental nitrogen and phosphorus produced by livestock (cattle, chickens, hogs, turkeys) in 1987 (U.S. Bureau of Census, 1990b).



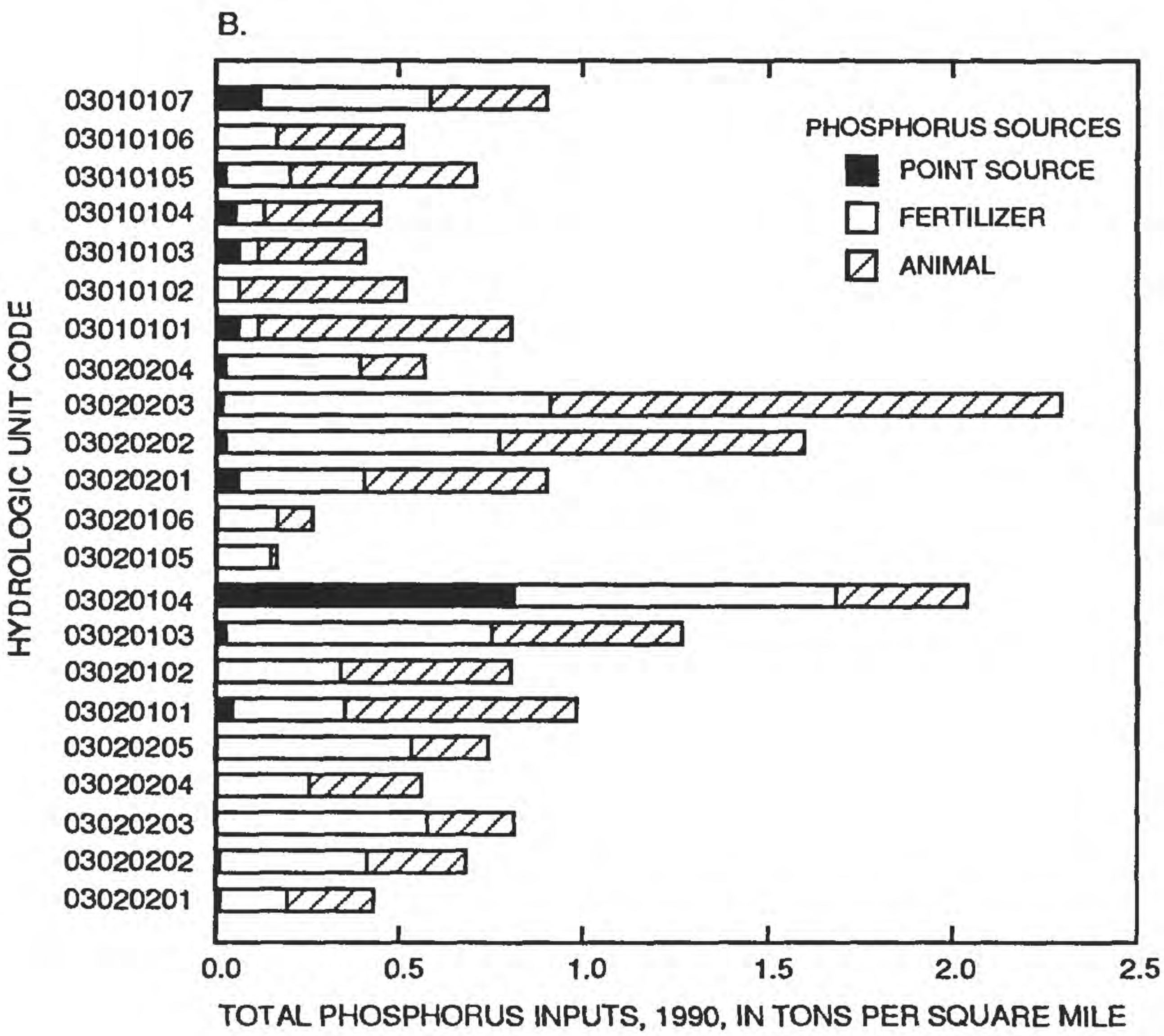


Figure 27. Estimated (A) nitrogen and (B) phosphorus inputs to waters of the Albemarle-Pamlico drainage study area, 1990. (See table 2 and fig. 3 for hydrologic unit names and locations.)

Table 12. Estimated use of selected pesticides, by hydrologic unit, for major crops grown in the Albemarle-Pamlico drainage study area, 1990

[Values are hundreds of pounds rounded to the nearest hundred pounds. Major crops are corn, cotton, grains, peanuts, potatoes, soybeans, and tobacco. The six-digit numbers in parentheses represent the first six digits of the eight-digit hydrologic unit code (table 2). The two-digit numbers at the top of each column represent the last two digits of the eight-digit hydrologic unit code (table 2). --, not applicable; <, less than]

Pesticide	Roanoke River Basin (030101__)							Chowan River Basin (030102__)					Tar-Pamlico River Basin (030201__)						Neuse River Basin (030202__)				Total
	01	02	03	04	05	06	07	01	02	03	04	05	01	02	03	04	05	06	01	02	03	04	
Herbicides[a]																							
2,4-D	2	2	7	12	6	--	--	1	14	--	41	263	--	31	15	28	44	--	25	2	161	62	778
2,4-DB	--	<1	<1	--	<1	--	--	<1	34	--	67	19	--	26	8	2	--	--	<1	<1	3	<1	161
Acifluorfen	2	7	2	<1	--	2	33	104	51	14	--	60	18	--	15	<1	--	5	24	9	--	--	347
Alachlor	10	12	36	28	33	--	--	4	347	--	1,048	2,238	--	572	228	213	290	--	73	12	1,090	480	6,714
Ametryn	--	--	<1	<1	--	--	--	--	--	--	4	28	--	3	2	3	6	--	1	<1	18	8	75
Atrazine	33	16	46	16	39	--	--	6	202	--	296	1,178	--	127	79	102	193	--	45	6	613	291	3,288
Benefin	<1	<1	1	--	4	--	--	<1	20	--	146	43	--	84	26	6	--	--	<1	<1	10	<1	342
Bentazon	--	2	3	2	7	--	--	1	116	--	135	206	--	34	13	16	19	--	5	1	79	34	673
Bromoxynil	<1	<1	<1	<1	2	--	--	<1	2	--	1	7	--	<1	<1	<1	1	--	1	<1	2	1	20
Butylate	7	4	13	7	8	--	--	1	44	--	100	482	--	55	36	47	88	--	17	3	278	132	1,322
Chloramben	--	--	<1	<1	--	--	--	--	1	--	2	2	--	3	<1	<1	--	--	1	<1	26	1	38
Chlorimuron	--	<1	<1	<1	<1	--	--	<1	1	--	2	9	--	1	<1	1	1	--	<1	<1	3	2	23
Clomazone	--	<1	<1	<1	<1	--	--	<1	2	--	2	12	--	1	<1	1	1	--	<1	<1	5	2	29
Cyanazine	2	1	3	1	3	--	--	<1	14	--	47	73	--	36	6	5	9	--	2	<1	35	13	251
Dacthal (DCPA)	--	--	<1	<1	--	--	--	--	--	--	<1	8	--	1	<1	1	--	--	<1	<1	12	1	25
Dicamba	2	1	2	1	3	--	--	<1	10	--	11	44	--	4	2	3	6	--	2	<1	20	9	120
Diclofop methyl	<1	1	1	4	--	1	1	<1	3	1	1	25	--	1	1	14	2	--	2	3	4	<1	65
Diphenamid	2	15	48	16	113	--	--	5	2	--	85	10	--	18	5	1	--	--	22	<1	161	18	521
DSMA	--	--	--	--	--	--	--	--	--	--	32	17	--	32	3	1	--	--	<1	--	9	--	94
Eptam (EPTC)	8	4	13	6	9	--	--	1	48	--	94	447	--	48	31	42	77	--	15	3	242	118	1,206
Ethalfluralin	--	--	1	1	--	--	--	--	--	--	61	79	--	32	11	8	8	--	2	<1	36	15	254
Fluazifop	--	1	1	1	2	--	--	<1	7	--	9	46	--	4	2	3	4	--	1	<1	24	8	113
Fluometuron	--	--	--	--	--	--	--	--	--	--	80	41	--	81	7	2	--	--	1	--	22	--	234
Fomesafen	--	1	<1	--	3	--	--	<1	9	--	8	14	--	--	--	--	--	--	--	--	--	--	35
Glyphosate	2	5	7	4	15	--	--	2	61	--	83	361	--	32	16	28	41	--	10	2	153	69	891
Imaziquin	--	1	1	1	3	--	--	<1	12	--	13	58	--	4	2	4	5	--	1	<1	21	9	135
Isopropalin	<1	2	18	12	14	--	--	1	<1	--	13	<1	--	10	4	<1	--	--	16	<1	59	12	162
Linuron	--	3	3	2	10	--	--	1	36	--	51	241	--	23	7	18	17	--	5	1	73	37	528
Methazole	--	--	--	--	--	--	--	--	--	--	8	4	--	8	1	<1	--	--	<1	--	2	--	23
Metolachlor	22	15	40	9	14	16	--	6	309	4	184	846	17	152	174	66	80	--	16	58	149	140	2,133
Metribuzin	--	1	1	1	2	--	--	<1	7	--	10	93	--	5	2	8	6	--	2	<1	24	15	177

Table 12. Estimated use of selected pesticides, by hydrologic unit, for major crops grown in the Albemarle-Pamlico drainage study area, 1990--Continued

[Values are hundreds of pounds rounded to the nearest hundred pounds. Major crops are corn, cotton, grains, peanuts, potatoes, soybeans, and tobacco. The six-digit numbers in parentheses represent the first six digits of the eight-digit hydrologic unit code (table 2). The two-digit numbers at the top of each column represent the last two digits of the eight-digit hydrologic unit code (table 2). --, not applicable; <, less than]

Pesticide	Roanoke River Basin (030101__)							Chowan River Basin (030102__)					Tar-Pamlico River Basin (030201__)						Neuse River Basin (030202__)				Total
	01	02	03	04	05	06	07	01	02	03	04	05	01	02	03	04	05	06	01	02	03	04	
Herbicides[a] (Continued)																							
MSMA	--	--	--	--	--	--	--	--	--	--	121	62	--	122	10	3	--	--	2	--	33	--	353
Napropamide	<1	3	9	3	24	--	--	1	<1	--	18	<1	--	2	1	<1	--	--	3	<1	12	3	80
Naptalam	--	--	--	--	--	--	--	--	70	--	81	17	--	17	5	1	--	--	<1	<1	2	<1	195
Norflurazon	--	--	--	--	--	--	--	--	--	--	36	18	--	36	3	2	--	--	<1	--	10	--	105
Oryzalin	--	2	2	<1	8	--	--	1	27	--	23	41	--	<1	<1	<1	--	--	<1	<1	1	<1	107
Paraquat	6	6	9	3	17	--	--	2	77	--	86	257	--	24	12	17	27	--	7	1	97	45	693
Pebulate	<1	4	26	16	28	--	--	1	<1	--	24	1	--	13	5	1	--	--	22	<1	79	17	237
Pendimethalin	4	11	31	13	59	--	--	4	86	--	252	300	--	140	30	20	19	--	20	1	154	45	1,189
Sethoxydim	--	1	1	<1	2	--	--	<1	14	--	22	42	--	8	3	3	4	--	1	<1	15	6	122
Simazine	9	4	11	3	10	--	--	2	52	--	63	224	--	22	14	18	34	--	7	1	108	51	633
Trifluralin	--	2	3	3	5	--	--	1	18	--	60	234	--	47	11	19	24	--	7	1	107	44	586
Vernolate	--	2	2	2	5	--	--	1	72	--	200	189	--	98	33	17	14	--	4	1	68	25	733
Total herbicides for river basin				**1,265**						**13,782**					**4,552**					**6,211**			**25,810**
Insecticides[b]																							
Carbaryl	<1	2	14	16	7	--	--	1	101	--	292	747	--	167	63	68	81	--	31	4	372	154	2,120
Carbofuran	15	14	41	15	63	--	--	5	200	--	229	517	--	48	26	34	57	--	26	2	242	110	1,644
Chlorothalonil	--	--	--	<1	--	--	--	--	15	--	400	173	--	254	80	19	--	--	<1	<1	31	6	979
Diazinon	<1	<1	4	3	<1	--	--	<1	2	--	2	3	--	3	1	<1	--	--	4	<1	28	4	55
Disulfoton	1	7	25	21	17	--	--	2	2	--	43	22	--	12	4	1	1	--	15	<1	54	13	240
Ethoprop	3	18	108	66	118	--	--	6	141	--	258	186	--	97	36	14	17	--	91	2	468	95	1,724
Malathion	<1	4	4	2	13	--	--	2	45	--	40	85	--	3	1	2	2	--	4	<1	15	4	226
Methyl parathion	<1	<1	6	5	1	--	--	<1	<1	--	7	59	--	9	4	6	7	--	8	<1	53	18	185
Parathion	<1	<1	<1	<1	<1	--	--	<1	<1	--	7	7	--	6	1	1	1	--	1	<1	4	1	32
PCNB	--	--	--	--	--	--	--	--	--	--	33	17	--	33	3	--	--	--	<1	--	2	--	88
Phorate	--	--	1	1	--	--	--	--	87	--	159	94	--	62	20	9	7	--	2	<1	35	13	490
Total insecticides for river basin				**619**						**3,991**					**1,260**					**1,913**			**7,783**

[a]Herbicide data were calculated using application rates from Gianessi and Puffer, 1991.

[b]Insecticide data were calculated using application rates from Gianessi and Puffer, 1988.

of active ingredient (table 12). Use of nine pesticides listed in table 12 exceeded 100,000 pounds each in 1990. Alachlor was the most used herbicide on the list, followed by atrazine, metolachlor, butylate, eptam, and pendimethalin. Carbaryl was the most used insecticide, followed by ethoprop and carbofuran.

About 53 percent of this herbicide use was in the hydrologic units in the Chowan River Basin, 24 percent in the Neuse, 18 percent in the Tar-Pamlico, and 5 percent was in the Roanoke River Basin. Application rates for the herbicide and insecticide with the highest overall use—alachlor and carbaryl—were highest in the Chowan and Neuse River Basins (fig. 28). Most of the use in the Chowan River Basin was in the Meherrin and Albemarle Sound hydrologic units; in the Neuse River Basin, the largest use was in the Contentnea Creek hydrologic unit.

The 1990 pesticide use estimates are based on knowledge of pesticide use and crops grown in the study area. An estimate of use can be obtained for any particular crop when the application rate for that crop (table 13) is multiplied by the number of harvested acres (table 5). Although the application rates shown in this table represent estimates for herbicides (1991) and pesticides (1988), these values should provide fair estimates of relative use for the listed pesticides for 1990. Similar estimates can be made for other years by using appropriate crop acreage data that are published yearly in North Carolina and Virginia agricultural statistics reports.

Different combinations of pesticides are used on different crops in the study area (table 13). More of the listed herbicides are used on soybeans than on any other crop, with peanuts and corn ranked second and third, respectively. The largest number of listed insecticides was used on tobacco.

The spatial distribution of the most-used herbicides (alachlor and atrazine) and the most-used insecticide (carbaryl) by hydrologic unit in 1990 is similar throughout the study area (fig. 29). The largest use occurred in the Meherrin and Albemarle Sound hydrologic units in the Chowan River Basin, in the

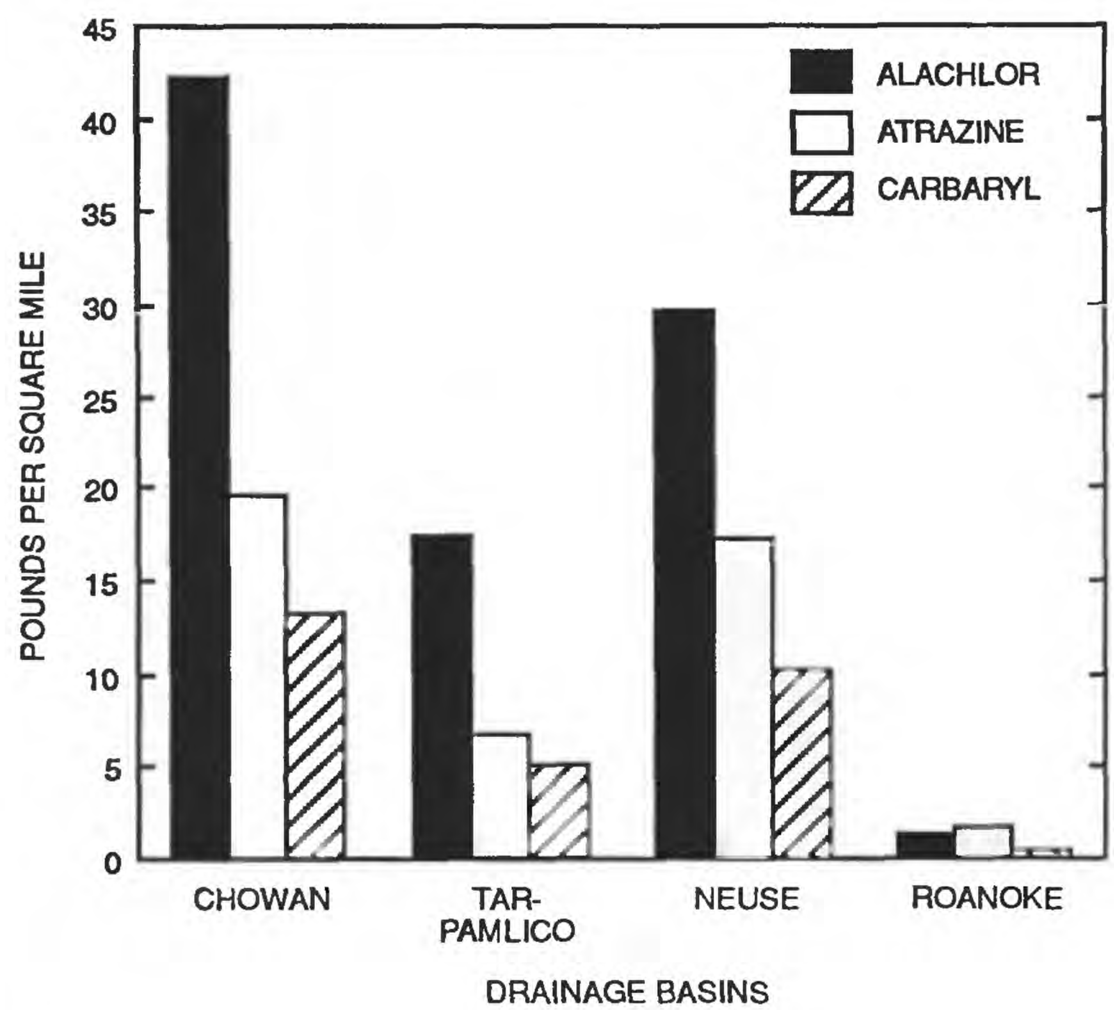


Figure 28. Usage of selected pesticides in four major basins of the Albemarle-Pamlico drainage study area, 1990.

Table 13. Herbicide and insecticide use for major crops produced in the Albemarle-Pamlico drainage study area, 1991 and 1988

[Values represent median application rate for indicated herbicide (1991 data) and insecticide (1988 data) in pounds per acre over percent of acres of specified crop treated with indicated pesticide. See table 5 for number of acres of specified crop harvested in 1990. Crop acreage data from North Carolina Department of Agriculture (1990); Virginia Department of Agriculture and Consumer Services (1990). --, not applicable]

Pesticide	Major crop										
	Corn	Soybeans	Cotton	Peanuts	Tobacco	Sorghum	Barley	Oats	Wheat	Irish potatoes	Sweet potatoes
					Herbicides[a]						
2,4-D	0.49/29	--	--	--	--	0.50/25	0.25/20	0.50/15	0.25/20	--	--
2,4-DB	--	0.03/20	--	0.25/60	--	--	--	--	--	--	--
Acifluorfen	--	0.34/9	--	0.50/20	--	--	--	--	--	--	--
Alachlor	1.66/43	1.98/39	--	3.00/70	--	1.50/30	--	--	--	--	--
Ametryn	1.30/2	--	--	--	--	--	--	--	--	--	--
Atrazine	1.16/78	--	--	--	--	1.00/60	--	--	--	--	--
Benefin	--	--	--	1.20/40	1.00/5	--	--	--	--	--	--
Bentazon	--	0.50/21	--	0.75/15	--	--	--	--	--	--	--
Bromoxynil	--	--	--	--	--	--	0.38/5	--	0.38/5	--	--
Butylate	3.43/12	--	--	--	--	--	--	--	--	--	--
Chloramben	--	--	--	0.50/1	--	--	--	--	--	--	3.00/20
Chlorimuron	--	0.03/16	--	--	--	--	--	--	--	--	--
Chlomazone	--	0.66/1	--	--	--	--	--	--	--	--	--
Cyanazine	2.00/2	--	1.00/17	--	--	--	--	--	--	--	--
Dacthal (DCPA)	--	--	--	--	--	--	--	--	--	9.00/1	9.00/3
Dicamba	0.35/7	--	--	--	--	0.25/5	0.13/20	0.12/7	0.13/20	--	--
Diclofop methyl	--	--	--	--	--	--	0.60/5	--	0.60/5	--	--
Diphenamid	--	--	--	--	2.00/15	--	--	--	--	5.00/1	4.00/50
DSMA	--	--	2.25/8	--	--	--	--	--	--	--	--
Eptam (EPTC)	4.48/8	--	--	--	--	--	--	--	--	4.00/5	--
Ethalfluralin	--	0.90/5	--	0.75/20	--	--	--	--	--	--	--
Fluazifop	--	0.25/10	--	--	--	--	--	--	--	--	0.50/25
Fluometuron	--	--	0.67/67	--	--	--	--	--	--	--	--
Fomesafen	--	0.31/12	--	--	--	--	--	--	--	--	--
Glyphosate	1.50/5	1.16/12	--	0.75/2	--	0.50/2	--	--	--	1.00/1	1.00/2
Imaziquin	--	0.11/26	--	--	--	--	--	--	--	--	--
Isopropalin	--	--	--	--	1.00/24	--	--	--	--	--	--
Linuron	--	0.97/10	1.25/4	--	--	--	--	--	--	1.50/35	--
Methazole	--	--	0.25/17	--	--	--	--	--	--	--	--
Metolachlor	1.51/18	1.51/8	--	2.00/20	--	1.50/30	--	--	--	2.50/45	--
Metribuzin	--	0.41/8	--	--	--	--	--	--	--	0.75/55	--

Table 13. Herbicide and insecticide use for major crops produced in the Albemarle-Pamlico drainage study area, 1991 and 1988--Continued

[**Values represent median application rate for indicated herbicide (1991 data) and insecticide (1988 data) in pounds per acre over percent of acres of specified crop treated with indicated pesticide.** See table 5 for number of acres of specified crop harvested in 1990. Crop acreage data from North Carolina Department of Agriculture (1990); Virginia Department of Agriculture and Consumer Services (1990). --, not applicable]

Pesticide	Major crop										
	Corn	Soybeans	Cotton	Peanuts	Tobacco	Sorghum	Barley	Oats	Wheat	Irish potatoes	Sweet potatoes
Herbicides[a] (Continued)											
MSMA	--	--	4.00/17	--	--	--	--	--	--	--	--
Napropamide	--	--	--	--	1.00/5	--	--	--	--	--	--
Naptalam	--	--	--	2.00/5	--	--	--	--	--	--	--
Norflurazon	--	--	0.80/25	--	--	--	--	--	--	--	--
Oryzalin	--	0.75/15	--	--	0.50/1	--	--	--	--	--	--
Paraquat	0.50/16	0.38/15	0.07/4	0.12/20	--	0.25/15	0.38/5	--	0.38/5	0.50/5	0.50/2
Pebulate	--	--	--	--	4.00/8	--	--	--	--	--	--
Pendimethalin	1.25/10	0.71/15	0.75/54	1.00/25	0.75/28	--	--	--	--	1.00/1	--
Sethoxydim	--	0.20/10	--	0.19/15	--	--	--	--	--	0.30/20	--
Simazine	2.00/8	--	--	--	--	--	--	--	--	--	--
Trifluralin	--	0.85/16	0.75/21	--	--	--	--	--	--	--	--
Vernolate	--	2.62/3	--	2.00/25	--	--	--	--	--	--	--
Insecticides[b]											
Carbaryl	1.00/3	1.13/36	--	1.20/48	2.00/5	1.80/2	--	--	1.60/2	3.50/12	2.00/10
Carbofuran	0.86/24	1.05/7	--	1.10/1	4.40/5	--	--	--	--	1.60/50	--
Chlorothalonil	--	--	--	2.70/54	--	--	--	--	--	5.00/10	--
Diazinon	1.00/1	--	--	--	0.50/12	--	--	--	--	--	3.00/1
Disulfoton	--	--	--	1.50/1	2.20/9	--	1.00/1	1.00/1	0.80/1	3.40/5	--
Ethoprop	1.50/4	1.18/2	--	2.00/8	6.30/20	--	--	--	--	--	3.70/60
Malathion	--	1.10/17	--	--	1.20/1	--	1.20/5	1.20/5	0.69/5	--	--
Methamidophos	--	--	--	--	--	--	--	--	--	1.60/2	--
Methyl parathion	--	0.69/6	--	--	3.80/2	--	--	--	--	--	--
Parathion	--	--	0.30/11	--	0.70/1	--	1.80/1	0.50/1	0.96/1	--	--
PCNB	--	--	0.77/24	--	--	--	--	--	--	--	--
Phorate	0.80/1	1.04/3	0.30/1	1.40/23	--	--	--	--	--	3.00/1	--

[a]Herbicide data were calculated using application rates from Gianessi and Puffer, 1991.
[b]Insecticide data were calculated using application rates from Gianessi and Puffer, 1988.

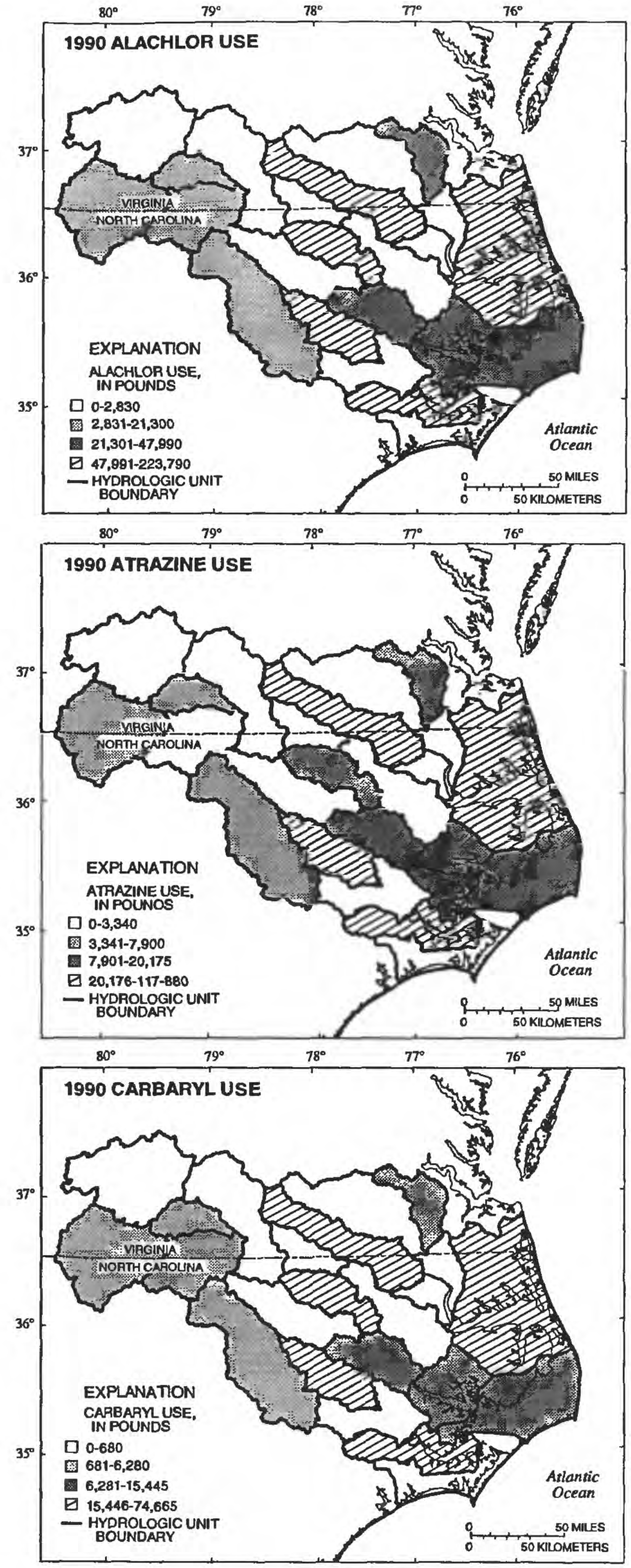


Figure 29. Distribution of alachlor, atrazine, and carbaryl use, by hydrologic unit in the Albemarle-Pamlico drainage study area, 1990. The four divisions shown on each map represent quartiles of pesticide use across the 22 hydrologic units. (Herbicide data were calculated using applciation rates from Gianessi and Puffer, 1991; insecticide data were calculated using application rates from Gianessi and Puffer, 1988; crop acreage data are from North Carolina Department of Agriculture, 1990, and Virginia Department of Agriculture and Consumer Services, 1990b). (See table 2 and fig. 3 for hydrologic unit names and locations.)

Fishing Creek hydrologic unit in the Tar-Pamlico River Basin, and in the Contentnea and Lower Neuse hydrologic units of the Neuse River Basin.

Pesticide water solubility and half-life, the infiltration-drainage characteristics of soils (fig. 6), the time of pesticide application, and crop-specific pesticide-use practices can be used to identify hydrologic units whose waters might have relatively high concentrations of certain pesticides. For example, one might expect relatively high concentrations of atrazine and(or) its metabolites to be present in surface water during the spring (heavy-use period) in the Albemarle Sound hydrologic unit. This is because atrazine is highly soluble, and the greatest use in the study area was in the Albemarle Sound hydrologic unit, which tends to have poorly drained soils.

Sediment

Suspended sediment affects water quality and aquatic life in streams. Sediment in the water column reduces light penetration, eliminating some aquatic organisms from affected stream reaches. Excessive accumulation of sediments on the stream bottom can smother benthic organisms, which serve as the source of food for fish, and cover spawning beds. This can degrade the suitability for game fish and leave a population of more resistant fish, such as gar, sucker, and carp (U.S. Department of Agriculture, 1982). Reservoirs, locks, streams, and navigation channels can be clogged with sediment resulting in the need for channelization of streams and dredging of lakes to restore their former depth and storage volume (Weaver, 1994).

Suspended sediment is frequently cited as a cause of stream degradation in the study area. In North Carolina, for example, sediment accounts for over one-half of the degraded stream miles (North Carolina Department of Environment, Health, and Natural Resources, 1990). The U.S. Department of Agriculture (1982) singled out the Piedmont areas of the Tar-Pamlico and Neuse River Basins as the most severely eroded areas in North Carolina. The Piedmont area of the Roanoke River Basin is also susceptible to erosion and high suspended-sediment concentrations.

Sediment is also a problem as it relates to the distribution, transport, and availability of some nutrients and contaminants, such as organochlorine pesticides. It is widely recognized that, in many streams, lakes, and estuaries, suspended sediment and the top few centimeters of bed material contain many times the amount of certain nutrients, trace metals, and organic compounds than are dissolved in the water column. When transported by streamflow, sediment serves as a vehicle for the transport of these sorbed constituents. Many of these constituents, depending on other chemical and physical factors, can return to solution in the water column or enter the food web.

Sources of sediment in the Piedmont Province of North Carolina have been studied by Simmons (1993). The mean suspended-sediment yields for selected forested, rural-agricultural, and urban basins in the North Carolina Piedmont indicate that sediment yields from rural and urban basins are about 6 and 11 times greater, respectively, than yields from forested basins, which are assumed to represent natural, undisturbed conditions (fig. 30). In small urban basins in the Virginia and Maryland Piedmont, during the late 1960's and early 1970's when construction and house-building activities were intense, sediment yields were reported as high as 200 times those from forested basins (Wolman and Schick, 1967; Guy, 1970; Yorke and Davis, 1972).

The mean annual suspended-sediment yield for selected medium-sized (less than 400 mi^2) forested, rural-agricultural, and urban basins in the Tar-Pamlico, Neuse, and southern part of the Roanoke River Basins were about 50 $tons/mi^2$, 250 $tons/mi^2$, and 550 $tons/mi^2$, respectively (fig. 30). On a regional scale, yields ranged from 250 $tons/mi^2$ for four basins in the southern part of the Roanoke River Basin to 12 $tons/mi^2$ in a basin in the Coastal Plain part of the Tar-Pamlico River Basin (fig. 31). In addition, the average annual suspended-sediment yield is about 10 $tons/mi^2$ for the 90-percent flow duration (low-flow conditions) in all of the basins for which data are available; the yield for the 0.1-percent flow duration (high-flow conditions) ranges from about 8 times that for low flow in the western part of the area to only slightly more than that for low flow in the eastern part of the area. For comparison purposes, the largest average annual suspended-sediment yields reported by Simmons (1993) were 300 $tons/mi^2$ from the Piedmont Province area of the Upper Pee Dee River Basin, which is west of the Albemarle-Pamlico drainage study area.

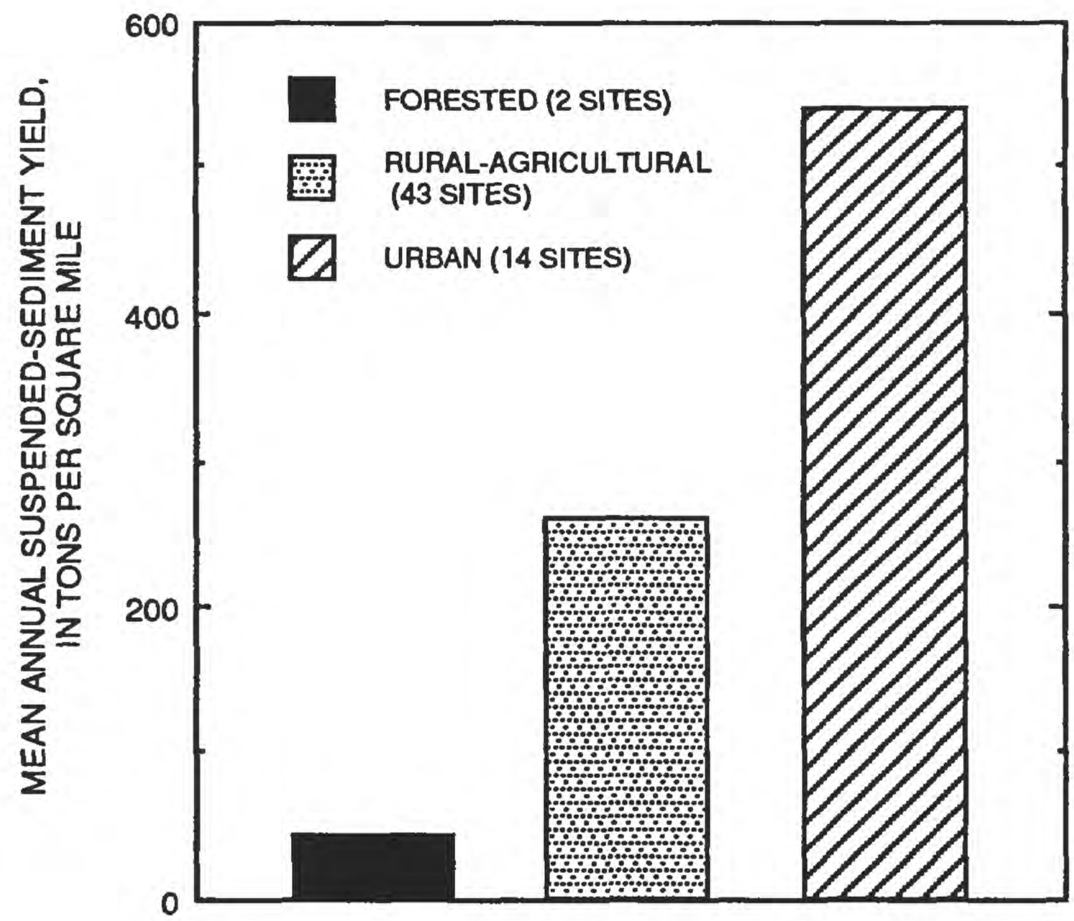


Figure 30. Mean annual suspended-sediment yield for selected pristine forested, rural-agricultural, and urban basins in the North Carolina Piedmont Province, 1970-79 (Simmons, 1993).

CLASSIFICATION OF STUDY-UNIT LAND AREAS ACCORDING TO NATURAL AND CULTURAL FEATURES

Spatial relations between the natural and cultural features of the Albemarle-Pamlico drainage study area are important. For example, the land area within a hydrologic unit can be described in terms of population density or predominant land use or soil type. Many of these features, including land use, hydrogeology, and soil hydrologic group, were digitized from maps and entered into a geographic information system (GIS) data base. In order to develop a better understanding of a potential relation between land use, hydrogeology, and soil hydrologic groups, digital maps of these features for the Albemarle-Pamlico study area, and associated data, were superimposed and the resulting information classified into land areas with homogeneous land-use, soil, and hydrogeologic characteristics. These homogeneous categories are called *strata*. Methods used to carry out this classification are described in the Appendix.

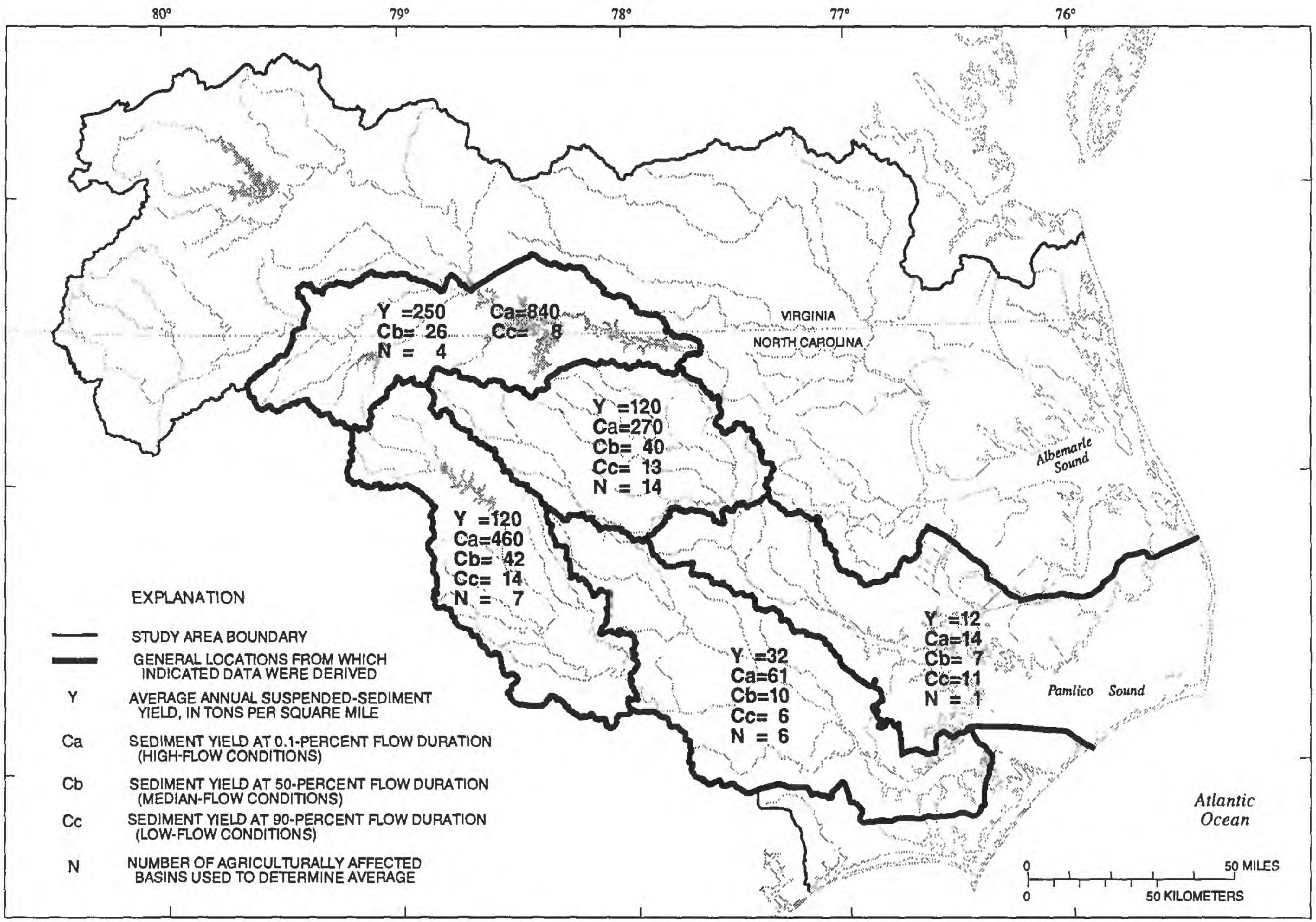


Figure 31. Suspended-sediment characteristics for some predominately rural basins affected by agriculture in the Albemarle-Pamlico drainage study area (Simmons, 1993).

This procedure resulted in the designation of 12 distinct strata (A-K and M) that potentially influence water quality in the study area. An additional stratum (L), "nonstrata area," was designated for parcels too small to classify. The strata are defined below according to land use (fig. 7), hydrogeologic zone (fig. 5), and soil hydrologic group (fig. 6; table 3).

Many strata are present in each hydrologic unit (table 14). A comparison of stratum L to the Total Area column indicates that, on average, about half of the land area in the Chowan (4,327 mi^2), Tar-Pamlico (4,177 mi^2), and Neuse River (2,488 mi^2) Basins, and about 40 percent in the Roanoke River Basin (3,810 mi^2) are classified in the nonstrata category. The remainder of the Chowan, Tar-Pamlico, and Neuse River Basins are dominated by Coastal Plain agriculture (2,465 mi^2 from strata A and B), Coastal Plain forest (3,135 mi^2 from stratum J), and wetlands (2,047 mi^2 from stratum M). The remaining land area in the Roanoke River Basin is predominantly Piedmont agriculture (1,715 mi^2 from strata C, D, E, and F) and forest (3,248 mi^2 from strata I and K). As previously mentioned in the section, "Cultural Factors," the small total area of stratum H does not reflect its significance with respect to potential influence on water quality in the area.

Strata	Land use (fig. 7)	Hydrogeologic zone (fig. 5)	Soil hydrologic group (fig. 6)	Explanation
A	Agriculture	Coastal Plain	Poorly drained	All parcels coded as agricultural, located in the inner or outer Coastal Plain hydrogeologic zone, and contain soil hydrologic groups other than A or B.
B	Agriculture	Coastal Plain	Well drained	All parcels coded as agricultural, located in the inner or outer Coastal Plain hydrogeologic zone, and contain soil hydrologic groups of A or B.
C	Agriculture	Granitic (Piedmont)	Poorly drained	All parcels coded as agricultural, located in the Granitic hydrogeologic zone, and contain a hydrologic soil group of either C, C/D, or B/C.
D	Agriculture	Granitic (Piedmont)	Well drained	All parcels coded as agricultural, located in the Granitic hydrogeologic zone, and contain a hydrologic soil group B.
E	Agriculture	Slate Belt (Piedmont)	All soil groups	All parcels coded as agricultural and located in the Slate Belt hydrogeologic zone.
F	Agriculture	Triassic Basin (Piedmont)	All soil groups	All parcels coded as agricultural and located in the Triassic Basin hydrogeologic zone.
G	Agriculture	Coastal Plain Carbonate	All soil groups	All parcels coded as agricultural and located in the Coastal Plain Carbonate hydrogeologic zone.
H	Developed	All hydro-geologic zones	All soil groups	All land parcels coded as developed.
I	Forest	Granitic (Piedmont)	All soil groups	All land parcels coded as forested and located in the Granitic hydrogeologic zone.
J	Forest	Coastal Plain	All soil groups	All land parcels coded as forested and located in either inner or outer Coastal Plain hydrogeologic zones.
K	Forest	Slate Belt (Piedmont)	All soil groups	Parcels coded as forested and located in the Slate Belt hydrogeologic zone.
L	Nonstrata area	--	--	Parcels with an area less than 1 square mile.
M	Wetlands	All hydro-geologic zones	All soil groups	All land parcels coded as wetlands.

Table 14. Area of strata, by hydrologic unit in the Albemarle-Pamlico drainage study area

[Values represent area in square miles rounded to the nearest square mile. STRATA: A, Agriculture/Coastal Plain/poorly drained; B, Agriculture/Coastal Plain/well drained; C, Agriculture/Granitic (Piedmont)/poorly drained; D, Agriculture/Granitic (Piedmont)/well drained; E, Agriculture/Slate Belt (Piedmont); F, Agriculture/Triassic Basin (Piedmont); G, Agriculture/Coastal Plain Carbonate; H, Developed; I, Forest/Granitic (Piedmont); J, Forest/Coastal Plain; K, Forest/Slate Belt (Piedmont); L, Nonstrata area; M, Wetlands; --, not applicable]

Hydrologic unit (fig. 3)		Strata (area in square milea)													Total area[a] (in square miles)
Name	Code	A	B	C	D	E	F	G	H	I	J	K	L	M	
Roanoke River Basin															
Upper Roanoke River	03010101	--	--	51	372	--	--	--	44	736	--	--	977	--	2,180
Middle Roanoke River	03010102	--	--	34	179	144	7	--	3	389	--	250	744	--	1,750
Upper Dan River	03010103	--	--	29	241	--	51	--	32	1,033	--	11	643	--	2,040
Lower Dan River	03010104	--	--	52	124	112	1	--	16	237	--	179	519	--	1,240
Banister River	03010105	--	--	8	180	--	18	--	--	184	--	1	199	--	590
Roanoke Rapids	03010106	--	--	--	67	42	--	--	--	155	--	67	258	1	590
Lower Roanoke River	03010107	113	84	--	--	3	--	--	6	--	385	6	470	223	1,290
Total		113	84	174	1,163	301	77	--	101	2,734	385	514	3,810	224	9,680
Chowan River Basin															
Nottoway River	03010201	23	43	1	99	1	--	--	5	399	359	6	717	47	1,700
Blackwater River	03010202	62	8	--	--	--	--	--	2	--	256	--	394	22	744
Chowan River	03010203	96	12	--	--	--	--	--	1	--	220	--	460	68	857
Meherrin River	03010204	56	92	--	70	60	--	--	2	282	172	176	610	80	1,600
Albemarle Sound	03010205	416	26	--	--	--	--	--	23	--	336	--	2,146	803	3,750
Total		653	181	1	169	61	--	--	33	681	1,343	182	4,327	1,020	8,651
Tar-Pamlico River Basin															
Upper Tar River	03020101	14	44	--	163	100	6	--	10	226	15	138	523	41	1,280
Fishing Creek	03020102	36	63	--	35	8	--	--	2	187	24	47	427	47	876
Lower Tar River	03020103	155	105	--	--	--	--	--	6	--	247	--	373	81	967
Pamlico River	03020104	237	26	--	--	--	--	--	5	--	313	--	443	116	1,140
Pamlico Sound	03020105	71	10	--	--	--	--	--	2	--	75	--	1,639	263	2,060
Bogue and Core Sounds	03020106	--	1	--	--	--	--	15	7	--	148	--	772	207	1,150
Total		513	249	--	198	108	6	15	32	413	822	185	4,177	755	7,473
Neuse River Basin															
Upper Neuse River	03020201	102	237	--	58	136	26	2	45	284	165	222	1,092	11	2,380
Middle Neuse River	03020202	116	104	--	--	--	--	40	12	--	306	--	417	85	1,080
Contentnea Creek	03020203	65	215	--	6	29	--	--	6	14	96	46	469	64	1,010
Lower Neuse River	03020204	13	17	--	--	--	--	56	9	--	403	--	510	112	1,120
Total		296	573	--	64	165	26	98	72	298	970	268	2,488	272	5,590

[a]Total area column sums to 31,394 square miles. This value includes almost 3,200 square miles of estuaries and sounds in the eastern part of the study area (see table 4). The area of these water bodies constitutes the difference between the total area reported in the introductory section of this report and that shown here.

SUMMARY

The Albemarle-Pamlico drainage study unit is among the first 20 study units in the full-scale National Water-Quality Assessment Program of the U.S. Geological Survey. The quality of water resources in the Albemarle-Pamlico drainage study area is influenced by the environmental setting—an interrelated set of natural, cultural, and hydrologic factors. Natural factors include physiography, geology, and soils; cultural factors include land use and population distribution; and hydrologic factors include climate and the amount and distribution of surface-water runoff and ground-water discharge.

The physiography, geology, and soils form the container over and through which surface and ground water flows. The kind and amount of rock, soil, and the land-surface slope influence the kind and amount of mineral matter in water. In the mountains where slopes are steep, surface and ground water move fast and have less opportunity to dissolve rock and soil; consequently, the water generally contains very little dissolved mineral matter. In the Piedmont and Coastal Plain, slopes are flatter and water moves more slowly; consequently, surface water generally has two to three times the mineral content of surface and ground waters in the mountains.

Land use and land cover, population distribution, and manmade reservoirs have significant influences on water quality in the area. In general, the study area is dominated by a patchwork of forested (50 percent of the area) and agricultural (more than 30 percent) land, with large tracts of wetlands (about 15 percent) in the eastern Coastal Plain. Less than 5 percent of the overall basin area contains developed land. The agricultural sector is devoted to growing corn, soybeans, cotton, peanuts, tobacco, grains, and potatoes, and raising chickens, turkeys, hogs, and cattle. Agricultural and developed areas have the greatest potential to influence water quality because these land uses introduce the greatest amounts of nutrients, sediments, and pesticides into the hydrologic system. About 3 million people live in the Albemarle-Pamlico drainage area, with urban areas located in the Upper Roanoke and Upper Neuse River Basins. Wetlands and manmade reservoirs have a beneficial effect on water quality because they slow water flow, thus allowing the deposition of suspended sediments and their sorbed compounds and providing an opportunity for aquatic vegetation to use mineral matter dissolved in the water.

Characteristics of climate, topography, geology, and soil influence water quality and control the amount and routing of freshwater resources in the study area. Annual precipitation (1961-90) ranged from 36 to 52 in. in the mountains, from 40 to 44 in. in the Piedmont, and from 44 in. at the Piedmont/Coastal Plain boundary to 52 in. near the coast. Evapotranspiration consumes about 30 in. (about 55 percent) of average annual precipitation in the mountains, where the average annual temperature is about 52 °F. Evapotranspiration consumes about 36 in. (about 70 percent) of average annual precipitation in the southeastern part of the area, where the average annual temperature is about 62 °F. The remaining 12 to 18 in. of precipitation flows from the area in streams as runoff.

On average, more than half of the water that reaches streams first infiltrates the land surface, percolates through soil to the water table, and moves through the aquifers as ground water before it is discharged to the streams. Thus, the quality of ground water has substantial influence on surface-water quality. Major aquifers in the Valley and Ridge, Blue Ridge, and Piedmont Provinces are consolidated, fractured rocks; in the Coastal Plain Province, they are primarily unconsolidated sands with some consolidated to partly consolidated limestone and sandy limestone. Fresh ground water in the aquifers generally has median concentrations of dissolved solids, nitrate (as nitrogen), fluoride, iron (except in the shallow aquifers), and chloride that are generally below the maximum contaminant level for public water supply set by the U.S. Environmental Protection Agency.

Water-quality issues in the study area are associated with nutrients, pesticides, and suspended sediments. Point- and nonpoint-source discharges can lead to nutrient enrichment and accelerated eutrophication in surface water and high concentrations of nitrate-nitrogen in ground water. Pesticides in water is an issue because, by design, they are toxic and can affect some nontarget organisms. Sediment can harm aquatic life and transports nutrients and pesticides.

Approximately 250 permitted point sources discharged about 410 Mgal/d of treated effluent throughout the study area in 1990, along with 5,800 tons of nitrogen and 1,800 tons of phosphorus. Deposition of nitrogen from the atmosphere was 50,500 tons during 1990. Crop-related nutrients and manure produced by livestock are also important

potential nonpoint sources of nitrogen and phosphorus. A total of about 153,000 tons of nitrogen and 10,500 tons of phosphorus were used as fertilizer or fixed by leguminous crops in 1990. About 43,500 tons of nitrogen and 12,200 tons of phosphorus were produced as animal wastes in the area in 1987.

About 2.5 million pounds of selected herbicides and 800,000 pounds of selected insecticides were used in the study area in 1990. Alachlor, atrazine, metolachlor, butylate, eptam, pendimethalin, carbaryl, ethoprop, and carbofuran were each used at annual rates exceeding 100,000 pounds. Alachlor and atrazine were the most used herbicides—about 670,000 and 330,000 pounds per year, respectively—and carbaryl was the most used insecticide—about 20,000 pounds per year.

Sediment data (1970-79) for North Carolina indicate that mean annual suspended-sediment yields for selected forested, rural-agricultural, and urban basins were about 50 tons/mi^2, 250 tons/mi^2, and 550 tons/mi^2, respectively. Across the study area, yields ranged from 250 tons/mi^2 in the southern part of the Roanoke River Basin to about 12 tons/mi^2 in the eastern part of the Coastal Plain in the Tar-Pamlico River Basin.

To facilitate study of the relation between the environmental-setting factors and water-quality issues, all land in the study area was classified, using a geographic information system, into 12 strata. Each stratum represents homogeneous combinations of natural, cultural, and hydrologic factors. The classification reveals large areas of poorly drained agricultural lands and wetlands in the Coastal Plain that can have significant general influences on water quality. Large areas of agricultural and forested land and smaller areas of developed land can exert a significant influence on Piedmont water quality due to associated point-source discharges.

Water quality in the Albemarle-Pamlico drainage study area is influenced by natural, cultural, and hydrologic factors. These factors define the "environmental setting" of the study area and influence the occurrence and spatial distribution of sediments, nutrients, and pesticides. Subsequent investigations undertaken as part of the Albemarle-Pamlico study effort will generate additional data and analysis to meet the overall study objectives of NAWQA.

SELECTED REFERENCES

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Baier, W.G., and Cohn, T.A., 1993, Trend analysis of sulfate, nitrate, and pH data collected at National Atmospheric Deposition Program/National Trends Network stations between 1980 and 1991: U.S. Geological Survey Open-File Report 93-56, 13 p.

Barker, J.C., 1991, Considerations in developing a waste management plan: North Carolina State University, Cooperative Extension Service Waste Management Institute, June 13, 1991.

Brown, P.M., ed., 1985, Geologic map of North Carolina: North Carolina Department of Natural Resources and Community Development, Division of Land Resources, Geological Survey Map, scale 1:500,000, 1 sheet.

Caldwell, W.S., 1992, Selected water-quality and biological characteristics of streams in some forested basins of North Carolina, 1985-88: U.S. Geological Survey Water-Resources Investigations Report 92-4129, 114 p.

Coble, R.W., Giese, G.L., and Eimers, J.L., 1985, North Carolina ground-water resources, *in* National water summary 1984—Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 329-334.

College of Agriculture and Life Sciences, 1991, Chapter 10: Fertilizer use, *in* 1991 North Carolina Agricultural Chemicals Manual: Raleigh, North Carolina State University, College of Agriculture and Life Sciences, 345 p.

Connell, D.W., and Miller, G.J., 1984, Chemistry and ecotoxicology of pollution: New York, John Wiley and Sons, 444 p.

Cooper, A.W., McCracken, R J., and Aull, L.E., 1975, Vegetation and soil resources, *in* North Carolina Atlas: Chapel Hill, University of North Carolina Press, 331 p.

Craig, N., and Kuenzler, E.J., 1983, Land use, nutrient yield, and eutrophication in the Chowan River Basin: Raleigh, The University of North Carolina Water Resources Research Institute, Report No. 205.

Daniel, C.C., III, 1989, Statistical analysis relating well yield to construction practices and siting of wells in the Piedmont and Blue Ridge Provinces of North Carolina: U.S. Geological Survey Water-Supply Paper 2341-A, 27 p.

Dodd, R.C., McMahon, G., and Stichter, S., 1992, Watershed planning in the Albemarle-Pamlico estuarine system, Report 1: Annual average nutrient budgets: Research Triangle Park, N.C., Center for Environmental Analysis, Research Triangle Institute, August 1992, 31 p.

Fenneman, N.M., 1938, Physiography of Eastern United States: New York, McGraw-Hill, 714 p.

Fisher, D.C., Graso, J., Mathew, T., and Oppenheimer, U., 1988, Polluted coastal waters: The role of acid rain: Oakland, Calif., Environmental Defense Fund, April 1988, 73 p.

Gianessi, L.P., and Puffer, C.A., 1988, Use of selected pesticides for agricultural crop production in the United States, 1982-85: Washington, D.C., Resources for the Future, 490 p.

_____1991, Herbicide use in the United States: Washington, D.C., Resources for the Future, 124 p.

Giese, G.L., Eimers, J.L., and Coble R.W., 1991, Simulation of ground-water flow in the coastal plain aquifer system of North Carolina: U.S. Geological Survey Open-File Report 90-372, 178 p.

Giese, G.L., Mason, R.R., and Strickland, A.G., 1988, North Carolina ground-water quality, *in* National water summary 1986—Hydrologic events and ground-water quality: U.S. Geological Survey Water-Supply Paper 2325, p. 393-400.

Gilliom, R.J., Alexander, R.B., and Smith, R.A., 1985, Pesticides in the nation's rivers, 1975-1980, and implications for future monitoring: U.S. Geological Survey Water-Supply Paper 2271, 23 p.

Guy, H.P., 1970, Sediment problems in urban areas: U.S. Geological Survey Circular 601-E, 8 p.

Harned, D.A., 1994, Effects of agricultural land-management practices on water quality in northeastern Guilford County, North Carolina, 1985-90: U.S. Geological Survey Open-File Report 94-60, 114 p.

Harned, D.A., and Davenport, M.S., 1990, Water-quality trends and basin activities and characteristics for the Albemarle-Pamlico estuarine system, North Carolina and Virginia: U.S. Geological Survey Open-File Report 90-398, 164 p.

Harned, D.A., McMahon, G., Spruill, T.B., and Woodside, M.D., in press, Water-quality assessment of the Albemarle-Pamlico drainage basin, North Carolina and Virginia—Summary of water-quality data for suspended sediment, nutrients, and pesticides: U.S. Geological Survey Open-File Report 95-191.

Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hill, C.L., Rinehardt, J.F., and Dillard, T.E., 1985, Water resources data, North Carolina, water year 1985: U.S. Geological Survey Water-Data Report NC-85-1, 550 p.

Hitt, K.J., 1990, Summary of selected characteristics of larger reservoirs of the United States and Puerto Rico (computerized file for Ruddy, B.C., and Hitt, K.J., U.S. Geological Survey Open-File Report 90-163).

Johnston, C.A., 1991, Sediment and nutrient retention by freshwater wetlands: Effects on surface water quality: Critical Reviews in Environmental Control, v. 21, p. 491-565.

Khorram, S., Cheshire, H., Siderelis, K., and Nagy, Z., 1991, Mapping and GIS implementation of land use and land cover categories for the Albemarle-Pamlico drainage basin: Raleigh, N.C., Computer Graphics Center, North Carolina State University and the Center for Geographic Information and Analysis, North Carolina Department of Environment, Health, and Natural Resources, 53 p.

Leahy, P.P., Rosenshein, J.S., and Knopman, D.S., 1990, Implementation plan for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 90-174, 10 p.

LeGrand, H.E., 1954, Geology and ground water in the Statesville area, North Carolina: North Carolina Department of Conservation and Development, Bulletin 68, 68 p.

LeGrand, H.E., and Mundorff, M.J., 1952, Geology and ground water in the Charlotte area, North Carolina: North Carolina Department of Conservation and Development, Bulletin 63, 88 p.

Madison, R.J., and Brunett, J.O., 1985, Overview of the occurrence of nitrate in ground water of the United States, *in* National water summary 1984—Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 93-105.

Mason, R.R., and Jackson, N.M., Jr., 1986, North Carolina surface-water resources, *in* National water summary 1985—Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, p. 355-360.

Meng, A.A., III, Harsh, J.F., and Kull, T.K., 1985, Virginia ground-water resources, *in* National water summary 1984—Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 427-432.

Mitchell, W.B., Guptill, S.C., Anderson, K.E., Fegras, R.G., and Hallam, C.A., 1977, GIRAS—A geographic information retrieval and analysis system for handling land use and land cover data: U.S. Geological Survey Professional Paper 1059, 16 p.

Mixon, R.B., Berquist, C.R., Newell, W.L., Johnson, G.H., Powars, D.S., Schlinder, J.S., and Rader, E.K., 1989, Geologic map and generalized cross sections of the Coastal Plain and adjacent parts of the Piedmont, Virginia: U.S. Geological Survey, Miscellaneous Investigations Series, Map I-2033, 1:250,000.

Musgrave, G.W., and Holtan, H.N., 1964, Infiltration, *in* Te Chow, Ven, ed., Handbook of applied hydrology—A compendium of water-resources technology: New York, McGraw-Hill Book Co., Section 12, p. 12-26.

National Atmospheric Deposition Program (NADP)/National Trends Network (NTN) Coordination Office, 1983, NADP/NTN annual data summary—Precipitation chemistry in the United States, 1985: Fort Collins, Colorado State University, National Resources Ecology Laboratory, 130 p.

_____1987, NADP/NTN annual data summary—Precipitation chemistry in the United States, 1985: Fort Collins, Colorado State University, National Resources Ecology Laboratory, 340 p.

_____1991, NADP/NTN annual data summary—Precipitation chemistry in the United States, 1990: Fort Collins, Colorado State University, National Resources Ecology Laboratory, 475 p.

National Oceanic and Atmospheric Administration, 1975-85, Landsat data users notes: Sioux Falls, S.D., Landsat Customer Services.

North Carolina Department of Agriculture, 1990, North Carolina agricultural statistics—1990: Agricultural Statistics Division, Report No. 168, 76 p.

North Carolina Department of Environment, Health, and Natural Resources, 1990, Water quality progress in North Carolina, 1988-1989: Division of Environmental Management, Report No. 90-07 (305B Report), 303 p.

_____1992, Discharge monitoring report data, 1986-1992, selected parameters, digital files: Division of Environmental Management.

North Carolina Department of Natural Resources and Community Development, 1985a, Animal operations and water quality in North Carolina: Division of Environmental Management, Report No. 86-05.

_____1985b, Geologic map of North Carolina, Division of Land Resources, scale 1:500,000.

_____1988, Water quality progress in North Carolina, 1986-1987: Division of Environmental Management, Report No. 88-02 (305B Report), 312 p.

Omernik, J.M., 1986, Ecoregions of the United States: U.S. Environmental Protection Agency map, scale about 1:5,000,000, 1 sheet.

Organization for Economic Cooperation and Development, 1982, Eutrophication of waters—Monitoring, assessment and control: Paris, France, Organization for Economic Cooperation and Development Publications and Information Center, 154 p.

Paerl, H.W., 1987, Dynamics of blue-green algal blooms in the lower Neuse River, North Carolina—Causitive factors and potential controls: Raleigh, The University of North Carolina Water Resources Research Institute, Report No. UNC-WRRI-87-229, 164 p.

Pettyjohn, W.A., and Henning, R., 1979, Preliminary estimate of ground-water recharge rates, related to streamflow and water quality in Ohio: Columbus, Ohio State University, Water Resources Center, Project Completion Report No. 552, 323 p.

Powell, J.D., and Hamilton, P.A., 1988, Virginia ground-water quality, *in* National water summary 1986—Hydrologic events and ground-water quality: U.S. Geological Survey Water-Supply Paper 2325, p. 509-514.

Prugh, B.J., Easton, F.J., and Belval, D.L., 1991, Water resources data, Virginia, water year 1990: U.S. Geological Survey Water-Data Report VA-90-1, 407 p.

Prugh, B.J., Easton, F.J., and Lynch, D.D., 1986, Water resources data, Virginia, water year 1985: U.S. Geological Survey Water-Data Report VA-85-1, 410 p.

Prugh, B.J., and Scott, W.B., 1986, Virginia surface-water resources, *in* National water summary 1985—Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, p. 467-472.

Ragland, B.C., Barker, R.G., Eddins, W.H., and Rinehardt, J.F., 1991, Water resources data, North Carolina, water year 1990: U.S. Geological Survey Water-Data Report NC-90-1, 389 p.

Rutledge, A.T., 1991, Methods of using streamflow records for estimating total and effective recharge in the Appalachian Valley and Ridge, Piedmont, and Blue Ridge physiographic provinces, in aquifers of the Southern and Eastern States: American Water Resources Association Monograph Series No. 17, p. 59-73.

_____1993, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records: U.S. Geological Survey Water-Resources Investigations Report 93-4121, 45 p.

Rutledge, A.T., and Daniel, C.C., III, 1994, Testing an automated method to estimate ground-water recharge from streamflow records, Ground Water, v. 32, no. 2, p. 180-189.

Seaber, P.R., Kapinos, F.P., and Knapp, G.L., 1987, Hydrologic unit maps: U.S. Geological Survey Water-Supply Paper 2294, 63 p.

Selby, M.J., 1985, Earth's changing surface, an introduction to geomorphology: Oxford, Mass., Clarendon Press, 607 p.

Simmons, C.E., 1993, Sediment characteristics of North Carolina streams, 1970-79: U.S. Geological Survey Water-Supply Paper 2364, 84 p.

Simmons, C.E., and Heath, R.C., 1979, Water-quality characteristics of streams in forested and rural areas of North Carolina: U.S. Geological Survey Water-Resources Investigations 79-108, 49 p.

Sisterson, D.L., 1990, Appendix A: Detailed SO_x-S and NO_x-N mass budgets for the United States and Canada, *in* Venkatram, A., McNaughton, D., Karamchandani, P.K., Shannon, J., Sisterson, D.L., and Fernau, M., Acidic deposition: State of science and technology, Report 8, Relationships between atmospheric emissions and deposition/air quality, National Acid Precipitation Assessment Program, p. 8A-1—8A-10.

Stanley, D.W., 1988, Water quality in the Pamlico River estuary, 1967-86—A report to Texasgulf Chemicals Company: Greenville, N.C., East Carolina University, Institute for Coastal and Marine Resources, ICMR Technical Report 88-01, 199 p.

Tant, P.L., Byrd, H.J., and Horton, R.E., 1974, General soil map of North Carolina: U.S. Department of Agriculture, Soil Conservation Service map, scale 1:1,000,000, 1 sheet.

U.S. Bureau of Census, 1970, Census of population and housing, 1970: Washington, D.C., U.S. Department of Commerce.

_____1980, Census of population and housing, 1980: Washington, D.C., U.S. Department of Commerce.

_____1990a, Census of population and housing, 1990: Washington, D.C., U.S. Department of Commerce.

_____1990b, Census of agriculture, 1987, Part 1—Agricultural atlas of the United States: U.S. Bureau of Census Subject Series, v. 2, 199 p.

U.S. Department of Agriculture, 1982, Upper Tar River erosion study report, phase V: Soil Conservation Service, U.S. Department of Agriculture Report, 57 p.

U.S. Department of Commerce, 1951-1990, Climatological data—Annual summaries (for North Carolina and Virginia): U.S. Weather Bureau (1951-64), U.S. Environmental Science Services Administration (1965-69), U.S. National Atmospheric and Oceanic Administration (1970-90).

_____1992, National Climatic Data Center, 1961-90 Monthly station normals, all elements for North Carolina and Virginia,TD-9641:(digital data set), Asheville, N.C.

U.S. Environmental Protection Agency, 1986a, Maximum contaminant levels (Subpart B of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, parts 100 to 149, revised July 1, 1986, p. 524-528.

_____1986b, Secondary maximum contaminant levels (Section 143.3 of part 143, National secondary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, parts 100 to 149, revised July 1, 1986, p. 587-590.

U.S. Geological Survey, 1981a, Water resources data, North Carolina, water year 1980: U.S. Geological Survey Water-Data Report NC-80-1, 459 p.

_____1981b, Water resources data, Virginia, water year 1980: U.S. Geological Survey Water-Data Report VA-80-1, 609 p.

_____1988, National Atmospheric Deposition/National Trends Network annual data summary, precipitation chemistry in the United States: U.S. Geological Survey Report on National Atmospheric Deposition Program.

_____1991a, Aggregated water use data system, North Carolina: U.S. Geological Survey digital data base of county water use.

_____1991b, Aggregated water use data system, Virginia: U.S. Geological Survey digital data base of county water use.

_____1992, U.S. Geodata: Land use and land cover data: U.S. Geological Survey Earth Science Information Center, 4 p. (1:250,000 quadrangles used in this study included Beaufort, Bluefield, Greensboro, Manteo, Norfolk, Raleigh, Richmond, Roanoke, Rocky Mount, and Winston-Salem).

Virginia Department of Agriculture and Consumer Services, 1990, Virginia agricultural statistics, 1990: Virginia Agricultural Statistics Service Bulletin 60, 154 p.

Virginia Department of Conservation and Economic Development, 1963, Geologic map of Virginia, compiled by R.C. Milici and others: Division of Mineral Resources Map, scale 1:500,000, 1 sheet.

Virginia Water Control Board, 1992, Virginia water quality assessment—1992: Virginia Water Control Board Information Bulletin 588 (305B report), 3 volumes.

_____1993, Discharge monitoring report data, 1990, selected parameters, digital files.

Walton, G., 1951, Survey of literature relating to infant methemoglobinemia due to nitrate-contaminated water: American Journal of Public Health, v. 41, p. 986-996.

Ware, G.W., 1989, The pesticide book: Fresno, Calif., Thomson Publications, 340 p.

Weaver, J.C., 1994, Sediment characteristics and sedimentation rates in Lake Michie, Durham County, North Carolina, 1990-92: U.S. Geological Survey Water-Resources Investigations Report 94-4123, 34 p.

Wolman, M.G., and Schick, A.P., 1967, Effects of construction on fluvial sediment in urban and suburban areas of Maryland: Water Resources Research, v. 3, no. 2, p. 451-464.

Yorke, T.H., and Davis, W.J., 1972, Sediment yields of urban construction sources, Montgomery County, Maryland: U.S. Geological Survey Open-File Report, 39 p.

Younos, M.Y., and Weigmann, D.L., 1988, Pesticides—A continuing dilemma: Journal of the Water Pollution Control Federation, v. 60, p. 1199-1205.

Zublena, J.P., 1991, Soil facts: Nutrient removal by crops in North Carolina: North Carolina Cooperative Extension Service, 4 p.

Zublena J.P., and Barker, J.C., 1991, County-by-county nutrient assessment and distribution of animal manure in North Carolina, NWQEP notes: Raleigh, N.C., North Carolina State University, Water Quality Group, Department of Biological and Agricultural Engineering, September 1991, no. 49, p. 3-4.

APPENDIX

METHODS OF DATA PREPARATION

Methods used to develop and analyze information presented in the accompanying report are described in this appendix. Methodologies are discussed regarding land use, agriculture, atmospheric deposition of nitrogen, climate, point sources, population, and stratification data-estimation techniques.

Land Use

Spatial land-use information used in this report was retrieved from the U.S. Geological Survey (USGS) land-use and land-cover data base referred to as Geographic Information Retrieval and Analysis System (GIRAS). These data were compiled from aerial photographs acquired during the late 1970's and mid-1980's, and are used by all National Water-Quality Assessment (NAWQA) study units because they are the only digital land-use data base available for the entire United States. The digital maps were compiled at a scale of 1:250,000 and have a minimum resolution, or mapping unit, of 10 acres for urban land and 40 acres for other land cover types. This common spatial framework allows for comparison of land-use information across study units.

One concern with these data is the degree to which land-use changes over the past 10 to 15 years limit the accuracy of the GIRAS information for the Albemarle-Pamlico study unit drainage area. In the late 1980's, remotely sensed data from the Landsat Thematic Mapper sensor was acquired and a land-use classification was completed as part of the Albemarle-Pamlico Estuarine Study (Khorram and others, 1991). Because the spatial extent of the Landsat data excluded the upper part of the Roanoke River Basin, it could not be used for this study. A comparison of the GIRAS and Landsat data was made, however, for several hydrologic units where data from both sources existed, so that a qualitative evaluation could be made of the extent to which the earlier GIRAS data matched the more recent Landsat data.

Land-cover data for six hydrologic units were compared, and the results of the comparison are shown below. Under each land-cover category, two numbers separated by a slash are reported. The first number refers to the percentage of land in that hydrologic unit that was classified in that particular land-cover category in the GIRAS classification; the second number refers to the percentage of land designated as that land cover in the Albemarle-Pamlico Study classification.

Basin	Cataloging unit	Forest	Agri-culture	Wet-lands	Urban
Roanoke	03010107	47/34	29/32	16/23	4/2
Tar-Pamlico	03020101	48/43	41/40	5/7	6/6
Tar-Pamlico	03020102	55/52	35/33	8/11	3/1
Tar-Pamlico	03020103	40/30	43/52	11/10	5/0.4
Tar-Pamlico	03020104	37/26	29/33	15/17	2/1
Neuse	03020201	37/36	36/34	1/7	9/11

Although the percentages associated with the two classification systems appear similar, there are several patterns to note. In all hydrologic units, the GIRAS forest percentages are higher than the Albemarle-Pamlico Study classification percentages. In some cases, the decrease in forest land is accompanied by an increase in agricultural land (for hydrologic units 03010107, 03020103, and 03020104) suggesting the possibility of conversion of forest land for agricultural purposes. In four of the six hydrologic units, the amount of urban land actually decreases; in one it stays the same; and in the relatively urban upper Neuse hydrologic unit (03020201), the percentage of urban land increased between the GIRAS and Albemarle-Pamlico Study classification. In all hydrologic units, the percentage of wetlands increased between the GIRAS and Albemarle-Pamlico Study classification.

Agriculture

County-level crop harvest data collected by the Virginia and North Carolina Departments of Agriculture for 1980-92 were obtained from the U.S. Department of Agriculture offices in Raleigh, N.C. Animal inventory data were obtained from the U.S. Department of Agriculture 1987 Census of Agriculture. These data were used to develop nutrient estimates associated with fertilizer application and biological fixation of nitrogen, the nutrient content of animal waste, and for nutrient content of harvested crop materials.

Fertilizer Application and Biological Nitrogen Fixation

Estimation of the amount of total nitrogen and total phosphorus applied to, or biologically fixed by, major agricultural crops relied on calculation of crop acreages within a watershed and fertilizer application rates for various major crops (table A-1). Calculation of acreages for 11 major crops (barley, corn, cotton, Irish potatoes, oats, peanuts, sorghum, soybeans, sweet potatoes, tobacco, and wheat) in each of the major drainage basins in the Albemarle-Pamlico study area was a three-step process. First, 1990 county-level crop statistics were collected from the State Departments of Agriculture. Crop-planting acreage data were not available for all 11 crops, although acreages of harvested crop and amounts of each crop harvested (for example, bushels of corn, 480-pound bales of cotton) were available.

Next, an estimate was made of the location of these crops in each county. USGS land-use data from the late 1970's (GIRAS data; Anderson and others, 1976) were processed using a geographic information system (GIS) to locate all agricultural land in each of the study unit counties. Although cropping patterns have changed since the late 1970's, it was assumed that the relative location of agricultural land remained the same. An assumption was also made that the spatial distribution of the 11 major crops was equal across a county's agricultural land. Thus, a part of the county containing 25 percent of the county's agricultural land was assumed to contain 25 percent of the harvested acres of each of the 11 crops.

Finally, county-level crop information was apportioned among the major drainage basins. A GIS map of the major drainage basins was overlain on a county land-use map identifying the proportion of each county's agricultural land falling within the associated drainage basin. This proportion was used to allocate the county crop and livestock inventory data to the respective drainage basin.

Once harvested acreages of each of the 11 crops were determined for each drainage area, estimates of fertilizer use for all crops except soybeans and peanuts were made by multiplying application rates and harvested acres of each crop, and summing all crop types. The quantity of biologically fixed nitrogen produced by soybeans and peanuts was estimated by multiplying harvested acres of these crops by the areal nitrogen fixation rate listed in table A-1. The use of

Table A-1. North Carolina Cooperative Extension Service recommended fertilizer application rates applied to major agricultural crops.

Crop	Nitrogen (pounds per acre)				Phosphorus (pounds per acre)			
	Applied at planting[a]	Applied as side-dressing[a]	Renge of application[a]	Application rate used in mass balance	Applied at planting[a]	Applied as side-dressing[a]	Renge of application[a]	Application rate used in mass balance
Barley	20	80-100	100-120	110	0-20	0	0-20	10
Corn (as grain)	20-25	100-140	120-160	140	30-50	0	30-50	40
Cotton	20	50-70	70-90	80	0-20	0	0-20	10
Irish potatoes	120-160	0	120-160	140	60-80	0	60-80	70
Oats	20	80-100	100-120	110	0-20	0	0-20	10
Peanuts	0	0	0	112[b]	0	0	0	0
Sorghum	20	60-80	80-100	90	0-20	0	0-20	10
Soybeans	0	0	0	105[b]	0-20	0	0-20	10
Sweet potatoes	30	60	90	90	60	0	60	60
Tobacco[c]	35-40	0-40	35-80	50	0	0	0	0
Wheat	20	80-100	100-120	110	0-20	0	0-20	10

[a]Unless otherwise noted, amounts reported for application at planting, at sidedressing, and range are from North Carolina State University, College of Agriculture and Life Sciences (1991).

[b]Biological fixation (Craig and Kuenzler, 1983).

[c]Flue-cured; does not include plant bed fertilizer.

harvested rather than planted acres will produce a conservative estimate of fertilizer use because there will be fewer harvested acres than planted acres on which fertilizer was originally applied.

Livestock Waste-Related Nutrients

County-level livestock inventories for cattle, chickens, hogs, and turkeys were obtained from the 1987 U.S. Department of Agriculture's Census of Agriculture, which were the most recent data available for all study unit counties. County livestock inventories were allocated to major drainage areas using the crop-allocation method described above. Resulting inventories of each livestock type were multiplied by estimates of annual per-animal waste-nutrient content reported in Barker (1991) (table A-2). Waste content was summed for all livestock types in a drainage basin to estimate total livestock-related nutrient generation.

Crop Harvest Nutrient Removal

As with crop acreages and livestock inventories, drainage basin estimates of crop harvest nutrient removal were developed by first allocating 1990 county-level crop harvest data to major drainage basins. Average nutrient content of harvested crop materials were used in conjunction with drainage basin crop harvest estimates to calculate harvest nutrient removal (table A-3). These estimates are reported in the retrospective report for the Albemarle-Pamlico drainage study unit (Harned and others, in press).

Table A-3. Nutrient removal by crop harvest[a,b] (From Zublena, 1991)
[lb(s), pound(s)]

Crop	Harvest unit	Nitrogen	Phosphorus
Barley	bushel	0.875	0.161
Corn	bushel	.900	.152
Cotton	480-lb bale	11.631	1.985
Oats	bushel	.625	.108
Peanuts	lb	.035	.002
Sorghum	bushel	.833	.186
Soybeans	bushel	3.760	.353
Sweet potatoes	100 lbs	.267	.052
Tobacco[c]	lb	.028	.002
Wheat	bushel	1.250	.269
White potatoes	100 lbs	.300	.069

[a]Pounds per harvest unit of elemental nitrogen and phosphorus.
[b]Nutrient removal is only in harvested part of plant.
[c]Flue-cured tobacco.

Atmospheric Deposition

The total nitrogen contribution from atmospheric deposition was calculated as the sum of nitrate nitrogen (NO_3_N) and ammonia nitrogen (NH_4_N) wet deposition, NO_3_N dry deposition, NO_3_N droplet deposition, NO_3_N urban area wet deposition, and NO_3_N urban dry deposition.

Table A-2. Nutrients produced in animal wastes
[Units of measure are in pounds per animal per year]

Nutrient	Cattle			Chickens				
	All cattle	Dairy	Beef	All chickens	Layers	Broilers	Hogs	Turkeys
				Fisher and others (1988)				
Nitrogen	75.8	122.7	60.9	--	0.95	0.77	31.9	3
Phosphorus	--	--	--	--	--	--	--	--
			North Carolina Department of Natural Resources and Community Development (1985a)					
Nitrogen	142.7	237.2	113.1	--	1.46	0.73	21.9	7.3
Phosphorus	33.5	47.5	29.2	--	.37	.18	7.3	1.8
				Barker (1991)				
Nitrogen	106.5	156	90.8	0.9	0.95	0.89	20.3	2
Phosphorus	26.7	32.8	24.8	.26	.34	.25	6.6	.79

Deposition in each of these categories was calculated by multiplying the associated deposition rate [kilograms/hectare/year (kg/ha/hr)] by the corresponding area of the drainage basin and a conversion factor changing the nitrogen units from ionic to elemental nitrogen (Sisterson, 1990).

NO_3 and NH_4 wet deposition rates (9.9 and 2.8 kg/ha/yr, respectively) were calculated as the average of wet deposition rates during water year 1990 (October 1989-September 1990) at four National Atmospheric Deposition Program/National Trends Network (NADP/NTN) sites located in and adjacent to the Albemarle-Pamlico drainage basin (National Atmospheric Deposition Program/National Trends Network, 1991). Average wet deposition values for the entire study area were used because there was little variability in NO_3 and NH_4 deposition rates among the four stations, and interpolation of these data using contours to indicate spatial variability would not have provided substantially different information. These wet deposition rates were multiplied by the land area of the entire study unit to estimate NO_3_N and NH_4_N wet 1990 deposition.

Other deposition rates were calculated using a methodology described in Sisterson (1990). A dry NO_3 deposition rate (8.2 kg/ha/yr) was estimated by multiplying the wet NO_3 deposition rate by a ratio of dry to wet deposition in North Carolina and Virginia reported in Sisterson (1990). This dry deposition rate was multiplied by the entire study unit land area to estimate dry NO_3_N deposition.

The nitrate nitrogen droplet deposition rate associated with higher (greater than 610 meters [m]) elevations was calculated by multiplying the sum of the wet and dry nitrate rates (18.1 kg/ha/year) by 3, which reflects the increased exposure of land surfaces to clouds and fog. Areas with an elevation greater than 610 m were identified using elevation values reported for a network of 190 meteorological monitoring stations in the study area. A GIS was used to develop elevation contours from these data and locate the small (less than 10 square miles [mi^2]) area in the basin above 610 m. The droplet deposition rate was multiplied by the land area in these higher elevation zones to estimate droplet deposition.

Urban wet and dry NO_3_N deposition rates were estimated by multiplying wet and dry nitrate deposition rates by 1.75 (for wet) and 5 (for dry), again, reflecting "perturbation" factors reported in Sisterson (1990). Urban deposition rates were multiplied by urban land areas calculated using a GIS to estimate urban deposition.

Climate

A data set containing North Carolina and Virginia monthly average temperature and precipitation data for 1961-90 was obtained from the National Climatic Data Center in Asheville, N.C. (U.S. Department of Commerce, 1992). A map of all stations in the data set was created using a GIS and overlain with a map of the study unit identifying 190 weather stations in the Albemarle-Pamlico study unit with climate data. The GIS was used to generate contour maps of mean annual precipitation and temperature for the study unit.

Point Sources

Because of differences in available data, different methods were used to estimate 1990 total nitrogen and total phosphorus loads generated by Virginia and North Carolina point-source dischargers. The Virginia Water Control Board was able to supply daily discharge data (measured in millions of gallons per day [Mgal/d]) for 103 dischargers in the Virginia part of the study unit with an National Pollution Discharge Elimination System (NPDES) permit, along with Standard Industrial Codes (SIC) describing the type of activity, such as municipal wastewater-treatment plant or tobacco processing, associated with each permit. The combined discharge from these facilities was 121 Mgal/d in 1990.

Total nitrogen and total phosphorus concentrations associated with each SIC code were compiled by the Potomac NAWQA team. For example, the SIC code associated with municipal wastewater-treatment plants was assumed to have nutrient concentrations for total nitrogen and total phosphorus of 11.2 and 7 milligrams per liter, respectively.

A wide range of discharge measurements was reported for each discharger, from a low of 2 measurements for the year to a high of 48 measurements. The median value of these daily discharge values was calculated, multiplied by the appropriate total nitrogen and total phosphorus concentration to estimate daily nutrient loads, and summed over 365 days to produce annual nutrient load estimates.

The North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management, was able to supply 1990 daily discharge and nutrient concentration data for 175 dischargers in the study unit, representing 288 Mgal/d of discharge. Many dischargers reported 12 months of data. For these dischargers, monthly load estimates were calculated by multiplying the average daily discharge for the month by the average total nitrogen and total phosphorus concentration. Monthly load estimates were summed over the year, and the process was completed for each discharger with a 12-month data set.

For dischargers with less than 12 months of 1990 data, the method used with Virginia dischargers was used to calculate annual nutrient loads. The median of all reported daily discharge data was multiplied by the median of total nitrogen and phosphorus concentration data to estimate daily loads, and these loads were summed to produce an annual estimate.

Eleven dischargers reported nitrogen data as ammonia nitrogen, rather than total nitrogen. In the North Carolina 1990 NPDES data set, there were 801 records with data for both ammonia nitrogen and total nitrogen. These 801 records were used in a regression analysis resulting in the following equation:

$$\text{total nitrogen concentration (milligrams per liter)} = 11.97 + 0.55 \times \text{ammonia nitrogen concentration (milligrams per liter)}$$

This equation was used to estimate total nitrogen concentrations for the 11 dischargers. The total discharge represented by these 11 dischargers is approximately 6 Mgal/d.

Population

For this report, county-level census statistics for 1970, 1980, and 1990 were allocated to hydrologic units according to the proportion of a county's land area within any individual hydrologic unit. For example, if 10 percent of Wake County's land area was in hydrologic unit A and 90 percent in hydrologic unit B, then 10 percent of the county's population was allocated to hydrologic unit A and 90 percent to hydrologic unit B.

A digital coverage of points, representing the geographic center or centroid of census blocks, has been completed for use in estimating population for drainage areas. Each point in the digital coverage contains 1990 population information for that census block, and this point coverage can be overlain with a digital map of drainage boundaries for surface-water gaging stations in order to allocate the census block centroids to their associated drainage basin.

Stratification

The stratification categories were developed by overlaying land use, soils (hydrologic groups), and hydrogeologic zone coverages. Soils data were compiled for the Albemarle-Pamlico study unit using 1:250,000 STATSCO coverages developed by the U.S. Soil Conservation Service (SCS), where individual soil polygons represent soil-association information. An individual soil association combines information from as many as 21 soil series. The soil-association characteristics used in the Albemarle-Pamlico retrospective analysis are referred to as hydrologic soil groups. These characteristics are commonly reported on SCS soil-association maps (indicating at least some measure of confidence in the spatial reliability of this information), and the concept is commonly used in county and local government environmental regulations.

Several different geologic coverages were used as the basis for the Albemarle-Pamlico hydrogeologic zone coverage. The North Carolina study unit area was developed using the 1985 Geologic Map of North Carolina, compiled by the State Geologic Survey at a 1:500,000 scale (North Carolina Department of Natural Resources and Community Development, 1985b). The Virginia study unit area was developed using a 1:500,000 State geology map (Virginia Department of Conservation and Economic Development, 1963) for the western Virginia area and a 1989 USGS compiled map for the Virginia Coastal Plain (1:250,000) (Mixon and others, 1989). The seven hydrogeologic zones are (1) Coastal Plain Carbonate, (2) Granitic, (3) Inner Coastal Plain, (4) Outer Coastal Plain, (5) Slate Belt, (6) Triassic Basin, and (7) Valley and Ridge Carbonate.

The resulting stratification coverage was compiled by first distinguishing polygons greater than 1 mi^2 and then by determining logical groupings among the combined land use, soil, and hydrogeologic zone polygons. The polygons were screened by size recognizing that each individual coverage has a certain amount of horizontal error. Assuming each of the maps meets National Map Accuracy Standards (accurate to 0.03 inch), then the land-use data map (1:250,000) is accurate within 625 feet (ft), the soils map (1:250,000) within 625 ft, and the hydrogeology map (1:500,000) within 1,250 ft. It is difficult, however, to estimate map error when individual maps are combined. Simple addition results in an error of 2,500 ft, or about one-half mile. A minimum size of 1 mi^2 for polygons in the three-way coverage probably provides a reasonable margin of error.

CONVERSION FACTORS, TEMPERATURE, VERTICAL DATUM, AND DEFINITION

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
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
	Flow	
cubic foot per second (ft^3/s)	28.32	liter per second
	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
gallon per day (gal/d)	0.0038	cubic meter per day
	Flow per area	
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
	Mass	
ton (short, 2,000 pounds)	0.9072	megagram or metric ton
pound (lb)	453.59	gram
	Specific conductance	
microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C)	1.000	micromhos per centimeter at 25 degrees Celsius

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

$$°C = 5/9\ (°F - 32)$$

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

Definition used in this report:

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