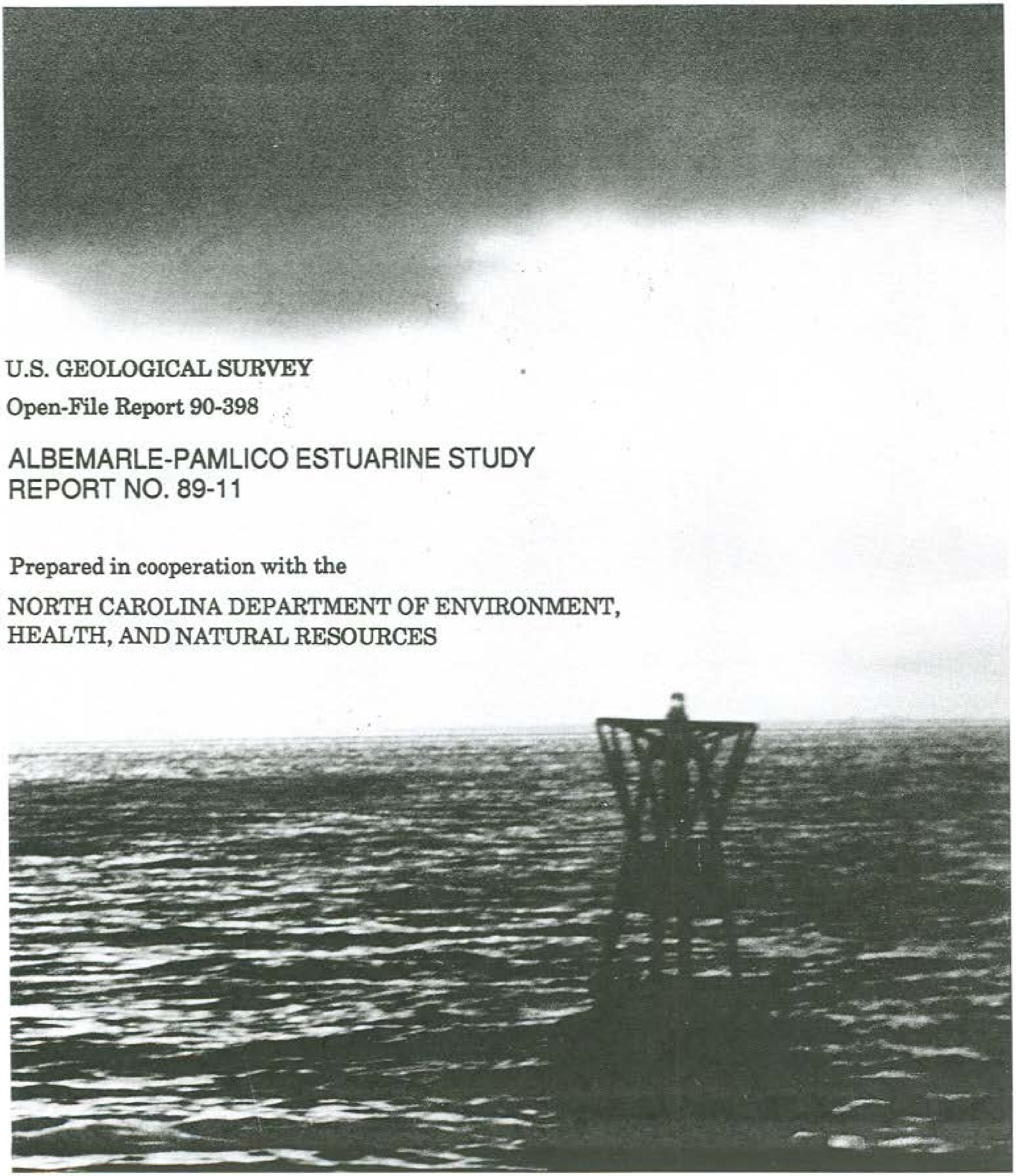
WATER-QUALITY TRENDS AND BASIN ACTIVITIES AND CHARACTERISTICS FOR THE ALBEMARLE-PAMLICO ESTUARINE SYSTEM, NORTH CAROLINA AND VIRGINIA



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Open-File Report 90-398

ALBEMARLE-PAMLICO ESTUARINE STUDY
REPORT NO. 89-11

Prepared in cooperation with the

NORTH CAROLINA DEPARTMENT OF ENVIRONMENT, HEALTH, AND NATURAL RESOURCES

COVER PHOTOGRAPH: Buoy in Albemarle Sound, North Carolina. Photographer unknown.

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By Douglas A. Harned and Marjorie S. Davenport

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Raleigh, North Carolina

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CONTENTS

ILLUSTRATIONS

Page

Page

Page

Page

Page

TABLES

Page

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By Douglas A. Harned and Marjorie S. Davenport

ABSTRACT

The Albemarle-Pamlico estuarine system has a total basin area of nearly 31,000 square miles and includes the Neuse, Tar, Pamlico, Roanoke, Chowan, and Alligator Rivers, and the Albemarle, Pamlico, Currituck, Croatan, and Roanoke Sounds. Albemarle Sound receives the greatest freshwater inflow of all the sounds in the estuarine system. Inflow to this sound averages about 13,500 cubic feet per second. Inflow to Pamlico Sound from the Pamlico River averages around 5,400 cubic feet per second, and average inflow into the Neuse River estuary is about 6,100 cubic feet per second. Approximately one-half of the inflow into the system is from ground-water discharge.

The Neuse River basin has had the greatest increases in wastewater discharges (650 percent since the 1950's) and had the greatest total wastewater discharges of any of the basins in the study area, averaging about 200 million gallons per day in 1988. Wastewater discharges into the Neuse and Tar Rivers were nearly equal to the 7-day, 10-year low flows for these rivers.

Land-use data compiled in 1973 for the lower parts of the Neuse River basin and lower part of the Tar-Pamlico River basin indicate that 25 percent of the area was evergreen forest, 25 percent was forested wetlands, 20 percent was cropland and pasture, 12 percent was mixed forest, 10 percent was nonforested wetland, and 4 percent was urban. The amount of nonforested wetland in the part of the study area along the Outer Banks declined 6.5 percent from 1973 to 1983.

The numbers of farms and acreage in agricultural use in the study area have declined since the 1920's. A decrease of more than 60 percent in the number of farms was shown between the early 1950's and 1982. Fertilizer sales increased through the 1970's, but declined in the 1980's. Manufacturing employment has increased in the last 30 years, while agricultural employment has decreased.

Data from seven stations of the U.S. Geological Survey National Stream Quality Accounting Network were used to evaluate water quality for the major streams flowing into the Albemarle-Pamlico estuarine system. Water-quality data for 296 stations in the estuarine system were examined for the period 1945-88.

The statistical test used for trend analysis was the Seasonal Kendall test (Hirsch and others, 1982). This nonparametric procedure is useful for analyses of water-quality properties that show non-normally distributed frequency distributions. The Seasonal Kendall trend analyses of water-quality data indicate that change has occurred in the water quality of the Albemarle-Pamlico estuarine system from 1945 to 1988. Dissolved-oxygen concentrations increased at a mean rate of 0.1 milligram per liter per year throughout the estuarine system, except in the Chowan River where decreases of approximately 0.06 milligram per liter per year occurred. In general, pH increased in streams throughout the area at a mean rate of 0.04 pH unit per year, except in the Pamlico River where pH decreased by 0.03 pH unit per year. A general increase in pH and dissolved-oxygen concentrations (if daytime measurements) might be indicative of more productive estuary conditions for algal growth. Suspended-solids concentrations decreased throughout the area at a mean rate of 1.1 milligrams per liter per year, probably as a result of a general decrease in suspended inorganic material. Increasing trends of salinity concentrations, as much as 0.1 part per thousand per year, were detected in Albemarle Sound.

Total ammonia plus organic nitrogen concentrations decreased (-0.03 milligram per liter per year) in streams throughout most of the area but increased (0.02 milligram per liter per year) in the Pamlico River. However, ammonia nitrogen concentrations decreased (-0.0035 milligram per liter per year) in the Pamlico River; therefore, increases in organic nitrogen probably caused the observed increase in combined ammonia plus organic nitrogen concentrations. This probably results from increased eutrophication in the system and its associated increased production of plant biomass. Nitrogen concentrations generally increased downstream and were usually sufficient for development of algal blooms.

Total phosphorus concentrations increased (0.003 milligram per liter per year) in the Pamlico River and decreased (-0.004 milligram per liter per year) elsewhere. There was a general pattern of decreasing phosphorus concentrations downstream for the Neuse and Pamlico Rivers; however, phosphorus concentrations in the Pamlico River peaked near Durham Creek.

Soluble nutrient concentrations, including ammonia nitrogen, nitrite plus nitrate, and dissolved phosphorus, are a net result of the effects of biological uptake, solution and dissolution of nutrients available in sediment, and new nutrient inputs. If plant biomass increases over time, this could be reflected in decreases in soluble nutrients such as observed ammonia nitrogen and phosphorus concentrations in the estuary system.

On the basis of annual median concentrations, nitrogen was the limiting nutrient for algal growth in the Neuse and Pamlico Rivers. Phosphorus was the limiting nutrient in most of the rest of the Albemarle-Pamlico system. Direct tests for specific nutrient limitations need to be made to confirm limitations at specific sites in the estuarine system.

Trends in chlorophyll-a concentrations increased in the Neuse River, upper Pamlico River, in the upstream end of Albemarle Sound, and near Bull Bay in Albemarle Sound (maximum rate, 1.0 microgram per liter per year). Chlorophyll-a concentrations decreased in the part of the Chowan River near Mount Gould. A pattern of increases in chlorophyll-a concentrations downstream in the Neuse, Chowan, and Alligator Rivers is apparent. Chlorophyll-a concentrations in the Pamlico River increased downstream, peaked in Durham Creek, and declined farther downstream. Chlorophyll-a concentrations were largest in the Pamlico (interquartile range 3-27 micrograms per liter) and Neuse Rivers (interquartile range 3-17 micrograms per liter) and in Currituck Sound (interquartile range 7-22 micrograms per liter).

Evaluation of water-quality data and more than 50 basin variables indicated 121 significant correlations between 11 basin activities or characteristics and 12 water-quality constituents at 21 estuary zones or locations and 7 National Stream Quality Accounting Network stations. Dissolved oxygen, suspended solids, total ammonia nitrogen, total ammonia plus organic nitrogen, and total phosphorus are among the constituents that correlated significantly (alpha = 0.01) with basin activities and characteristics.

Increases of dissolved oxygen with increases in crop acreages and fertilizer use could reflect increased plant biomass in the estuary, probably as a result of agricultural activities. Decreases in suspended solids in the estuarine system probably reflect decreases in corn and tobacco production or improved agricultural soil management.

Decreases in ammonia nitrogen in the Pamlico River correlated with decreases in tobacco acreage and fertilizer use, and increases in total ammonia plus organic nitrogen in the Pamlico River correlated with increases in crops and livestock. A decrease in ammonia nitrogen could occur with an increase in production of plant biomass, which in turn may be reflected in an increase in total ammonia plus organic nitrogen. These correlations might indicate that expanding agricultural operations are associated with nitrogen concentrations in the Pamlico River.

INTRODUCTION

The rivers, streams, and estuaries of the Albemarle-Pamlico estuarine system of coastal North Carolina (fig. 1) are undergoing substantial land-use and water-quality changes. Increasing population and changes in agricultural practices, urbanization, and industrialization in the region are reflected in changing quality of surface water. Identifying how and where water quality is changing and the nature of the relations between water quality and development of the basin are problems critical to the understanding and management of the system.

The Albemarle-Pamlico estuarine system is currently (1989) the focus of a comprehensive research effort by the North Carolina State government, Federal water-resources agencies, university researchers, and local interests. This research is being conducted as part of the National Estuary Program authorized by the Clean Water Bill Amendments of 1987 (Rader, 1988). The research goals are to: define trends in water quality; collect data needed to identify environmental problems; define constituent loads and their relation to land and water uses; and develop and implement plans for management of the regional environment.

The U.S. Geological Survey (USGS) in cooperation with the North Carolina Department of Environment, Health, and Natural Resources (DEHNR),

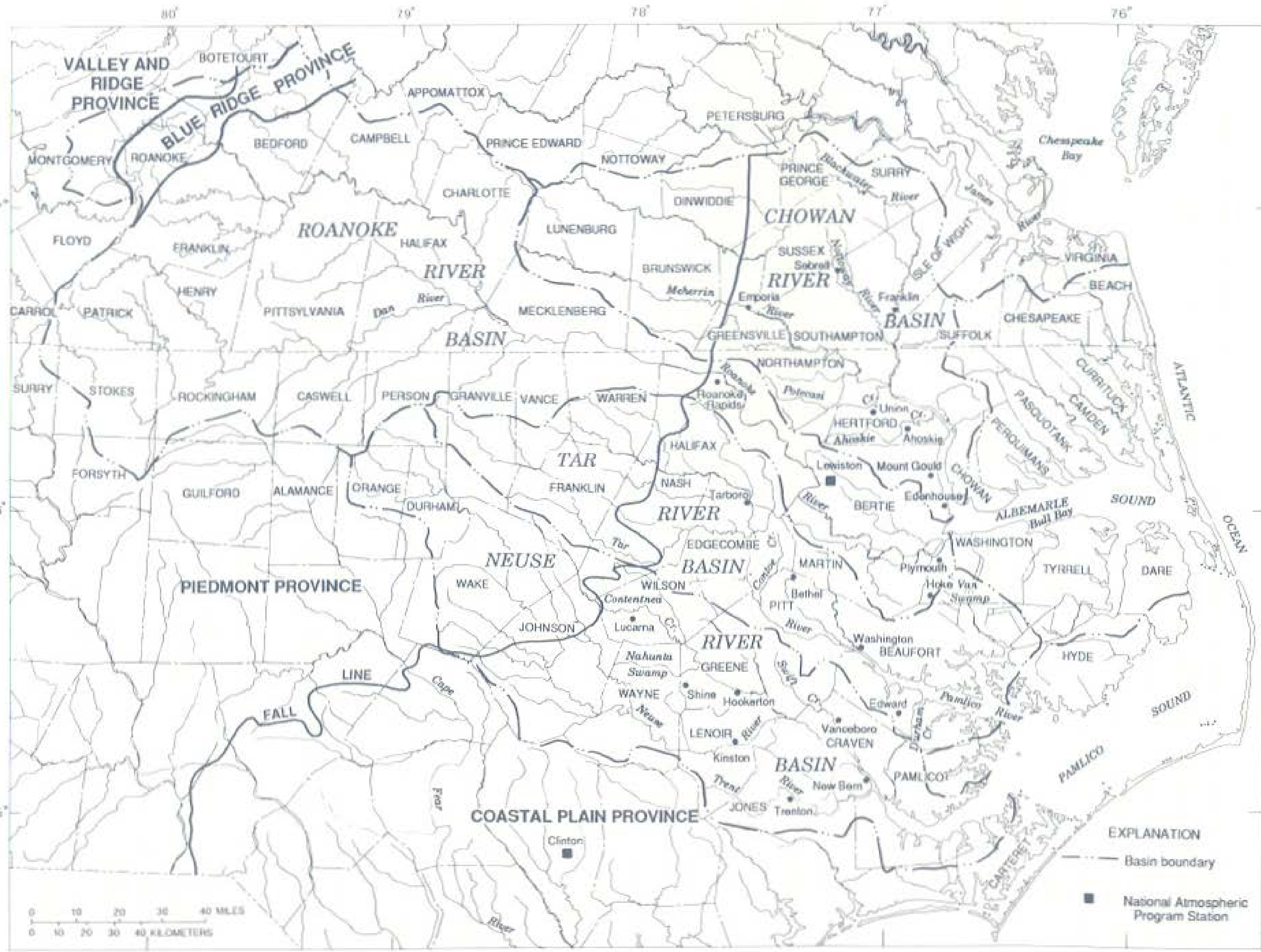

Figure 1.--Location of the Albemarle-Pamlico estuarine system in North Carolina and Virginia, including the drainage basins of streams flowing into the estuaries and physiographic provinces.

formerly known as the North Carolina Department of Natural Resources and Community Development (NRCD), is participating in a study to identify current and emerging water-quality issues in the Albemarle-Pamlico area. As part of this study, existing stream and estuary water-quality data were analyzed to evaluate long-term trends in water quality and to provide a perspective on the changing character of the streams and estuaries.

Purpose and Scope

This report describes results of a study to identify temporal and spatial trends in water quality in the Albemarle-Pamlico estuarine system and the major rivers that flow into the system, and to investigate relations between basin activities and characteristics and river and estuary water quality. The data examined include water-quality information collected at 7 USGS National Stream Quality Accounting Network (NASQAN) stations, 2 National Atmospheric Deposition Program/National Trends Network (NADP/NTN) stations, 162 estuary stations for which data are stored in the U.S. Environmental Protection Agency (USEPA) Storage and Retrieval System (STORET), and 125 estuary stations established by private and university investigators. The water-quality data were collected from 1945 through 1988.

The basin activities and characteristics examined consisted of measurable basin development and activities that could be represented over time. These included: streamflow, water use and waste disposal, land use, agricultural crop data, livestock data, fertilizer use, population, employment, and highway construction data. A special effort was made to calculate land-use areas from the National Wetlands Inventory (Cowardin and others, 1979) and from land-use land-cover maps (Anderson and others, 1976).

Records of water-quality properties and constituents examined were limited to those with the most observations and greatest period of record. These properties and constituents include: dissolved oxygen, biochemical oxygen demand, pH, alkalinity, hardness, suspended sediment, turbidity, suspended solids, specific conductance, salinity, dissolved solids, chloride, bicarbonate, carbon, nitrogen, phosphorus, bacteria, and chlorophyll-a.

Statistical techniques, including regression and residual analyses, were used to adjust the water-quality data for variations in discharge; nonparametric techniques were used for trend detection and correlation analysis. Water-quality data from the NASQAN stations were adjusted for discharge; discharge adjustment was not applied to the estuary stations where no discharge data were available. Trend analysis was applied to constituent concentrations and not loads because estuary flows are not currently known. The trend analysis technique used was the Seasonal Kendall test and slope estimator procedure as described by Crawford and others (1983). The Kendall tau-b test was used to test correlations between basin activities and characteristics and water quality.

Recent Water-Quality Studies

An extensive bibliography (Bales and Nelson, 1988) was produced as an initial step in the Albemarle-Pamlico study. About 1,100 references are indexed by location and investigation topic. Topics include artificial drainage, hydrology, hydrodynamics, water quality, and land-use effects on water quality.

There are several investigations that merit particular mention for their generalized analysis of water quality in parts of the Albemarle-Pamlico study area. The North Carolina Department of Natural Resources and Community Development (1987) defined the principal concerns about surface-water quality for the Albemarle-Pamlico study area. These concerns include: pronounced changes in water quality resulting in noxious algal blooms in the Chowan and Neuse Rivers; recent outbreaks of fish disease, large sediment loads, and small dissolved-oxygen concentrations in the Tar-Pamlico system; declines in submerged macrophyte populations in the Pamlico River; and declines in fish stocks and changes in salinity regimes throughout the system.

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

A 1989 report by DEHNR also gives a 1988 nutrient budget and details the effect of phosphorous detergent restrictions. An 8-percent reduction in the phosphorous budget was observed beginning in 1988.

Stanley (1988a) gives an overall synthesis of 20 years of water quality and an assessment of water-quality trends data for three sections of the Pamlico River estuary. The methodological and statistical problems in grouping data from many different sources are discussed. These problems are of paramount concern in the current USGS study.

In the Pamlico River, Stanley detected trends of decreasing pH, decreasing concentrations of nitrate nitrogen (in the upstream half of the river), and decreasing concentrations of ammonia nitrogen between 1967 and 1986. According to Stanley (1988a), phosphorus concentrations have increased dramatically in the middle and downstream parts of the Pamlico River estuary. Stanley also observed that chlorophyll-a concentrations have increased in the upstream and middle zones of the Pamlico River. In a comparison of Pamlico River estuary chemical water quality to other estuaries, Stanley inferred that the Pamlico is very similar to the Neuse River estuary except for the Pamlico's larger phosphorus concentrations. Indeed, Pamlico River estuary phosphorus concentrations are among the largest measured nationally (Nixon, 1983). Stanley concluded that nitrogen is the primary nutrient that limits algal growth in the Pamlico River.

Trends in nutrient loading in the Neuse River estuary were evaluated by Stanley (1988b) using computations of nutrient loadings from different land uses and sewered population in the Neuse basin (as demonstrated by Craig and Kuenzler, 1983). Stanley estimated that total phosphorus loads have increased by 60 percent and total nitrogen loads have increased by 70 percent between 1880 and 1985.

Paerl (1987) reported symptoms of accelerated eutrophication in the lower Neuse River. In describing the dynamics of blue-green algal blooms in the Neuse River, he noted the importance of the complex interplay of causative factors, including water discharge, temperature, and nutrient loading. Paerl determined nitrogen to be the limiting nutrient for algal growth, with phosphorus generally available at levels exceeding the need for phytoplankton growth demands.

In a more recent analysis (1989), Paerl reported seasonality in the nutrients limiting phytoplankton productivity in the Albemarle-Pamlico estuary system. Paerl reported that nitrogen was limiting during summer and fall, and nitrogen and phosphorus were colimiting during the winter and spring.

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

The Chowan/Albemarle Action Plan of the NRCD (1982a) gives an overview of the principal water-quality problems of the Chowan River and Albemarle Sound and recommends management options to mitigate these problems. Albemarle Sound is much less saline than Pamlico Sound as the result of a larger freshwater inflow than that for Pamlico Sound and the lack of any direct connection with the ocean. Although the nutrient concentrations in the Chowan River are greater than in the Roanoke River (North Carolina Department of Natural Resources and Community Development, 1982a), nutrient loadings to Albemarle Sound from the Chowan and Roanoke Rivers are comparable as a result of the greater flow of the Roanoke River. In Albemarle Sound, nutrient concentrations are as much as 40 percent less than those measured in the Chowan River. The Chowan nutrient concentrations, which have been associated with extensive algal blooms, increased during 1970-82. In the Chowan-Albemarle basin, nonpoint sources of nutrients account for 55 percent of the nitrogen and 46 percent of the phosphorus input into the system.

Craig and Kuenzler (1983) estimated nutrient yields based on land-use changes in the Chowan River basin. They estimated that agriculture contributes 62 percent of the nitrogen and 72 percent of the phosphorus input to the Chowan River. Point sources were determined to contribute 17 percent of the nitrogen and 6 percent of the phosphorus.

A detailed hydrologic overview of the estuaries of North Carolina is given by Giese and others (1985). They describe the generalized water budgets and flows, salinity, and other aspects of water quality for each of the major river estuaries in the Albemarle-Pamlico study area.

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D.N. Rader and R.E. Holman of the North Carolina Department of Environment, Health, and Natural Resources (DEHNR) helped to define the objectives of the study. D.M. Reid (DEHNR) retrieved the STORET data used in this study and served as a liaison for other data obtained from researchers within DEHNR. Much of the data in the STORET system were collected by DEHNR researchers.

D.W. Stanley of East Carolina University graciously supplied his Pamlico River data set and reviewed the report. The following people are authors of previous investigations used in this report:

D.B. Albert	D.A. Daniel	E.J. Kuenzler
R.T. Barber	G.J. Davis	D.D. Lauritsen
W.B. Bowden	T.R. Fisher	E.A. Matson
M.M. Brinson	W.G. Harrison	S.C. Mozley
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R.R. Christian	W.W. Kirby-Smith	J.B. Upchurch
B.J. Copeland	J.P. Koenings	

M.W. Treece of the USGS evaluated the data on water use and assisted the authors in the preparation of this section of the report. S.A. Berg of North Carolina State University devised the sampling methodology and compiled the land-use and wetlands data from available maps.

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BASIN DESCRIPTION

The Albemarle-Pamlico estuarine system (fig. 1) is the second largest estuary system in the United States. The total basin area of the system is approximately 30,900 mi^2 (square miles), including the Neuse River system (5,600 mi^2); the Tar-Pamlico River system (4,300 mi^2); the Roanoke River (9,700 mi^2); the Chowan River (4,900 mi^2); North Albemarle Penninsula (1,100 mi^2); Perquimans River, Little River, and North River (1,700 mi^2); and a small (100 mi^2) area of the Outer Banks (Giese and others, 1985). The open-water area of Albemarle, Pamlico, and smaller sounds and estuaries is 3,500 mi^2. In this report, the total Albemarle-Pamlico study area was used in the compilation of basin activities and characteristics data. This area contains all or parts of 74 counties in eastern North Carolina and southern Virginia.

The upstream limit of the study area from which water-quality data were obtained is defined by seven of the stations of the National Stream Quality Accounting Network (NASQAN) of the U.S. Geological Survey (fig. 2). Downstream of these stations, the area contains all or parts of 33 counties in eastern North Carolina and Virginia.

Climate

Annual mean air temperature in the Albemarle-Pamlico study area in the northern Coastal Plain is 60 °F. The area is usually frost-free from late March through early November (Wilder and others, 1978). Water temperatures in the sounds generally follow air temperatures, which are warmest in July and coldest in January.

Mean annual precipitation in the study area is about 50 in/yr (inches per year) (Wilder and others, 1978). However, the variability in precipitation from year to year is large, as annual rainfall ranges from 35 to 80 in/yr. There also is a slight variation in mean annual precipitation between the northern and southern sections of the Albemarle-Pamlico study area. Average precipitation is about 48 in/yr in the northern part and 56 in/yr in the southern part. Average monthly precipitation is greatest in July, August, and September and lowest during April and October (Giese and others, 1985).

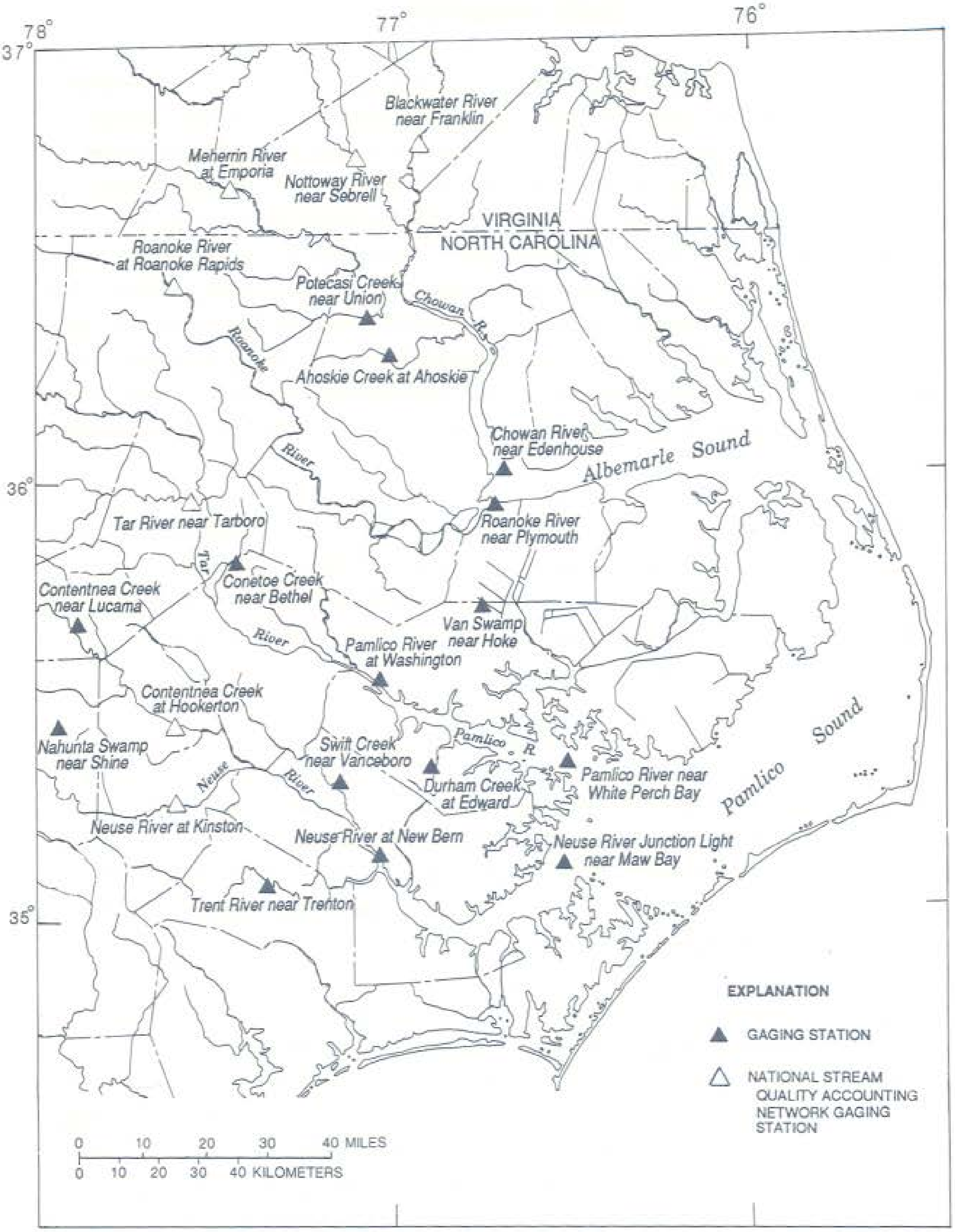

Figure 2.--Locations of selected streamflow gaging stations.

Evapotranspiration is approximately 34 in/yr and generally exceeds rainfall only during April, May, and June. Wilder and others (1978) indicated that almost two-thirds of the precipitation that falls in the Albemarle-Pamlico study area is returned to the atmosphere as evapotranspiration.

Physiography and Geology

Most of the basin area of the rivers that flow into the Albemarle-Pamlico estuarine system drain parts of two physiographic provinces: the Piedmont and Coastal Plain (fig. 1). A small part of the upper Roanoke River drains parts of the Blue Ridge and Valley and Ridge provinces (fig. 1). Each of these provinces has a distinctly different physiography and geology.

The Piedmont extends eastward from the foothills of the Blue Ridge Mountains to the Fall Line, which, as described by Fenneman (1938, p. 39), is a transition zone between the Piedmont and Coastal Plain. Deeply eroded valleys and rolling hills characterize the Piedmont. In the study area, the land-surface elevations in the Piedmont range from more than 1,500 ft (feet) above sea level in the western area of the Roanoke River basin to 300 to 600 ft above sea level along the Fall Line. Rocks of the Piedmont province are crystalline and include granite, massive slates and schists, and compact shales.

The Coastal Plain extends from the Fall Line to the Atlantic Ocean. This province is characterized by gently rolling topography in the west and flatlands near the coast. Swampy areas are common, flood plains are broad, and streams are slow moving in this area. Land-surface elevations gradually decline from along the Fall Line eastward to sea level at the coast. Rocks of the Coastal Plain province are sedimentary in origin and composed of sand, clay, limestone, and marl.

BASIN ACTIVITIES AND CHARACTERISTICS

The water quality of the estuary system is intrinsically related to the characteristics of the basin upstream from the estuary. Although the causality of relations between basin activities and characteristics and downstream water quality is difficult to quantify, changes in the upstream environment may be associated with changes in downstream water quality.

Basin activities and characteristics such as streamflow, water use and wastewater disposal, land use, agricultural practices, population, employment, and highway construction change with time. If measurements of the basin activities and characteristics are available at different points in time, then the variation of the basin characteristics can be compared to the variation of measurements of water quality with time. The method of analysis used in this report is statistical correlation. The description of the basin activities and characteristics that follows aids in defining environmental changes that have occurred with time in the Albemarle-Pamlico study area. A complete list of compiled basin activities and characteristics data is shown in table 1.

Streamflow

The NASQAN stations shown in figure 2 are the downstream-most gaging stations for the major rivers flowing into the Albemarle-Pamlico estuarine system. Estimates of total flows, water budgets, tide-affected flow, and water levels into the estuaries are given by Giese and others (1985). Estimates of average annual inflows from major tributaries to the system in North Carolina are summarized in table 2. Inflow into the Pamlico River from the Tar River is about 3,100 ft^3/s (cubic feet per second). The flow from the Neuse River into the Neuse River estuary averages about 5,000 ft^3/s, and the flow into Albemarle Sound from the Roanoke River is almost 9,000 ft^3/s. In this report, the flows at the NASQAN stations have been used in the correlation analysis and to compensate for discharge-related variation in trend analysis.

The two components of streamflow--ground-water discharge and overland runoff--can be estimated graphically for a given stream. Additionally, if it is assumed that there is no long-term change in ground-water storage, ground-water discharge is equal to the ground-water recharge. The Rorabaugh (1964) method of streamflow separation (as described by Daniel and others, 1982; and Wilder and Simmons, 1982), was used to separate ground water and overland runoff for 10 years of discharge record for each of the NASQAN stations on the Neuse, Tar, and Roanoke Rivers.

Table 1.--*Basin activities and characteristics used in the correlation analyses*

Characteristic	Definition
	Crops
Corn	All corn, acres harvested
Wheat	Wheat, acres harvested
Oats	Oats, acres harvested
Rye	Rye, acres harvested
Tobacco	Tobacco, acres harvested
Cowpeas	Cowpeas, acres harvested
Peanuts	Peanuts, acres harvested
Sorghum	Sorghum, acres harvested
Sweet potatoes	Sweet potatoes, acres harvested
Irish potatoes	Irish potatoes, acres harvested
Soybeans	Soybeans, acres harvested
Cotton	Cotton, acres harvested
Hay	All hay, acres harvested
Lespedeza	Lespedeza, acres harvested
Barley	Barley, acres harvested
	Agricultural activities
Land	Total acres in farms
Harvested cropland	Acres of harvested cropland, excluding pasture
Idle cropland	Acres of idle cropland, excluding pasture and including land used for soil improving crops and crop failures
Improved pasture	Acres of improved pasture
Unimproved pasture	Acres of unimproved open pasture
Pasture	Acres of all pasture land, including improved and unimproved pasture
Farms	Number of farms
	Livestock
Cattle	All cattle on farms
Milk cows	Number of cows
Beef cows	Number of cows
Hogs	Number of all hogs on farms
Chickens	Number of all chickens on farms
Sheep	Number of sheep on farms
Horses	Number of horses on farms
Mules	Number of mules on farms
	Fertilizers
Commercial fertilizer	Tons of mixed fertilizer and fertilizer materials shipped
Total fertilizer materials	Tons of total fertilizer materials sold
Total mixed fertilizer	Tons of total mixed fertilizers sold
Lime	Tons of lime sold
Landplaster	Tons of landplaster sold

Table 1.--*Basin activities and characteristics used in the correlation analyses*--Continued

Characteristic	Definition
	Population
Total population	Number of all people
Urban population	Sum of all urban areas per county with populations greater than 1,000 people
	Employment
Total employment	All civilian workers who work for pay or profit for 15 hours or more per week in a family farm or a business
Manufacturing employment	All individuals who work in the food processing, textile, furniture, paper, printing, chemical, petroleum, rubber, stone, and machinery manufacture
Nonmanufacturing employment	All individuals who work in the construction trade, financial, government, agricultural services, forestry, fisheries, and mining industries
Nonagricultural employment	All individuals who work full-time or part-time non-farm production and non-production employees who worked in or received compensation from non-farm establishments, including manufacturing and non-manufacturing employment
Agricultural employment	All operators, managers, unpaid family workers, and other hired workers on farm establishments, including domestic workers in farm households
	Transportation
Paved, rural, primary roads	Miles of paved, rural, primary roads
Unpaved, rural, primary roads	Miles of unpaved, rural, primary roads
Paved, municipal, primary roads	Miles of paved, municipal, primary roads
Unpaved, municipal, primary roads	Miles of unpaved, municipal, primary roads
Paved, primary roads	Total miles of paved, primary roads
Unpaved, primary roads	Total miles of unpaved, primary roads
Paved, rural, secondary roads	Miles of paved, rural, secondary roads
Unpaved, rural, secondary roads	Miles of unpaved, rural, secondary roads
Paved, municipal, secondary roads	Miles of paved, municipal, secondary roads
Unpaved, municipal, secondary roads	Miles of unpaved, municipal, secondary roads
Paved, secondary roads	Total miles of paved, secondary roads
Unpaved, secondary roads	Total miles of unpaved, secondary roads

Table 2.--*Surface-water inflows at selected streamflow gaging stations in the study area*

[mi^2, square mile; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; TR, Tar River at Tarboro used as index station. Drainage area ratio is 1.02 $(ft^3/s)/mi^2$; --, not available; Est., estimates were determined on the basis of discharge records at gaged location adjusted for ungaged areas (Giese and others, 1985); NR, Neuse River at Kinston used as index station. Drainage area ratio is 0.93 $(ft^3/s)/mi^2$]

Station name (fig. 2)	Station number[a]	Latitude	Longitude	Drainage area (mi^2)	Mean annual flow (ft^3/s)	Mean annual flow ($(ft^3/s)/mi^2$)	Period of record	Method of determining flow
Tar River at Tarboro[b]	02083500	35°53'38"	77°37'00"	2,183	2,216	1.02	1923-88	Measured
Conetoe Creek near Bethel	02083800	35°46'33"	77°27'45"	78.1	78.7	1.01	1956-88	Measured
Pamlico River at Washington	020844720	35°32'33"	77°00'43"	3,080	3,142	1.02	1923-88	TR
Durham Creek at Edward	02084540	35°19'25"	76°52'26"	26	36.3	1.40	1965-88	Measured
Van Swamp near Hoke	02084557	35°43'49"	76°44'49"	23	26.2	1.14	1977-88	Measured
Pamlico River near White Perch Bay	0208458875	35°19'50"	76°26'50"	4,300	5,400	1.26	--	Est.
Roanoke River at Roanoke Rapids[b]	02080500	36°27'37"	77°38'04"	8,384	7,674	.92	1911-88	Measured
Roanoke River near Plymouth	020811430	35°56'35"	76°41'45"	9,666	8,900	.92	--	Est.
Potecasi Creek near Union	02053200	36°22'14"	77°01'36"	225	230.3	1.02	1958-88	Measured
Ahoskie Creek at Ahoskie	02053500	36°16'48"	77°00'00"	63.3	61.9	.98	1950-88	Measured
Chowan River near Edenhouse	0205365200	36°02'51"	76°41'46"	4,943	4,600	.94	--	Est.
Neuse River at Kinston[b]	02089500	35°15'29"	77°35'09"	2,692	2,498	.93	1930-88	Measured
Contentnea Creek near Lucama	02090380	35°41'29"	78°06'38"	161	151.9	.94	1964-88	Measured
Contentnea Creek at Hookerton[b]	02091500	35°25'44"	77°34'54"	729	752.1	1.03	1928-88	Measured
Nahunta Swamp near Shine	02091000	35°29'20"	77°48'22"	80.4	81.9	1.02	1954-88	Measured
Swift Creek near Vanceboro	02092000	35°20'42"	77°11'45"	182	201	1.10	1950-88	Measured
Trent River near Trenton	02092500	35°03'54"	77°27'24"	168	192.4	1.14	1951-88	Measured
Neuse River at New Bern	020921620	35°06'42"	77°01'59"	4,467	4,914	1.10	1964-88	NR
Neuse River Junction Light near Maw Bay	020926900	35°08'42"	76°30'06"	5,600	6,100	1.09	--	Est.

a/ U.S. Geological Survey downstream order number.
b/ National Stream Quality Accounting Network (NASQAN) station.

The ground-water contribution to streamflow for the Neuse, Tar, and Roanoke Rivers averages 62 percent of total flow and ranges from 42 to 76 percent (table 3). These values illustrate the importance of ground-water discharge in the total flow of the Albemarle-Pamlico study area.

Table 3.--*Mean annual discharge and estimates of groundwater and overland runoff contributions to discharge in the Neuse, Tar, and Roanoke Rivers*

Station name (fig. 2)	Station number[1]	Period of record examined	Mean annual discharge (cubic feet per second)	Mean percent ground-water discharge (range)	Mean percent overland runoff (range)
Neuse River at Kinston	02089500	1978-87	2,692	70 (59-76)	30 (24-41)
Tar River at Tarboro	02083500	1978-87	2,216	60 (42-76)	40 (24-58)
Roanoke River at Roanoke Rapids	02080500	[2]1940-49	8,384	57 (49-65)	43 (35-51)
Mean for 3 stations				62	38

[1]U.S. Geological Survey downstream order number.
[2]Record representative of period before regulation by the Kerr/Gaston reservoir system.

In general, the streams and estuaries are discharge areas for ground-water flow (Winner and Coble, 1989, p. 15). One estimate of ground-water movement in and out of the estuaries is given by the calculated surficial aquifer boundary condition used by the U.S. Geological Survey Regional Aquifer Systems Analysis (RASA) Coastal Plain ground-water model (G.L. Giese and others, U.S. Geological Survey, written commun., 1990). The RASA model indicates that most of the Albemarle-Pamlico estuaries are areas where ground water is discharging from aquifers into the surface water (fig. 3). However, due to the effects of 65 Mgal/d (million gallons per day) pumpage for phosphate mining, water that would normally be discharged to parts of the Pamlico River and estuary is now being diverted to the pumping center at the phosphate mine (Coble and others, 1989).

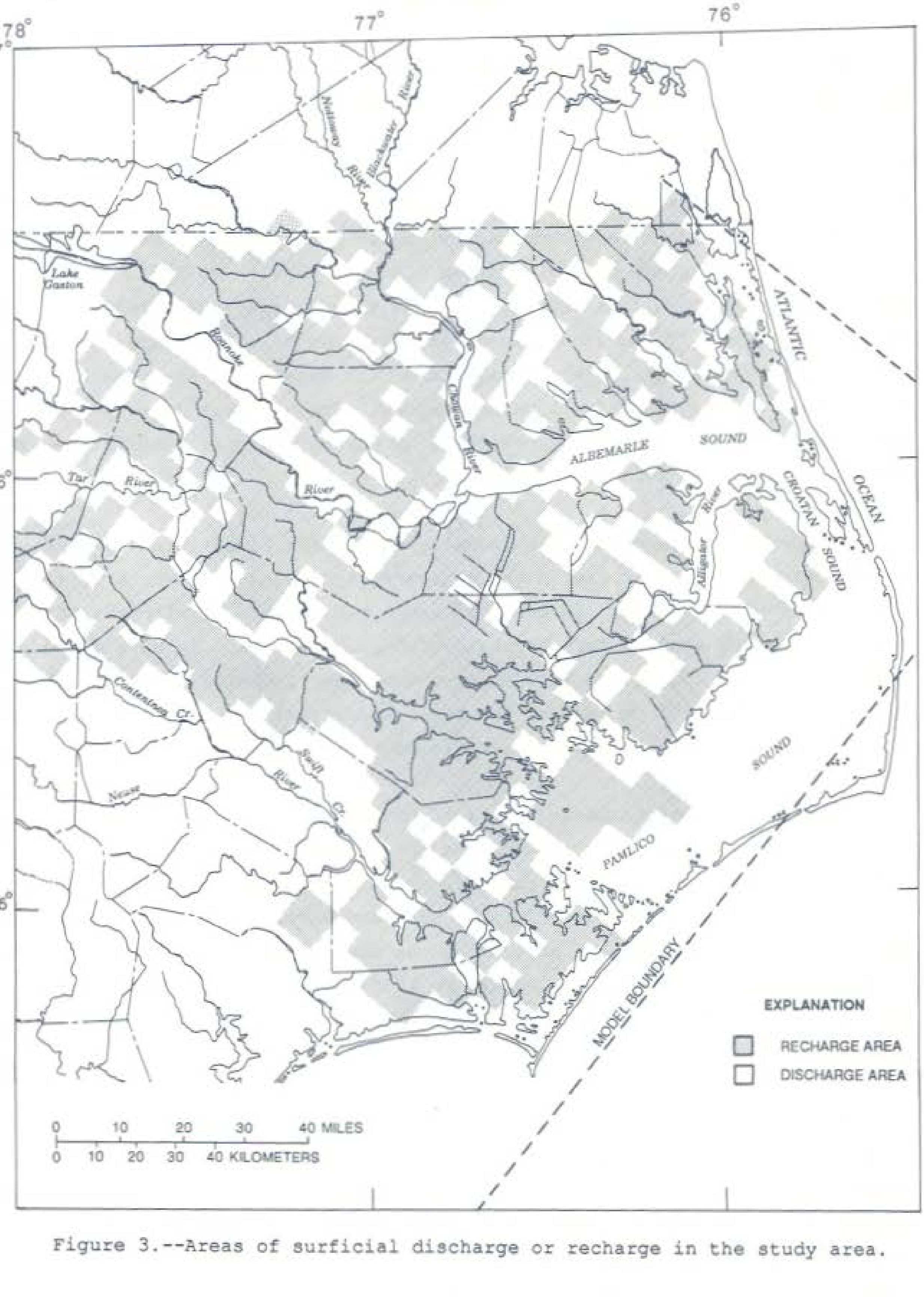

Figure 3.--Areas of surficial discharge or recharge in the study area.

Water Use

The section of the Albemarle-Pamlico basin examined for water use includes the following counties in the Coastal Plain of eastern North Carolina: Beaufort, Bertie, Camden, Carteret, Chowan, Craven, Currituck, Dare, Gates, Hertford, Hyde, Jones, Lenoir, Martin, Pamlico, Pasquotank, Perquimans, Pitt, Tyrrell, and Washington (fig. 1). Water-use estimates were made for 1985 and were compiled by county and hydrologic unit (M.W. Treece, U.S. Geological Survey, written commun., 1989). In 1985, about 286 Mgal/d were withdrawn from the surface- and ground-water resources in the 20-county region. The consumptive water use or water not returned to the system was about 99 Mgal/d or 35 percent of the water, and the remaining 187 Mgal/d was returned to natural water sources. Ground water accounted for about half of the water used in the area by rural, domestic, and farm users, municipalities, and mining operations.

Withdrawals associated with industry and mining constituted the largest single category of water use in the region (184 Mgal/d or 64 percent of the total water withdrawals). In Beaufort County, 67 Mgal/d is withdrawn from the Castle Hayne aquifer for phosphate-mining operations. In Martin and Craven Counties, 100 Mgal/d is withdrawn for paper industry and quarrying operations. About 57 percent of the total industrial and mining withdrawals in the study area was from surface-water sources.

Public-supply withdrawals increased by almost 50 percent between 1975 and 1985. Many municipalities expanded their service areas during that period, and many self-supplied rural areas were connected to county water systems. In 1985, public water supply provided water to about 60 percent of the region's population, and per capita use was 141 gallons per day. Of the 47 Mgal/d withdrawn for public supply in 1985, 75 percent (35 Mgal/d) was from ground-water sources and 25 percent (12 Mgal/d) was from surface-water sources.

Self-supplied domestic and commercial water use totaled 17 Mgal/d, all of which was supplied by ground-water sources. Self-supplied domestic-use withdrawals in 1985 were about 13 Mgal/d and was the source of water for an estimated 215,000 people, compared to withdrawals in 1975 of about 14.3 Mgal/d for 238,000 people. These numbers indicate that some rural communities were connected to county water systems during this period.

Agricultural water withdrawals are greatest in comparison to other water-use categories in the 20-county region than in other areas of the State. Total agricultural withdrawals were 37.5 Mgal/d in 1985 (or 13 percent of total water use). Irrigation withdrawals were 33.7 Mgal/d, which accounted for nearly 90 percent of the agricultural water use. Livestock watering accounted for most of the remaining 3.8 Mgal/d. More water is used in eastern North Carolina for irrigating corn and tobacco than for other crops.

Wastewater Disposal

All points of major municipal and industrial wastewater discharge in the State are catalogued by DEHNR. Three sources of data on wastewater discharges at three different periods of time were available for analysis for this report (North Carolina State Stream Sanitation Committee, 1955, 1956, 1959, 1960, 1961; North Carolina Department of Natural and Economic Resources, 1974 and 1975a-e; and M.L. Toler-McCullen, North Carolina Department of Natural Resources and Community Development, written commun., 1989). Although the wastewater discharges reported were often estimates and were sometimes incomplete listings of the wastewater discharges, these data for the three different periods were the information available on wastewater discharges. Comparisons of the summed discharges for each of the three periods of time can be made. The total reported wastewater discharged in the Neuse River basin, the Tar River basin, and the Roanoke River basin downstream from Lake Gaston for three different periods is shown in figure 4. The total amount of wastewater discharged has increased from 1955 to 1988 in all of the river basins. The Neuse River basin, which contains several rapidly growing municipalities, had both the greatest wastewater increases (around 650 percent) and the greatest total wastewater discharges of all the rivers in the study area. Although the trend of increasing wastewater discharge into the estuary system is evident, it is unknown if constituent concentrations in the wastewater have changed because of improved wastewater-treatment technology and practices from 1955 to 1988.

The 1989 reported discharges and the 7-day, 10-year minimum low flows at the NASQAN stations on the Neuse, Tar, and Roanoke Rivers are given in table 4. Both the Tar River and the Neuse River wastewater discharge totals are nearly equal to or greater than the 7-day, 10-year low flows. The

Roanoke wastewater discharge total, which represents only the sum of the sources downstream from Lake Gaston, is approximately 11 percent of the 7-day, 10-year low flow at Roanoke Rapids.

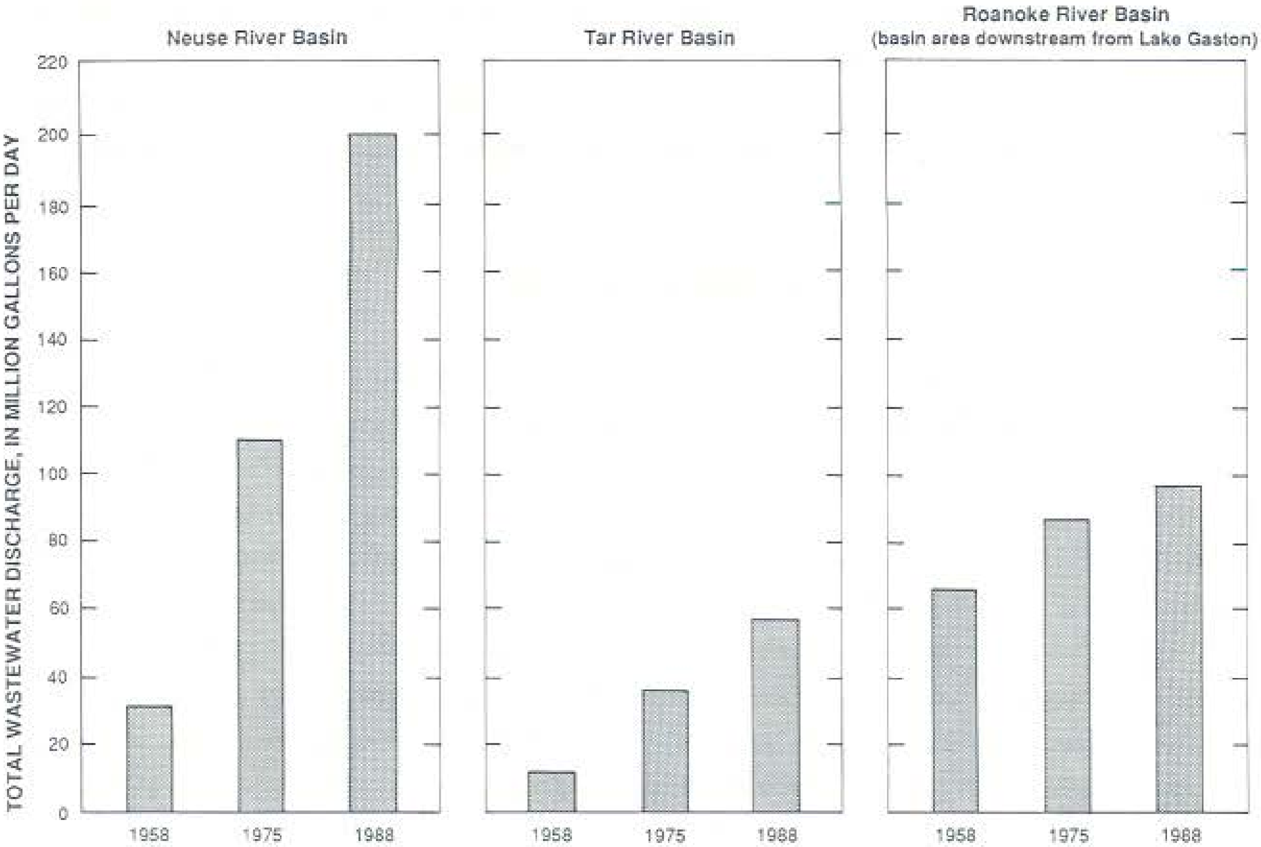

Figure 4.--Total wastewater discharges for the Neuse, Tar, and Roanoke River basins, North Carolina and Virginia.

Locations of all permitted wastewater discharges in the North Carolina section of the study area as of 1989 are shown in figure 5. Although there is a direct causal relation between wastewater discharges and instream water quality, there are not enough wastewater discharge data over time to correlate with observed river and estuary water quality.

Land Use

Residential and commercial development and population changes are reflected by changes in land use, which in turn may cause changes in downstream water quality. Land-use changes affecting wetlands in the Albemarle-Pamlico study area are of particular concern in assessing environmental effects.

Table 4.--*Total wastewater discharges in 1989*[a/] *and 7-day, 10-year low flows at selected National Stream Quality Accounting Network stations in the study area*

[Mgal/d, million gallons per day; ft³/s, cubic feet per second; mi², square mile]

River basin	Station name (fig. 2)	Station number[b/]	Number of wastewater sources	Total sum of wastewater discharges (Mgal/d)	Total sum of wastewater discharges (ft³/s)	7-day, 10-year low flow[c/] (ft³/s)	Drainage area (mi²)
Neuse	Neuse River at Kinston	02089500	218	192	298	205	2,692
Tar	Tar River at Tarboro	02083500	100	44	68	94	2,183
Roanoke	Roanoke River at Roanoke Rapids[d/]	02080500	35	72	112	1,103	8,384

[a/] M.L. Toler-McCullen, North Carolina Department of Natural Resources and Community Development, written commun., 1989.
[b/] U.S. Geological Survey downstream order number.
[c/] The period of record used for the Neuse River was 1930-90, for the Tar River was 1896-89, and for the Roanoke River was 1912-89.
[d/] Downstream from Lake Gaston.

Land-use data have been compiled in a variety of forms by numerous State and Federal agencies. In general, the land-use categories and classifications chosen by different agencies are inconsistent with each other, making comparison difficult. Further, land-use data usually are available only in map form, which must be digitized or compiled to obtain numeric information.

Two sources of land-use data were examined for this study to evaluate land-use change. Land Use Data Analysis (LUDA) maps produced by the USGS (Anderson and others, 1976) provide data on a regional scale (1:250,000) for general land-use categories in the study area. These maps were generated in 1972-74 using remote-sensing satellite data and available USGS 7 1/2-minute quadrangle maps. The minimum resolution of the LUDA maps is 10 acres. More recently, in 1982-83, the U.S. Fish and Wildlife Service began classifying and mapping (1:24,000) the wetlands and deep water habitats of the United States (Cowardin and others, 1979). Although the wetlands maps include a more restricted set of land-use categories than the LUDA maps, the wetlands maps are more detailed, having a minimum resolution of 1 acre. A comparison of the two maps indicates how these land uses changed from 1972 to 1983.

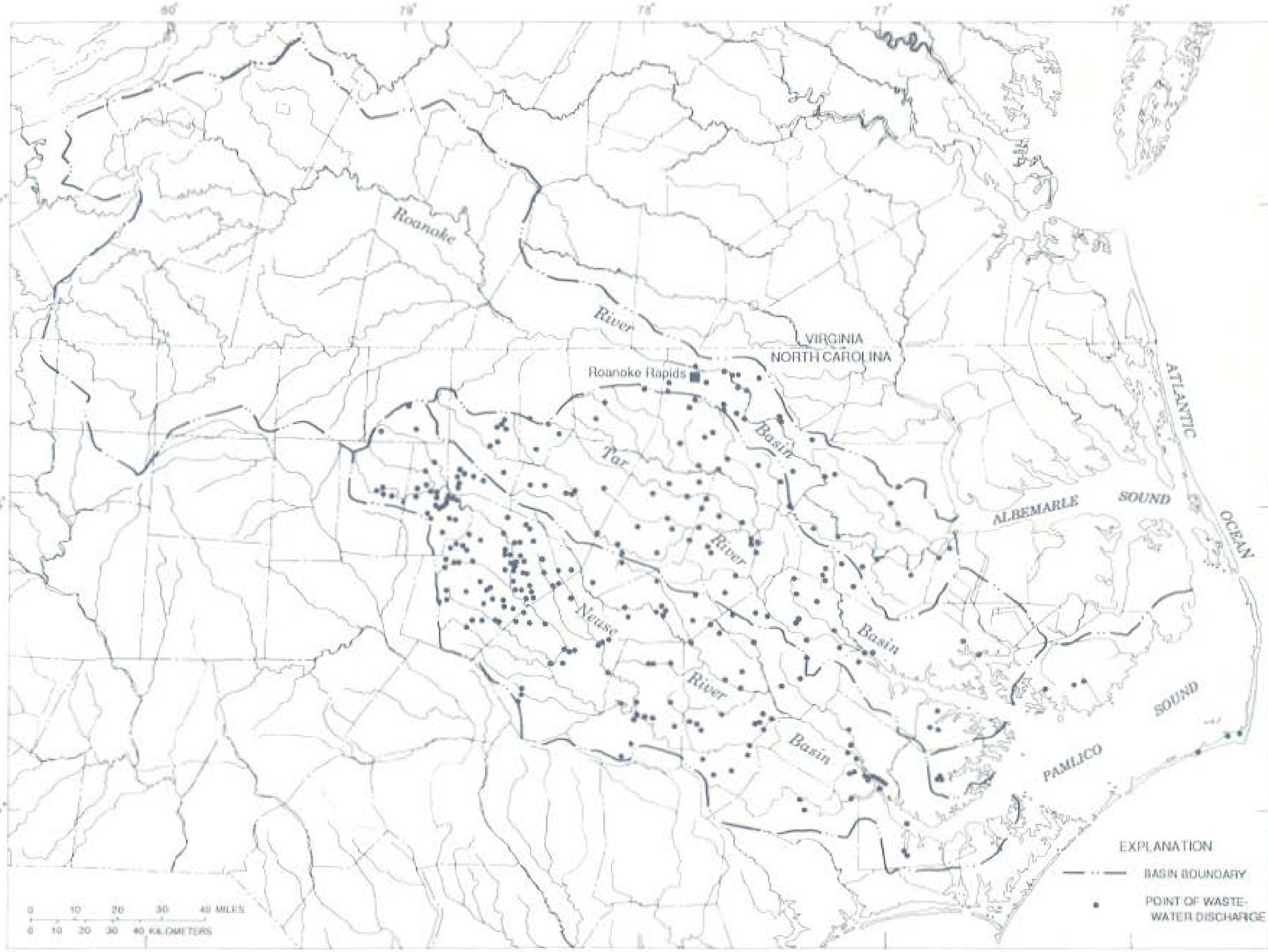

Figure 5.--Locations of points of wastewater discharge in the Roanoke River basin below Roanoke Rapids, the Tar River basin, and the Neuse River basin, 1989.

Both sets of map data were quantified for the lower parts of the Tar-Pamlico River basin, lower part of the Neuse River basin, and Outer Banks as shown in figure 6. The quantification was limited to these three areas in order to give a representation of land uses in the central part of the study area and yet not duplicate the ongoing digitization of the maps by the Land Resources Information Service of DEHNR. For this report, the smaller scale LUDA maps were sectioned into 7 1/2-minute quadrangles for comparison with the higher resolution U.S. Fish and Wildlife Service maps, and both were sampled with a square 10-acre point grid. The 10-acre sample size was chosen to match the minimum resolution of the LUDA series maps. The number of points for each category in each quadrangle were counted. Several quadrangles were done twice and also checked with a planimeter. The total number of points and the sum of points within each land-use category were compared for each quadrangle. If the difference for the U.S. Fish and Wildlife Service maps was greater than 3 percent, the quadrangle was redone. Because of nonlinear paper stretch, this error was kept less than 8 percent in the older LUDA maps.

The LUDA map results give the approximate land areas and percentages of major land uses of parts of the Tar-Pamlico, lower Neuse, and Outer Banks areas in 1972-74 (table 5). Evergreen forests (1,296.8 mi^2) and forested wetlands (1,245.4 mi^2) were the primary land uses in the area, each at approximately 25 percent of the land area. Cropland and pasture (1,049.8 mi^2 or approximately 20 percent of the total land area), mixed forest land (607.2 mi^2 or 12 percent), and nonforested wetland (530.0 mi^2 or 10 percent) were also major land uses in the area. The total urban land uses composed only 4 percent (210.9 mi^2) of the area examined. For comparison, in estimates of land uses based on LUDA data for the entire North Carolina Piedmont, Harned (1989) calculated a slightly higher amount of urban land uses (6 percent), slightly more cropland and pasture (25 percent), a much greater amount of forest (65 percent), and very little wetland (less than 1 percent) for the same period. This comparison illustrates that the Piedmont is more urban than the study area in the Coastal Plain and that much of the land in the Coastal Plain is wetlands.

The U.S. Fish and Wildlife Service map results give the approximate percentages of the major wetlands land uses of the Tar-Pamlico area for the period from 1982 to 1983 (table 6). Estuaries compare about 36 percent of

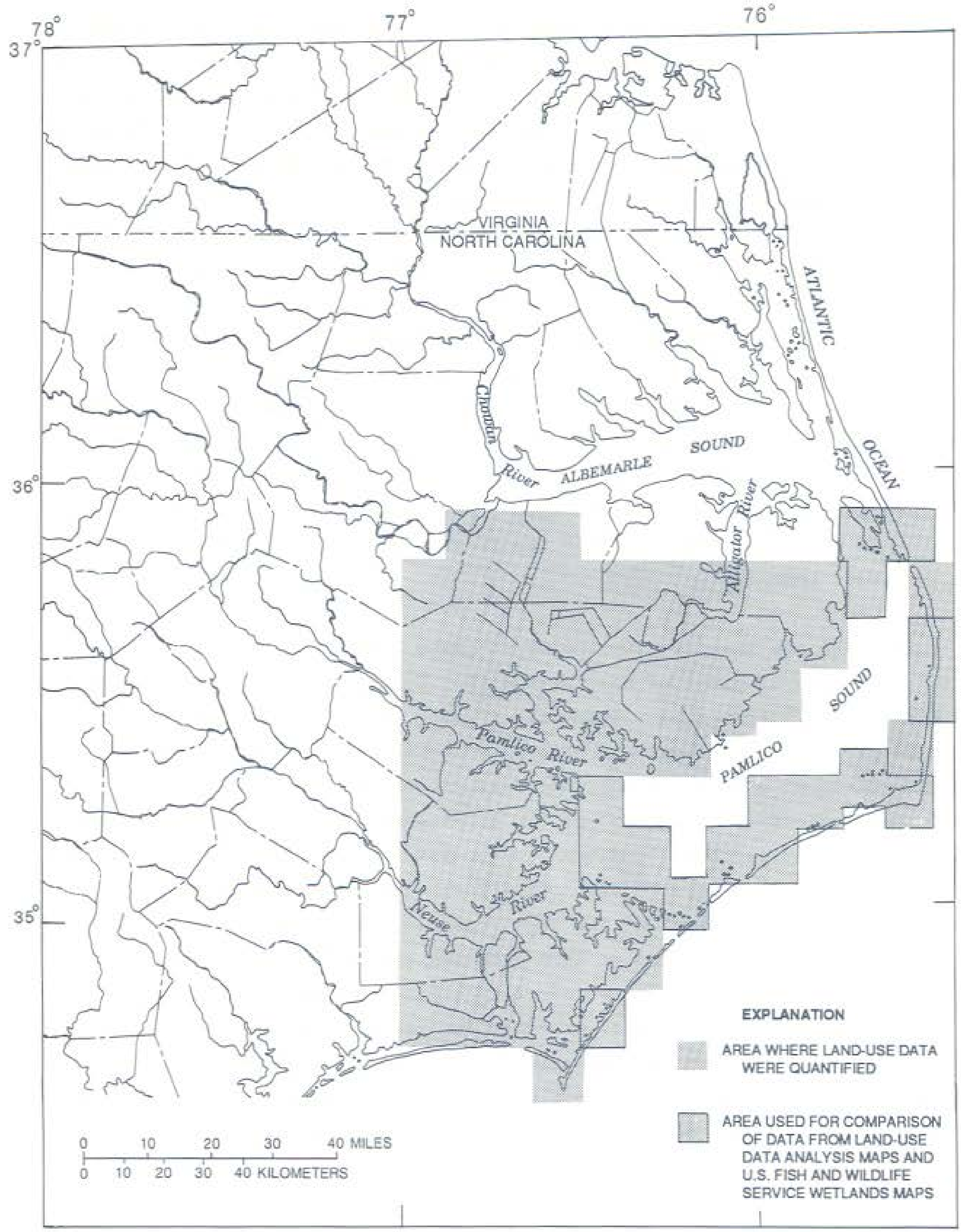

Figure 6.--Land-use areas.

Table 5.--*Major land uses (excluding water bodies) for parts of the lower Tar-Pamlico River basin, parts of the lower Neuse River basin, and parts of the Outer Banks areas, 1972-74*

[Data compiled from Land Use Data Analysis Maps (Anderson and others, 1976)]

Land-use type	Total land area (in square miles)	Percent of land area
Residential	149.2	2.9
Commercial and services	25.7	.5
Industrial	5.1	.1
Transportation	20.6	.4
Other urban	10.3	.2
Total urban	**210.9**	**4.1**
Cropland and pasture	**1,049.8**	**20.4**
Shrub rangeland	**25.7**	**.5**
Deciduous forest land	87.5	1.7
Evergreen forest land	1,296.8	25.2
Mixed forest land	607.2	11.8
Total forest land	**1,991.5**	**38.7**
Forested wetland	1,245.4	24.2
Nonforested wetland	530.0	10.3
Total wetland	**1,775.4**	**34.5**
Beaches	**46.3**	**.9**
Not listed	**46.3**	**.9**
Total	**5,145.9**	**100.0**

the total land area for the area examined. The definition of forest is an important consideration in a comparison between the LUDA land-use data and the U.S. Fish and Wildlife Service land-use data. The LUDA category system classifies many of the U.S. Fish and Wildlife Service wetlands categories as forest.

A comparison between the two sets of land-use data indicates that changes in land use with time can be determined for a limited number of the quadrangle maps that are of nonforested areas. The quadrangles used in this comparison are shown in figure 6. This subset of quadrangles is composed primarily of barrier island areas which are predominantly wetland. A total point count comparison between the LUDA data and the U.S. Fish and Wildlife Service maps yields a 2.1-percent error, well within the 3-percent maximum acceptable error established in the map sampling procedure. The LUDA data for 1972-74 show a total wetlands area of 97.7 percent for the subset of quadrangles. The U.S. Fish and Wildlife Service data for 1982-83 show a total wetlands area of 91.2 percent. Therefore, this comparison shows a decline in the area classified as wetlands of 6.5 percent over 10 years or a rate of loss of wetlands of 0.65 percent per year. This compares to rates of wetland loss that can be calculated from data from North Carolina Environmental Defense Fund (1989) for Washington County wetlands of 1.9 percent per year between 1956-82 and 0.13 percent per year between 1982-89. There are not enough data on changes in land use to test for correlations of land use with water quality.

Table 6.--*Major wetlands land uses in parts of the lower Tar-Pamlico River basin, parts of the lower Neuse River basin, and parts of the Outer Banks areas, 1982-83*
[Data compiled from U.S. Fish and Wildlife Service maps]

Category	Land area (in square miles)	Total land area (in square miles)	Percent of land area	Percent of total land area
Estuarine		**1,837.1**		**35.7**
Subtidal	1,512.9		29.4	
Intertidal	324.2		6.3	
Lacustrine		**102.9**		**2**
Littoral-aquatic bed	66.9		1.3	
Marine		**530.1**		**10.3**
Subtidal-unconsolidated bottom	524.9		10.2	
Palustrine		**1,039.6**		**20.2**
Emergent	41.2		.8	
Forested	813.1		15.8	
Scrub shrub	185.3		3.6	
Upland	1,636.2	**1,636.2**	31.8	**31.8**
Not listed	41.2		.8	
Total	**5,145.9**	5,145.9	**100.0**	**100.0**

Acreages of forested land in the Albemarle-Pamlico study area were obtained from the United States Department of Agriculture (USDA), Forest Service, for the early 1950's, 1960's, 1970's, and 1980's (Cost, 1974; Welch and Knight, 1974; Tansey, 1984; and Davenport, 1984). Total acres of forested land in each county in the Albemarle-Pamlico study area included commercial, noncommercial, unproductive, and productive-reserved forest acreages.

The acreage total (noncommercial, commercial, unproductive, and productive-reserved) forest land in the study area has decreased from 5,215,200 acres in 1962 to about 4,658,000 acres in 1984 (a decrease of about 25,000 acres per year), whereas the acres of nonforested land have steadily increased from about 3,063,400 acres in 1954 to more than 3,650,000 acres in 1984 (an increase of about 19,500 acres per year). Commercial forest land decreased from about 4,984,700 acres in 1954 to about 4,598,000 acres in 1984 (a decrease of about 18,000 acres per year), with the greatest decrease between 1954 and 1962.

Agriculture

Data relating to acres of agricultural land types and crop harvests, livestock counts, and tonnages of fertilizer sales were obtained from yearly publications prepared by the Federal-State Crop Reporting Service of the North Carolina Department of Agriculture (Federal-State Crop Reporting Service, 1919, 1925, 1932, 1933, 1938, 1943, 1947, 1951, 1953, 1954, 1956, 1958, 1960, 1962-65 (annual), 1967, 1968-87 (annual), 1969-74, 1975-78, and 1979-82). Data were retrieved by county for all North Carolina counties in the Albemarle-Pamlico study area. Fertilizer data were obtained for all counties in the river basins in the study area, including headwater areas in the Piedmont of North Carolina and Virginia (fig. 1). For analysis of trends in the agricultural data, data from the counties were summed by year and plotted for each year in which data were available.

The numbers of farms and acres of land in these farms were obtained from the North Carolina Agricultural Statistics annual publications (Federal-State Crop Reporting Service, 1919, 1925, 1932, 1933, 1938, 1943, 1947, 1951, 1953, 1954, 1956, 1958, 1960, 1962-65 (annual), 1967, 1968-87 (annual), 1969-74, 1975-78, and 1979-82). Both the mean number of farms in counties and mean number of acres of land in these farms within the Albemarle-Pamlico study area have generally decreased since the 1920's. A decrease of more than 60 percent in the number of farms was shown between the early 1950's and 1982.

Crops

Acreages of specific harvested crops and total harvested cropland greater than 50 acres per county were obtained for the period 1910 through the 1980's from the North Carolina Agricultural Statistics annual publications (Federal-State Crop Reporting Service, 1919, 1925, 1932, 1933, 1938, 1943, 1947, 1951, 1953, 1954, 1956, 1958, 1960, 1962-65 (annual), 1967, 1968-87 (annual), 1969-74, 1975-78, and 1979-82). Yearly acreages of soybeans, tobacco, corn, hay, wheat, peanuts, cotton, sweet and Irish potatoes, oats, rye, cowpeas, sorghum, lespedeza, and barley by county were compiled; however, only acreages of corn, soybeans, and tobacco significantly correlated with water-quality trends (see Correlation Analysis).

The percentages of corn, soybeans, and tobacco of the total acres of crops within the four major river basins in the North Carolina part of the study area for 1967 to 1986 are listed in table 7. An examination of these data shows that total acreages of corn harvests were highly variable from the 1910's through the 1980's. Two peaks occurred in corn harvests. The first peak (about 83,000 acres) occurred during the late 1940's; the second peak (about 83,000 acres) occurred during the early 1970's. Total acreage of soybeans per county ranged from 5 to 80,000 acres. Tobacco acreages generally decreased steadily from the 1950's to the present (1986).

Livestock

The number of chickens, cattle, milk and beef cows, hogs, sheep, horses, and mules by county for selected years from 1910 to 1986 were compiled (Federal-State Crop Reporting Service, 1919, 1925, 1932, 1933, 1938, 1943, 1947, 1951, 1953, 1954, 1956, 1958, 1960, 1962-65 (annual), 1967, 1968-87 (annual), 1969-74, 1975-78, and 1979-82). Only the number of chickens per county over time were significantly correlated with water-quality constituents (see Correlation Analysis). The number of chickens in the Albemarle-Pamlico study area has steadily increased since the 1950's; the number of chickens per county ranged from 1,500 to 2,730,000.

Fertilizer Use

The tons of fertilizer and (or) fertilizer constituents (such as ammonium nitrate) sold on a county basis within the Albemarle-Pamlico study area were obtained from Federal-State Crop Reporting Service Fertilizer Tonnage Reports for the years 1973 through 1987. Fertilizer data for years

Table 7.--*Summary of acreage of selected crops harvested and farmland in major river basins, 1967-86* [a]

	Neuse basin		Tar-Pamlico basin		Roanoke basin[b]		Chowan basin		All basins	
	Percent of total crops	Percent of basin	Percent of total crops	Percent of basin	Percent of total crops	Percent of basin	Percent of total crops	Percent of basin	Percent of total crops	Percent of basin
Corn	47.7	19.4	37.9	16.9	36.8	3.0	35.6	23.2	40.6	13.7
Soybeans	29.9	12.2	33.8	15.1	24.6	2	38	24.8	32.9	11.1
Tobacco	10.9	4.4	7.4	3.3	4.8	.4	.9	.6	6.6	2.2
Other crops	11.5	4.7	20.9	9.3	33.8	2.8	25.5	16.6	19.9	6.7
Total mean annual acreage[c]	737,000		655,000		195,000		585,000		2,172,000	
Total mean annual acreage of farmland	986,000		857,000		299,000		685,000		2,827,000	

[a] Federal-State Crop Reporting Service, 1967, 1968-87 (annual), 1969-74, 1975-78, and 1979-82.
[b] Includes North Carolina data only.
[c] Total acreages include multiple crops grown on the same land during a year.

prior to 1973 were retrieved from yearly North Carolina Agricultural Statistics publications (Federal-State Crop Reporting Service, 1956, 1958, 1960, 1962, 1964, 1965, 1967, and 1969-74). Tonnages of commercial fertilizers include tons of mixed fertilizers and fertilizer materials. Mixed fertilizers include all ratios of nitrogen, phosphorus, and potassium, such as 10-10-10 and 10-0-30, whereas fertilizer materials include chemical compounds, such as urea, anhydrous ammonia, super-phosphate, muriate of potash, dried manure, and others. Lime (calcium and magnesium carbonates) and landplaster (calcium sulfate) are considered soil conditioners and, for purposes of this report, are included with the commercial fertilizers, in calculating total fertilizer tonnage per county. Nitrogen concentrations in fertilizer have increased in recent years; therefore, total fertilizer tonnage does not give a direct measure of the nitrogen application.

Mixed fertilizer and fertilizer material sales between 1958 and 1987 indicate opposite trends--tonnages of mixed fertilizer steadily decreased, whereas sales of fertilizer material steadily increased. Commercial fertilizer sales increased from 1958 through the mid-1970's but declined in the 1980's. Comparison of mean tonnages of mixed fertilizers and fertilizer materials data indicates that the majority of the commercial fertilizer used is sold in the form of mixed fertilizers. Lime and landplaster data were only available for the years 1972 through 1987; therefore, reported fertilizer tonnages include these soil conditioners only for those years. Commercial fertilizers and lime constitute the greatest part of fertilizers and soil conditioners sold.

Population and Employment

Increases in population are inevitably accompanied by increases in amounts of human-produced wastes. Changes in population and demographic measures such as employment can, therefore, be related to possible changes in water quality.

Population and employment data were obtained from a number of sources. Population data were obtained from three sources: North Carolina Agricultural Statistics publications (Federal-State Crop Reporting Service, 1919, 1925, 1932, 1943, 1953, 1963); The North Carolina Office of State Budget and Management (1987, 1988); and publications prepared by the

Carolina Population Center for the Office of State Planning (Hamilton, 1974). Projections of population for the years 1990 through 2010 were obtained from the North Carolina Office of State Budget and Management (1988). Population in the Albemarle-Pamlico study area steadily increased from the 1910's through the 1980's, except for 1970 when there was a slight decrease.

Employment data were obtained from Employment Security Commission of North Carolina. Employment categories used in the analyses included mean total, manufacturing, nonmanufacturing, agricultural, and nonagricultural employment per county per year.

Manufacturing and nonmanufacturing employment generally increased from 1950 into the 1980's, whereas agricultural employment decreased. From 1962 to 1986, agricultural employment generally decreased and manufacturing employment slightly increased; nonmanufacturing and total employment increased substantially. Nonagricultural employment increased slightly from 1962 to 1983 and decreased from 1984 to 1986.

Roads

The miles of paved and unpaved roads in an area is an indicator of general growth. Mileages of paved and unpaved primary and secondary roads were obtained for the years 1966 through 1988 from the North Carolina Department of Transportation for the counties in the Albemarle-Pamlico study area. The total miles of unpaved secondary roads steadily decreased between 1966 and 1980. The miles of paved secondary roads in the North Carolina section of the Albemarle-Pamlico study area substantially increased since the 1960's; the miles of paved primary roads has increased at a slower rate. Mileages of total primary roads in the North Carolina section of the Albemarle-Pamlico study area increased more rapidly from 1968 to 1982 than from 1982 to 1988.

WATER-QUALITY TRENDS

An objective of this report is to identify long-term temporal and spatial trends in water quality in the Albemarle-Pamlico study area. This analysis was begun with a 5-step program to:

1. Construct the water-quality data base,
2. Evaluate sampling and analytical techniques,
3. Divide the data base into regional zones,
4. Edit the data within each zone, and
5. Establish trend-analysis methodology.

Trend-analysis results are discussed for selected water-quality properties, major dissolved constituents, macronutrients, and biological characteristics. Graphical representations of selected data are given in the form of box plots to illustrate some of the results of the trend analysis.

Sources of Data

There are three principal sources of water-quality data for the Albemarle-Pamlico study area. A number of individual investigators have collected data in various parts of the area. The U.S. Environmental Protection Agency data base, STORET, contains much of the data collected by DEHNR; and the USGS data base, National Water Data Storage and Retrieval System (WATSTORE), contains NASQAN data and atmospheric precipitation data for the stations in the NADP/NTN network. The data from these sources were merged into one data base for purposes of this report.

In addition to STORET and WATSTORE data values, water-quality data from 33 previous investigations in various parts of the study area were entered into the data base. The references for these studies, study locations, and principal constituents entered into the data base are given in table 8. The locations of water-quality data-collection stations used in these investigations are shown in figure 7, and the data-collection stations for data stored in the STORET data base are shown in figure 8. Many of the stations in the previous investigations are also stations for which there are other data in the STORET system.

Data collected by the USGS in the Albemarle-Pamlico study area, including data for the seven NASQAN stations (fig. 2) and two NADP/NTN stations (fig. 1), are stored in the WATSTORE data base and other related USGS data bases. Discharge data from NASQAN stations are the most complete available long-term flow data for the Albemarle-Pamlico estuarine system.

Table 8.--*List of selected previous water-quality investigations in parts of the study area and principal types of data collected*

Principal investigator or agency[1]	Date of publi-cation	Specific conductance	pH	Salinity	Temperature	Dissolved oxygen	Alkalinity	Nutrients: Nitrate	Nutrients: Nitrite	Nutrients: Ammonia nitrogen	Nutrients: Total nitrogen	Nutrients: Total phosphorus	Nutrients: Dissolved phosphorus	Nutrients: Ortho phosphorus	Nutrients: Dissolved organic carbon	Nutrients: Chlorophyll-a	River or water body of study
Bowden and Hobbie	1977			X	X	X		X	X	X	X	X	X	X		X	Albemarle Sound
Copeland and Davis	1972					X								X			Pamlico River
Davis, Brinson, and Burke	1978	X	X	X	X	X	X	X	X	X	X	X	X	X	X		Pamlico River
Fisher, Carlson, and Barber	1982				X					X						X	South, Neuse, and Newport Rivers
Hobbie	1970a											X	X	X			Pamlico River
Hobbie	1970b			X	X	X											Pamlico River
Hobbie	1972		X	X	X	X		X		X	X	X	X	X		X	Pamlico River
Hobbie	1974		X	X	X	X		X		X	X	X	X	X		X	Pamlico River
Hobbie and Smith	1975			X	X	X		X	X	X	X	X	X	X		X	Neuse River
Institute for Coastal & Marine Resources	1976		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
Institute for Coastal & Marine Resources	1977		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
Institute for Coastal & Marine Resources	1978		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
Institute for Coastal & Marine Resources	1980		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
Institute for Coastal & Marine Resources	1981		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
Institute for Coastal & Marine Resources	1982		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
Institute for Coastal & Marine Resources	1983		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
Kirby-Smith and Barber	1979		X	X	X	X		X	X	X				X			Neuse River
Kuenzler, Stanley, and Koenings	1979		X	X	X	X		X	X	X	X	X	X	X		X	Pamlico River
North Carolina Department of Natural and Economic Resources	1975a	X	X	X	X	X		X		X		X		X			Chowan River, Albemarle Sound
North Carolina Department of Natural Resources and Community Development	1979	X	X		X	X		X		X		X					Chowan River
North Carolina State Stream Sanitation Committee	1955		X		X	X	X	X	X	X							Chowan River
North Carolina State Stream Sanitation Committee	1956		X		X	X	X										Roanoke River
North Carolina State Stream Sanitation Committee	1959		X		X	X	X										Neuse River
North Carolina State Stream Sanitation Committee	1960		X		X	X	X										Pasquotank River, Currituck and Croatan Sounds
North Carolina State Stream Sanitation Committee	1961		X		X	X	X										Pamlico River
Paerl	1982							X		X				X			Chowan River
Stanley	1984		X	X	X	X		X		X	X	X	X	X		X	Pamlico River
Stanley	1986a		X	X	X	X		X		X	X	X	X	X		X	Pamlico River
Stanley	1986b		X	X	X	X		X		X	X	X	X	X		X	Pamlico River
Stanley	1987		X	X	X	X		X		X	X	X	X	X		X	Pamlico River
Stephenson, O'Rear, Jr., and Kornegay	1975		X	X	X	X		X		X	X	X	X	X		X	Pamlico River
Upchurch	1972			X	X	X									X		Pamlico River
U.S. Army Corps of Engineers	1977			X	X	X											Pamlico River

[1]See "References Cited" for complete citations.

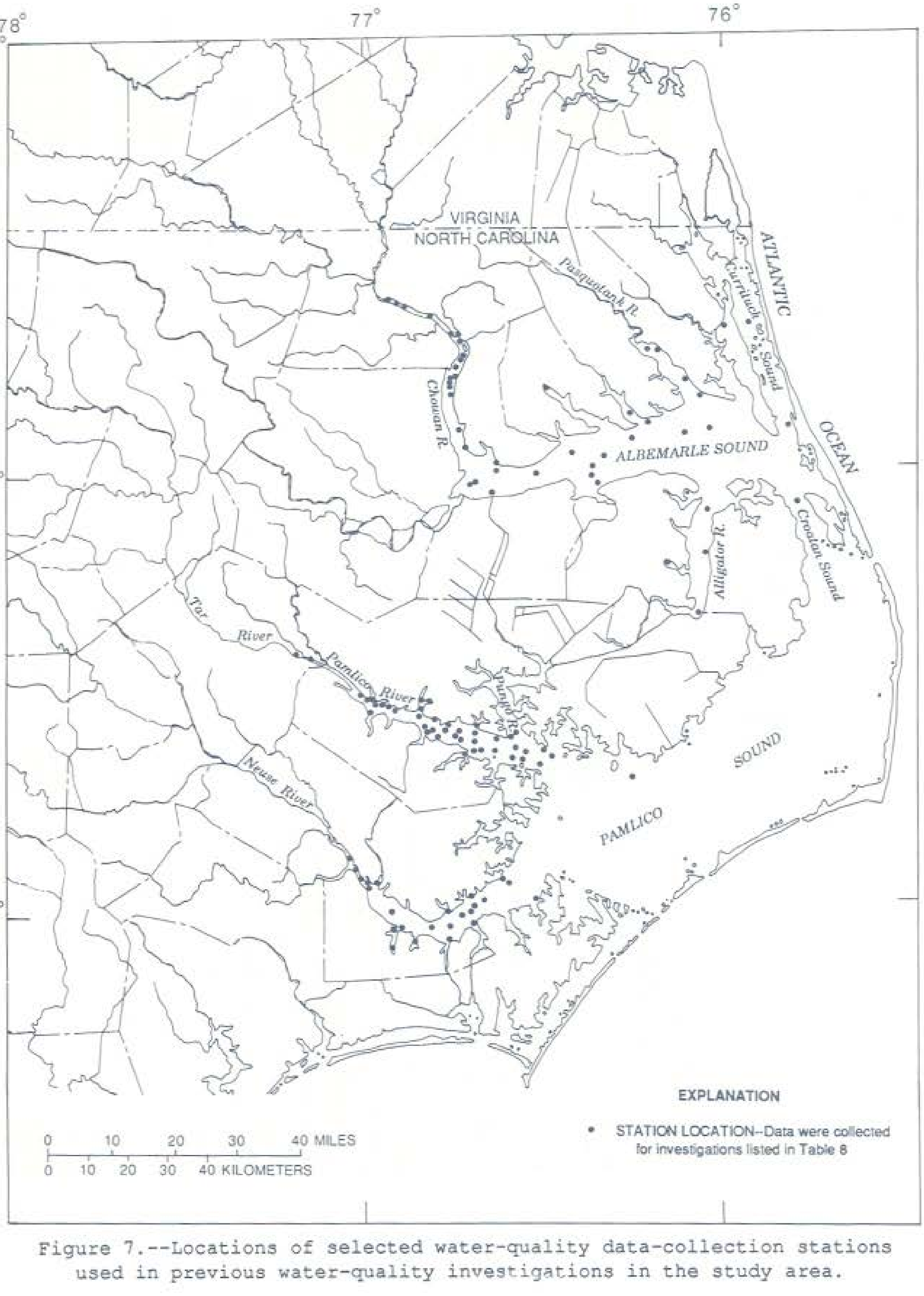

Figure 7.--Locations of selected water-quality data-collection stations used in previous water-quality investigations in the study area.

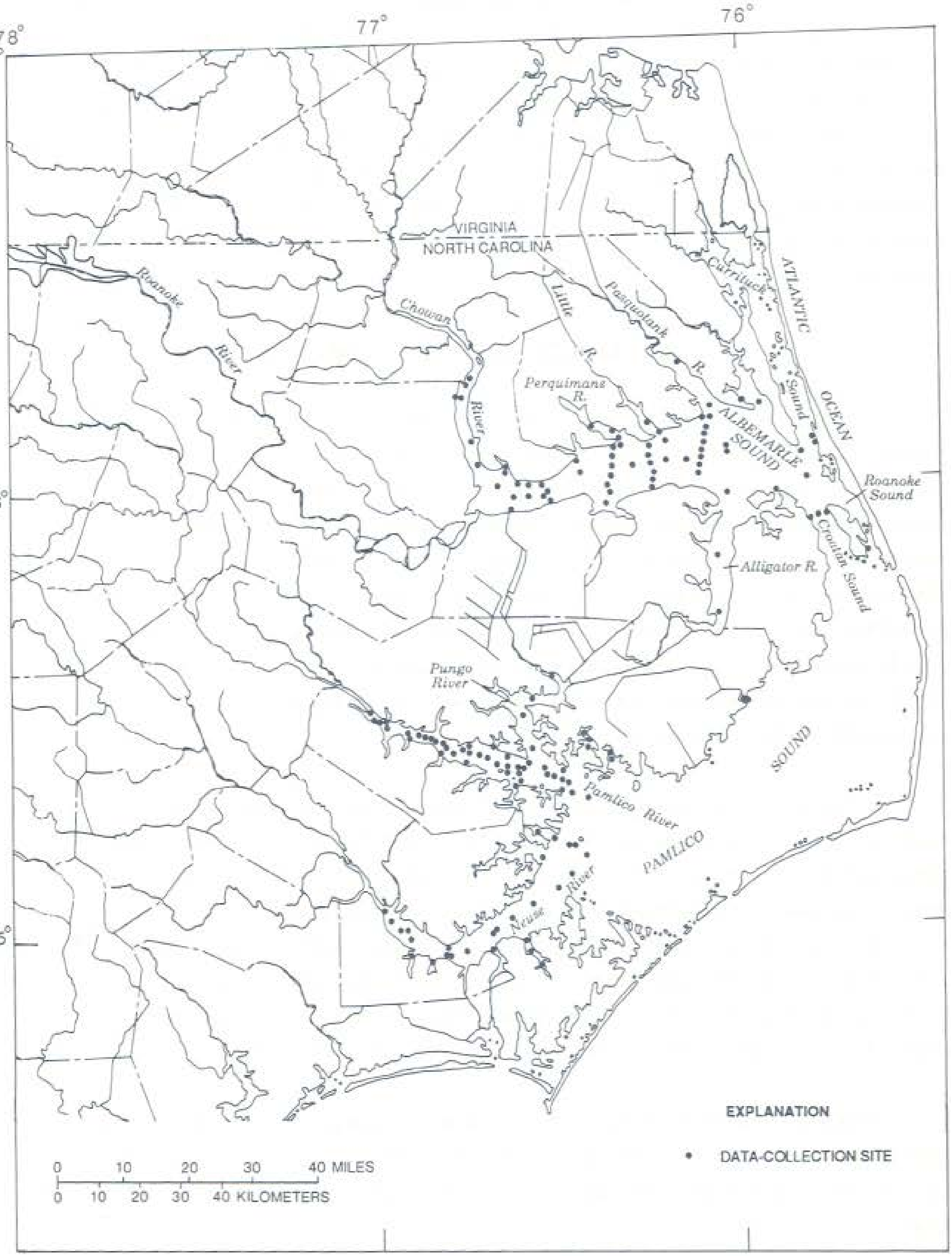

Figure 8.--Locations of water-quality data-collection sites having data stored in the U.S. Environmental Protection Agency Storage and Retrieval system data base.

Several sources of data were identified that could not, because of time limitations, be entered into the data base evaluated in this report. Notably, data from the Chowan River collected by NRCD (1979 and 1982b) from 1978 to 1981; data from the Chowan River collected by Union Camp (Joseph Stutts, Union Camp Corporation, oral commun., 1989); data from the Neuse and Roanoke Rivers collected by Weyerhaeuser Company (R.B. Herrmann, Weyerhaeuser Company, written commun., 1988) from 1979 to 1988; and data from Back Bay-Currituck Sound by the U.S. Fish and Wildlife Service (1966) were not used.

Variation in Analytical Techniques

One of the principal concerns about analyzing data combined from a number of different sources is that different sampling and analytical techniques are used, and the different techniques may result in noncomparable data. The primary problems associated with analytical techniques in water-column monitoring programs include: (1) use of a limited sensitivity range, (2) reporting of results as nondetectables or less-than values, (3) lack of use of direct elemental analysis of particulates, (4) unavailability of satisfactory measurement methods, and (5) problems of contamination in the analysis of metals and organic compounds (D'Elia and others, 1989).

Stanley (1988a) reports the variations in the analytical techniques for Pamlico River data compiled from four different sources. This detailed cataloging of techniques illustrates the complexity of the problem of comparing results obtained from different sources and the importance of recording analytical methodology as part of any monitoring program. Stanley made corrections for two years of dissolved phosphorus data that he found to be in error and deleted some ammonia nitrogen values measured at a limited sensitivity range. These data were not used in this report.

Detailed information on analytical methodology was not generally available in a form that would allow additional data transformation or correction. There were no data of this kind available for the STORET data base.

In order to address concerns about analytical techniques, the methods used in the individual studies (table 7) were catalogued and reviewed for inconsistencies. A literature review of the methods of analysis used by the various studies for their principal properties or constituents indicated that although the sensitivity of different analysis methods will vary, the results should be comparable among the studies. Systematic bias that might have been introduced in the data by an improperly functioning laboratory apparatus or variation due to different sampling and sample processing methods cannot easily be detected in the data and, therefore, were not addressed in this analysis.

In this manner, some constituents, including metals and organic compounds, were deleted completely from consideration of trend analysis. Other constituents, including ammonia nitrogen, although showing some limited sensitivity ranges and containing some reported less-than values, were retained; however, trend analysis was limited to those constituents where there were relatively few less-than values, and where there was no evidence of changes in lower detection limits with time. Finally, the trend analysis technique chosen--nonparametric Seasonal Kendall test for trends (Hirsch and others, 1982)--is valid for water-quality records containing less-than values.

Friedman and Fishman (1989) have reviewed analytical methodologies used from 1965 through 1982 to determine inorganic constituents in water samples as part of the interlaboratory Standard Reference Water Samples (SRWS) program of the USGS. This quality control program was designed to alert participating laboratories of possible analytical deficiencies, while allowing a means of comparison of analytical methodologies and their relative precision.

The Friedman and Fishman evaluation found no significant difference in constituent concentrations for the different analytical methodologies for ammonia nitrogen, ammonia plus organic nitrogen, nitrite plus nitrate nitrogen, and phosphorus. However, significant differences were observed in nitrate nitrogen concentrations between the cadmium reduction colorimetric method and the brucine and automated cadmium reduction colorimetric methods. Analysis of nitrate trends was dropped from this evaluation.

Significant differences also were observed in alkalinity values when comparing automated electrometric titration and electrometric titration techniques and in comparing automated electrometric titration and indicator titration techniques (Friedman and Fishman, 1989). However, it is unclear how methodology changes have affected the observed alkalinity trends, and analysis of these trends is included in this report.

Water-Quality Zones or Locations

In order to provide a sufficient period of record to test for trends, data from different stations were combined. The study area, which includes 255 data-collection stations, was divided into 42 zones or locations on the basis of the placement of collection sites. Each zone included stations within a defined section of one of the major rivers or sounds in the Albemarle-Pamlico study area (fig. 9). In general, the size of each zone was determined by the amount of data available at each station, particularly by the presence of one or more stations having an extensive period of record. However, the zones for the Pamlico River were defined to coincide with the zones used by Stanley (1988a) as closely as possible. Pamlico Sound locations P2, P3, and P4; Roanoke River location RO1; Chowan River location CH2; and Currituck Sound location CU2 are represented by single stations. A list of the zones or locations, their identifiers, latitude and longitude, and number of stations in each is given in table 9.

Data from the NASQAN stations (fig. 2) represent water quality upstream from the Albemarle-Pamlico estuary. The water quality for the NASQAN stations was examined separately from that of the water quality for zones or locations in figure 9.

The process of dividing the area into zones or locations for which water-quality data are available also allowed identification of areas that lack data. There are few data available for much of Pamlico, Croatan, Roanoke, and Currituck Sounds. Much more data are available for the Pamlico River than for the Neuse River, and both of these areas have more data available than for the Albemarle Sound. Finally, virtually no flow data were available before February 1988 for the system downstream from the NASQAN stations.

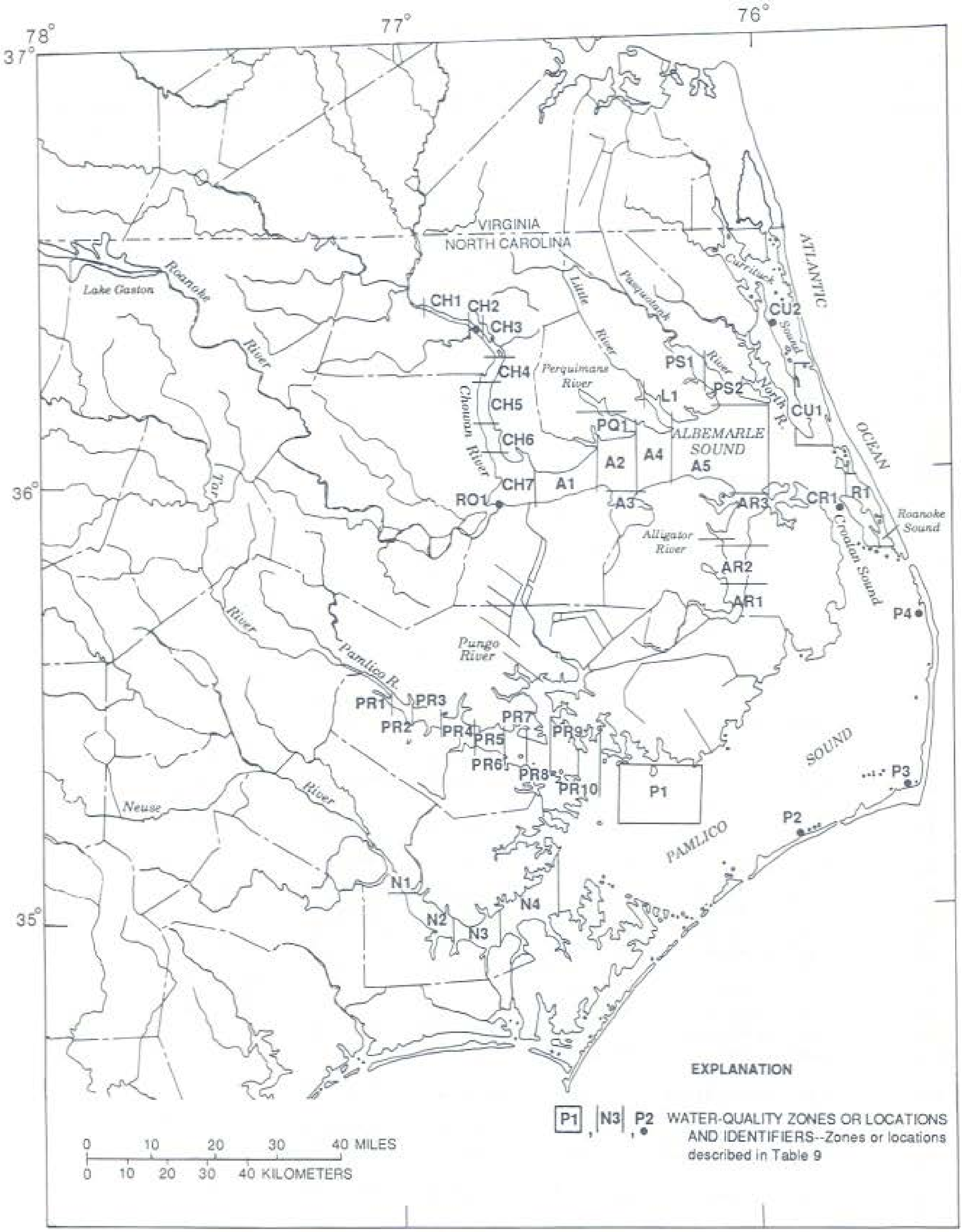

Figure 9.--Water-quality zones and locations used in trend analysis.

Table 9.--*Water-quality zones or locations*

Water-quality zone or location identifier (fig. 9)	Location	Boundaries of water-quality zones				Number of stations in the water-quality zone
		Latitude		Longitude		
		North	South	East	West	
A1	Albemarle Sound	36°05'00"	35°56'15"	76°22'30"	76°34'30"	9
A2	Albemarle Sound	36°05'45"	35°57'30"	76°17'00"	76°22'30"	12
A3	Albemarle Sound	35°57'30"	35°54'30"	76°15'00"	76°22'30"	3
A4	Albemarle Sound	36°05'45"	35°57'30"	76°11'15"	76°17'00"	8
A5	Albemarle Sound	36°10'15"	35°57'30"	75°55'00"	76°11'15"	19
AR1	Alligator River	35°45'00"	35°38'15"	75°55'00"	76°07'30"	2
AR2	Alligator River	35°51'00"	35°45'00"	75°55'00"	76°07'30"	2
AR3	Alligator River	35°57'30"	35°51'00"	75°55'00"	76°07'30"	2
CH1	Chowan River	36°24'00"	36°21'15"	76°49'00"	76°55'00"	3
CH2	Chowan River[1]	36°17'30"	36°17'30"	76°42'00"	76°42'00"	1
CH3	Chowan River	36°20'30"	36°17'45"	76°40'30"	76°45'00"	2
CH4	Chowan River	36°17'45"	36°14'30"	76°40'00"	76°43'00"	5
CH5	Chowan River	36°14'30"	36°09'30"	76°41'30"	76°45'15"	7
CH6	Chowan River	36°09'30"	36°03'15"	76°40'00"	76°44'00"	2
CH7	Chowan River	36°05'15"	35°35'45"	76°34'30"	76°44'00"	12
CR1	Croatan Sound	36°00'00"	35°49'30"	75°41'30"	75°48'00"	4
CU1	Currituck Sound	36°15'00"	36°03'30"	75°44'30"	75°50'00"	4
CU2	Currituck Sound[1]	36°19'30"	36°19'30"	75°53'00"	75°53'00"	1
L1	Little River	36°10'15"	36°05'45"	76°11'15"	76°15'00"	2
N1	Neuse River	35°10'45"	35°02'30"	76°56'00"	77°07'30"	6
N2	Neuse River	35°02'30"	34°55'30"	76°51'30"	76°59'00"	12
N3	Neuse River	35°02'00"	34°51'30"	76°42'15"	76°51'30"	9
N4	Neuse River	35°05'30"	34°57'00"	76°32'45"	76°42'15"	15
P1	Pamlico Sound	35°20'30"	35°13'15"	76°07'00"	76°21'45"	6
P2	Pamlico Sound[1]	35°09'30"	35°09'30"	75°52'10"	75°52'10"	1
P3	Pamlico Sound[1]	35°17'30"	35°17'30"	75°32'00"	75°32'00"	1
P4	Pamlico Sound[1]	35°41'18"	35°41'18"	75°30'00"	75°30'00"	1
PR1	Pamlico River	35°33'30"	35°28'15"	77°00'00"	77°05'20"	5
PR2	Pamlico River	35°30'30"	35°25'00"	76°56'00"	77°00'00"	8
PR3	Pamlico River	35°29'00"	35°25'00"	76°52'00"	76°56'00"	7
PR4	Pamlico River	35°30'00"	35°21'30"	76°46'00"	76°52'00"	16
PR5	Pamlico River	36°26'15"	35°21'30"	76°42'00"	76°46'00"	10
PR6	Pamlico River	35°21'30"	35°17'30"	76°42'00"	76°47'45"	8
PR7	Pamlico River	36°26'15"	35°20'00"	76°37'15"	76°42'00"	10
PR8	Pamlico River	36°23'30"	35°18'30"	76°33'00"	76°37'15"	10
PR9	Pamlico River	36°23'30"	35°18'30"	76°30'00"	76°33'00"	9
PR10	Pamlico River	36°22'00"	35°18'30"	76°24'45"	76°30'00"	7
PQ1	Perquimans River	36°08'45"	36°05'45"	76°14'45"	76°24'00"	3
PS1	Pasquotank River	36°19'00"	36°12'15"	76°05'30"	76°14'45"	4
PS2	Pasquotank River	36°15'00"	36°10'15"	76°00'00"	76°05'30"	3
R1	Roanoke Sound	36°00'00"	35°49'30"	75°35'00"	75°41'30"	3
RO1	Roanoke River[1]	35°55'20"	35°55'20"	76°42'50"	76°42'50"	1

[1]Location is represented by a single station.

In general, it is important to note that, except for the NASQAN station data, none of the data used in this report were collected to be used in an evaluation of long-term trends. There is an immediate and continuing need for a network designed to monitor the water quality of the Albemarle-Pamlico estuarine system, coupled with discharge measurements. The monitoring network established in this system by the USGS in February 1988 (J.D. Bales, U.S. Geological Survey, written commun., 1989) addresses this need and, if operated for an extended period of time, could provide data for evaluations of long-term water-quality trends in the study area.

Verification of Data

Data verification and editing procedures were used to delete outliers from the data set. Because of the wide-scale nature of the retrieval, some data for wastewater effluents were included in the original data base. These outliers were detected using scatter plots and frequency histograms for subsets of the data. Extreme values above the upper 95th percentile were deleted from the data base. The data removed represents only selected values above the 95th percentile thought to represent nonambient water-quality conditions. A preponderance of less-than values for a particular constituent also indicated variables unsuitable for trend analysis because of low analytical sensitivity, changing detection levels over time, or changing analytical techniques. These constituents were deleted from the data base. However, not all constituents with less-than values were removed from the data base. The statistical methods used in the trend analyses are not substantially affected by less-than values.

Plots of chemical constituent or physical property data values and time were used to identify data coding errors and to help determine if the time periods of available data were suitable for trend analyses. In general, only constituents or properties with 6 or more years of available record per water-quality zone or location were considered for trend analysis.

A statistical summary of selected constituent or property data values after the data verification step for the NASQAN stations is presented in table 10. Similarly, a summary of data for the individual investigations and STORET stations is provided in table 11. These summaries illustrate the range of water-quality conditions encountered in the study area but do not represent conditions in any one area.

Table 10.--*Statistical summary of selected water-quality data collected at the National Stream Quality Accounting Network stations*

[ft^3/s, cubic feet per second; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter]

Water-quality variable	Number of observations	Minimum value or concentration	Value or concentration at indicated percentile 25	50	75	Maximum value or concentration
Neuse River at Kinston, [1]02089500						
Discharge, instantaneous (ft^3/s)	381	238	614.5	1,405	3,915	16,000
Specific conductance (µS/cm at 25 °C)	381	38	70.5	89	114	205
Field pH (standard units)	381	5.3	6.2	6.5	6.8	9.3
Dissolved oxygen (mg/L)	381	5.1	6.6	8.4	10.4	13.8
Total hardness (mg/L as $CaCO_3$)	381	9	16	18	22	32
Field alkalinity (mg/L as $CaCO_3$)	381	3	13	18	29.3	51
Bicarbonate ion (mg/L as HCO_3)	381	4	15	18.5	24	45
Dissolved chloride (mg/L as Cl)	381	3	6.8	8.8	11	20
Dissolved solids (residue on evaporation, mg/L at 180 °C)	381	36	60	70	79	126
Total nitrite plus nitrate nitrogen (mg/L as N)	381	.01	.32	.61	.80	1.2
Total ammonia plus organic nitrogen (mg/L as N)	381	.10	.56	.70	.90	4.7
Total phosphorus (mg/L as P)	381	.05	.15	.22	.29	.46
Suspended sediment (mg/L)	381	8	19	26	36	211
Contentnea Creek at Hookerton, [1]02091500						
Discharge, instantaneous (ft^3/s)	152	37.5	143.5	407	1,525	6,030
Specific conductance (µS/cm at 25 °C)	152	37	78	93	113	175
Field pH (standard units)	152	5.0	5.9	6.2	6.4	7.5
Dissolved oxygen (mg/L)	152	4.6	6.5	7.6	10	13
Total hardness (mg/L as $CaCO_3$)	152	10	15	18	21	27
Field alkalinity (mg/L as $CaCO_3$)	152	3	9	12	16	40
Bicarbonate ion (mg/L as HCO_3)	152	5	10	13	19	49
Dissolved chloride (mg/L as Cl)	152	3.7	8.8	10	13	25
Dissolved solids (residue on evaporation, mg/L at 180 °C)	152	26	66.8	78	85	118
Total nitrite plus nitrate nitrogen (mg/L as N)	152	.22	.85	1.3	1.6	2.2
Total ammonia plus organic nitrogen (mg/L as N)	152	.43	.70	.88	1.1	1.9
Total phosphorus (mg/L as P)	152	.09	.21	.33	.53	1.6
Suspended sediment (mg/L)	152	0	9.3	15	26	123
Tar River near Tarboro, [1]02083500						
Discharge, instantaneous (ft^3/s)	425	127	442	1,200	2,510	18,900
Specific conductance (µS/cm at 25 °C)	425	45	69	84.5	100	270
Field pH (standard units)	425	5.5	6.3	6.7	7	9.1
Dissolved oxygen (mg/L)	425	4.2	6.8	8.2	9.8	15.2
Total hardness (mg/L as $CaCO_3$)	425	9	18	21	24	37
Field alkalinity (mg/L as $CaCO_3$)	425	4	13.8	21	27.3	51.0
Bicarbonate ion (mg/L as HCO_3)	425	5	17	25	32	69

[1]U.S. Geological Survey downstream order number.

Table 10.--*Statistical summary of selected water-quality data collected at the National Stream Quality Accounting Network stations*--Continued

[ft^3/s, cubic feet per second; μS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter]

Water-quality variable	Number of observations	Minimum value or concentration	Value or concentration at indicated percentile 25	50	75	Maximum value or concentration
Tar River near Tarboro, [1]02083500--Continued						
Dissolved chloride (mg/L as Cl)	425	2.5	5.9	7.5	9.5	54
Dissolved solids (residue on evaporation, mg/L at 180 °C)	425	29	61	69	80	122
Total nitrite plus nitrate nitrogen (mg/L as N)	425	.03	.25	.32	.44	.89
Total ammonia plus organic nitrogen (mg/L as N)	425	.09	.50	.60	.73	1.2
Total phosphorus (mg/L as P)	425	0	.10	.13	.18	1.1
Suspended sediment (mg/L)	425	1	12	22	35	454
Roanoke River at Roanoke Rapids, [1]02080500						
Discharge, instantaneous (ft^3/s)	171	996	2,310	6,135	17,750	35,400
Specific conductance (μS/cm at 25 °C)	171	60	82.8	95	108	128
Field pH (standard units)	171	5.5	6.4	6.8	7.1	7.8
Dissolved oxygen (mg/L)	171	5.6	8.1	9.5	11.9	15.8
Total hardness (mg/L as $CaCO_3$)	171	21	26	29	31	41
Field alkalinity (mg/L as $CaCO_3$)	171	16	25	30	33	49
Bicarbonate ion (mg/L as HCO_3)	171	19	31	36	40	54
Dissolved chloride (mg/L as Cl)	171	3.2	5.4	6.4	8.1	12
Dissolved solids (residue on evaporation, mg/L at 180 °C)	171	44	61.8	65	71	88
Total nitrite plus nitrate nitrogen (mg/L as N)	171	.01	.05	.18	.24	.66
Total ammonia plus organic nitrogen (mg/L as N)	171	.10	.25	.32	.42	2.4
Total phosphorus (mg/L as P)	171	.01	.02	.02	.04	.24
Suspended sediment (mg/L)	171	1.0	5	8	11.5	47
Meherrin River at Emporia, Virginia, [1]02052000						
Discharge, instantaneous (ft^3/s)	370	19	163	390	843	13,400
Specific conductance (μS/cm at 25 °C)	370	15	67	75	89	205
Field pH (standard units)	370	6.2	6.8	7.0	7.1	7.6
Dissolved oxygen (mg/L)	370	1.8	7.8	9.8	11.8	15.0
Total hardness (mg/L as $CaCO_3$)	370	11	20	22	28	85
Field alkalinity (mg/L as $CaCO_3$)	370	7	19	25	30	45
Bicarbonate ion (mg/L as HCO_3)	370	9	24	30	36	74
Dissolved chloride (mg/L as Cl)	370	1.6	4.2	5.0	6.3	21
Dissolved solids (residue on evaporation, mg/L at 180 °C)	370	42	61	66	73	164
Total nitrite plus nitrate nitrogen (mg/L as N)	370	.02	.06	.09	.12	.22
Total ammonia plus organic nitrogen (mg/L as N)	370	.08	.30	.40	.60	3.7
Total phosphorus (mg/L as P)	370	.01	.03	.05	.06	.19
Suspended sediment (mg/L)	370	7	14	19.5	28.3	169

[1]U.S. Geological Survey downstream order number.

Table 10.--*Statistical summary of selected water-quality data collected at the National Stream Quality Accounting Network stations*--Continued

[ft^3/s, cubic feet per second; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter]

Water-quality variable	Number of observations	Minimum value or concentration	Value or concentration at indicated percentile 25	50	75	Maximum value or concentration
Nottoway River near Sebrell, Virginia, [1]02047000						
Discharge, instantaneous (ft^3/s)	136	33	219	905	2,245	13,800
Specific conductance (µS/cm at 25 °C)	136	36	56	67	90	125
Field pH (standard units)	136	5.9	6.5	6.7	7.0	7.5
Dissolved oxygen (mg/L)	136	4.9	6.9	8.3	10.4	16.2
Total hardness (mg/L as $CaCO_3$)	136	9	16.5	20	24.5	36
Field alkalinity (mg/L as $CaCO_3$)	136	4	10	17	23	36
Bicarbonate ion (mg/L as HCO_3)	136	5.0	18	24.5	30	52
Dissolved chloride (mg/L as Cl)	136	2.2	4	4.6	5.5	10
Dissolved solids (residue on evaporation, mg/L at 180 °C)	136	34	52	59	67	95
Total nitrite plus nitrate nitrogen (mg/L as N)	136	0	.09	.13	.18	.25
Total ammonia plus organic nitrogen (mg/L as N)	136	.10	.30	.44	.58	2.2
Total phosphorus (mg/L as P)	136	.01	.03	.04	.06	.15
Suspended sediment (mg/L)	136	1	9	13	19.8	82
Blackwater River near Franklin, Virginia, [1]02049500						
Discharge, instantaneous (ft^3/s)	215	.18	68	364	1,120	4,870
Specific conductance (µS/cm at 25 °C)	215	49	78	94.5	120	366
Field pH (standard units,	215	5.2	6.4	6.7	6.9	10.0
Dissolved oxygen (mg/L)	215	1.5	5.4	7.2	10	13.6
Total hardness (mg/L as $CaCO_3$)	215	15	24.3	28	41	140
Field alkalinity (mg/L as $CaCO_3$)	215	5	11.5	16	23.5	55
Bicarbonate ion (mg/L as HCO_3)	215	6.0	13.3	18	25	48
Dissolved chloride (mg/L as Cl)	215	1.8	6.6	8.1	9.7	16
Dissolved solids (residue on evaporation, mg/L at 180 °C)	215	40	65.3	77.5	96	267
Total nitrite plus nitrate nitrogen (mg/L as N)	215	0	.06	.19	.34	.68
Total ammonia plus organic nitrogen (mg/L as N)	215	.17	.48	.63	.78	1.5
Total phosphorus (mg/L as P)	215	.01	.03	.04	.06	.11
Suspended sediment (mg/L)	215	2	7	10	14.3	50

[1]U.S. Geological Survey downstream order number.

Table 11.--*Statistical summary of selected stream water-quality data collected during previous investigations in parts of the study area and stored in the U.S. Environmental Protection Agency Storage and Retrieval System*

[µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; ppt, parts per thousand; NTU, nephelometric turbidity unit; mg/L, milligram per liter; mL, milliliter; µg/L, microgram per liter]

Water-quality variable	Number of observations	Minimum value or concentration	Value or concentration at indicated percentile			Maximum value or concentration
			25	50	75	
Specific conductance (µS/cm at 25 °C)	5,201	0.0	90	420	4,200	60,000
Field pH (standard units)	19,571	2.9	6.8	7.4	7.9	10
Salinity (ppt)	20,256	0	2	6	10	28
Turbidity (NTU)	1,861	.2	5.4	8.4	14	60
Dissolved oxygen (mg/L)	21,517	0	6.7	8.2	9.9	14.4
Biochemical oxygen demand (BOD) 5-day at 20 °C (mg/L)	5,379	.1	1.3	1.8	2.6	11
Fecal coliform, membrane filter (colonies per 100 mL)	4,673	0	10	10	40	35,000
Fecal streptococci (colonies per 100 mL)	668	0	4	23	113	30,000
Total hardness (mg/L as $CaCO_3$)	663	0	38	390	1,500	5,000
Dissolved chloride (mg/L)	1,733	1	535	2,200	5,000	20,000
Field alkalinity (mg/L as $CaCO_3$)	2,878	0	19	31	46	120
Total solids, residue (mg/L)	3,313	6	104	144	1,100	45,500
Total volatile solids (mg/L)	2,535	3	43	59	299	15,000
Total solids, nonvolatile (mg/L)	2,545	5	61	99	1,495	30,900
Suspended solids, residue at 105 °C (mg/L)	4,451	0	6	10	15	170
Nonfilterable, volatile residue (mg/L)	3,435	0	3	5	7	103
Suspended solids (mg/L)	3,447	0	2	5	10	93
Total nitrite plus nitrate nitrogen (mg/L as N)	7,433	0	.05	.13	.25	1.60
Total ammonia nitrogen (mg/L as N)	17,882	0	.042	.060	.10	5.99
Total ammonia plus organic nitrogen (mg/L as N)	13,420	.02	.40	.52	.71	2.65
Total phosphorus (mg/L as P)	17,191	.003	.076	.12	.19	1.00
Dissolved phosphorus (mg/L as P)	4,210	0	.050	.080	.13	.60
Total organic carbon (mg/L)	1,271	5	10	12	18	71
Chlorophyll-a, fluorometric, corrected (µg/L)	2,213	0	3	7	17	190
Chlorophyll-a, fluorometric (µg/L)	10,110	.2	4	8	14	170

Trend-Analysis Methodology

The statistical test used for trend analysis was the Seasonal Kendall test as described by Hirsch and others (1982); see also Crawford and others (1983) and Schertz and Hirsch (1985). The Seasonal Kendall test is a nonparametric or distribution-free procedure. Frequency distributions of water-quality properties and constituents generally are skewed, serially correlated, and affected by seasonality. Parametric procedures, such as linear regression, assume a frequency distribution that can be approximated by a randomly distributed normal curve and are, therefore, difficult to use correctly when applied to the analysis of water-quality data.

The Seasonal Kendall test was developed to detect monotonically (one direction) increasing or decreasing trends over time in water-quality data that show seasonality. The test examines pairs of values over time, assigning a plus if an increase occurs from one value to the next, or a minus if a decrease occurs. The pairs of values compared are selected only from the same seasonal period. In this analysis, each year was divided into 12 "seasons" (months). The values within each month are summarized as medians, and the test is done on the median values (Crawford and others, 1983; Schertz and Hirsch, 1985). In the monthly version of the test used, January median values were compared with later January median values; February median values were compared with later February median values, and so on. If the count of pluses found is greater than the count of minuses, then an increasing trend is indicated. If more minuses occur, then a decreasing trend is indicated. The use of the median by the Seasonal Kendall test reduces the effect of outliers and provides some protection against serial correlation in the data (Schertz and Hirsch, 1985). In the Seasonal Kendall test used for this study, a significance level (alpha) of 0.05 was considered to show statistical significance of the trend test.

The magnitude of a trend can be quantified using the Seasonal Kendall slope estimator (Hirsch and others, 1982). This procedure calculates the median of the slopes of lines drawn between all the monthly value pairs compared. The resultant estimate of slope is in units of concentration (generally milligrams per liter) change per year. This slope estimator is shown only to allow some estimate of the magnitude of the detected trends and is not used in the determination of trend significance.

Annual box plots are used for graphical representation of water-quality trends in a zone or location. Because the Seasonal Kendall test only identifies monotonic trends, a graphical presentation of the data could show patterns of increasing and decreasing trends with time. These graphs were also used to check for questionable statistical results given by the Seasonal Kendall test.

A box plot is a summary display of the data distribution (Chambers and others, 1983). The top of the box indicates the 75th percentile of the data set, and the bottom of the box indicates the 25th percentile. The difference between the 75th and 25th percentiles is the interquartile range. The median (50th percentile) is depicted by a horizontal line drawn through the box. The mean is designated by a dot. The line above the box extends to the largest value that is less than or equal to the 75th percentile plus the interquartile range times 1.5. The line below the box extends to the smallest value that is greater than or equal to the 25th percentile minus the interquartile range times 1.5. Extreme values are those that occur above or below these lines and are not shown. There is no calculated relation between the slope estimator value and the observable slopes in the mean or median values seen in the box plots. Furthermore, derivation of the box plots was completely independent from the assessment of trend significance by the Seasonal Kendall test.

Variation of discharge causes variation in constituent concentration (Harned, 1982). Discharge data were available for the NASQAN stations but nowhere else downstream. To compensate for the effect of discharge on water-quality constituents collected at the NASQAN stations, regression-residuals analysis was used (Crawford and others, 1983). In regression-residuals analysis, the regression relations between specific conductance (sc) and discharge (Q) were tested for the seven NASQAN stations. Specific conductance has been measured on a daily basis at the NASQAN stations for periods of 6 to 26 years. Thus, specific conductance is a particularly useful property to test for relation to daily discharge. Four different regression models were tested for each station:

$$sc = b + m\,Q \quad \text{(linear)}, \tag{1}$$

$$sc = b + m\,1/Q \quad \text{(inverse)}, \tag{2}$$

$$sc = b + m \log Q \quad \text{(semi-log), and} \tag{3}$$

$$\log sc = b + m \log Q \quad \text{(log-log)}, \tag{4}$$

where b is the intercept on the x axis and m is the slope.

The log-log model (equation 4) had the overall best fit of the four models and was used in subsequent analyses. The log-log function was fitted using least-squares regression to the water-quality data for each constituent or property. The residuals from this regression model are considered to have the effects of discharge removed. The residuals were then adjusted by adding them to the period of record mean to keep the values positive and were converted to antilogs. Finally, the adjusted residuals were tested for trends using the Seasonal Kendall test, and box plots were prepared for graphical detection of nonmonotonic trends with time.

Although discharge compensation was not possible for the zones or locations downstream from the NASQAN stations, the Seasonal Kendall test provides some limited adjustment for seasonal variations of discharge. Freshwater inflow to the estuaries varies seasonally and is, therefore, one source of seasonal variation in water quality. Because the Seasonal Kendall test is designed to remove seasonality, the component of seasonal variability in water quality that freshwater inflow may cause is accounted for by the test.

The water-quality data in the zones downstream from the NASQAN stations were correlated with discharge at the NASQAN stations to test for relations. When the annual mean discharges were compared to annual median values of water quality, no meaningful systematic correlations were found. This test lends some assurance that water-quality comparisons on an annual basis in the downstream zones are not largely a function of annual discharge variation.

Trend-Analysis Results

The results of the Seasonal Kendall test for trends in selected water-quality constituents for the NASQAN stations and NADP/NTN precipitation-quality stations are listed in table 12, and trends test results for the combined STORET and individual investigation stations are presented in table 13. In these tables, only results with a significance level (alpha) equal to or less than 0.05 are shown.

All of the trend results were examined individually using annual box plots for each zone or location. The box plots were used to identify generalized nonmonotonic trends with time and to identify spatial trends; they were also used as a means of identifying questionable data. These box plots can be used to provide a frame of reference for the relative change in values of the slopes cited in the trend analyses. It is important to note that these annual box plots are shown to illustrate the amount and distribution of the data used in the Seasonal Kendall trend tests. However, it is emphasized that the means and medians shown in the box plots are not the seasonal medians actually used in the trends test, so that trends that may be evident in the annual values are not necessarily the trends evaluated by the Seasonal Kendall test. Conversely, the annual values may show little or no trend, where the Seasonal Kendall test detects one. Also, years with few data points should not by themselves bias the trend test results. The trend test procedure examines the data seasonally so that data from a period of the year with generally high values will be compared to data from a like period of the next year. The nonmonotonic trends observed in the box plots are qualitative and have not been tested statistically. Finally, only data from 1970 to 1988 are shown in the box plots for consistency. The Seasonal Kendall trend test was applied to all the data for a zone, including the data available before 1970.

Properties

Dissolved oxygen

Dissolved oxygen is essential for aquatic life and the breakdown of waste materials that may be present in a stream. The U.S. Environmental Protection Agency (1986) has established a concentration of 5.0 milligrams

Table 12.--*Summary of the Seasonal Kendall trend test results for selected discharge-unadjusted and discharge-adjusted water-quality data collected at National Stream Quality Accounting Network stations, and National Atmospheric Deposition Program/National Trends Network stations*

[Only results with a probability less than 0.05 are shown. The alpha significance level was 0.05. The null hypothesis tested was that there is no trend. µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; "Raw" indicates discharge-unadjusted data; "Adjusted" indicates discharge-adjusted data; * indicates that trend tests were made but trends were insignificant or data were questionable; <0.001 indicates probability level less than 0.001; --, insufficient data for analysis; NADP/NTN, National Atmospheric Deposition Program/National Trends Network]

River or station name and number[1] / Probability (P) / Trend slope (Slope)[2] / Number of observations (N) / Period of record (Record)	Dissolved oxygen Raw	Dissolved oxygen Adjusted	pH Raw	pH Adjusted	Alkalinity Raw	Alkalinity Adjusted	Bicarbonate Raw	Bicarbonate Adjusted	Suspended sediment Raw	Suspended sediment Adjusted	Hardness Raw	Hardness Adjusted
Nottoway River, 02047000												
P	.047	*	*	*	*	*	*	*	*	*	*	*
Slope	-.085	--	--	--	--	--	--	--	--	--	--	--
N	75	67	109	101	51	51	46	46	76	67	89	89
Record	1977-88		1945-88		1968-87		1945-78		1977-88		1945-85	
Blackwater River, 02049500												
P	<.001	.025	*	.017	*	*	*	*	*	*	.001	<.001
Slope	-.23	-.21	--	-.010	--	--	--	--	--	--	.306	.283
N	86	78	146	138	65	65	48	48	118	110	96	96
Record	1977-88		1945-88		1968-87		1945-78		1974-88		1945-85	
Meherrin River, 02052000												
P	*	*	*	*	*	*	*	*	*	*	*	*
Slope	--	--	--	--	--	--	--	--	--	--	--	--
N	54	66	289	223	331	272	304	245	56	48	334	275
Record	1977-88		1952-88		1967-87		1952-79		1979-88		1952-85	
Roanoke River, 02080500												
P	*	*	*	*	.002	.002	*	*	.006	.035	*	*
Slope	--	--	--	--	.775	.805	--	--	-.333	-.211	--	--
N	99	83	110	98	81	81	80	80	125	110	72	72
Record	1976-88		1957-88		1976-87		1957-85		1975-88		1957-86	
Tar River, 02083500												
P	*	*	<.001	<.001	*	*	.045	*	*	*	<.001	<.001
Slope	--	--	-.014	-.017	--	--	.112	--	--	--	.200	.150
N	166	149	297	269	218	209	280	268	145	130	271	260
Record	1968-88		1955-88		1953-88		1953-85		1973-88		1953-86	
Neuse River, 02089500												
P	*	*	*	*	*	*	.029	.006	*	*	<.001	<.001
Slope	--	--	--	--	--	--	.111	.070	--	--	.167	.158
N	169	154	299	284	158	156	238	238	159	146	227	227
Record	1973-88		1955-88		1973-88		1955-86		1973-88		1955-87	
Contentnea Creek, 02091500												
P	*	*	--	--	.031	*	.035	.057	.002	*	<.001	<.001
Slope	--	--	--	--	.354	--	.191	.114	-1.19	--	.391	.305
N	87	72	107	92	73	73	67	67	104	89	55	55
Record	1968-88		1955-88		1968-88		1955-86		1975-88		1955-86	
Lewiston NADP/NTN station, 0340320												
P	--		*		--		--		--		*	
Slope	--		--		--		--		--		--	
N	0		232		0		0		0		382	
Record		0	1978-87			0		0		0	1978-87	
Clinton NADP/NTN station, 0340560												
P	--		*		--		--		--		*	
Slope	--		--		--		--		--		--	
N	0		259		0		0		0		386	
Record		0	1978-87			0		0		0	1978-87	

River or station name and number[1] / Probability (P) / Trend slope (Slope)[2] / Number of observations (N) / Period of record (Record)	Specific conductance (µS/cm at 25 °C) Daily values Raw	Specific conductance Daily values Adjusted	Specific conductance Periodic samples Raw	Specific conductance Periodic samples Adjusted	Dissolved solids Raw	Dissolved solids Adjusted	Chloride Raw	Chloride Adjusted	Total ammonia plus organic nitrogen Raw	Total ammonia plus organic nitrogen Adjusted	Total phosphorus Raw	Total phosphorus Adjusted
Nottoway River, 02047000												
P	*	*	.042	*	.045	*	<.001	<.001	*	.028	*	*
Slope	--	--	1.40	--	.144	--	.071	.042	--	.035	--	--
N	3,846	3,846	83	75	117	109	117	109	76	68	77	69
Record	1968-80		1952-88		1945-88		1945-88		1978-88		1977-88	
Blackwater River, 02049500												
P	*	*	.005	.006	<.001	.003	<.001	<.001	*	*	*	*
Slope	--	--	.893	.723	.714	.535	.104	.090	--	--	--	--
N	3,846	3,846	136	128	116	108	124	116	114	106	118	110
Record	1968-80		1951-88		1945-88		1945-88		1974-88		1974-88	
Meherrin River, 02052000												
P	*	*	*	*	*	*	*	*	*	*	*	*
Slope	--	--	--	--	--	--	--	--	--	--	--	--
N	3,846	3,846	362	295	354	289	362	295	58	50	58	50
Record	1968-80		1952-88		1952-88		1952-88		1979-88		1979-88	
Roanoke River, 02080500												
P	*	.022	.009	.028	*	*	<.001	.001	*	*	*	*
Slope	--	1.48	.926	.857	--	--	.133	.125	--	--	--	--
N	2,922	2,922	110	94	90	90	90	90	81	81	86	86
Record	1976-84		1957-88		1957-88		1957-88		1976-88		1976-88	
Tar River, 02083500												
P	<.001	<.001	<.001	<.001	<.001	<.001	.023	.023	*	*	.005	.022
Slope	.766	.647	.643	.400	.727	.627	.040	.024	--	--	.004	.006
N	9,485	9,485	310	284	269	269	288	277	116	116	122	122
Record	1953-86		1953-88		1953-88		1953-88		1973-88		1972-88	
Neuse River, 02089500												
P	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	*	*	*	*
Slope	1.200	.894	1.29	.783	.810	.614	.092	.042	--	--	--	--
N	7,969	7,969	310	284	248	248	252	252	130	130	135	135
Record	1955-86		1953-88		1955-88		1955-88		1973-88		1973-88	
Contentnea Creek, 02091500												
P	*	.006	<.001	<.001	.002	.014	.004	*	*	*	.011	.027
Slope	--	1.907	1.85	.958	1.09	.815	.145	--	--	--	.0271	.011
N	2,463	2,463	277	262	82	82	82	82	64	64	65	65
Record	1979-84		1955-88		1955-88		1955-88		1979-88		1972-88	
Lewiston NADP/NTN station, 0340320												
P	--		.001		--		*		--		--	
Slope	--		1.92		--		--		--		--	
N	0		226		0		385		0		0	
Record		0	1978-87			0	1978-87			0		0
Clinton NADP/NTN station, 0340560												
P			*		--		*		--		--	
Slope	--		--		--		--		--		--	
N	0		254		0		357		0		0	
Record		0	1978-87			0	1978-87			0		0

[1]U.S. Geological Survey downstream order number.

[2]Positive slope values indicate increasing trends; negative slope values indicate decreasing trends.

Table 13.--*Summary of the Seasonal Kendall trend test results for selected water-quality data stored in U.S. Environmental Protection Agency Storage and Retrieval System and collected for selected previous investigations in the study area*

[Only results with a probability less than 0.05 are shown. The alpha significance level was 0.05. The null hypothesis tested was that there is no trend. * indicates that trend tests were made but trends were insignificant or data were questionable; <0.001 indicates probability level less than 0.001; --, insufficient data for analysis]

Water-quality zone or location identifier (table 9) Probability (P) Trend slope (Slope) Number of observations (N) Period of record (Record)	Dissolved oxygen	pH	Alkalinity	Turbidity	Total solids	Total volatile solids	Total non-volatile solids	Suspended solids	Volatile suspended solids	Nonvolatile suspended solids	Total hardness	Salinity
Neuse River water-quality zones												
N1												
P	*	0.001	*	*	*	*	*	<0.001	*	<0.001	*	*
Slope	--	.036	--	--	--	--	--	-.586	--	-.500	--	--
N	2,299	1,062	720	308	436	695	707	692	955	969	102	1,100
Record	1956-88	1956-88	1969-87	1973-88	1970-88	1970-85	1970-85	1970-88	1970-86	1970-86	1973-88	1970-88
N2												
P	<0.001	.001	*	*	*	*	*	.006	*	.005	*	*
Slope	.100	.050	--	--	--	--	--	-.800	--	-1.00	--	--
N	627	226	133	55	84	141	150	147	206	209	27	502
Record	1956-88	1956-88	1969-85	1973-88	1979-86	1979-82	1979-82	1979-88	1979-86	1979-86	1973-88	1970-88
N3												
P	.004	*	*	--	--	--	--	--	--	--	--	--
Slope	-.250	--	--	--	--	--	--	--	--	--	--	--
N	385	81	73	16	0	0	0	0	0	0	12	406
Record	1956-75	1956-73	1969-73	1973	0	0	0	0	0	0	1973	1970-74
N4												
P	<.001	.019	*	*	--	--	--	.009	*	.019	*	*
Slope	.119	.022	--	--	--	--	--	-1.29	--	-1.47	--	--
N	939	313	125	86	14	9	26	90	61	63	46	886
Record	1956-88	1956-88	1969-87	1973-88	1977-82	1977-80	1977-80	1976-88	1976-86	1976-86	1973-88	1970-88

Water-quality zone or location identifier (table 9) Probability (P) Trend slope (Slope) Number of observations (N) Period of record (Record)	Dissolved chloride	Total organic carbon	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Biochemical oxygen demand	Fecal streptococci	Fecal coliform	Chlorophyll-a, corrected for phaeopigments	Chlorophyll-a
Neuse River water-quality zones												
N1												
P	*	*	*	*	*	*	--	*	--	--	0.013	*
Slope	--	--	--	--	--	--	--	--	--	--	.950	--
N	385	42	840	725	728	727	156	855	78	63	334	481
Record	1973-88	1976-85	1970-88	1973-88	1972-88	1972-88	1970-74	1969-88	1969-80	1979-84	1981-88	1970-88
N2												
P	*	--	*	*	.002	*	--	.052	--	--	*	.001
Slope	--	--	--	--	-.012	--	--	.100	--	--	--	.738
N	94	3	250	145	146	145	117	130	50	53	73	182
Record	1973-88	1979	1970-88	1979-88	1979-88	1979-88	1970-74	1973-88	1973-80	1979-80	1981-88	1970-88
N3												
P	--	--	--	--	--	--	--	--	--	--	--	--
Slope	--	--	--	--	--	--	--	--	--	--	--	--
N	9	0	140	9	15	12	117	24	35	0	0	147
Record	1973	0	1970-73	1973	1972-73	1972-73	1970-74	1969-73	1969-73	0	0	1970-73
N4												
P	.010	--	*	.002	<.001	.014	--	*	.045	<.001	--	.009
Slope	216.7	--	--	-.013	-.004	-.003	--	--	-.383	-.222	--	.332
N	134	16	573	144	145	144	156	219	132	169	26	499
Record	1973-88	1976-85	1970-88	1973-88	1973-88	1973-88	1970-74	1973-88	1969-85	1976-86	1983-88	1970-88

Table 13.--*Summary of the Seasonal Kendall trend test results for selected water-quality data stored in U.S. Environmental Protection Agency Storage and Retrieval System and collected for selected previous investigations in the study area*--Continued

[Only results with a probability less than 0.05 are shown. The alpha significance level was 0.05. The null hypothesis tested was that there is no trend. * indicates that trend tests were made but trends were insignificant or data were questionable; <0.001 indicates probability level less than 0.001; --, insufficient data for analysis]

Water-quality zone or location identifier (table 9) Probability (P) Trend slope (Slope) Number of observations (N) Period of record (Record)	Dissolved oxygen	pH	Alkalinity	Turbidity	Total solids	Total volatile solids	Total nonvolatile solids	Suspended solids	Volatile suspended solids	Nonvolatile suspended solids	Total hardness	Salinity	Dissolved chloride	Total organic carbon	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Biochemical oxygen demand	Fecal streptococci	Fecal coliform	Chlorophyll-a, corrected for phaeopigments	Chlorophyll-a
Pamlico River water-quality zones																								
PR1																								
P	*	<.001	*	*	*	--	--	.001	*	.032	--	*	*	--	*	<.001	*	<.001	*	*	--	.017	--	*
Slope	--	-.038	--	--	--	--	--	-.500	--	-.429	--	--	--	--	--	.022	--	.005	--	--	--	2.5	--	--
N	1,252	1,496	99	59	51	38	38	106	70	70	21	635	75	7	932	693	87	1,051	319	135	5	175	24	928
Record	1958-88	1958-88	1968-86	1973-88	1973-87	1973-85	1973-85	1973-88	1973-86	1973-86	1983-88	1977-88	1976-88	1976-77	1969-88	1970-88	1973-88	1967-88	1969-74	1969-88	1969-70	1973-88	1983-88	1970-88
PR2																								
P	<.001	*	*	*	*	*	*	*	*	*	--	.023	*	--	<.001	<.001	.006	.02	*	*	--	--	--	.020
Slope	.070	--	--	--	--	--	--	--	--	--	--	.032	--	--	-.004	.019	-.005	.002	--	--	--	--	--	.175
N	1,358	1,073	102	46	53	49	49	74	63	63	20	1,154	87	14	877	725	114	962	127	162	5	1	8	856
Record	1958-88	1958-88	1968-86	1973-88	1976-85	1976-85	1976-85	1976-88	1976-86	1976-86	1983-88	1968-88	1975-88	1976-77	1969-88	1970-88	1973-88	1968-88	1969-74	1974-87	1968-70	1982	1982-88	1970-88
PR3																								
P	.001	.024	--	--	--	--	--	--	--	--	--	*	--	--	<.001	<.001	--	.001	*	--	--	--	--	*
Slope	.066	-.017	--	--	--	--	--	--	--	--	--	--	--	--	-.004	.025	--	.003	--	--	--	--	--	--
N	387	629	0	0	0	0	0	0	0	0	0	836	0	0	354	265	0	464	249	0	0	0	0	373
Record	1968-85	1969-86	0	0	0	0	0	0	0	0	0	1967-86	0	0	1969-86	1970-86	0	1967-85	1969-74	0	0	0	0	1970-86
PR4																								
P	*	.003	*	<.001	--	--	--	*	*	*	--	*	<.001	*	*	<.001	*	*	*	*	--	--	--	*
Slope	--	-.023	--	-1.05	--	--	--	--	--	--	--	--	500	--	-.004	.017	--	--	--	--	--	--	--	--
N	1,375	1,773	55	72	6	5	4	59	60	60	21	2,193	56	46	1,296	947	83	1,599	326	55	2	2	28	1,319
Record	1958-88	1958-88	1968-87	1973-88	1982-85	1982-85	1982	1982-88	1982-88	1982-88	1983-88	1967-88	1982-88	1982-86	1969-88	1970-88	1973-88	1967-88	1969-74	1978-88	1968-78	1982	1982-88	1970-88
PR5																								
P	<.001	.006	*	*	--	--	--	.002	*	*	--	*	*	--	<.001	<.001	.001	.038	*	*	*	*	--	*
Slope	.081	-.025	--	--	--	--	--	-1.417	--	--	--	--	--	--	-.004	.015	-.005	.002	--	--	--	--	--	--
N	915	1,289	77	36	15	11	9	39	25	25	21	1,321	46	0	788	710	76	987	359	107	85	89	10	673
Record	1968-88	1968-88	1968-86	1973-88	1978-82	1978-85	1978-80	1978-88	1978-86	1978-86	1983-88	1967-88	1977-88	0	1969-88	1970-88	1973-88	1967-88	1969-74	1977-88	1968-84	1977-85	1984-88	1970-88
PR6																								
P	*	.008	--	--	--	--	--	--	--	--	--	*	--	--	<.001	<.001	--	.001	*	--	--	--	--	*
Slope	--	-.029	--	--	--	--	--	--	--	--	--	--	--	--	-.004	.026	--	.006	--	--	--	--	--	--
N	593	565	22	4	0	0	0	0	0	0	0	602	0	0	344	246	0	435	165	0	8	0	0	365
Record	1958-86	1958-86	1968-73	1973	0	0	0	0	0	0	0	1967-86	0	0	1969-86	1970-86	0	1967-85	1969-74	0	1968-70	0	0	1970-86
PR7																								
P	<.001	.005	--	*	*	--	--	*	*	*	--	*	*	*	<.001	<.001	*	*	*	*	--	--	*	*
Slope	.044	-.025	--	--	--	--	--	--	--	--	--	--	--	--	-.003	.019	--	--	--	--	--	--	--	--
N	1,230	1,578	15	109	54	15	15	103	73	73	47	1,983	98	81	1,107	754	103	1,513	322	72	1	0	48	354
Record	1957-88	1957-88	1968-84	1973-88	1982-88	1982-85	1982-85	1982-88	1982-86	1982-86	1983-88	1967-88	1982-88	1982-88	1969-88	1970-88	1973-88	1967-88	1969-74	1982-88	1968	0	1982-88	1970-88
PR8																								
P	*	<.001	--	--	--	--	--	--	--	--	--	*	--	--	<.001	*	--	<.001	*	--	--	--	--	*
Slope	--	-.043	--	--	--	--	--	--	--	--	--	--	--	--	-.003	--	--	.004	--	--	--	--	--	--
N	75	1,078	0	0	0	0	0	0	0	0	0	1,391	0	1	530	198	1	763	443	0	0	0	0	789
Record	1958-76	1958-86	0	0	0	0	0	0	0	0	0	1967-86	0	1976	1969-86	1970-77	1976	1967-85	1969-74	0	0	0	0	1970-86
PR9																								
P	--	<.001	--	--	--	--	--	--	--	--	--	*	--	--	<.001	.008	--	<.001	*	--	--	--	--	*
Slope	--	<.034	--	--	--	--	--	--	--	--	--	--	--	--	-.003	.015	--	.005	--	--	--	--	--	--
N	12	706	0	0	0	0	0	0	0	0	0	684	0	0	425	273	0	483	245	0	0	0	0	435
Record	1958-77	1958-86	0	0	0	0	0	0	0	0	0	1969-86	0	0	1969-86	1970-86	0	1968-85	1969-74	0	0	0	0	1970-86
PR10																								
P	<.001	<.001	--	--	--	--	--	--	--	--	--	.004	--	--	<.001	<.001	--	<.001	*	--	--	--	--	*
Slope	.110	-.053	--	--	--	--	--	--	--	--	--	-.157	--	--	-.003	.015	--	.003	--	--	--	--	--	--
N	455	822	0	0	0	0	0	0	0	0	0	997	0	0	488	235	0	563	319	0	0	0	0	457
Record	1968-86	1969-86	0	0	0	0	0	0	0	0	0	1967-86	0	0	1969-86	1970-86	0	1967-85	1969-74	0	0	0	0	1970-86

Table 13.--*Summary of the Seasonal Kendall trend test results for selected water-quality data stored in U.S. Environmental Protection Agency Storage and Retrieval System and collected for selected previous investigations in the study area*--Continued

[Only results with a probability less than 0.05 are shown. The alpha significance level was 0.05. The null hypothesis tested was that there is no trend. * indicates that trend tests were made but trends were insignificant or data were questionable; <0.001 indicates probability level less than 0.001; --, insufficient data for analysis]

Water-quality zone or location identifier (table 9) Probability (P) Trend slope (Slope) Number of observations (N) Period of record (Record)	Dissolved oxygen	pH	Alkalinity	Turbidity	Total solids	Total volatile solids	Total non-volatile solids	Suspended solids	Volatile suspended solids	Non-volatile suspended solids	Total hardness	Salinity	Dissolved chloride	Total organic carbon	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Biochemical oxygen demand	Fecal streptococci	Fecal coliform	Chlorophyll-a, corrected for phaeo-pigments	Chlorophyll-a
Pamlico Sound water-quality zone or locations																								
P1																								
P	*	*	*	*	--	--	--	*	--	.001	--	--	*	--	*	*	*	*	--	*	.023	*	--	--
Slope	--	--	--	--	--	--	--	--	--	-4.00	--	--	--	--	--	--	--	--	--	--	-.750	--	--	--
N	156	131	28	29	18	14	14	37	29	29	13	19	31	9	43	43	43	42	0	62	32	53	2	2
Record	1957-86	1957-86	1974-82	1974-86	1976-86	1976-82	1977-82	1976-86	1976-85	1976-85	1983-86	1981-86	1974-86	1976-80	1974-86	1974-86	1974-86	1974-86	0	1974-86	1977-86	1976-86	1982-84	1982-84
P2																								
P	*	*	--	--	--	--	--	.030	--	.023	--	--	*	--	*	*	*	*	--	*	*	*	--	--
Slope	--	--	--	--	--	--	--	-3.71	--	-4.33	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	66	27	30	19	9	5	5	22	18	18	6	13	31	4	38	38	38	36	0	66	31	52	0	0
Record	1974-84	1974-84	1974-82	1974-84	1974-82	1974-77	1974-77	1974-84	1974-84	1974-84	1983-84	1981-84	1974-84	1976-77	1974-84	1974-84	1974-84	1974-84	0	1974-84	1977-84	1976-84	0	0
P3																								
P	*	.006	.024	*	--	--	*	.022	*	*	--	--	*	--	*	*	*	<.001	--	*	*	.010	--	--
Slope	--	.086	6.70	--	--	--	--	-2.00	--	--	--	--	--	--	--	--	--	-.003	--	--	--	-1.00	--	--
N	83	39	37	27	10	7	5	30	24	24	12	18	43	7	50	51	49	49	0	81	37	60	0	0
Record	1973-86	1973-86	1973-86	1973-86	1974-82	1974-77	1974-77	1974-86	1974-86	1974-86	1983-86	1981-86	1973-86	1976-77	1973-86	1973-86	1973-86	1973-86	0	1973-86	1977-85	1976-86	0	0
P4																								
P	.026	*	.035	*	--	--	--	.020	--	.021	--	--	*	--	*	*	*	*	--	*	*	.037	--	--
Slope	.100	--	5.00	--	--	--	--	-1.75	--	-2.62	--	--	--	--	--	--	--	--	--	--	--	-.310	--	--
N	78	34	36	26	10	7	5	28	25	25	12	17	43	7	49	49	45	48	0	76	33	60	0	0
Record	1973-86	1973-86	1973-86	1973-86	1974-82	1974-77	1974-77	1974-86	1974-85	1974-85	1983-86	1981-86	1973-86	1976-77	1973-86	1973-86	1973-86	1973-86	0	1973-86	1977-85	1976-86	0	0
Croatan Sound water-quality zone																								
CR1																								
P	*	.005	.015	*	--	--	--	.024	--	--	--	*	*	--	*	*	*	*	--	*	.002	*	--	--
Slope	--	.043	2.75	--	--	--	--	-3.00	--	--	--	--	--	--	--	--	--	--	--	--	-11.3	--	--	--
N	106	62	48	34	18	0	0	51	32	32	15	50	36	16	50	51	47	46	0	98	47	66	22	22
Record	1957-86	1957-86	1974-85	1974-86	1974-83	0	0	1974-86	1974-86	1974-86	1983-86	1974-86	1974-86	1975-83	1974-86	1974-86	1974-86	1974-86	0	1973-86	1978-86	1978-86	1982-84	1982-84
Roanoke Sound water-quality zone																								
R1																								
P	*	<.001	.012	*	--	--	--	*	*	.003	--	*	*	--	*	*	*	*	--	.018	.004	*	--	--
Slope	--	.050	3.13	--	--	--	--	--	--	-1.93	--	--	--	--	--	--	--	--	--	.050	-18.5	--	--	--
N	168	106	54	39	21	0	0	54	41	39	15	48	63	20	63	65	62	61	0	117	81	89	22	22
Record	1957-86	1957-86	1973-85	1973-86	1974-82	0	0	1974-86	1974-86	1974-85	1983-86	1974-86	1973-86	1975-83	1973-86	1973-86	1973-86	1973-86	0	1973-86	1968-85	1976-86	1982-84	1982-84
Currituck Sound water-quality zone or location																								
CU1																								
P	*	.024	.030	*	*	--	--	*	*	.087	--	*	*	--	*	.026	*	*	--	.015	*	<.001	--	*
Slope	--	.028	2.00	--	--	--	--	--	--	-1.43	--	--	--	--	--	-.015	--	--	--	-.071	--	-2.25	--	--
N	127	72	52	43	27	11	11	61	38	37	14	47	65	19	59	61	59	60	0	113	45	69	18	21
Record	1957-88	1957-88	1973-85	1973-88	1974-84	1974-81	1974-81	1974-88	1974-86	1974-85	1983-86	1975-88	1973-88	1975-83	1973-86	1973-86	1973-86	1973-86	0	1973-86	1977-85	1976-86	1982-84	1982-84
CU2																								
P	*	*	*	--	*	--	--	*	--	--	--	--	*	--	*	.010	*	*	--	<.001	--	--	--	--
Slope	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.050	--	--	--	-.245	--	--	--	--
N	71	43	45	21	31	18	19	32	22	22	0	15	26	6	31	32	31	30	0	74	12	23	12	12
Record	1977-84	1978-84	1978-83	1980-84	1977-84	1977-81	1977-81	1977-84	1977-84	1977-84	0	1981-84	1977-84	1982-83	1977-84	1977-84	1977-84	1977-84	0	1977-84	1977-81	1977-83	1982-84	1982-84

Table 13.--*Summary of the Seasonal Kendall trend test results for selected water-quality data stored in U.S. Environmental Protection Agency Storage and Retrieval System and collected for selected previous investigations in the study area*--Continued

[Only results with a probability less than 0.05 are shown. The alpha significance level was 0.05. The null hypothesis tested was that there is no trend. * indicates that trend tests were made but trends were insignificant or data were questionable; <0.001 indicates probability level less than 0.001; --, insufficient data for analysis]

Water-quality zone or location identifier (table 9) Probability (P) Trend slope (Slope) Number of observations (N) Period of record (Record)	Dissolved oxygen	pH	Alkalinity	Turbidity	Total solids	Total volatile solids	Total non-volatile solids	Suspended solids	Volatile suspended solids	Non-volatile suspended solids	Total hardness	Salinity	Dissolved chloride	Total organic carbon	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Biochemical oxygen demand	Fecal streptococci	Fecal coliform	Chlorophyll-*a*, corrected for phaeopigments	Chlorophyll-*a*
Albemarle Sound water-quality zones																								
A1																								
P	*	*	--	--	*	--	--	--	--	--	--	*	--	--	--	*	*	*	*	--	--	--	*	*
Slope	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	182	154	3	5	50	5	5	48	5	4	0	134	0	32	81	145	77	77	66	27	0	0	77	43
Record	1957-85	1957-85	1985	1985	1981-85	1985	1985	1981-85	1982-85	1985	0	1970-85	0	1975-83	1975-85	1970-85	1981-85	1981-85	1970-74	1982-83	0	0	1981-85	1982-85
A2																								
P	*	*	--	--	*	--	--	*	--	--	--	<.001	*	.001	<.001	*	.018	.005	--	--	--	--	.018	.006
Slope	--	--	--	--	--	--	--	--	--	--	--	.100	--	-.367	-.005	--	-.005	-.003	--	--	--	--	1.00	1.00
N	403	194	10	9	87	9	8	88	10	10	1	395	80	155	143	205	129	129	36	31	0	0	147	146
Record	1957-88	1957-88	1984-86	1985-86	1977-88	1977-85	1977-85	1977-88	1977-86	1977-86	1985	1970-88	1985-88	1975-88	1975-88	1970-88	1977-88	1977-88	1970-74	1977-85	0	0	1982-88	1982-88
A3																								
P	*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Slope	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	54	29	26	8	6	6	6	5	4	5	0	2	17	8	11	12	10	10	0	19	14	18	0	0
Record	1957-78	1957-77	1968-73	1973	1976-77	1976-77	1976-77	1976-77	1976-77	1976-77	0	1975	1968-77	1975-77	1975-78	1975-78	1976-78	1976-78	0	1976-78	1968-78	1976-78	0	0
A4																								
P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Slope	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	28	10	0	0	0	0	0	0	0	0	0	57	0	11	12	12	0	0	33	0	0	0	0	0
Record	1957-75	1957-75	0	0	0	0	0	0	0	0	0	1970-75	0	1975	1975	1975	0	0	1970-74	0	0	0	0	0
A5																								
P	*	.018	*	--	*	*	*	*	.004	--	--	.026	--	*	*	*	.001	*	*	*	--	--	--	--
Slope	--	.017	--	--	--	--	--	--	1.00	--	--	.083	--	--	--	--	.020	--	--	--	--	--	--	--
N	171	109	33	28	64	46	46	63	46	44	7	209	12	48	95	225	75	75	99	71	0	2	45	46
Record	1957-85	1957-85	1978-85	1979-85	1977-85	1977-85	1977-85	1977-85	1977-85	1977-85	1983-85	1970-85	1977-84	1975-83	1975-85	1970-85	1977-85	1977-85	1970-74	1977-84	0	1979-80	1982-85	1982-85
Roanoke River water-quality location																								
RO1																								
P	*	<.001	.015	*	<.001	*	*	.014	*	.037	*	*	--	<.001	*	<.001	.039	.002	--	*	--	--	*	*
Slope	--	.036	-.667	--	-2.00	--	--	-.400	--	-.293	--	--	--	-.500	--	-.014	.003	.001	--	--	--	--	--	--
N	717	368	194	138	304	154	150	308	153	149	58	111	0	111	304	303	298	272	0	359	3	5	110	99
Record	1957-88	1957-88	1968-86	1973-88	1969-88	1971-85	1972-85	1969-88	1971-85	1971-85	1983-88	1975-88	0	1975-88	1973-88	1973-88	1973-88	1973-88	0	1969-88	1970	1972-80	1981-88	1981-88
Little River water-quality zone																								
L1																								
P	.007	*	*	*	*	*	*	*	*	*	--	*	*	--	*	*	*	*	--	*	--	--	--	--
Slope	.08-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	197	91	59	34	55	41	41	63	42	37	16	40	44	18	63	65	64	65	0	173	1	1	11	11
Record	1957-85	1957-88	1974-85	1974-88	1976-85	1976-85	1976-85	1976-88	1976-86	1976-86	1976-86	1981-88	1975-88	1976-83	1974-86	1974-86	1974-86	1974-86	0	1973-86	1976	1976	1982-85	1982-85
Perquimans River water-quality zone																								
PQ1																								
P	<.001	*	*	*	*	*	*	.010	*	*	--	*	*	--	*	*	*	*	--	*	--	--	--	--
Slope	.088	--	--	--	--	--	--	-.500	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	254	145	70	38	61	43	43	77	44	44	15	75	42	21	80	81	79	79	33	186	1	1	12	12
Record	1957-88	1957-88	1974-85	1974-88	1976-86	1976-86	1976-86	1976-88	1976-86	1976-86	1976-86	1970-88	1975-88	1975-83	1975-88	1975-88	1975-88	1975-88	1970-74	1973-86	1976	1976	1982-87	1982-87

Table 13.--*Summary of the Seasonal Kendall trend test results for selected water-quality data stored in U.S. Environmental Protection Agency Storage and Retrieval System and collected for selected previous investigations in the study area*--Continued

[Only results with a probability less than 0.05 are shown. The alpha significance level was 0.05. The null hypothesis tested was that there is no trend. * indicates that trend tests were made but trends were insignificant or data were questionable; <0.001 indicates probability level less than 0.001; --, insufficient data for analysis]

Water-quality zone or location identifier (table 9) Probability (P) Trend slope (Slope) Number of observations (N) Period of record (Record)	Dissolved oxygen	pH	Alkalinity	Turbidity	Total solids	Total volatile solids	Total non-volatile solids	Suspended solids	Volatile suspended solids	Non-volatile suspended solids	Total hardness	Salinity	Dissolved chloride	Total organic carbon	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Biochemical oxygen demand	Fecal streptococci	Fecal coliform	Chlorophyll-a, corrected for phaeopigments	Chlorophyll-a
Pasquotank River water-quality zones																								
PS1																								
P	<.001	<.001	*	*	*	*	*	.010	*	*	--	.003	*	--	*	.001	.006	<.001	*	*	--	--	--	--
Slope	.162	.059	--	--	--	--	--	-.764	--	--	--	.080	--	--	--	-.028	-.015	-.006	--	--	--	--	--	--
N	252	160	95	38	76	32	32	80	33	33	19	72	49	22	92	92	91	91	32	158	6	2	12	12
Record	1957-88	1957-88	1968-85	1980-88	1976-87	1976-85	1976-85	1976-88	1976-86	1976-86	1976-88	1970-88	1968-88	1976-83	1974-88	1974-88	1974-88	1974-88	1970-74	1974-86	1970-76	1976	1982-85	1982-85
PS2																								
P	.002	*	*	--	*	*	*	*	*	*	--	*	*	--	*	*	*	*	--	*	--	--	--	--
Slope	.086	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	210	106	78	35	54	39	39	64	41	41	15	43	45	21	65	67	66	66	0	164	8	2	9	9
Record	1968-88	1968-88	1968-85	1974-88	1976-86	1976-86	1976-86	1976-88	1976-86	1976-86	1976-86	1975-88	1975-88	1975-83	1975-86	1975-86	1975-86	1975-86	0	1974-86	1969-76	1976	1982-83	1982-83
Alligator River water-quality zones																								
AR1																								
P	*	*	--	--	*	--	--	--	--	--	--	*	--	*	*	*	*	*	--	--	--	--	--	--
Slope	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	32	30	0	12	20	11	12	19	10	9	8	28	7	18	51	47	21	21	33	16	12	11	12	11
Record	1982-88	1982-88	0	1982-88	1982-88	1982-86	1982-86	1982-88	1982-86	1982-86	1983-86	1982-88	1985-88	1982-86	1970-88	1970-88	1982-88	1982-88	1970-74	1982-86	1982-83	1982-83	1982-83	1982-83
AR2																								
P	.019	*	--	--	<.001	.002	<.001	*	--	*	--	*	--	*	<.001	<.001	*	*	--	*	*	*	*	*
Slope	.115	--	--	--	263.1	43.83	260	--	--	--	--	--	--	--	-.023	-.073	--	--	--	--	--	--	--	--
N	186	47	0	16	159	150	152	147	121	117	9	26	13	156	192	185	148	155	33	154	21	20	21	20
Record	1975-88	1976-88	0	1975-88	1975-88	1975-86	1975-86	1975-88	1975-86	1975-85	1983-86	1982-88	1976-88	1975-86	1970-88	1971-88	1975-88	1975-88	1970-74	1975-86	1982-88	1982-88	1982-88	1982-88
AR3																								
P	*	*	--	--	--	--	--	--	--	--	--	*	--	--	*	*	*	*	--	--	*	*	*	*
Slope	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	33	30	0	13	21	12	13	21	12	12	9	31	8	18	20	21	21	21	0	17	19	18	19	18
Record	1982-88	1982-88	0	1982-88	1982-88	1982-86	1982-86	1982-88	1982-86	1982-86	1983-86	1982-88	1985-88	1982-86	1982-88	1982-88	1982-88	1982-88	0	1982-86	1982-88	1982-88	1982-88	1982-88

Table 13.--*Summary of the Seasonal Kendall trend test results for selected water-quality data stored in U.S. Environmental Protection Agency Storage and Retrieval System and collected for selected previous investigations in the study area*--Continued

[Only results with a probability less than 0.05 are shown. The alpha significance level was 0.05. The null hypothesis tested was that there is no trend. * indicates that trend tests were made but trends were insignificant or data were questionable; <0.001 indicates probability level less than 0.001; --, insufficient data for analysis]

Water-quality zone or location identifier (table 9) Probability (P) Trend slope (Slope) Number of observations (N) Period of record (Record)	Dissolved oxygen	pH	Alkalinity	Turbidity	Total solids	Total volatile solids	Total non-volatile solids	Suspended solids	Volatile suspended solids	Non-volatile suspended solids	Total hardness	Salinity	Dissolved chloride	Total organic carbon	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Dissolved phosphorus	Biochemical oxygen demand	Fecal streptococci	Fecal coliform	Chlorophyll-a, corrected for phaeo-pigments	Chlorophyll-a
Chowan River water-quality zones or location																								
CH1																								
P	.029	.028	*	.018	.002	*	*	.001	*	*	--	*	--	--	.027	<.001	*	<.001	--	*	--	--	*	*
Slope	-.047	.024	--	-.650	-2.00	--	--	-.33	--	--	--	--	--	--	-.003	-.023	--	-.005	--	--	--	--	--	--
N	721	538	40	42	272	108	108	301	147	145	8	53	13	0	2,178	2,246	2,115	2,237	1	168	1	0	214	48
Record	1953-88	1953-88	1969-87	1973-88	1974-88	1974-85	1974-85	1974-88	1974-85	1974-85	1983-85	1981-88	1969-73	0	1953-88	1969-88	1971-88	1969-88	1982	1969-88	1969	0	1981-88	1982-88
CH2																								
P	*	.006	--	--	*	--	--	<.001	--	--	--	--	--	--	*	*	*	*	--	--	--	--	*	--
Slope	--	-.079	--	--	--	--	--	-1.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	280	239	0	0	88	33	33	111	42	43	0	15	0	0	166	184	167	171	0	35	0	0	100	13
Record	1973-83	1973-83	0	0	1974-83	1974-75	1974-75	1974-83	1974-75	1974-75	0	1981-82	0	0	1974-83	1973-83	1974-83	1974-83	0	1974-75	0	0	1981-83	1982-83
CH3																								
P	.012	*	--	--	*	--	--	*	--	--	--	--	--	--	*	.011	*	*	--	--	--	--	--	--
Slope	-.150	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.014	--	--	--	--	--	--	--	--
N	264	221	0	0	84	54	54	117	70	68	0	19	0	25	173	176	165	166	0	60	0	0	69	5
Record	1953-82	1953-83	0	0	1974-82	1974-75	1974-75	1974-82	1974-75	1974-75	0	1981-82	0	1982	1953-82	1973-82	1974-82	1974-82	0	1974-75	0	0	1981-82	1982
CH4																								
P	.001	*	.021	.040	*	*	*	<.001	*	*	--	*	--	--	*	*	*	*	--	*	--	--	<.001	--
Slope	-.075	--	-.833	-1.12	--	--	--	-.544	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-1.27	--
N	756	470	65	48	267	234	235	305	293	293	2	79	5	19	475	483	463	475	0	328	0	0	119	40
Record	1961-88	1961-88	1974-87	1980-88	1974-88	1974-85	1974-85	1974-88	1974-85	1974-85	1983	1981-88	1976-84	1972-77	1971-88	1971-88	1971-88	1971-88	0	1974-81	0	0	1981-88	1982-88
CH5																								
P	.004	*	.003	*	*	*	*	<.001	*	<.001	--	*	--	--	*	*	*	*	--	.037	--	--	<.001	*
Slope	-.038	--	-1.00	--	--	--	--	-.50	--	-.388	--	--	--	--	--	--	--	--	--	-.033	--	--	-.50	--
N	1,087	743	136	96	312	234	230	387	290	293	21	255	10	30	946	648	635	625	32	394	5	2	233	92
Record	1953-88	1953-88	1969-87	1973-88	1974-88	1974-85	1974-85	1974-88	1974-85	1974-85	1983-86	1962-88	1976-84	1972-83	1953-88	1972-88	1972-88	1971-88	1970-74	1974-86	1969	1980	1981-88	1982-88
CH6																								
P	*	*	--	--	--	--	--	--	--	--	--	--	--	--	--	*	--	--	--	--	--	--	--	--
Slope	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N	131	114	0	0	26	0	0	49	0	0	0	12	0	0	71	84	74	74	0	0	0	0	48	0
Record	1973-88	1973-81	0	0	1981-82	0	0	1981-82	0	0	0	1981	0	0	1981-82	1973-82	1981-82	1981-82	0	0	0	0	81	0
CH7																								
P	*	*	.001	*	.014	.008	.010	<.001	*	<.001	--	*	*	*	*	*	<.001	*	*	<.001	--	--	*	.003
Slope	--	--	-1.00	--	1.80	.875	2.36	-.500	--	-.400	--	--	--	--	--	--	-.003	--	--	-.036	--	--	--	.333
N	1,666	944	361	260	496	312	296	605	351	343	64	577	99	238	811	833	874	735	66	709	1	5	334	263
Record	1953-88	1953-88	1968-87	1973-88	1974-88	1974-86	1974-86	1974-88	1974-86	1974-86	1983-88	1970-88	1976-88	1972-88	1953-88	1972-88	1958-88	1972-88	1970-86	1969-88	1970	1972-80	1981-88	1981-88

of oxygen per liter of water to be the minimum level for adequate maintenance of a varied fish population. Dissolved oxygen can exhibit wide daily variation in concentration due to biological production and uptake. Unfortunately, variability due to sample location in the water column and sampling time could not be removed from the data used in the trend analyses of this constituent.

In general, dissolved-oxygen concentrations increased at a rate of about 0.1 (mg/L)/yr (milligrams per liter per year) throughout the Albemarle-Pamlico estuarine system except at the Blackwater River NASQAN station and in the Chowan River where concentrations decreased approximately 0.06 (mg/L)/yr. Zone N3 in the Neuse River estuary also showed a significant decreasing trend in dissolved-oxygen concentration (fig. 10).

Trends in dissolved-oxygen concentration for selected water-quality zones in the Albemarle-Pamlico estuary system are represented by box plots in figures 11 and 12. The increase in dissolved-oxygen concentrations in the Neuse River zone N4 (fig. 11A) places these values generally above the 5.0 mg/L (milligram per liter) U.S. Environmental Protection Agency criterion level after 1979. A decreasing trend in dissolved-oxygen concentrations in zone N4 since 1983 is also apparent.

The dissolved-oxygen trends for Pamlico River zones PR2 and PR10 are shown in figures 11B and 11C, respectively. Both zones had dissolved-oxygen concentrations that generally exceed 5.0 mg/L. Location P4 in Pamlico Sound had dissolved-oxygen concentrations that exceed the 5.0 mg/L criterion, although a slight decline occurred in 1985-86 (fig. 11D).

Trends in dissolved-oxygen concentrations in the Pasquotank River (zones PS1, fig. 12A and PS2, fig. 12B) also increased. At times, however, dissolved-oxygen concentrations at zone PS1 were less than the 5.0 mg/L criterion until 1985 when they increased substantially. Dissolved-oxygen concentrations in zone PS2 exceeded 5.0 mg/L throughout the period of record.

Dissolved-oxygen concentrations at Perquimans zone PQ1 (fig. 12C) consistently have exceeded the 5.0 mg/L criterion since 1974. But, a decreasing trend is apparent at zone CH4 (fig. 12D) in the Chowan River,

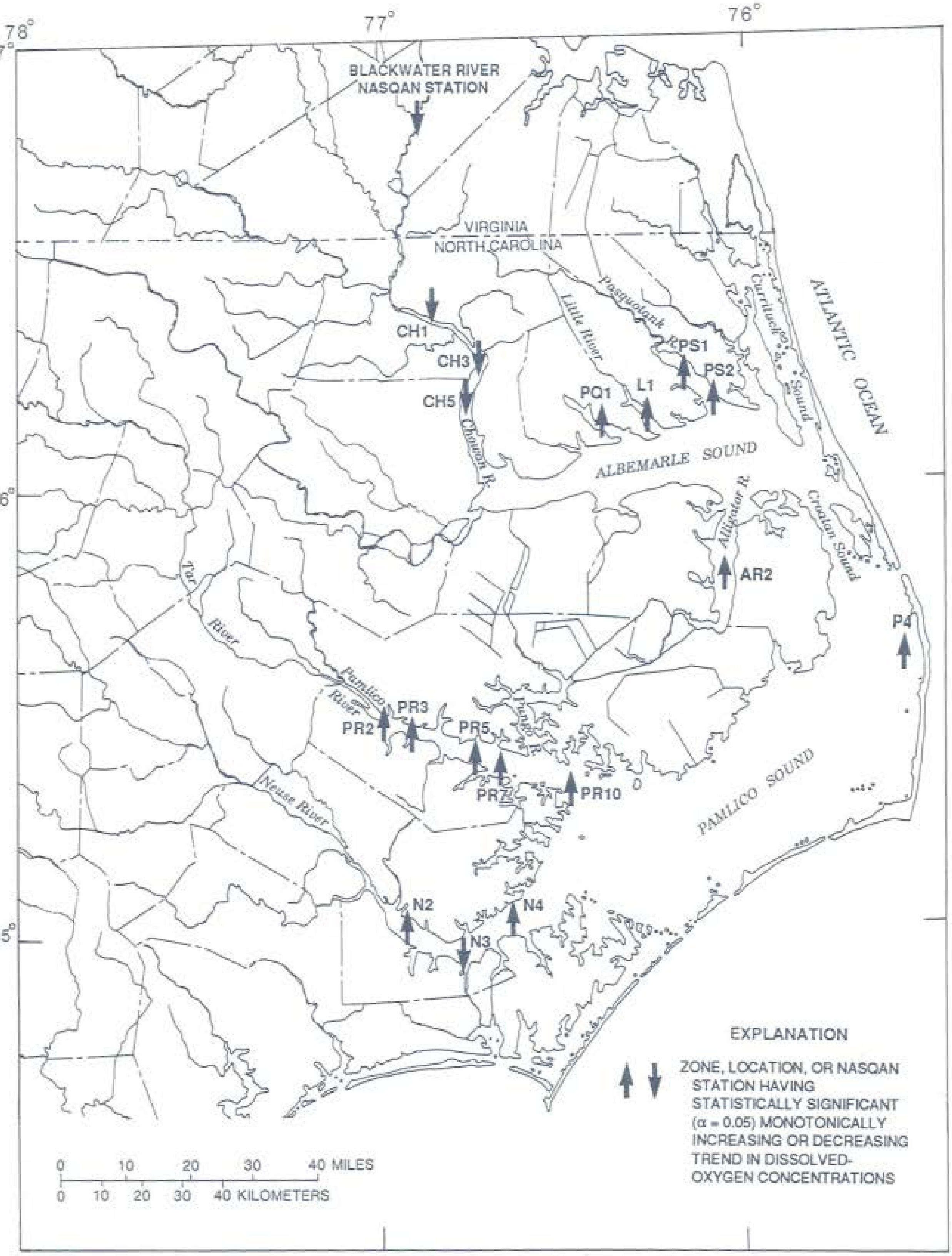

Figure 10.--Locations of water-quality zones or stations having statistically significant trends of increasing or decreasing dissolved-oxygen concentrations, 1970-88.

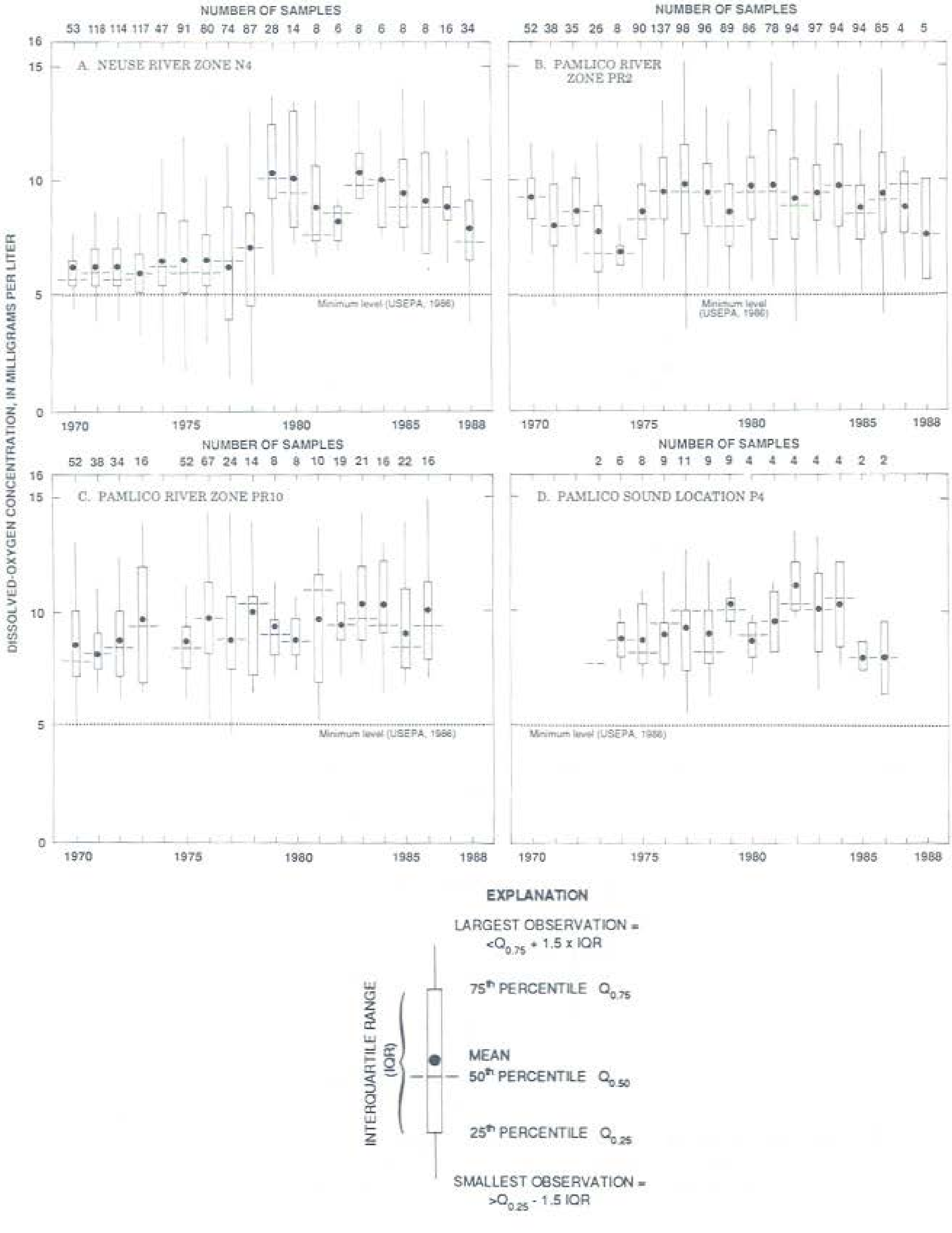

Figure 11.--Box plots of dissolved-oxygen concentrations for selected water-quality zones and location, by year: A. Neuse River zone N4, B. Pamlico River zone PR2, C. Pamlico River zone PR10, and D. Pamlico Sound location P4.

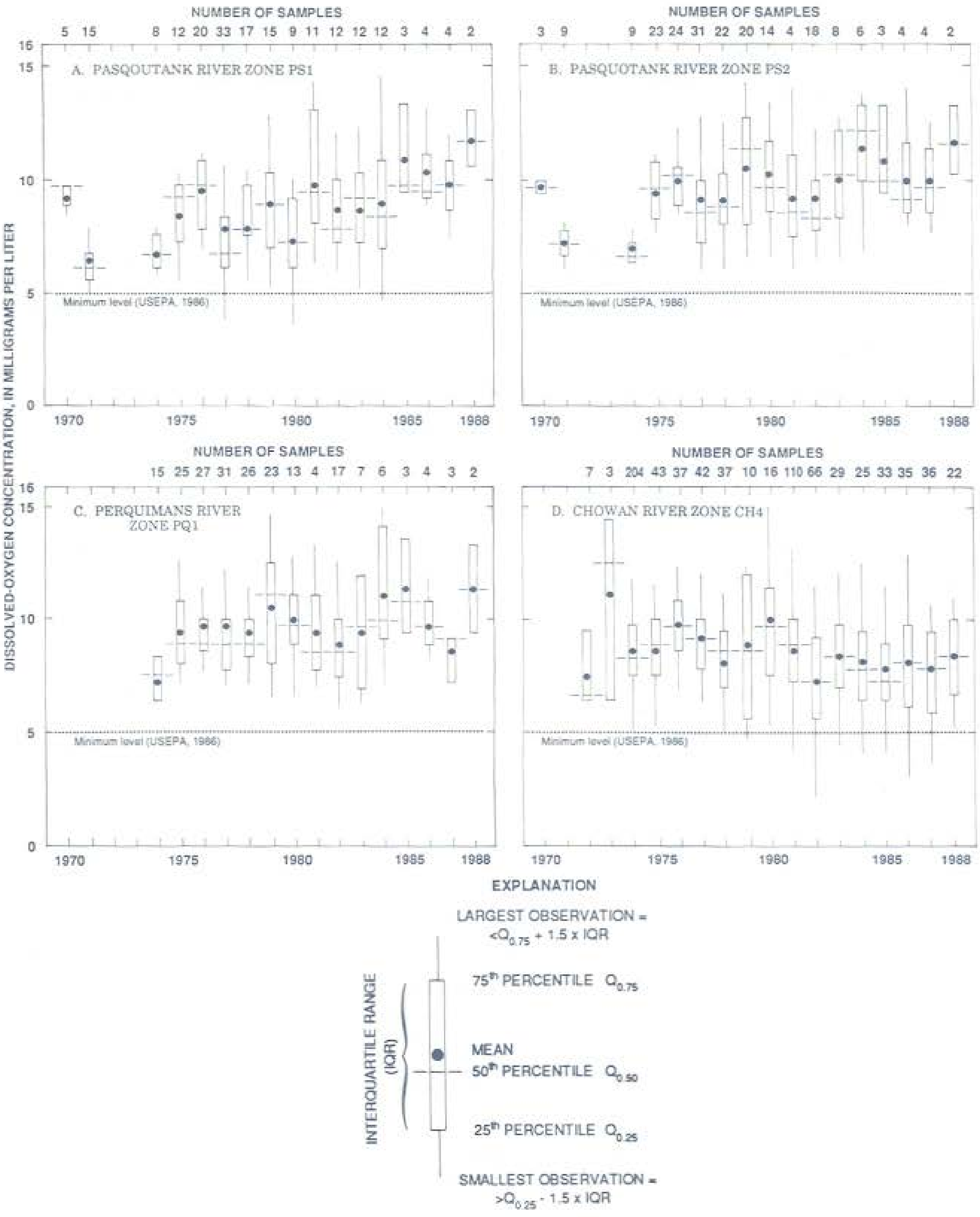

Figure 12.--Box plots of dissolved-oxygen concentrations for selected water-quality zones, by year: A. Pasquotank River zone PS1, B. Pasquotank River zone PS2, C. Perquimans River zone PQ1, and D. Chowan River zone CH4.

where some dissolved-oxygen concentrations began to drop below the 5.0 mg/L concentration in the early 1980's.

If daytime sampling is assumed, a general increase in dissolved oxygen may be an indication of more productive estuary conditions. Increased plant biomass over time could result in high daytime photosynthetically generated dissolved-oxygen levels.

Biochemical oxygen demand

The use of dissolved oxygen during the metabolism of organisms and the oxidation of biologically oxidizable organic material in water can be measured by a 5-day biological oxygen demand test (BOD5). The BOD5 is useful to evaluate the amount of oxidizable organic material in the water. BOD5 values of 1 to 8 mg/L are common for streams moderately contaminated with domestic wastewater (Nemerow, 1974).

Trends of increasing BOD5 values were detected at Neuse River zone N2 (0.10 (mg/L)/yr; fig. 13A) and at Roanoke Sound zone R1 (0.05 (mg/L)/yr; fig. 13B). Decreasing trends occurred at Currituck Sound zone CU1 (-0.07 (mg/L)/yr; fig. 13C) and location CU2 (-0.24 (mg/L)/yr for 1977 through 1984); and in Chowan River zones CH5 (-0.03 (mg/L)/yr) and CH7 (-0.04 (mg/L)/yr; fig. 13D). A nonmonotonic pattern showing a peak in 1981 followed by a decline of BOD5 values was observed at Pamlico Sound location P3 (fig. 14).

Biological oxygen demand values generally increase downstream in the Neuse River (fig. 15A) and the Pamlico River (fig. 15B). BOD5 values for several zones of the Albemarle Sound area are shown in figure 15C and are presented for those zones of Currituck, Croatan, and Roanoke Sounds in figure 15D. Overall, BOD5 values are slightly lower in the sounds than in the Neuse and Pamlico Rivers.

pH

The pH of water is fundamental to the nature of the chemical reactions that occur in the water. In general, aquatic life requires pH to be within a range of 6.5 and 9 units (U.S. Environmental Protection Agency, 1986).

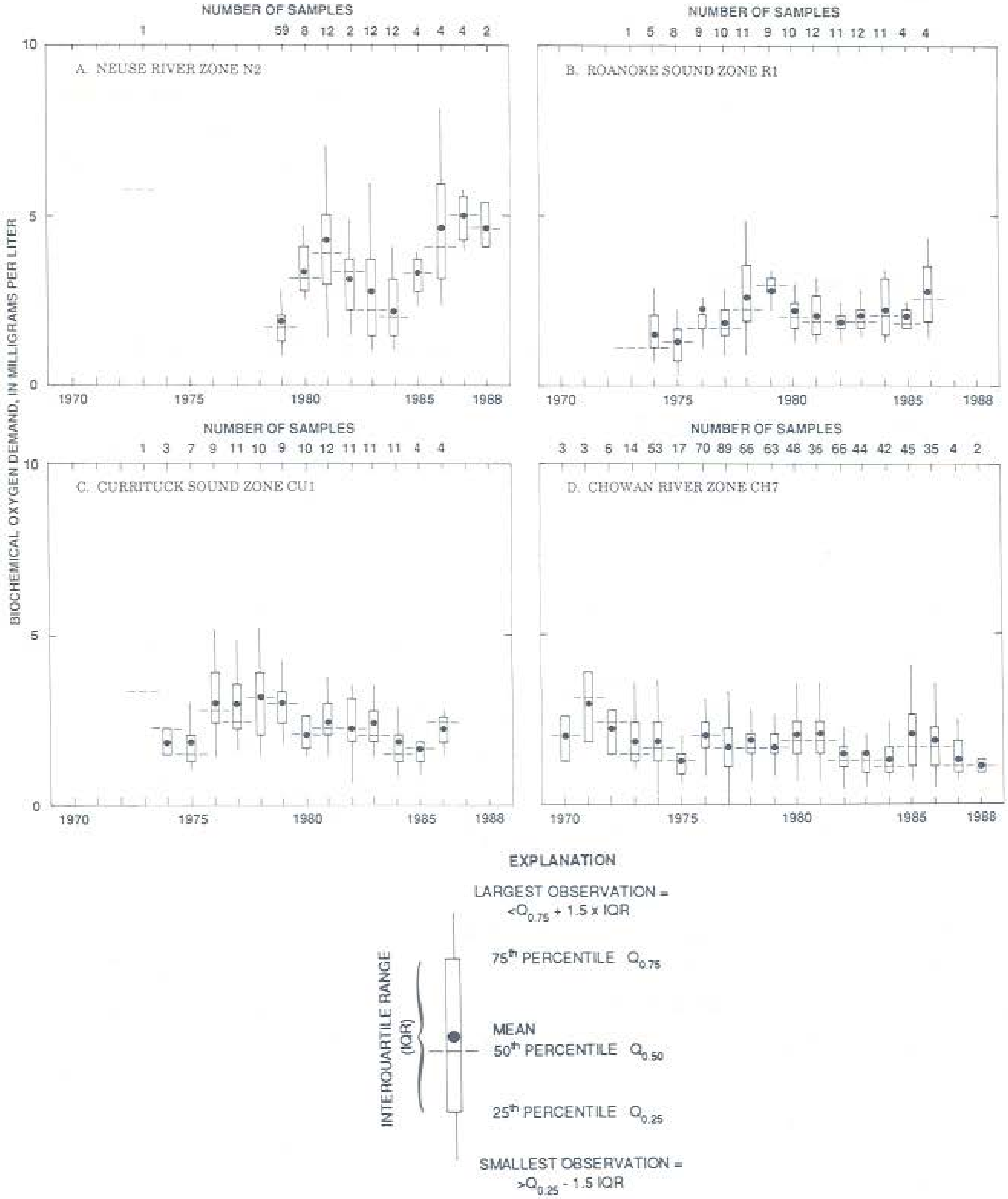

Figure 13.--Box plots of biochemical oxygen demand for selected water-quality zones, by year: A. Neuse River zone N2, B. Roanoke Sound zone R1, C. Currituck Sound zone CU1, and D. Chowan River zone CH7.

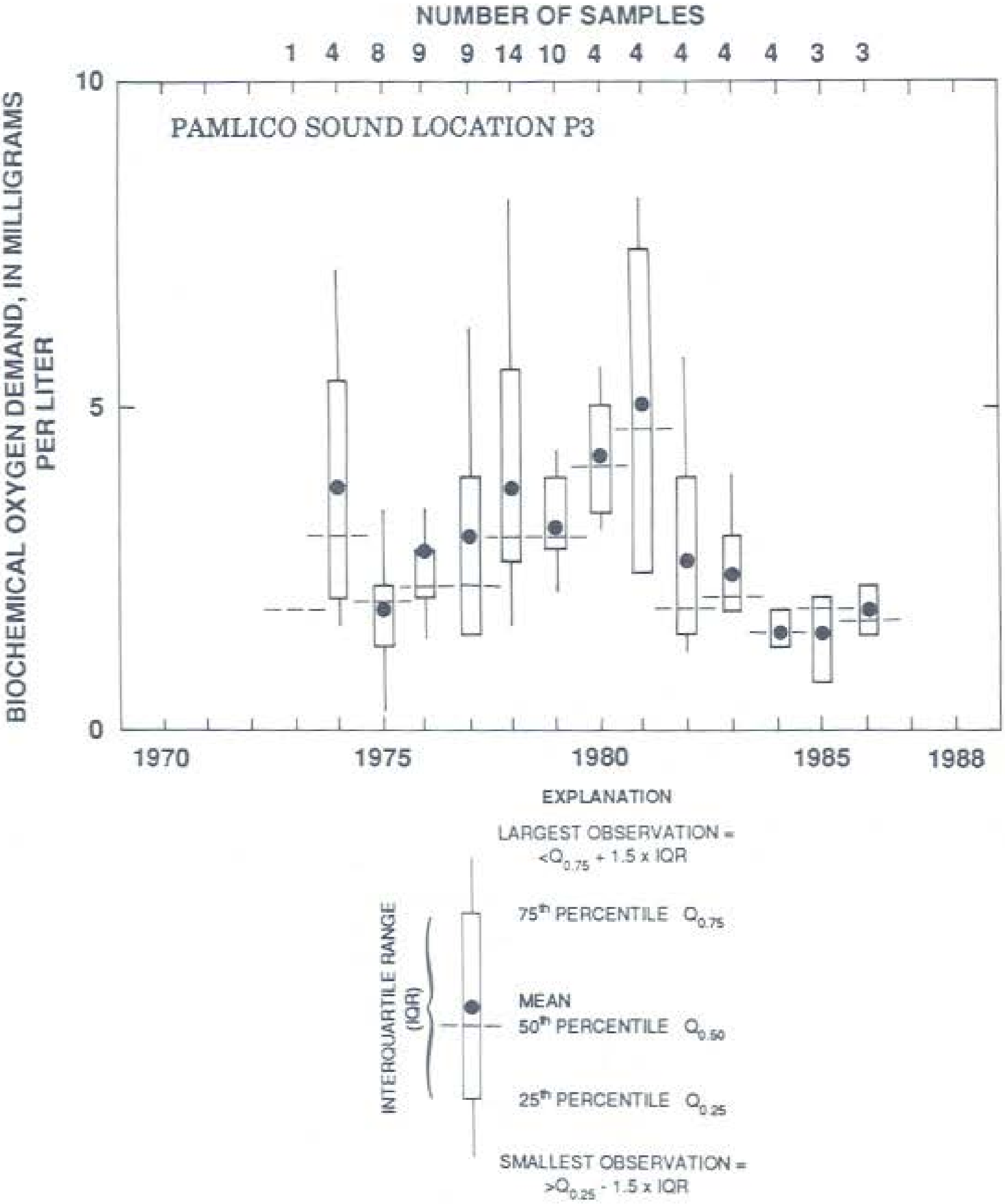

Figure 14.--Box plots of biochemical oxygen demand, by year, for Pamlico Sound location P3.

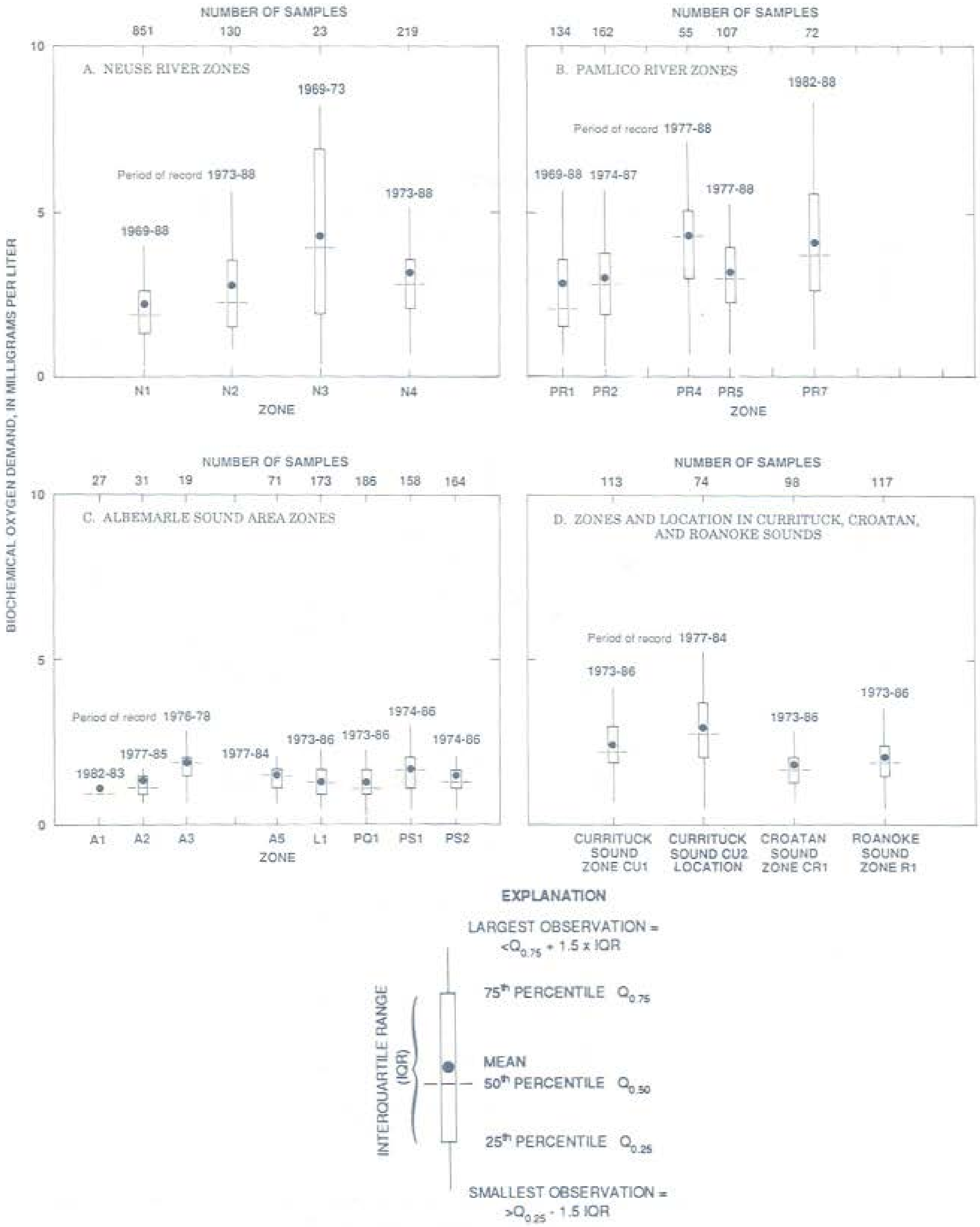

Figure 15.--Box plots of biochemical oxygen demand for: A. Neuse River zones, B. Pamlico River zones, C. Albemarle Sound area zones, and D. zones and location in Currituck, Croatan, and Roanoke Sounds.

Low pH values can increase the solubility of materials toxic to aquatic life and cause detrimental effects. A lower limit of 6.0 pH units has been established by the N.C. Environmental Management Commission (1979) as the criterion for waters used for fishing and recreation, such as those of the Albemarle-Pamlico estuarine system.

The pH trend of water in the Albemarle-Pamlico study area generally increased during the period 1970 to 1988 except for the Tar and Pamlico Rivers (fig. 16). An annual increase of approximately 0.04 pH unit occurred in many of the Albemarle-Pamlico estuary zones, whereas a decrease of about 0.03 pH unit per year occurred in the Pamlico River.

Examples of increasing pH trends are shown in Pamlico Sound at location P3 in figure 17D, in Currituck Sound at zone CU1 in figure 18A, and in Albemarle Sound at zone A5 in figure 18B. The pH values in these sounds are above the 6.0 criterion level. The decreasing trends in pH in the Pamlico River are illustrated by the box plots for zone PR1 (fig. 17A), zone PR5 (fig. 17B), and zone PR10 (fig. 17C). Values of pH below 6.0 began occurring in the early 1980's in these Pamlico River zones.

The observed trends in pH throughout the Albemarle-Pamlico study area are an indication of changes in chemistry of the system. Because the NADP/NTN precipitation-quality stations do not show significant trends in pH (table 11), changes in land use or wastewater inputs in the individual stream basins may have caused the observed trends in pH. However, because of the substantial buffering capacity of the estuary waters, any changes in acidity from precipitation will be masked. A general increase in pH might also be indicative of more eutrophic estuary conditions. Consumption of carbon dioxide by algae causes a decreased acidity, causing pH to rise.

Alkalinity

Alkalinity buffers acidity of water reducing changes in pH that may occur, for example, in response to algal activity, acid precipitation, and wastewater discharges. The bicarbonate ion is a major contributor to the alkalinity of water in the Albemarle-Pamlico system. Because bicarbonate can reduce the toxicity of certain metals to aquatic life, the U.S. Environmental Protection Agency recommends a minimum of 20 mg/L of alkalinity (as

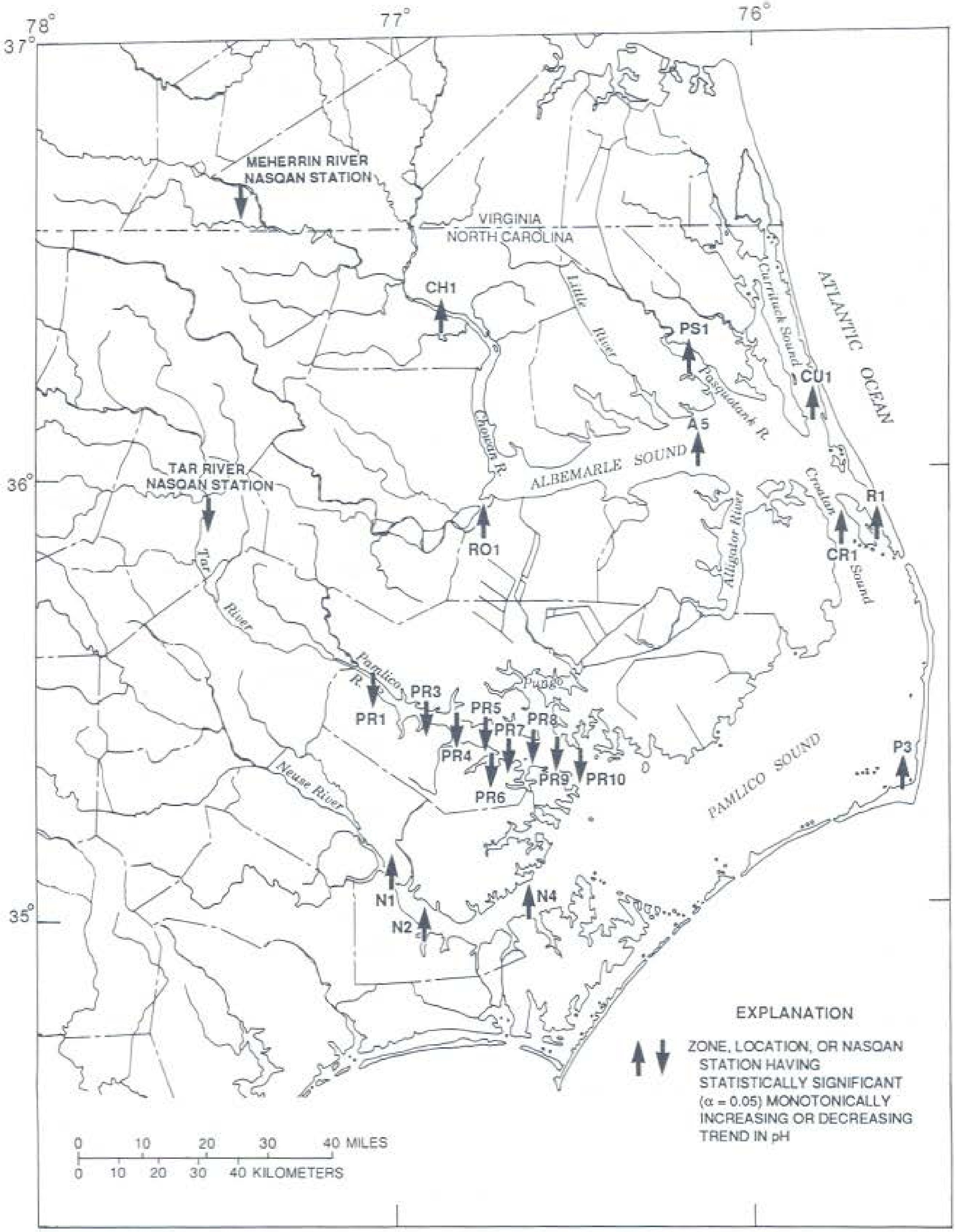

Figure 16.--Locations of water-quality zones or stations having statistically significant trends of increasing or decreasing pH, 1970-88.

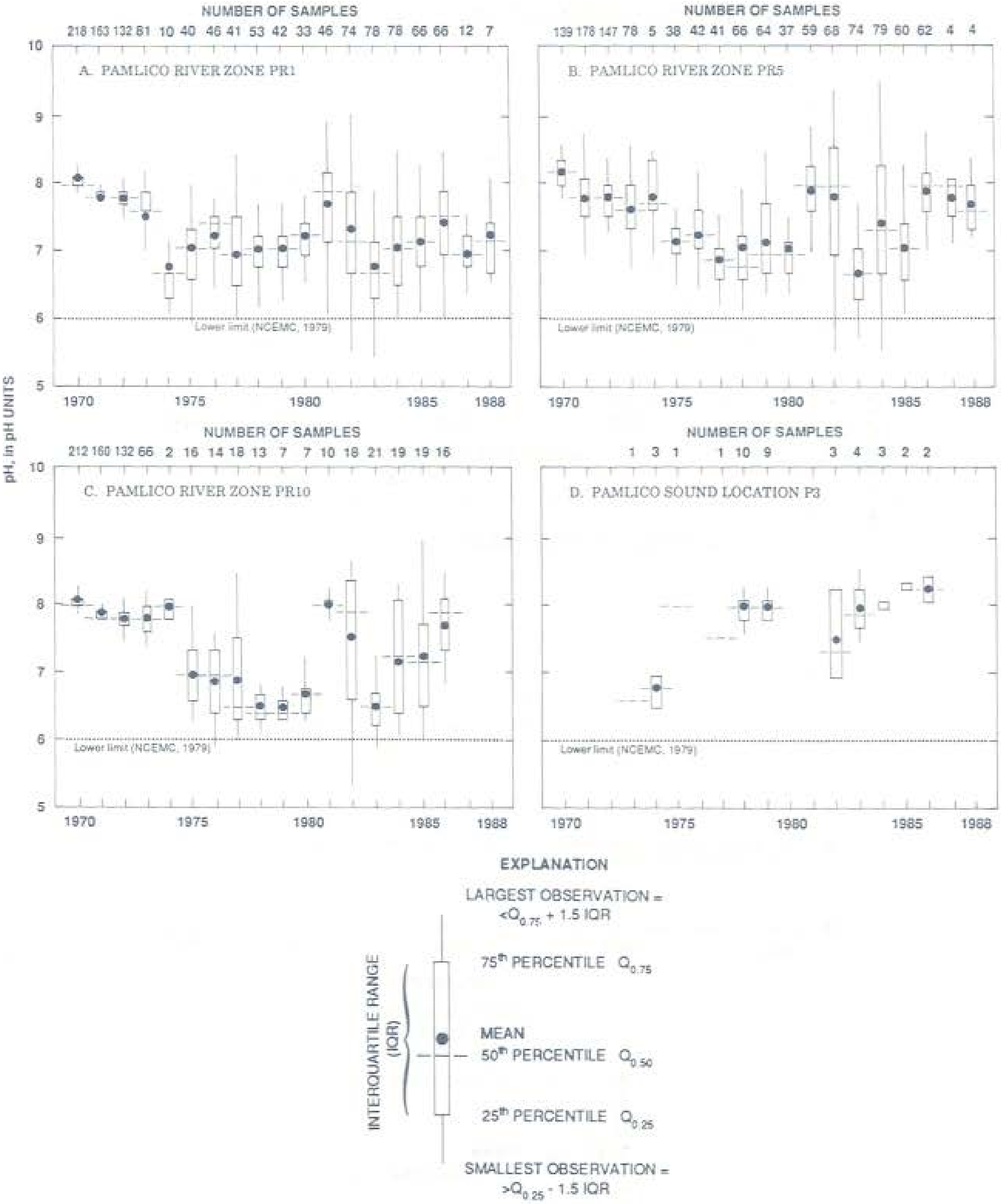

Figure 17.--Box plots of pH for selected water-quality zones and location, by year: A. Pamlico River zone PR1, B. Pamlico River zone PR5, C. Pamlico River zone PR10, and D. Pamlico Sound location P3.

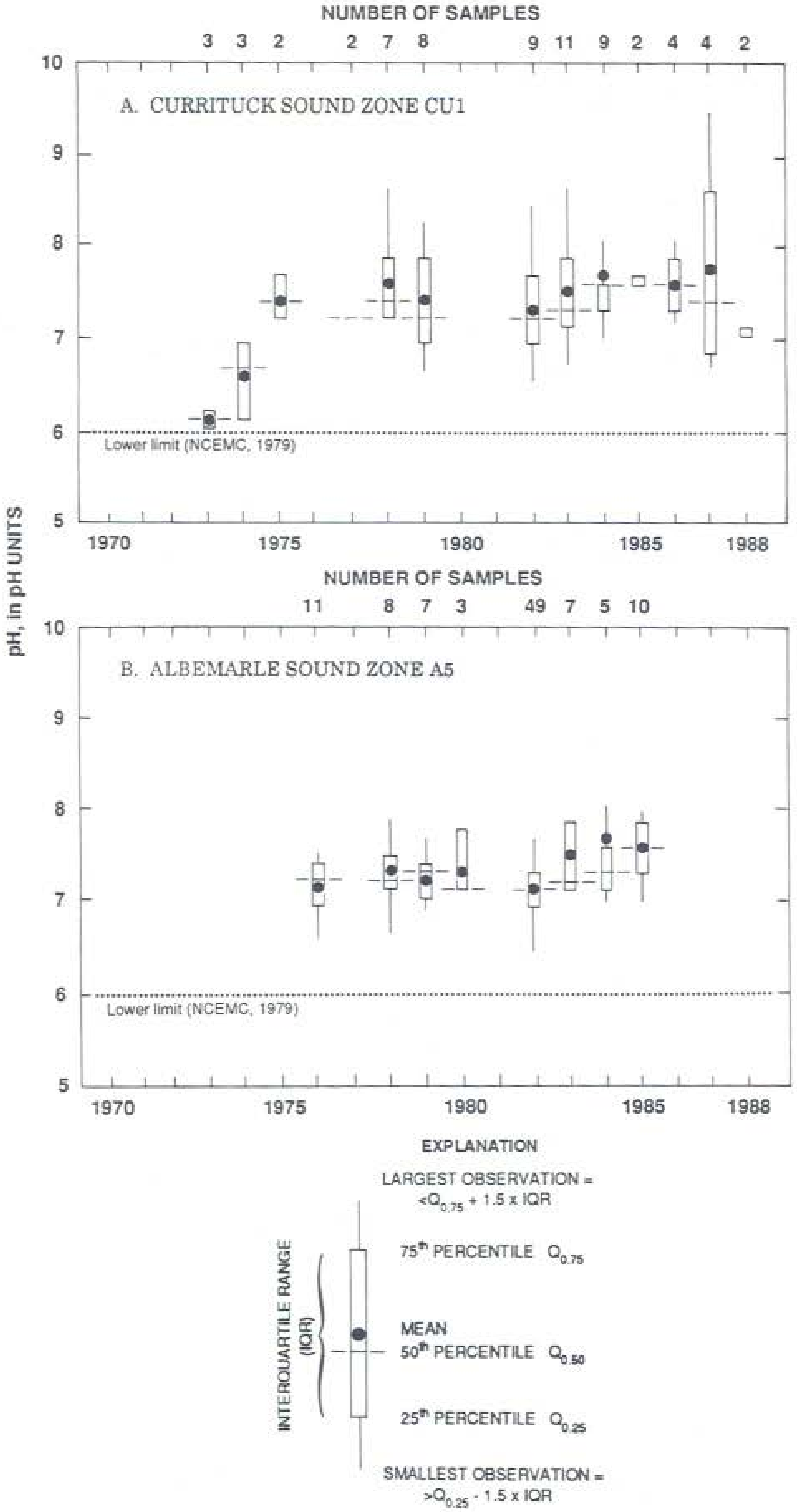

Figure 18.--Box plots of pH for selected water-quality zones, by year: A. Currituck Sound zone CU1 and B. Albemarle Sound zone A5.

$CaCO_3$) for the protection of aquatic life (U.S. Environmental Protection Agency, 1986).

A trend of increasing alkalinity was detected at the NASQAN station in the Roanoke River (0.80 (mg/L)/yr), where alkalinity generally has been above the 20 mg/L concentration since the early 1980's (fig. 19A). Other increasing trends were noted in Pamlico Sound locations P3 (6.7 (mg/L)/yr) and P4 (5.0 (mg/L)/yr), in Croatan Sound zone CR1 (2.8 (mg/L)/yr), in Roanoke Sound zone R1 (3.1 (mg/L)/yr), and in Currituck Sound zone CU1 (2.0 (mg/L)/yr).

A trend of decreasing alkalinity was observed at the mouth of the Roanoke River in location RO1. Overall, the long-term trend of decreasing alkalinity in the Roanoke River became less pronounced in the late 1970's but has increased recently. At the other stations showing statistically significant trends, alkalinity has increased and appears to be well above the criterion level throughout the period of record.

Alkalinity decreased over time in Chowan River zones CH4 (-0.83 (mg/L)/yr) and CH5 (-1.0 (mg/L)/yr). In contrast to alkalinity at most other sites, alkalinity at zone CH5 appears to have decreased since the late 1970's to concentrations regularly below the 20 mg/L criterion (fig. 19B).

Alkalinity also varies spatially. Alkalinity concentrations in upstream reaches of streams, such as at the NASQAN stations, tend to be lower than those in downstream reaches and in the estuary. This effect is illustrated in the box plots for zones in the Neuse River (fig. 20A) and the Pamlico River (fig. 20B). A corresponding increase in alkalinity from the upstream to the downstream areas of Pamlico Sound also was detected (fig. 20C).

Hardness

Hardness in water is caused by the presence of polyvalent cations, primarily calcium and magnesium, and to a lesser extent strontium, ferrous iron, and the manganous ion. Hardness generally is dependent on contact of the water with certain chemicals and minerals in soils and local rock

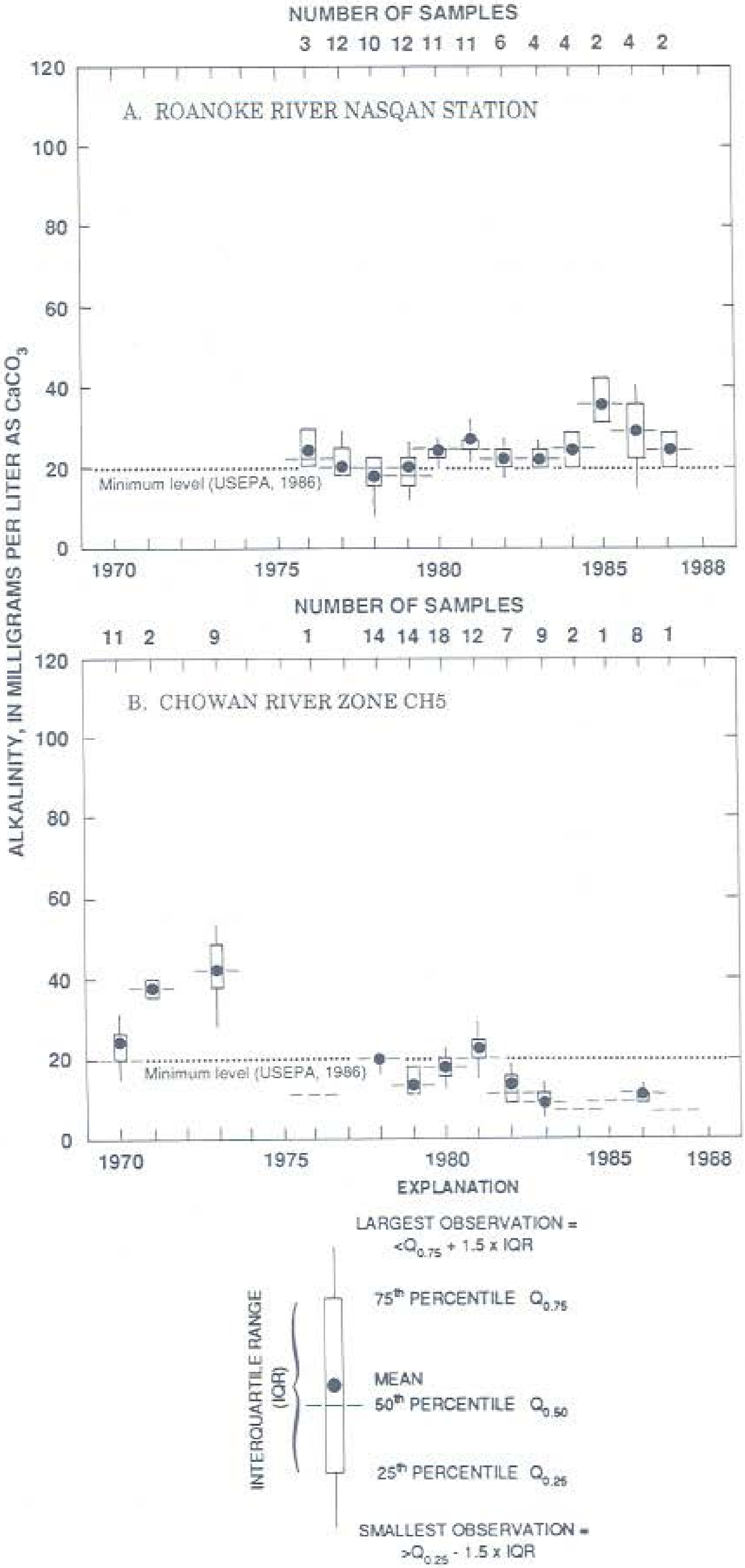

Figure 19.--Box plots of alkalinity, by year, for: A. Roanoke River National Stream Quality Accounting Network station (discharge adjusted) and B. Chowan River zone CH5.

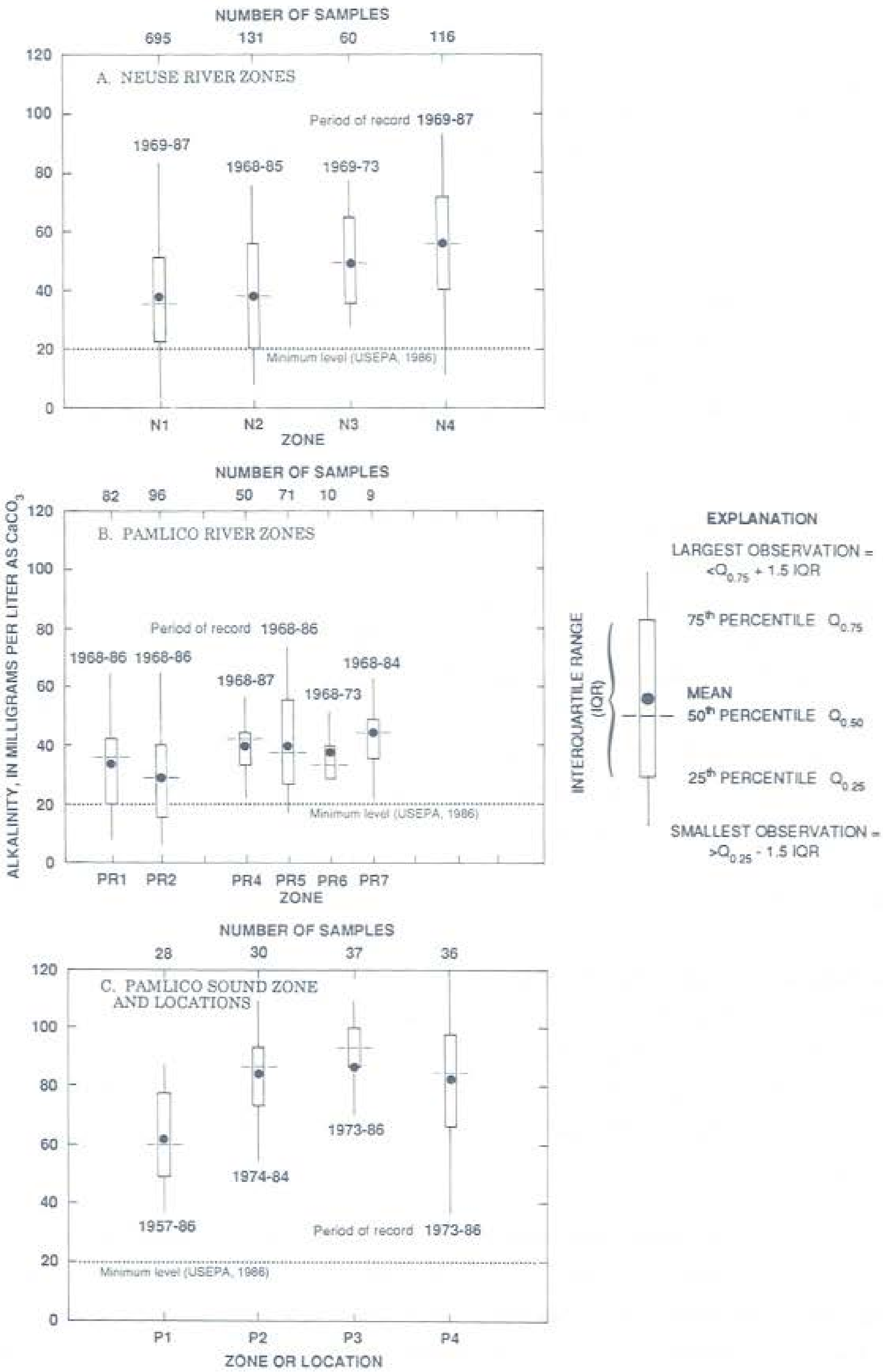

Figure 20.--Box plots of alkalinity for: A. Neuse River zones, B. Pamlico River zones, and C. Pamlico Sound zone and locations.

formations. In addition, calcium and magnesium are abundant in seawater, so hardness generally increases with increased mixing of freshwater with seawater. Many of the aquatic-life criteria (U.S. Environmental Protection Agency, 1986) vary depending on the water hardness because toxicity of metals and other constituents to aquatic life increase as water hardness decreases.

Increasing trends in flow-adjusted hardness were detected for the NASQAN stations on the Blackwater River (0.28 (mg/L)/yr), the Tar River (0.15 (mg/L)/yr), the Neuse River (0.16 (mg/L)/yr), and Contentnea Creek (0.31 (mg/L)/yr). The median hardness of the water at the NASQAN stations is 22 mg/L.

No significant trends over time were detected for hardness in the streams and estuaries downstream from the NASQAN stations. However, some spatial variation in hardness was apparent. Box plots by zone for the Neuse River (fig. 21A) and the Pamlico River (fig. 21B) show a progressive increase in hardness downstream; a slight downstream increase is apparent for the Alligator River (fig. 21C). In Pamlico Sound (fig. 21D), zone P1 had the lowest hardness, and location P3 shows the highest. All of the downstream estuary zones and locations have hardness values characterized as very high (greater than 180 mg/L).

Suspended Sediment

Sediment is the solid material transported by stream discharge, either in suspension or along the stream bottom, and consists primarily of the fragmental material that originates from weathering of rocks and includes soils and organic debris. Many nutrients, metals, and synthetic organic materials, such as pesticides, are readily sorbed and transported by sediment particles.

The only sediment data available were for samples collected at the NASQAN stations and analyzed for suspended sediment. Although decreasing trends in discharge-unadjusted sediment concentrations are indicated in table 12 for the Contentnea Creek and Roanoke River stations, the discharge-adjusted concentrations indicated a significant trend only in the Roanoke River (-0.21 (mg/L)/yr). The decreasing trend in sediment concentration at

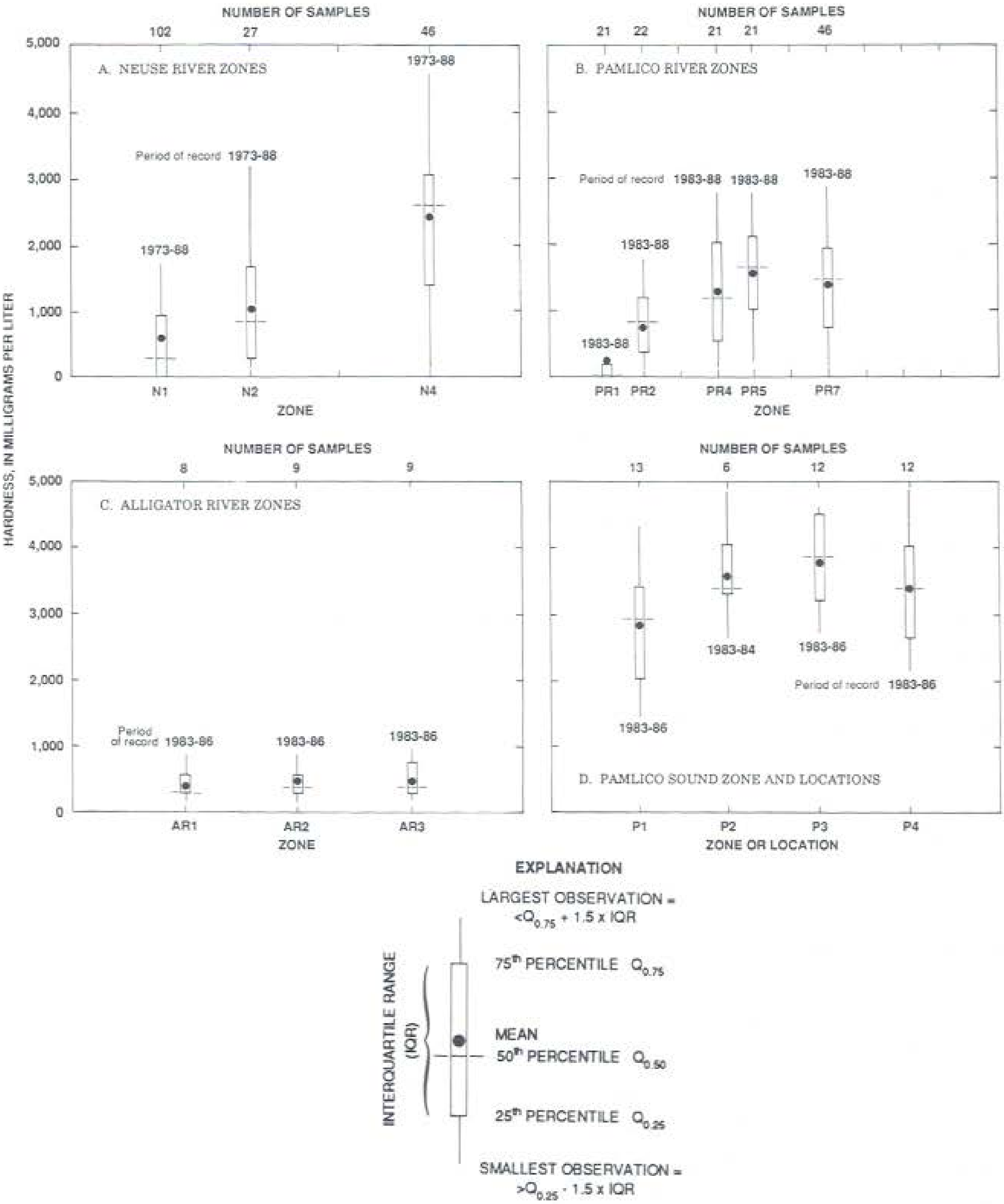

Figure 21.--Box plots of hardness for: A. Neuse River zones, B. Pamlico River zones, C. Alligator River zones, and D. Pamlico Sound zone and locations.

this station is probably a result of the upstream reservoir system for the Roanoke River.

The Roanoke River station had the lowest suspended-sediment concentration of the NASQAN stations (fig. 22A). The highest concentration for the NASQAN stations occurred at the Tar River station. The Virginia stations, including the Nottoway River, Blackwater River, and Meherrin River, generally had lower suspended-sediment concentrations than the Tar River, Neuse River, and Contentnea Creek stations.

Turbidity

Turbidity is caused by suspended material in water. High turbidity reduces sunlight penetration and may limit algal growth capacity. The available turbidity data for the Albemarle-Pamlico study area show few trends. Decreasing turbidity trends were detected at Pamlico River station PR4 (-1.1 nephelometric turbidity units per year (NTU/yr)) and Chowan River stations CH1 (-0.65 NTU/yr) and CH4 (-1.2 NTU/yr) (table 13). A substantial reduction in turbidity was apparent at all three of these stations in the late 1980's. The reduction in turbidity is reflected in the box plot for Chowan River zone CH1 in figure 22B.

Spatial trends in turbidity are apparent in the data for Pamlico Sound. Turbidity is highest at location P1 near the mouth of the Pamlico River and lowest near locations P3 and P4 nearer the Atlantic Ocean (fig. 22C).

Suspended Solids

The matter that remains as residue after a water sample is evaporated is generally referred to as total solids. This residue can be further defined by measurements to determine (1) dissolved solids, which is primarily inorganic salts, and (2) suspended solids, which is the undissolved constituent generally comparable to suspended sediment. Solids can be further subdivided into volatile and nonvolatile fractions. The volatile fraction is primarily the organic material in the sample; the nonvolatile fraction of the residue is primarily the inorganic material in the sample.

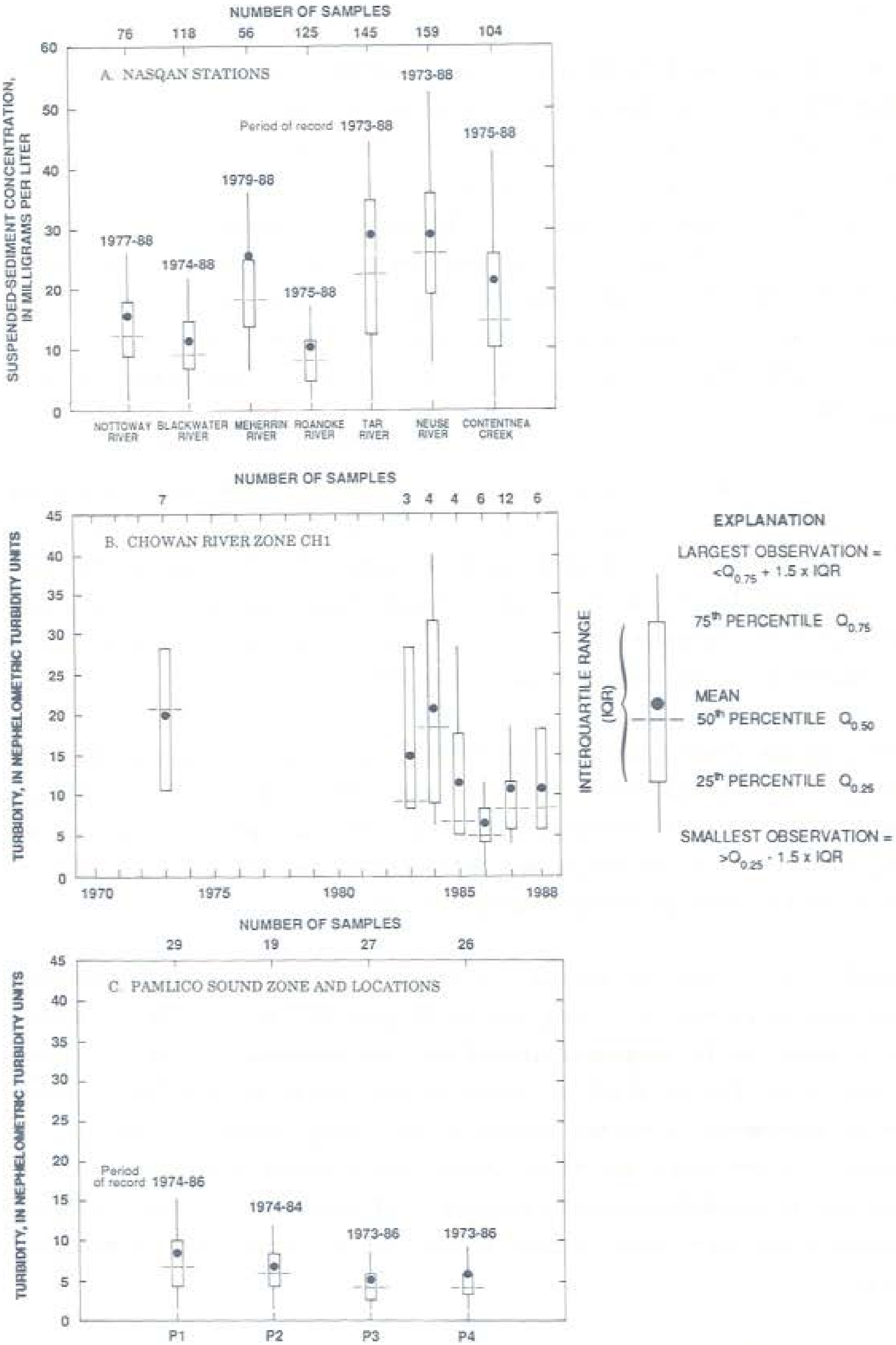

Figure 22.--Box plots of: A. Discharge-adjusted suspended-sediment concentrations for the National Stream Quality Accounting Network stations, B. turbidity, by year, for Chowan River zone CH1, and C. turbidity for Pamlico Sound zone and locations.

Suspended-solids concentrations have decreased throughout the Albemarle-Pamlico estuarine system at a mean rate of 1.1 (mg/L)/yr during the study period. A map showing the locations of zones or stations with statistically significant decreasing trends of suspended-solids concentrations is shown in figure 23. Box plots of suspended-solids concentrations by year illustrate general declines in suspended solids since the mid-1970's at Neuse River zone N4 (fig. 24A), Pamlico River zone PR1 (fig. 24B), Pamlico Sound location P2 (fig. 24C), Chowan River zone CH7 (fig. 25A), Perquimans River zone PQ1 (fig. 25B), and Pasquotank River zone PS1 (fig. 25C).

Nonvolatile suspended-solids concentrations decreased at a mean rate of 1.5 (mg/L)/yr. Trends of decreasing nonvolatile suspended-solids concentrations were detected at Neuse River zones N1, N2, and N4 (N4 shown in fig. 26A); Pamlico River zone PR1; Pamlico Sound zone P1 and locations P2 (fig. 26B) and P4; Roanoke Sound zone R1; Currituck Sound zone CU1; Roanoke River location RO1; and Chowan River zones CH5 and CH7.

Total solids concentrations, including the volatile and nonvolatile components of that total, have increased since the mid-1970's at Alligator River zone AR2 and at Chowan River zone CH7. In the case of Chowan River zone CH7, the total solids increased while the suspended solids decreased, indicating an increase in the dissolved solids.

Overall, the suspended-solids concentrations in the Albemarle-Pamlico estuarine system decreased during the study period. Because these decreases are in the nonvolatile component of solids, the decrease probably did not result from a decline in algal or other organic material but from a general decrease of suspended inorganic material resulting, perhaps, from construction of new lakes and ponds in the basin which trap sediment, including the suspended-inorganic component of sediment, or from changes in agricultural practices, such as crop production or improved soil management practices.

<u>Specific conductance</u>

Specific conductance is a measure of the ability of water to conduct electric current and is measured in μS/cm (microsiemens per centimeter at 25

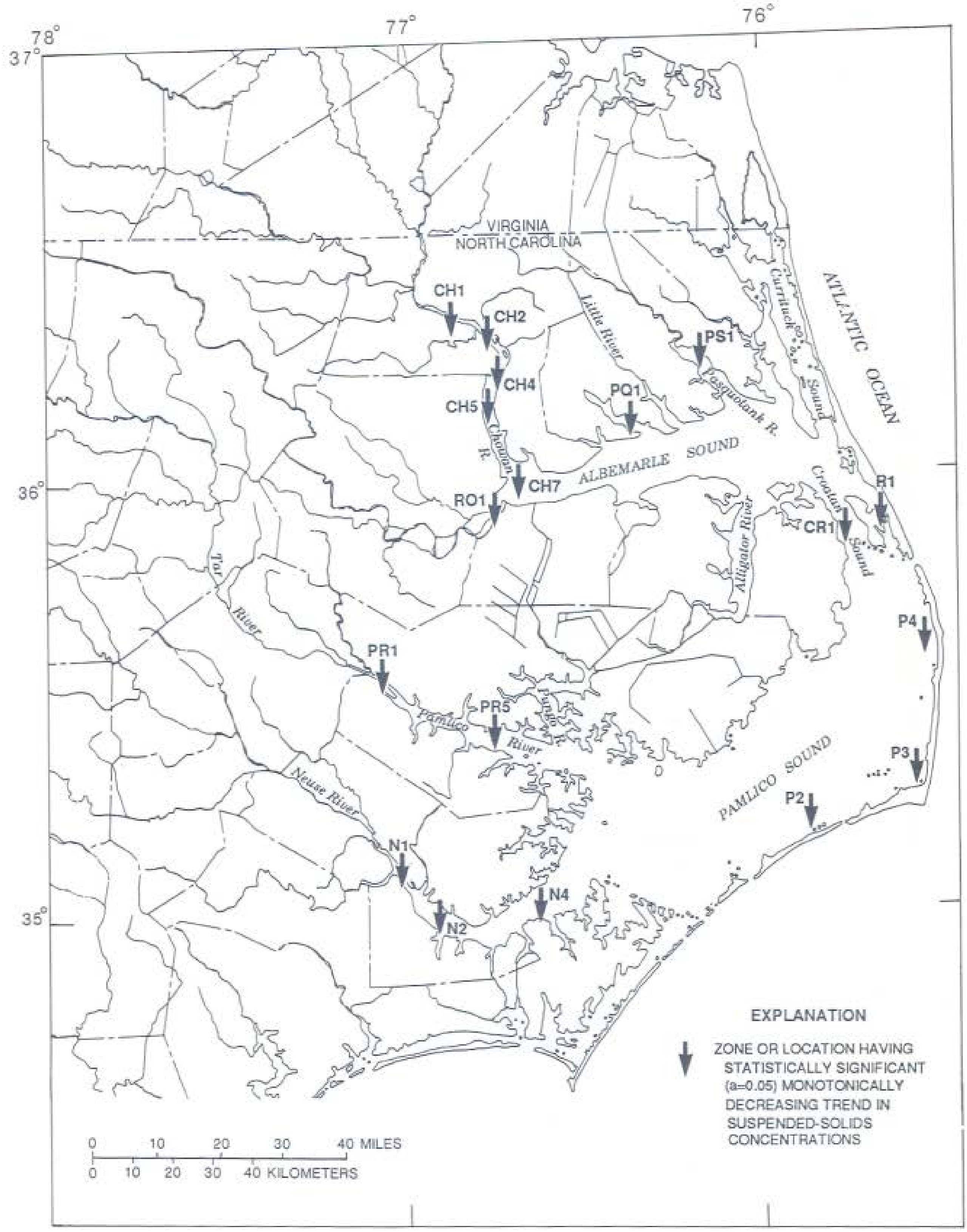

Figure 23.--Locations of water-quality zones or stations having statistically significant trends of decreasing suspended-solids concentrations, 1970-88.

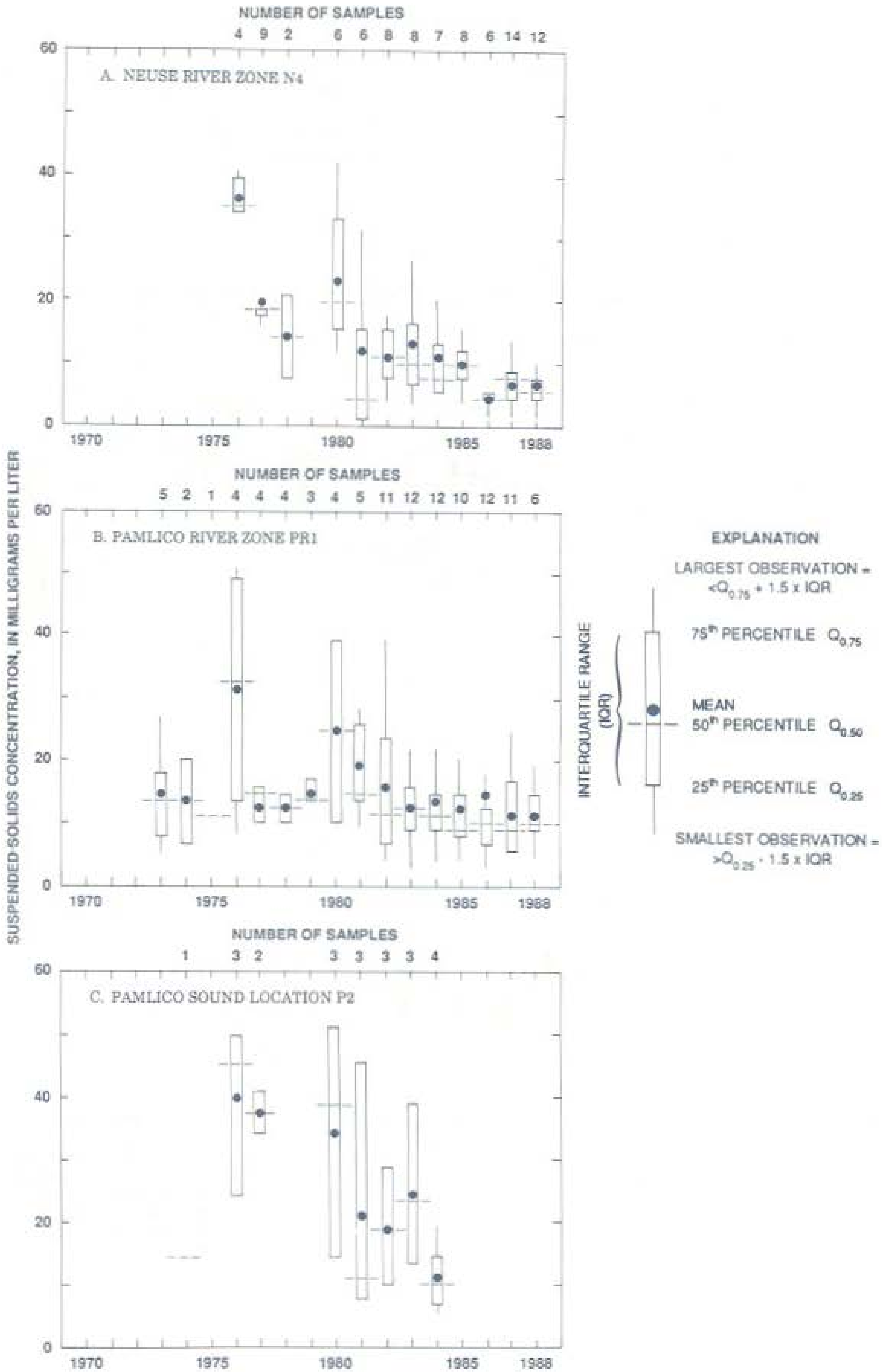

Figure 24.--Box plots of suspended-solids concentrations for selected water-quality zones and location, by year: A. Neuse River zone N4, B. Pamlico River zone PR1, and C. Pamlico Sound location P2.

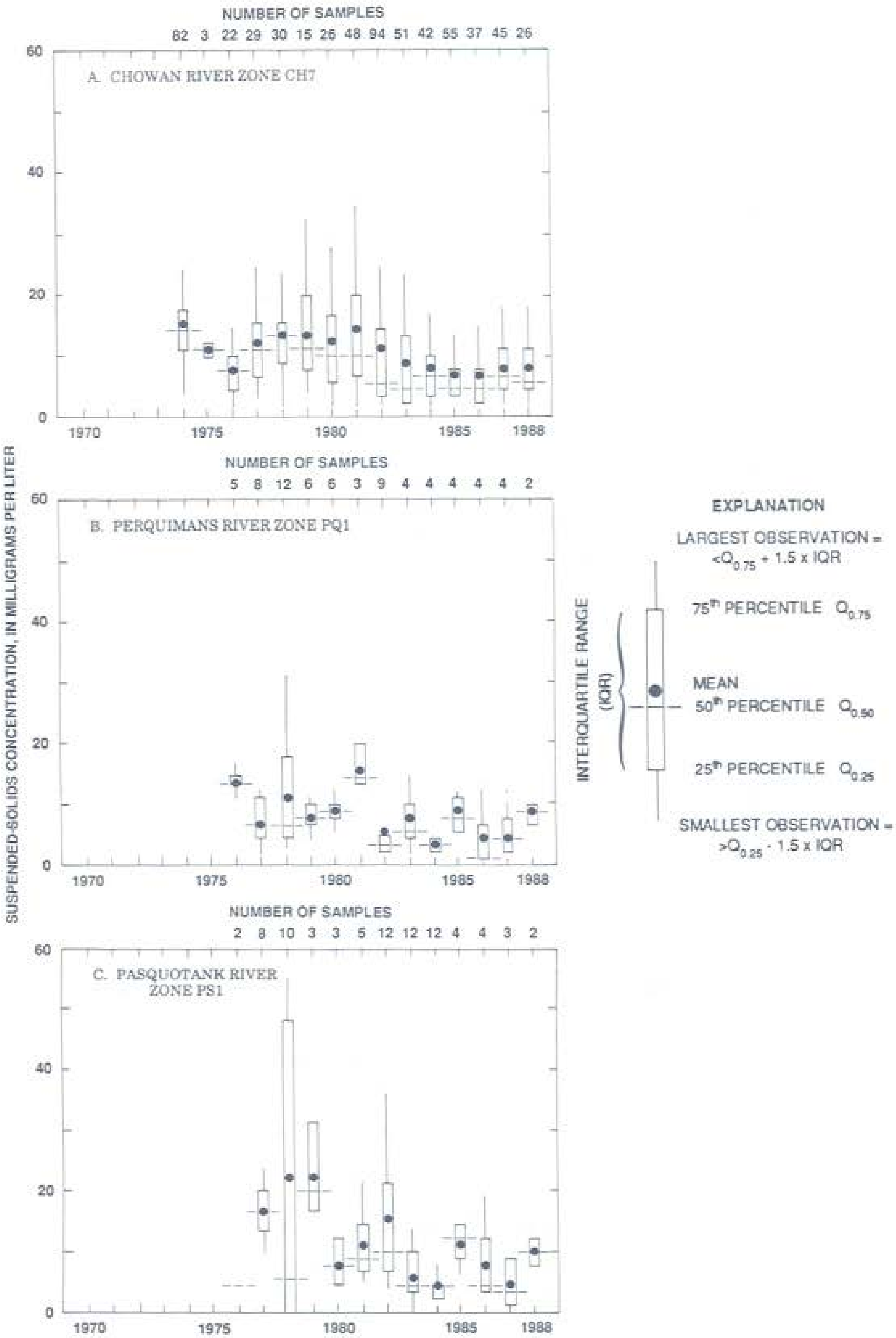

Figure 25.--Box plots of suspended-solids concentrations for selected water-quality zones, by year: A. Chowan River zone CH7, B. Perquimans River zone PQ1, and C. Pasquotank River zone PS1.

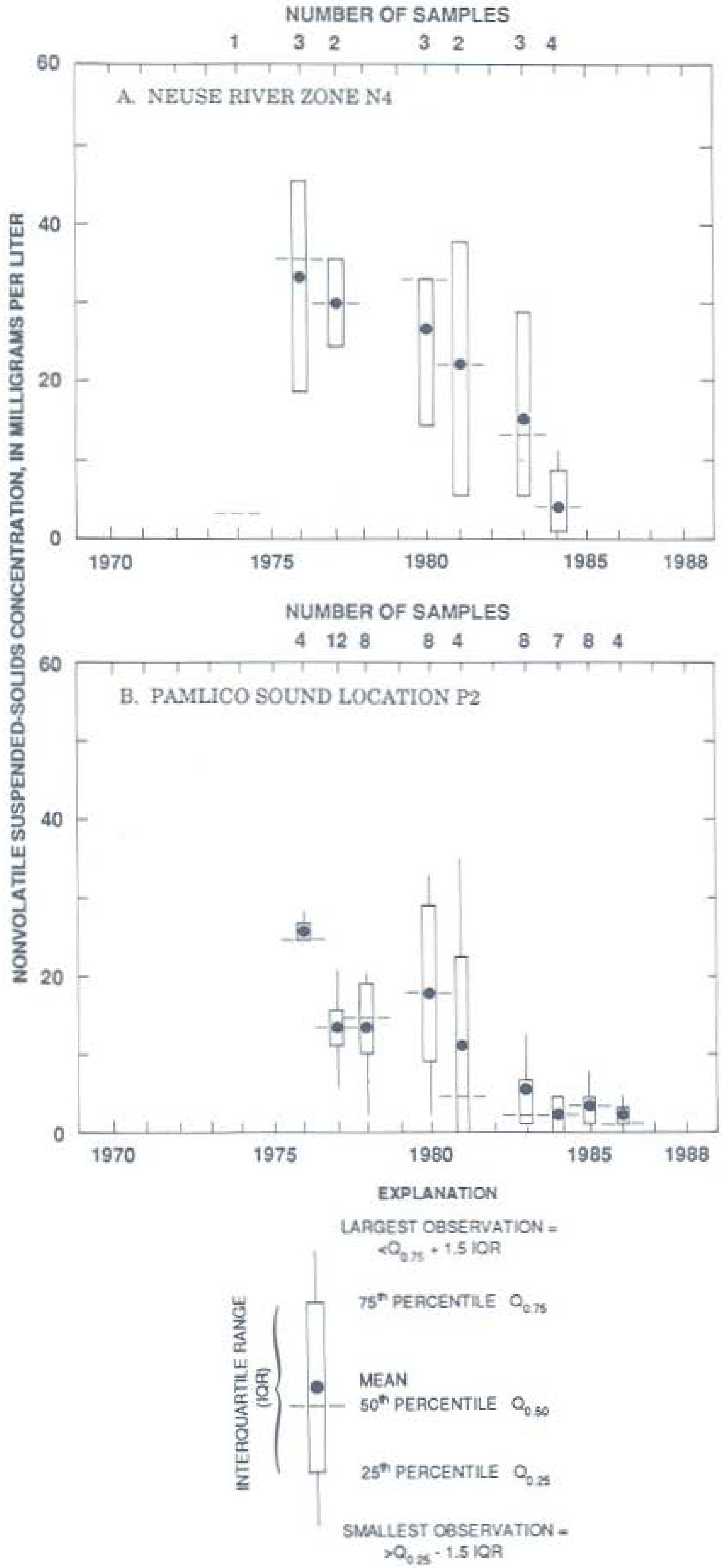

Figure 26.--Box plots of nonvolatile suspended-solids concentrations for a selected water-quality zone and location, by year: A. Neuse River zone N4 and B. Pamlico Sound location P2.

degrees Celsius). Specific conductance is dependent upon the number and types of ions dissolved in the water and is, therefore, useful as an indirect measure of the relative amounts of chemical ions in solution.

The greatest amount of specific-conductance data is available for the NASQAN stations. Specific conductance has been continuously monitored at many of the NASQAN stations for periods of more than 10 years. In addition, specific conductance was measured when water-quality samples were periodically collected at the stations, usually at intervals of one month to 6 weeks.

Tests for trends in specific conductance were run separately for the daily-value records and for the periodic measurements made in connection with the collection of water-quality samples. Increasing trends in flow-adjusted specific conductance were detected in the Neuse River (0.8 (μS/cm)/yr for periodic samples), the Tar River (0.6 (μS/cm)/yr for daily values), the Roanoke River (1.5 (μS/cm)/yr, for daily values), Contentnea Creek (1.9 (μS/cm)/yr for daily values), and the Blackwater River (0.7 (μS/cm)/yr for the periodic record). This increasing trend is exemplified in the box plot for periodic samples from the Neuse River NASQAN station (fig. 27A).

An increasing trend in specific conductance of atmospheric deposition during 1979-87 was detected at the Lewiston station (1.9 (μS/cm)/yr; fig. 27B). However, this trend was not reflected in concentrations of major dissolved substances in precipitation.

Spatial trends in specific conductance are evident in the Pamlico River (fig. 27C). Specific conductance increases from zone PR1 to zone PR10 as the freshwater mixes with saltwater in the estuaries and sounds.

Major Dissolved Substances

Dissolved solids and salinity

Dissolved solids, reported in milligrams per liter, is mostly used in reference to freshwater quality. The amount of dissolved material in water is environmentally important because it helps managers determine the

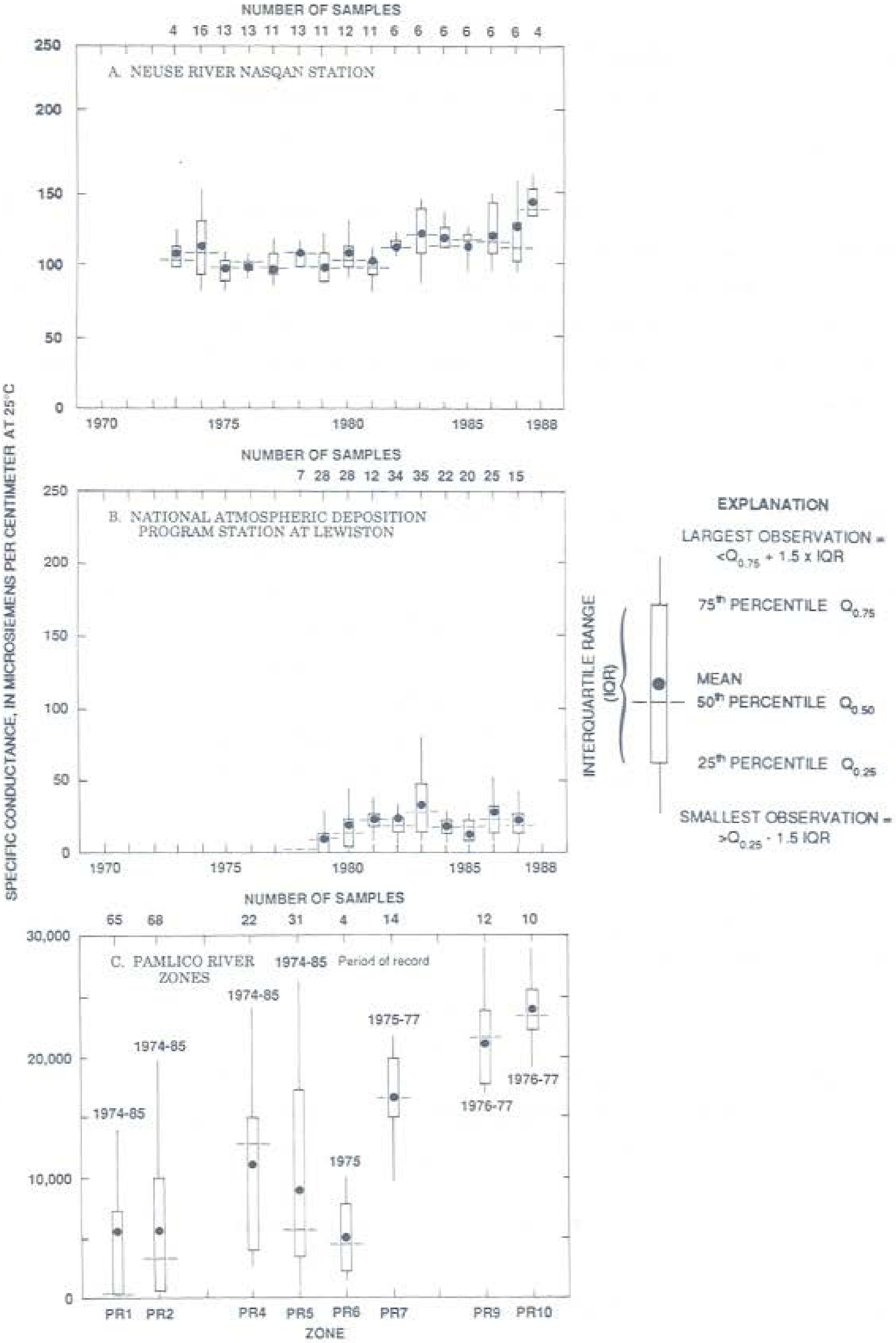

Figure 27.--Box plots of specific conductance for: A. Neuse River National Stream Quality Accounting Network station, 1973-88 (discharge adjusted), B. National Atmospheric Deposition Program station at Lewiston, 1978-87, and C. Pamlico River zones for the period of record.

ultimate use or treatment of water and plays a critical role in the types of aquatic life that populate the waters. Salinity is a measure of the concentration of dissolved material in water, usually reported in parts per thousand (ppt) and is used in reference to the quality of saltwater. Giese and others (1985) give a detailed discussion of salinity, the mixing of fresh and saltwater in estuaries, and spatial variation of salinity in North Carolina's estuaries.

A map showing the locations of zones or stations where significant increasing or decreasing trends of dissolved solids or salinity were detected is shown in figure 28. Although the NASQAN stations show trends of increasing dissolved-solids concentrations and an increasing trend in salinity at Pamlico River zone PR2 was detected (0.03 ppt/yr), a trend of decreasing salinity was apparent in the Pamlico River at its mouth in zone PR10 (-0.16 ppt/yr). Increasing trends in flow-adjusted dissolved-solids concentrations were detected at all the NASQAN stations except for those on the Nottoway and Meherrin Rivers. The mean increase for all NASQAN stations was 0.6 (mg/L)/yr. Generally, the dissolved-solids concentrations increased through the 1970's, peaked about 1981 during a very dry year, and then declined through the 1980's, as exemplified in the box plots for the Tar River in figure 29.

Increasing trends in salinity were detected at Albemarle Sound zones A2 (0.1 ppt/yr) and A5 (0.08 ppt/yr) and at Pasquotank River zone PS1 (0.08 ppt/yr). This increase in salinity is illustrated in the box plot for Albemarle Sound zone A2 (fig. 30C). The peak in concentration of salinity values at the Pamlico River zones PR10 and PR2 in 1981 (figs. 30A and 30B) may be compared with similar peaks in dissolved-solids concentrations at the NASQAN stations during the same period (fig. 29, for example).

Salinity levels in the estuaries and sounds vary spatially. In general, salinities increase from west to east as freshwater mixes with saltwater entering the sounds through the inlets. This increase in salinity in a seaward direction can be seen in the box plots for the Neuse River in figure 31A; the Pamlico River in figure 31B; Pamlico Sound in figure 31C; Albemarle Sound, the Little River, the Perquimans River, and the Pasquotank River in figure 32A; the Alligator River in figure 32B; and Currituck, Croatan, and Roanoke Sounds in figure 32C. Changes in salinity should be

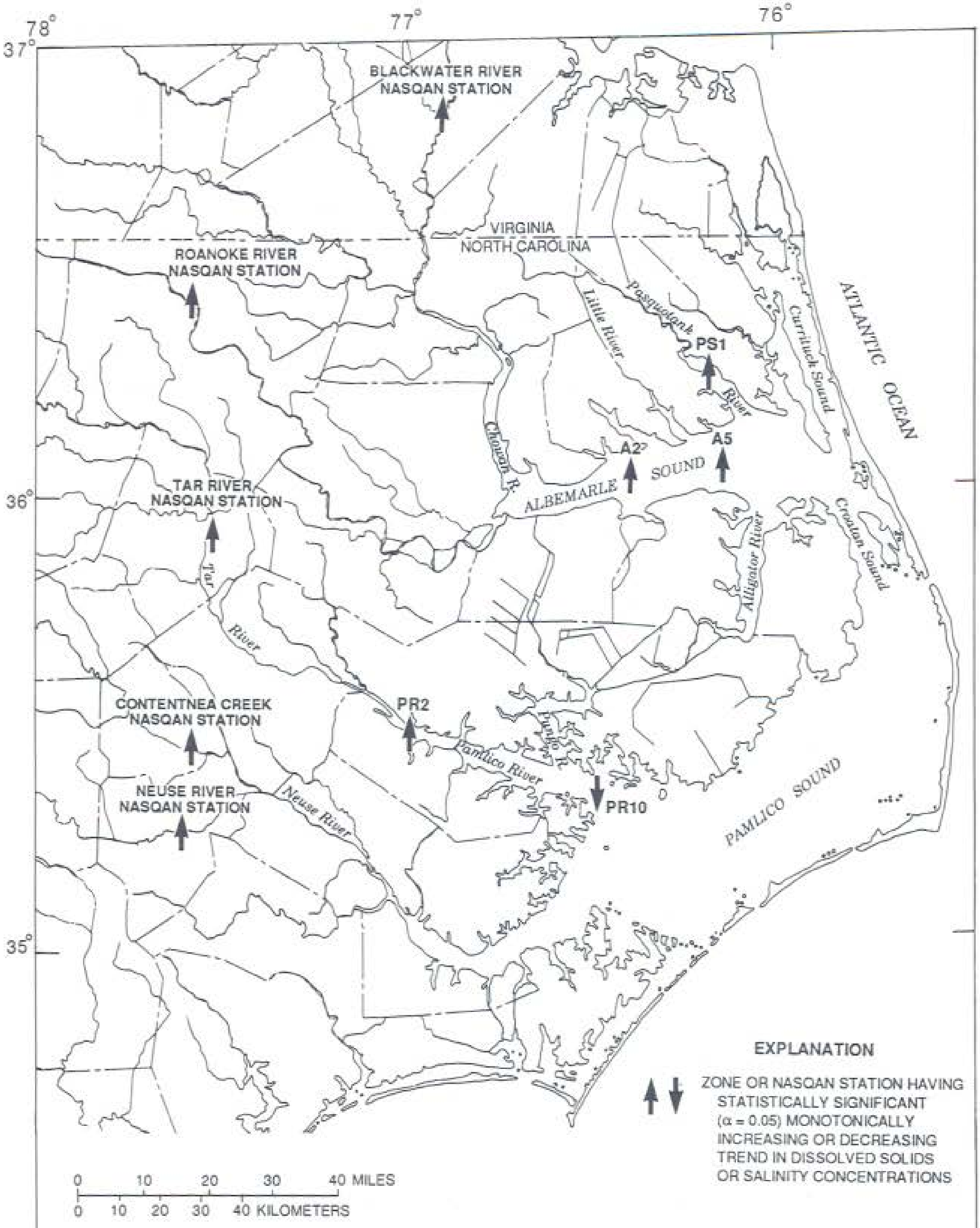

Figure 28.--Locations of water-quality zones or stations having statistically significant trends of increasing or decreasing dissolved-solids or salinity concentrations, 1970-88.

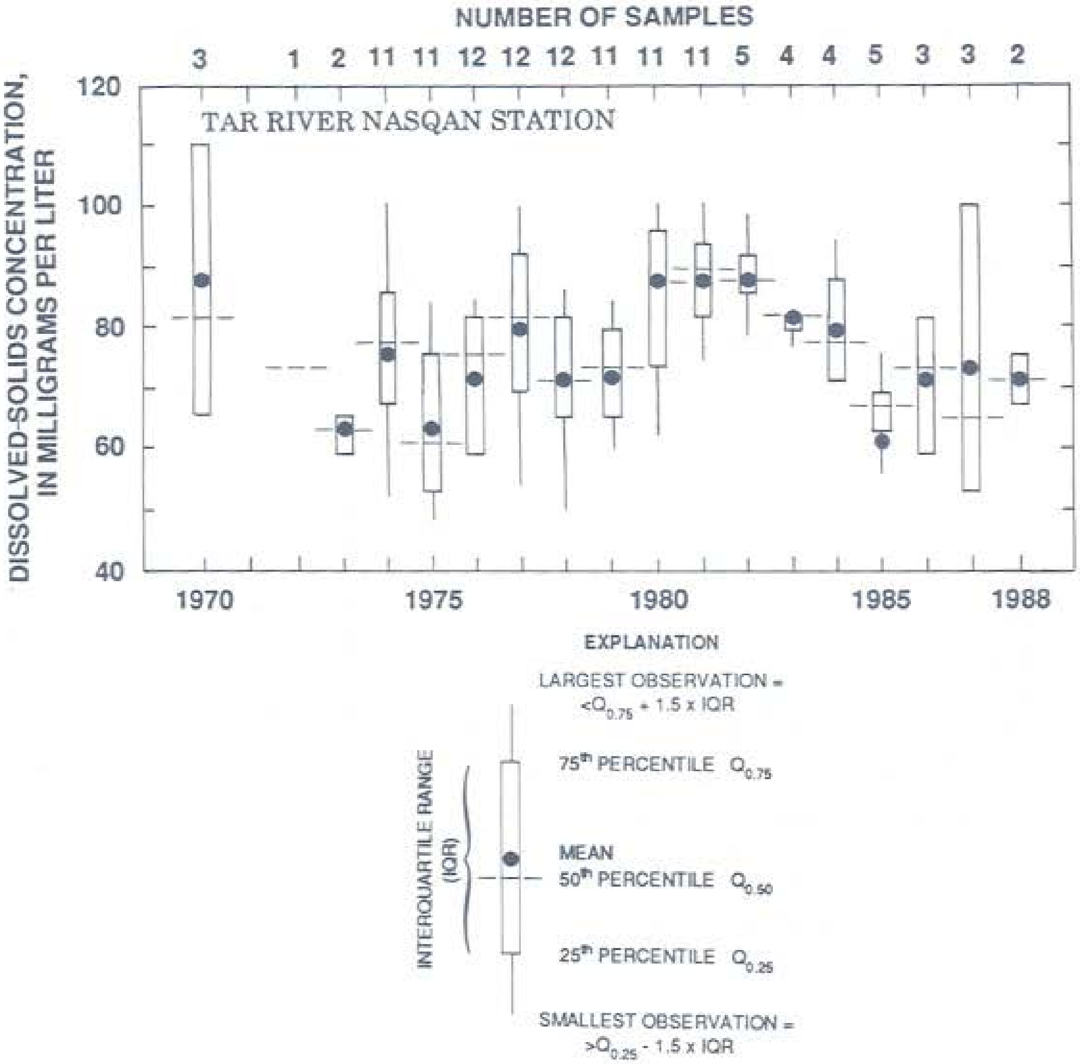

Figure 29.--Box plots of discharge-adjusted dissolved-solids concentrations, by year, for the Tar River National Stream Quality Accounting Network station.

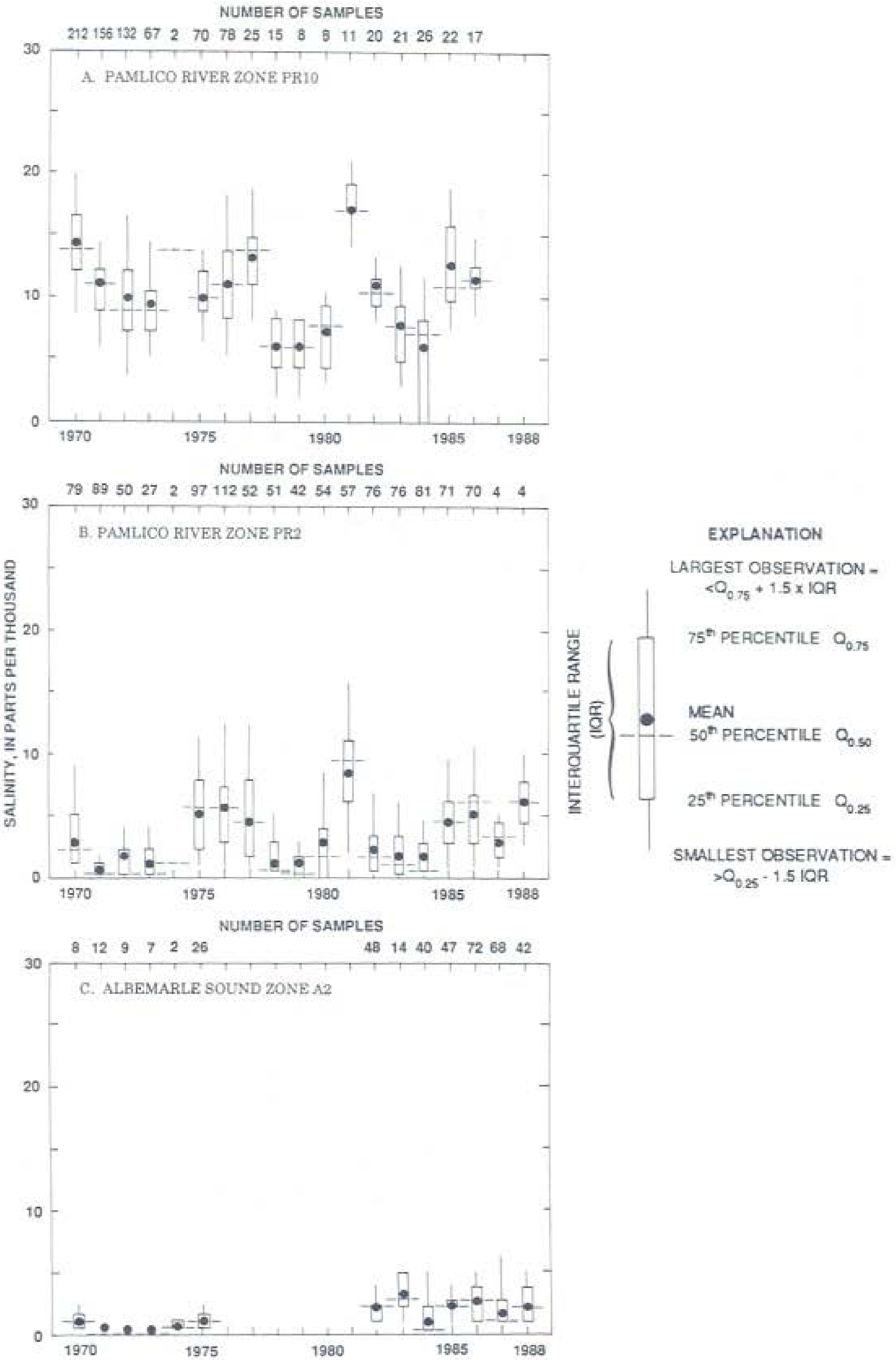

Figure 30.--Box plots of salinity for selected water-quality zones, by year: A. Pamlico River zone PR10, B. Pamlico River zone PR2, and C. Albemarle Sound zone A2.

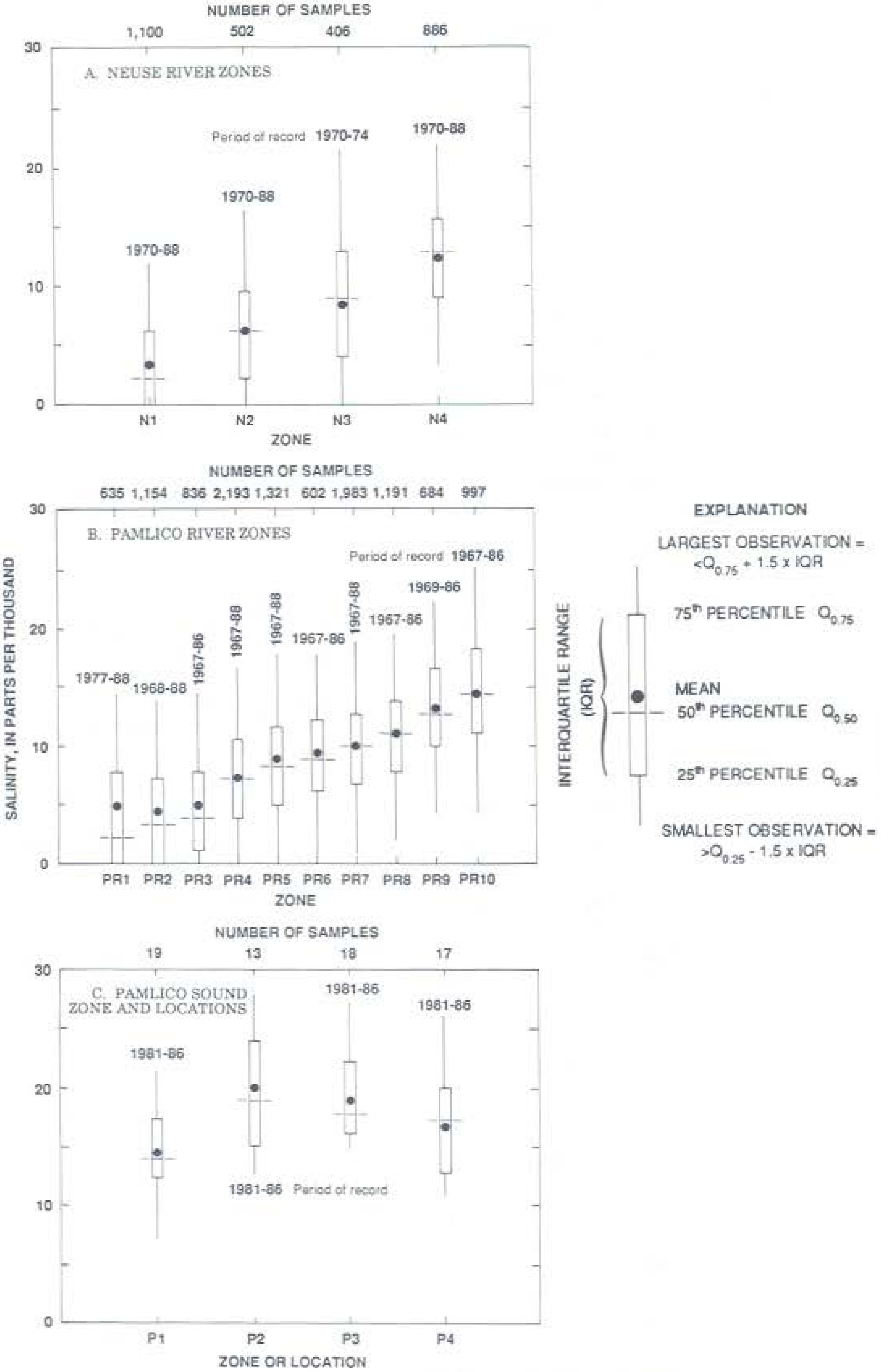

Figure 31.--Box plots of salinity for: A. Neuse River zones, B. Pamlico River zones, and C. Pamlico Sound zone and locations.

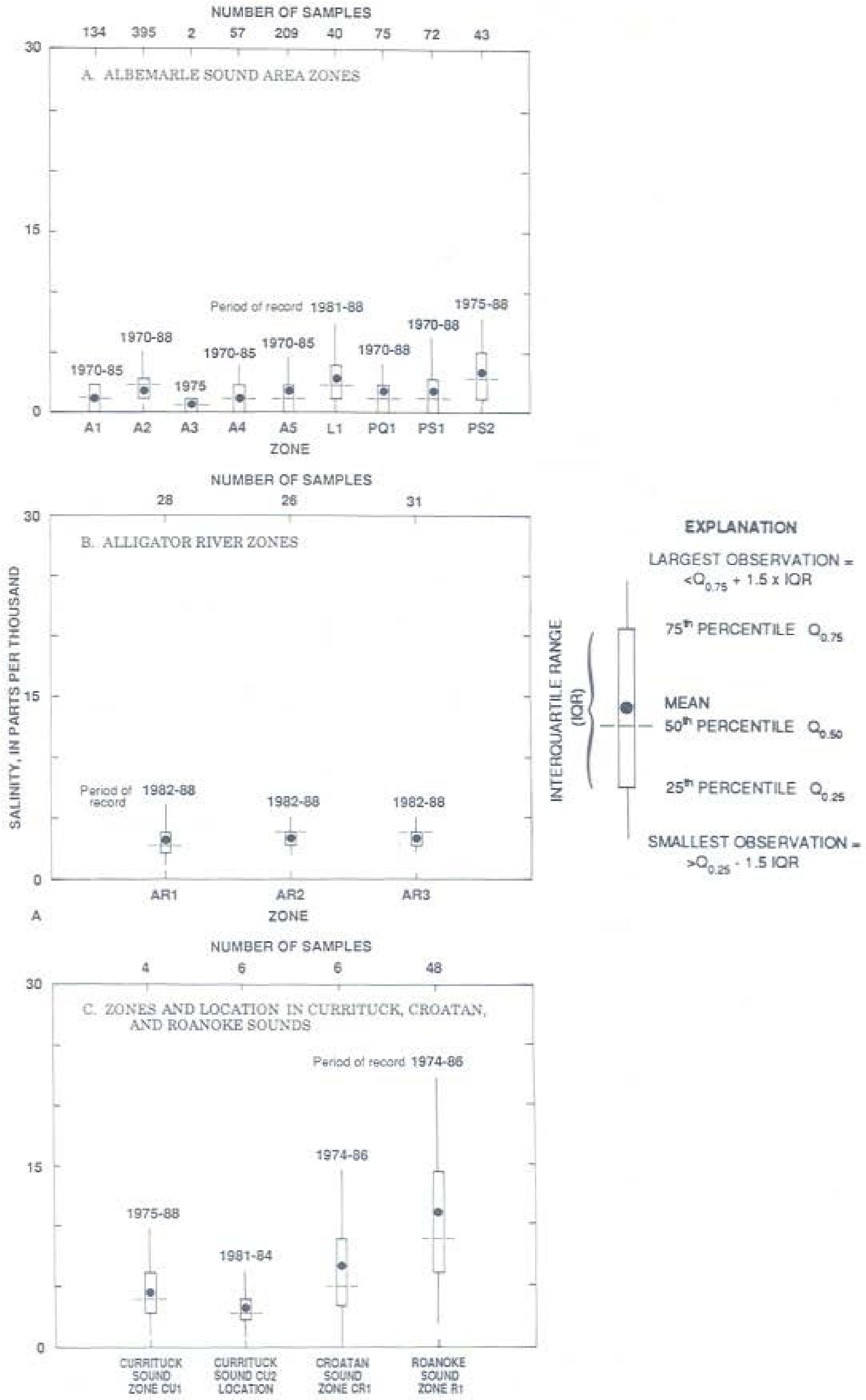

Figure 32.--Box plots of salinity for: A. Albemarle Sound area zones, B. Alligator River zones, and C. zones and location in Currituck, Croatan, and Roanoke Sounds.

reflected in specific conductance also. However, the available data for specific conductance in the estuary zones were sparse, and direct comparisons were not possible.

Chloride

Chloride is one of the major constituents of dissolved solids in seawater. Locally, trends detected in chloride are expected to be similar to those seen for dissolved solids and salinity. Unfortunately, there were not many available data for chloride in the estuary system; however, there are considerable chloride data for the NASQAN stations.

Flow-adjusted chloride concentrations increased over time at all the NASQAN stations except the Meherrin River and Contentnea Creek stations. The mean for the increases observed in the NASQAN stations was 0.07 (mg/L)/yr. Box plots of chloride concentrations with time are shown for the Neuse River in figure 33A, for the Roanoke River in figure 33B, and for the Nottoway River in figure 33C. This increase is probably due to increased upstream wastewater discharges over time.

A trend of increasing chloride concentration was detected at zone N4 in the Neuse River. Short-term (1982-88) increasing chloride trends were apparent at zones PR4 and PR7 in the Pamlico River.

A peak in chloride concentration occurred around 1981 during a relatively dry period at NASQAN stations on the Roanoke River, Contentnea Creek, Tar River, and the Blackwater River. This 1981 peak is reflected in salinities observed in Pamlico River zones PR2 (fig. 30B) and PR10 (fig. 30A). A peak in chloride concentration in the early 1980's was evident also at Currituck Sound zone CR1, Little River zone L1, Perquimans zone PQ1, and at Pasquotank River zones PS1 and PS2; however, none of these zones showed statistically significant increasing or decreasing trends.

Some spatial variations in chloride concentrations are evident from the available data. Overall, for chloride concentrations at the NASQAN stations (fig. 33D), Contentnea Creek had the highest relative distribution of concentrations of chloride followed by the Neuse River, Blackwater River, Tar River, Roanoke River, and the Nottoway and Meherrin Rivers. Variations

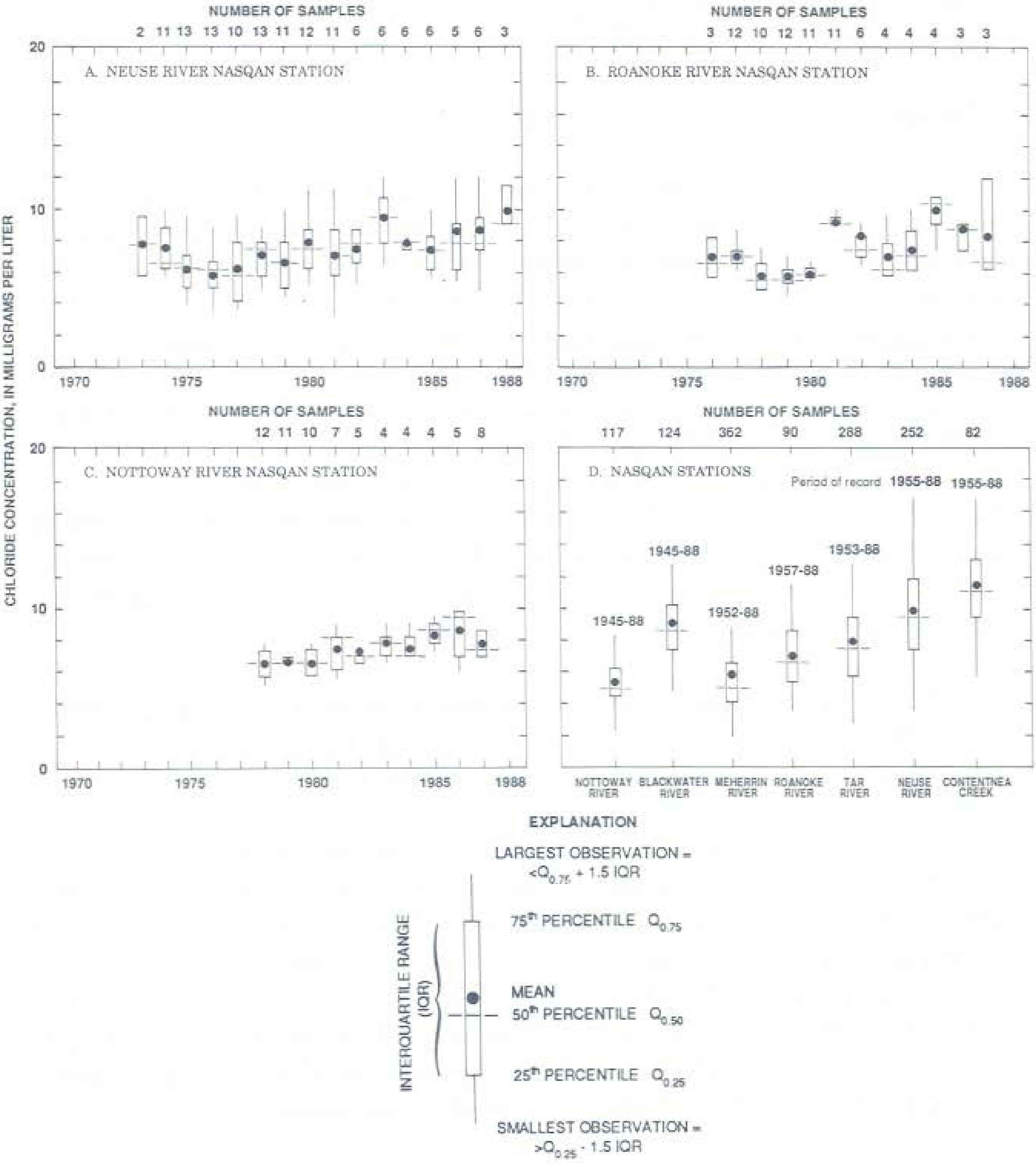

Figure 33.--Box plots of discharge-adjusted chloride concentrations for National Stream Quality Accounting Network stations at: A. Neuse River, 1973-88, B. Roanoke River, 1975-88, C. Nottoway River, 1977-88, and D. all stations for the period of record.

in chloride concentrations between the zones and locations in Pamlico Sound are shown in figure 34A, in Albemarle Sound in figure 34B, and in Currituck, Croatan and Roanoke Sounds in figure 34C. The variations in chloride concentrations in Pamlico, Currituck, Croatan, and Roanoke Sounds are similar to those seen for salinity (figs. 31C and 32C) at these areas. Chloride and salinity concentrations are generally greater in Pamlico Sound locations P2 and P3 than in zone P1 and location P4; lower in Currituck Sound location CU2 than in zone CU1; and higher in Roanoke Sound than Croatan Sound.

Bicarbonate

Data for bicarbonate concentrations were available only for the NASQAN stations. Increasing trends in flow-adjusted bicarbonate levels were detected at the Neuse River (0.07 (mg/L)/yr) and Contentnea Creek (0.11 (mg/L)/yr) stations for the period 1973-85.

Macronutrients

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

This section examines trends in macronutrients carbon, nitrogen, and phosphorus, as well as the ratios of these elements. The available nutrient data for the Albemarle-Pamlico estuarine system includes measures of total organic carbon, ammonia nitrogen, total ammonia plus organic nitrogen, nitrate plus nitrite nitrogen, total phosphorus, and dissolved phosphorus.

Carbon

A range of 5 to 15 mg/L total organic carbon (TOC) is characteristic of the upstream edge of the tidal zone of river and estuary waters of the area

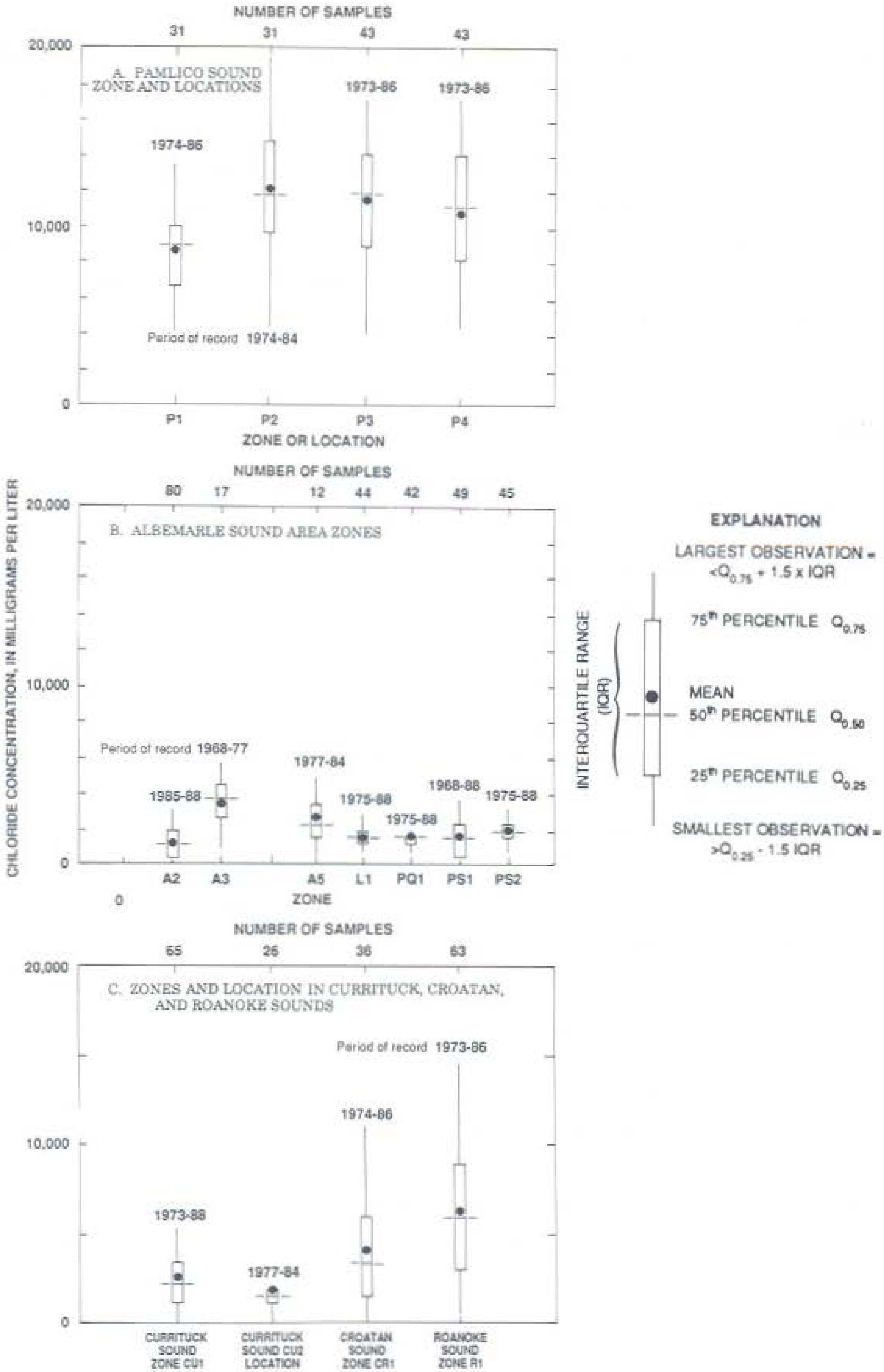

Figure 34.--Box plots of chloride concentrations for: A. Pamlico Sound zone and locations, B. Albemarle Sound area zones, and C. zones and location in Currituck, Croatan, and Roanoke Sounds.

(Thurman, 1985). However, TOC concentrations in swamps and bogs, which can be relatively high, generally range from 30 to 40 mg/L (Thurman, 1985). Because carbon is readily available in the environment as carbon dioxide or bicarbonate, it is unusual that carbon would limit the growth of algae (Crawford, 1985).

Decreasing trends in TOC concentrations since 1982 were detected in Roanoke River location RO1 (-0.50 (mg/L)/yr) and Albemarle Sound zone A2 (-0.37 (mg/L)/yr). Concentrations were within the normal range described by Thurman (1985). The TOC data for the Chowan River (fig. 35A) and the Alligator River (fig. 35B) indicate that TOC concentrations decreased downstream.

Nitrogen

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

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

Decreasing trends in ammonia nitrogen concentrations were detected at zone A2 (-0.005 (mg/L)/yr) in Albemarle Sound, Alligator River zone AR2 (-0.023 (mg/L)/yr), and zone CH1 (-0.003 (mg/L)/yr) in the Chowan River (fig. 36A), shown on table 13. A decline in ammonia nitrogen concentrations also was significant for all of the Pamlico River zones except PR1; the mean for 9 zones was -0.003 (mg/L)/yr. Box plots for zones PR2 (fig. 36B), PR5 (fig. 36C), and PR9 (fig. 36D) illustrate this decline. Only Chowan River zone CH1 had ammonia concentrations greater than 0.5 mg/L (in

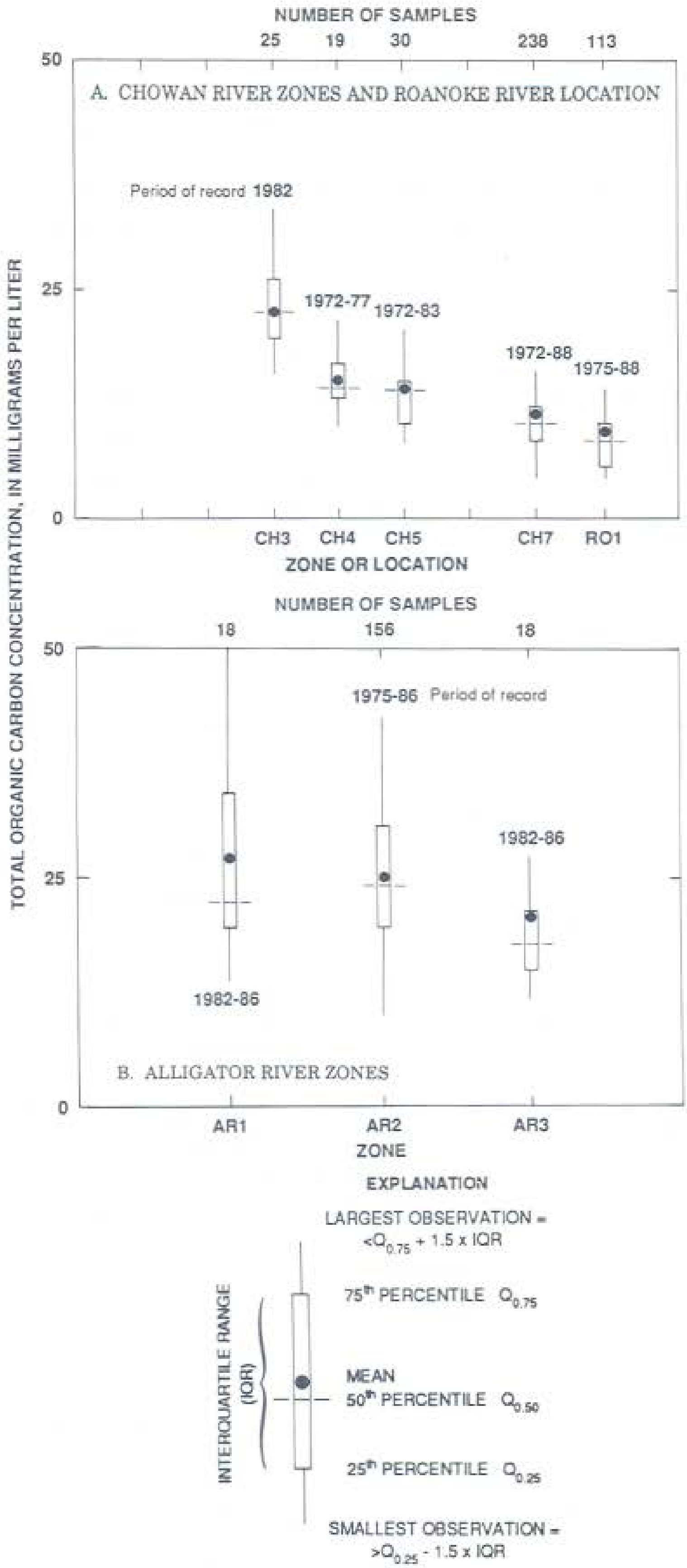

Figure 35.--Box plots of total organic carbon concentrations for: A. Chowan River zones and Roanoke River location and B. Alligator River zones.

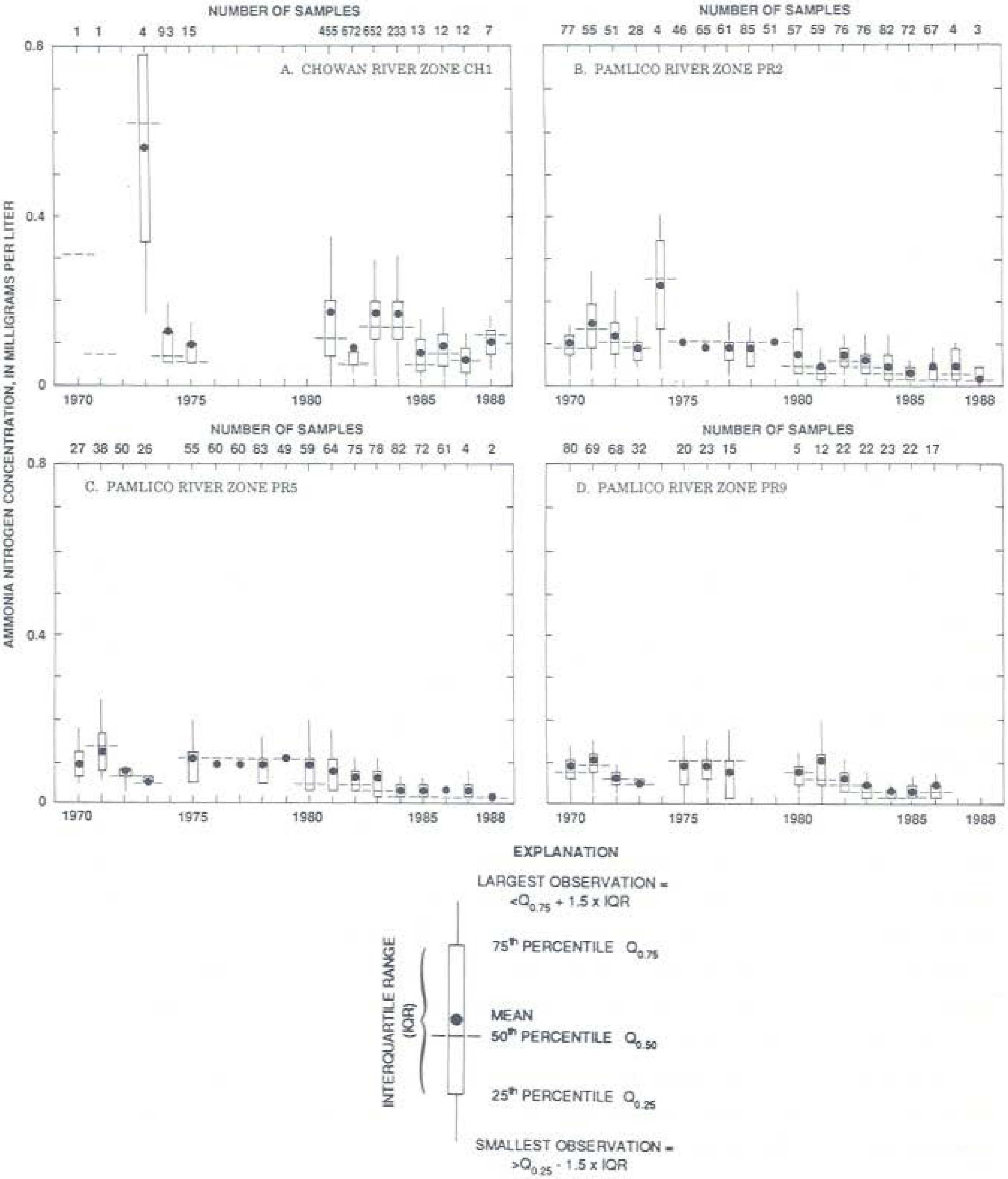

Figure 36.--Box plots of ammonia nitrogen concentrations for selected water-quality zones, by year: A. Chowan River zone CH1, B. Pamlico River zone PR2, C. Pamlico River zone PR5, and D. Pamlico River zone PR9.

1973), and concentrations at all zones showing decreasing trends fell below 0.3 mg/L in the late 1980's. Although there are substantial ammonia nitrogen data available for NASQAN and NADP/NTN stations (table 12), recent changes in lower analytical detection limits of the analysis made trend analysis questionable for these stations.

Total ammonia plus organic nitrogen concentrations generally decreased (mean of 7 zones, -0.03 (mg/L)/yr) throughout the Albemarle-Pamlico study area except in the Pamlico River, Chowan River zones CH1 and CH3, and the Nottoway River NASQAN station (fig. 37). Because ammonia nitrogen generally decreased in the Pamlico River zones whereas total ammonia plus organic nitrogen increased (mean of 9 zones, 0.02 (mg/L)/yr), it appears that the increase in nitrogen in the Pamlico River is due to an increase of organic nitrogen. This is most likely due to increased production of biomass. Soluble ammonia nitrogen is used by algae and converted into organic nitrogen in algal cells.

Box plots of total ammonia plus organic nitrogen at Neuse River zone N4 (fig. 38A), Currituck Sound location CU2 (fig. 38B), Pasquotank River zone PS1 (fig. 38C), and Chowan River zone CH1 (fig. 38D) demonstrate trends of decreasing total ammonia plus organic nitrogen since the late 1970's or early 1980's. In the late 1980's, the concentrations of total ammonia plus organic nitrogen at these zones decreased to about 0.5 mg/L or less.

Increasing trends in total ammonia plus organic nitrogen concentrations were detected at all of the Pamlico River stations, as illustrated in the box plots for zones PR1 (fig. 39A) and PR7 (fig. 39B). However, a decrease in concentrations of total ammonia plus organic nitrogen beginning in the early 1980's is apparent for zones PR1 (fig. 39A), PR2, PR4, and PR5. In general, the zones downstream from PR5 show the pattern of increase similar to that observed for zone PR7 (fig. 39B). It is important to note that increases detected in three zones (PR2, PR5, and PR9) of the Pamlico River by Stanley (1988a) were speculatively discounted as results of different analytical methodologies.

Total ammonia plus organic nitrogen concentrations vary spatially in the Albemarle-Pamlico estuary. In general, concentrations decreased slightly downstream as seen in the Neuse River zones (fig. 40A), the Pamlico

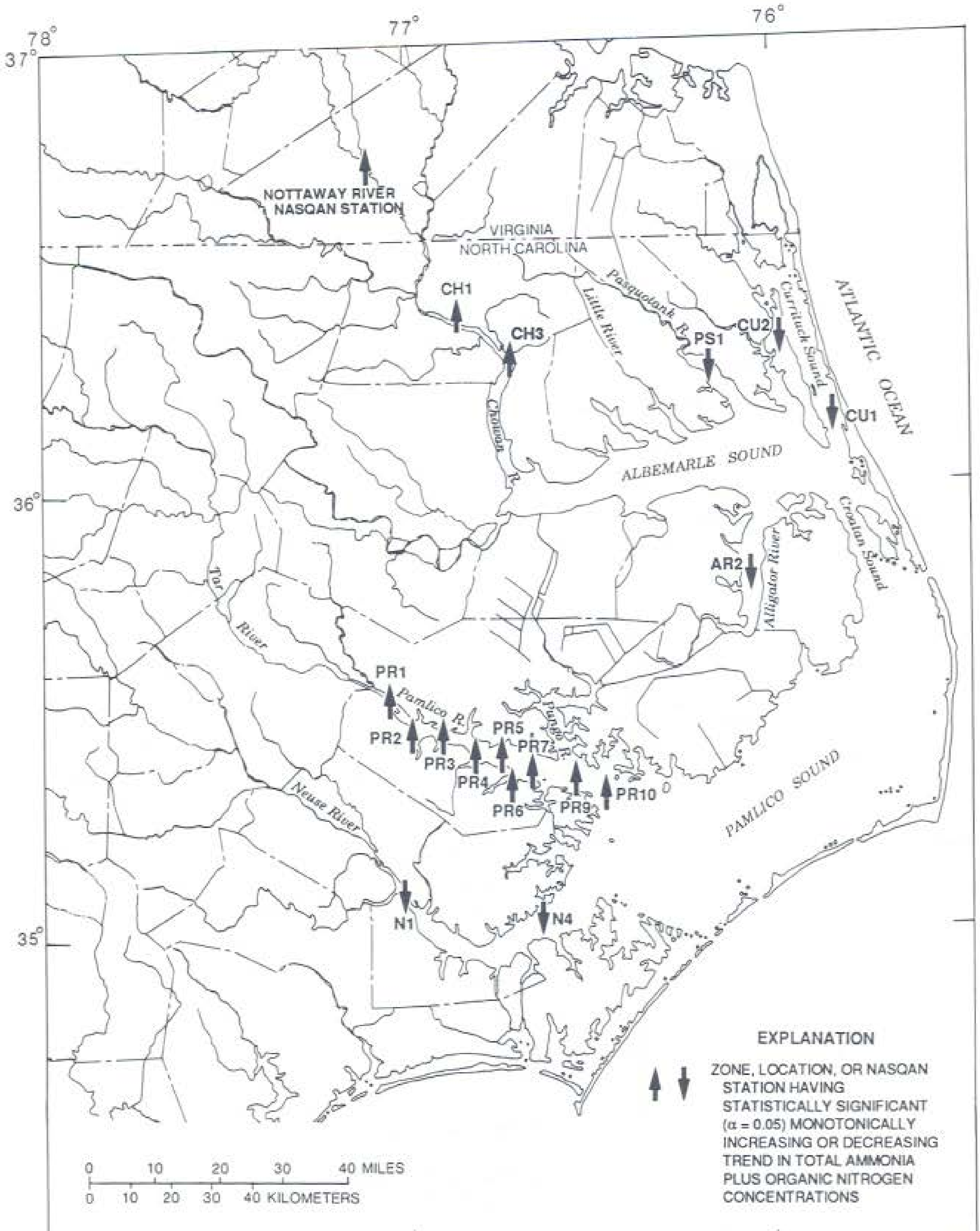

Figure 37.--Locations of water-quality zones or stations having statistically significant trends of increasing or decreasing total ammonia plus organic nitrogen concentrations, 1970-88.

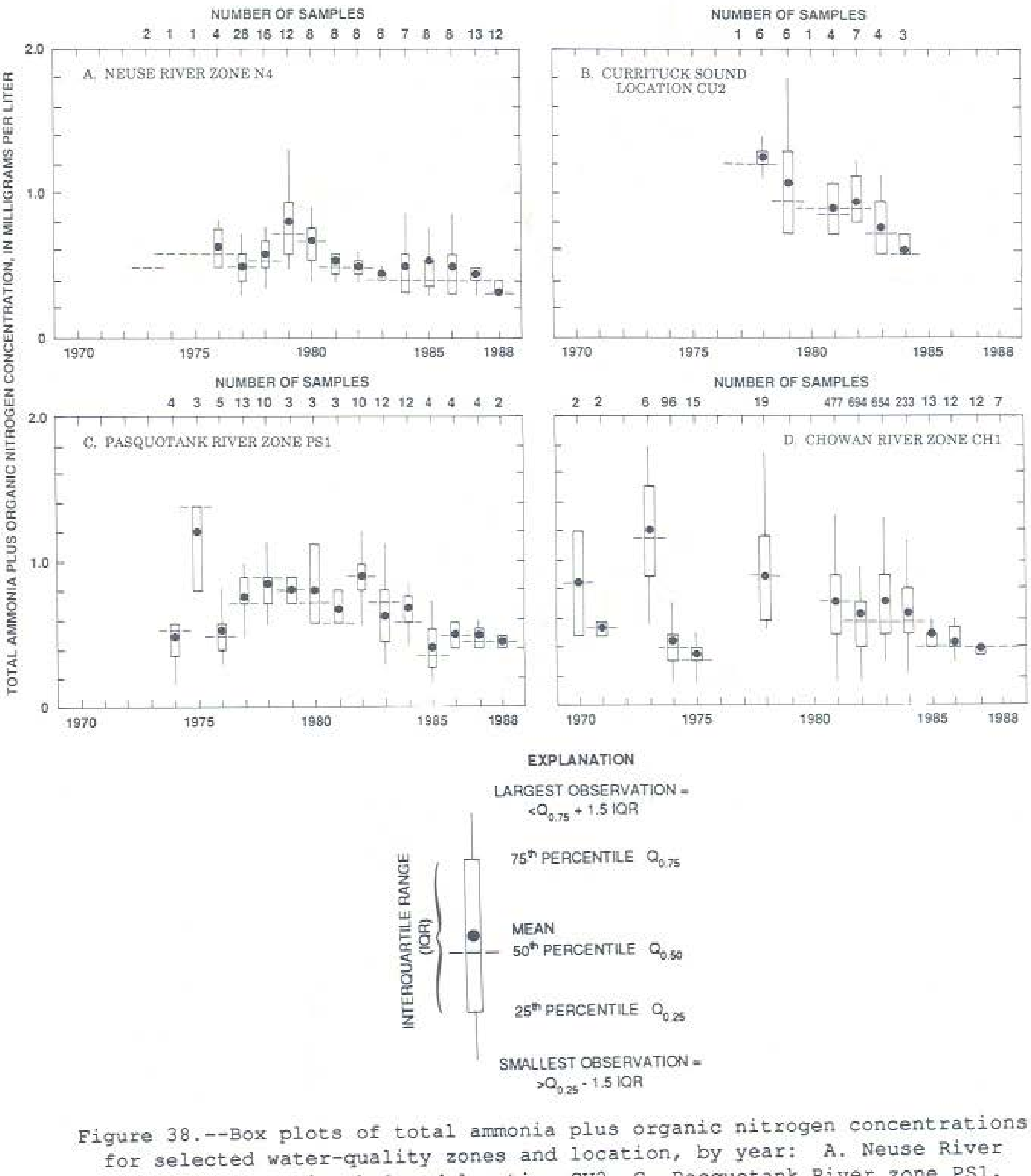

Figure 38.--Box plots of total ammonia plus organic nitrogen concentrations for selected water-quality zones and location, by year: A. Neuse River zone N4, B. Currituck Sound location CU2, C. Pasquotank River zone PS1, and D. Chowan River zone CH1.

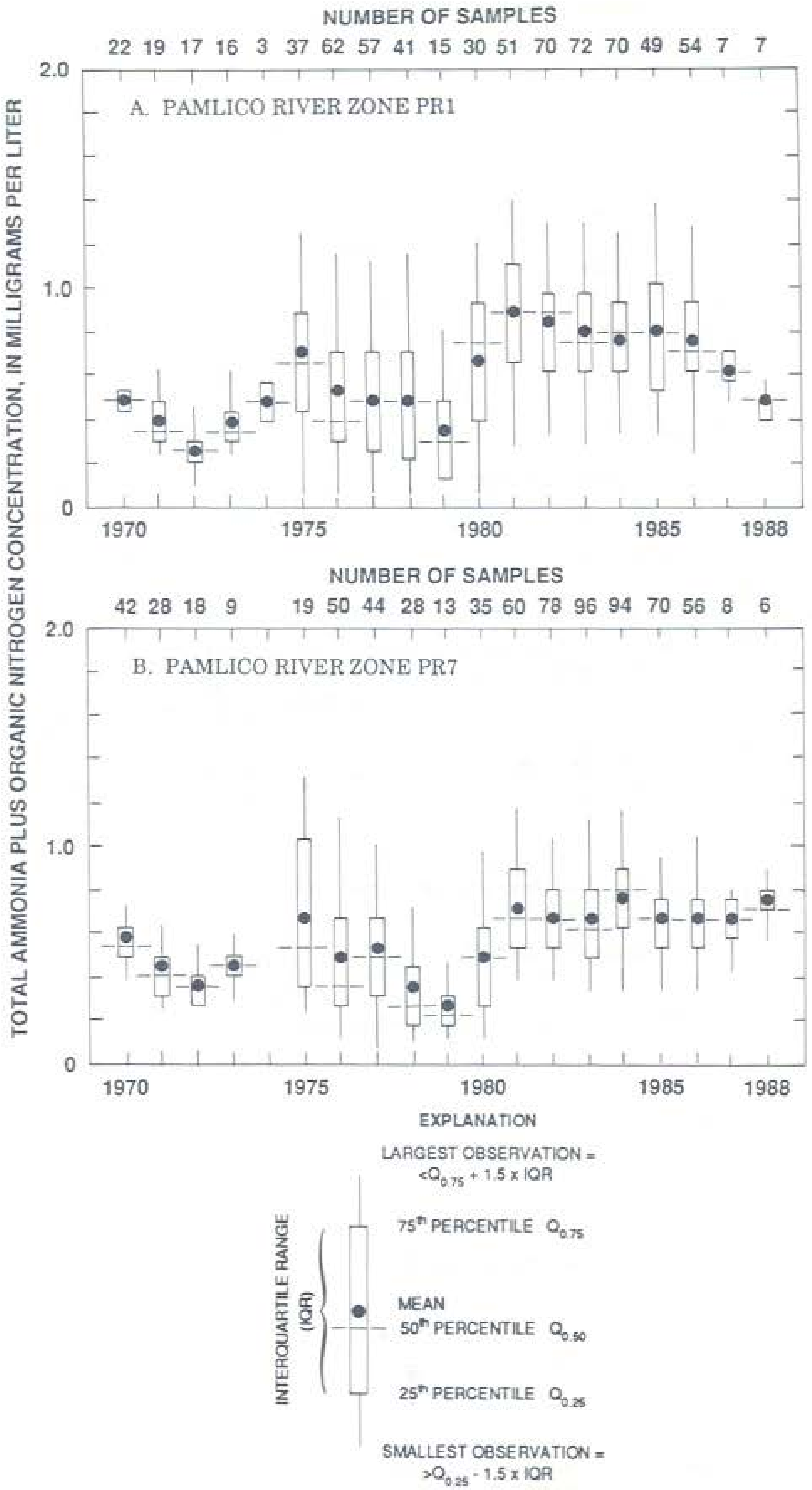

Figure 39.--Box plots of total ammonia plus organic nitrogen concentrations for selected water-quality zones, by year: A. Pamlico River zone PR1 and B. Pamlico River zone PR7.

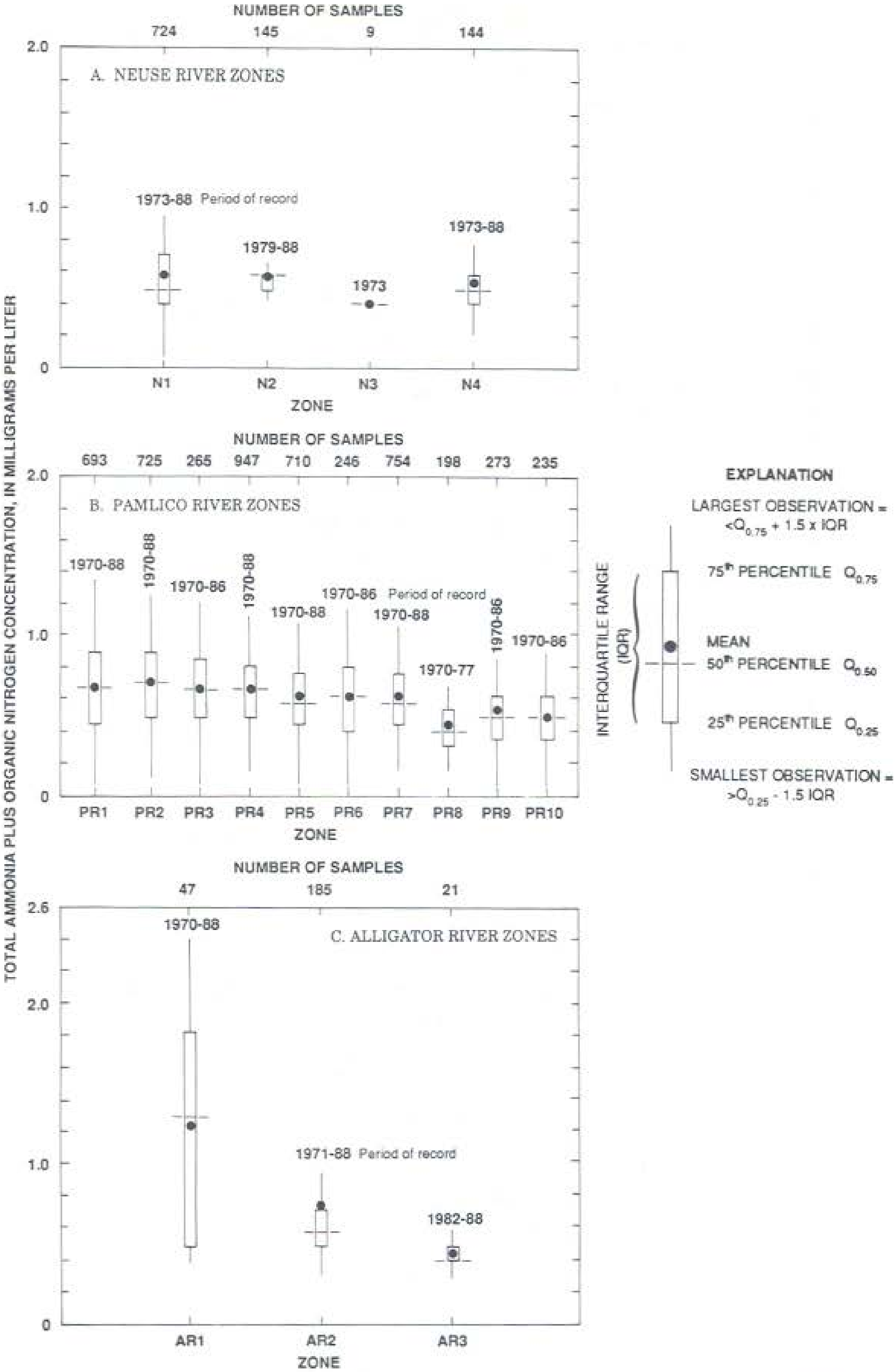

Figure 40.--Box plots of total ammonia plus organic nitrogen concentrations for: A. Neuse River zones, B. Pamlico River zones, and C. Alligator River zones.

River (fig. 40B), the Alligator River (fig. 40C), and the Chowan and Roanoke Rivers (fig. 41A). Currituck Sound location CU2 had higher concentrations than zone CU1 (fig. 41B). However, the Albemarle Sound area (fig. 41C) showed no distinct spatial pattern. In all cases except at Albemarle Sound zones A1, A2, and A5, total ammonia plus organic nitrogen concentrations were higher than 0.3 mg/L suggesting an ample supply of nitrogen for algal growth.

Trends of decreasing nitrite plus nitrate nitrogen concentrations during the period 1978-88 occurred at Neuse River zones N2 (-0.012 (mg/L)/yr) and N4 (-0.004 (mg/L)/yr), Pamlico River zones PR2 (-0.005 (mg/L)/yr) and PR5 (-0.005 (mg/L)/yr), and Albemarle Sound zone A2 (-0.005 (mg/L)/yr). The decreasing trends in nitrite plus nitrate nitrogen at the Pamlico River zones may be compared to the decreases detected in total ammonia plus organic nitrogen trends for the same period at Chowan River zone CH1 (fig. 38D). An increasing trend of nitrite plus nitrate nitrogen was detected at Roanoke River location RO1 for the period 1973-88, although a decreasing trend was noted there for total ammonia plus organic nitrogen.

Spatial variation in nitrite plus nitrate nitrogen values is evident for the NASQAN stations (fig. 41D), and this pattern of variation is similar to the other nutrients measured at these stations. The Virginia stations (Nottoway, Blackwater, and Meherrin Rivers) generally had lower nutrient levels than the North Carolina stations (Roanoke, Tar, and Neuse Rivers and Contentnea Creek), with the Neuse River and Contentnea Creek having higher concentrations than the other stations.

Phosphorus

Phosphorus is the third major nutrient (in addition to carbon and nitrogen) essential to algal growth. The National Technical Advisory Committee (1968) recommends 0.05 mg/L total phosphorus (as P) as the maximum limit for waters entering impoundments. Other sources (Sawyer, 1947; Sakamoto, 1966; and Vollenweider, 1971) note that total phosphorus concentrations in lakes above 0.01 mg/L promote nuisance algal growth. A concentration below 0.1 mg/L is recommended by Mackenthum (1969) to prevent algal blooms in streams.

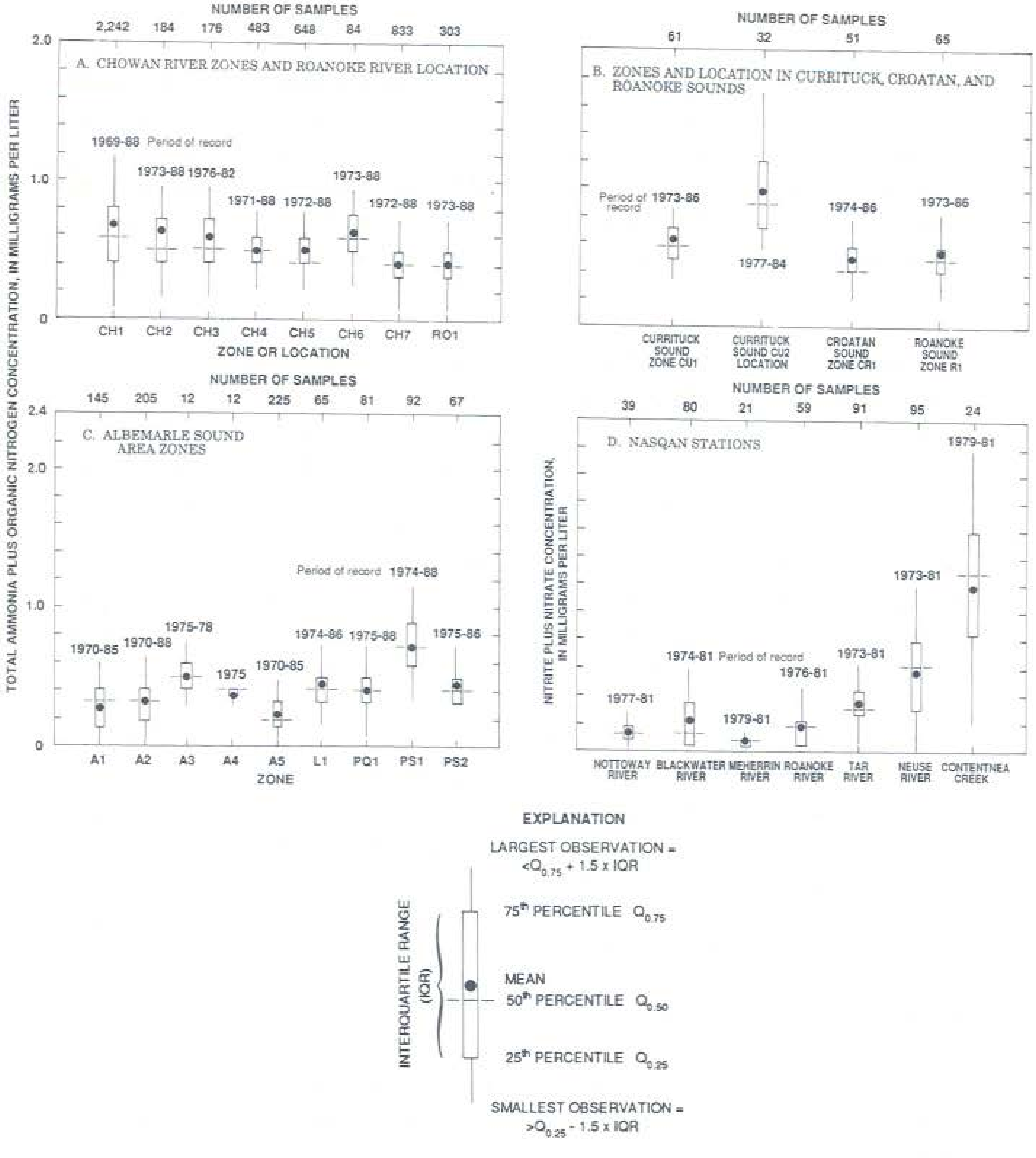

Figure 41.--Box plots of total ammonia plus organic nitrogen concentrations for: A. Chowan and Roanoke River zones and locations, B. zones and location in Currituck, Croatan, and Roanoke Sounds, C. Albemarle Sound area zones, and D. discharge-adjusted nitrite plus nitrate nitrogen concentrations for the National Stream Quality Accounting Network stations.

Zones or stations with statistically significant trends in total phosphorus concentrations in the Albemarle-Pamlico study area are shown in figure 42. Total phosphorus concentrations increased at a mean rate of 0.003 (mg/L)/yr in the Pamlico River and decreased at a mean rate of 0.004 (mg/L)/yr elsewhere in the study area.

The increasing trend of total phosphorus concentrations at the Pamlico River zones is illustrated in figures 43A and 43B for zones PR1 and PR5, respectively. However, an apparent decreasing trend is evident for zone PR5 for the period 1978-88. Trends of increasing total phosphorus concentrations were detected at the NASQAN stations in Contentnea Creek and the Tar River (fig. 42). Trends of decreasing total phosphorus concentrations were detected at Neuse River zone N4 (fig. 44A), Pamlico Sound location P3, Albemarle Sound zone A2, Roanoke River location RO1 (fig. 44B), Pasquotank River zone PS1 (fig. 44C), and Chowan River zone CH1.

Spatial variation in total and dissolved phosphorus concentrations is evident in the Albemarle-Pamlico estuarine system. There is a generalized pattern of decreasing total and dissolved phosphorus concentrations downstream for the Neuse and Pamlico Rivers (fig. 45). Total phosphorus concentrations in the Pamlico River peak in zone PR4 and decrease from there downstream (fig. 45A); similarly, dissolved phosphorus concentrations peak at PR5 and decrease downstream (fig. 45B). In the Neuse River, the highest concentrations of total and dissolved phosphorus were in upstream zone N1 (figs. 45C and 45D).

A comparison of the total or dissolved phosphorus concentrations for all the estuary zones shows that the highest concentrations generally occurred in the Pamlico River zones PR4, PR5, PR6, and PR7 (fig. 45); in the Neuse River zones N1 and N2 (fig. 45); and in the Chowan River zone CH1 (fig. 46A). The lowest relative concentrations occurred in Albemarle, Currituck, Croatan, and Roanoke Sounds (figs. 46B and 46C).

Although trends of decreasing concentrations were observed in certain areas, total phosphorus concentrations in all cases tested for trends were above the 0.01 mg/L concentration for freshwater lakes cited by Sawyer (1947), Sakamoto (1966), and Vollenweider (1971) as sufficient for abundant algal growth. Only the Roanoke River NASQAN station and Albemarle Sound

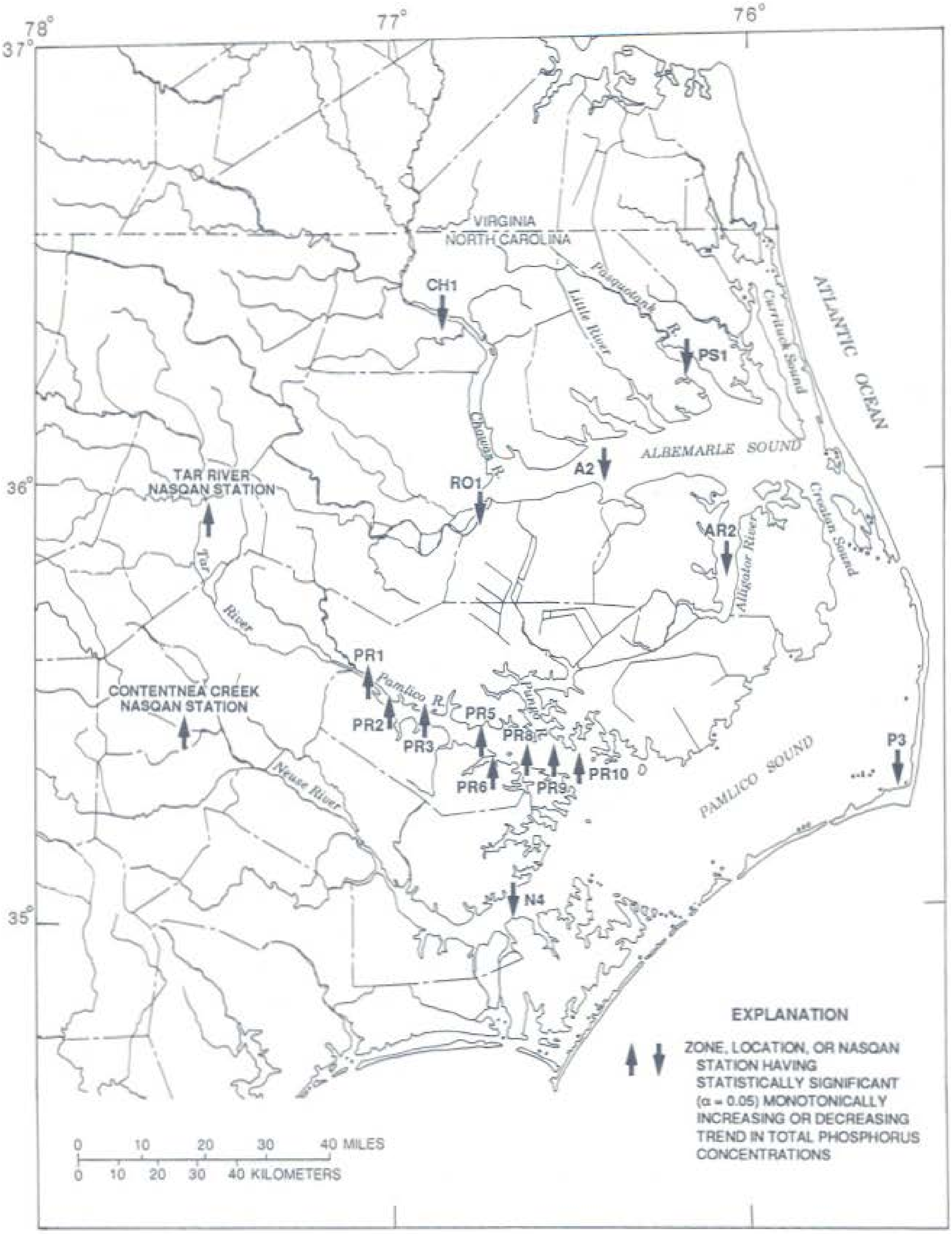

Figure 42.--Locations of water-quality zones or stations having statistically significant trends of increasing or decreasing total phosphorus concentrations, 1970-88.

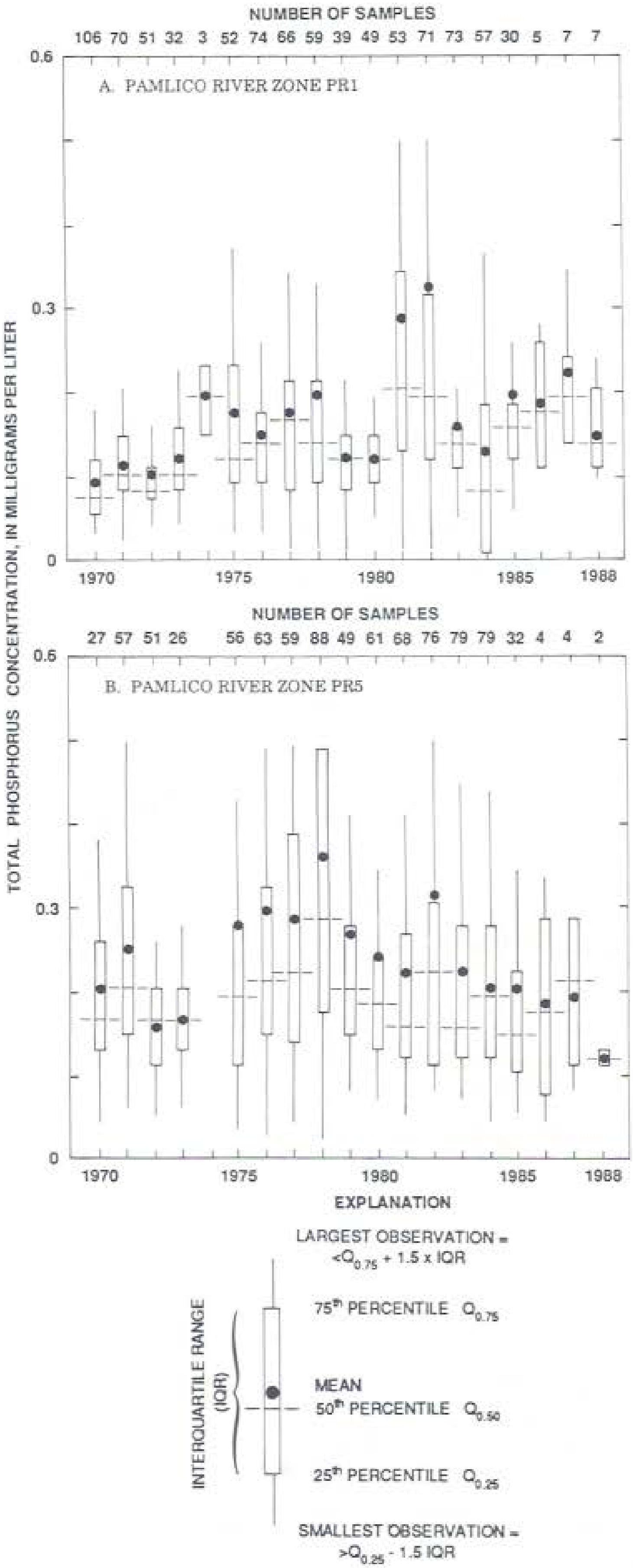

Figure 43.--Box plots of total phosphorus concentrations for selected water-quality zones, by year: A. Pamlico River zone PR1 and B. Pamlico River zone PR5.

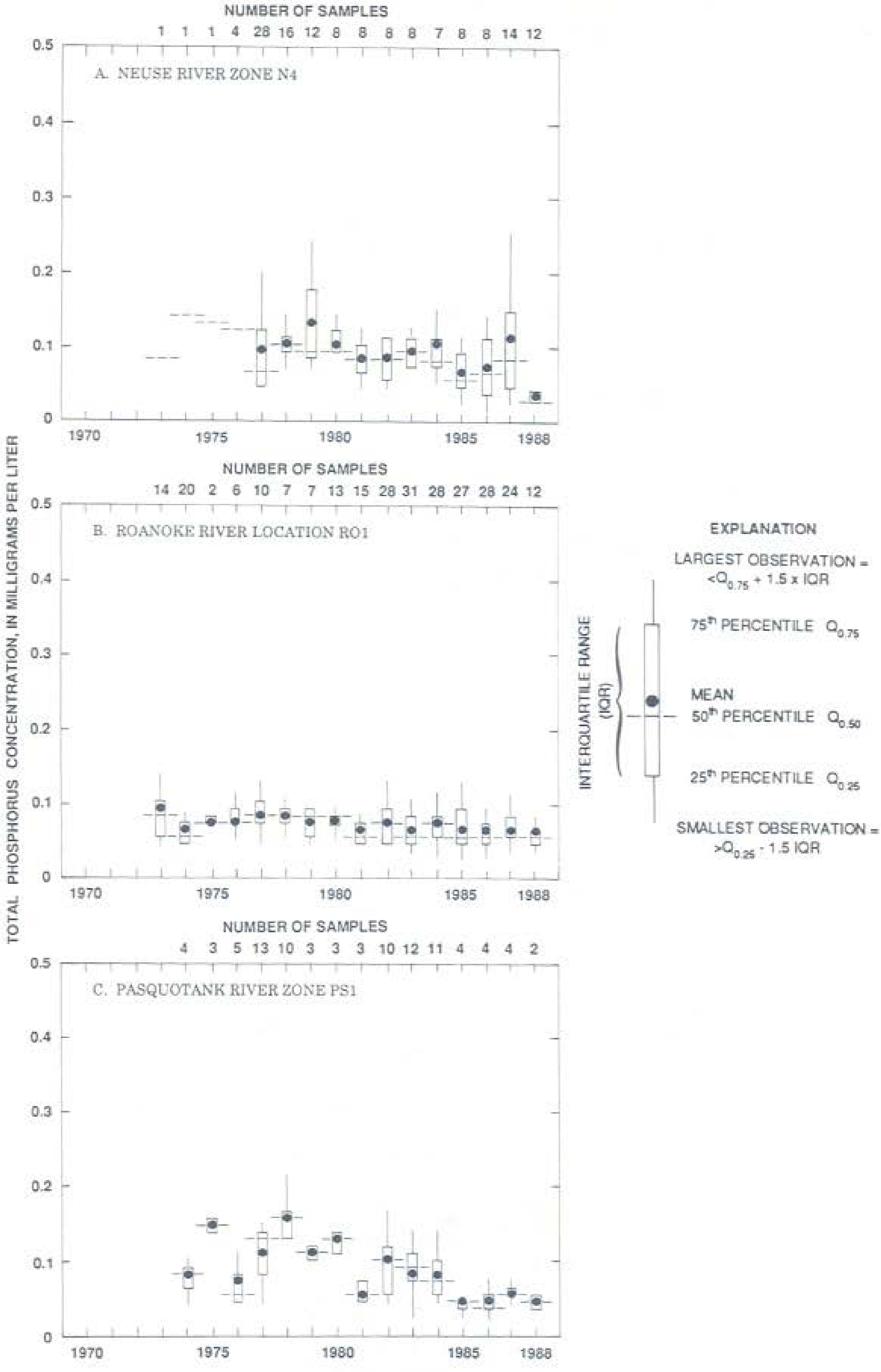

Figure 44.--Box plots of total phosphorus concentrations for selected water-quality zones and location, by year: A. Neuse River zone N4, B. Roanoke River location RO1, and C. Pasquotank River zone PS1.

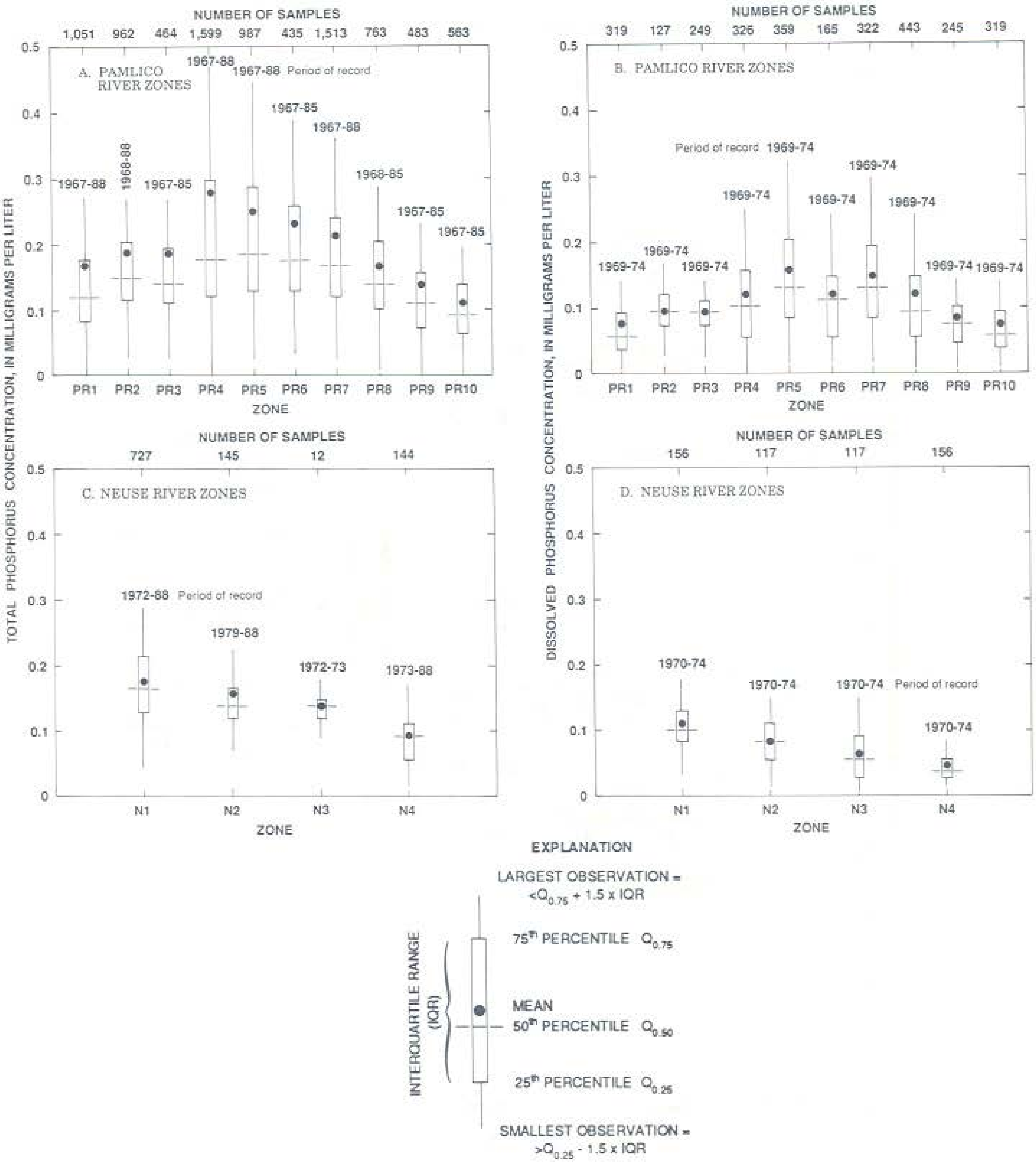

Figure 45.--Box plots of: A. total phosphorus concentrations for the Pamlico River zones, B. dissolved phosphorus concentrations for the Pamlico River zones, C. total phosphorus concentrations for the Neuse River zones, and D. dissolved phosphorus concentrations for the Neuse River zones.

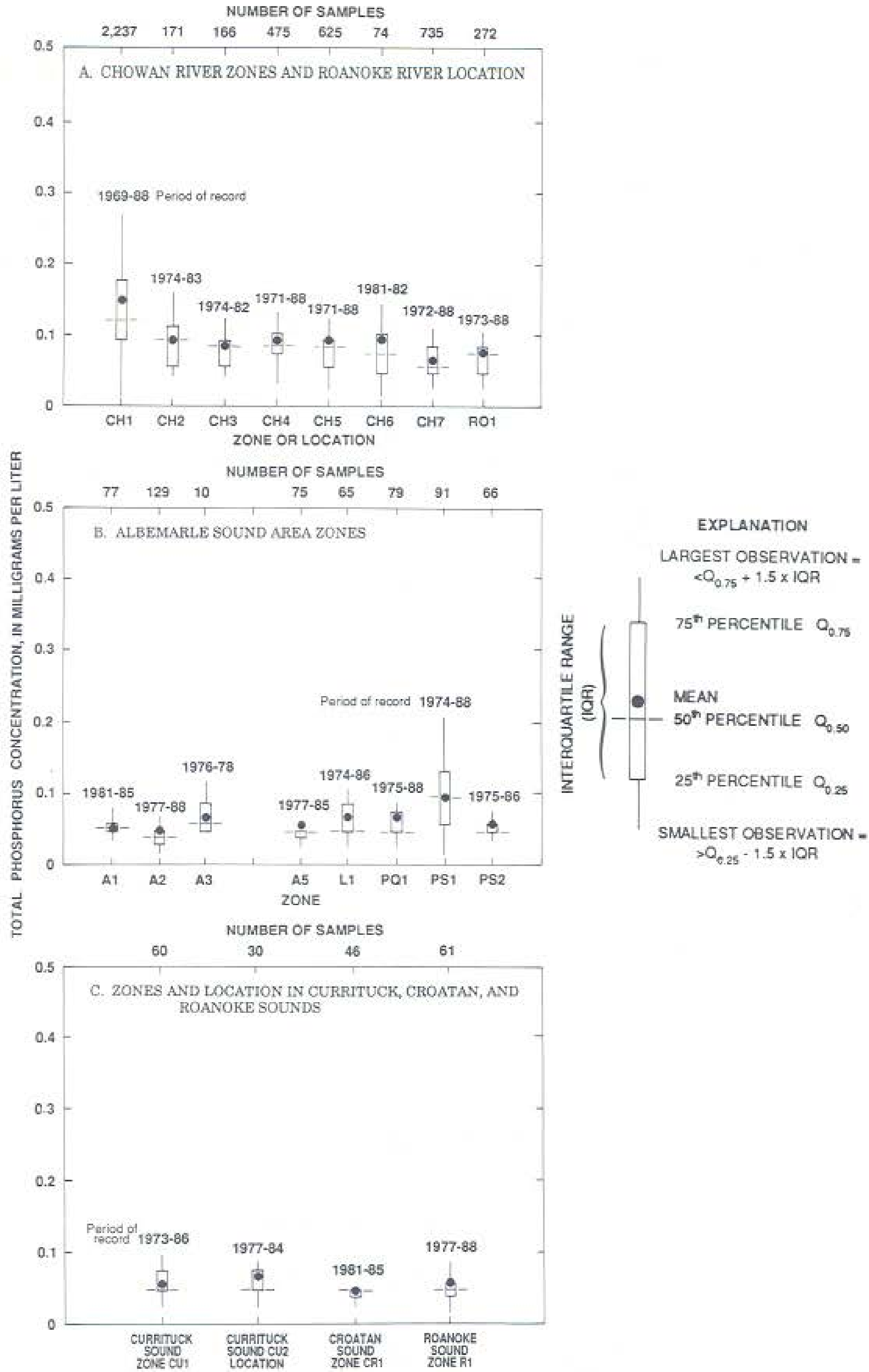

Figure 46.--Box plots of total phosphorus concentrations for: A. Chowan River and Roanoke River zones and locations, B. Albemarle Sound area zones, and C. zones and location in Currituck, Croatan, and Roanoke Sounds.

zones A2 and A5 had total phosphorus concentrations generally less than 0.05 mg/L. General long-term decreases in dissolved phosphorus may, in part, be accounted for by uptake in biomass under conditions of increasing levels of eutrophication.

Carbon:nitrogen:phosphorus ratios

Ratios of carbon to nitrogen to phosphorus can be used to evaluate which nutrient is limiting algal growth (Vallentyne, 1974). A comparison of the measured ratios to an average plant tissue composition carbon:nitrogen: phosphorus ratio of 40:7:1 (Vallentyne, 1974) can show which nutrient is in relatively limited supply. A list of the ratios of the median values of nutrients at the NASQAN stations and estuary zones is given in table 14. The limiting nutrients at each zone as determined by this ratio comparison are indicated in figure 47. It is important to note that nutrient ratios based strictly on observed water column concentrations of nutrients do not always clearly indicate the limiting nutrient. In particular, seasonal variation in nutrient limitation and limits of nutrient chemical forms available to phytoplankton are not reflected in a simple nutrient ratio comparison. With these restrictions in mind, this approach generally shows that nitrogen is the limiting nutrient in the Neuse and Pamlico Rivers and that phosphorus is the limiting nutrient in most of the rest of the area. Direct tests for specific nutrient limitations must be made to confirm limitations at specific sites in the estuarine system.

Biological Characteristics

Methods of assessment of biological water-quality conditions include the use of indicator organisms, such as fecal coliform and fecal streptococci bacteria and the measurement of chlorophyll-a concentrations. Although additional biological data are available for the Albemarle-Pamlico estuarine system, these biological measures are the only ones for which the period of record is sufficient to allow trend testing.

Bacteria

Fecal coliform bacteria commonly live in the gut and feces of warmblooded animals. Although all species of this group are not human

Table 14.--*Nutrient ratios for the study area*

[NASQAN, National Stream Quality Accounting Network; mg/L, milligrams per liter; C, total organic carbon; P, total phosphorus; N, the sum of total organic and ammonia nitrogen plus nitrite and nitrate nitrogen; >, greater than; --, no data]

NASQAN station and zone or location identifier (figs. 2 and 9)	Median concentration (mg/L)[a]			Ratio C:P	Ratio N:P	Ratio P:P	Probable order of importance as limiting nutrient for algal growth
	C	N	P	C	N	P	
NASQAN stations							
Nottoway River	6.8	0.59	0.04	168.8	14.6	1.0	P > N > C
Blackwater River	10.0	.81	.04	248.8	20.3	1.0	P > N > C
Meherrin River	6.6	.49	.04	165.0	12.3	1.0	P > N > C
Roanoke River	5.0	.50	.02	250.0	25.0	1.0	P > N > C
Tar River	9.2	.92	.13	70.8	7.1	1.0	P > N > C
Neuse River	9.5	1.31	.22	43.0	6.0	1.0	N > P > C
Contentnea Creek	10.0	2.18	.33	30.3	6.6	1.0	N and C > P
Water-quality zones or locations							
N1	14.0	.95	.17	82.4	5.6	1.0	N > P > C
N2	14.0	.89	.14	100.0	6.3	1.0	N > P > C
N3	--	.6	.14	--	4.3	1.0	N > P
N4	12.0	.55	.09	133.3	6.1	1.0	N > P > C
PR1	12.0	1.10	.12	103.5	9.5	1.0	P > N > C
PR2	11.0	.81	.15	76.1	5.6	1.0	N > P > C
PR3	--	[b].65	.13	--	5.0	1.0	N > P
PR4	12.5	.68	.16	76.1	4.1	1.0	N > P > C
PR5	--	.65	.18	--	5.7	1.0	N > P
PR6	--	[b].60	.17	--	3.6	1.0	N > P
PR7	17.0	.62	.15	113.3	4.1	1.0	N > P > C
PR8	10.0	.46	.13	75.9	3.5	1.0	N > P > C
PR9	--	[b].49	.11	--	4.6	1.0	N > P
PR10	--	[b].47	.83	--	.57	1.0	N > P
A1	10.0	.4	.05	200.0	8.0	1.0	P > N > C
A2	9.0	.35	.04	225.0	8.8	1.0	P > N > C
A3	10.0	.55	.06	166.7	9.2	1.0	P > N > C
A4	10.0	[b].4	--	--	--	--	
A5	10.0	.23	.05	200.0	4.6	1.0	N > P > C

[a]Values have been rounded. Ratios calculated from these rounded values will not equal those reported.

[b]Nitrite plus nitrate data missing; ratios calculated using total organic and ammonia nitrogen only.

Table 14.--*Nutrient ratios for the study area*--Continued

[NASQAN, National Stream Quality Accounting Network; mg/L, milligrams per liter; C, total organic carbon; P, total phosphorus; N, the sum of total organic and ammonia nitrogen plus nitrite and nitrate nitrogen; >, greater than; --, no data]

NASQAN station and zone or location identifier (figs. 2 and 9)	Median concentration (mg/L)[a]			Ratio C:P	Ratio N:P	Ratio P:P	Probable order of importance as limiting nutrient for algal growth
	C	N	P	C	N	P	
Water-quality zones or locations--Continued							
L1	10.0	.45	.05	200.0	9.0	1.0	P > N > C
PQ1	12.0	.46	.05	240.0	9.2	1.0	P > N > C
PS1	26.0	0.92	0.09	288.9	10.2	1.0	P > N > C
PS2	10.0	.45	.05	200.0	9.0	1.0	P > N > C
CU1	14.0	.65	.05	280.0	13.0	1.0	P > N > C
CU2	16.0	.95	.05	320.0	19.0	1.0	P > N > C
P1	10.0	.45	.05	200.0	9.0	1.0	P > N > C
P2	10.0	.45	.05	200.0	9.0	1.0	P > N > C
P3	10.0	.55	.05	200.0	11.0	1.0	P > N > C
P4	10.0	.55	.05	200.0	11.0	1.0	P > N > C
AR1	22.5	1.39	.05	450.0	27.8	1.0	P > N > C
AR2	24.0	.68	.05	480.0	13.6	1.0	P > N > C
AR3	17.5	.46	.03	583.3	15.3	1.0	P > N > C
CH1	--	.74	.12	--	6.2	1.0	N > P
CH2	--	.64	.09	--	7.1	1.0	P > N
CH3	22.0	.57	.08	275.0	7.1	1.0	P > N > C
CH4	14.0	.64	.08	175.0	8.0	1.0	P > N > C
CH5	14.0	.49	.08	175.0	6.1	1.0	N > P > C
CH6	--	.65	.07	--	9.3	1.0	P > N
CH7	10.0	.57	.06	166.7	9.5	1.0	P > N > C
CH8	8.0	.56	.07	114.3	8.0	1.0	P > N > C
R1	10.0	.55	.05	200.0	11.0	1.0	P > N > C
CR1	10.5	.45	.05	210.0	9.0	1.0	P > N > C

[a]Values have been rounded. Ratios calculated from these rounded values will not equal those reported.

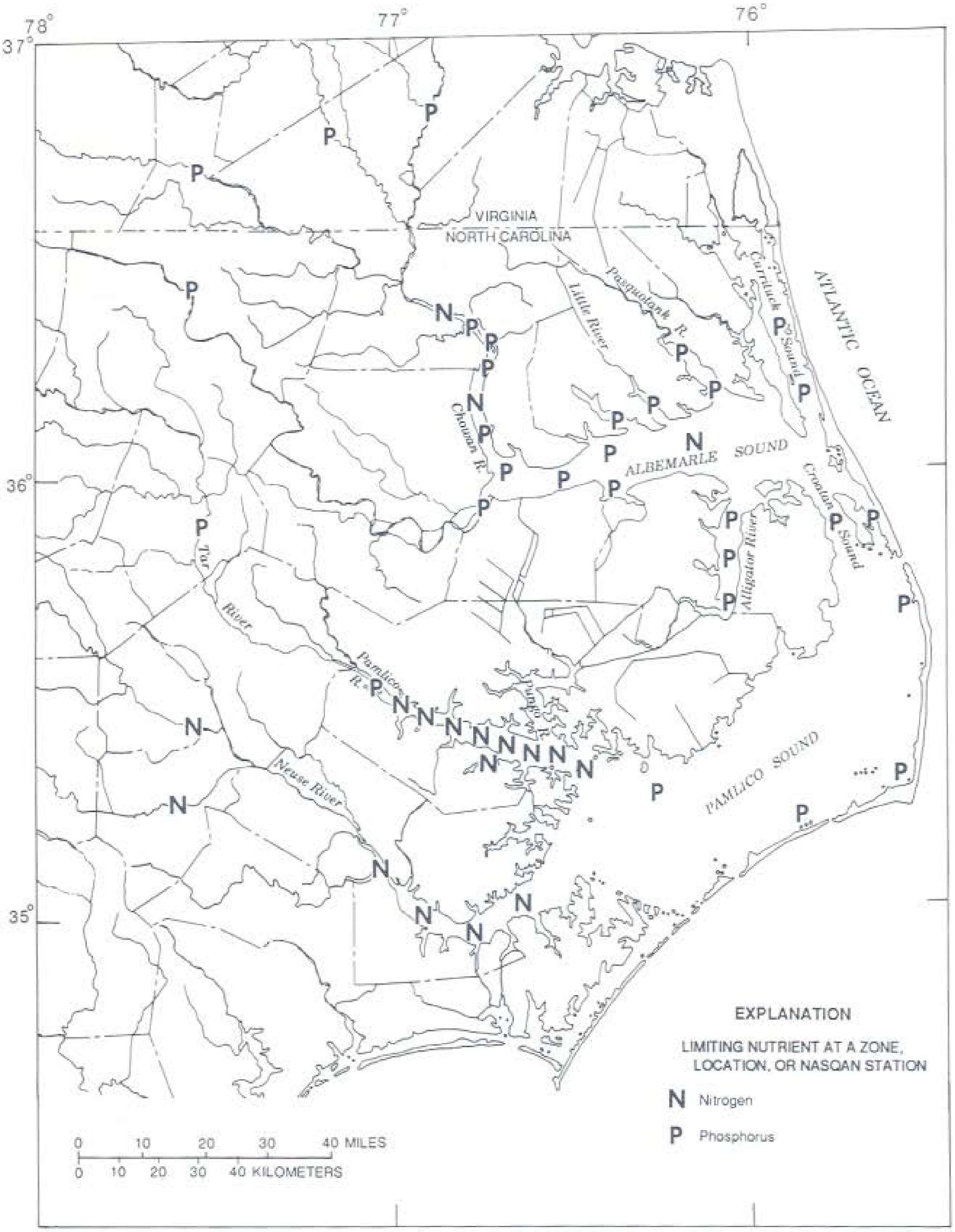

Figure 47.--Limiting nutrients for algal growth for the study area.

pathogens, the occurrence of fecal coliform bacteria indicates probable fecal contamination and possible presence of pathogenic species. The U.S. Environmental Protection Agency (1986) raw-water criteria for body contact is a geometric mean of 200 fecal coliform colonies per 100 milliliters of water.

Trends of decreasing fecal coliform bacteria counts were detected for Neuse River zone N4 (-0.22 (colonies/100 mL)/yr), Pamlico River zone PR1 (-2.5 (colonies/100 mL)/yr), Pamlico Sound locations P3 (-1.0 (colonies/100 mL)/yr) and P4 (-0.31 (colonies/100 mL)/yr), and Currituck Sound zone CU1 (-2.3 (colonies/100 mL)/yr). The box plot of coliform bacteria for Currituck Sound zone CU1 is indicative of the general declining trend in these zones and locations (fig. 48). Coliform bacteria concentrations generally were less than 120 colonies/100 mL for the estuary zones and locations.

Fecal streptococci bacteria also indicate fecal contamination from warmblooded animals. Trends of decreasing fecal streptococci bacteria were observed for Neuse River zone N4 (-0.38 (colonies/100 mL)/yr), Pamlico Sound zone P1 (-0.75 (colonies/100 mL)/yr), Croatan Sound zone CR1 (-11.3 (colonies/100 mL)/yr), and Roanoke Sound zone R1 (-18.5 (colonies/100 mL)/yr). Together with the decreasing trends in coliform bacteria, the fecal streptococci results indicate a general reduction of fecal contamination in the Albemarle-Pamlico estuarine system.

The ratio of fecal coliforms to fecal streptococci is sometimes used to identify the origin of bacterial contamination (Geldriech, 1966). Ratios greater than 4.0:1 indicate contamination primarily of human origin, whereas ratios less than 0.6:1 indicate animal origin. The median fecal coliform/fecal streptococci ratio for the available data (N = 490) was 0.3:1, and the highest ratio calculated was 1.3:1. These ratios indicate that the fecal contamination is probably of animal origin.

Chlorophyll-a

Algae are simple plants that are ubiquitous in surface waters. In nutrient-enriched waters, massive growths or blooms of algae may cause objectionable odors, impair water use, and decrease aesthetic values. Major

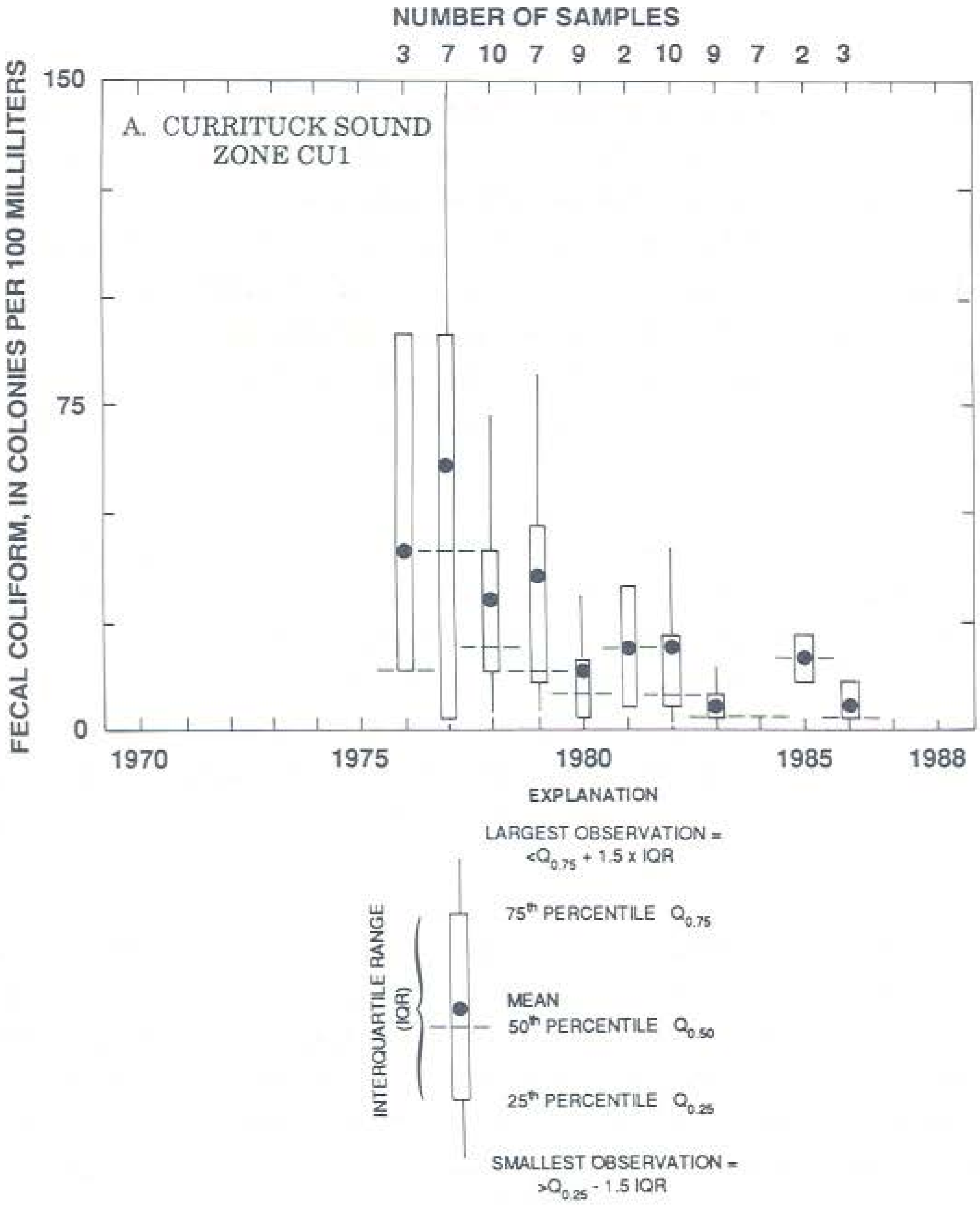

Figure 48.--Box plots of fecal coliform bacteria counts, by year, for Currituck Sound zone CU1.

blooms of blue-green algae occurred in 1972, 1978, and 1983 in the Chowan River, and high concentrations of algae were reported in the Neuse River in 1987 (North Carolina Department of Natural Resources and Community Development, 1987). During 1986-87 algal blooms most frequently occurred in the Tar-Pamlico River system and in the Neuse River (North Carolina Department of Natural Resources and Community Development, 1988).

A method of estimating levels of plant material in water is measurement of the plant pigment chlorophyll-a. The amount of chlorophyll-a present varies somewhat with plant species and the state of nutrition of the species (Strickland and Parsons, 1972), but it gives a useful quantitative indicator of the plant population. The two chlorophyll-a constituents listed in table 13 represent different analytical methods. The standard method reports available chlorophyll-a in the sample, whereas the other method differentiates between chlorophyll-a and the products of degraded chlorophyll-a (phaeo-pigments) and allows a correction to be made (Strickland and Parsons, 1972, p. 186). The data available for the two methods are comparable, however. The North Carolina water-quality standard is 40 μg/L (micrograms per liter) of chlorophyll-a (Administrative Code Section:15NCAC 2B.0200-Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina).

Where trends were significant, chlorophyll-a concentrations increased with time in parts of the Neuse and Pamlico Rivers and in Albemarle Sound, and decreased in parts of the Chowan River (fig. 49). Trends of increasing chlorophyll-a concentrations since 1970 were detected at Neuse River zones N1 (0.95 (μg/L)/yr), N2 (0.74 (μg/L)/yr; fig. 50A), and N4 (0.33 (μg/L)/yr) and Pamlico River zone PR2 (0.17 (μg/L)/yr; fig. 50B). Increases since 1982 were detected at Albemarle Sound zone A2 (1.0 (μg/L)/yr; fig. 50C) and Chowan River zone CH7 (0.33 (μg/L)/yr). Decreases since 1982 in chlorophyll-a concentrations were detected at Chowan River zones CH4 (-1.3 (μg/L)/yr) and CH5 (-0.50 (μg/L)/yr).

Spatial patterns of chlorophyll-a were detected also. A general pattern of decrease downstream is apparent for the Neuse River (fig. 51A), and slight increases downstream also occur in zones of the Chowan (fig. 51B) and Alligator Rivers (fig. 51C). However, the pattern for the Pamlico River (fig. 51D) shows an increase in chlorophyll-a concentrations downstream,

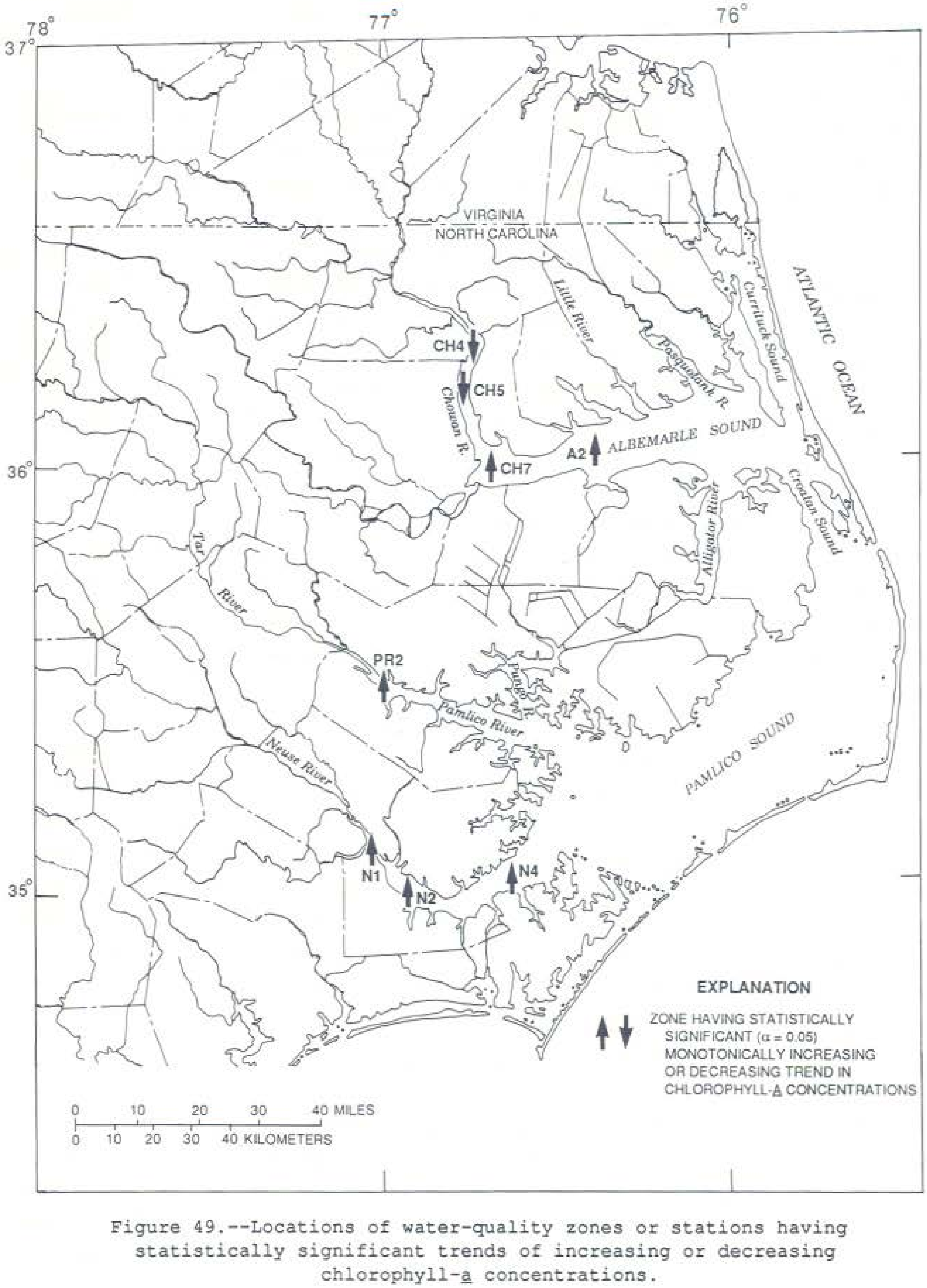

Figure 49.--Locations of water-quality zones or stations having statistically significant trends of increasing or decreasing chlorophyll-a concentrations.

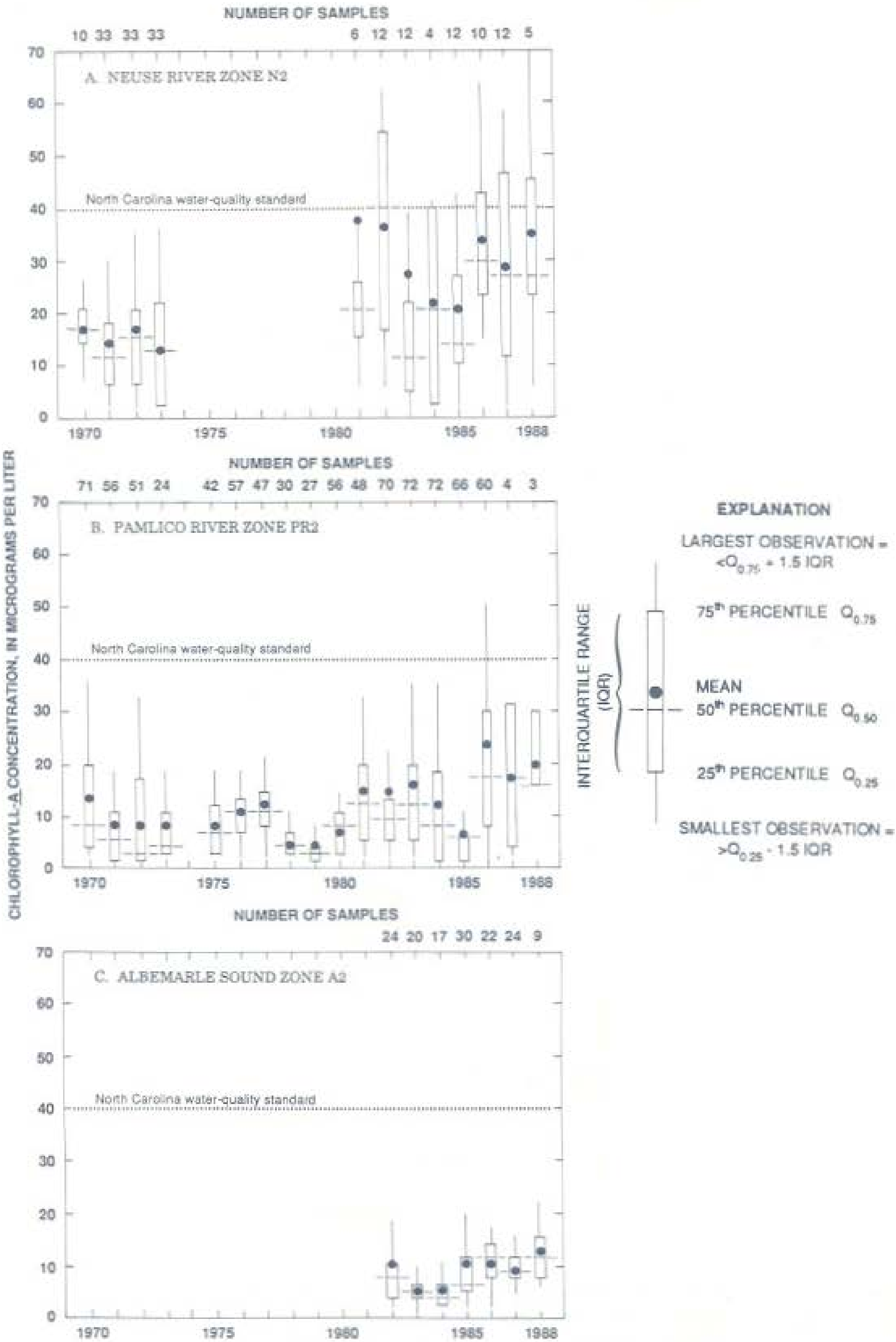

Figure 50.--Box plots of chlorophyll-a concentrations for selected water-quality zones, by year: A. Neuse River zone N2, B. Pamlico River zone PR2, and C. Albemarle Sound zone A2.

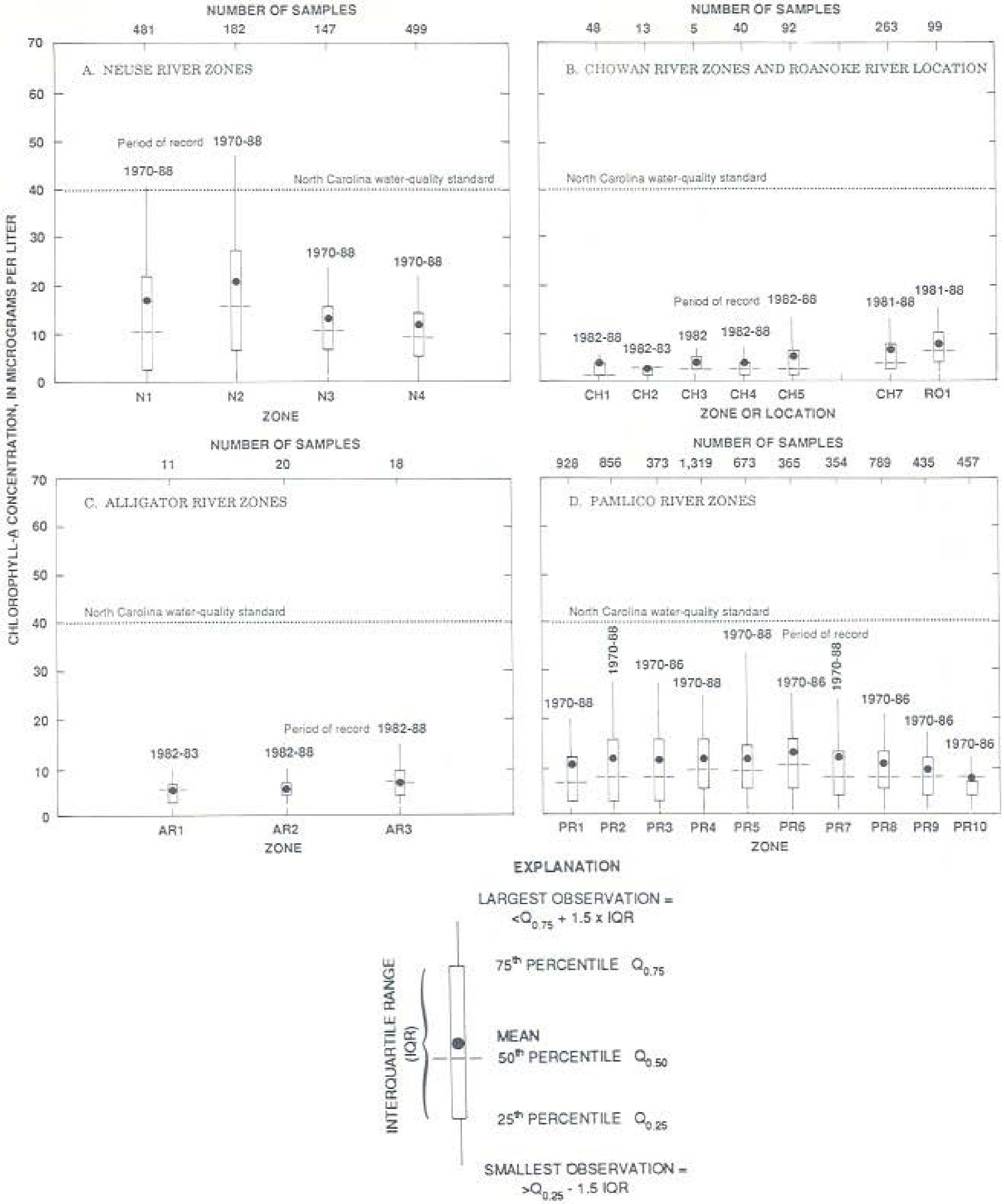

Figure 51.--Box plots of chlorophyll-a concentrations for: A. Neuse River zones, B. Chowan River and Roanoke River zones and locations, C. Alligator River zones, and D. Pamlico River zones.

peaking at zone PR6, followed by a decline downstream. This pattern is similar to that noted for total phosphorus concentrations (fig. 45A). The relative spatial distribution of chlorophyll-a concentrations at zones in the Albemarle Sound area are shown in figure 52A and for Currituck, Croatan, and Roanoke Sounds in figure 52B.

In general, chlorophyll-a concentrations are greatest in the Pamlico River (interquartile range 3-27 μg/L) and Neuse River (interquartile range 3-17 μg/L) and in Currituck Sound (interquartile range 7-22 μg/L). Chlorophyll-a concentrations were usually below 40 μg/L throughout the Albemarle-Pamlico estuarine area except in Neuse River zones N1 and N2.

CORRELATION ANALYSES

The degree of association between the water quality in the Albemarle-Pamlico estuarine system and the acreages of crops, numbers of livestock, tons of fertilizer applied, total population and employment, and miles of highways in the study basin was examined by statistical correlation. A list of the basin activity and characteristic variables tested in correlation analyses is given in table 1. Annual median values of selected water-quality data for each water-quality zone were correlated with the annual mean basin activities and characteristics in the drainage area upstream from the water-quality zone and downstream from the NASQAN station in the basin. Annual median values of selected water-quality data for each NASQAN station also were correlated with the annual mean basin activities and characteristics in the drainage-basin area upstream from that station.

Nonparametric statistical correlation (Kendall's tau-b analysis) was used to measure the number of concordances and discordances between pairs of means and medians for each year of data. Correlations were considered significant at an alpha level of 0.01. It is important to note that although correlation analysis is useful for identifying variables that have some association, causality is not implied. Cross correlation analyses were also used to identify intercorrelation among the variables.

Water-quality data collected at the NASQAN stations were correlated with water-quality data collected in each downstream water-quality zone on an annual basis to test for significant relations (alpha = 0.01) between

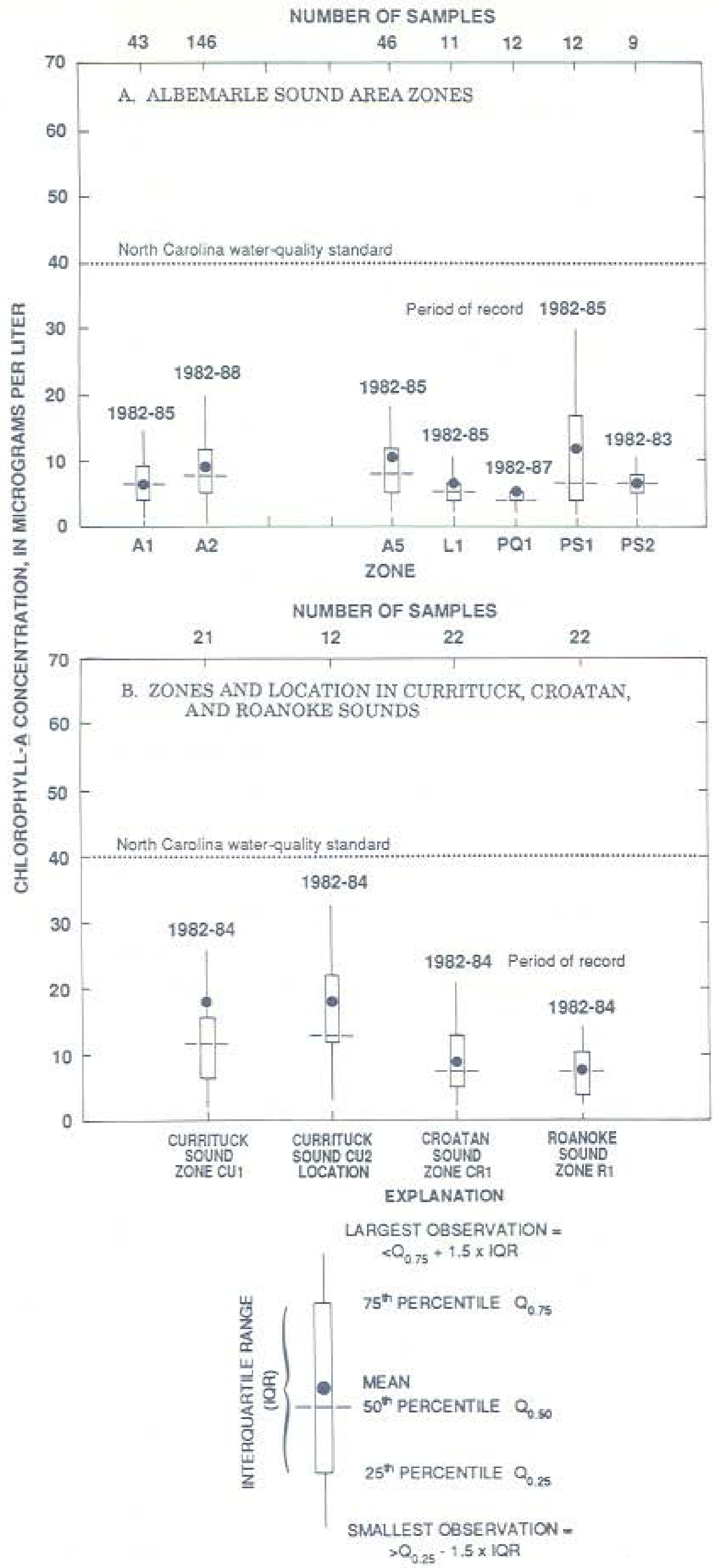

Figure 52.--Box plots of chlorophyll-a concentrations for: A. Albemarle Sound area zones and B. zones and location in Currituck, Croatan, and Roanoke Sounds.

upstream and downstream water quality. No significant upstream-downstream water-quality correlations were detected. This result indicates that local estuary water quality might be largely a function of relatively localized estuary processes and basin activities and characteristics.

All basin activity and characteristic variables were correlated with each other to identify any significant relations. The only variables that significantly correlated to one another were the number of chickens and the total miles of unpaved secondary roads (tau = -.762). Since the late 1970's, the number of chickens being raised in the area has steadily increased, whereas the number of miles of unpaved secondary roads has decreased. There seems to be no relevant causal relation in this correlation other than that the growing poultry business in northeastern North Carolina is occurring simultaneously with increasing development that is reflected in the reduction of the miles of unpaved secondary roads. No other pairs of variables were significantly correlated.

Water-Quality Constituents and Properties Correlated with Basin Activities and Characteristics

Statistically significant (alpha = 0.01) correlations between water-quality constituent concentrations and basin activity and characteristic variables for the estuary water-quality zones are listed in table 15. Of the 52 basin activity or characteristic variables tested, 11 were significantly correlated with water-quality characteristics in 21 of 42 water-quality zones or locations and at 7 NASQAN stations. A total of 121 correlations were detected in the analysis. The 11 basin activity and characteristic variables were primarily agricultural statistics, including acreages of crops and amounts of fertilizers applied. In addition, secondary unpaved roads were significantly correlated with water quality in some cases. A summary of the total number of possible correlations and the number of significant correlations detected between water quality and the basin activity and characteristic variables is shown in table 16.

Selected correlations of water-quality constituents with basin activities and characteristics are discussed in this section under the headings dissolved oxygen, suspended solids, total ammonia nitrogen, total ammonia plus organic nitrogen, and total phosphorus had correlations with

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Water-quality variable: Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Bacteria: Fecal streptococci	Bacteria: Fecal coliform
Neuse River water-quality zone N2												
	Corn	--	--	--	--	--	--	--	--	--	--	--
tau	0.604											
P	0.0026											
N	14											
	Soybeans	--	--	--	--	--	--	--	--	--	--	--
tau	0.582											
P	0.0037											
N	14											
	HC	--	--	--	--	--	--	--	--	--	--	--
tau	0.778											
P	0.0035											
N	9											
	FM	--	--	--	--	--	--	--	--	--	--	--
tau	0.692											
P	0.0006											
N	14											
	Chickens	--	--	--	--	--	--	--	--	--	--	--
tau	0.538											
P	0.0073											
N	14											
Neuse River water-quality zone N4												
	Chickens	--	--	Tobacco	Tobacco	--	--	Tobacco	Tobacco	Tobacco	FM	--
tau	0.474			0.689	0.833			0.641	0.627	0.595	-0.751	
P	0.0046			0.0056	0.0018			0.0024	0.0037	0.0039	0.0018	
N	19			10	9			14	14	14	11	
	SUR	--	--	MF	SUR	--	--	Chickens	Chickens	Chickens	Chickens	--
tau	-0.505			0.778	0.833			-0.546	-0.627	-0.595	-0.636	
P	0.0018			0.0035	0.0018			0.0096	0.0037	0.0039	0.0083	
N	20			9	9			14	14	14	11	

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

	Water-quality variable											
											Bacteria	
Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Dis-solved oxygen	pH	Alka-linity	Sus-pended solids	Nonvol-atile sus-pended solids	Total hard-ness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phos-phorus	Fecal strepto-cocci	Fecal coliform
Neuse River water-quality zone N4--Continued												
	--	--	--	SUR	--	--	--	SUR	SUR	SUR	--	--
tau				0.667				0.549	0.648	0.557		
P				0.0026				0.0048	0.0013	0.0035		
N				12				16	16	16		
Pamlico River water-quality zone PR1												
	--	Soybeans	--	Corn	--	--	--	Soybeans	--	Corn	--	Soybeans
tau		-0.905		0.596				0.468		0.449		-0.505
P		0.0043		0.0035				0.0092		0.0058		0.0038
N		7		14				17		20		18
	--	--	--	Tobacco	--	--	--	--	--	HC	--	FM
tau				0.704						0.685		-0.505
P				0.0088						0.0007		0.0038
N				9						14		18
	--	--	--	MF	--	--	--	--	--	SUR	--	SUR
tau				0.649						-0.558		0.625
P				0.0025						0.0003		0.0004
N				13						22		18
	--	--	--	CF	--	--	--	--	--	--	--	--
tau				0.676								
P				0.0017								
N				13								
	--	--	--	AF	--	--	--	--	--	--	--	--
tau				0.546								
P				0.0053								
N				5								
	--	--	--	SUR	--	--	--	--	--	--	--	--
tau				0.570								
P				0.0024								
N				16								

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

	Water-quality variable											
											Bacteria	
Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Fecal streptococci	Fecal coliform
						Pamlico River water-quality zone PR2						
	--	--	--	--	--	--	MF	Soybeans	--	--	--	--
tau							0.535	0.480				
P							0.0034	0.0074				
N							17	17				
	--	--	--	--	--	--	Chickens	MF	--	--	--	--
tau							-0.669	-0.561				
P							0.0001	0.0025				
N							18	16				
	--	--	--	--	--	--	SUR	Chickens	--	--	--	--
tau							0.562	0.465				
P							0.0007	0.0094				
N							20	17				
						Pamlico River water-quality zone PR3						
	--	--	--	--	--	--	MF	Soybeans	--	--	--	--
tau							0.618	0.483				
P							0.0015	0.0090				
N							15	16				
	--	--	--	--	--	--	AF	SUR	--	--	--	--
tau							0.562	-0.533				
P							0.0083	0.0040				
N							13	16				
	--	--	--	--	--	--	Lime	--	--	--	--	--
tau							0.562					
P							0.0083					
N							13					
	--	--	--	--	--	--	Chickens	--	--	--	--	--
tau							-0.617					
P							0.0006					
N							17					

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

	Water-quality variable											
											Bacteria	
Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Fecal streptococci	Fecal coliform
	Pamlico River water-quality zone PR4											
	CF	--	--	--	SUR	--	--	--	--	--	--	--
tau	0.454				-0.878							
P	0.0089				0.0062							
N	18				7							
	Pamlico River water-quality zone PR5											
	FM	CF	--	Tobacco	--	--	Tobacco	Chickens	Tobacco	Corn	--	--
tau	0.529	-0.493		0.704			0.539	0.517	0.731	0.474		
P	0.0012	0.0044		0.0088			0.0034	0.0052	0.0019	0.0046		
N	20	18		9			17	16	12	19		
	SUR	--	--	AF	--	--	MF	--	Lime	--	--	--
tau	-0.565			0.719			0.673		0.575			
P	0.0004			0.0041			0.0004		0.0097			
N	21			10			6		13			
	--	--	--	Lime	--	--	AF	--	Chickens	--	--	--
tau				0.764			0.672		-0.661			
P				0.0023			0.0013		0.0050			
N				10			14		12			
	--	--	--	--	--	--	Lime	--	--	--	--	--
tau							0.696					
P							0.0009					
N							14					
	--	--	--	--	--	--	Chickens	--	--	--	--	--
tau							-0.631					
P							0.0006					
N							17					
	--	--	--				SUR	--	--	--	--	--
tau							0.450					
P							0.0088					
N							19					

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

	Water-quality variable										Bacteria	
Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Dis-solved oxygen	pH	Alka-linity	Sus-pended solids	Nonvol-atile sus-pended solids	Total hard-ness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phos-phorus	Fecal strepto-cocci	Fecal coliform
Pamlico River water-quality zone PR6												
	--	--	--	--	--	--	Tobacco	--	--	Corn	--	--
tau							0.476			0.459		
P							0.0089			0.0080		
N							17			18		
Pamlico River water-quality zone PR7												
	SUR	--	--	--	--	--	MF	--	--	--	--	--
tau	-0.578						0.522					
P	0.0004						0.0060					
N	20						16					
	--	--	--	--	--	--	Chickens	--	--	--	--	--
tau							-0.642					
P							0.0004					
N							17					
	--	--	--	--	--	--	Tobacco	--	--	--	--	--
tau							0.565					
P							0.0020					
N							17					
Pamlico River water-quality zone PR8												
	--	CF	--	--	--	--	Tobacco	--	--	--	--	--
tau		-0.498					0.565					
P		0.0077					0.0020					
N		16					17					

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Water-quality variable: Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Bacteria: Fecal streptococci	Bacteria: Fecal coliform
Pamlico River water-quality zone PR8--Continued												
	--	--	--	--	--	--	MF	--	--	--	--	--
tau							0.591					
P							0.0029					
N							15					
	--	--	--	--	--	--	Chickens	--	--	--	--	--
tau							-0.642					
P							0.0004					
N							17					
Pamlico River water-quality zone PR9												
	--	--	--	--	--	--	Tobacco	--	--	--	--	--
tau							0.676					
P							0.0005					
N							15					
	--	--	--	--	--	--	MF	--	--	--	--	--
tau							0.667					
P							0.0017					
N							13					
	--	--	--	--	--	--	Chickens	--	--	--	--	--
tau							-0.715					
P							0.0002					
N							15					
Pamlico River water-quality zone PR10												
	--	CF	--	--	--	--	Tobacco	FM	--	--	--	--
tau		-0.538					0.581	0.494				
P		0.0039					0.0015	0.0078				
N		16					17	16				
	--	--	--	--	--	--	MF	Chickens	--	--	--	--
tau							0.571	0.494				
P							0.0040	0.0078				
N							15	16				

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Water-quality variable										Bacteria	
	Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Fecal streptococci	Fecal coliform
Pamlico River water-quality zone PR10--Continued												
tau P N	--	--	--	--	--	--	Chickens -0.657 0.0003 17	--	--	--	--	--
Pamlico River water-quality zone P1												
tau P N	--	--	--	--	Corn 0.857 0.0030 8	--	--	--	--	--	--	--
tau P N	--	--	--	--	Tobacco 0.786 0.0065 8	--	--	--	--	--	--	--
tau P N	--	--	--	--	Chickens -0.857 0.0030 8	--	--	--	--	--	--	--
Pamlico Sound water-quality location P3												
tau P N	--	Soybeans -0.851 0.0090 7	--	Chickens -0.778 0.0017 10	--	--	--	--	--	--	--	MF 0.791 0.0044 9
tau P N	--	--	--	SUR 0.689 0.0056 10	--	--	--	--	--	--	--	CF 0.791 0.0044 9
Pamlico Sound water-quality location P4												
tau P N	--	--	--	Tobacco 0.733 0.0032 10	--	--	--	--	--	--	--	--

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Water-quality variable: Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Bacteria: Fecal streptococci	Fecal coliform
Croatan Sound water-quality zone CR1												
	--	--	FM	--	SUR	--	--	--	--	--	--	--
tau			0.636		0.857							
P			0.0064		0.0030							
N			11		8							
Roanoke Sound water-quality zone R1												
	--	--	--	--	Tobacco	--	--	--	--	--	Chickens	--
tau					0.704						-0.745	
P					0.0088						0.0014	
N					9						11	
Pasquotank River water-quality zone PS1												
	--	--	--	--	--	--	SUR	--	--	--	--	--
tau							-0.608					
P							0.0063					
N							15					
Chowan River water-quality zone CH4												
	Tobacco	--	SUR	Tobacco	--	--	--	--	--	--	--	--
tau	0.567		0.644	0.553								
P	0.0022		0.0095	0.0097								
N	16		10	13								
	MF	--	--	--	--	--	--	--	--	--	--	--
tau	0.494											
P	0.0057											
N	17											
	CF	--	--	--	--	--	--	--	--	--	--	--
tau	0.465											
P	0.0094											
N	16											
	SUR	--	--	--	--	--	--	--	--	--	--	--
tau	0.494											
P	0.0057											
N	17											

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

	Water-quality variable											
											Bacteria	
Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Fecal streptococci	Fecal coliform
Chowan River water-quality zone CH5												
	--	--	SUR	Tobacco	--	--	--	--	--	--	--	--
tau			0.567	0.560								
P			0.0034	0.0095								
N			15	13								
Chowan River water-quality zone CH7												
	--	--	--	Tobacco	--	--	--	--	Corn	--	--	--
tau				0.570					-0.447			
P				0.0080					0.0009			
N				13					28			
	--	--	--	Chickens	--	--	--	--	--	--	--	--
tau				-0.570								
P				0.0080								
N				13								
National Stream Quality Accounting Network station, Tar River at Tarboro												
	--	FM	--	--	--	--	--	--	--	--	--	--
tau		-0.382										
P		0.0055										
N		27										
National Stream Quality Accounting Network station, Neuse River at Kinston												
	--	--	--	--	--	Soybeans	--	--	--	--	--	--
tau						0.481						
P						0.0034						
N						20						
	--	--	--	--	--	Tobacco	--	--	--	--	--	--
tau						-0.556						
P						0.0007						
N						20						
	--	--	--	--	--	Chickens	--	--	--	--	--	--
tau						0.556						
P						0.0007						
N						20						

Table 15.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics upstream from selected estuary water-quality zones and locations and National Stream Quality Accounting Network stations*--Continued

[Only results with a significance level less than or equal to an alpha of 0.01 are shown. --, no data or no significant correlation; HC, harvested cropland; FM, fertilizer materials; SUR, secondary unpaved roads; MF, mixed fertilizer; CF, mixed fertilizer and fertilizer materials; AF, all fertilizers, including lime]

	Water-quality variable											
											Bacteria	
Correlation coefficient (tau) Probability level (P) Number of annual observations (N)	Dissolved oxygen	pH	Alkalinity	Suspended solids	Nonvolatile suspended solids	Total hardness (as $CaCO_3$)	Total ammonia nitrogen	Total ammonia plus organic nitrogen	Total nitrite plus nitrate	Total phosphorus	Fecal streptococci	Fecal coliform
	National Stream Quality Accounting Network station, Contentnea Creek near Hookerton											
	--	--	--	--	--	Soybeans	--	--	--	--	--	--
tau						0.627						
P						0.0005						
N						17						
	--	--	--	--	--	Tobacco	--	--	--	--	--	--
tau						-0.568						
P						0.0015						
N						17						
	--	--	--	--	--	MF	--	--	--	--	--	--
tau						-0.718						
P						0.0012						
N						12						
	--	--	--	--	--	Chickens	--	--	--	--	--	--
tau						0.583						
P						0.00011						
N						17						
	--	--	--	--	--	SUR	--	--	--	--	--	--
tau						-0.626						
P						0.0048						
N						12						

Table 16.--*Summary of statistically significant correlations between selected water-quality data and basin activities and characteristics in the study area, including total number of possible correlations (N) and the observed number of positive (+) and negative (-) correlations significant at an alpha (α) level of 0.01*

Basin activity or characteristic	Dissolved oxygen			pH			Alkalinity			Suspended solids		
		α=0.01			α=0.01			α=0.01			α=0.01	
	N	+	-	N	+	-	N	+	-	N	+	-
Corn	43	1	0	46	0	0	35	0	0	35	1	0
Soybeans	43	1	0	46	0	2	35	0	0	35	0	0
Tobacco	43	1	0	46	0	0	35	0	0	35	7	0
Harvested crops	43	1	0	46	0	0	35	0	0	35	0	0
Chickens	43	2	0	46	0	0	35	0	0	35	0	2
Mixed fertilizers	43	1	1	46	0	0	35	0	0	35	2	0
Fertilizer materials	43	2	0	46	0	1	35	0	0	35	0	0
Commercial fertilizers	43	2	1	46	0	3	35	0	0	35	1	0
All fertilizers, including lime	43	0	1	46	0	0	35	0	0	35	2	0
Lime	43	0	0	46	0	0	35	0	0	35	1	0
Secondary, unpaved roads	43	1	3	46	0	0	35	2	0	35	3	0

Basin activity or characteristic	Nonvolatile suspended solids			Total hardness			Total ammonia nitrogen			Total ammonia plus organic nitrogen		
		α=0.01			α=0.01			α=0.01			α=0.01	
	N	+	-	N	+	-	N	+	-	N	+	-
Corn	32	1	0	33	0	0	33	0	0	41	0	0
Soybeans	32	0	0	33	2	0	33	0	0	41	3	0
Tobacco	32	3	0	33	0	2	33	6	0	41	1	0
Harvested crops	32	0	0	33	0	0	33	0	0	41	0	0
Chickens	32	0	1	33	2	0	33	0	7	41	3	1
Mixed fertilizers	32	0	0	33	0	1	33	7	0	41	0	1
Fertilizer materials	32	0	0	33	0	0	33	0	0	41	1	0
Commercial fertilizers	32	0	0	33	0	0	33	0	0	41	0	0
All fertilizers, including lime	32	0	0	33	0	0	33	2	0	41	0	0
Lime	32	0	0	33	0	0	33	2	0	41	0	0
Secondary, unpaved roads	32	2	1	33	0	1	33	6	1	41	1	1

Basin activity or characteristic	Total nitrite plus nitrate			Total phosphorus			Fecal streptococci			Fecal coliform		
		α=0.01			α=0.01			α=0.01			α=0.01	
	N	+	-	N	+	-	N	+	-	N	+	-
Corn	34	0	1	42	3	0	17	0	0	32	0	0
Soybeans	34	0	0	42	0	0	17	0	0	32	0	1
Tobacco	34	2	0	42	1	0	17	0	0	32	0	0
Harvested crops	34	0	0	42	1	0	17	0	0	32	0	0
Chickens	34	0	2	42	0	1	17	0	1	32	0	1
Mixed fertilizers	34	0	0	42	0	0	17	0	0	32	0	0
Fertilizer materials	34	0	0	42	0	0	17	0	1	32	0	1
Commercial fertilizers	34	0	0	42	0	0	17	0	0	32	0	0
All fertilizers, including lime	34	0	0	42	0	0	17	0	0	32	0	0
Lime	34	1	0	42	0	0	17	0	0	32	0	0
Secondary, unpaved roads	34	1	1	42	1	1	17	1	0	32	1	0

basin activities and characteristics. In particular, significant correlations between dissolved oxygen and basin activities and characteristics were detected in Neuse River zones N2 and N4; in central Pamlico River zones PR1, PR4, PR5, and PR7; and in Chowan River zone CH4. Significant correlations between suspended solids and basin activities and characteristics were detected in Neuse River zone N4; Pamlico River zones PR1 and PR5; Pamlico Sound locations P3 and P4; and Chowan River zones CH4, CH5, and CH7. Significant correlations between total ammonia nitrogen and basin activities and characteristics were detected in the Pamlico River in zones PR2, PR3, PR5, PR6, PR7, PR8, PR9, and PR10 and in the Pasquotank River zone PS1. Significant correlations between total ammonia plus organic nitrogen and basin activities and characteristics were detected for Neuse River zone N4; and Pamlico River zones PR1, PR2, PR3, PR5, and PR10. Significant correlations between total phosphorus and basin activities and characteristics were detected for Neuse River zone N4; Pamlico River zones PR1, PR5, and PR6; and Chowan River zone CH7.

The water-quality zones and locations that had significant correlations between water quality and basin activities and characteristics are shown in figure 53. Significant correlations between basin activities and characteristics (predominantly agricultural statistics) and several water-quality constituents were detected in many of the zones or locations. It is important to note that significant correlations that are clustered in any one particular area might reflect interdependence of the water-quality data between the zones or locations in the area because they share upstream basin-drainage area. Consequently, the water quality might be similar in adjacent or nearby downstream zones or locations.

Water-quality zones of the Neuse, Pamlico, and Chowan Rivers had the greatest numbers of significant correlations between measures of agricultural characteristics and water quality. In general, these correlations were detected in the zones that had the greatest numbers of stations and in the stations having the most water-quality records. However, in order to identify a link between agricultural activity and water quality at a particular zone, a more detailed study is required that examines (1) the proximity of the water-quality specific basin activities and characteristics, (2) other possible sources of the water-quality constituents, such as wastewater inputs, and (3) the relative magnitudes of the different inputs at each station.

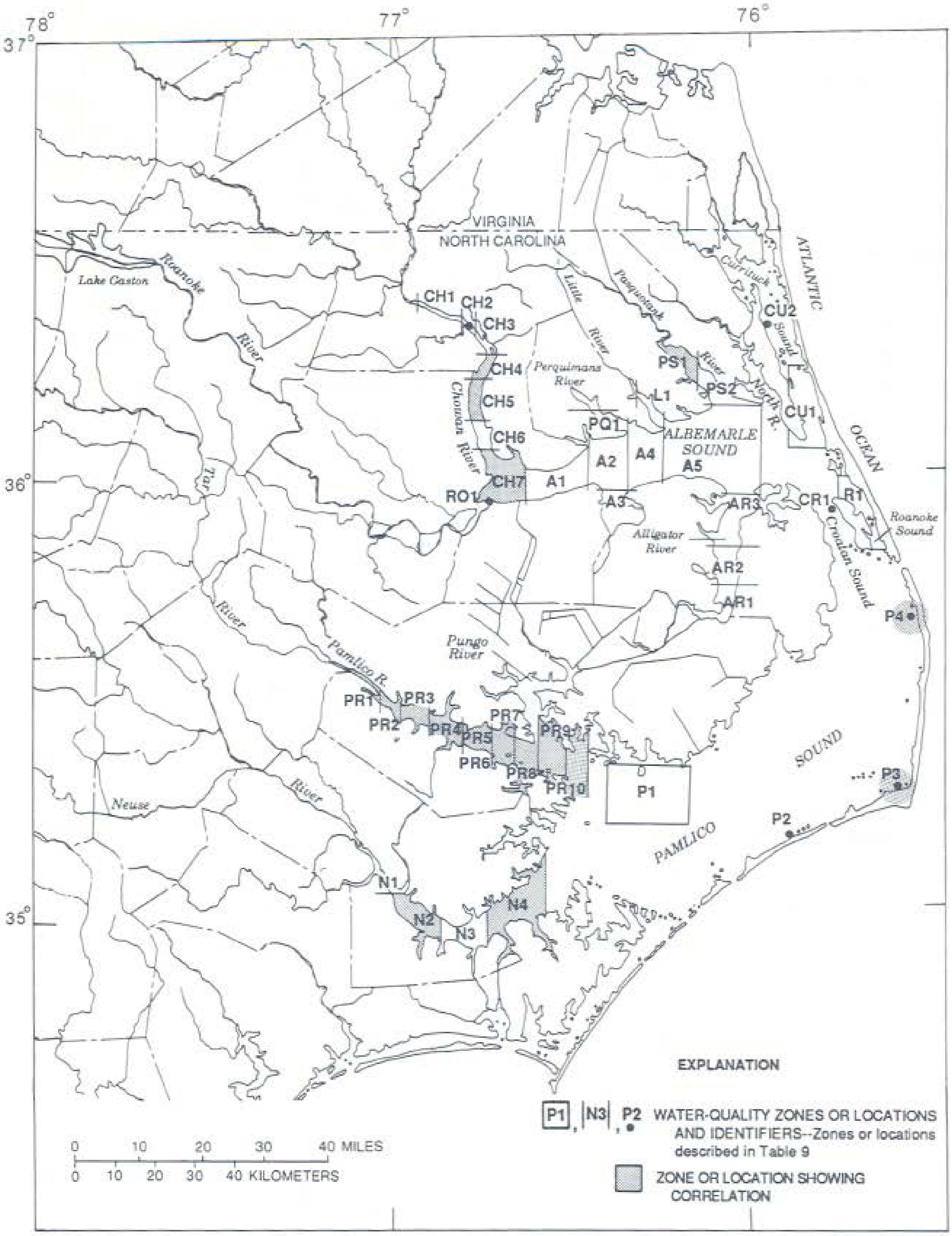

Figure 53.--Zones and locations with statistically significant correlations between basin activities and characteristics and water-quality variables, 1970-88.

Dissolved Oxygen

Annual median dissolved-oxygen concentrations in water-quality zones N2 and N4 in the Neuse River, in zones PR1, PR4, PR5, and PR7 in the Pamlico River, and in zone CH4 in the Chowan River were significantly correlated with basin activities and characteristics in upstream drainage areas. In general, an increase in dissolved-oxygen concentration was associated with increases in acreages of crops harvested and the number of chickens in the basins. An example of an association between dissolved oxygen for zone N2 and acreages of crops harvested is shown in figure 54.

Both positive and negative correlations were observed between dissolved oxygen and the fertilizer variables and also the numbers of miles of secondary unpaved roads (table 15). Because positive and negative correlations between dissolved-oxygen and fertilizer variables were detected at different locations, it is unclear what the nature of the generalized association between variables may be. A possible reason for these correlations may be that an increase in nutrient inputs to the estuary due to agricultural fertilizer application for crop production may increase plant productivity in the estuary. In the diurnal growth cycle of algae, oxygen is released during daylight hours. An increase in daytime production of oxygen by estuary plants would be reflected in daytime dissolved-oxygen measurements. Further, consumption of carbon dioxide by the plants causes decreased acidity, and pH rises. The generalized increase in pH observed in the trends analysis (see section on pH and figure 17) may also reflect an increase in plant productivity in the estuary system. An example of a positive correlation between dissolved oxygen in zone PR1 and the total number of tons of fertilizer materials applied in upstream areas is shown in figure 55.

Suspended Solids

Annual median suspended-solids concentrations in water-quality zone N4 in the Neuse River, in zones PR1 and PR5 in the Pamlico River, in locations P3 and P4 in Pamlico Sound, and in zones CH4, CH5, and CH7 in the Chowan River were significantly correlated with basin activities and characteristics in upstream drainage areas. Decreases in acreages of corn and tobacco harvested corresponded to decreases in suspended-solids

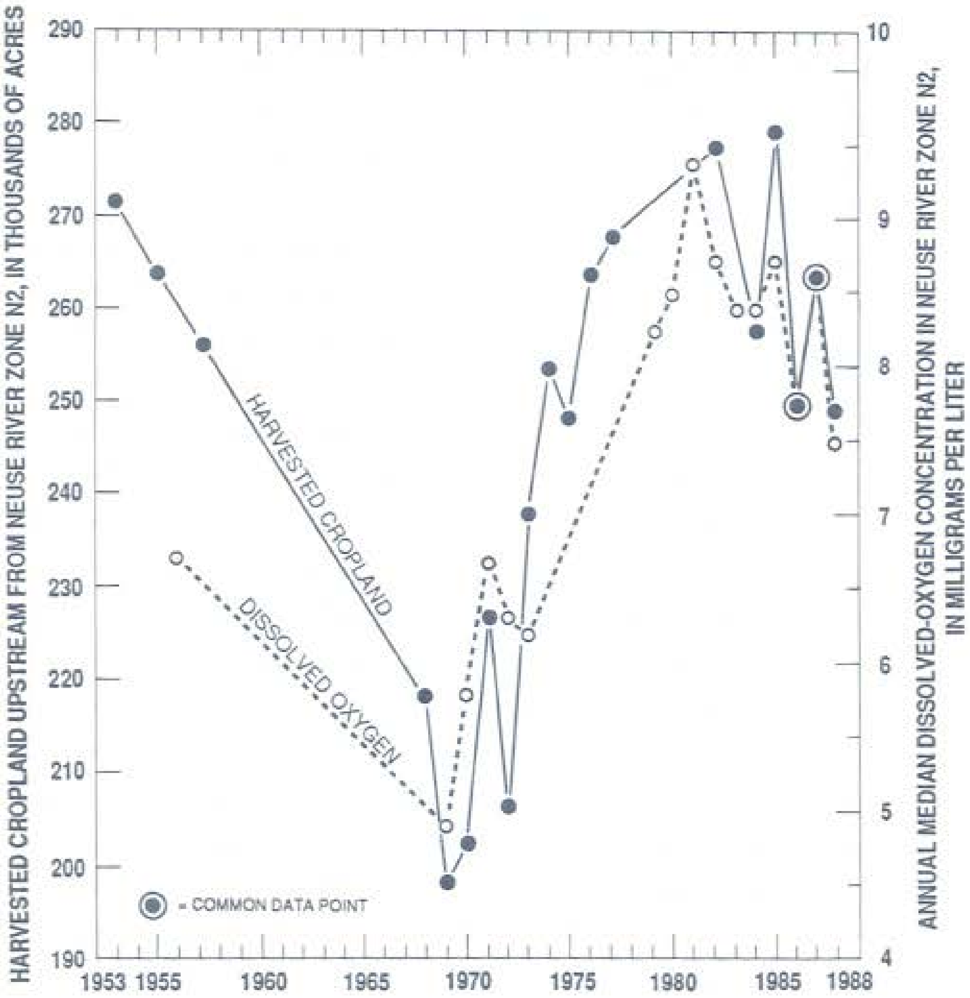

Figure 54.--Annual variation in total acreages of harvested cropland upstream from Neuse River water-quality zone N2 and annual median dissolved-oxygen concentrations. Lines connecting data points only reflect trends, not actual data values.

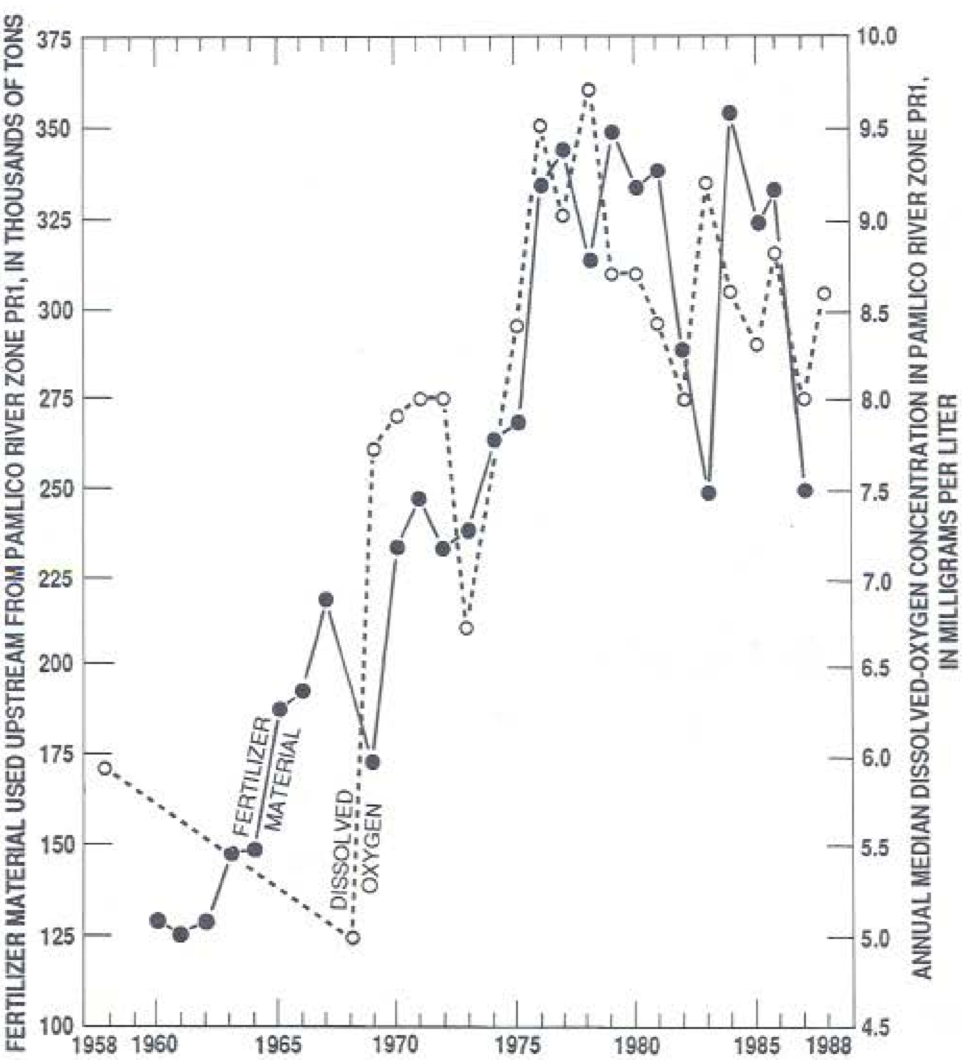

Figure 55.--Annual variation in total fertilizer material used upstream from Pamlico River water-quality zone PR1 and annual median dissolved-oxygen concentrations. Lines connecting data points only reflect trends, not actual data values.

concentrations (table 15). An example of this association is shown for Pamlico River zone PR5 in figure 56. In addition, decreases in fertilizer use were associated with decreases in suspended solids (fig. 57). In addition, decreases in miles of roads were associated with decreases in suspended solids. These correlations indicate an association between suspended solids and agricultural practices and sediment from roads. Trend analysis indicated a generalized system-wide reduction of suspended inorganic material in the Albemarle-Pamlico estuarine system (fig. 24). This might be due largely to construction of new lakes and ponds in the basin and the subsequent loss to the estuarine system of inorganic material trapped by those impoundments. However, decreases in suspended solids also might reflect decreases in acreages of corn and tobacco harvested or improved agricultural soil-management techniques.

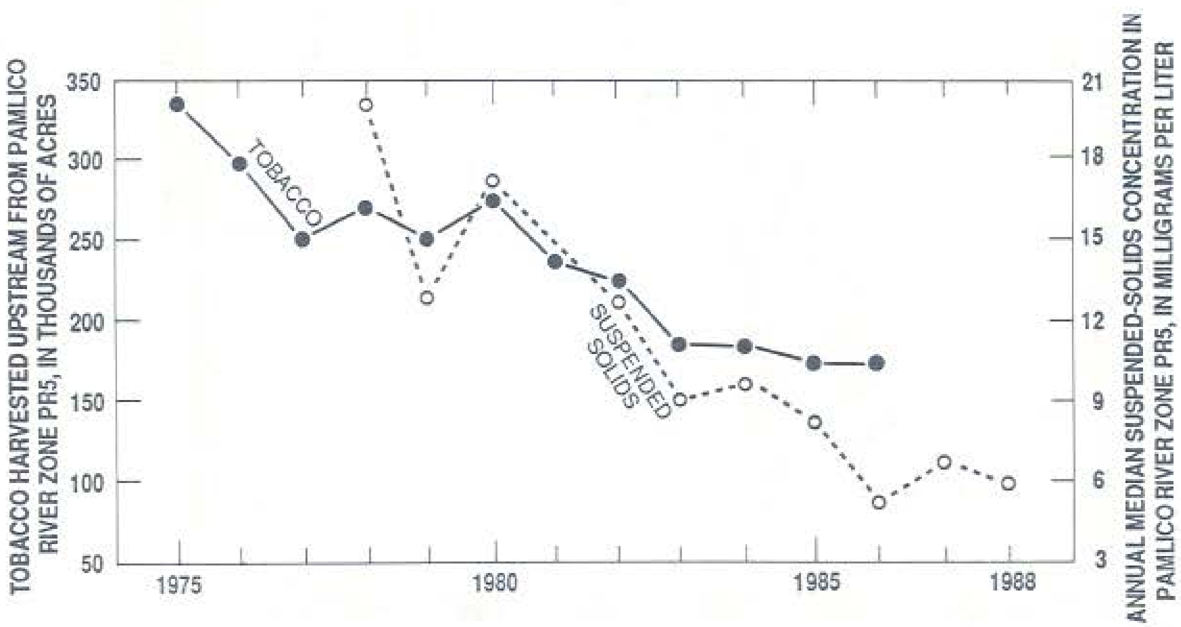

Figure 56.--Tobacco acreage upstream from Pamlico River water-quality zone PR5 and annual median suspended-solids concentrations. Lines connecting data points only reflect trends, not actual data values.

Total Ammonia Nitrogen

Annual median ammonia nitrogen concentrations in water-quality zones PR2, PR3, PR5, PR6, PR7, PR8, PR9, and PR10 in the Pamlico River and in zone PS1 in the Pasquotank River were significantly correlated with basin activities and characteristics in upstream drainage areas. Decreases in acreages of tobacco harvested and fertilizer tonnages corresponded to decreases in total ammonia nitrogen concentrations (table 15). An example of correlation between total ammonia nitrogen concentrations and acreages of tobacco harvested for Pamlico River zone PR1 is shown in figure 58. Although the correlation indicates an association between decreases in total ammonia nitrogen concentrations and acreages of tobacco harvested and fertilizer use, it is not necessarily an important or meaningful relation. A more important relation may be that total ammonia nitrogen concentration decreases reflect an overall increase in algal and bacterial uptake with increases in plant biomass.

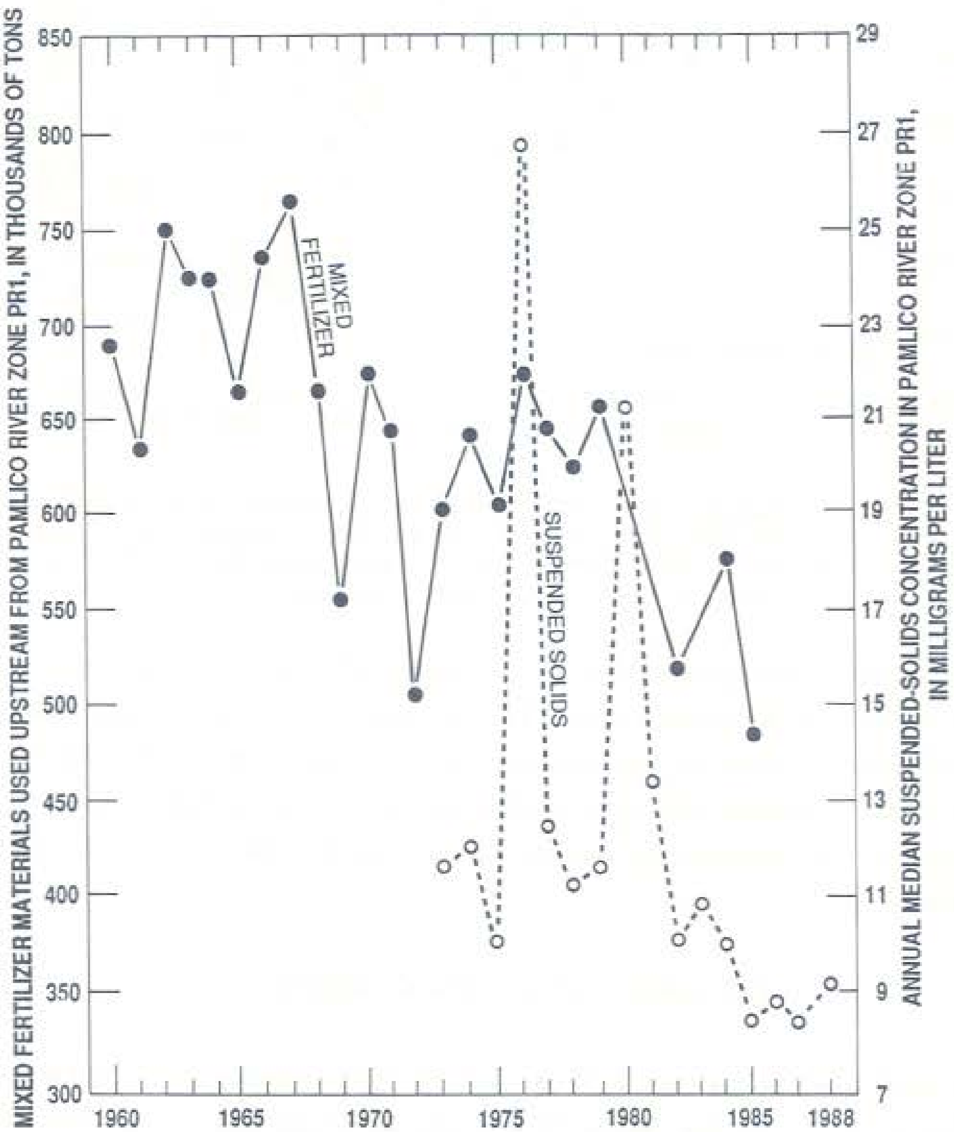

Figure 57.--Annual variation in mixed fertilizer tonnage used upstream from Pamlico River water-quality zone PR1 and annual median suspended-solids concentrations. Lines connecting data points only reflect trends, not actual data values.

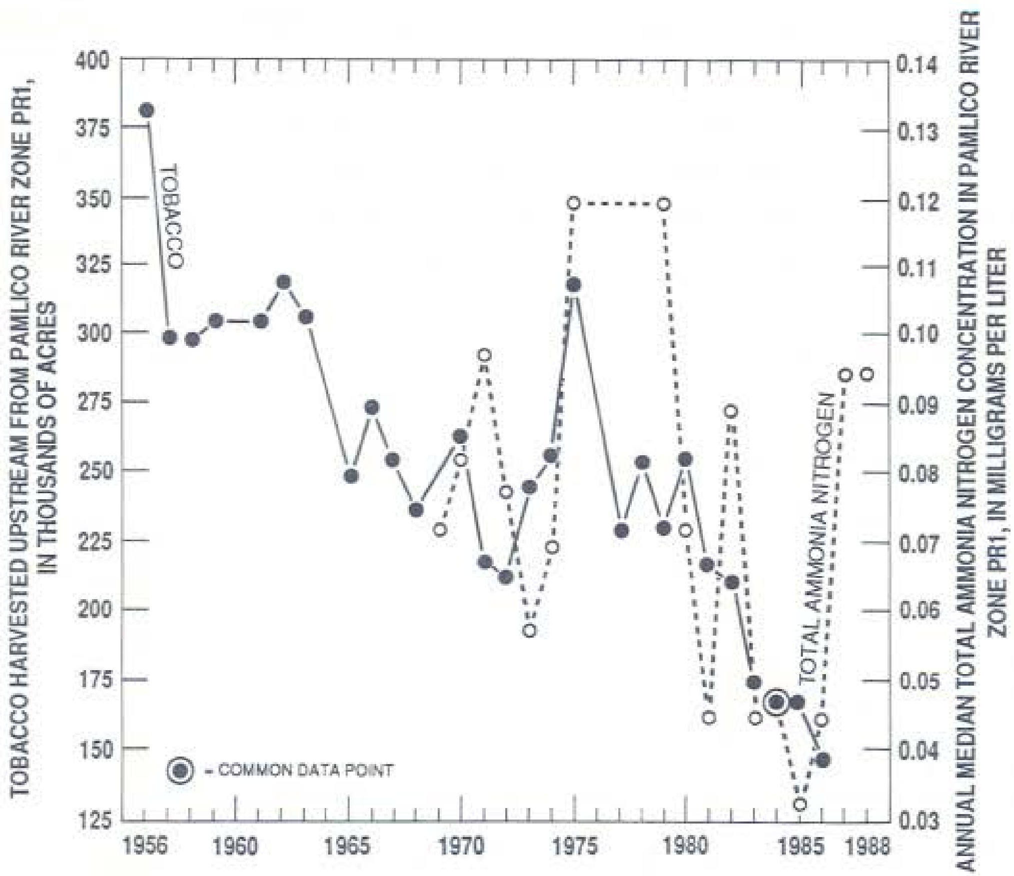

Figure 58.--Annual variation in tobacco acreage upstream from Pamlico River water-quality zone PR1 and annual median total ammonia nitrogen concentrations. Lines connecting data points only reflect trends, not actual data values.

Total ammonia nitrogen concentration also correlated negatively with the numbers of chickens being raised in the basin. Increases in total number of chickens raised in the Pamlico River zones were associated with a decrease in total ammonia nitrogen concentrations. This association is counterintuitive and perhaps is due to inverse but substantial slopes of both variables.

Total Ammonia Plus Organic Nitrogen

Annual median total ammonia plus organic nitrogen concentrations in water-quality zone N4 in the Neuse River and in zones PR1, PR2, PR3, PR5, and PR10 in the Pamlico River were significantly correlated with basin activities and characteristics in upstream drainage areas. Increases in total ammonia plus organic nitrogen concentrations are associated with increases in crops harvested and numbers of chickens raised (table 15). An example of the association between total ammonia plus organic nitrogen and acreages of soybeans harvested for zone PR1 is shown in figure 59. The association between total ammonia plus organic nitrogen and numbers of chickens raised is shown in figure 60.

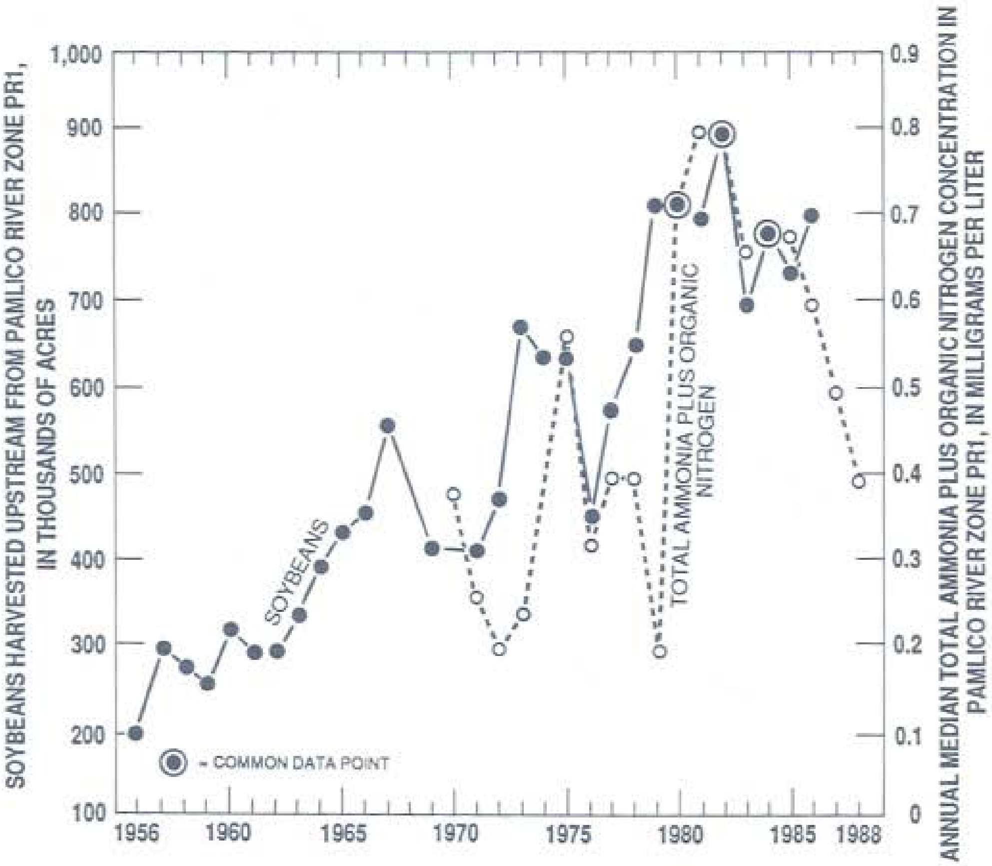

Figure 59.--Annual variation in soybean acreage upstream from Pamlico River water-quality zone PR1 and annual median total ammonia plus organic nitrogen concentrations. Lines connecting data points only reflect trends, not actual data values.

Trend analysis showed an increase in total ammonia plus organic nitrogen concentrations in the Pamlico River in spite of decreasing total ammonia nitrogen concentrations described earlier. These observations are in accord with the hypothesis that a decrease in total ammonia nitrogen concentrations could occur with an increase in production of plant biomass, which in turn may be reflected in an increase in total ammonia plus organic nitrogen. The positive correlation of total ammonia plus organic nitrogen concentrations with soybean cropping and chicken farming suggests that these expanding agricultural operations are associated with organic nitrogen concentrations in the Pamlico River.

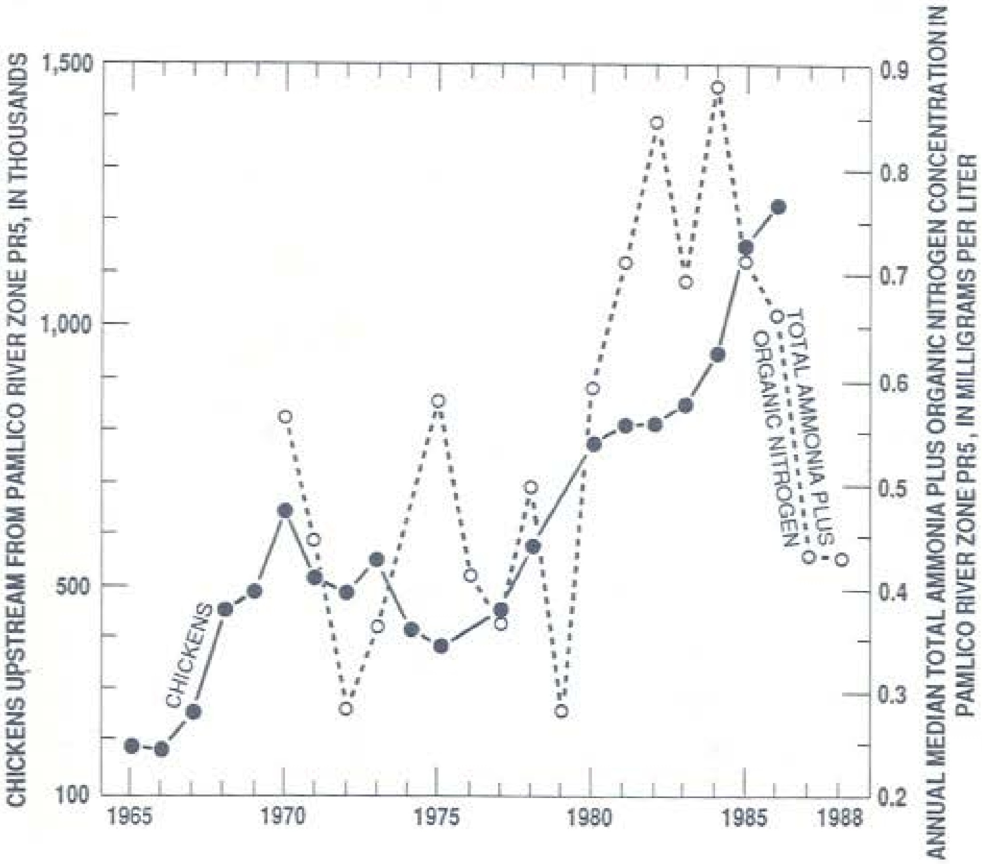

Figure 60.--Annual variation in total number of chickens upstream from Pamlico River water-quality zone PR5 and annual median total ammonia plus organic nitrogen concentrations. Lines connecting data points only reflect trends, not actual data values.

Total Phosphorus

Crop variables correlated positively with total phosphorus concentrations, again suggesting a link to estuary nutrient concentrations to agricultural practices. An example of the association of total phosphorus concentrations with acreages of corn harvested for Pamlico River zone PR1 is shown in figure 61. However, at least in the case of Pamlico River zones PR5 and PR6, it is likely that effects of the phosphate mining operation near Durham Creek is the dominant variable affecting estuary phosphorus concentrations. Annual median total phosphorus concentrations in water-quality zones N4 in the Neuse River, PR1, PR5, and PR6 in the Pamlico River, and CH7 in the Chowan River were significantly correlated with basin activities and characteristics in upstream drainage areas (table 15).

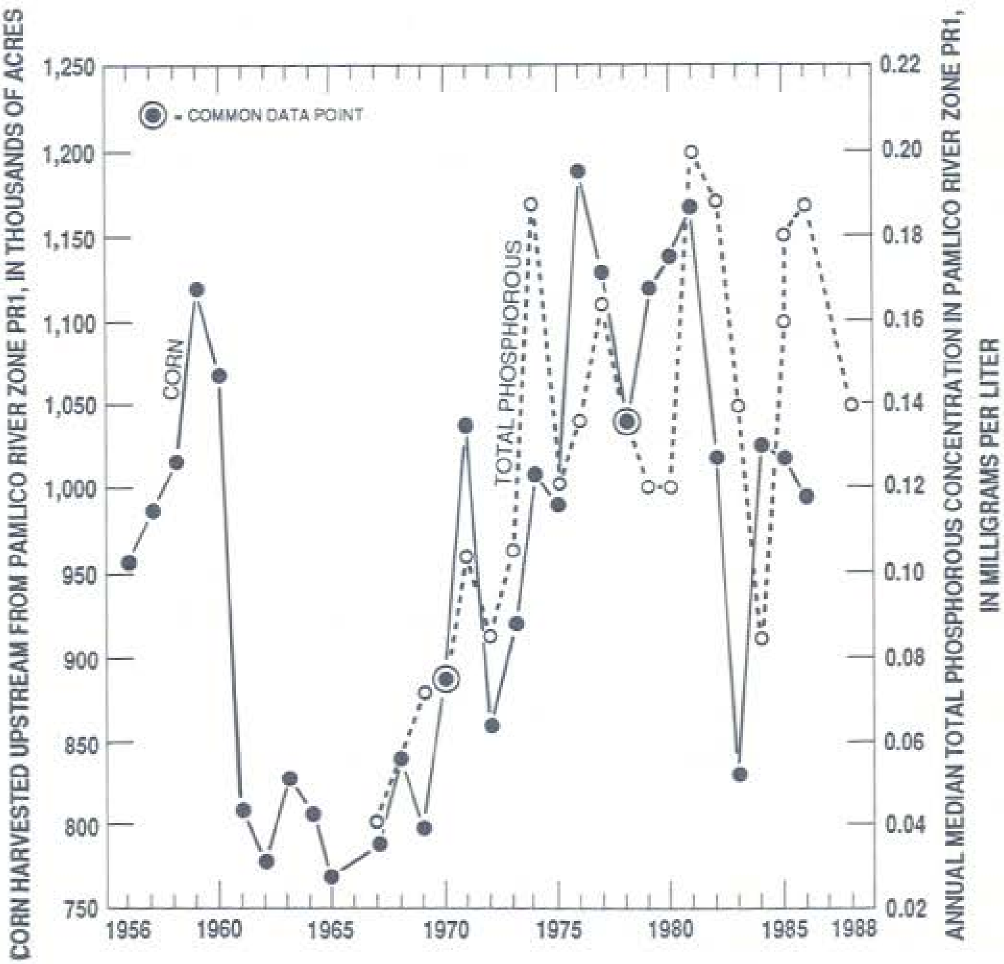

Figure 61.--Annual variation in corn acreage upstream from Pamlico River water-quality zone PR1 and annual median total phosphorus concentrations. Lines connecting data points only reflect trends, not actual data values.

SUMMARY

This report identifies trends in water quality in the Albemarle-Pamlico estuarine system of North Carolina and Virginia and describes significant relations between water-quality constituents and certain basin activities and characteristics. The data included water-quality information collected at 7 U.S. Geological Survey stations in the National Stream Quality Accounting Network (NASQAN), 2 stations in the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), 162 estuary stations having data stored in the U.S. Environmental Protection Agency Storage and Retrieval System, and 125 estuary stations having water-quality data collected as part of previous investigations in the study area. The period of record examined was primarily from 1970 to 1988, but some data from as early as 1945 were used.

The Albemarle-Pamlico estuarine system is the second largest in the United States and has a total basin area of about 30,900 mi^2. The principal water bodies are the Neuse River, the Tar-Pamlico River system, the Roanoke River, the Chowan River, the Alligator River, and the Albemarle, Pamlico, Currituck, Croatan, and Roanoke Sounds.

The basin activities and characteristics examined were those quantifiable measures of basin development and activities that could be represented over time. These characteristics included streamflow, water use and disposal, land use, agricultural statistics, population, employment, and highway mileage.

Albemarle Sound receives the greatest amount of freshwater inflow, which averages about 8,900 ft^3/s from the Roanoke River and about 4,600 ft^3/s from the Chowan River. Inflow into the Pamlico Sound from the Pamlico River averages about 5,400 ft^3/s, and the flow from the Neuse River into the Neuse River estuary is about 6,100 ft^3/s. Approximately half of the inflow into the system is from ground-water discharge.

In the Coastal Plain section of the Albemarle-Pamlico region, ground water supplies about half of the water used in the area. Industry and mining account for about 64 percent of the water use in the entire region. Public water-supply withdrawals increased by almost 50 percent between 1975 and 1985. Total agricultural withdrawals accounted for about 13 percent of total water use in 1985.

The total amount of wastewater discharged into the estuary system has increased over the last 30 years for all the river basins. The Neuse River basin had both the greatest increases (650 percent) and the greatest total wastewater discharges of any of the basins in the study area, averaging about 200 million gallons per day in 1988. Wastewater-discharge totals for the Tar and Neuse Rivers are nearly equal to the 7-day, 10-year low flows for each of these streams.

Land-use data compiled for the lower Tar-Pamlico area is typical of the major land uses in the region. Evergreen forests and forested wetlands were the primary land uses in the lower part of the Neuse River basin and the lower part of the Tar-Pamlico River basin, each at about 25 percent of the land area. Cropland and pasture (about 20 percent of the total land area), mixed forest (about 12 percent), and nonforested wetland (about 10 percent) also were major land uses in the area. About 4 percent of the lower Neuse and Tar-Pamlico River basins was in urban land use. A comparison of wetlands land uses for two different time periods for nonforested areas, primarily on the Outer Banks, indicated a decline in wetland area of 6.5 percent from 1973 to 1983.

Agricultural, population, employment, and highway characteristics are summarized as follows:

- Numbers of farms decreased about 60 percent from the 1950's to 1982;
- Acreages of soybeans have increased since the 1920's while those of tobacco have decreased;
- Fertilizer sales increased from 1958 to about 1975, then declined;
- Population has generally increased since 1910;
- Manufacturing employment has increased since the 1950's, but agricultural employment has decreased; and
- Total miles of unpaved secondary roads decreased from 1966 to 1988.

Data from seven NASQAN stations were used to evaluate water quality for the major streams flowing into the Albemarle-Pamlico estuarine system. Water-quality data for 296 stations in the estuarine system were examined for the period 1945-88.

The water-quality data base was edited and divided into subsets for water-quality zones and locations within the estuary system. Data checking and editing procedures were used to delete outlying values and constituents and properties having less-than values and differing lower detection limits. The water-quality data for each zone and location were tested for temporal and spatial trends.

The statistical test used for temporal trend analysis was the Seasonal Kendall test, which is a nonparametric procedure developed for use with water-quality data having seasonality characteristics; the test is useful for detections of monotonically increasing or decreasing water-quality trends over time. Annual box plots were used for graphical representation of trends and to provide a means of showing spatial variations.

Regression-residuals analysis was used to compensate for the effect of discharge on water-quality constituents collected at the NASQAN stations. Adjusted residual constituent values were tested for trends using the Seasonal Kendall test, and box plots were used to portray trends that were not simply increasing or decreasing.

Dissolved-oxygen concentrations increased at a rate of about 0.1 (mg/L)/yr throughout the Albemarle-Pamlico estuarine system, except in the Chowan River where levels decreased approximately 0.06 (mg/L)/yr. In general, dissolved-oxygen concentrations rose to concentrations greater than 5 mg/L after the late 1970's in the Neuse River, Tar River, and in Pamlico Sound. If daytime sampling is assumed, a general increase in dissolved oxygen could be an indication of more productive estuary conditions.

Trends of increasing biochemical oxygen demand were detected in parts of the Neuse River zone N2 (0.1 (mg/L)/yr) and Roanoke Sound zone R1 (0.05 (mg/L)/yr). Decreasing trends occurred in Currituck Sound zone CU1 (-0.07 (mg/L)/yr) and location CU2 (-0.24 (mg/L)/yr) and in the Chowan River zones CH5 (-0.03 (mg/L)/yr) and CH7 (-0.04 (mg/L)/yr). Biochemical oxygen demand generally increases downstream in the Neuse and Pamlico Rivers.

An annual increase of approximately 0.04 pH unit occurred in many of the Albemarle-Pamlico estuary zones, but a decrease of about 0.03 pH unit per year occurred in the Pamlico River. Because data from the NADP/NTN precipitation-quality stations do not indicate significant trends in pH, it is likely that changes in land use or wastewater inputs within the individual stream basins have caused the observed pH trends. A general increase in pH in the estuarine system might be indicative of more productive estuary conditions.

Significant trends of increasing alkalinity were detected for the Roanoke River at Roanoke Rapids (0.80 (mg/L)/yr), Pamlico Sound locations P3 (6.7 (mg/L)/yr) and P4 (5.0 (mg/L)/yr), Croatan Sound zone CR1 (2.8 (mg/L)/yr), Roanoke Sound zone R1 (3.1 (mg/L)/yr), and Currituck Sound zone

CU1 (2.0 (mg/L)/yr). Alkalinity decreased in the Chowan River zones CH4 (-0.83 (mg/L)/yr) and CH5 (-1.0 (mg/L)/yr), declining to concentrations less than 20 mg/L in the later 1970's. Alkalinity increased downstream in the Neuse River and increased from west to east in Pamlico Sound.

Suspended-sediment concentrations decreased for the Roanoke River at Roanoke Rapids (-0.21 (mg/L)/yr), probably because of the effect of the upstream reservoir system. The NASQAN station on the Roanoke River had the lowest sediment concentrations (interquartile range 5-11.5 mg/L); the NASQAN station on the Neuse River had the highest (interquartile range 19-36 mg/L).

Suspended-solids concentrations generally decreased throughout the Albemarle-Pamlico study area (-1.1 (mg/L)/yr). Nonvolatile suspended-solids concentrations also decreased at a mean rate of 1.5 (mg/L)/yr. These decreases are not likely to result from a decline in algal or other organic material but to a general decrease of suspended inorganic material. These decreases are possibly a result of construction of new lakes and ponds in the basin which trap sediment, including the suspended inorganic component of sediment, and improved agricultural soil management.

Trends of increasing specific-conductance values were detected for the following NASQAN stations: Neuse River (0.8 (μS/cm)/yr), Contentnea Creek (1.9 (μS/cm)/yr), Tar River (0.6 (μS/cm)/yr), Roanoke River (1.5 (μS/cm)/yr), and Blackwater River (0.7 (μS/cm)/yr). A trend of increasing specific conductance from 1979 to 1987 (1.9 (μS/cm)/yr) of atmospheric deposition was detected at the Lewiston NADP/NTN station.

Trends of increasing dissolved-solids concentrations occurred at the NASQAN stations at a mean rate of (0.6 (mg/L)/yr). In addition, a peak in dissolved-solids concentrations around 1980 was seen at these sites. Trends of increasing salinity were detected in Pamlico River zone PR2 (0.03 ppt/yr), Albemarle Sound zones A2 (0.1 ppt/yr) and A5 (0.08 ppt/yr), and the Pasquotank River zone PS1 (0.08 ppt/yr). A trend of decreasing salinity was apparent for Pamlico River zone PR10 (-0.2 ppt/yr).

Chloride concentrations increased with time at a mean rate of 0.07 (mg/L)/yr at the NASQAN stations, except at the Meherrin River and Contentnea Creek stations where trends were not significant. The available data for chloride trend analysis in the estuary system is sparse.

Soluble nutrient concentrations, including total ammonia nitrogen, nitrite plus nitrate, and dissolved phosphorus are a net result of the effects of biological uptake, solution and dissolution of nutrients available in sediment, and new nutrient inputs. If biomass increases over time, this may be reflected in decreases in soluble nutrients as observed total ammonia nitrogen and phosphorus concentrations in the estuary system.

Trends in total ammonia plus organic nitrogen concentrations decreased significantly throughout the study area (mean of 7 zones, -0.03 (mg/L)/yr), except at the Pamlico River zones where the trend increased at the rate of 0.02 (mg/L)/yr and at the Nottoway River NASQAN station. However, at 9 zones on the Pamlico River, total ammonia nitrogen concentration trends alone showed a mean decrease of 0.003 (mg/L)/yr. Therefore, the increase in total ammonia plus organic nitrogen concentrations in the Pamlico River is apparently a result of an increase in organic nitrogen concentrations.

In general, total ammonia plus organic nitrogen concentrations increased downstream. In all cases except for Albemarle Sound, total ammonia plus organic nitrogen levels were above 0.3 mg/L, indicating an ample supply of nitrogen for algal growth.

Total phosphorus concentrations generally decreased throughout the study area at a mean rate of 0.004 (mg/L)/yr, except for the Pamlico River zones where they increased at a mean rate of 0.003 (mg/L)/yr. A spatial pattern showed total phosphorus concentrations decreasing downstream in the Neuse and Chowan Rivers. In all cases, total phosphorus concentrations remained well above 0.01 mg/L, a concentration often cited as sufficient for abundant algal growth in freshwater. General long-term decreases in dissolved phosphorus may, in part, be accounted for by biological uptake.

An evaluation of carbon:nitrogen:phosphorus ratios using median values of these constituents was done to indicate which nutrient was in relative short supply for algal growth at each zone and NASQAN station. Nitrogen was the limiting nutrient in the Neuse River and the Pamlico River, and phosphorus was the limiting nutrient elsewhere. Direct tests for specific nutrient limitations need to be made to confirm conditions at specific sites in the estuarine system.

Significant decreasing trends in fecal coliform bacteria counts were observed at zones and locations on the Neuse and Pamlico Rivers and at Pamlico and Currituck Sounds. Decreasing trends ranged from 0.22 (colonies/100 mL)/yr at Neuse River zone N4 to 2.5 (colonies/100 mL)/yr at Pamlico Sound location P3. Decreasing trends in fecal streptococci were also noted in zones of the Neuse River and Pamlico, Croatan, and Roanoke Sounds. These trends ranged from -0.38 (colonies/100 mL)/yr at Pamlico Sound zone P1 to -18.5 (colonies/100 mL)/yr at Roanoke Sound zone R1. The ratios of fecal coliforms to fecal streptococci indicate that the sources are probably of animal origin.

Chlorophyll-a concentrations increased significantly at Neuse River zones N1 (0.95 (μg/L)/yr) and N2 (0.74 (μg/L)/yr), Pamlico River zone PR2 (0.17 (μg/L)/yr), and Albemarle Sound zone A2 (1.0 (μg/L)/yr). Decreasing trends were observed at Chowan River zones CH4 (-1.3 (μg/L)/yr) and CH5 (-0.50 (μg/L)/yr). A general pattern of decreasing concentrations downstream occurred in the Neuse River, but increases downstream were noted in the Chowan and Alligator Rivers. The pattern for the water-quality zones in the Pamlico River shows an increase downstream peaking near PR6 followed by a decline farther downstream. Chlorophyll-a concentrations are highest in the Pamlico (interquartile range 3-27 μg/L) and Neuse (interquartile range 3-17 μg/L) Rivers and in Currituck Sound (interquartile range 7-22 μg/L).

Evaluation of water-quality data and more than 50 basin activity and characteristic variables were significantly correlated with water-quality constituents in 21 estuary zones and 7 NASQAN stations. A total of 121 significant correlations were detected in this analysis. Dissolved oxygen, suspended solids, total ammonia nitrogen, total ammonia plus organic nitrogen, and total phosphorus were significantly (alpha = 0.01) correlated with basin activities and characteristics in many zones and locations.

Increases in dissolved-oxygen concentrations with increases in crop acreages and fertilizer use might be indicative of more photosynthetically productive estuary conditions related to agricultural activities. Decreases in suspended solids in the estuarine system might reflect decreases in corn and tobacco production, or improved agricultural soil-management techniques.

Decreases in total ammonia nitrogen in the Pamlico River correlated with decreases in tobacco acreage and fertilizer use, and increases in total ammonia plus organic nitrogen in the Pamlico River correlated with increases in crops and livestock. A decrease in total ammonia nitrogen could occur with an increase in production of biomass, which in turn may be reflected in an increase in total ammonia plus organic nitrogen. These correlations could indicate that expanding agricultural operations are associated with organic nitrogen concentrations in the Pamlico River.

Overall, the review of available data for the Albemarle-Pamlico estuarine system indicates a complex, evolving system undergoing water-quality changes. The changes in the character of the river basins are reflected in the changes in water quality of the estuaries and sounds.

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METRIC CONVERSION FACTORS

The following factors may be used to convert inch-pound units used in this report to metric (International System) units.

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Velocity	
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
	Mass	
pound (lb)	0.4536	kilogram (kg)
ton (short, 2,000 pounds)	0.9072	megagram (Mg) or metric ton (t)

Temperature: Temperature given in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the following equation: °F = 1.8(°C) + 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.

ALBEMARLE-PAMLICO