Water-Quality Trends for Streams and Reservoirs in the Research Triangle Area of North Carolina, 1983-95

U.S. Geological Survey – Water-Resources Investigations Report 97-4061

Jordan Lake, N.C. Courtesy of N.C. Division of Travel and Tourism

Prepared in cooperation with the

Triangle Area Water Supply Monitoring Project Steering Committee

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This report presents the results of analyses of trends in concentrations of nitrogen, phosphorus, suspended sediment, suspended solids, sodium, chloride, iron, zinc, manganese, and chlorophyll *a* at 34 stream and reservoir sites that are part of the Triangle Area Water Supply Monitoring Project. Trend results are discussed in relation to broad-scale changes in land cover that have occurred in the area since the mid-1970's.

Data used for trend analysis of stream sites are from samples collected by the U.S. Geological Survey (USGS) from 1982 through 1987 for a study for the U.S. Army Corps of Engineers (Garrett, 1990a and b), by the North Carolina Division of Water Quality (DWQ) from 1982 through 1995 for the statewide ambient water-quality monitoring network, and by the USGS from 1988 through 1995 for the Triangle Area Water Supply Monitoring Project (Childress and Treece, 1996; Ragland and others, 1996). These three sources provide stream water-quality data, collected monthly, which are ideally suited for trend analysis. Using continuous streamflow data from USGS gages, stream water-quality data were statistically adjusted to eliminate the effects of changing streamflow.

Lake samples were collected from 1988 to 1995 by the DWQ for the North Carolina Lake Assessment Program and by the USGS for the Triangle Area Water Supply Monitoring Project. Generally, these data were collected only between April and October and were collected at variable time intervals.

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Significant Findings

- The most significant regionwide water-quality trend was a decline in total phosphorus concentration after 1988 that coincided with substantial phosphorus removal measures at many municipal wastewater-treatment facilities in the region and the removal of phosphates in detergent. The decline in total phosphorus as P ranged from 25 to 81 percent.
- Total nitrogen concentrations at most sites were stable from 1983 through 1995. Increasing concentrations occurred in the Neuse River at Clayton and at Smithfield. Decreasing concentrations occurred in headwater streams and small lakes, including the Eno River at Hillsborough, Little River and Little River Reservoir, Lake Michie, Swift Creek, Cane Creek Reservoir, and Morgan Creek near White Cross. Total nitrogen also decreased in the Cape Fear River near Brickhaven.
- Nitrate concentrations at most sites were stable from 1983 through 1995; however, at all but one stream site where a trend was recorded, the trend was increasing. These sites —the Eno River near Durham, Knap of Reeds Creek, Neuse River near Clayton and at Smithfield, and New Hope Creek— drain basins with substantial population increases since 1980.
- Organic nitrogen concentrations were either stable or declining from 1983 to 1995. Sites with declining concentrations were headwater sites (Cane Creek and Morgan Creek), sites downstream from impoundments (Swift Creek, Haw River near Moncure, and Neuse River near Falls), sites receiving WWTP effluents (Eno River near Weaver and Knap of Reeds Creek), and the Cape Fear River near Brickhaven.
- Suspended-sediment concentrations were stable at all sites tested; suspended-solids concentrations also were stable except for decreasing concentrations at Knap of Reeds Creek and Haw River at Bynum.
- Sodium concentrations have decreased at Neuse River at Smithfield and Cane Creek near Orange Grove, and increased in University Lake.
- Chlorophyll *a* concentrations have increased by 17 to 52 percent per year from 1989 to 1995 at monitored lakes except Cane Creek Reservoir and Lake Michie. In the upper Neuse River Basin, increases coincide with stable or decreasing total phosphorus concentrations. The reasons for this apparent contradiction will require further, more detailed study.
- No clear patterns emerged linking water-quality trends to development and growth patterns. Swift Creek is the most rapidly developing of the basins studied—developed land cover increased from 30 to 75 percent from 1975 to 1988. Ellerbe Creek is the most populated watershed in terms of numbers of people per square mile. Continued monitoring of these small watersheds is needed to assess the effects of growth and development on water quality.

ABSTRACT

Water-quality and streamflow monitoring data, collected from 1983 to 1995, were analyzed for 34 stream and reservoir sites in a seven-county region within the upper Neuse and upper Cape Fear River Basins. Early data (1983-88) were compiled from U.S. Geological Survey water-quality studies and from the ambient water-quality monitoring network of the North Carolina Department of Environment, Health, and Natural Resources. Analyses of major ions, nutrients, metals, trace elements, and synthetic organic compounds were compiled from samples collected by the U.S. Geological Survey from 1988 to 1995 as part of a continuing project to monitor the water quality of surface-water supplies in the Research Triangle area of North Carolina, and from the North Carolina Department of Environment, Health, and Natural Resources ambient water-quality monitoring network.

This report presents the results of analysis of consistently increasing or decreasing trends in concentrations of nitrogen and phosphorus species, suspended sediment, suspended solids, sodium, chloride, iron, manganese, zinc, and chlorophyll *a* from seasonal Kendall trend analysis on flow-adjusted concentrations for streams and concentrations in lakes. Total phosphorus concentrations also were tested for a step decrease in concentration (step trend) associated with the North Carolina phosphate-detergent ban of 1988. For some other constituents, insufficient data or values below laboratory detection limits precluded trend analysis.

A regionwide decrease in total phosphorus, ranging from 25 to 81 percent, was observed that coincided with increased phosphorus removal efforts at municipal wastewater-treatment facilities in the region and the statewide phosphate-detergent ban. Most sites had stable or decreasing trends in nitrogen concentrations; however, increasing trends occurred in the Neuse River near Clayton and at Smithfield, both of which are downstream from the developing Raleigh-Durham area. Chlorophyll *a* concentrations have increased by 17 to 52 percent per year at monitored reservoirs, except at Cane Creek Reservoir and Lake Michie where there was no trend. No significant trends in suspended-sediment concentrations were observed. Long-term sodium concentrations were available for only a few sites. Of these, decreasing concentrations were observed in the Neuse River at Smithfield and Cane Creek near Orange Grove, and an increasing concentration was observed in University Lake.

Terry Middleton preserving a water sample for trace metal analysis for shipment to the USGS National Water Quality Laboratory.

At most sites, concentrations of manganese, iron, and zinc were stable. Decreasing iron trends were observed in Little River and Cane Creek Reservoirs and Lake Michie. Cane Creek Reservoir also had a decreasing manganese trend.

Seven sites, all downstream from wastewater-treatment facilities, were analyzed for zinc trends. A decreasing trend was observed in two of these—Knap of Reeds Creek and Little Lick Creek.

INTRODUCTION

The Triangle area (fig. 1), including Raleigh, Cary, Research Triangle Park, Durham, Chapel Hill, and their surrounding communities, is one of the most rapidly developing areas of North Carolina. According to the 1990 census, 77 percent of the households in the area depend on public drinking-water supplies withdrawn from area streams and lakes. Among the most important of these water supplies are Falls of the Neuse Reservoir (hereafter referred to as Falls Lake), B. Everett Jordan Reservoir (hereafter referred to as Jordan Lake), Lake Michie, Little River Reservoir, Cane Creek Reservoir, University Lake, Eno River, Neuse River, Deep River, and the Cape Fear River. Because of heavy reliance on surface water for public water supply and recognition of the importance of protecting area surface-water resources, local governments established the Triangle Area Water Supply Monitoring Project in 1988 with the assistance of the Triangle J Council of Governments.

The goals of the Project are to:

- Supplement existing data on major ions, nutrients, and trace elements to enable determination of long-term trends;
- Examine differences in water quality among water supplies within the region, especially differences among smaller upland sources, large multipurpose reservoirs, and run-of-river supplies;
- Provide tributary loading and in-lake data for predictive modeling of Falls and Jordan Lakes; and
- Establish a data base for the presence of synthetic organic compounds in surface water in the region.

With cooperative assistance from the U.S. Geological Survey (USGS), the Project has funded collection and analysis of water-quality samples from reservoirs and streams, and collection of continuous discharge records from streams in the study area (fig. 1). In October 1988, the USGS began water-quality sampling and streamflow monitoring, in cooperation with the Triangle Area Water Supply Monitoring Project Steering Committee, at sites located at area run-of-river and reservoir water supplies and tributaries (Garrett and others, 1994; Childress and Treece, 1996). These sites and sites monitored by the North Carolina Division of Water Quality (DWQ; formerly known as the Division of Environmental Management) form the Triangle Area Water Supply Monitoring Network.

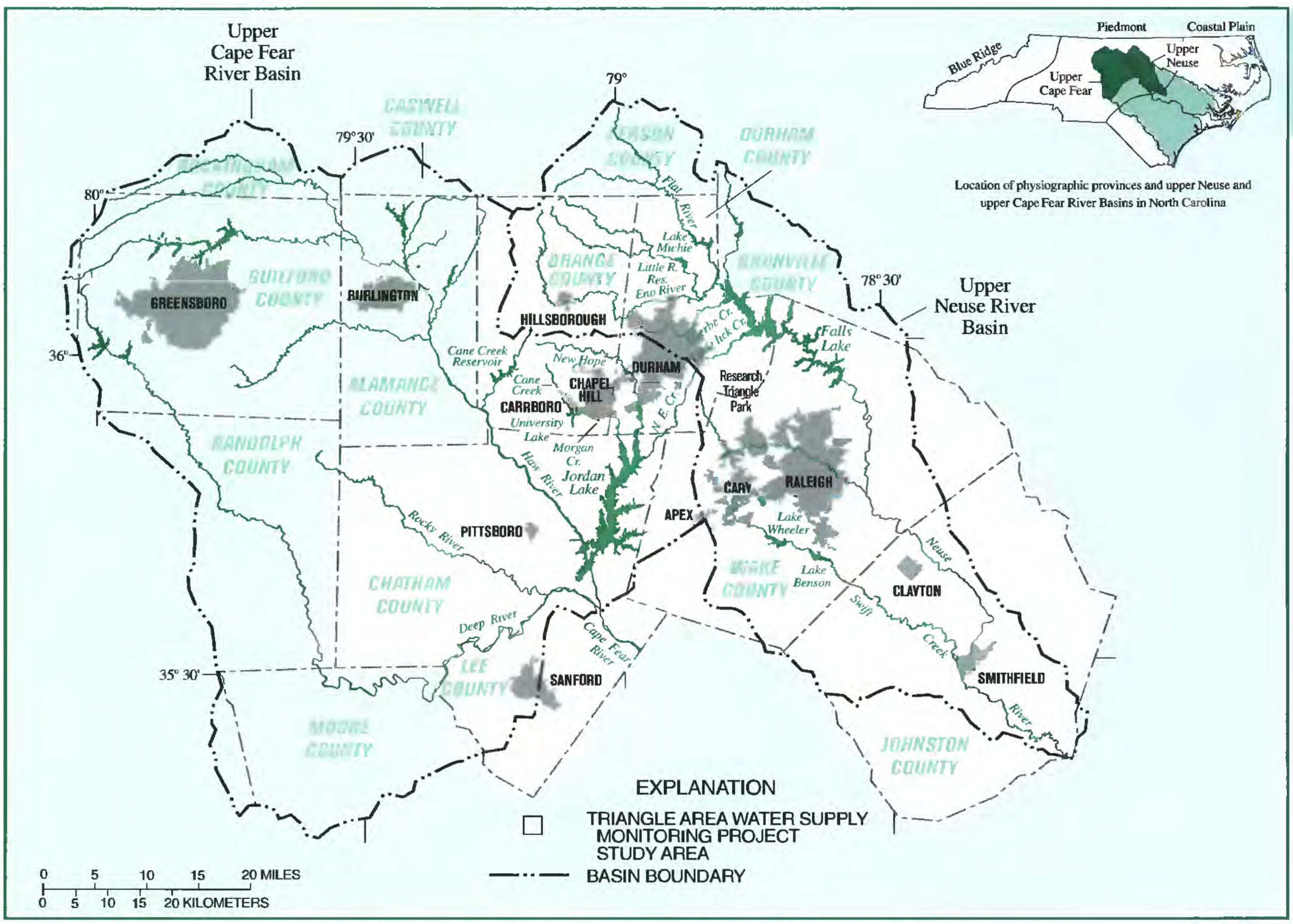

Figure 1.–The Triangle Area Water Supply Monitoring Project study area within the upper Neuse and upper Cape Fear River Basins of North Carolina.

Description of the Study Area

The study area is located in the Piedmont Province of North Carolina. It includes part of a seven-county area within the upper part of the Neuse and Cape Fear River Basins (fig. 1).

The headwaters of the Neuse River are formed by the Flat River, the major tributary to Lake Michie which was filled in 1926; the Little River, the major tributary to Little River Reservoir which was filled in 1988; and the Eno River. These rivers drain to Falls Lake, a reservoir filled in 1983. Lake Michie and Little River Reservoir provide water supply to Durham, the Eno River provides water supply to Hillsborough, and Falls Lake provides water supply to Raleigh. From Falls Lake, the Neuse River flows south through the eastern part of Wake County receiving runoff from Raleigh and its suburbs and wastewater effluent from the City of Raleigh Wastewater Treatment Plant. Farther south, the Neuse River serves as a water supply for Smithfield, Johnston County, and several municipalities served by Johnston County.

The headwaters of the Cape Fear River Basin are formed by the Haw River and its tributaries. Jordan Lake, which was filled in 1982, impounds the Haw River and New Hope Creek. Although the Haw River supplies 80 percent of the inflow to Jordan Lake, most of the storage is in the New Hope arm (Moreau and Challa, 1985). Jordan Lake is a water-supply source for the towns of Cary and Apex, for Chatham County, and potentially for other jurisdictions in and around the Triangle area. Other tributaries to Jordan Lake are Northeast Creek and Morgan Creek.

University Lake, a water-supply reservoir filled in 1932, impounds water from about 30 square miles (mi^2) in the upper Cape Fear River Basin. The lake was formed from Morgan Creek and two tributaries to provide drinking water for Chapel Hill, Carrboro, and the University of North Carolina at Chapel Hill. Cane Creek Reservoir, filled in 1989, is a public water supply for Carrboro and Chapel Hill and impounds water from about 31 mi^2 in the upper Cape Fear River Basin. A more detailed description of the study area is provided in Childress and Treece (1996).

Current Land Cover

The Piedmont part of the Neuse River Basin (the upper Neuse River Basin) is the most densely populated and industrialized part of the basin and has the greatest density of waste dischargers (North Carolina Department of Environment, Health, and Natural Resources, 1993). Falls Lake receives inflow from a 771-mi^2 watershed of combined forested and agricultural lands, and urban and residential areas. Based on data from 1988, land use for 53 percent of the watershed is forest (including wetlands) and 29 percent is agriculture (fig. 2C). Developed areas account for about 18 percent. The Lake Michie drainage area (167 mi^2) accounts for approximately 22 percent of the drainage to Falls Lake and is 52 percent forest and wetlands, 40 percent agriculture, and only 7 percent developed. The Little River Basin (98 mi^2) accounts for approximately 13 percent of the drainage to Falls Lake and is about 55 percent forested, 38 percent agriculture, and only 7 percent developed.

The part of the study area that lies in the upper Neuse River Basin above Smithfield is about 25 percent developed (fig. 2C). The part from the Falls Lake dam to Smithfield is 39 percent developed and includes the city of Raleigh and its suburbs. From 1970 to 1990, the population in the upper Neuse River Basin grew steadily and increased by approximately 70 percent (North Carolina Department of Environment, Health, and Natural Resources, 1993). Lake Benson, just south of Raleigh, receives drainage from the 65-mi^2 Swift Creek watershed, of which about 50 percent is forested. However, urban and residential land uses in the watershed are increasing as Raleigh, Cary, and surrounding communities continue to develop. For example, the Swift Creek Basin near Apex was about 75 percent developed in 1988 (fig. 2C), a 40-percent increase in developed land cover since 1975 (fig. 2B).

Municipal wastewater-treatment plants (WWTP's) that discharged to tributaries of Falls Lake prior to 1995 include Durham's Northside WWTP, which discharged to Ellerbe Creek; Little Lick WWTP, which discharged to Little Lick Creek; Butner WWTP, which discharged to Knap of Reeds Creek; and Durham's Eno River WWTP, which discharged to the Eno River (fig. 3). In November 1994, Durham's Northside WWTP was upgraded to tertiary treatment and renamed North Durham Water Reclamation Facility. This facility receives wastewater previously sent to the Eno River and Little Lick WWTP's. The Eno River and Little Lick WWTP's ceased operation in June and November 1994, respectively.

In the Cape Fear River Basin, most of the population and industry are located near the headwaters of the Haw and Deep Rivers between Burlington and Greensboro. Drainage from the Haw River Basin, a 1,300-mi^2 watershed of mixed forested and agricultural lands and urban and residential areas, is to Jordan Lake. Jordan Lake also receives drainage from the New Hope Creek Basin, a 400-mi^2 watershed that is mostly developed (including Durham, Chapel Hill, and Research Triangle Park) but includes forested and agricultural land uses, much of which are undergoing industrial and residential development (fig. 2C).

Cane Creek Reservoir is in the Haw River Basin and receives drainage from 31 mi^2 of mostly forested and some agricultural lands (fig. 2C). University Lake is in the Morgan Creek Basin and receives drainage from an approximately 30-mi^2 area mostly west of Carrboro. More than half of the area is forested with some agricultural and residential development.

Municipal WWTP's that discharge to tributaries of the New Hope Creek arm of Jordan Lake include Durham County Triangle WWTP, which discharges to Northeast Creek; South Durham Water Reclamation Facility, which discharges to New Hope Creek; and Orange Water and Sewer Authority (OWASA) Mason Farm WWTP, which discharges to Morgan Creek near Farrington (fig. 4).

Previous Studies

Previous studies of water-quality trends in the Neuse and Cape Fear Rivers have been for earlier time periods and generally were for sites in the downstream parts of the watershed. Crawford (1985) tested for trends in major ions, nutrients, and physical properties in the Cape Fear River near Lock 1 for the period 1955-80. Increases in specific conductance and concentrations of dissolved manganese, sodium, potassium, sulfate, solids, and total nitrite plus nitrate were reported and were related to increases in population and manufacturing operations. Decreases in dissolved silica and pH levels also were reported.

Harned and Davenport (1990) reported trends for nutrients, chlorophyll *a*, and other water-quality constituents in the lower Neuse River for the period 1945-88. These trends were related to general changes in land use and basin characteristics. For the lower Neuse River, declines in total phosphorus, total ammonia plus organic nitrogen, nitrate, and orthophosphorus were reported. Increases in concentrations were reported for chlorophyll *a*. The decrease in nitrogen and

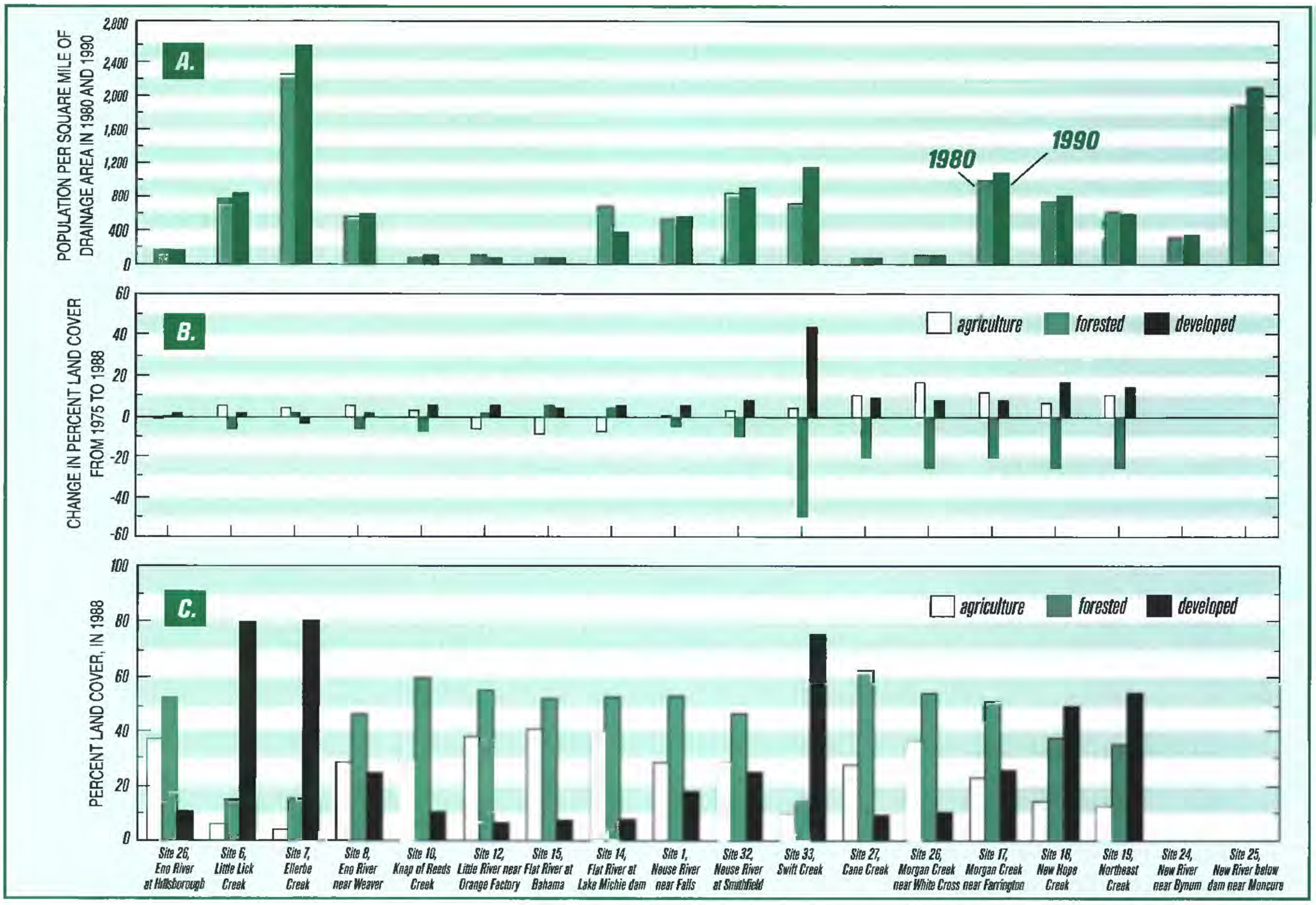

FIGURE 2

Figure 2.– (A) Population per square mile of drainage basin area in 1980 and 1990, (B) change in percentage of land cover from 1975 to 1988, and (C) percentage of land cover in 1988 for generalized categories.

phosphorus species was correlated with changes in agricultural land-use factors, such as tobacco and soybean acreages, quantities of fertilizers sold, and numbers of chickens raised.

Harned and others (1995) used seasonal Kendall trend analysis to detect trends in water quality in the Neuse River from its headwaters to Kinston for the period 1980-90. Several sites analyzed for this report coincide with sites analyzed by Harned and others (1995). Decreasing trends in total phosphorus in North Carolina streams were attributed to the 1988 phosphate-detergent ban. A decreasing trend in total nitrogen below Falls Lake was probably due to the 1983 impoundment that formed Falls Lake. An increasing trend in total nitrogen was detected in the middle part of the Neuse River Basin and was probably due to increased development and changing agricultural practices.

METHODS OF LAND-COVER ESTIMATION

Land-cover information was obtained from two data bases—one from about 1975 and the other from about 1988. This allowed a comparative study of land-cover change over an approximate 15-year time period. The 1975 land-cover data were acquired from the USGS geographic information retrieval and analysis system (GIRAS) coverages. Information on land cover in GIRAS is compiled from aerial photography collected during the mid-1970's. Land-cover categories in GIRAS are defined based upon the USGS Anderson classification scheme in which six primary (Level I) and 36 detailed (Level II) land covers are identified. The 1988 land-cover information was obtained from the Albemarle-Pamlico Estuarine Study (APES) data base in which land cover was determined from LANDSAT Thematic Mapper digital data collected during 1987-88. Although these data were 7 years older than the most current water-quality data used in this study, this was the best available current land-cover information for the study area. As with the GIRAS data base, land cover for the APES data set was based upon Level II categories as defined by the Anderson classification scheme. However, the APES data set only classified 20 detailed categories for land-cover information compared to 36 levels classified in the GIRAS coverages.

For the purposes of this report, the detailed categories for land cover as defined in either the GIRAS or APES data sets were consolidated into seven general classifications—residential, urban, agriculture, forests, lakes/reservoirs, forested wetlands, and transitional areas. For representation purposes, these seven categories were further grouped into three main land covers—

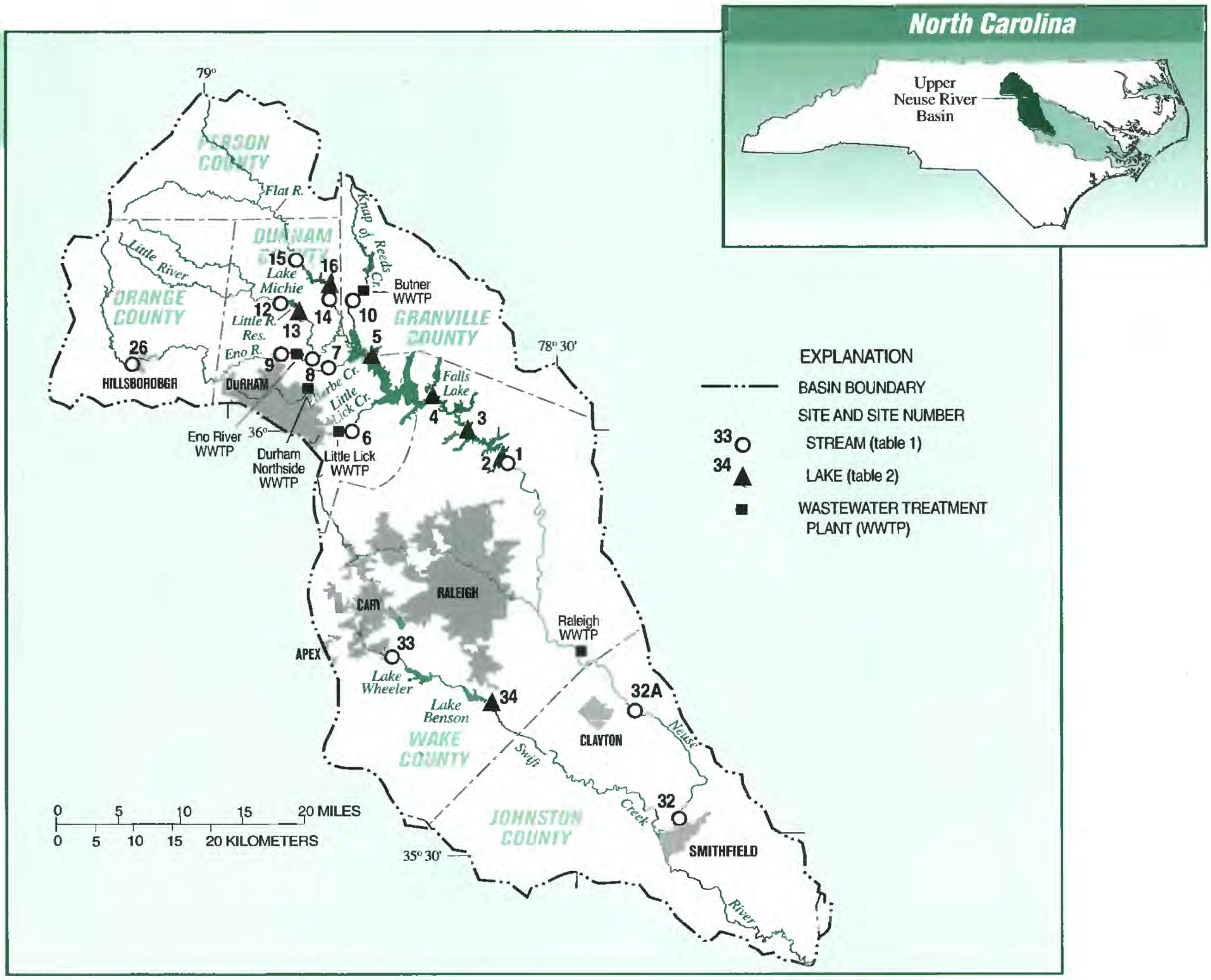

Figure 3.–Water-quality sampling and streamflow monitoring sites in the upper Neuse River Basin, North Carolina.

developed (residential and urban), agricultural, and forested/other (forests, lakes/reservoirs, forested wetlands, and transitional areas).

Due to the differences in photo interpretation and land-use classification schemes, discrepancies exist in the categorization of land cover between the two data bases. For example, in the GIRAS data base, land-cover features are delineated by polygons with a minimum 4-hectare size (Mitchell and others, 1977). Thus, a small watershed with fragmented numerous land uses may be misrepresented in classification due to the limited extent of land cover expressed in the imagery. The urban classification category, as defined in the APES data base, may be the least accurate in representation of actual land cover (Dodd and others, 1992). Additionally, areas unable to be classified have been integrated into a "transitional area" category which may increase the disparity between the two land-use coverages. To minimize errors in the urban and residential land-cover categories, 1975 and 1988 data bases were overlain with population coverages from the 1980 and 1990 censuses, respectively. Land-cover polygons with census-derived populations exceeding 1,000/mi^2 were reclassified as urban regardless of the original land-cover classification. Polygons with populations exceeding 500/mi^2 but less than 1,000/mi^2 were classified as residential. The unlikely small decrease in developed area from 1975 to 1988 shown for the Ellerbe Creek watershed (fig. 2B) is probably a result of this type of error.

TRENDS IN LAND COVER AND WATER QUALITY

Temporal trends in water quality were analyzed based on data compiled from the USGS and DWQ for the 1983 through 1995 water years[1]. The USGS data-collection stream sites were ambient water-

[1]A water year is defined as the period October 1 through September 30 and is identified by the year in which it ends.

quality sites, whereas most DWQ data-collection sites were located just downstream from WWTP effluent discharges. The integration of the two data bases enhanced areal coverage of the study area rather than temporal coverage at any particular site. Few sites were sampled by both the DWQ and USGS. Exceptions were three Falls Lake sites (2, 3, and 5; fig. 3) that were sampled by the DWQ from 1983 to 1987 and by the USGS from 1989 to 1995, and several DWQ stream sites that were sampled up to five times by the USGS during storm events (sites 6, 7, 8, 17, 18, 19; figs. 3, 4).

Constituents analyzed were total nitrogen, nitrate, organic nitrogen, total phosphorus, phosphate, sodium, chloride, iron, manganese, and zinc. Additionally, suspended solids and suspended sediment were analyzed for streams, and chlorophyll *a* was analyzed for lakes.

Land Cover

The change in population from 1980 to 1990, the change in percentage of land-cover type between 1975 and 1988, and the percentage of land cover in 1988 for selected basins in the study area are shown in figure 2. In general, there has been an increase in developed land cover and a decrease in forested land cover between 1975 and 1988 associated with population growth in the Durham, Raleigh, Cary, Research Triangle Park, and Chapel Hill areas. Loss of forested lands has occurred more in the upper Cape Fear River subbasin than in the upper Neuse River subbasin. However, the greatest percentage of decrease in forested land cover occurred in the Swift Creek Basin in the Cary area (fig. 2B). Ellerbe and Little Lick Creek watersheds are the two most developed watersheds (about 80 percent), although neither changed substantially from 1975 to 1988. Swift Creek was more than 75 percent developed in 1988, a change from 30 percent in 1975. New Hope and Northeast Creek watersheds, which are rapidly urbanizing, are more than 50-percent developed and, consequently, lost forested land cover from 1975 to 1988. The most populated watershed, in numbers of people per square mile, was Ellerbe Creek followed by Swift Creek.

At the time of this study, seven wastewater-treatment facilities discharged effluents to Ellerbe Creek, Little Lick Creek, Knap of

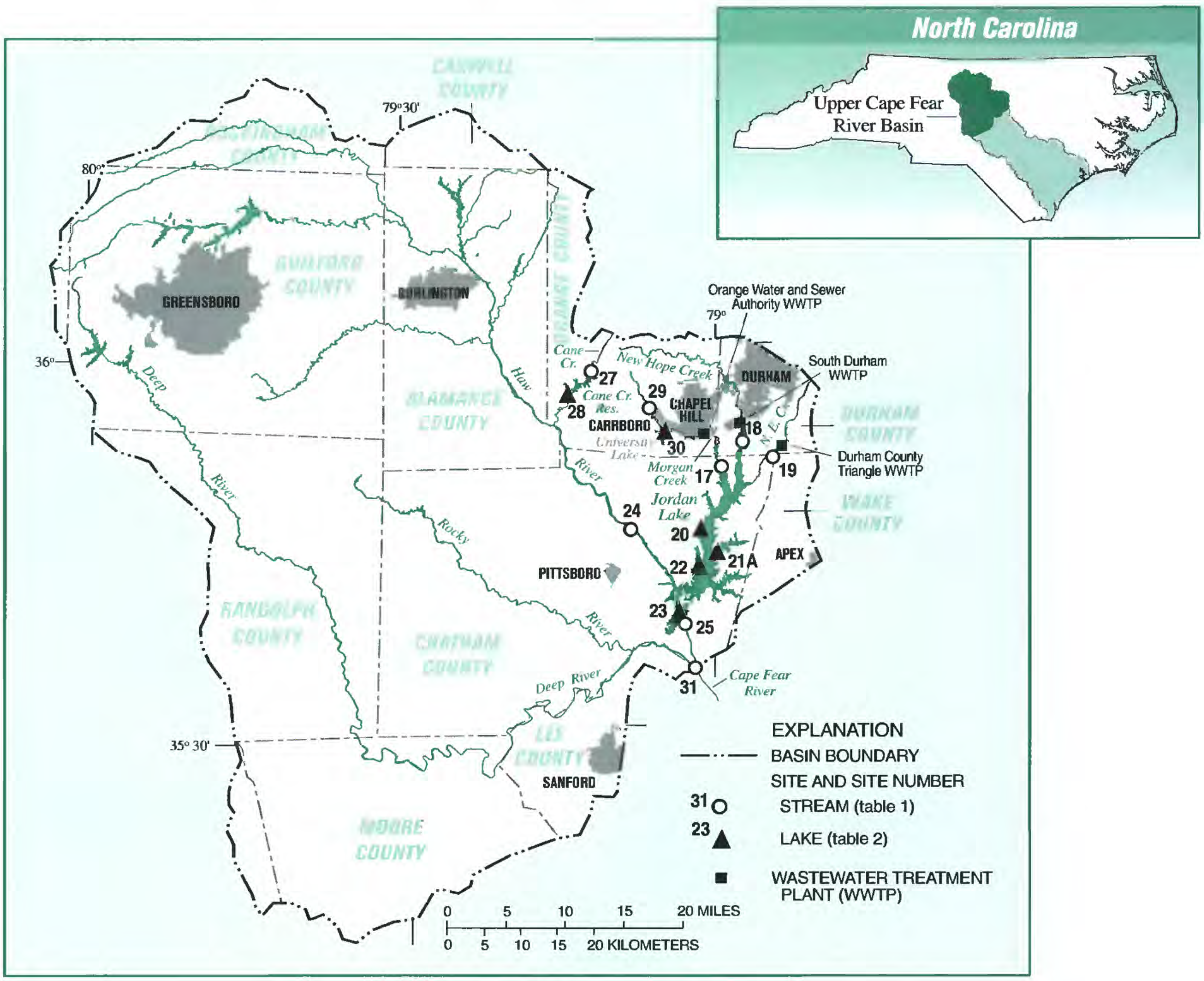

Figure 4.–Water-quality sampling and streamflow monitoring sites in the upper Cape Fear River Basin, North Carolina.

Reeds Creek, Eno River, Morgan Creek, New Hope Creek, and Northeast Creek. Effluent discharges were located immediately upstream from the water-quality sample-collection sites on those streams.

Nitrogen

Nitrogen has been identified as a limiting nutrient in the Neuse River estuary (Crawford, 1985; Stanley, 1988; North Carolina Department of Environment, Health, and Natural Resources, 1996a). Control of point and non-point sources of nitrogen to surface waters, especially those draining to the State's coastal waters, is a top priority for State regulators (North Carolina Department of Environment, Health, and Natural Resources, 1993). Nitrogen is a major nutrient for plants and, in excess, stimulates algal growth and the process of eutrophication. Nitrogen occurs in water as ammonia, nitrite, and nitrate, and occurs in some organic compounds. Ammonia and organic forms of nitrogen are oxidized to nitrate in surface waters and are present in insignificant amounts except in proximity to wastewater effluents, animal wastes, or fertilized farmland. Trend analysis was performed on total nitrogen (the sum of all nitrogen forms), nitrite plus nitrate, and organic nitrogen. Ammonia concentrations generally were less than the detection limit of 0.01 milligram per liter (mg/L); therefore, trends in ammonia could not be determined.

Total nitrogen concentrations were stable at most stream and lake sites (table 1; figs. 5, 6). A decreasing trend in total nitrogen concentration was observed in the Eno River at Hillsborough, Little River, Morgan Creek near White Cross, Swift Creek, and Cape Fear River near Brickhaven. The first three sites are in headwater basins where development has been relatively minor (less than 10 percent of land cover) and agricultural land uses comprise about 35 to 40 percent of land cover. Harned and others (1995) noted decreases in nitrogen in other parts of the Neuse River Basin from 1980 to 1989 that were attributed to changing agricultural practices. The decreasing trend in total nitrogen concentrations for the Swift Creek Basin is somewhat surprising considering the significant amount of development from 1975 to 1988 (fig. 2B) and may be due to the extensive use of impoundments to control runoff. An increase in nitrogen concentration was observed at only two sites—Neuse River at Smithfield and near Clayton (fig. 5)—and may be related to land cover changes in the Neuse River Basin between the Falls Lake dam and Smithfield. The percentage of forested and wetlands land cover in that area has decreased 19 percent from 1975 to 1988, whereas agricultural land cover has increased 7 percent, and developed land cover has increased 12 percent. Stable nitrate concentrations were reported by Harned and others (1995) at Smithfield for the period 1980-89. The shorter time period and the fact that concentrations were not adjusted for streamflow probably account for the different result.

The concentration of total nitrogen in lakes varied seasonally. Concentrations tended to peak in winter months and decline in summer months when lake productivity increases (site 2, fig. 7). Most lake sites had no trends in total nitrogen concentrations

Table 1.-Summary of trend analysis data for streams in the Research Triangle area of North Carolina (Dates indicate the period of trend analysis; white, insufficient data or data below detection limits; red, increasing trend; green, decreasing trend; gray, no trend; *a*, step trend; *b*, uncorrected for discharge)

Station number	Site no.	Station name	Total nitrogen	Nitrate	Organic nitrogen	Total phosphorus 1983-95[a]	Total phosphorus 1988-95	Phosphate	Sodium	Chloride	Total suspended sediment	Total suspended solids	Total zinc	Total iron	Total manganese
NEUSE RIVER BASIN															
02085000	26	Eno River at Hillsborough	90-95	90-95	90-95		90-95	90-95	89-95	89-95	90-95			90-95	90-95
02085070	9	Eno River near Durham	83-95	83-95	83-95	83-95	89-95					82-95			
02085079	8	Eno River near Weaver	83-95	83-95	83-95	83-95	89-95	89-95	89-95	89-95	83-95	89-95	83-95	89-95	89-95
0208521324	12	Little R. near Orange Factory	88-95	89-95	89-95		88-95	89-94	89-93	89-93	88-93	89-95			89-95
02085500	15	Flat River at Bahama	88-95	89-95	89-95		88-95	89-95	89-94	89-95	89-95			89-95	89-95
02088500	14	Flat River near Bahama	83-91	83-91	83-91	83-91	88-92	89-91			83-93				89-95
02086624	10	Knap of Reeds Cr. nr. Butner	83-95	83-95	83-95	83-95	89-95	90-95				82-95	83-95		
0208700780	6	Little Lick Cr. near Oak Grove	83-95	83-95	83-95	83-95	89-95	90-95				89-95	83-95		
02086849	7	Eilerbe Creek near Oorman	83-95	83-93	83-95	83-95	89-95					82-89	83-95		
02087183	1	Heuse River near Faiis	83-95	83-95	83-95	83-95	89-95					83-92			
02087580	33	Swift Creek near Apex[b]	90-95	90-95	90-95		90-95		90-95	90-95	90-95			90-95	90-95
02087500	32A	Heuse River near Clayton	81-95	81-95	81-95	81-95	89-95					82-95			
02087570	32	Heuse River at Smithfield	83-95	83-95	83-95	83-95	88-94	89-95	89-95	89-95	89-95	82-95		89-95	89-95
CAPE FEAR RIVER BASIN															
02096846	27	Cane Creek nr. Orange Grove	89-95	89-95	89-95		89-95	89-95	89-95	89-95	89-95			89-95	89-95
02097464	29	Morgan Cr. nr. White Cross	89-95	89-95	89-95		89-95	89-95	89-95	99-95	89-95			89-95	89-95
02097521	17	Morgan Cr. nr. Fnrrington	83-95	83-94	83-94	83-94	89-94	90-94				82-92			
02097314	18	Hew Hope Cr. nr. Blands	83-95	83-95	83-95	83-95	88-95					82-92	83-95		
0209741955	19	Hortheast Cr. near Genlee	83-95	83-95	83-95	83-95	89-95						83-95		
02096960	24	Haw River near Bynum	83-95	83-95	83-95	83-95	89-95	90-95			83-94	82-95	83-95	92-95	
02098198	25	Haw River nenr Moncure	83-95	83-95	83-95	83-95	88-94					83-95			
0210215985	31	Cape Fear R. nr. Brickhaven	89-95	89-95	89-95		89-95	89-95	89-95	89-95	89-95			89-95	89-95

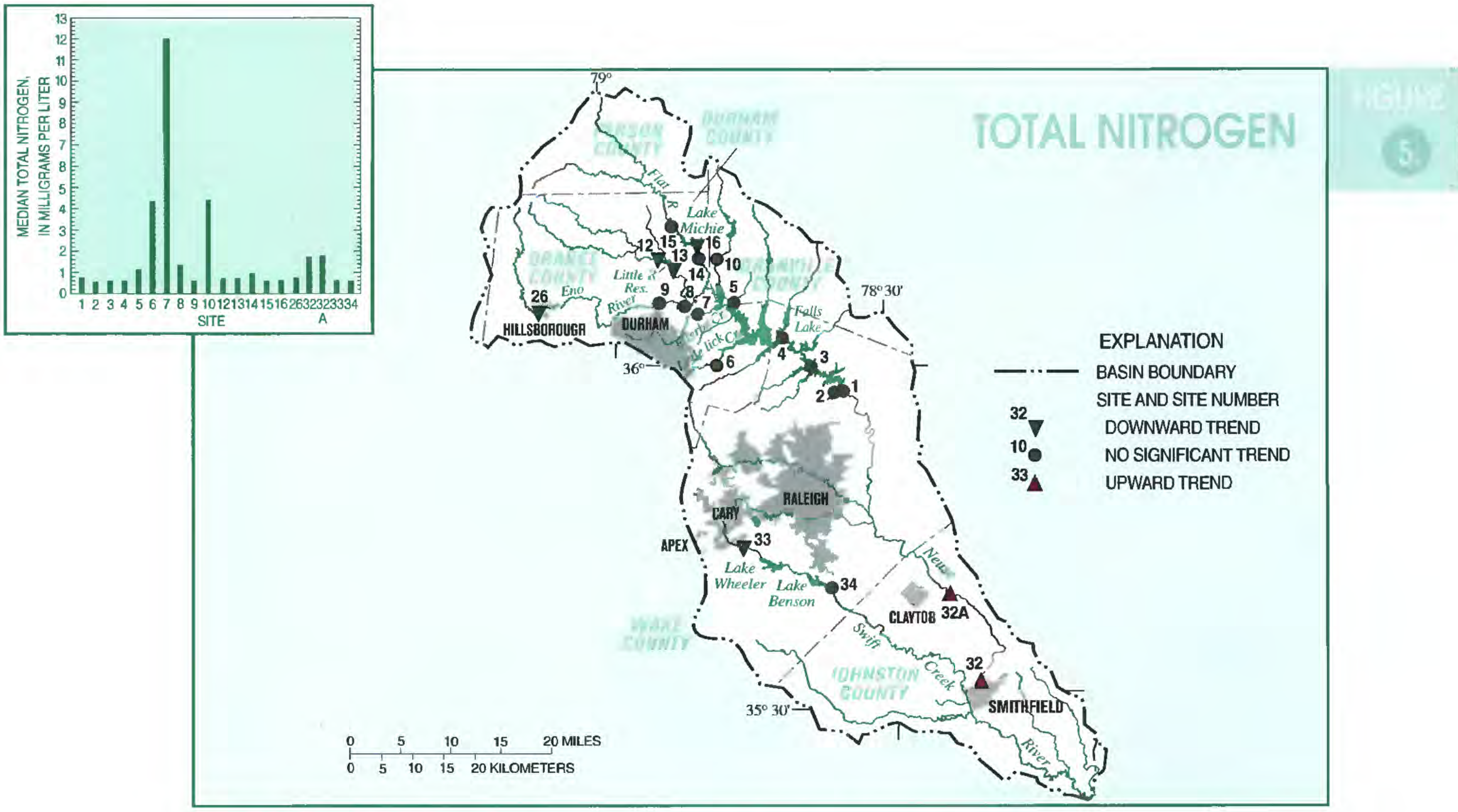

Figure 5.–Total nitrogen trends in the upper Neuse River Basin, North Carolina.

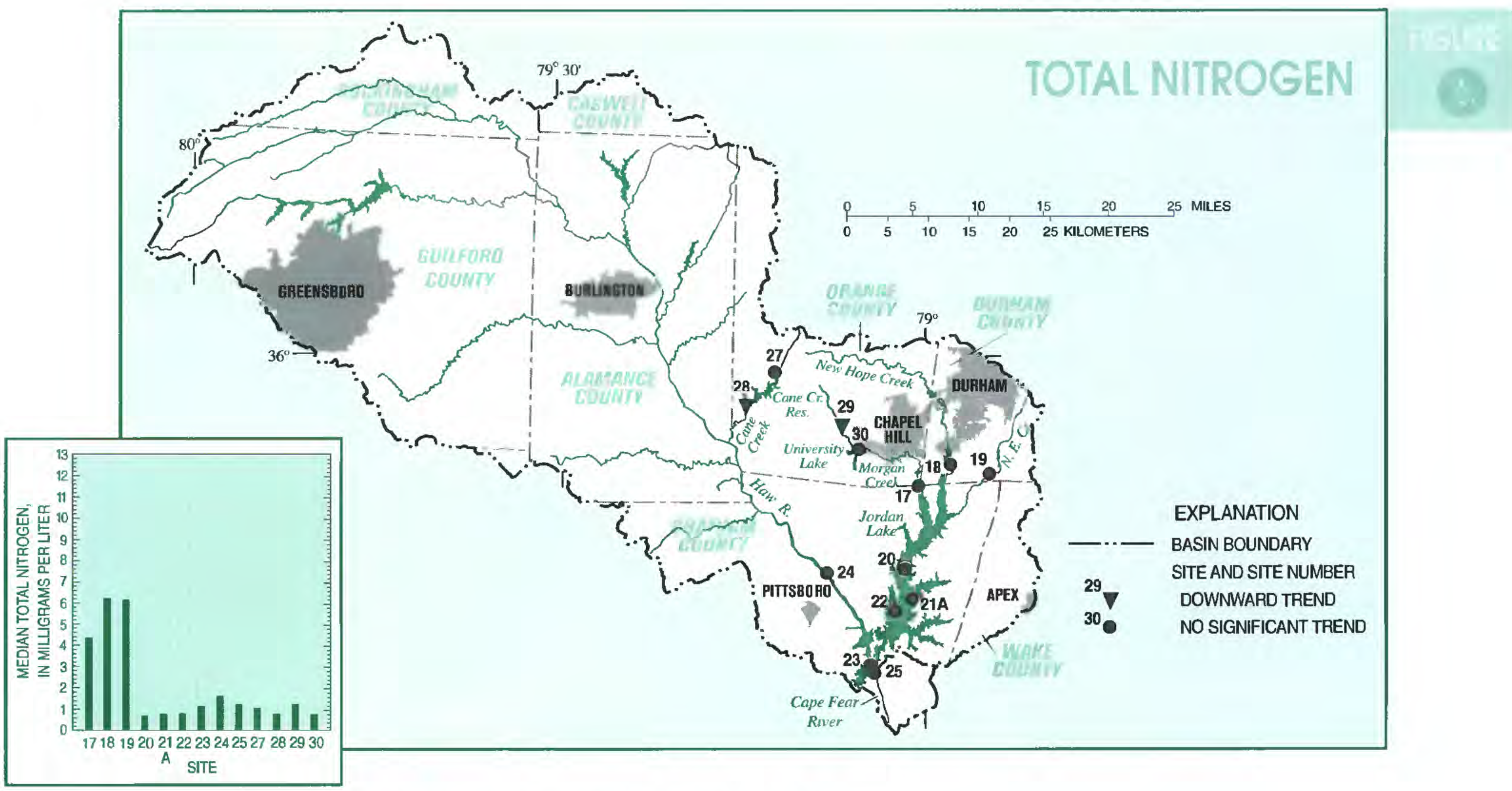

Figure 6.–Total nitrogen trends in the upper Cape Fear River Basin, North Carolina.

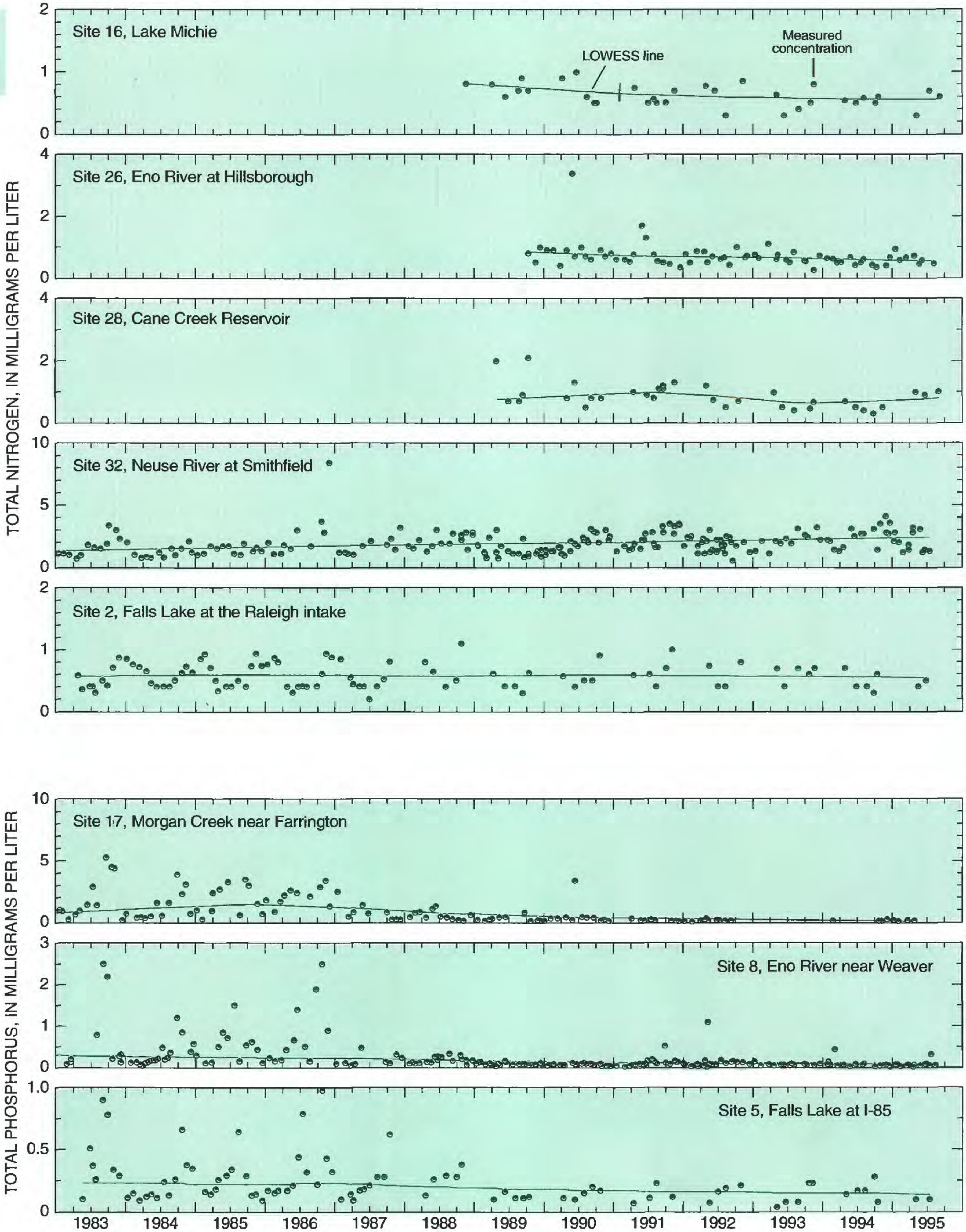

Figure 7.–Measured and locally weighted scatterplot smoothed (LOWESS) lines for total nitrogen and total phosphorus concentrations at selected sites in the Research Triangle area of North Carolina, 1983-95.

Table 2.-Summary of trend analysis data for lakes in the Research Triangle area of North Carolina (Dates indicate the period of trend analysis; white, insufficient data or data below detection limits; red, increasing trend; green, decreasing trend; gray, no trend; [a] step trend)

Station number	Site no.	Station name	Total nitrogen	Nitrate	Organic nitrogen	Total phosphorus 1983-95[a]	Total phosphorus 1989-95	Chlorophyll *a*	Total suspended solids	Total iron	Total manganese
NEUSE RIVER BASIN											
02087182	2	Falls Lake near the dam	83-95	90-95	90-95	83-95	88-95	88-95	83-95	83-92	90-95
0208708905	3	Falls Lake at NC 98	83-95	90-95	90-95	83-95	88-95	89-95	83-95	83-95	90-95
0208703850	4	Falls Lake at NC 50	89-95	90-95	90-95		89-95	89-95	83-95	83-95	90-95
02086920	5	Falls Lake at I-85	83-95	90-95	90-95	83-95	88-95	89-95	83-95	83-95	90-95
0208524845	13	Little River Reservoir	89-95	89-95	89-95		89-95	89-95	89-95	89-95	89-95
02086490	16	Lake Michie	89-95	89-95	89-95		89-95	89-95	89-95	89-95	89-95
02087701	34	Lake Benson	89-95	90-95	90-95		90-95	90-95	90-95	90-95	90-95
CAPE FEAR RIVER BASIN											
0209684980	28	Cane Creek Reservoir	89-95	89-95	89-95		89-95	89-95	89-95	89-95	89-95
0209749990	30	University Lake	89-95	89-95	89-95		89-95	89-95	89-95	89-95	89-95
0209771550	20	Jordan Lake at buoy 9	83-92			83-92	88-92		83-92	83-92	
0209799150	21A	Jordan Lake at Cary/Apex Intake	91-95	91-95	91-95		91-95	91-95	91-95	91-95	
0209801100	22	Jordan Lake at Bell's Landing	91-95	91-95	91-95		91-95	91-95	91-95	81-95	91-95
0209719700	23	Jordan Lake, Haw River arm	91-95	91-95	91-95		91-95	89-95	89-95	91-95	91-95

during the 1983 through 1995 water years (table 2). Declines in total nitrogen concentrations were observed at Little River Reservoir, Lake Michie, and Cane Creek Reservoir—all located in headwater areas where development is minor and agriculture is about 29 to 40 percent of land cover. In addition, Little River and Cane Creek Reservoirs are relatively new, impounded in 1988 and 1989, respectively; thus, reservoir aging may be an additional factor.

Trends in nitrate and organic nitrogen, two components of total nitrogen, also were examined. Most stream sites had stable concentrations of nitrate for the period tested (table 1). Increasing nitrate trends were detected for the Eno River near Durham, Knap of Reeds Creek, Neuse River near Clayton and at Smithfield, and New Hope Creek. For Knap of Reeds Creek there was a coinciding decrease in organic nitrogen, probably indicating improvement in wastewater treatment at the Butner facility. Although an increase in nitrate was observed at Eno River near Durham, no trend was detected at Eno River near Weaver, which is only about 4 miles downstream and received WWTP effluents from the former Durham WWTP until 1994. A decrease in nitrate and organic nitrogen occurred at Cape Fear River near Brickhaven. Land-cover data for this basin are incomplete, and the cause of the decreasing nitrate trend is unknown.

Decreasing trends in nitrate at lake sites occurred at Lake Michie, Lake Benson, Cane Creek Reservoir, University Lake, and Falls Lake near the dam (table 2). Nitrate concentrations have increased at Falls Lake at Highway NC-98. Because dissolved nutrients are taken up by algae, a productive algal population, indicated by measuring chlorophyll *a* concentrations, may account for the decreasing nitrate concentrations. Similar nitrate trends were not observed at the major lake tributaries.

Decreasing organic nitrogen trends occurred at Eno River near Weaver, Knap of Reeds Creek, Cape Fear River, Swift Creek, Cane Creek, Morgan Creek near White Cross, and downstream from Falls and Jordan Lakes. Various causes may account for these decreases, among these are improved nitrification in wastewater treatment (Eno River, Knap of Reeds Creek), improved agricultural practices (Cane and Morgan Creeks), and the presence of impoundments (Swift Creek, Falls and Jordan Lake outflows). Decreasing organic nitrogen trends also were observed for the period 1980-89 in parts of the Neuse River Basin (Harned and others, 1995). Organic nitrogen concentrations were stable at lake sites except at Little River and Cane Creek Reservoirs. Concentrations at these relatively young reservoirs were decreasing.

Phosphorus

Phosphorus is a major nutrient for plants and has long been recognized as an important factor in the eutrophication of surface waters. Phosphorus readily adsorbs to particulates, and 95 percent of the phosphorus transported by streams occurs in that form. A smaller amount, typically measured in tenths of milligrams per liter, occurs in the dissolved state and is available to the biota. A major anthropogenic source of phosphorus has been in wastewater effluents because of past use of phosphates as a "chelating agent" in household detergents and because of the presence of phosphorus in human waste. The State of North Carolina ban on phosphates in detergents has been shown to be a successful effort in decreasing the quantities of phosphorus discharging to surface waters (Childress and Treece, 1996).

Phosphorus data were tested for two types of trends: (1) a step trend (change between two time periods) to determine if a decrease occurred following the 1988 phosphate-detergent ban, and (2) a monotonic (consistently increasing or decreasing) trend to determine if phosphorus concentrations were decreasing, increasing, or stable after the phosphate-detergent ban. The results of step-trend analysis indicate that a significant phosphorus-concentration decrease, ranging from 25 to 81 percent in 1988, occurred at all stream sites (figs. 8 and 9). Greatest decreases occurred at those stream sites that are located just downstream

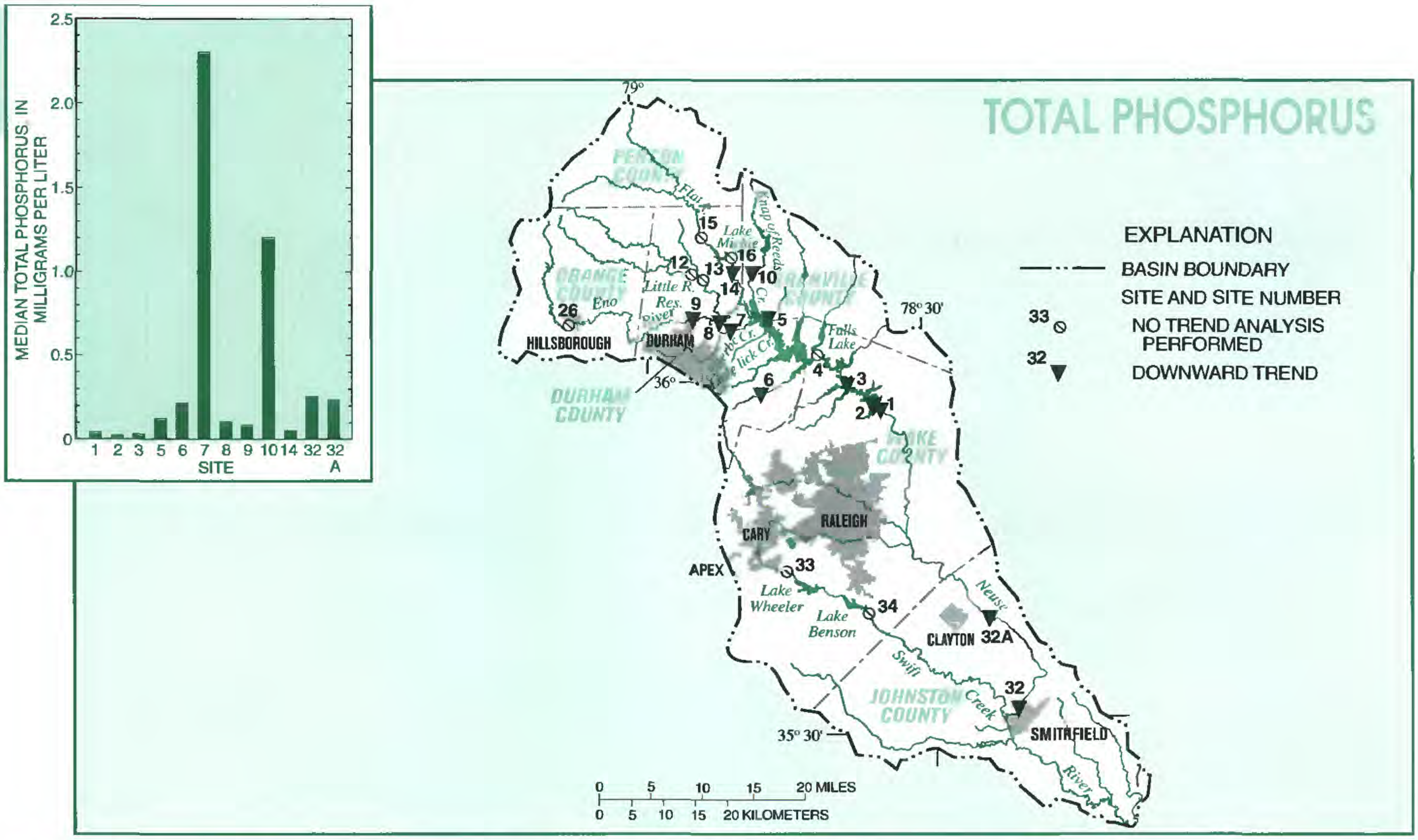

Figure 8.–Total phosphorus trends in the upper Neuse River Basin, North Carolina.

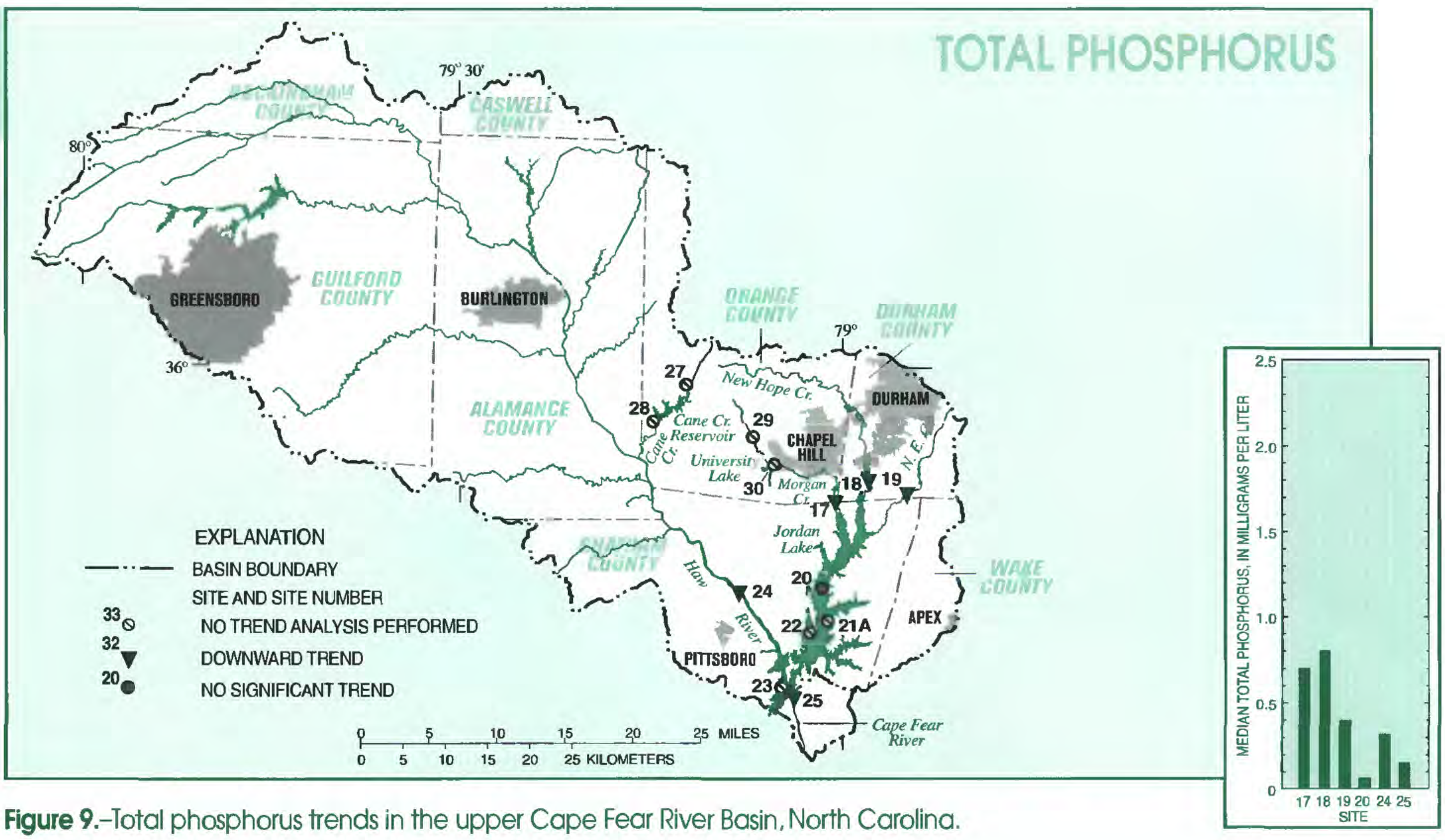

Figure 9.–Total phosphorus trends in the upper Cape Fear River Basin, North Carolina.

from WWTP effluents where concentrations have been greatest and the effects of improvements in wastewater treatment would be most pronounced. Smallest decreases occurred in outflow from Falls and Jordan Lake dams where concentrations of total phosphorus were low because of nutrient trapping that occurs in the lakes.

Only three sites on Falls Lake and one on Jordan Lake had sufficient pre-1988 data for analysis of a step trend in total phosphorus. A significant downward trend was detected at Falls Lake at I-85, NC-98, and near the Falls Lake dam. Total phosphorus concentrations were stable at Jordan Lake at buoy 9.

Data also were tested for a monotonic trend in total phosphorus and phosphate concentrations during the 7-year period from 1988 to 1995. Significant decreasing trends in total phosphorus were detected for the Eno River near Weaver (site 8), Ellerbe Creek near Gorman (site 7), and Morgan Creek near Farrington (site 17). The large downward step trend in phosphorus concentration following the phosphate-detergent ban for sites downstream from WWTP's and the continuing downward trend in phosphorus concentration after 1988 indicate the effects of both the phosphate-detergent ban and improvements in wastewater-treatment processes on removal of phosphorus. A significant increasing trend was detected at Little Lick Creek near Oak Grove for 1989-95. The WWTP discharging to Little Lick Creek was taken out of service in 1994, and monitoring was discontinued after 1995. More post-1994 data are needed to determine if closing the WWTP has reversed the phosphorus trend. Significant downward trends were observed at Falls Lake (fig. 7; for example, site 5), Little River Reservoir, Lake Michie, and Jordan Lake at buoy 9.

Phosphate concentrations at the lake sites generally were below the analytical detection limit of 0.01 mg/L. This was too low for trend analysis.

Suspended Sediment and Suspended Solids

Suspended sediment and suspended solids (TSS) are mineral and organic particles transported by and suspended in surface waters. Such particles are transported largely during periods of high runoff when soil is dislodged from the land surface and carried to streams by overland runoff, eroded from the stream channel, or resuspended from the streambed. The analytical procedure for TSS excludes large particle sizes that are included in suspended sediment. Thus, for a typical stream sample, analysis of TSS yields a lower concentration than analysis of the same sample for suspended sediment. Because of this method difference, USGS suspended-sediment data were not aggregated with DWQ TSS data.

Suspended-sediment concentrations were stable at the 11 stream sites with suspended-sediment data. Of these, Swift and Cane Creek Basins and Morgan Creek Basin near White Cross had substantial (greater than 20 percent) conversion of forested land cover to agricultural and developed land cover between 1975

Lake samples being prepared for laboratory analysis.

Sample Collection and Analysis Methods

USGS stream samples were collected with a depth-integrating sampler from a bridge or while wading. Multiple samples from the stream cross-section were composited by using a polycarbonate churn splitter and were processed and preserved on site (Garrett and others, 1994). DWQ stream samples were grab samples collected at the center of flow. USGS and DWQ lake samples were collected from a boat by using an interval sampler. Except as noted below, nutrient and chlorophyll *a* samples were integrated within the photic zone (twice the secchi depth), whereas major ion and trace-element samples were collected at 0.5 foot (ft) below the water surface. From April 1989 through March 1992, USGS chlorophyll *a* and nutrient samples were collected at 0.5 ft below the water surface at University Lake, Cane Creek Reservoir, Lake Michie, Little River Reservoir, and Lake Benson (beginning in 1990).

USGS samples collected for analysis of nutrients, chlorophyll *a*, major ions, and trace elements were filtered (if required), packed on ice, and shipped to the USGS National Water Quality Laboratory in Arvada, Colo., for analysis. Results were stored in the USGS National Water Information System data base. DWQ samples collected for analysis of nutrients and selected metals were analyzed by the DWQ laboratory in Raleigh, N.C. Results were stored in the USEPA Storage and Retrieval (STORET) data base. The USGS sample-collection and analysis methods used for this project are detailed by Garrett and others (1994).

USGS

and 1988 (fig. 2B) and might be expected to evidence an increase in suspended sediment. However, Cane and Morgan Creek Basins were still more than 50-percent forested in 1988 (fig. 2C), and suspended-sediment yields in these basins are among the smallest in the study area (Childress and Treece, 1996).

More unexpected was the lack of trend for Swift Creek Basin, which is more than 75 percent developed above the study site (fig. 2C). No yield or load data are available for this site because continuous streamflow data were not collected; however, the mean suspended-sediment concentration at this site for 1989-94 was similar to the mean for Cane and Morgan Creeks (Garrett and others, 1994). The lack of a suspended-sediment trend in the Swift Creek Basin may be due to several factors or combination of factors including the short period for suspended-sediment data (1989-95) that does not predate most development in the basin, the presence of several small reservoirs on tributaries, the use of sediment holding ponds and other erosion mitigation efforts required during building construction, or the transient nature of most construction activities in a developing urban area. More data, particularly streamflow data, are needed to evaluate suspended-sediment loads in Swift Creek.

Suspended-solids concentrations were stable during the study period at stream and lake sites. Downward trends were observed only for Knap of Reeds Creek and Haw River near Bynum. Improved wastewater treatment is likely the most important factor for Knap of Reeds Creek, which is a very small watershed that received substantial wastewater discharges. No cause could be identified for the downward trend at Haw River near Bynum, a large, mixed land-use basin.

Sodium and Chloride

Sodium concentrations were available for USGS sampled sites for water years 1989-95. These sites do not include any of the sites directly downstream from WWTP effluents. Sodium is often indicative of development because of the elevated concentration in municipal wastewater effluent (Tchobanoglous and Schroeder, 1985). Sodium is one of the dominant cations in surface waters in developed parts of the Triangle area, whereas calcium and magnesium are dominant cations in streams draining undeveloped parts of the Triangle area (Childress and Treece, 1996). Most sites showed no trends for sodium. Increasing trends in sodium concentrations occurred for University Lake, and a decreasing trend occurred for Cane Creek and Neuse River at Smithfield.

Chloride concentration also may indicate development. Chloride is generally low in natural waters in the Triangle (Childress and Treece, 1996) but may be present in elevated concentrations in waters receiving industrial and municipal wastewater effluent. No trends were observed for chloride concentration.

Iron, Manganese, and Zinc

Iron occurs naturally in abundance in the environment, is an essential nutrient, and is found in streams in the study area at a median concentration of 1,000 micrograms per liter (μg/L). Manganese also occurs naturally in abundance in the environment. It occurs in streams and lakes in the study area at a median concentration of 110 μg/L. Iron and manganese behave similarly in the environment. Both have low solubility in oxgenated systems within the normal pH range. Their concentrations generally increase with depth in eutrophic, stratified lakes. Total iron and total manganese are measures of the concentration dissolved in water and adsorbed to sediments and colloids; thus, in streams, their concentrations are directly related to streamflow. High manganese concentration is undesirable in water supplies for aesthetic reasons (causes a black deposit).

Concentrations of iron and manganese were stable at all stream sites except Morgan Creek near White Cross where iron concentration was increasing. This may be from increased land disturbance; forested land cover has decreased by nearly 25 percent, and agricultural land cover has increased by about 18 percent. However, no increasing trend in suspended-sediment concentration was detected at this site.

At lake sites, decreasing iron trends were observed for Little River and Cane Creek Reservoirs and Lake Michie, and a decreasing manganese trend was observed for Cane Creek Reservoir. These trends did not coincide with decreasing suspended solids trends suggesting that the trend is for the dissolved form of iron and manganese. Both Cane Creek and Little River Reservoirs are relatively new, and these trends could be related to reservoir aging.

An increasing manganese trend occurred in Falls Lake near the dam. Here the concentration ranged from 14 to 1,000 μg/L with a median of 64 μg/L.

Zinc is a trace metal often observed in elevated concentrations near urban areas, especially in streams receiving wastewater effluents (Elder, 1988). Trends were analyzed for seven sites with concentration and streamflow data from 1983 to 1995. Most were collected by the DWQ. Decreasing zinc concentrations were observed at Little Lick Creek and Knap of Reeds Creek.

Chlorophyll *a*

Chlorophyll *a* is the primary photosynthetic pigment of all photosynthetic organisms and is found in all algae (Wetzel, 1983). The concentration of chlorophyll *a* in the water column is a general measure of algal biomass although it is not a perfect measure because the concentration is also related to the species composition. The North Carolina water-quality standard for chlorophyll *a* is 40 μg/L (North Carolina Department of Environment, Health, and Natural Resources, 1996b). Only samples collected by the USGS which were analyzed by high-pressure liquid chromatography (HPLC) were used for trend analysis. This was because results from the HPLC method did not correlate well with results from the fluorometric method used for analysis of DWQ samples (Garrett and others, 1994). A sample collection method change made by the USGS in April 1992 could affect trend analysis results for Cane Creek, University Lake, Little River Reservoir, Lake Michie, and Lake Benson (see "Sample Collection and Analysis Methods"). The effect of the method change is hard to predict—although algal biomass tends to decrease with increasing depth (Wetzel, 1983), biomass at any single point in the water column can be highly variable. LOWESS (locally weighted scatterplot smooth) plots of chlorophyll *a* concentration with time indicate a change from relatively stable concentrations before about 1991 followed by increasing concentration thereafter at Little River Reservoir, University Lake, and Lake Benson; decreasing followed by increasing concentration at Lake Michie; and stable concentrations at Cane Creek Reservoir (fig. 10).

Trend Analysis Methods

Trend analyses were used to determine whether the concentrations of a water-quality constituent had consistently increased or decreased over a particular time period. Because water-quality constituents vary due to factors such as season and streamflow amount, the seasonal Kendall trend test (Hirsch and others, 1982) was selected for most tests. The seasonal Kendall trend test is a non-parametric test that accounts for seasonal variations in concentrations by comparing only data from the same season. Because it is a non-parametric test, it does not require assumptions about normality and constant variance. Data are grouped according to the "season[2]" in which the sample was collected irrespective of the year. Within each "season," data are ordered according to year; comparisons are made between data-pair concentrations at year = t and year = t+1. An increasing trend exists when significantly more data pairs increase than decrease; a decreasing trend exists when significantly more data pairs decrease than increase; and if pairs decrease and increase at the same frequency, no trend exists.

[2]The number of seasons is established by the user according to the available data and hydrologic factors. For the analysis presented herein, each month was considered a "season" because monthly data were available.

Many constituent concentrations in streams are strongly related to the amount of streamflow. Typically, the concentrations of constituents associated with sediments or in suspended form increase as streamflow increases, whereas concentrations of constituents in the dissolved form decrease as streamflow increases. A particularly wet or dry year or period of years can mask an underlying trend. Stream data were adjusted for the effects of streamflow by using regression analysis of log-transformed streamflow and water-quality data (Helsel and Hirsch, 1992). If the streamflow-to-constituent concentration was not significant at $\alpha = 0.05$, LOWESS—a non-parametric smoothing technique (Helsel and Hirsch, 1992)—was used. Data for sites having more than 10 years of record were adjusted for serial correlation. All trend analyses were conducted by using a seasonal Kendall-tau test accounting for monthly data (12 "seasons" per year). A Wilcoxon rank-sum test (Mann-Whitney test) was applied to total phosphorus data to determine differences between pre- and post-phosphate-detergent-ban concentrations.

USGS

Servicing the USGS streamflow gage on the Eno River at Hillsborough.

Terry Middleton and John Taylor collecting a representative suspended-sediment sample with a depth integrating sampler.

Two-thirds of all the sites analyzed had significantly increasing trends in chlorophyll *a* (table 2) ranging from 17 to 52 percent per year. Increasing trends for Falls Lake at sites 2, 3, and 4 (fig. 11) and Jordan Lake at sites 21A and 22 (fig. 12), where data collection began in 1992, were not affected by the sample collection method change. Sites that did not have significant trends for chlorophyll *a* were Falls Lake at I-85, Lake Michie, Cane Creek Reservoir, and the Haw River arm of Jordan Lake.

Chlorophyll *a* trends in this study increased during a period in which total phosphorus concentrations were decreasing or stable (table 2). Reservoir dynamics are complex and many factors other than phosphorus concentration affect algal populations including temperature, suspended solids concentrations (light penetration), and nitrogen concentrations. Chlorophyll *a* trends may indicate the effect of phosphorus stored in lake sediments. More intense study of processes affecting algal populations in these reservoirs is needed.

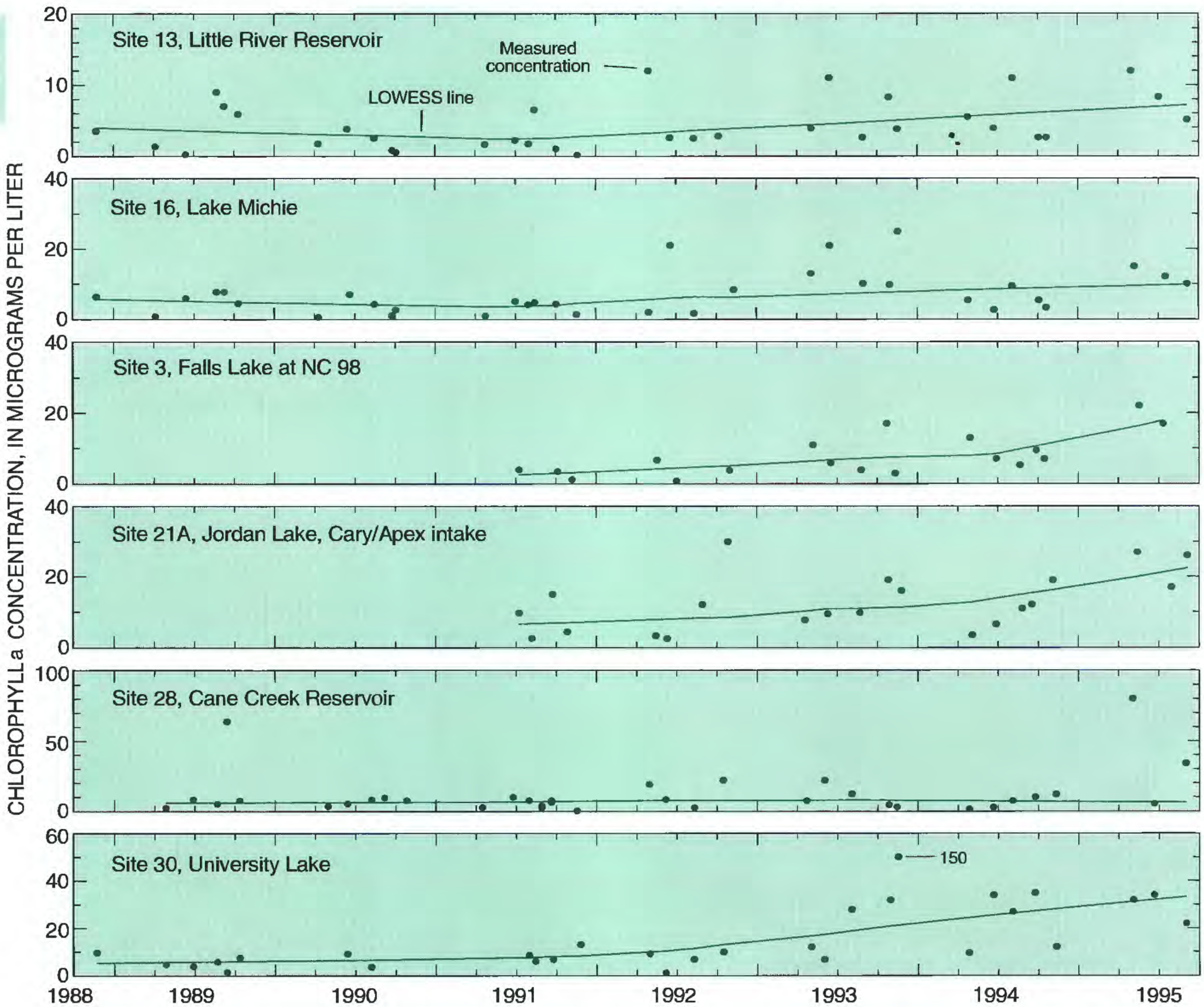

Figure 10.–Measured and locally weighted smoothed (LOWESS) lines for chlorophyll *a* concentrations at selected sites in the Research Triangle area of North Carolina, 1988-95.

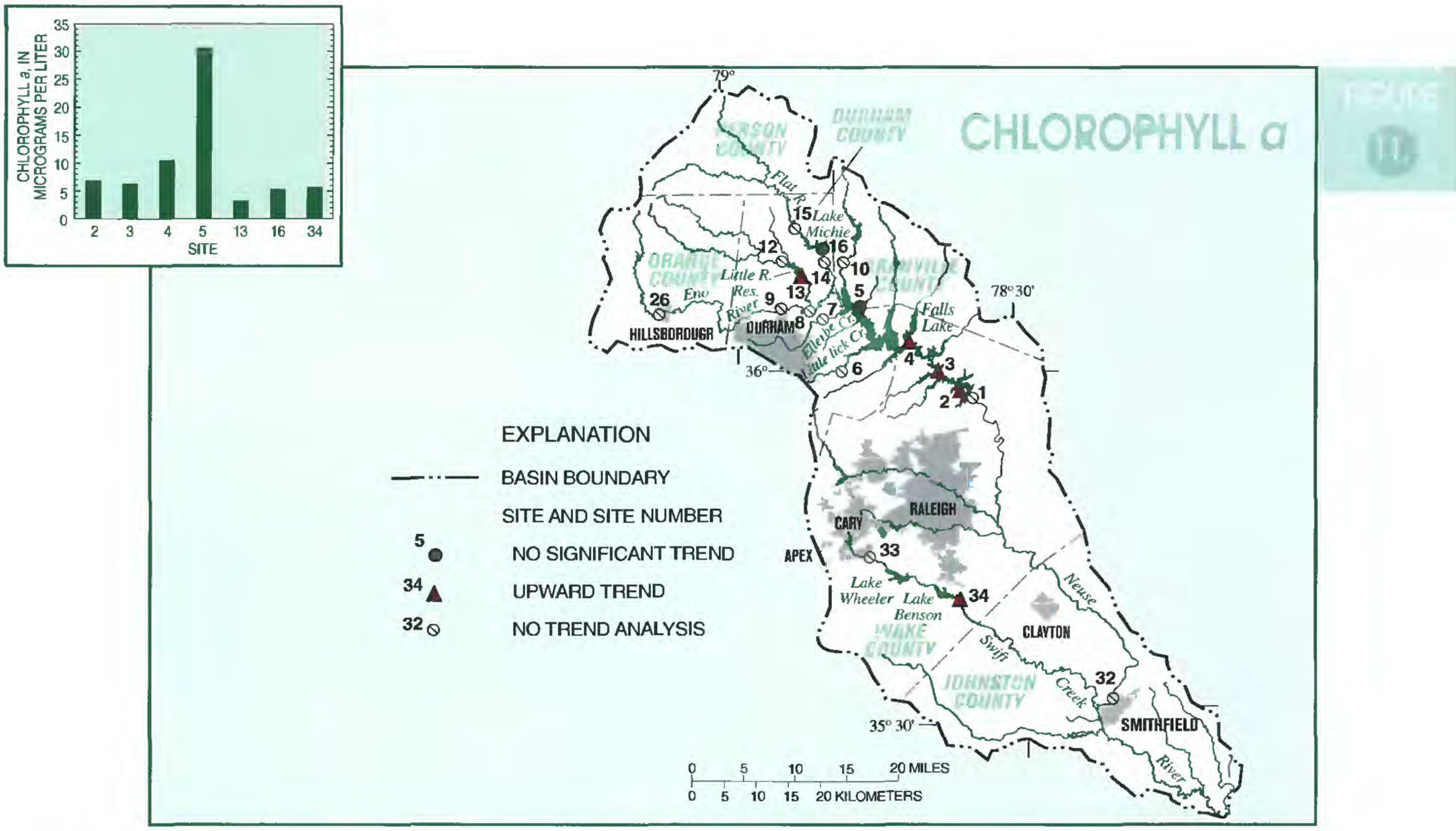

Figure 11.–Chlorophyll *a* trends in the upper Neuse River Basin, North Carolina.

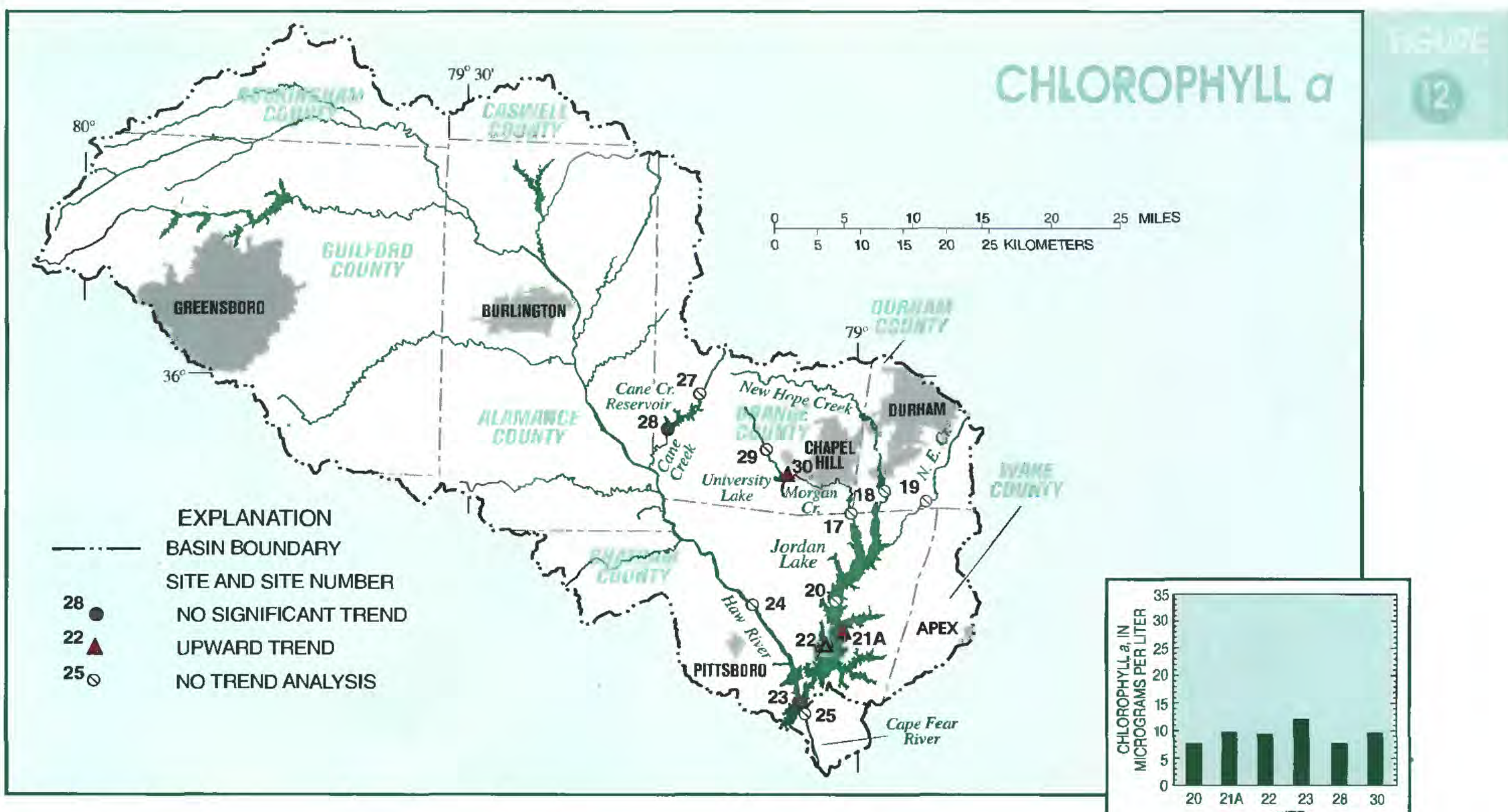

Figure 12.–Chlorophyll *a* trends in the upper Cape Fear River Basin, North Carolina.

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The Division of Water Quality of the North Carolina Department of Environment, Health, and Natural Resources maintains a Surface Water Ambient Monitoring System with approximately 380 sampling locations throughout the State. The USGS wishes to acknowledge the assistance of the Division in collecting water-quality samples and providing data from ambient monitoring sites located within the study area.

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