Water and Bed-Material Quality of Selected Streams and Reservoirs in the Research Triangle Area of North Carolina, 1988-94

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Town of Cary
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Town of Hillsborough
Town of Pittsboro
Town of Smithfield
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City of Raleigh
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WATER AND BED-MATERIAL QUALITY OF SELECTED STREAMS AND RESERVOIRS IN THE RESEARCH TRIANGLE AREA OF NORTH CAROLINA, 1988-94

By Carolyn J. Oblinger Childress *and* M.W. Treece, Jr.

ABSTRACT

The Triangle Area Water Supply Monitoring Project was formed by a consortium of local governments and governmental agencies in cooperation with the U.S. Geological Survey to supplement existing data on conventional pollutants, nutrients, and metals to enable eventual determination of long-term trends; to examine spatial differences among water supplies within the region, especially differences between smaller upland sources, large multipurpose reservoirs, and run-of-river supplies; to provide tributary loading and inlake data for predictive modeling of Falls of the Neuse and B. Everett Jordan Reservoirs; and to establish a database for synthetic organic compounds.

Water-quality sampling began in October 1988 at 35 sites located on area run-of-river and reservoir water supplies and their tributaries. Sampling has continued through 1994. Samples were analyzed for major ions, nutrients, trace metals, pesticides, and semivolatile and volatile organic compounds. Monthly concentration data, high-flow concentration data, and data on daily mean streamflow at most stream sites were used to calculate loadings of nitrogen, phosphorus, suspended sediment, and trace metals to reservoirs.

Stream and lake sites were assigned to one of five site categories—(1) rivers, (2) large multipurpose reservoirs, (3) small water-supply reservoirs, (4) streams below urban areas and wastewater-treatment plants, and (5) headwater streams—according to general site characteristics. Concentrations of nitrogen species, phosphorus species, and selected trace metals were compared by site category using nonparametric analysis of variance techniques and qualitatively (trace metals). Wastewater-treatment plant effluents and urban runoff had a significant impact on water quality compared to reservoirs and headwater streams. Streams draining these areas had more mineralized water than streams draining undeveloped areas. Moreover, median nitrogen and nitrite plus nitrate concentrations were significantly greater than all other site categories. Phosphorus was significantly greater than for reservoir sites or headwater streams. Few concentrations of trace metals were greater than the minimum reporting limit, and U.S. Environmental Protection Agency drinking-water standards were rarely exceeded. Detections, when they occurred, were most frequent for sites below urban areas and wastewater-treatment plant effluents.

A small number of samples for analysis of acetanilide, triazine, carbamate, and chlorophenoxy acid pesticides indicate that some of these compounds are generally present in area waters in small concentrations. Organochlorine and organophosphorus pesticides are ubiquitous in the study area in very small concentrations.

Trihalomethanes were detected at sites below urban areas and wastewater-treatment plants. Otherwise, volatile organic compounds and semivolatile compounds were generally not detected.

Suspended-sediment, nitrogen, phosphorus, lead, and zinc loads into Falls Lake, Jordan Lake, University Lake, Cane Creek Reservoir, Little River Reservoir, and Lake Michie were calculated. In general, reservoirs act as traps for suspended sediment and constituents associated with suspended sediments.

During 1989-94, annual suspended-sediment load to Falls Lake ranged from 29,500 to 88,200 tons. Because Lake Michie trapped from 83 to 93 percent of the suspended sediment delivered by Flat River, Flat River is a minor contributor of suspended sediment to Falls Lake. Yields of suspended sediment from Little River, Little Lick Creek, and Flat River Basins were between 184 and 223 tons per square mile and appear to have increased slightly from yields reported in a study for the period 1970-79. Annual suspended-sediment load to Jordan Lake ranged from 271,000 to 622,000 tons from 1989 through 1994 water years. The Haw River contributed more than 75 percent of the total load to Jordan Lake. The suspended-sediment yields for Haw River and Northeast Creek were 252 and 284 tons per square mile, respectively. This is more than twice the yield reported for Haw River for the period 1970-79. University Lake received an estimated 1,560 tons per year and Cane Creek Reservoir an average of 2,420 tons per year. Yields in these basins were the lowest in the study area.

Nitrogen loads to Falls Lake ranged from 780 to 1,650 tons per year, and loads out of Falls Lake accounted for 20 to 56 percent of the inflow load. Ellerbe Creek had the greatest average annual nitrogen yield of the Falls Lake tributaries—12 tons per square mile. Nitrogen loads to Jordan Lake ranged from 2,710 to 4,410 tons per year, and loads out of Jordan Lake accounted for about 57 percent of the inflow load. Haw River contributed about 70 percent of the inflow load to Jordan Lake; however, New Hope and Northeast Creeks produced nitrogen yields that were almost double that of Haw River. Nitrogen loads to University Lake and Cane Creek Reservoir averaged less than 50 tons per year.

Annual phosphorus loads to Falls Lake averaged 103 tons, and loads out of the lake accounted for 28 percent of the inflow load. Among the tributaries to Falls Lake, the greatest load was from Knap of Reeds Creek (23 tons per year). Phosphorus yields declined in Little Lick and Ellerbe Creeks and Eno River for the study period compared to the period 1983-87. Annual phosphorus loads to Jordan Lake ranged from 418 to 701 tons per year, and loads out of the lake accounted for 40 percent of the inflow load. Average annual phosphorus yields declined at every site monitored for the study period compared to the period 1983-87.

Average annual lead loads to Falls Lake from tributaries ranged from 363 pounds from Little Lick Creek to 2,300 pounds from Ellerbe Creek. Average annual lead loads to Jordan Lake from tributaries ranged from 667 pounds from Northeast Creek to 40,000 pounds from Haw River. Average annual zinc loads to Falls Lake from monitored tributaries ranged from 1,150 pounds from Little Lick Creek to 10,600 pounds from Eno River. Average annual zinc loads to Jordan Lake from monitored tributaries averaged 135,000 pounds, with Haw River contributing about 75 percent of the load.

INTRODUCTION

The Research Triangle area, within the upper Cape Fear and upper Neuse River Basins (fig. 1), is one of the most rapidly developing areas of North Carolina. According to the 1990 census, 77 percent of the households in the region depend on public drinking-water supplies withdrawn from streams and lakes in the region. Surface-water quality depends on the chemical quality of inflows from precipitation, ground-water seepage, industrial and municipal wastewater effluents, and runoff from urban, agricultural, and other land uses. Forests and agriculture are still the predominant land cover in the

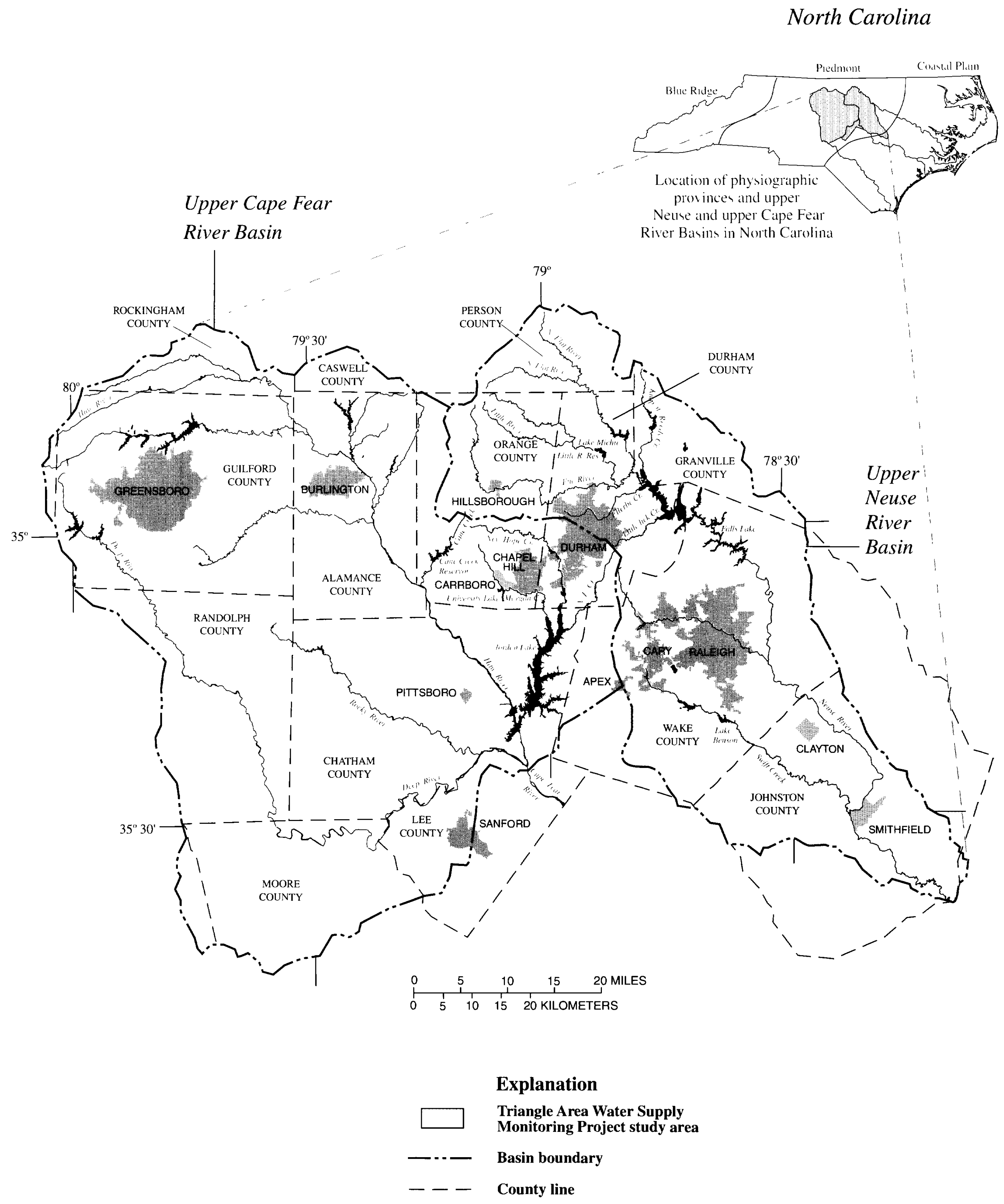

Figure 1. The Triangle Area Water Supply Monitoring Project study area within the upper Neuse River and the upper Cape Fear River Basins, North Carolina.

upper Cape Fear and upper Neuse River Basins. Although agriculture is an important source of nutrients and contaminants, urban/industrial land uses are potentially of greater importance in the study area due to the proximity of these land uses to local water supplies.

Because of the heavy reliance on surface water for public water supply, local governments recognized that protection of the Research Triangle's surface-water resources is imperative. Together, and with assistance from Triangle J Council of Governments (TJCOG), they formed the Triangle Area Water Supply Monitoring Project. The goals of the Project were to:

1. Supplement existing data on conventional pollutants, nutrients, and metals to enable eventual determination of long-term trends,
2. Examine differences in water quality among water supplies within the region, especially differences between smaller upland sources, large multipurpose reservoirs, and run-of-river supplies,
3. Provide tributary loading and inlake data for predictive modeling of Falls of the Neuse and B. Everett Jordan Reservoirs, and
4. Establish a database for synthetic organic compounds.

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. 2). Water-quality sampling and streamflow monitoring, in cooperation with the Triangle Area Water Supply Monitoring Project Steering Committee, began in October 1988 at 41 sites located at area run-of-river and reservoir water supplies and their tributaries (table 1). These data, along with water-quality data collected during the same period by the North Carolina Division of Environmental Management (DEM) and with streamflow and water-quality data collected from 1982 through 1987 as part of a cooperative program between the USGS and the U.S. Army Corps of Engineers, form a comprehensive database on the quality of area water supplies, tributaries, and reservoir outflows.

Purpose and Scope

This report presents a summary of the results of the first 6 years of data collection (October 1988 through September 1994) by the USGS and DEM in the study area. Water-quality conditions are described for nine locations on Falls of the Neuse and B. Everett Jordan Reservoirs, for one location on each of five small reservoirs, for selected tributaries to the reservoirs, for the outflow of four of the reservoirs, and for locations near five run-of-river water supplies.

Results include summary statistics of major ions, nutrients, and trace elements, and a statistical comparison of selected constituents grouped by site category. Where applicable, concentrations are compared to State and Federal drinking-water maximum contaminant levels (MCL) and(or) ambient water-quality standards for the protection of aquatic life. A summary of the occurrence of synthetic semi-volatile organic compounds, pesticides, and polychlorinated biphenyls (PCB's) in bed material and water, and of volatile organic compounds in water is presented. Annual loads and yields of nutrients and suspended sediment are calculated for the major tributaries to each reservoir, and annual loads of lead and zinc are calculated for selected sites.

Description of the Study Area

The study area is located in the Piedmont Province of North Carolina (fig. 1). The topography of the Piedmont Province has been largely developed by streams flowing across it. The province is typified by well-rounded hills, broad long-rolling ridges, and deeply eroded v-shaped stream valleys. Elevations in the study area range from about 800 to 300 feet (ft) above sea level. The region is underlain by older crystalline rock formations which trend northeast-southwest and vary greatly in their resistance to weathering and erosion (Stuckey, 1965). Most major streams in the province flow either eastward or southeastward; however, tributary streams most often follow the lay of the land. Typical stream gradients range from 10 to 20 feet per mile (Simmons, 1993).

The study area includes part of a 16-county area in the upper part of the Neuse and Cape Fear drainage basins (fig. 1). The Flat, Eno, and Little Rivers in Orange and Person Counties together form the headwaters of the Neuse River Basin (fig. 2A).

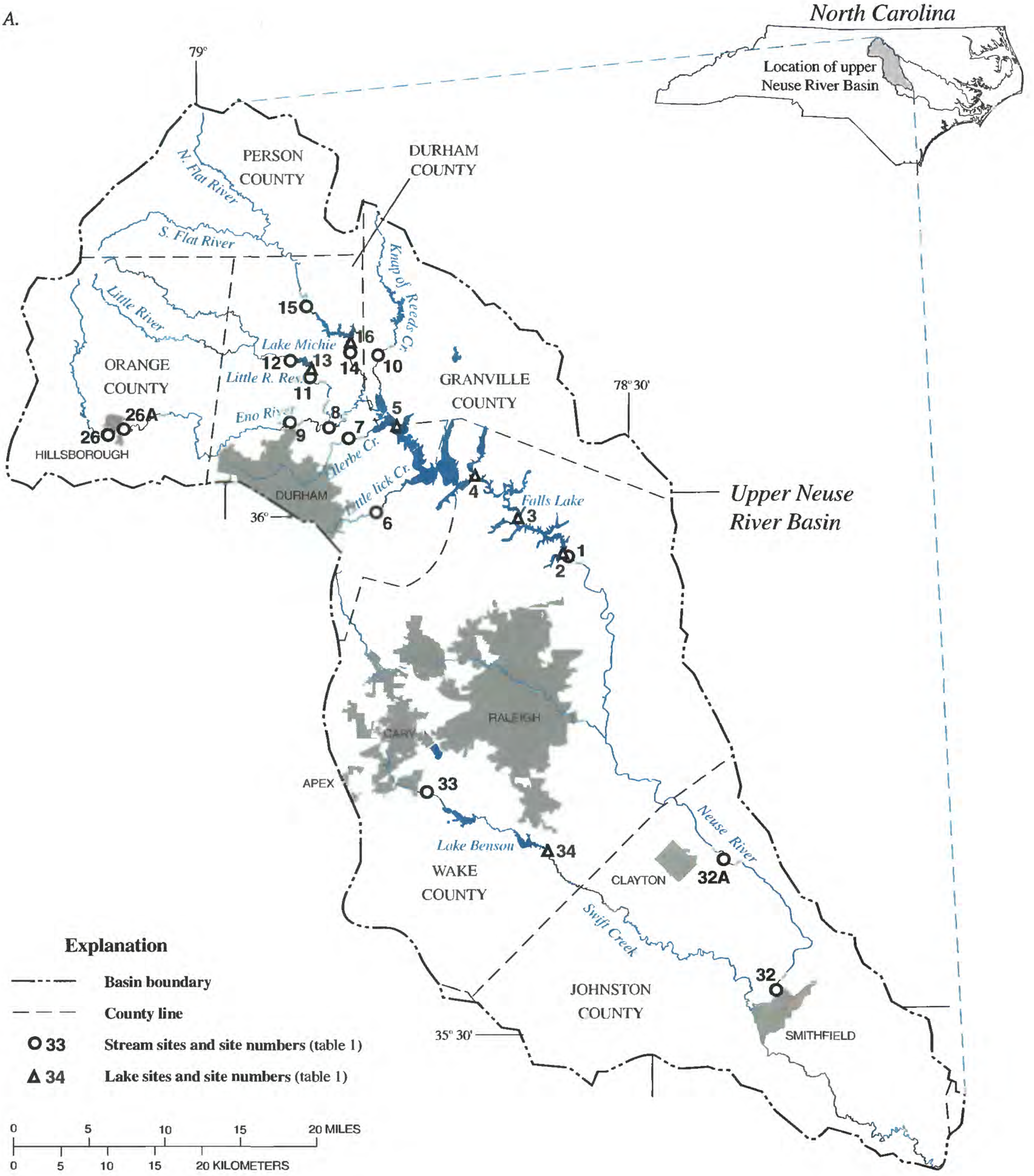

Figure 2. Water-quality sampling and streamflow monitoring sites in the (A) upper Neuse River Basin and (B) upper Cape Fear River Basin.

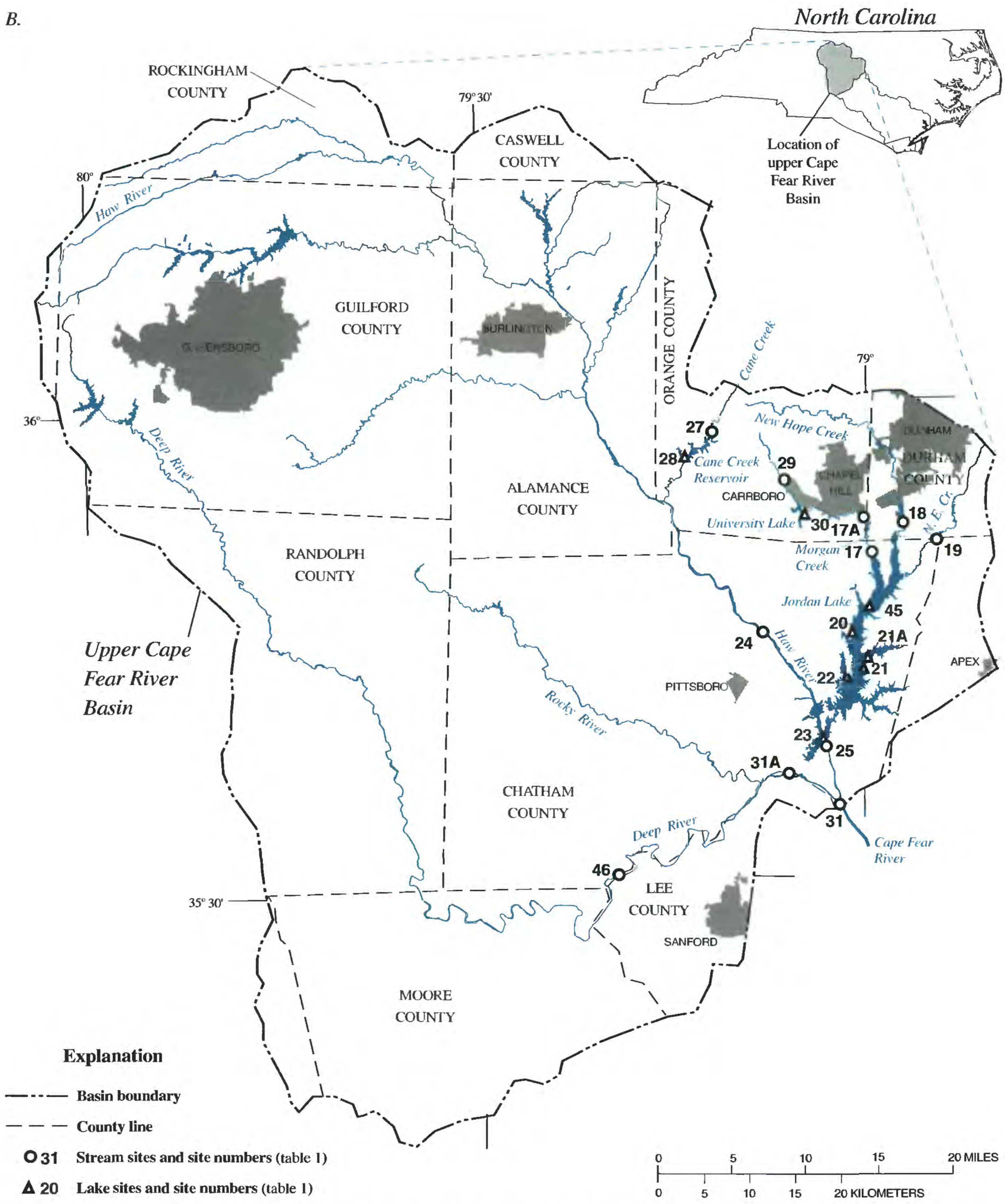

Figure 2. Water-quality sampling and streamflow monitoring sites in the (A) upper Neuse River Basin and (B) upper Cape Fear River Basin (Continued).

Table 1. Water-quality sampling and streamflow monitoring sites in the Triangle Area Water Supply Monitoring Project

[USGS number is U.S. Geological Survey downstream order number; mi^2, square miles; Site categories: 1—river, 2—large reservoir, 3—small reservoir, 4—downstream from urban areas and wastewater-treatment plants, 5—headwater stream, 6—sites near a water-supply intake; —, not determined]

Site number (fig. 2)	Station name and USGS number	Latitude	Longitude	Drainage area (mi^2)	Site category
1	Neuse River near Falls 02087183	35°56'25"	78°34'56"	771	1
2	Falls Lake above Dam at Falls 02087182	35°56'28"	78°35'02"	—	2,6
3	Falls Lake at State Highway 98 near Bayleaf 0208708905	35°58'42"	78°37'59"	—	2
4	Falls Lake at State Highway 50 near Sandy Plain 0208703650	36°00'54"	78°41'29"	—	2
5	Falls Lake at Interstate 85 near Redwood 02086920	36°04'14"	78°46'48"	—	2
6	Little Lick Creek above Secondary Road 1814 near Oak Grove 0208700780	35°59'11"	78°47'58"	10.1	4
7	Ellerbe Creek near Gorman[a] 02086849	36°03'33"	78°49'58"	21.9	4
8	Eno River near Weaver[b] 02085079	36°04'19"	78°51'47"	148	4
9	Eno River near Durham 02085070	36°04'20"	78°54'30"	141	4
10	Knap of Reeds Creek near Butner 02086624	36°07'40"	78°48'55"	43.0	4
11	Little River below Dam near Fairntosh 0208524850 (Discontinued 6/91)	36°06'43"	78°52'08"	97.7	1
12	Little River at Secondary Road 1461 near Orange Factory 0208521324	36°08'30"	78°55'10"	78.2	5
13	Little River Reservoir at Dam near Bahama 0208524845	36°06'53"	78°52'10"	97.7	3,6
14	Flat River at Dam near Bahama 02086500 (Discontinued 6/91)	36°08'55"	78°49'43"	168	1
15	Flat River at Bahama 02085500	36°10'57"	78°52'44"	149	5
16	Lake Michie at Dam near Bahama 02086490	36°09'02"	78°49'49"	167	3,6
17	Morgan Creek near Farrington[c] 02097521	35°51'48"	79°00'35"	45.6	4

Table 1. Water-quality sampling and streamflow monitoring sites in the Triangle Area Water Supply Monitoring Project (Continued)

[USGS number is U.S. Geological Survey downstream order number; mi^2, square miles; Site categories: 1—river, 2—large reservoir, 3—small reservoir, 4—downstream from urban areas and wastewater-treatment plants, 5—headwater stream, 6—sites near a water-supply intake; —, not determined]

Site number (fig. 2)	Station name and USGS number	Latitude	Longitude	Drainage area (mi^2)	Site category
17A	Morgan Creek near Chapel Hill 02097517	35°53'36"	79°01'10"	41.0	—[d]
18	New Hope Creek near Blands 02097314	35°53'05"	78°57'58"	75.9	4
19	Northeast Creek at Secondary Road 1100 near Genlee 0209741955	35°52'20"	78°54'49"	21.1	4
20	Jordan Lake at Buoy 9 near Farrington 0209771550 (Discontinued 7/92)	35°46'30"	79°01'38"	—	2
21	Jordan Lake at Buoy 7 below U.S. Highway 64 near Griffins Crossroads 0209801050 (Discontinued 9/92)	35°43'56"	79°01'30"	—	2
21A	Jordan Lake above U.S. Highway 64 near Wilsonville 0209799150 (Activated 7/91)	35°44'29"	79°01'10"	—	2,6
22	Jordan Lake at Bells Landing near Griffins Crossroads 0209801100 (Activated 7/91)	35°43'38"	79°02'35"	—	2
23	Jordan Lake, Haw River Arm above B. Everett Jordan Dam 0209719700	35°39'39"	79°04'23"	—	2
24	Haw River near Bynum 02096960	35°45'48"	79°08'02"	1,275	1,6
25	Haw River below B. Everett Jordan Dam near Moncure 02098198	35°39'11"	79°04'03"	1,689	1
26	Eno River at Hillsborough 02085000 (Activated 10/89)	36°04'18"	79°05'49"	66.0	1,6
26A	Eno River intakes at Hillsborough 0208491605 (Discontinued 9/89)	36°04'02"	79°07'39"	66.0	1
27	Cane Creek near Orange Grove 02096846	35°59'13"	79°12'23"	7.5	5
28	Cane Creek Reservoir at Dam near White Cross 0209684980 (Activated 4/89)	35°56'59"	79°14'29"	31.4	3,6
29	Morgan Creek near White Cross 02097464	35°55'25"	79°06'56"	8.4	5
30	University Lake at intakes near Chapel Hill 0209749990	35°53'48"	79°05'33"	30.0	3,6
31	Cape Fear River at State Highway 42 near Brickhaven[e] 0210215985	35°32'54"	79°01'34"	3,160	1,6
31A	Deep River at Moncure 02102000	35°37'38"	79°06'58"	1,434	—[d]

Table 1. Water-quality sampling and streamflow monitoring sites in the Triangle Area Water Supply Monitoring Project (Continued)

[USGS number is U.S. Geological Survey downstream order number; mi^2, square miles; Site categories: 1—river, 2—large reservoir, 3—small reservoir, 4—downstream from urban areas and wastewater-treatment plants, 5—headwater stream, 6—sites near a water-supply intake; —, not determined]

Site number (fig. 2)	Station name and USGS number	Latitude	Longitude	Drainage area (mi^2)	Site category
32	Neuse River at Smithfield[f] 02087570	35°30'46"	78°21'00"	1,206	1,6
32A	Neuse River near Clayton 02087500	35°38'50"	78°24'22"	1,150	—[d]
33	Swift Creek near Apex 02087580 (Activated 10/89)	35°43'07"	78°45'09"	21.0	1
34	Lake Benson at Dam near Garner 02087701 (Activated 10/89)	35°39'44"	78°36'52"	67.0	3,6
45	Jordan Lake at Buoy 12 at Farrington 0209768310 (Activated 8/92)	35°47'55"	79°00'22"	—	2
46	Deep River at Carbonton 0210140200 (Activated 3/92)	35°31'10"	79°20'51"	1,026	1,6

[a] Gage was discontinued April 1989 and was rebuilt September 1991.

[b] Discharge values for site 8 are from gage at site 9.

[c] Discharge values for site 17 are from gage at site 17A.

[d] Discharge site.

[e] Discharge was computed by adding the daily mean discharge values at sites 25 and 31A.

[f] Gage was discontinued September 1990. Discharge values after September 1990 are from gage at site 32A.

The drainage area of the Neuse River at Smithfield, the downstream terminus of the study area, is about 1,210 square miles (mi^2) or one-fifth of the total drainage area of the Neuse River Basin. Other tributaries to the Neuse River that were monitored for this study are Knap of Reeds Creek, Ellerbe Creek, Little Lick Creek, and Swift Creek. Falls of the Neuse Reservoir (hereafter referred to as Falls Lake), in Wake County, is the largest impoundment of the Neuse River forming a 12,490-acre reservoir with 114,700 acre-feet (acre-ft) of storage at normal pool elevation (table 2). It is a water supply for the city of Raleigh.

Lake Michie, a 508-acre reservoir just upstream from Falls Lake, impounds the Flat River and its tributaries, Dial Creek, Rocky Creek, and Dry Creek, and supplies drinking water for the city of Durham. Little River Reservoir, filled in 1988 as a water-supply source for the city of Durham, is a third water-supply reservoir in the upper Neuse River Basin. Little River Reservoir is a 530-acre reservoir, which impounds Little River and its tributaries—Mountain Creek, Buffalo Creek, and North Fork and South Fork Little Rivers. Lake Benson was impounded from Swift Creek in 1844 and was known as Rand's Mill Pond. It was purchased by the City of Raleigh in 1927 for water supply and was expanded in 1953 to a 440-acre reservoir. At present, the lake is used as a secondary water supply for the City of Raleigh and for recreation (North Carolina Department of Environment, Health, and Natural Resources, 1992).

The Cape Fear River (fig. 2B) is formed downstream from B. Everett Jordan Reservoir (hereafter referred to as Jordan Lake) by the confluence of the Haw River, which drains 1,695 mi^2 at the mouth, and the Deep River, which drains 1,441 mi^2 at the mouth (North Carolina Department of Natural Resources and Community Development, 1988). The drainage area of the Cape Fear River near Brickhaven, the downstream terminus of the study area, is 3,160 mi^2. Jordan Lake, a 14,300-acre multipurpose reservoir, was filled in 1982 and contains approximately 215,000 acre-ft of storage at normal pool elevation (table 2). The reservoir, formed from

Table 2. Description of reservoirs in the Research Triangle study area

[DEM, North Carolina Division of Environmental Management; —, no data]

Reservoir (year filled)	Drainage area (square miles)	Surface area[a] (acres)	Volume[a] (acre-feet)	Maximum depth (feet)	Average depth[b] (feet)	Volume/mean inflow[c] (days)	DEM trophic state classification	Resource use[d]
Falls Lake (1983)	771	12,490	114,700	—	9.2	80	eutrophic	water supply, flood control, recreation
Little River Reservoir (1988)	98	530	14,600	49	27	85	mesotrophic	water supply
Lake Michie (1926)	167	508	11,070	52	22	45	eutrophic	water supply, recreation
Lake Benson (1844)	65	440	3,070	20	7.0	—	mesotrophic	secondary water supply, recreation
Jordan Lake (1982)	1,690	14,300	215,000	66	15	62	eutrophic	flood control, fish and wildlife habitat, recreation, water supply
Cane Creek Reservoir (1989)	31	500	8,920	54	18	162	eutrophic	water supply
University Lake (1932)	30	200	2,100	23	10	39	eutrophic	water supply, recreation

[a] Normal pool elevation.

[b] Volume/surface area.

[c] Computed from U.S. Geological Survey records of reservoir volume and annual mean discharge for the period of record at each streamflow station tributary to each reservoir (Gunter and others, 1993).

[d] North Carolina Department of Environment, Health, and Natural Resources (1992).

the impoundment of the Haw River and New Hope Creek, is a water-supply source for the towns of Cary and Apex and is the future water supply for Chatham County and potentially for other jurisdictions in the Triangle area, including Orange County. 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 mi^2 in the upper Cape Fear River Basin (Bisese, 1994). The lake was formed from the partially flooded stream valleys of Morgan Creek and its two tributaries, Phils Creek and Price Creek. Cane Creek Reservoir, filled in 1989, is a public water supply for the towns of Carrboro and Chapel Hill and impounds water from about 31 mi^2 in the upper Cape Fear River Basin. The two main tributaries to the lake are Cane Creek and Turkey Hill Creek (North Carolina Department of Environment, Health, and Natural Resources, 1992).

Land Use

The Piedmont part of the Neuse River Basin (the upper Neuse River Basin) is the most populated and industrialized part 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. An estimated 339 mi^2 or 44 percent of the watershed is forested and 26 percent is agriculture. Urban areas account for about 13 percent and wetlands account for about 10 percent of the land use (North Carolina Department of Environment, Health, and Natural Resources, 1993). The Lake Michie drainage area (167 mi^2) accounts for approximately 22 percent of the drainage to Falls Lake and is mostly forested, although some agricultural and residential land use exists. The Little River drainage basin (98 mi^2) accounts for approximately 13 percent of the drainage to Falls Lake and is equally divided among forested, agricultural, and residential areas (North Carolina Department of Environment, Health, and Natural Resources, 1993).

The part of the study area in the upper Neuse River Basin from the Falls Lake dam to Smithfield (fig. 2A) is primarily urban and residential, and includes the city of Raleigh and its suburbs. The population in the upper Neuse Basin grew steadily and increased by approximately 70 percent from 1970 to 1990 (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 the surrounding communities continue to develop.

Municipal wastewater-treatment plants (WWTP's) that discharge to tributaries of Falls Lake include Durham's Northside WWTP, which discharges to Ellerbe Creek; Little Lick WWTP, which discharges to Little Lick Creek; Butner WWTP, which discharges to Knap of Reeds Creek; and Durham's Eno WWTP, which discharges to the Eno River. In November 1994, Durham's Northside WWTP was upgraded to tertiary treatment and renamed North Durham Water Reclamation Facility. This facility receives sewage formerly sent to the Eno WWTP and the Little Lick WWTP. The Little Lick and Eno WWTP's ceased operation in November and June 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 from Burlington to Greensboro. Drainage from the Haw River Basin, 1,300 mi^2 of mixed forested and agricultural lands and urban and residential areas, is to Jordan Lake. Jordan Lake also receives drainage from New Hope Creek Basin, a 400-mi^2 watershed that includes forested and agricultural land uses and urban areas (including Durham, Chapel Hill, and Research Triangle Park), much of which are undergoing industrial and residential development.

The morphometry of Jordan Lake is unusual because about 80 percent of the flow into the lake is from the Haw River; however, most of the storage is in the New Hope Creek arm (fig. 2B). This results in periods when flow from the Haw River is pushed uplake into the New Hope Creek arm (Moreau and Challa, 1985). Moreover, materials entering the northern New Hope Creek arm of the reservoir likely remain in the reservoir longer than materials entering from the Haw River.

Cane Creek Reservoir is in the Haw River Basin and receives drainage from 31 mi^2 of mostly forested and some agricultural lands (North Carolina Department of Environment, Health, and Natural Resources, 1992). University Lake is in the Morgan Creek Basin and receives drainage from an approximately 30-mi^2 area mostly west of Carrboro. Three quarters of the area is forested with some agriculture and residential development (North Carolina Department of Environment, Health, and Natural Resources, 1992).

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; Durham's Southside WWTP, which discharges to New Hope Creek; and Orange Water and Sewer Authority (OWASA) WWTP, which discharges into Morgan Creek. In 1994, Durham's Southside WWTP was upgraded to tertiary treatment and renamed the South Durham Water Reclamation Facility.

Water Use

Public water-supply systems deliver water to about 600,000 people in the upper Cape Fear River Basin and 525,000 people in the upper Neuse River Basin. Municipalities and other privately owned water suppliers withdraw approximately 150 million gallons per day (Mgal/d) from surface-water sources in the study area. Total off-stream surface-water withdrawals in the upper Neuse River and upper Cape Fear River Basins totaled an estimated 75 and 260 Mgal/d, respectively, for 1990. Of the 260 Mgal/d withdrawn in the upper Cape Fear River Basin, 149 Mgal/d or

57 percent was withdrawn for thermoelectric power generation, and 91 Mgal/d (35 percent) was withdrawn for industrial uses. In the upper Neuse River Basin, 57 Mgal/d or about 76 percent of total surface-water withdrawals were for industrial processes.

Sewage-treatment water releases to surface waters in the basins from wastewater-treatment plants (municipal and industrial) totaled about 150 Mgal/d in 1990 (Terziotti and others, 1994)—50 Mgal/d in the upper Neuse Basin and 100 Mgal/d in the upper Cape Fear Basin. Of the total amount of wastewater releases, about 90 percent are from publicly owned wastewater-treatment facilities.

Previous Investigations

Water-quality characteristics of flow into and out of water-supply reservoirs in the Piedmont Province of North Carolina have been studied by several investigators. These studies focused on a variety of water-quality issues, including the effects of land uses on water quality, sedimentation rates and trapping efficiency of reservoirs, and nutrient loadings into reservoirs. None of the previous studies maintained a comprehensive, long-term streamflow and water-quality monitoring network as was done in this investigation.

Harned (1982) summarized water quality of the upper Neuse River from 1955 to 1978 and concluded that it was satisfactory for most uses. Harned reported that dissolved oxygen, manganese, and iron concentrations, pH, and bacteria counts often reached undesirable levels. Nutrient concentrations were sufficient to support rich algal growth.

Studies conducted by DEM (1981-83) in the Cape Fear Basin identified low dissolved-oxygen concentrations and high bacteria counts as major problems in the basin. Also, concerns arose in the 1970's as a result of mercury contamination of fish in the Cape Fear Basin. Surveys in the mid-1970's by the U.S. Army Corps of Engineers and DEM reported that 30 to 50 percent of the fish sampled contained concentrations of mercury that exceeded the U.S. Food and Drug Administration allowable concentrations in fish tissue of 0.5 part per million (ppm). However in 1978, based on extensive studies of actual human consumption of fish, the U.S. Food and Drug Administration increased the allowable limit of mercury in fish flesh from 0.5 to 1 ppm. During 1980 and 1981, a DEM survey of mercury in tissues of fish from streams in the basin showed concentrations ranged from 0.1 to 0.33 ppm, substantially less than the recommended allowable concentration. Tissue samples taken from Jordan Lake fish analyzed in 1982 by DEM showed that the average mercury concentration was less than 0.2 ppm.

In 1987, the North Carolina Division of Water Resources (1987) recommended that a 150-mi^2 area of the Eno River watershed upstream from the confluence with the Little River be designated as a "capacity-use area," which would require coordination and limited regulation for the use of ground or surface water in the area. This recommendation was based on evidence of deteriorated water-quality conditions in the Eno River associated with low-flow periods which provide less water to dilute pollutants from point and nonpoint sources. The report suggested that minimum flows be maintained in the Eno River to assimilate existing wastewater discharges without resulting in violation of the applicable water-quality standards. The report also suggested that future development in the watershed would further stress the system and make suitable water quality scarce, particularly during dry years.

Water-quality characteristics and annual nitrogen and phosphorus yields into and out of Falls and Jordan Lakes were determined by Garrett (1990a and b) for water years[1] 1983 through 1986. Garrett reported that mean concentrations of major ions and nutrients in tributaries to Falls Lake ranged from 10 to 110 times greater than background concentrations reported by Simmons and Heath (1982) for streams draining undeveloped areas. The mean concentrations of Falls Lake outflow were generally 2 to 3 times greater than background concentrations. Sodium and calcium were the predominant cations, and bicarbonate was the predominant anion. Of the metals, iron and manganese were detected in the greatest concentrations. Mean annual loads of total nitrogen and total phosphorus out of Falls Lake were as much as 66 and 21 percent of mean annual loads into the lake, respectively. For Jordan Lake, Garrett (1990b) reported that average annual loads of total nitrogen and total phosphorus in the outflow were as much as

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[1] Water year is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and includes 9 months of that calendar year. Thus, the period beginning October 1, 1982, and ending September 30, 1983, is the 1983 water year.

67 and 40 percent of estimated inflow loads, respectively.

Kuenzler and others (1986) studied nutrient cycling and productivity of Jordan Lake by including measurements of nitrogen and phosphorus uptake rates in relation to algal abundance and primary productivity. The study included 1 year of data collection at three stations on Jordan Lake. Nutrient concentrations were lowest in the summer when algal abundance was the greatest. Uptake rates of nitrate and ammonium by phytoplankton were highest in the summer. Nitrate concentrations were higher than ammonium concentrations, and phytoplankton took up ammonium more rapidly. Of possible factors controlling primary productivity, temperature was most statistically related. According to the report, Jordan Lake supports a large phytoplankton standing crop which can reduce ammonium, nitrate, and phosphate to very low concentrations when gross primary productivity is highest during the warm months. However, algal assays conducted with water from Jordan Lake indicated that neither nitrogen nor phosphorus concentrations alone were consistently low enough to limit further phytoplankton growth.

Reckhow and others (1989) assessed the similarity and differences between surface-water quality data collected in Jordan and Falls Lakes. They reported that concentrations of total phosphorus and total nitrogen exhibit the same seasonal pattern at the sampling sites in the two reservoirs. Analysis of deterministic patterns and cycles in Jordan Lake and three river sampling sites indicated that there were linear trends with time in a few of the data sets, seasonal patterns in much of the data, and an inverse relation between flow and concentrations in most of the data from streams. This investigation focused on determining the sample size required for trend analysis and the amount of redundancy and autocorrelation among data sets, to provide a means to consider reducing sample sites or sampling frequency.

Bisese and Paull (1994) studied the type, spatial distribution, and amount of sediment deposited in University Lake from 1988 through 1992. They reported that the maximum sediment thickness was 14 ft and the average thickness was 2.1 ft. The volume of sediment was determined to be 440 acre-ft, resulting in an average sedimentation rate over 57 years of 7.7 acre-feet per year (acre-ft/yr) or 11,035 tons per year (tons/yr).

Weaver (1994) investigated present (1992) and historic (1926-92) rates of sedimentation in Lake Michie. Weaver reported that about 2,541 acre-ft of sediment, about 20 percent of the original volume, has been trapped in the lake. At present, the average sedimentation rate is 38 acre-ft/yr—a decline from the rate of 45.1 acre-ft/yr in 1935. Weaver estimated the trap efficiency of Lake Michie is 89 percent.

In 1983, DEM recommended nutrient management in the Falls Lake watershed and in 1987 recognized the need for nutrient management in the entire Neuse River Basin. The North Carolina Division of Environmental Management (1993) Neuse River Basinwide Water Quality Management Plan describes the status of water quality in the basin and the causes and sources of water pollution. Agricultural runoff and municipal wastewater-treatment plants are recognized as the two major sources of nutrients in addition to urban runoff and forestry. Nutrients in nonpoint-source runoff originate primarily from fertilizer use and animal wastes. Nutrients in point-source discharges are from human wastes, food residues, and some cleaning agents. The report also offers recommended management actions and projected long-range water-quality goals for the basin. The report lists increased urban development and population growth as the primary factors contributing to degradation of some water resources in the Neuse Basin. Nutrient and organic enrichment, as evidenced by low dissolved-oxygen concentrations, algal blooms, and fish kills are notable causes of water-quality degradation in the upper Neuse Basin (North Carolina Department of Environment, Health, and Natural Resources, 1993). Municipal WWTP's were identified as the major contributors to the elevated nutrient loadings to the arms of Falls Lake, especially during low-flow summer months. Exceedences of copper and zinc action levels and the mercury water-quality criterion have occurred downstream from some of these facilities. Biological indexes rate water quality as "poor" to "very poor" downstream from several WWTP's, whereas headwater streams generally have a bioclassification of "good" to "excellent."

Acknowledgments

The Division of Environmental Management 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 DEM in providing water-quality sample collections and data from ambient monitoring sites located within the study area.

WATER QUALITY OF STREAMS AND RESERVOIRS

Samples for the analysis of water quality were collected from stream sites (table 1) once per month beginning October 1, 1988. Lake samples were collected 5 times per year in October, April, June, July, and August. A detailed accounting of the number of samples collected at each site by USGS and DEM through September 1992 is in Garrett and others (1994). The report also describes methods of sample collection, methods of sample analysis, and quality-assurance practices and results.

General Characteristics

The general chemical characteristics of surface water can be defined by measuring the concentrations of major ions—calcium, magnesium, sodium + potassium, bicarbonate, sulfate, and chloride. The chemical composition, in terms of these major ions, is largely regulated by the geology of the watershed and by the chemistry of precipitation. Point and nonpoint sources of contamination can alter baseline chemistry, most often by increasing the concentration of one or more major ions resulting in an increase in the dissolved solids concentration. Simmons and Heath (1982) describe five geochemical zones in North Carolina based on major ion data from streams draining relatively pristine forested and rural watersheds in North Carolina (fig. 3). The upper Neuse and upper Cape Fear River Basins, the area encompassing nearly all of the sites in this study, lie in geochemical zone II. Zone II coincides with the Carolina Slate Belt and the Durham and Wadesboro Triassic Basins. The Slate Belt is underlain by metamorphosed volcanic and sedimentary rocks. The Triassic Basins are underlain by cemented conglomerates, sandstones, siltstones, and shales (Simmons and Heath, 1982, p. B22). The Neuse River Basin, between Raleigh and Smithfield, lies in geochemical zone I and is underlain by rocks of the granite group and, in limited areas, by rocks of the diorite group (Simmons and Heath, 1982).

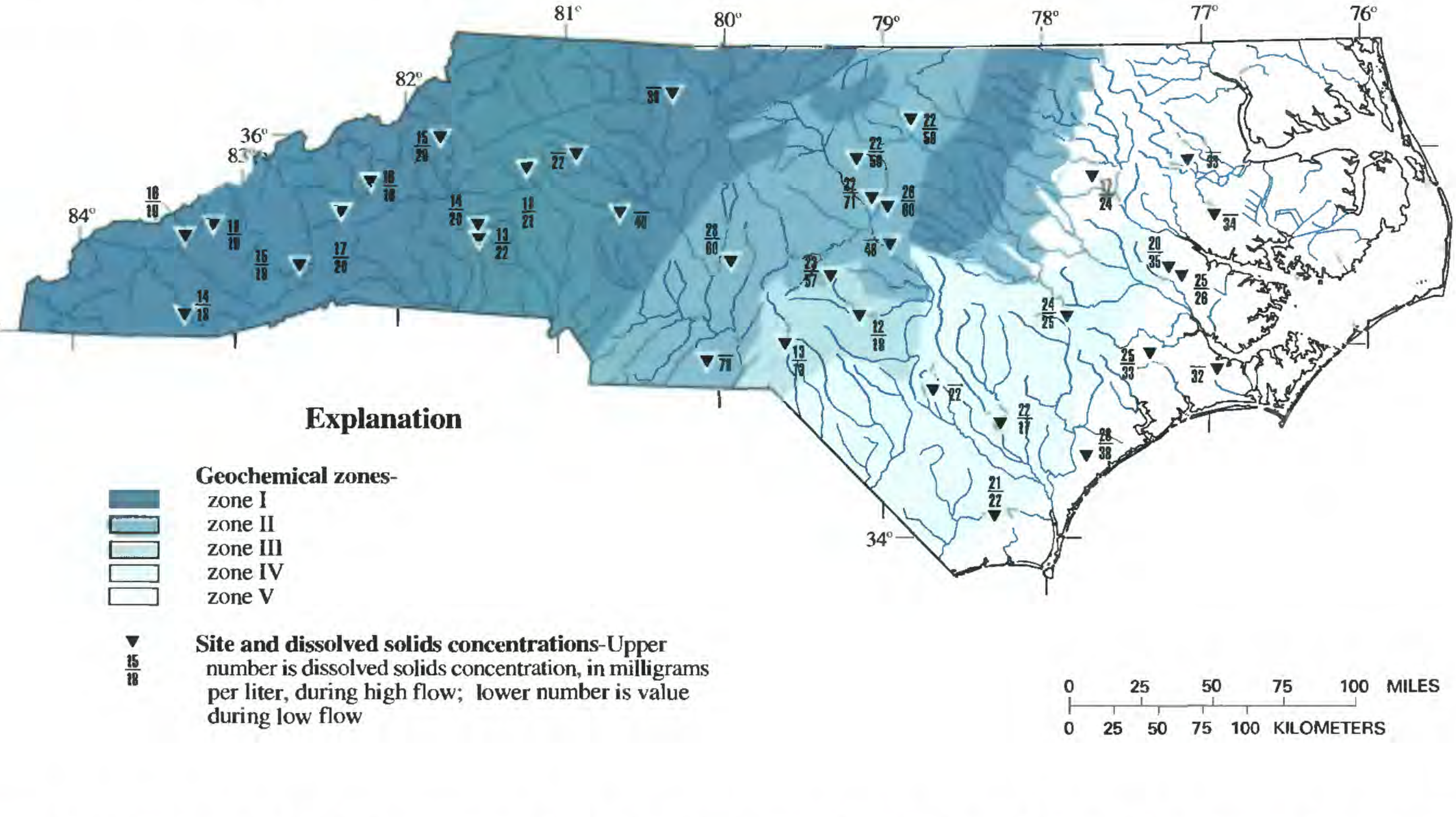

Figure 3. Mean dissolved solids concentrations and major geochemical zones in North Carolina (from Simmons and Heath, 1982).

Geochemical zones I and II produce waters of similar chemical composition. However, water from geochemical zone II typically is more mineralized. Stiff diagrams of mean concentrations of the major ions—calcium, magnesium, sodium + potassium, bicarbonate, sulfate, and chloride—are shown in figures 4 and 5 for the study area. Stiff diagrams indicate the concentration of each major cation (calcium, magnesium, and sodium + potassium) to the left of the vertical axis and the concentration of each major anion (bicarbonate, sulfate, and chloride) to the right of the vertical axis. Concentrations are expressed in milliequivalents per liter. The shape of the resulting polygon indicates water composition in terms of the major ions and provides a means of comparing sites. The width of the polygon indicates the total concentration of dissolved minerals. The geochemical zone II water type (fig. 3) is identified by the major cations—calcium, magnesium, and sodium + potassium—and the major anion—bicarbonate.

The Stiff diagrams of samples collected from Little River near Orange Factory (site 12), Flat River at Bahama (site 15), and Eno River at Hillsborough (site 26) in the headwaters of the Neuse River Basin (fig. 4) are similar to that of baseline water quality for geochemical zone II. That is, they have similar shape (indicating dominate ions) and width (indicating the total concentration of dissolved minerals). Likewise, Stiff diagrams of water samples from Little River Reservoir (site 13, fig. 4) and Lake Michie (site 16) are similar to Stiff diagrams for baseline water quality for geochemical zone II.

A comparison of Stiff diagrams for baseline water quality in geochemical zones I and II to Stiff diagrams for data from other sites shows the effect of point sources on water quality. Data from streams located downstream from urban areas and major municipal WWTP effluents produce Stiff diagrams that substantially differ in width and shape from those of baseline water quality for the geochemical zone in which these sites are located. The Eno River near Durham (site 9, fig. 4) is a sodium + potassium and sulfate water type. Ellerbe Creek near Gorman (site 7, fig. 4) downstream from the Durham Northside WWTP has relatively mineralized water of sodium + potassium and bicarbonate type. Less mineralized sodium + potassium and bicarbonate waters also characterize the sites farther downstream from the urban areas and WWTP effluents, including the uplake segment of Falls Lake (site 5, fig. 4), Eno River near Weaver (site 8), and Neuse River at Smithfield (site 32). Domestic water use has the effect of increasing the concentration of dissolved minerals. Typically, in domestic waste, calcium concentration increases by 20 milligrams per liter (mg/L), sodium by 50 mg/L, sulfate by 20 mg/L, and chloride by 40 mg/L (Tchobanoglous and Schroeder, 1985, p. 174).

Cane Creek (sites 27 and 28, fig. 5) and Morgan Creek (sites 29 and 30), on streams draining parts of the upper Cape Fear River Basin, produce a calcium, sodium + potassium, and bicarbonate water type characteristic of baseline water quality for geochemical zone II. New Hope Creek (site 18, fig. 5), Northeast Creek (site 19), and Jordan Lake (sites 20 to 23) are sodium + potassium and bicarbonate waters that are more mineralized than the baseline type. Statistical summaries of major anion and cation concentrations for 1989-92 water years at each monitoring site are reported in Garrett and others (1994).

Water-Quality Characteristics by Site Category

Summary statistics by site category were calculated by determining the median concentration of each constituent for each site. The median concentration for each category is determined from the median concentrations for sites within that category. The maximum and minimum values are the absolute maximum and minimum concentrations for all data collected for sites in each category (table 3).

Each site was assigned to one of the following five categories: (1) river, (2) large reservoir, (3) small reservoir, (4) stream site immediately downstream from an urban area and WWTP, and (5) headwater stream. In addition, sites near water-supply intakes were further identified as a sixth category (table 1). To determine if concentration varied according to site category, analysis of variance using nonparametric statistical procedures was applied to the data. To avoid potential bias that could occur when more data were collected for some sites than for others, analysis of variance was applied to median concentrations for each site. For a site where the median concentration was below the minimum reporting limit (MRL), the median was set equal to the MRL.

The analysis of variance procedure used was the Kruskal-Wallis rank transformation procedure. When more that two categories are tested, the Kruskal-Wallis

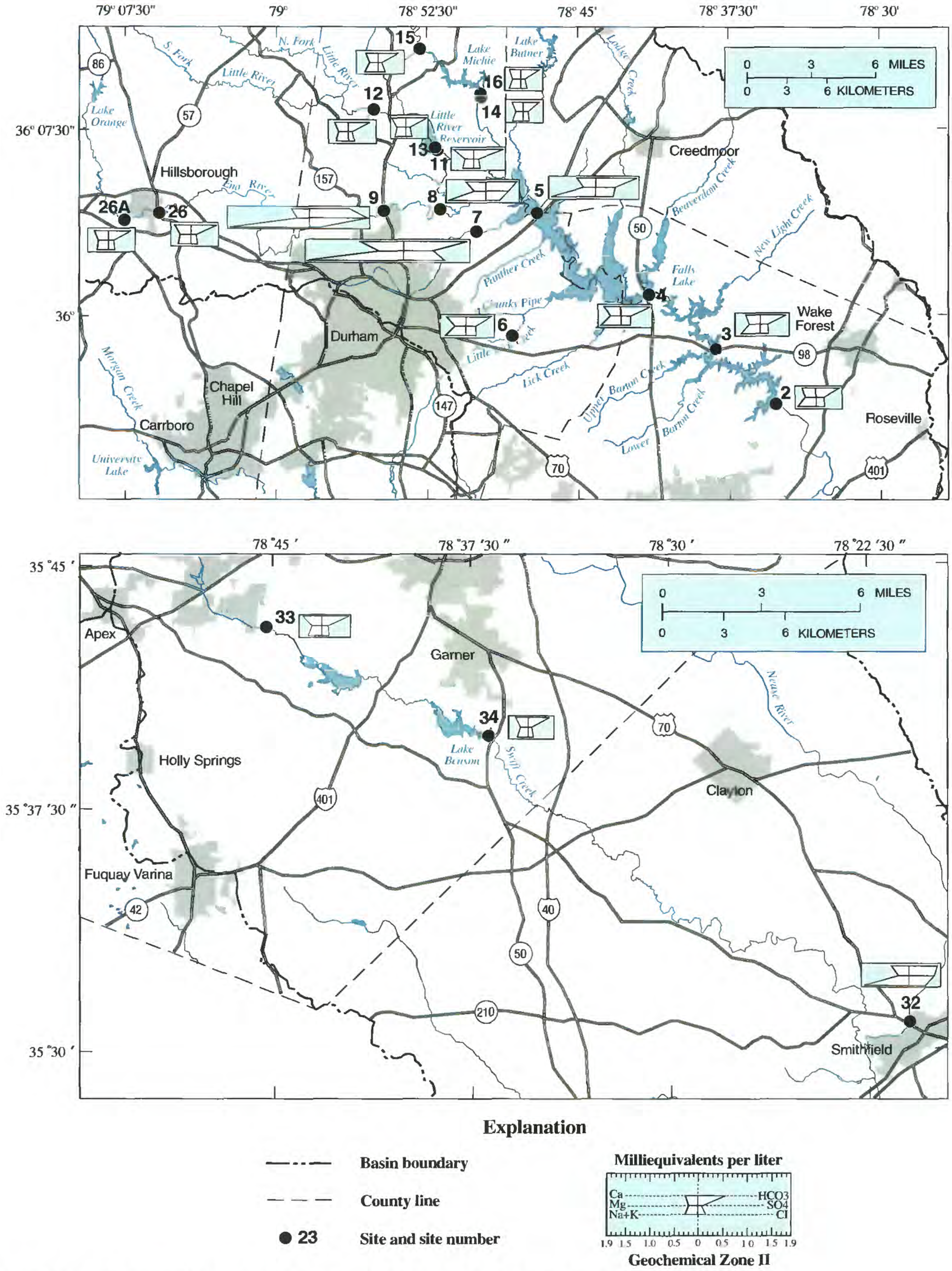

Figure 4. Stiff diagrams of major ions for sites in the upper Neuse River Basin.

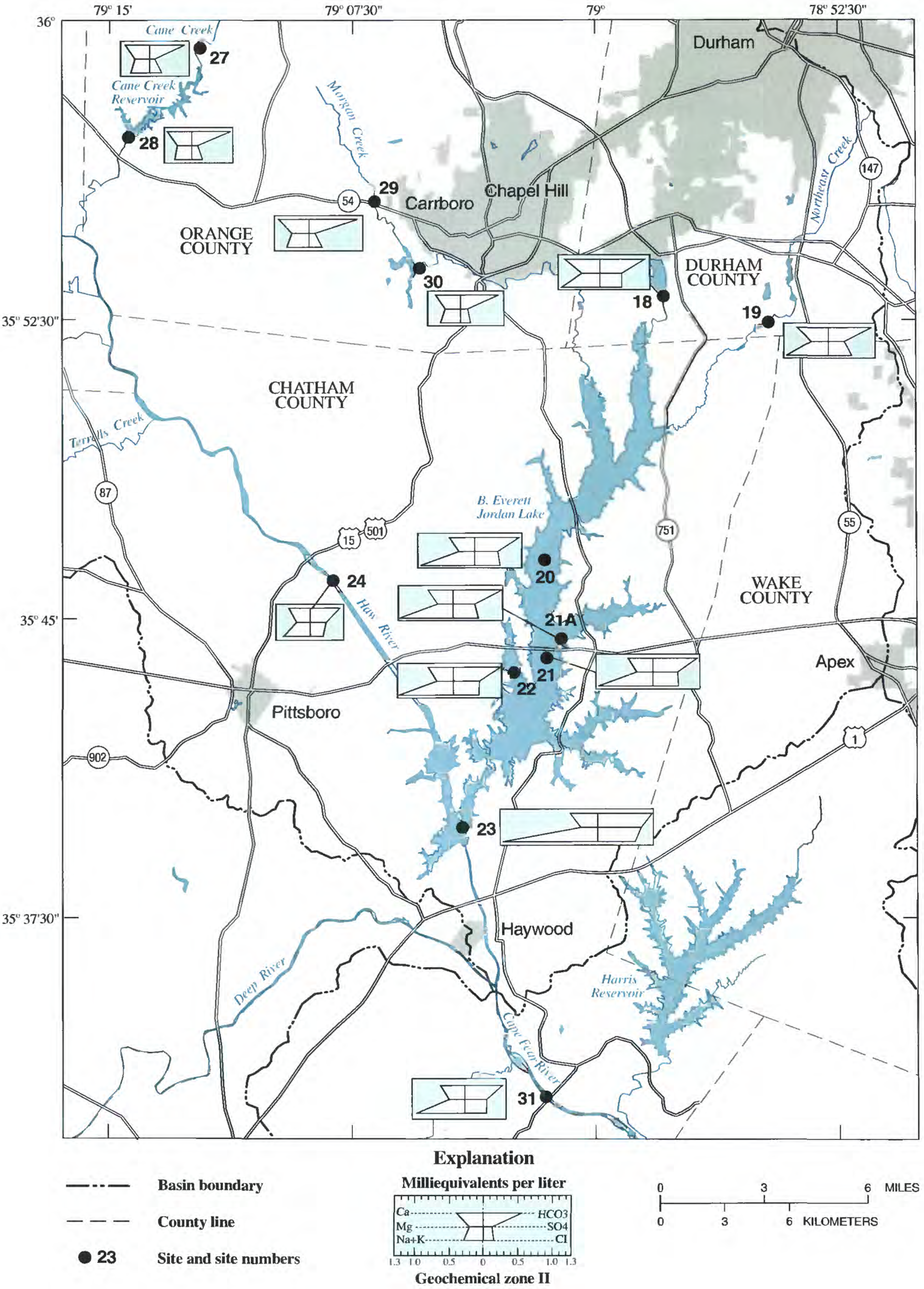

Figure 5. Stiff diagrams of major ions for sites in the upper Cape Fear River Basin.

Table 3. Statistical summary of selected nutrients, metals, and trace element constituents for site categories,

[n, number of sites; WWTP, wastewater-treatment plant; Min, minimum; Max, maximum; Med, median; mg/L, milligrams per liter; µg/L,

Chemical constituent	Minimum reporting level[a]	Site category								
		(1) Rivers (n=10)			(2) Large reservoirs (n=10)			(3) Small reservoirs (n=5)		
		Min	Max	Med	Min	Max	Med	Min	Max	Med
Nutrients										
Nitrite plus nitrate	0.01 mg/L as N	<0.01	5.5	0.42	<0.01	7.6	<0.05	<0.05	1.7	0.07
Ammonia	0.01 mg/L as N	<.01	.9	.07	<.01	.51	.04	<.01	2.3	.06
Ammonia plus organic nitrogen	0.2 mg/L as N	<.2	2.9	.6	.2	2.9	.6	.2	3.8	.6
Total nitrogen	0.01 mg/L as N	.2	5.9	1.0	.21	9.1	.7	.3	3.8	.68
Total phosphorus	0.01 mg/L as P	.01	.73	.08	<.01	1.2	.04	<.01	.23	.03
Orthophosphate	0.01 mg/L as P	<.01	.71	.03	<.01	.16	<.01	<.01	.2	<.01
Metals and trace elements										
Aluminum	10, 50 µg/L	20	6,800	485	20	1,300	70	<10	4,000	60
Arsenic	1, 10 µg/L	<1	2	<1	<1	2	<1	<1	1	<1
Cadmium	1, 2 µg/L	<1	6	<1	<1	1	<1	<1	3	<1
Chromium	1, 25 µg/L	<1	48	<1	<1	4	<1	<1	5	<1
Cobalt	1, 50 µg/L	<1	10	<1	<1	3	<1	<1	4	<1
Copper	1, 2, 5, 10 µg/L	<1	99	3.5	<1	23	<1	<1	400	<2
Iron	10 µg/L	10	18,000	930	40	2,600	178	100	7,400	380
Lead	1, 5, 10 µg/L	<1	59	<10	<1	22	<1	<1	7	<1
Manganese	10 µg/L	<10	1,200	140	<10	950	89	30	7,900	160
Mercury	0.1 µg/L	<.1	5.3	.1	<.1	.2	.1	<.1	.6	.2
Molybdenum	1 µg/L	<1	4	<1	<1	4	<1	<1	32	<1
Nickel	1, 10, 50 µg/L	<1	420	<10	<1	8	<1	<1	6	<1
Selenium	1 µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1
Silver	1,5, 25 µg/L	<1	2	<1	<1	1	<1	<1	2	<1
Zinc	10 µg/L	<10	3,400	<10	<10	380	<10	<10	70	<10

[a] Multiple minimum reporting levels are due to differences between laboratories and changes in analysis methods during the study.

[b] Maximum possible level of a contaminant in water which is delivered to any user of a public water system.

[c] Maximum permissible levels to protect aquatic life applicable to all fresh surface waters.

[d] Maximum contaminant level goal (MCLG)—A nonenforceable concentration of a drinking-water contaminant that is protective of adverse human health effects and allows an adequate margin of safety.

[e] Action levels.

October 1988 through September 1994

micrograms per liter; <, less than; MCL, maximum contaminant level]

Site category									MCL[b]	North Carolina water-quality standard[c]
(4) Streams below urban areas and WWTP's (n=8)			(5) Headwater streams (n=4)			(6) River and reservoir intake sites (n=12)				
Min	Max	Med	Min	Max	Med	Min	Max	Med		
Nutrients										
0.03	29	4	<0.01	1.7	0.46	0.05	1.35	0.10	10 mg/L	--
.01	2	.08	<.01	1.6	.03	.03	.10	.06	--	--
.03	11	.7	.1	3.3	.35	.4	.8	.6	--	--
.18	30	4.65	.13	4.4	.81	.57	2.0	.7	--	--
.01	5.8	.25	.01	2.8	.05	.02	.2	.03	--	--
<.01	3.5	.14	<.01	.9	.02	<.01	.08	<.01	--	--
Metals and trace elements										
80	24,000	1,460	<10	4,700	300	<10	6,800	85	--	--
<1	<10	<10	<1	15	<10	<1	<10	<1	50 µg/L	50
<2	2	<2	<1	34	<1	<1	6	<1	5	2.0
<1	18	<25	<1	130	3	<1	48	<1	100	50
<1	20	<50	<1	5	<1	<1	<50	<1	--	--
<2	72	6	<1	81	<2	<1	2,200	3	1,300[d]	7[e]
50	18,000	822	270	8,300	840	<10	18,000	550	--	1,000[e]
<1	18	<10	<1	21	<10	<1	59	<1	15[d]	25
15	2,100	110	13	1,100	50	<10	7,900	130	--	--
<.1	2.6	.15	<.1	.5	.2	<.1	5.3	<.1	.2	.012
<1	21	<1	<1	4	<1	<1	32	<1	--	--
<1	94	<10	<1	44	<10	<1	420	1	3[d]	88
<1	2	<1	<1	<1	<1	<1	5	<1	50	5
<1	860	<1	<1	57	<1	<1	<5	<1	--	.06[e]
<2	980	20	<10	60	<10	<10	3,400	4.7	--	--

procedure does not identify which categories are significantly different. Therefore, when a significant difference at alpha=0.05 was detected using the Kruskal-Wallis test, Tukey's multiple-comparison procedure (Tukey's W) was used to identify which site categories were statistically different from the others.

Nitrogen and Phosphorus

Nitrogen and phosphorus are among the most important of the constituents that are essential to the growth of plants and animals. The availability of nitrogen and phosphorus is the primary factor that determines the level of productivity of fresh and marine waters in terms of phytoplankton and macrophyte biomass. Excessive concentrations of nitrogen and phosphorus can lead to an undesirably high level of productivity and to a simplified biotic structure, a process referred to as eutrophication.

The forms of nitrogen and phosphorus analyzed for this study include nitrite plus nitrate, ammonia plus organic nitrogen, total nitrogen, total phosphorus, and orthophosphate. Concentrations of nitrogen forms are reported in equivalent units of elemental nitrogen, and phosphorus forms are reported in equivalent units of elemental phosphorus. Statistical summaries of data from the study area for these forms of nitrogen and phosphorus, as well as other forms, are reported in Garrett and others (1994) for water years 1989 through 1992.

Nitrogen

Nitrogen occurs in the environment in the form of ammonia, nitrite, nitrate, dissolved molecular nitrogen, and at various oxidation states as organic compounds. It is present in fresh waters primarily as nitrate and ammonia. Nitrogen undergoes biological and nonbiological transformations within the environment. In the reduced or organic forms, it is converted by soil bacteria into nitrite and nitrate. It is used by plants largely in the oxidized form (Cole, 1979). Excessive concentrations, usually associated with anthropogenic sources, such as municipal wastes, urban runoff, and agricultural runoff, are an important factor causing eutrophication.

Excessive concentrations of nitrate in drinking water is a public health concern, especially for small children. Cases have been documented where bottle-fed infants developed methemoglobinemia, which was attributed to the use of formula made with well water having a nitrate concentration in excess of 10 mg/L as N. Elderly persons are also at particular risk when ingesting water with high nitrate levels. For these reasons, careful monitoring of nitrogen concentrations in the area's drinking-water supplies is an important component of this study.

Concentrations of total nitrogen and nitrite plus nitrate were significantly greater for sites below urban areas and WWTP's (category 4) than for sites in the other site categories (fig. 6). The median nitrite plus nitrate concentration for sites below urban areas and WWTP's was 4.0 mg/L, which is more than 8 times the median concentrations that were recorded for the other categories. No significant differences were detected between small and large reservoirs or among other site categories for these constituents.

Of those sites below urban areas and WWTP's, the greatest median nitrite plus nitrate concentration was at Ellerbe Creek, site 7 (15 mg/L), which is located approximately 3 miles (mi) downstream from the Durham Northside WWTP. Ellerbe Creek also had the maximum nitrite plus nitrate concentration recorded at any site (29 mg/L). Both concentrations exceed the 10 mg/L U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) for nitrate in treated drinking water. Six of the eight sites in this category had median nitrite plus nitrate concentrations greater than 2.5 mg/L and maximum nitrite plus nitrate concentrations greater than 9 mg/L. Of the 29 monitoring sites in other site categories, only one had a median nitrite plus nitrate concentration greater than 1.0 mg/L, and only three sites had maximum concentrations in excess of 4 mg/L during the study period (table 3)—Neuse River at Smithfield (site 32), Haw River at Bynum (site 24), and Falls Lake at Interstate 85 (site 5).

Median concentrations of total ammonia plus organic nitrogen varied little among site categories; the only significant difference was between sites below urban areas and WWTP's (category 4, median 0.7 mg/L) and sites on headwater streams (category 5, median 0.35 mg/L, fig. 6). The median concentration for the remaining three categories was 0.6 mg/L. The maximum total ammonia plus organic nitrogen concentration was 11 mg/L measured in a sample from Little Lick Creek (site 6). The presence of large concentrations of organic nitrogen and ammonia are indications of upstream sewage disposal. Organic nitrogen accounted for 80 to 90 percent of the concentration of ammonia plus organic nitrogen for all

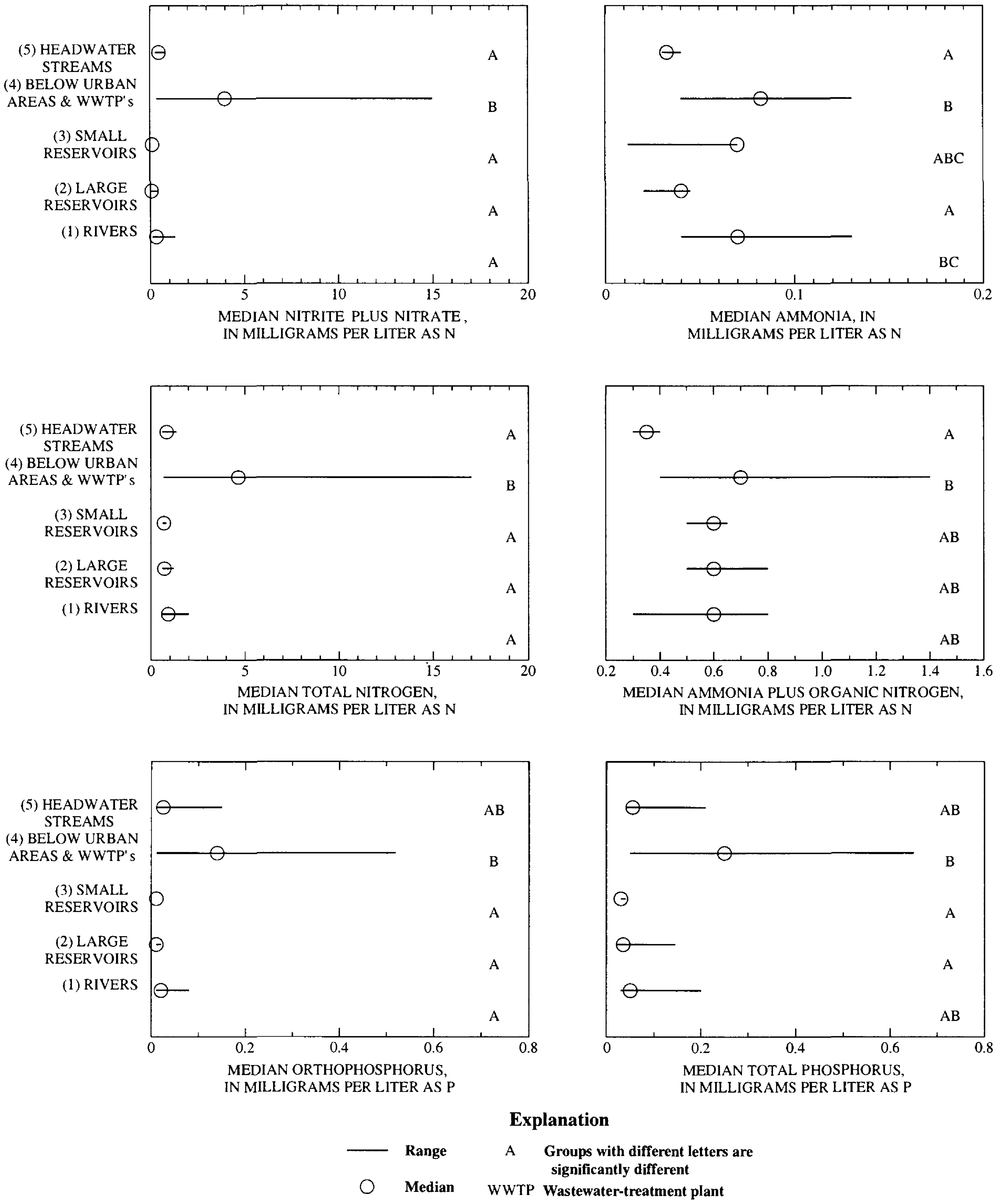

Figure 6. The distribution of median concentrations of selected nutrients by site category in the Research Triangle study area, North Carolina.

site categories. Median ammonia concentrations were significantly less for headwater streams and large reservoirs than for sites below urban areas and WWTP's and river sites (fig. 6). Greatest ammonia concentrations (2 mg/L or more) occurred at Ellerbe Creek (site 7) and University Lake (site 30).

Total nitrogen concentrations were significantly greater at sites below WWTP's than at other sites. Nitrite, nitrate, ammonia, and organic nitrogen are all components of total nitrogen; for large and small reservoir sites, organic nitrogen (based on median concentrations) was the predominant form of nitrogen probably because of its presence in algae. For sites below urban areas and WWTP's, nitrate was the predominant nitrogen form. For rivers and headwater streams, nitrate and organic nitrogen forms were about equal.

Median concentrations of nitrite plus nitrate and total nitrogen were significantly different for water-supply intake sites on rivers and reservoirs. Median concentrations of nitrite plus nitrate were 0.7 mg/L for river intake sites and 0.06 mg/L for reservoir intake sites. Median concentrations of total nitrogen were 1.3 mg/L for river intake sites and 0.64 mg/L for reservoir intake sites. River intake sites are located downstream from urban areas and receive the accumulated effluents from urban point sources which tend to have relatively high concentrations of nitrate. No significant difference was detected between river and reservoir intake sites for ammonia or organic nitrogen. Maximum concentrations among river intake sites for nitrite plus nitrate (5.5 mg/L) and total nitrogen (5.9 mg/L) occurred at Deep River at Carbonton (site 46).

Phosphorus

Phosphorus is essential for the metabolism of all living organisms and can be the single most critical factor in the maintenance of biogeochemical cycles. In freshwater aquatic environments, phosphorus enrichment can stimulate the growth of aquatic plants, including algae, leading to eutrophication, disruption of the normal aquatic community composition, and oxygen depletion as plants die and decay. It can also cause water-supply problems such as filter clogging and unpleasant taste and odors.

Phosphorus occurs naturally in igneous rock and is frequently abundant in sediments. Phosphorus occurs in natural waters as phosphate in various forms—orthophosphate, condensed phosphate, and organically bound phosphate. Concentrations of phosphorus present in solution in natural surface waters are rarely greater than a few tenths of a milligram per liter (Hem, 1985). Mean concentrations of total phosphorus for selected streams in forested basins throughout North Carolina ranged from 0.01 mg/L to 0.04 mg/L (Caldwell, 1992). Mean total phosphorus concentrations in surface waters of agricultural drainages ranged from 0.16 mg/L to 1.4 mg/L (Harned, 1982).

The forms of phosphorus are analytically defined. In this study, orthophosphorus and total phosphorus concentrations were analyzed. Total phosphorus includes all forms of phosphorus that are oxidized to orthophosphorus with rigorous phosphomolybdate digestion. Orthophosphate is the bioavailable form of phosphorus. Sources for orthophosphate include agricultural and residential fertilizers. Organically bound forms of phosphorus, another part of total phosphorus, are formed by biological wastewater-treatment processes, by instream biota, or from body wastes. Industrial- and domestic-sewage effluents have been an important potential source of phosphorus in the form of acid-hydrolyzable phosphates, which are added to detergents. A ban on phosphate detergents was imposed in North Carolina in 1988.

Median total phosphorus concentrations ranged from less than 0.01 mg/L at Falls Lake at the City of Raleigh intake (site 2) and at NC-98 (site 3), Little River Reservoir (site 13), and Jordan Lake at Bells Landing (site 22) to 5.8 mg/L at Knap of Reeds Creek (site 10). Median concentrations of total phosphorus for sites below urban areas and WWTP's were significantly greater than for reservoir sites (fig. 6) but were not significantly greater than headwater and river sites indicating that both the contributions of phosphorus from point sources and resuspension of phosphorus from streambeds are important factors determining total phosphorus concentration. Municipal point sources are important contributors to the total phosphorus load in surface waters. That and the fact that total phosphorus strongly adsorbs to particulates and, therefore, is associated with suspended sediments probably accounts for the greater concentration in streams compared to reservoir sites. The median total phosphorus concentration for sites below urban areas and WWTP's was 0.25 mg/L compared to median concentrations less than 0.05 mg/L for reservoir sites (table 3).

In general, orthophosphate was about 50 percent of total phosphorus concentration. Median concentrations of orthophosphate were significantly greater for sites below urban areas and WWTP's than for reservoir or river sites (fig. 6). The maximum concentration for sites below urban areas and WWTP's, 3.5 mg/L, occurred at Knap of Reeds Creek (site 10, table 3). The maximum concentration for sites in other categories was 0.9 mg/L at Morgan Creek near White Cross (site 29, table 3).

A marked seasonal pattern was observed for phosphorus at reservoir sites. Two examples are Falls Lake at Interstate 85, which is seasonally shallow, and the Haw River arm of Jordan Lake (fig. 7). Greatest concentrations of phosphorus (as much as 0.23 mg/L) generally occurred during late summer and fall months. Peaks in chlorophyll *a* concentration roughly corresponded to phosphorus peaks. Chlorophyll *a* concentrations ranged from less than 10 to 140 micrograms per liter (µg/L). The North Carolina State water-quality standard for chlorophyll *a* is 40 µg/L.

Trace Elements

Trace elements occur naturally in the environment from geochemical weathering. Trace elements, such as arsenic, cadmium, copper, chromium, lead, nickel, zinc, and mercury, generally are present in water in concentrations less than 25 µg/L. Metals such as iron, aluminum, and manganese, although abundant, are included here. Differences in local geology account for much of the variation in concentrations between streams and lakes in this study. However, industrial and municipal discharges, as well as urban land cover, often account for elevated trace-element concentrations.

Summary statistics by site category were calculated by determining the median concentration of each trace element for each site (table 3). The median concentration for each category is determined from the median concentrations for sites within that category. The maximum and minimum values are the absolute maximum and minimum concentrations for all data collected for sites in each category.

For most trace elements, data from samples collected by the DEM had higher MRL's than did data from samples collected by the USGS. This complicated data interpretation because trace-element concentrations generally were less than 1 or 2 µg/L, and many USGS detections were less than the DEM's MRL. Furthermore, most of the sites sampled by the DEM are located below urban areas and WWTP's (category 4). For sites with multiple MRL's, data were censored to the highest MRL unless the number of analyses with the highest MRL was minor. In that case, the highest MRL values were removed.

Because of the large number of concentrations below laboratory MRL's and because the database often contains multiple MRL's, analysis of variance could not be used to test for statistically significant differences between site categories. Instead, box plots of copper, lead, and zinc data illustrate general differences among categories (figs. 8 and 9). The distribution displayed by the box plots (Helsel and Hirsch, 1992, p. 453-454) was determined using the log-probability method of Helsel and Cohn (1988) and was based on reported concentrations above and below the MRL's. Distributions below the lowest MRL are not shown; the distribution between two MRL's is shaded to indicate it is based on log-probability assumptions.

Generally, greatest concentrations of trace elements were observed in streams during periods of greater than normal streamflow. This is likely the result of resuspension of silt, clay, and organic particles that are associated with adsorbed trace elements (Horowitz, 1991). In reservoirs, particulates tend to settle out of the water column and are not readily resuspended.

Iron and manganese are naturally abundant and commonly coat clay particles. This often causes concentrations of these metals in untreated surface waters to exceed the USEPA secondary drinking-water standards (aesthetic standards) for iron (1,000 µg/L) and manganese (50 µg/L). This occurs even in relatively undisturbed streams. Median concentrations were near or above the standards at river, headwater, and stream sites below urban areas and WWTP's (table 3). During the normal seasonal cycle of lake stratification, it is common for concentrations of soluble iron and manganese to increase by an order of magnitude in oxygen-poor bottom waters. Reservoir bottom waters were not sampled; however, median concentrations in surface reservoir waters were substantially less than in streams.

Arsenic is a naturally occurring trace element that is toxic in relatively small amounts. The USEPA drinking-water MCL and North Carolina State water-quality standard for arsenic are both 50 µg/L. Sources for arsenic include pesticides, a by-product of coal burning, and smelting of ore. Concentrations of

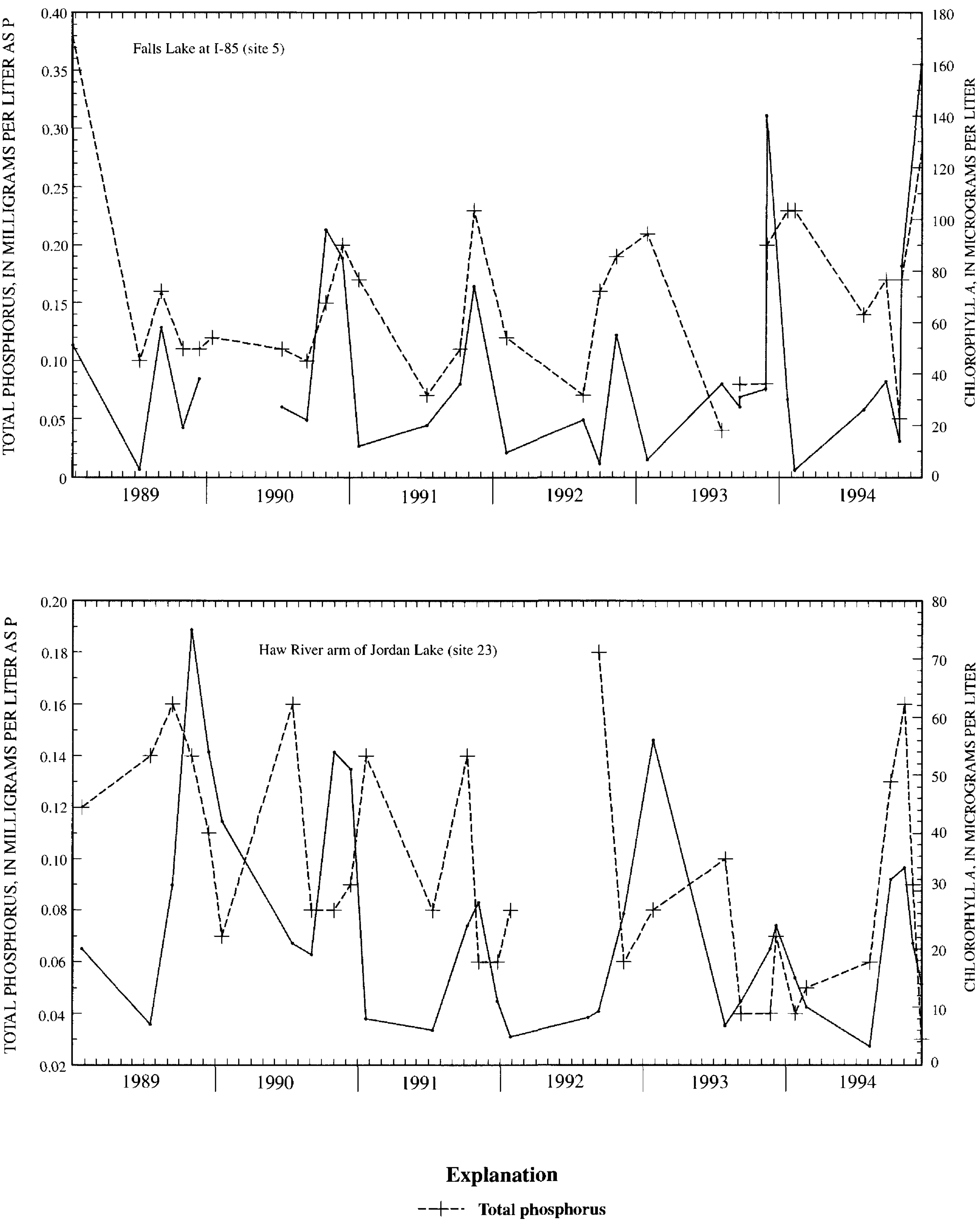

Figure 7. Total phosphorus and chlorophyll *a* concentrations for Falls Lake at I-85 and Haw River arm of Jordan Lake, 1988-94.

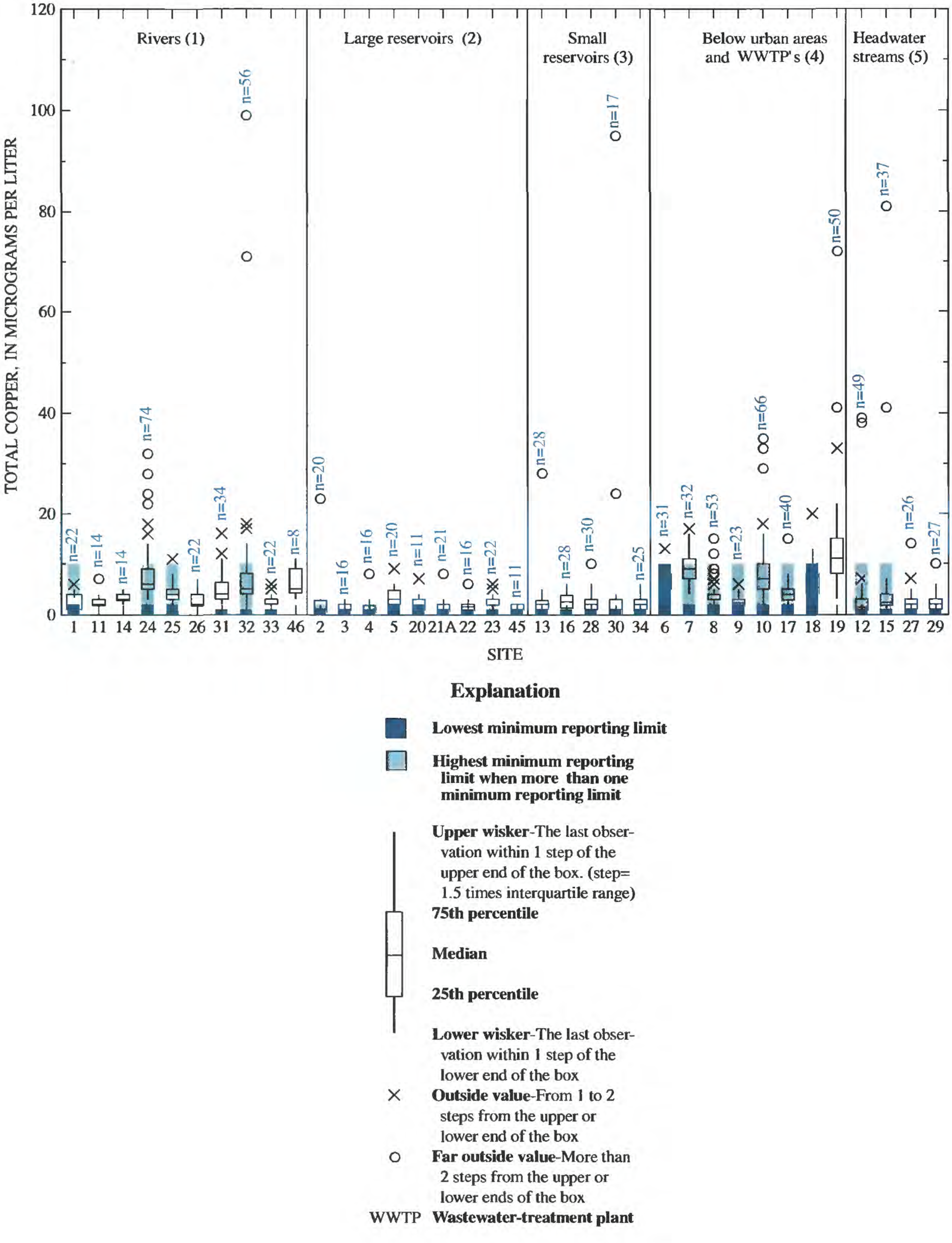

Figure 8. The distribution of copper concentrations by site and site category in the Research Triangle study area, North Carolina.

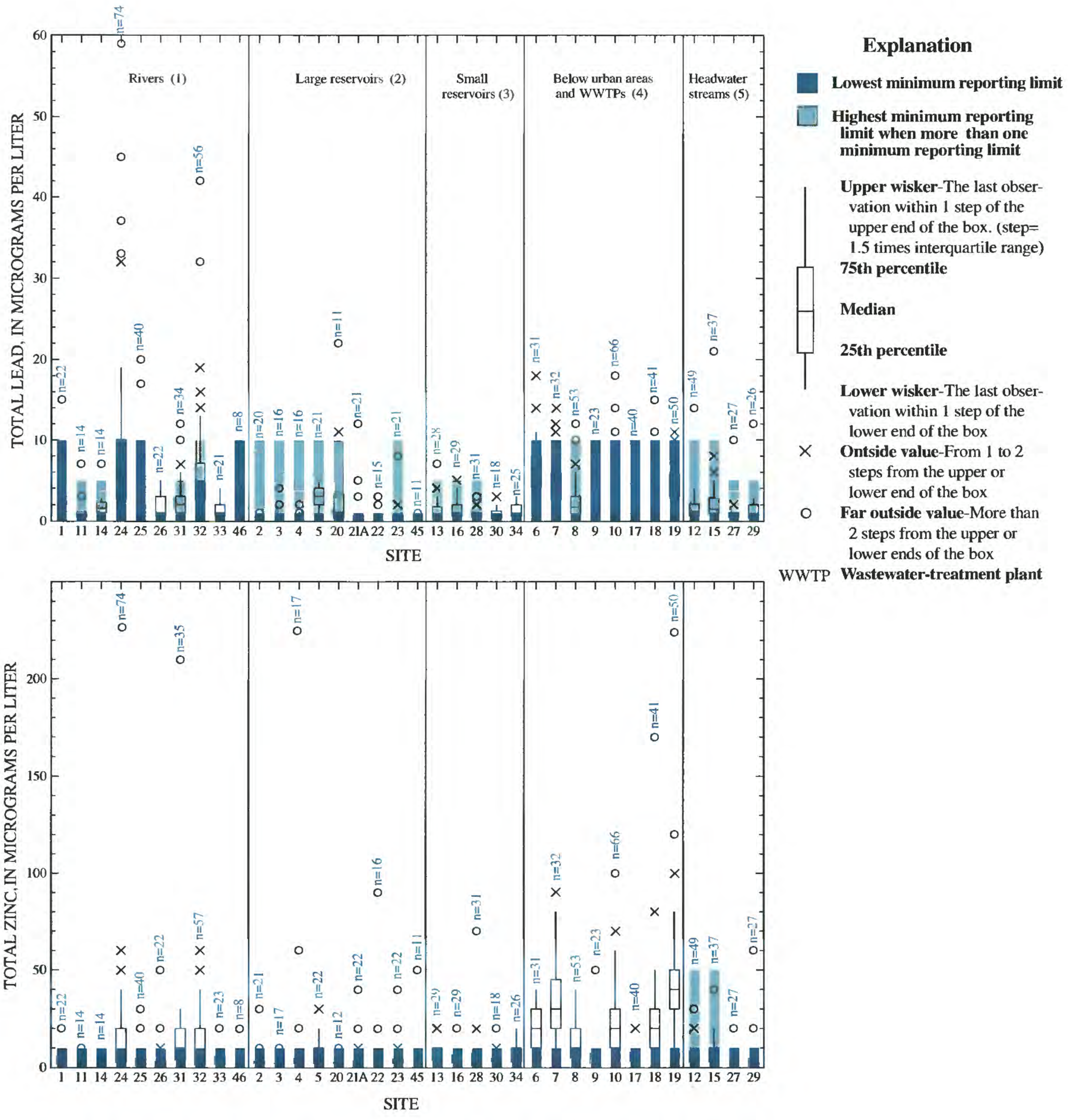

Figure 9. The distribution of lead and zinc concentrations by site and site category in the Research Triangle study area, North Carolina.

arsenic ranged from below detection (less than 1 µg/L) to 15 µg/L. Most analyses were less than the MRL. The greatest concentrations of arsenic, 15 and 11 µg/L, occurred at Flat River (site 15) and Little River (site 12) in 1988. Arsenic also occurred in bottom sediments at these sites possibly from past agricultural sources.

Cadmium occurs in some ores and is used extensively in industry. Cadmium can become an environmental contaminant through waste-disposal practices or from the atmosphere. The State water-quality standard for cadmium is 2 µg/L; the drinking-water MCL is 5 µg/L. Both standards were exceeded by fewer than 1 percent of the samples analyzed. The greatest concentration, 34 µg/L, was in a sample from Little River (site 12).

The concentration of chromium in natural waters is generally less than 10 µg/L; however, chromium may be introduced to surface waters in industrial wastes. The drinking-water MCL for chromium is 100 µg/L. Only five samples had chromium concentrations that exceeded 25 µg/L, the DEM MRL. Those samples were collected from Neuse River at Smithfield (site 32), Cape Fear River (site 31), Cane Creek (site 27), Flat River (site 15), and Little River (site 12). Cane Creek and Flat River concentrations also exceeded the State water-quality standard of 50 µg/L. The USGS MRL for chromium was 1 µg/L. An additional 21 percent of analyses and at least one analysis from each station sampled had concentrations between the 1 and 25 µg/L MRL's. When data with an MRL of 25 µg/L are not considered, data from sites below urban areas and WWTP's tended to have greater chromium concentrations than did other categories (table 3).

Cobalt is found naturally in very small concentrations. No drinking-water MCL's or water-quality standards have been set for cobalt. All but three concentrations were less than 5 µg/L. The greatest concentration was 20 µg/L.

Copper is common in the environment from natural and anthropogenic sources, including uses in industry and agriculture. For drinking water, the most common source is from dissolution of copper plumbing fixtures. The drinking-water action level is 1,300 µg/L. Concentrations in the study area ranged from less than 1 to 400 µg/L. MRL's were 1, 2, 5, and 10 µg/L depending on the agency performing the analyses and the date the sample was collected. About 9 percent of analyses exceeded 10 µg/L; most of these occurred in samples from large rivers and sites below urban areas and WWTP's. The median copper concentration exceeded 10 µg/L at Northeast Creek (site 19). In general, the smallest concentrations of copper were detected at large and small reservoir sites and headwater streams (fig. 8).

Lead occurs naturally at trace concentrations. It adsorbs readily to inorganic and organic surfaces so that it tends to be in low concentrations in surface waters. Environmental contamination from lead has resulted from industrial sources such as coal burning and from its use as an additive in gasoline. For drinking water, the major source of concern is dissolution of lead from plumbing. The drinking-water action level is 15 µg/L. The MRL's for lead were 1, 5, and 10 µg/L. Nearly all of the samples collected from sites below urban areas and WWTP's were analyzed with an MRL of 10 µg/L. The median concentrations for all site categories were less than 10 µg/L. Only 4 percent of analyses exceeded 10 µg/L. In general, greatest concentrations occurred in samples from rivers (fig. 9). Seven samples, five from the Haw River (site 24) and two from the Neuse River (site 32), exceeded the State water-quality standard for lead of 25 µg/L.

Molybdenum occurs naturally in streams and lakes in trace amounts (less than 1 µg/L). Fossil-fuel combustion is a probable source where higher concentrations are found. No drinking-water MCL's or water-quality standards have been set for molybdenum. Sixty-seven percent of analyses were less than 1 µg/L, and all but seven samples had concentrations less than 5 µg/L. The seven highest concentrations occurred at Northeast Creek (site 19), Ellerbe Creek (site 7), Eno River near Weaver (site 8), and University Lake (site 30).

Nickel is widely used in industry and is a common environmental contaminant. It is a constituent of stainless steel and other alloys. The drinking-water MCL for nickel is 100 µg/L; the State water-quality standard is 88 µg/L. Sixty-four percent of nickel analyses were below the MRL of 10 or 50 µg/L. Two samples from Haw River (site 24, 420 µg/L) and Knap of Reeds Creek (site 10, 94 µg/L) exceeded the State water-quality standard. Only 16 samples analyzed for nickel with an MRL of 10 µg/L exceeded the MRL—all were at stream sites. Nickel is relatively insoluble and adsorbs to iron and manganese oxides on particulates. Particulates tend to settle in reservoirs and are not readily subject to resuspension during storm-produced runoff as in streams.

Selenium is a naturally occurring element in trace amounts in North Carolina; the drinking-water MCL is 50 µg/L. Only one selenium concentration was greater than the MRL of 1 µg/L—a concentration of 2 µg/L in a sample from Little Lick Creek (site 6).

Silver has numerous anthropogenic sources, most notably photographic processing. Because of its value, silver is often recovered from industrial wastes. The State water-quality action level for silver is 0.06 µg/L; no drinking-water MCL has been established. Only five silver concentrations exceeded 1 µg/L; however, for a few samples the MRL was 25 µg/L.

Zinc occurs naturally but is also a common environmental contaminant. It is widely used for galvanizing steel, in paints, and in combination with other metals. The State water-quality action level for zinc is 50 µg/L; there is no drinking-water MCL. Median zinc concentrations were less than the MRL for all site categories except sites below urban areas and WWTP's; however, 39 percent of all analyses exceeded 10 µg/L. The distribution of zinc concentrations by site category indicates that river sites, especially those below urban areas and WWTP's, tended to have greater zinc concentrations than did other sites (fig. 9).

Volatile Organic Compounds

During the first 3 years of this study, water samples were collected 3 times per year at each monitoring site for the analysis of 35 volatile organic compounds (VOC's), including trihalomethanes (THM's) and USEPA priority pollutants. Because VOC's have high vapor pressures, they are easily lost to the atmosphere and do not adsorb to sediments. They are most appropriately sampled in the water column (Chapman and others, 1982) but seldom persist there and require special sampling methods.

Few VOC's were detected in concentrations above the MRL. The greatest percentage of VOC detections occurred at sites below urban areas and WWTP's (fig. 10). Most of these detections were very low concentrations of any of four THM's—chloroform, bromoform, dichlorobromomethane, and chlorodibromomethane. THM's are formed when chlorine reacts with naturally occurring dissolved organic carbon. This reaction often occurs in water and wastewater that have been disinfected with chlorine. Thus the concentration of dissolved organic carbon in water or wastewaters and chlorination are important factors in THM formation (Thurman, 1985). Treated tap water usually contains from 50 to 75 µg/L THM. The USEPA primary drinking-water MCL for THM is 100 µg/L.

THM's were found almost exclusively at sites below urban areas and WWTP's; however, at these sites, low concentrations were typical (table 4). The only sites where THM's were detected that were not immediately downstream from urban areas and WWTP's were Little River Reservoir (site 13), Falls Lake at Interstate 85 (site 5), and Neuse River at Smithfield (site 32). Very low concentrations of chloroform were measured at least once at each of these sites. Neuse River at Smithfield, while not immediately downstream from an urban area or WWTP, receives drainage from the Raleigh area.

Xylene, a component of gasoline, was found at a concentration of 1.6 µg/L in one sample from the Neuse River at Smithfield (site 32). The USEPA drinking-water MCL for total xylenes is 10 mg/L. Trace amounts (less than 1 µg/L) of other VOC's, mostly organic solvents, such as benzene, dichlorobenzene, tetrachloroethylene, and trichloroethane, were found in fewer than 20 percent of 298 samples collected. USEPA drinking-water MCL's for those VOC's for which MCL's have been set are 5 µg/L or greater. The presence of these compounds is related to their widespread commercial production and use.

Pesticides and PCB's

During the first 3 years of study, water samples were collected 3 times per year at each monitoring site for the analysis of 24 organochlorine and organophosphorus insecticides and PCB's[2] (Garrett and others, 1994). Because of their persistence in the environment, potential to bioaccumulate, and carcinogenic properties, organochlorine insecticides have been increasingly regulated over the past two decades and, in some cases, their use in the United States has been restricted (lindane and chlordane) or banned (DDT, mirex, dieldrin, and PCB's).

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[2] Polychlorinated biphenyls, although not pesticides, were analyzed with this group of compounds because they are chemically similar to organochlorine insecticides and behave in a similar way in the environment. PCB's were widely used in the electrical industry and also in lubricating oils, pesticides, adhesives, and plastics.

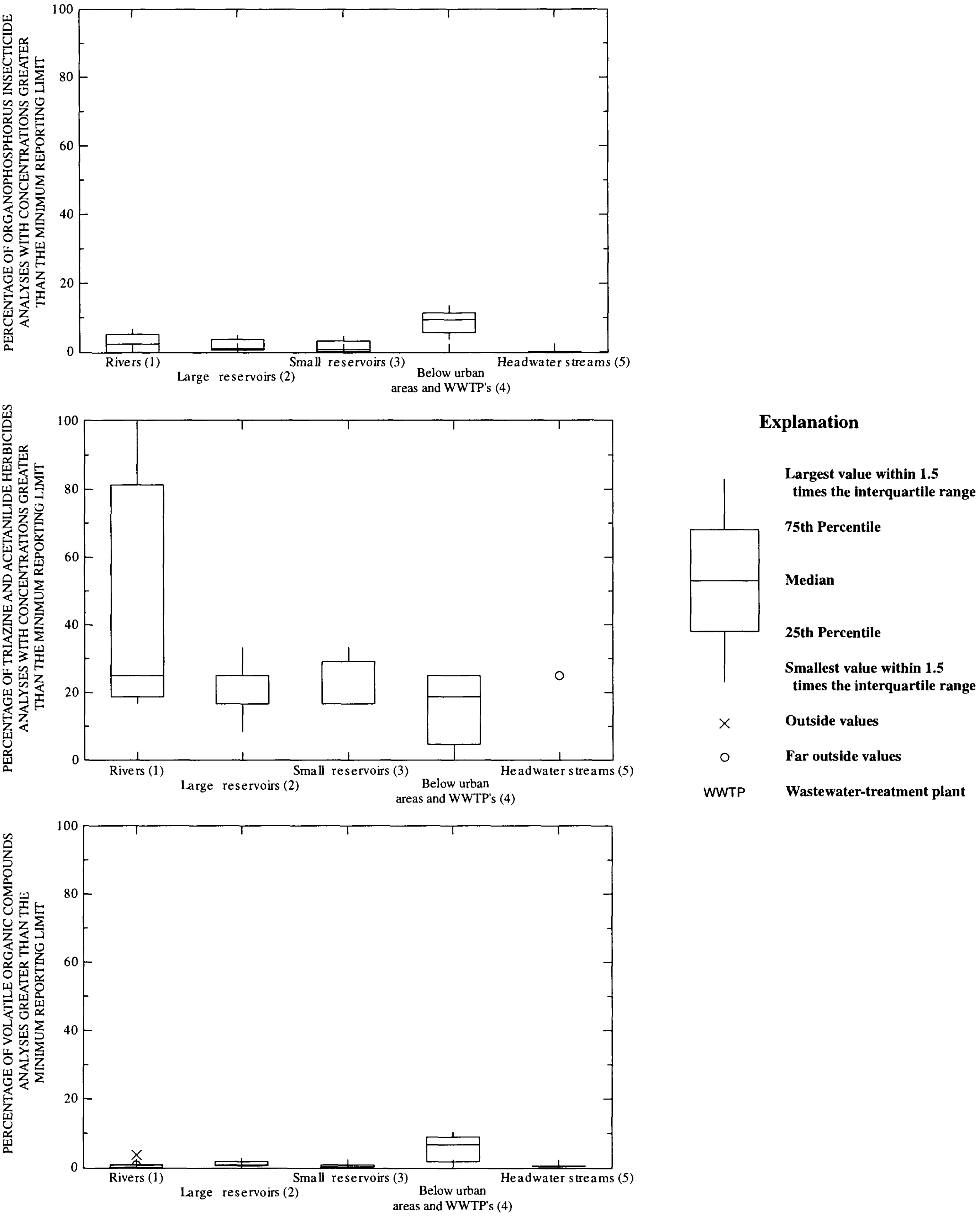

Figure 10. The distribution, by site category, of the percentage of pesticides or volatile organic compounds for which concentrations were above minimum reporting limits.

Table 4. Summary statistics of total trihalomethane concentrations measured at sites located downstream from urban areas and wastewater-treatment plants, water years 1989-91

[<, less than]

Site number (fig. 2)	Station name	Total trihalomethane concentration (micrograms per liter)			Number of observations	
		Median	Minimum	Maximum	Total	Detectable
6	Little Lick Creek above Secondary Road 1814 near Oak Grove	2.8	<0.8	7.8	8	7
7	Ellerbe Creek near Gorman	2.2	<.8	4	8	7
8	Eno River near Weaver	<.8	<.8	.9	9	2
9	Eno River near Durham	<.8	<.8	.9	8	1
10	Knap of Reeds Creek near Butner	4.6	<.8	86	8	7
17	Morgan Creek near Farrington	.9	<.8	1.8	7	4
18	New Hope Creek near Blands	3.15	1.3	7.9	8	8
19	Northeast Creek at Secondary Road 1100 near Genlee	4.75	1.2	11.9	8	8

Organophosphorus insecticides are generally less environmentally persistent and more water soluble than the organochlorine insecticides. Organochlorine and organophosphorus insecticides are used for insect control on crops, lawns, gardens, in homes, and on domestic animals. Because organochlorine and organophosphorus insecticides have low water solubility, they are typically detected in water in very low concentrations.

About 40 percent of 368 samples collected for insecticide and PCB analysis contained a detectable concentration of at least one of these compounds. The four most frequently detected were lindane, dieldrin, diazinon, and heptachlor epoxide—at least one of these was detected at each of 18 monitoring sites. Most frequent detections (6.9 to 13.7 percent of analyses) occurred in six tributaries to Falls and Jordan Lakes—that is, in streams downstream from urban areas and WWTP's—and at Swift Creek near Apex (fig. 10). Insecticides also were detected in the uplake segment of Falls Lake, the Haw River arm of Jordan Lake, Little River Reservoir, and Lake Benson. There were almost no detections of these compounds in headwater streams (fig. 10)—although most of those that occurred were from Cane Creek (site 28).

Nearly all concentrations of insecticides and PCB's were very small. For example, all concentrations for lindane and heptachlor epoxide were significantly less than their USEPA drinking-water MCL's of 0.2 µg/L. However, some dieldrin and lindane concentrations exceeded the State water-quality standards of 0.002 and 0.01 µg/L, respectively. A single sample from Northeast Creek contained 1 µg/L of diazinon; however, there are no Federal or State standards for diazinon.

In the spring of 1992, samples for the analysis of 13 acetanilide and triazine herbicides were collected at selected sites. These generally are preemergence herbicides that are used for crops, turf, and brush control. They range from slightly soluble (atrazine, simazine) to soluble (alachlor, prometon) in water and from nonpersistent (alachlor, metolachlor) to moderately persistent (atrazine, simazine) in the environment (Briggs, 1992). Alachlor, atrazine, and simazine are on the USEPA list of regulated constituents for drinking water.

Detectable concentrations of herbicides—mainly atrazine or simazine (table 5) were detected at every site sampled. With one exception, all detectable concentrations were less than 1 µg/L and less than the drinking-water MCL for alachlor (2 µg/L), atrazine (3 µg/L), and simazine (4 µg/L). The percentage of acetanilide and triazine herbicide analyses that were above the MRL was considerably greater than the

Table 5. Results of analyses of triazine and acetanilide herbicides in water samples collected at selected sites during the spring of 1992

[Concentrations are in micrograms per liter. Number in parentheses indicates U.S. Environmental Protection Agency drinking-water standard. <, less than; OWASA, Orange Water and Sewer Authority]

Site number (fig. 2)	Station name	Date	Simazine (4)	Prometryn	Prometon	Atrazine (3)	Deisopropylatrazine	Deethylatrazine	Cyanazine	Ametryn	Propazine	Alachlor (2)
26	Eno River at Hillsborough	4-21-92	<0.05	<0.05	<0.05	0.77	<0.05	<0.05	<0.20	<0.05	<0.05	0.05
8	Eno River near Weaver	5-08-92	<.05	.05	<.05	.08	<.05	<.05	<.20	<.05	<.05	<.05
		5-30-92	.06	<.05	<.05	.09	<.05	<.05	<.02	<.05	<.05	<.05
13	Little River Reservoir at Dam near Bahama	4-29-92	.19	<.05	<.05	.20	<.05	<.05	<.20	<.05	<.05	<.05
16	Lake Michie at Dam near Bahama	4-29-92	.46	<.05	<.05	1.3	<.05	.05	<.20	<.05	<.05	<.05
7	Ellerbe Creek near Gorman	4-21-92	.86	<.05	.09	<.05	.07	<.05	<.20	<.05	<.05	<.05
5	Falls Lake at Interstate 85 near Redwood	5-19-92	.14	<.05	<.05	.30	<.05	<.05	<.20	<.05	<.05	<.05
6	Little Lick Creek above Secondary Road 1814 near Oak Grove	4-22-92	.06	<.05	<.05	<.05	<.05	<.05	<.20	<.05	<.05	<.05
		5-08-92	<.05	<.05	<.05	<.05	<.05	<.05	<.20	<.05	<.05	<.05
		5-30-92	<.05	<.05	<.05	<.05	<.05	<.05	<.20	<.05	<.05	<.05
4	Falls Lake at State Highway 50 near Sandy Plain	5-19-92	.13	<.05	.05	.06	<.05	<.05	<.20	<.05	<.05	<.05
3	Falls Lake at State Highway 98 near Bayleaf	5-19-92	.11	<.05	<.05	<.05	<.05	<.05	<.20	<.05	<.05	<.05
2	Falls Lake above Dam at Falls (Raleigh intake)	5-19-92	.12	<.05	<.05	.05	<.05	<.05	<.20	<.05	<.05	<.05
27	Cane Creek near Orange Grove	4-21-92	<.05	<.05	<.05	.16	<.05	.05	<.20	<.05	<.05	.15
28	Cane Creek Reservoir at Dam near White Cross (OWASA intake)	4-30-92	<.05	<.05	<.05	.27	<.05	<.05	<.20	<.05	<.05	.06
24	Haw River near Bynum	4-23-92	.28	<.05	<.05	.54	<.05	<.05	<.20	<.05	<.05	<.05
23	Jordan Lake, Haw River Arm above B. Everett Jordan	5-13-92	.20	<.05	<.05	.32	<.05	<.05	<.20	<.05	<.05	<.05
19	Northeast Creek at Secondary Road 1100 near Genlee	4-22-92	.07	<.05	.08	.05	<.05	<.05	<.20	<.05	<.05	<.05
		5-08-92	.47	<.05	<.05	.30	<.05	<.05	<.20	<.05	<.05	<.05
		5-30-92	.07	<.05	<.05	.37	<.05	<.05	<.20	<.05	<.05	.07
		5-30-92	<.05	<.05	<.05	.38	<.05	<.05	<.20	<.05	<.05	.05

percentage of organochlorine and organophosphorus insecticides (fig. 10) probably because of the greater use and greater solubility of these herbicides in water.

In the spring of 1993 and 1994, pesticide data collection was targeted to three monitoring sites (Ellerbe Creek, Northeast Creek, and Little Lick Creek) located downstream from WWTP's and that had previous detections of organochlorine and organophosphorus pesticides. The purpose of this special pesticide sampling was to determine if the source of pesticides was WWTP effluent or runoff upstream from the WWTP. Samples for analyses of organochlorine and organophosphorus insecticides were collected from each stream at the regular monitoring site downstream from the WWTP, from the WWTP outfall, and upstream from the WWTP outfall. Because previous sample collections indicated the presence of acetanilide and triazine herbicides, samples collected at the regular monitoring site were analyzed for these compounds and for carbamate and chlorophenoxy acid herbicides. Samples were collected 3 times under low, medium, and high streamflow conditions.

Organochlorine and organophosphorus insecticides appear to be ubiquitous in very low concentrations in WWTP effluents, upstream from WWTP's, and downstream from WWTP's. Diazinon, lindane, dieldrin, DDD, DDE, DDT, and chlorpyrifos, were measured at concentrations near the MRL (table 6). (Compounds with no detections are not listed in table 6.) Of these, only lindane, chlorpyrifos, and diazinon are still in use in the United States. DDE is a degradation product of DDT. None of the organochlorine or organophosphorus compounds exceeded Federal drinking-water MCL's. Five samples exceeded the State water-quality standards for dieldrin; one exceeded the standard for lindane. Most notably, diazinon, a widely used compound for suburban and agricultural pest control, was detected in every sample.

Low concentrations of herbicides occurred in stream and WWTP effluent samples, providing no conclusive information on source. Simazine, prometon, deisopropylatrazine, deethylatrazine (triazine herbicides), 2,4-D, and 2,4-DP (chlorophenoxy acid) were measured at concentrations at or above the MRL (table 6). Deisopropylatrazine and deethylatrazine are degradation products of atrazine, and their presence in the absence of atrazine indicates a prior source of atrazine. In May 1993, simazine, prometon, 2,4-D, and 2,4-DP were measured at concentrations significantly greater than detection limits but at least an order of magnitude smaller than Federal drinking-water MCL's. Because the Northeast and Little Lick Creek samples were collected at only the downstream site, it is not known if these compounds were from local runoff or WWTP effluents. Ellerbe Creek samples were collected from only the upstream site indicating that, for Ellerbe Creek, local runoff is a source for simazine, prometon, and 2,4-D. Triazine herbicides samples were collected at upstream, downstream, and effluent sites in March 1994.

Semivolatile Organic Compounds

Water samples were collected at nine sites listed in table 7 for analysis of 51 semivolatile organic compounds—most identified as priority pollutants by the USEPA. None of the compounds analyzed were found above the limit of detection. The compounds analyzed included phenols, cresols, monocyclic and polycyclic aromatics, and phthalate esters. Most are relatively insoluble in water and, if present, are more likely to reside in bed materials or the biota.

BED-MATERIAL QUALITY

Samples of bed materials were collected from 24 sites in the study area and analyzed for selected semivolatile organic compounds, organochlorine and organophosphorus insecticides, and PCB's. Samples were collected, seived to remove material that exceeded a grain size of 2 millimeters (mm), and analyzed as described by Garrett and others (1994). To examine the effect of grain size on constituent concentration, four samples were collected at three sites and seived to retain the grain-size fraction less than 63 microns (μ). For Lake Michie and University Lake, data from multiple locations were combined. At five sites, more than one sample was collected between 1988 and 1990—Knap of Reeds Creek (site 10), Little River (site 12), Flat River (site 15), Haw River (site 24), and Cane Creek (site 27). For these sites, the median of multiple analyses was used to provide one median concentration per site.

Many of the 126 compounds for which USEPA will promulgate standards for the protection of aquatic life have very low solubility in water and

Table 6. Constituents having at least one detection in samples analyzed for concentrations of selected pesticides upstream from, downstream from, and in wastewater-treatment plant effluents in Ellerbe, Northeast, and Little Lick Creeks

[Concentrations are in micrograms per liter. WWTP, wastewater-treatment plant; ft³/s, cubic feet per second; —, no data; <, less than]

	Federal drinking-water standard	Ellerbe Creek								
		Upstream from WWTP effluent			Durham Northside WWTP effluent			Downstream from WWTP effluent		
		Date								
		5/20/93	5/26/93	3/29/94	5/20/93	5/26/93	3/29/94	5/20/93	5/26/93	3/29/94
Discharge (ft³/s)		13.6	111	365	—	—	—	30	72	770
Specific conductance		119	107	82	60	545	324	173	186	86
Organochlorine/organophosphorus insecticides										
Chlorpyrifos	100[a]	—	0.03	0.07	0.02	0.02	0.03	0.02	0.02	0.03
Chlordane	2	—	—	—	—	—	—	—	—	—
Lindane	.2	<0.01	<.01	<.01	.01	.011	.01	.002	.007	<.01
Dieldrin	2[a]	<.01	<.01	<.01	.006	.005	<.01	.004	.005	<.01
Diazinon	3[a]	—	.06	.04	.05	.11	.01	.06	.08	.02
Malathion	800[a]	—	<.01	.02	<.01	<.01	<.01	<.01	<.01	<.01
Carbamate insecticides										
Carbaryl	4,000[a]	—	—	0.03	—	—	<0.05	—	—	<0.05
Triazine and other herbicides										
Simazine	4	0.21	0.22	0.07	—	—	<0.01	—	—	0.03
Prometon	500[a]	.20	.26	.05	—	—	.04	—	—	.04
Atrazine	3	—	—	—	—	—	—	—	—	—
Deisopropylatrazine	—	.07	.07	—	—	—	—	—	—	—
Deethylatrazine	—	—	—	—	—	—	—	—	—	—
Alachlor	2	<.05	<.05	.09	—	—	.02	—	—	.07
Tebuthiuron	2,000[a]	—	—	.08	—	—	.02	—	—	.06
Pendimethalin	—	—	—	.08	—	—	<.02	—	—	.04
Benfluralin	—	—	—	.01	—	—	<.01	—	—	<.01
Metolachlor	3,500[a]	—	—	—	—	—	—	—	—	—
Napropamide	—	—	—	—	—	—	—	—	—	—
Chlorophenoxy acids herbicides										
2,4-D	70	0.21	0.13	<0.05	—	—	—	—	—	<0.05
2,4 -DP	—	<.01	<.01	<.05	—	—	—	—	—	<.05

Table 6. Constituents having at least one detection in samples analyzed for concentrations of selected pesticides upstream from, downstream from, and in wastewater-treatment plant effluents in Ellerbe, Northeast, and Little Lick Creeks (Continued)

[Concentrations are in micrograms per liter. WWTP, wastewater-treatment plant; ft^3/s, cubic feet per second; —, no data; <, less than]

	Federal drinking-water standard	Northeast Creek								
		Upstream from WWTP effluent			Durham Northside WWTP effluent			Downstream from WWTP effluent		
		Date								
		4/6/93	5/20/93	3/29/94	4/6/93	5/20/93	3/29/94	4/6/93	5/20/93	3/29/94
Discharge (ft^3/s)		1,074	—	372	—	—	—	938	28	503
Specific conductance		47	160	101	282	597	405	50	218	89
Organochlorine/organophosphorus insecticides										
Chlorpyrifos	100[a]	<0.01	0.01	0.01	0.04	0.02	0.02	<0.01	0.01	<0.01
Chlordane	2	—	—	—	—	—	—	—	—	—
Lindane	.2	<.002	.001	<.01	<.01	<.01	.01	<.01	<.01	<.01
Dieldrin	2[a]	<.002	<.001	<.02	<.01	<.01	<.02	<.01	<.01	<.02
Diazinon	3[a]	.05	.04	.02	.05	.06	.02	.04	.04	.02
Malathion	800[a]	—	—	—	—	—	—	—	—	—
Carbamate insecticides										
Carbaryl	4,000[a]	—	—	<0.05	—	—	0.02	—	—	<0.05
Triazine and other herbicides										
Simazine	4	—	—	<0.01	—	—	<0.01	<0.05	0.10	<0.01
Prometon	500[a]	—	—	.02	—	—	.02	<.05	.10	.02
Atrazine	3	—	—	.01	—	—	.02	<.05	<.05	.01
Deisopropylatrazine	—	—	—	—	—	—	—	<.05	.06	—
Deethylatrazine	—	—	—	—	—	—	—	—	—	—
Alachlor	2	—	—	—	—	—	—	—	—	—
Tebuthiuron	2,000[a]	—	—	.02	—	—	<.02	—	—	<.02
Pendimethalin	—	—	—	—	—	—	—	—	—	—
Benfluralin	—	—	—	—	—	—	—	—	—	—
Metolachlor	3,500[a]	—	—	.01	—	—	.08	<.05	<.05	.04
Napropamide	—	—	—	<.01	—	—	<.01	—	—	.03
Chlorophenoxy acids herbicides										
2,4-D	70	—	—	—	—	—	<0.05	0.30	1.2	<0.05
2,4 -DP	—	—	—	—	—	—	<.05	.08	.81	<.05

Table 6. Constituents having at least one detection in samples analyzed for concentrations of selected pesticides upstream from, downstream from, and in wastewater-treatment plant effluents in Ellerbe, Northeast, and Little Lick Creeks (Continued)

[Concentrations are in micrograms per liter. WWTP, wastewater-treatment plant; ft^3/s, cubic feet per second; —, no data; <, less than]

	Federal drinking-water standard	Little Lick Creek								
		Upstream from WWTP effluent			Durham Northside WWTP effluent			Downstream from WWTP effluent		
		Date								
		5/14/93	5/20/93	3/29/94	5/14/93	5/20/93	3/29/94	5/14/93	5/20/93	3/29/94
Discharge (ft^3/s)		0.77	2.9	103	—	—	—	2.8	3.8	341
Specific conductance		217	171	79	237	52	270	258	250	80
Organochlorine/organophosphorus insecticides										
Chlorpyrifos	100[a]	<0.01	0.02	0.01	<0.01	<0.01	0.03	0.01	<0.01	<0.01
Chlordane	2	<.1	<.1	<.1	<.1	<.1	.1	<.1	<.1	<.1
Lindane	.2	<.001	.001	<.01	.001	.009	<.01	<.01	<.01	<.01
Dieldrin	2[a]	.001	.001	<.01	.001	.003	<.01	<.01	<.01	<.01
Diazinon	3[a]	.04	.1	.07	.04	.04	.04	.04	.04	.05
Malathion	800[a]	—	—	—	—	—	—	—	—	—
Carbamate insecticides										
Carbaryl	4,000[a]	—	—	0.02	—	—	0.13	—	—	0.02
Triazine and other herbicides										
Simazine	4	—	—	0.01	—	—	<0.01	0.35	<0.05	0.07
Prometon	500[a]	—	—	.05	—	—	.02	.15	.11	.49
Atrazine	3	—	—	<.02	—	—	.01	<.05	<.05	.01
Deisopropylatrazine	—	—	—	—	—	—	—	.05	<.05	—
Deethylatrazine	—	—	—	<.02	—	—	<.02	.06	<.05	<.02
Alachlor	2	—	—	—	—	—	—	—	—	—
Tebuthiuron	2,000[a]	—	—	.04	—	—	.02	—	—	.02
Pendimethalin	—	—	—	—	—	—	—	—	—	—
Benfluralin	—	—	—	—	—	—	—	—	—	—
Metolachlor	3,500[a]	—	—	.01	—	—	.01	<.05	<.05	.01
Napropamide	—	—	—	—	—	—	—	—	—	—
Chlorophenoxy acids herbicides										
2,4-D	70	—	—	<0.05	—	—	<0.05	0.11	13	<0.05
2,4 -DP	—	—	—	<.05	—	—	<.05	.06	<.01	<.05

[a] Drinking-water equivalent level—A lifetime exposure concentration protective of adverse, noncancer health effects, that assumes all of the exposure is from drinking water.

preferentially adsorb to sediments. This provides a pathway for bioaccumulation by aquatic organisms. As a result, samples of the water column may not be useful for assessing the presence or absence of these compounds in the environment, instead, bed materials must be sampled. These compounds are, to varying degrees, hydrophobic and lipophilic. Organochlorine insecticides, phthalate esters, and polynuclear aromatic hydrocarbons are most insoluble in water and have the greatest potential for bioaccumulation. The halogenated ethers and phenols are more water soluble and less bioaccumulative.

Table 7. Number of samples collected for analysis of semivolatile organic compounds

Site number (fig. 2)	Station name	Number of samples
5	Falls Lake at Interstate 85 near Redwood	1
10	Knap of Reeds Creek near Butner	3
11	Little River below Dam near Fairntosh	1
12	Little River at Secondary Road 1461 near Orange Factory	2
15	Flat River at Bahama	5
23	Jordan Lake, Haw River Arm above B. Everett Jordan Dam	2
27	Cane Creek near Orange Grove	1
32	Neuse River at Smithfield	1
33	Swift Creek near Apex	1

Because of their physical properties, bed materials play an important role in the fate and transport of these compounds. Nonionic species preferentially adsorb to organic acids over inorganic particles (Witkowski and others, 1987). However, the organic coatings on inorganic sediment particles provide good adsorption sites. Furthermore, small grain sizes (silts and clays), because of their greater surface area to mass ratio, typically adsorb greater amounts of synthetic organic compounds than large-sized particles such as sand. For example, the analysis of bed-material samples from Knap of Reeds Creek shows the effect of grain size on adsorption of organochlorine insecticides. Two replicate bed-material samples, one seived to retain the fraction less than 2 mm and the other seived to retain the fraction 63 μ, were analyzed to compare the effect of grain size on concentration. The smaller grain-size sample contained detectable concentrations of chlordane, DDD, DDT, diazinon, dieldrin, lindane, mirex, and malathion, whereas the larger grain-size sample contained detectable concentrations of only diazinon and mirex in sums of 15.9 and 0.5 micrograms per kilogram (μg/kg), respectively. Likewise, at Cane Creek (site 27) four samples were collected on four different dates for analysis of different sediment size fractions—one with grain size less than 63 μ, one with grain size less than 0.25 mm, and two with grain sizes less than 2 mm. Detections of insecticides were greatest in the samples containing the smallest grain-size fraction; no insecticides were detected in the larger grain-size fractions.

Pesticides

Samples of streambed material were analyzed for 24 organochlorine and organophosphorus insecticides and PCB's. Chlorinated insecticides and PCB's are less water soluble and more persistent in the environment, adsorbing to bed materials and bioaccumulating, than are organophosphorus insecticides. Organophosphorus insecticides tend to undergo more rapid degradation by hydrolysis than do organochlorine insecticides, although this process may be slowed by sorption to sediments. Degradation products of organophosphorus insecticides, not analyzed for this study, may be more persistent than the parent compounds (Witkowski and others, 1987).

Of the 24 compounds analyzed, the insecticides chlordane, DDD, DDE, DDT, diazinon, dieldrin, lindane, mirex, and malathion were detected in at least one sample. PCB, an industrial chlorinated compound, was detected at 10 sites, including five Haw River sites, a Haw River tributary, Falls Lake, Jordan Lake, Ellerbe Creek, and Cane Creek. MRL's ranged from 0.1 to 1 μg/kg of bed material. In the upper Neuse River Basin, greatest concentrations of PCB's and insecticides in bed material (greater than 10 μg/kg) were found in the lake-bed materials of Falls Lake and Lake Michie and in Ellerbe Creek streambed materials (fig. 11A). Insecticides detected were primarily chlordane, DDE, and DDD. The elevated concentrations in lake-bed material may be due to the greater concentration of organic material and small grain-size inorganic material in the lake-bed samples compared to streambed samples. In Lake Michie samples, the

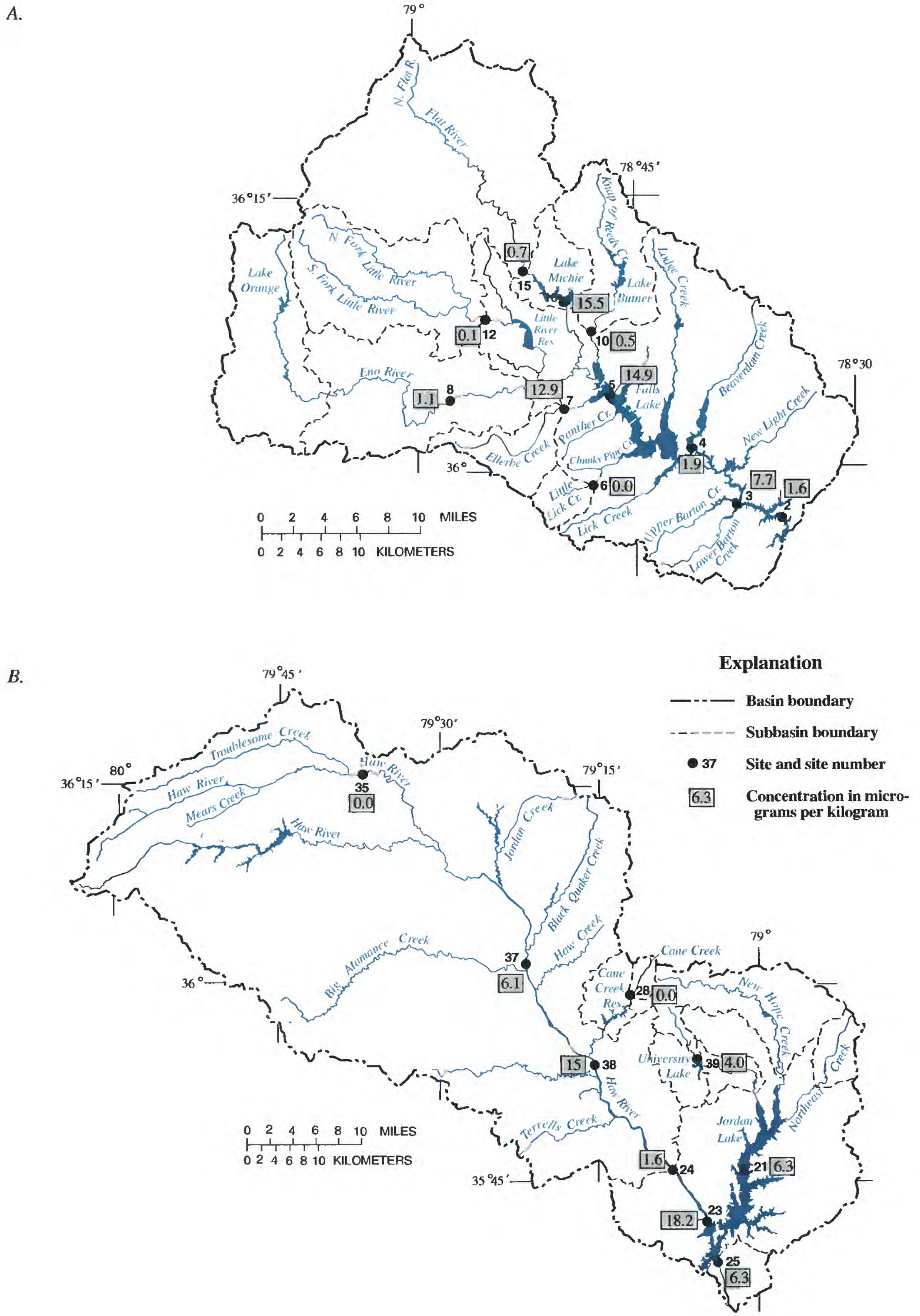

Figure 11. The sum of concentrations of organochlorine and organophosphorus pesticides detected in bed material collected at sites in the (A) upper Neuse River Basin and (B) upper Cape Fear River Basin.

percentage of bed material with grain size less than 63 μ ranged from 78 to 95. In Falls Lake, the range was from 37 to 94 percent, and in University Lake, the range was from 88 to 99 percent. Of the seven streambeds sampled, the percentage of material having grain size less than 63 μ ranged from 0 to 5 percent. The very low percentage of small grain sizes in streambed material is, in part, because samples were collected at the center of flow where scour occurs rather than in depositional zones of the stream channel. The source of elevated PCB and insecticide concentrations in Ellerbe Creek streambed materials is not known, but may be related to past wastewater discharge from the Durham WWTP.

In the upper Cape Fear River Basin, chlordane, DDD, DDE, and PCB were the primary contaminants. The concentration of PCB's and insecticides in bed material was greatest in the Haw River arm of Jordan Lake (fig. 11B) where chlordane was the primary contaminant (170 μg/kg). Otherwise, concentrations were similar to those observed in the upper Neuse River Basin.

Semivolatile Organic Compounds

Semivolatile organic compounds included over 50 acid and base/neutral extractable compounds recoverable from bed material. The MRL for these compounds in bed material ranges from 200 to 400 μg/kg wet weight. With the exception of a few phthalate compounds, no semivolatile organic compounds were found in concentrations that exceeded the MRL (Garrett and others, 1994). However, laboratory reports indicate the probable presence of phthalates, and aromatic and polyaromatic hydrocarbon compounds at detectable concentrations below the MRL at most of the sites sampled. Typically detected were fluoranthene, phenanthrene, anthracene, chrysene, pyrene, benzo(a)anthracene, benzo(b)anthracene, benzo(g,h,i)anthracene, benzo(k,a)anthracene, and fluorene. These polyaromatic hydrocarbons derive from combustion sources such as automobile exhaust, fossil fuel burning, and from natural combustion sources. These compounds are very common in small concentrations in bed materials because they are very insoluble in water and readily sorb to sediments. The concentration of these compounds in water is typically in the nanogram per liter range. Phthalate esters are derived from plastics and are ubiquitous in the environment.

TRIBUTARY LOADINGS TO RESERVOIRS

Annual loads of suspended sediment, nitrogen, phosphorus, zinc, and lead were computed for selected tributaries in the upper Neuse and upper Cape Fear River Basins for water years 1989 through 1994 using log-linear concentration-discharge equations developed from linear regression. Sediment, nitrogen, and phosphorus loads provide sediment and nutrient water budgets (loads in and out) for each reservoir in the study area. For some of the smaller reservoirs, loads into the reservoir were computed; however, loads out of the reservoir could not be computed but rather were estimated because outflow was not monitored. The loads contributed to reservoirs from unmonitored areas of the watersheds also were estimated to provide complete reservoir inflow estimates. Estimates were based on the assumption that yields (in tons per square mile) for unmonitored areas of the basin were similar to yields for monitored areas of the basin. This assumption could lead to overestimation or underestimation of loads in some instances. Inputs from atmospheric deposition were not considered in this study. Harned and others (1995) estimate nitrogen inputs from the atmosphere for the Neuse River Basin to be 2 tons per square mile (tons/mi^2). Phosphorus inputs are estimated to be 0.2 tons/mi^2. Reservoir input and outflow were not calculated for zinc or lead due to insufficient data.

Daily mean loads were calculated using logarithmic-linear equations that relate instantaneous water discharge (independent variable) to the concentration of a water-quality constituent (dependent variable). For each site, equations were developed from data collected for this study from October 1988 through September 1992 and, when available, from data collected for two earlier studies of loadings to Falls and Jordan Lakes (Garrett, 1990a and b). Not enough samples were collected during any one year (at most, 12 samples per year) to provide concentration data at the wide range of streamflow conditions needed for good definition of an annual concentration-discharge relation. To maximize the amount of data available to define a concentration-discharge relation and the likelihood of having data at the highest ranges of discharge where most transport of the constituents of interest occurs, all available data for each site were pooled except for phosphorus data. Because a phosphate-detergent ban was imposed in 1988 just before the start of this study, data from earlier studies when phosphorus concentrations may have been greater than after the ban were not used to develop concentration-discharge equations for phosphorus. Because data were pooled, year to year variation in estimated load at a site is due to annual variation in streamflow and not to a temporal change in the discharge-concentration relation.

For each site, one to four separate concentration-discharge equations, covering different flow ranges, were developed to provide best definition of the concentration-discharge relation over the full range of flow (Glysson, 1987; tables S-1 to S-5). An example of discharge-concentration plots and superimposed concentration-discharge equations is shown in figure 12.

Sediment-Record Calculations (SEDCALC), a program developed by the USGS (Koltun and others,

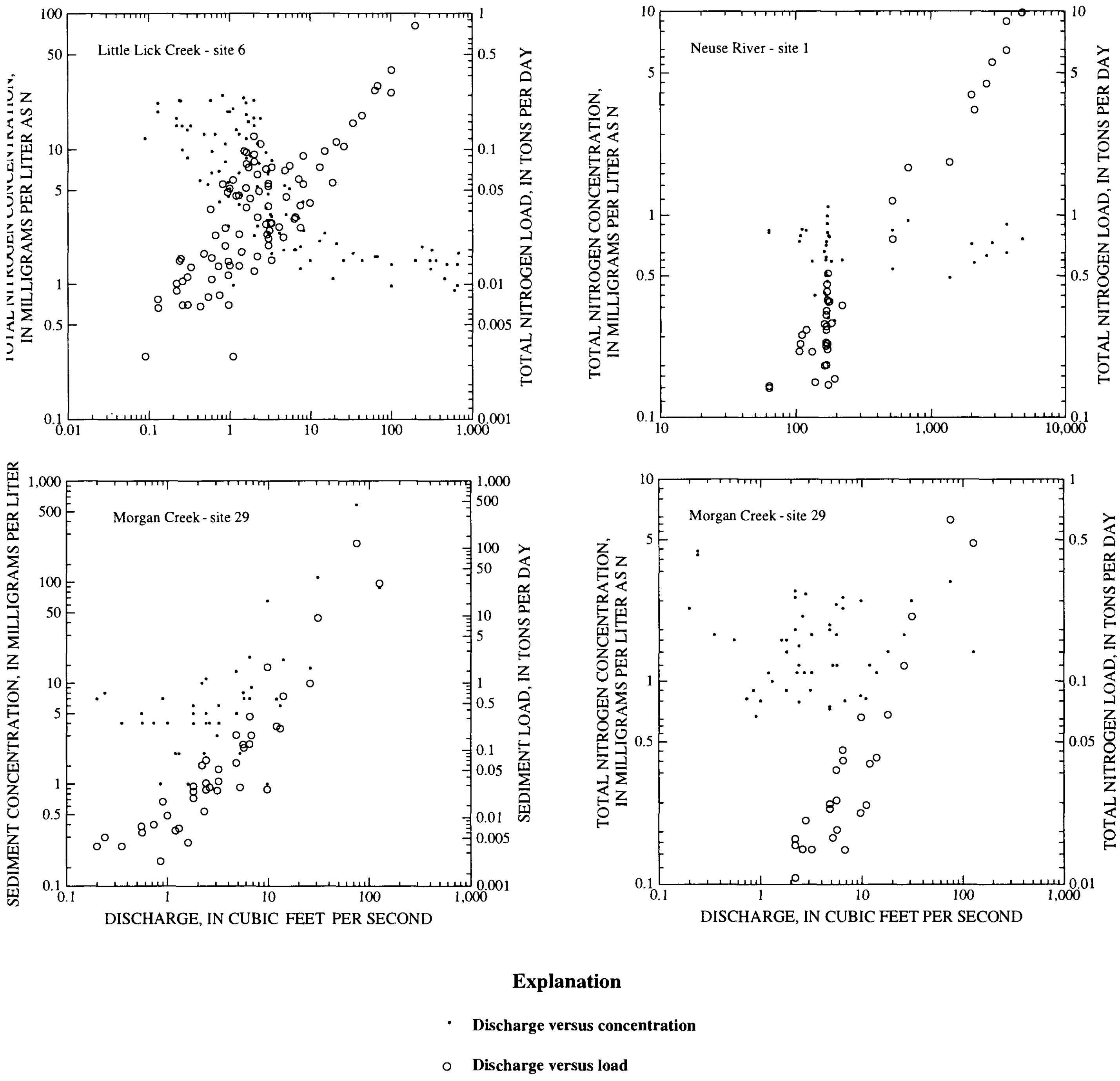

Figure 12. Comparison of the relation between discharge and concentration and discharge and load for selected streams.

1994), was used to calculate loads once the concentration-discharge equations were defined for each site. SEDCALC was developed to facilitate calculation of sediment loads but can be used to compute loads of any constituent that can be described by a discharge-concentration equation. Required inputs for SEDCALC are an equation(s) from the log-linear regressions of discharge and concentration, and a bias correction factor (*BCF*). The concentration-discharge equation is

$$\log C = (\log(b) + m) \times \log(Q) \ , \qquad (1)$$

where

C is instantaneous concentration in cubic feet per second,

b is regression constant (y-offset),

m is regression coefficient (slope), and

Q is instantaneous discharge in cubic feet per second.

Bias is introduced when data are retransformed from the log space of the concentration-discharge equation to base-10 space. The smearing estimator effectively corrects for this bias (Gilroy and others, 1990). The *BCF* used in this study is based on Duan's (1983) smearing estimator and is the mean of the antilog of the residuals from the log-linear regression. The *BCF* can be equal to or greater than 1.0; a *BCF* of 1.0 does not alter the load estimate and consequently is equivalent to applying no bias correction (Koltun and others, 1994).

Once a set of regression equations is determined for the range of discharge that occurred at a site, the daily load (in tons) of sediment, nutrients, or trace elements is calculated from record of daily discharge with the equation

$$Q_s = Q_w \times 10^{((m \times \log Q_w) + b)} \times k \times BCF \ , \qquad (2)$$

where

Q_S is total daily load in tons per day,

Q_w is daily mean water discharge in cubic feet per second, and

k is unit conversion factor (0.0027).

The daily loads were summed to derive annual loads for each water year. Supplemental tables S-1 to S-5 at the back of the report list the concentration-discharge equation, coefficient of determination (R^2), and *BCF* for each constituent and site. It should be noted that the R^2 value associated with the discharge-concentration equations for this study are, without exception, less than those associated with discharge-load equations reported by Garrett (1990a and b). This does not indicate that load calculations from concentration-discharge relations are less accurate than load calculations from load-discharge relations but is because load is a function of discharge (fig. 12). When results of load-discharge and concentration-discharge regressions were compared (without retransformation bias correction) using data for nine sites, calculated annual loads were virtually the same.

Retransformation bias was not corrected using a *BCF* in the earlier studies by Garrett (1990a and b) and Simmons (1993) and this could affect comparison of yields from this study with yields from the earlier studies. For comparison, annual nitrogen loads were calculated for nine of the sites (water years 1983-86) using regression equations reported by Garrett (1990a and b) and a *BCF* derived from these data. On average, nitrogen load increased by about 9 percent when retransformation bias correction was used.

Cohn and others (1992) reported that load estimates based on log-linear models are fairly insensitive to modest violations of regression assumptions. When modeling nutrient loads, residuals were non-normal in all cases; however, tests of residuals did not indicate a lack of fit, and it was concluded that log-linear models were useful and reasonably accurate. According to Walling and others (1992), errors associated with sediment-associated constituents, such as total phosphorus and metals, are likely to be less than those associated with suspended sediment because concentrations of these constituents tend to be less variable than suspended-sediment concentration. Errors are also likely to be smaller for large watersheds than for small watersheds because the storm hydrograph for large watersheds is more attenuated (Yorke and Ward, 1986; Walling and others, 1992).

Most suspended-sediment transport takes place during a few, large storm events. For example, 57 percent of the suspended-sediment load for the 1993 water year at Eno River near Weaver (site 8) was transported during 9 days at the beginning of March (fig. 13). Likewise, Simmons (1976) estimated that more than 44 percent of the annual suspended-

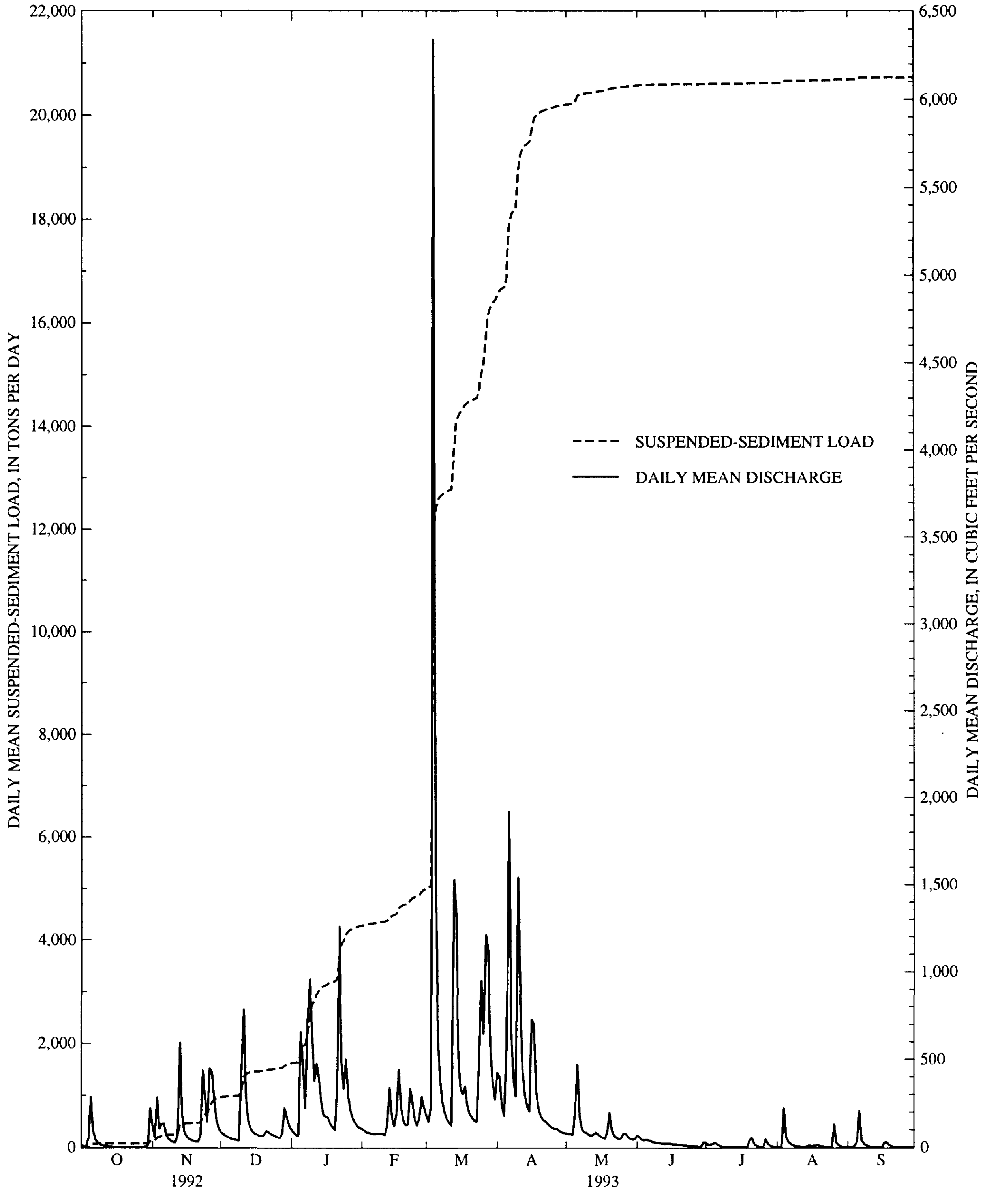

Figure 13. Cumulative suspended-sediment load and daily mean discharge for Eno River near Weaver (fig. 2, site 8), water year 1993.

sediment load for Yadkin River at Yadkin College was transported during only 9 percent of the 1973 water year.

If periodic measurements do not include storm event samples, estimates of annual suspended-sediment load can be seriously underestimated. Walling and others (1992) reported the significant potential for underestimation of loads when suspended-sediment sampling frequency decreased from weekly to monthly as well as when weekly sampling was not supplemented with flood sampling. For this study, efforts were made to sample a range of discharge conditions including major storm runoff events. Long-term flow-duration curves for Eno River near Durham and Neuse River at Smithfield corresponded closely to flow-duration curves for discharges at which samples were collected during this study (R.G. Garrett, U.S. Geological Survey, oral commun., 1994).

The frequency of discharge data used to calculate load affects the accuracy of results. For this study, discharges used to compute daily loads were based on daily mean discharge record from continuous gages.

The proportion of the annual nitrogen and phosphorus loads carried during large storm events depends, in part, on whether the source is primarily from nonpoint or point discharge. For Eno River near Weaver (site 8), 25 percent of the annual phosphorus load for the 1993 water year was carried during the same 9-day period in March that accounted for 57 percent of the annual suspended-sediment load (fig. 13). Eno River near Weaver is downstream from the Eno WWTP, but the effluent makes up less than 1 percent of the average streamflow. The Ellerbe Creek site (site 7) is located just downstream from the Durham Northside WWTP, which contributes approximately 25 percent of the average daily streamflow in Ellerbe Creek. At this site, total phosphorus concentration decreases with increased streamflow (slope = -0.9); thus, very large storm events have less effect on total phosphorus load than at sites where phosphorus concentration increases with increased streamflow.

Largest negative slopes, indicating decreasing nitrogen concentration with increasing streamflow, for nitrogen-load equations occurred for Knap of Reeds (site 10), Ellerbe (site 7), Little Lick (site 6), Morgan (site 17), New Hope (site 18), and Northeast Creeks (site 19). Largest negative slopes for total phosphorus occurred at Knap of Reeds, Ellerbe, New Hope, and Northeast Creeks (tables S-4 and S-5). All are relatively small streams receiving WWTP effluents. Greatest positive slopes, indicating increasing nutrient concentration with increasing streamflow, occurred at headwater sites—Little River (site 12), Eno River at Hillsborough (site 26), and Flat River (site 15)—indicating that nonpoint sources are important nutrient sources at these sites.

Streamflow Conditions

Streamflow was monitored continuously at most sites in the study area. Statistical summaries of streamflow data for water years 1989-94 for these sites are presented in table 8. Annual loads vary, in large part, because annual streamflow varies as climatic conditions change. To compare streamflow conditions during the study period to normal or average long-term streamflow conditions, streamflow records for two sites in the study area were examined (figs. 14 and 15). Comparison of streamflow for water years 1988-94 to the long-term average indicates whether the annual loads computed for the study period are likely to represent long-term average annual loads.

Eno River near Durham (site 9, fig. 14) was selected as characteristic of streamflow conditions in the upper Neuse River Basin for the study period. Streamflow has been monitored continuously at Eno River near Durham since 1963. A comparison of annual mean streamflow for water years 1989 through 1994 (table 8) with the mean annual streamflow of 128 cubic feet per second (ft^3/s) for the period of record, 1964-94, indicates that 1989 was an unusually wet year, 1990 and 1993 were moderately wet, 1991 was normal, 1994 was dry, and 1992 was an extremely dry year (fig. 14). The annual mean discharge of 87.5 ft^3/s for water year 1992 was approximately 32 percent lower than the long-term average of 128 ft^3/s. For water year 1989, the annual mean discharge was 191 ft^3/s—50 percent higher than the long-term average. The annual mean discharge for the 1990 water year was about 23 percent greater than the long-term average.

Haw River near Bynum (site 24, fig. 15) was selected as characteristic of streamflow conditions in the upper Cape Fear River Basin. Streamflow has been monitored continuously at this site since 1973. A comparison of annual mean streamflow for water years 1989 through 1994 (table 8) with the mean

Table 8. Mean and maximum daily discharges and total annual discharge at selected study sites, water years 1989-94

[—, no data]

Site number (fig. 2)	Station name (basin)		Discharge (cubic feet per second)					
			1989	1990	1991	1992	1993	1994
9	Eno River near Durham (Neuse)	Mean	191	157	130	87.5	158	109
		Maximum	3,280	1,540	2,310	4,290	6,340	3,030
		Total	69,600	57,400	47,600	32,000	57,755	39,757
12	Little River at Secondary Road 1461 near Orange Factory (Neuse)	Mean	105	89	72.3	46.8	94.8	54.0
		Maximum	2,200	1,160	1,700	3,200	5,420	2,080
		Total	38,400	32,500	26,400	17,100	34,607	19,696
15	Flat River at Bahama (Neuse)	Mean	209	151	115	82.2	193	122
		Maximum	4,240	1,640	2,990	5,940	9,680	4,310
		Total	76,400	55,100	41,900	30,100	70,505	44,466
10	Knap of Reeds Creek near Butner (Neuse)	Mean	78.9	65.1	43.4	21.4	57.4	30.2
		Maximum	2,260	1,260	1,110	988	2,920	1,210
		Total	28,800	23,800	15,800	7,840	20,952	11,018
6	Little Lick Creek above Secondary Road 1814 near Oak Grove (Neuse)	Mean	18.4	14	9.0	8.4	13.2	10.1
		Maximum	455	390	278	539	651	473
		Total	6,700	5,090	3,270	3,070	4,831	3,696
17A	Morgan Creek near Chapel Hill (Cape Fear)	Mean	45.2	51.1	39.5	33.9	60.6	32.9
		Maximum	736	466	767	861	1,810	959
		Total	16,500	18,600	14,400	12,400	22,129	12,021
18	New Hope Creek near Blands (Cape Fear)	Mean	113	96.6	108	82.3	115	75.1
		Maximum	1,860	869	2,400	1,250	2,390	1,400
		Total	41,400	35,300	39,500	30,100	41,852	27,411
19	Northeast Creek at Secondary Road 1100 near Genlee (Cape Fear)	Mean	42	38.3	28.6	27.9	33.5	—
		Maximum	778	560	667	817	855	—
		Total	15,300	14,000	10,500	10,200	12,239	—
24	Haw River near Bynum (Cape Fear)	Mean	1,470	1,490	1,520	903	1,529	1,098
		Maximum	23,800	16,900	25,200	18,300	25,800	22,200
		Total	536,000	545,000	554,000	330,000	558,104	400,727

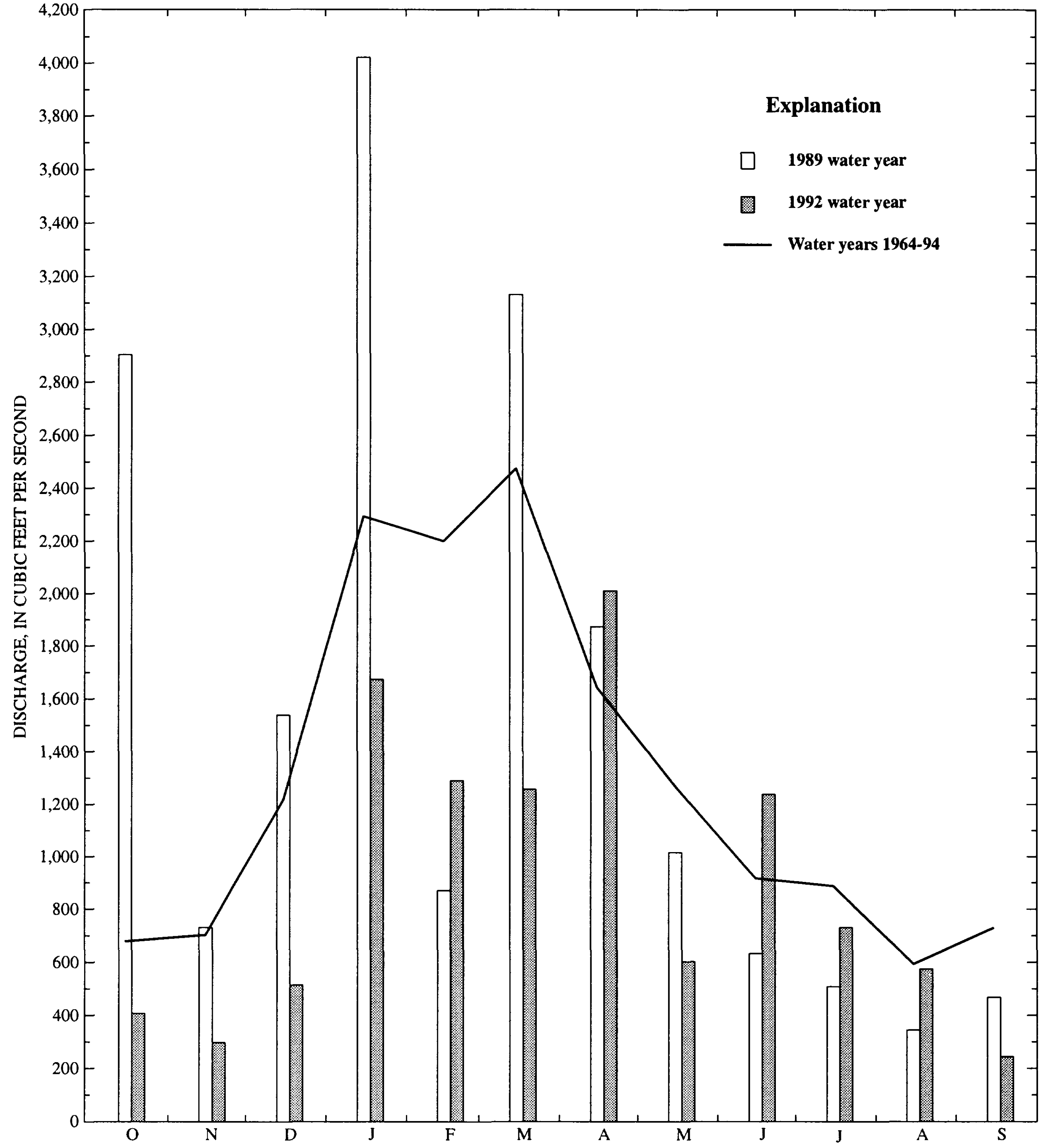

Figure 14. Monthly mean discharge at Eno River near Durham (fig. 2, site 9) for water years 1989 and 1992, and for the period of record, 1964-94.

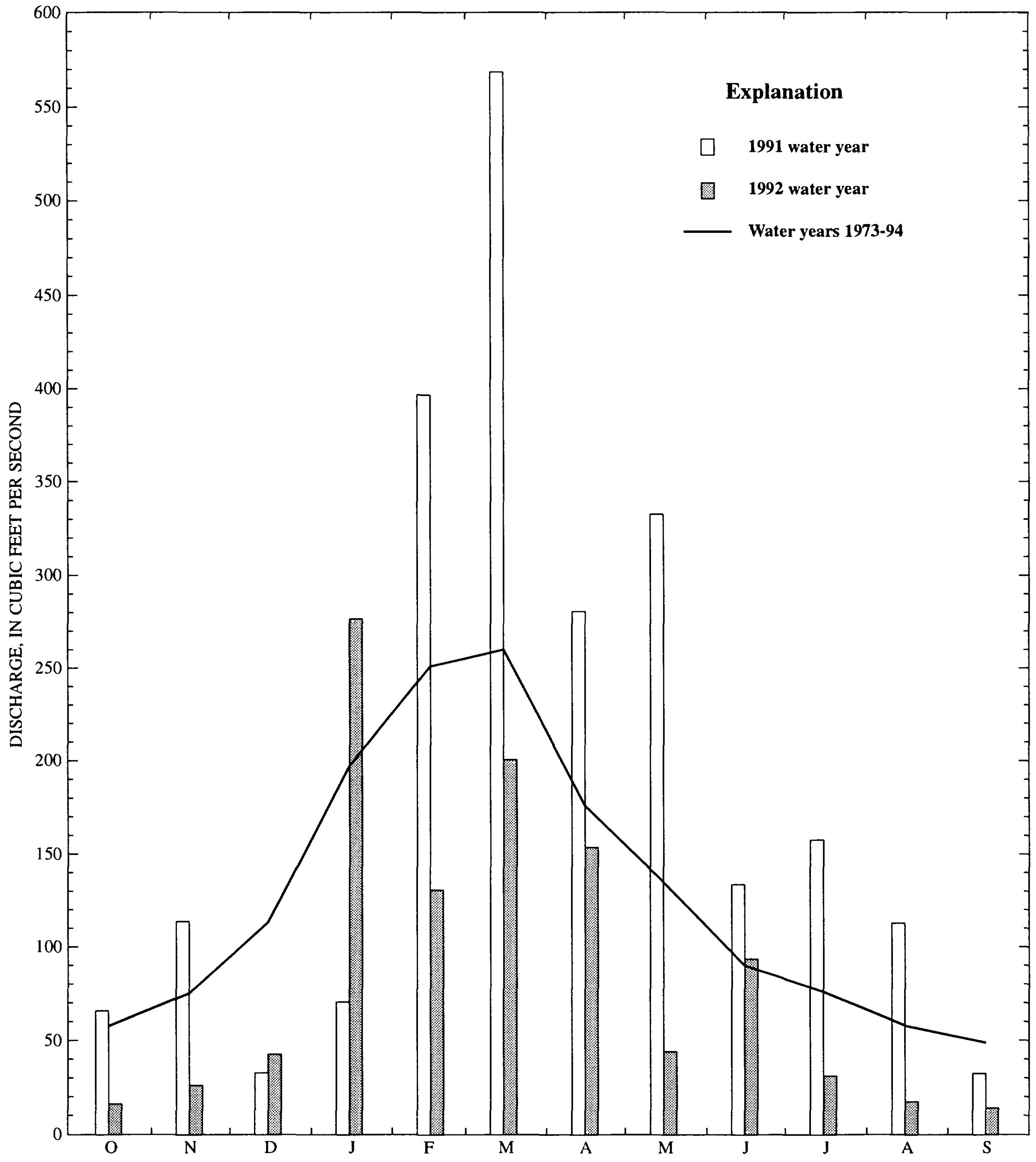

Figure 15. Monthly mean discharge at Haw River near Bynum (fig. 2, site 24) for water years 1991 and 1992, and for the period of record, 1973-94.

annual streamflow of 1,300 ft^3/s for the period of record, 1973-94, indicates that 1994 was a dry year and 1992 was an extremely dry year in the Cape Fear River Basin (fig. 15). The annual mean discharge of 903 ft^3/s in 1992 was about 30 percent lower than the long-term average of 1,300 ft^3/s. Flow during the other years of study exceeded the long-term average by 13 to 17 percent. Annual total discharges in water years 1989-91 and 1993 were nearly equal (table 8). Greatest total discharge occurred in 1993 and least total discharge occurred in 1992.

Suspended Sediment

Suspended-sediment loads were computed for each monitored reservoir tributary and outflow in the study area for water years 1989 through 1994. Suspended-sediment loads from unmonitored areas of the reservoir basins were estimated based on the yield from the monitored areas of the reservoir basins.

During 1989-94, annual suspended-sediment load into Falls Lake ranged from 29,500 to 88,200 tons (table 9). Because Lake Michie trapped from 83 to 93 percent of the suspended sediment delivered by Flat River, Flat River is a minor contributor of suspended sediment to Falls Lake—only 22,600 tons from 1989-94. Little River Reservoir, too, probably traps much of the suspended sediment delivered by Little River; however, the amount was not measured because Little River was not monitored below the Little River Reservoir. Little River above the Little River Reservoir, the third largest tributary to Falls Lake, transported 86,400 tons of suspended sediment to Little River Reservoir from the 1989 water year through the 1994 water year. Based on estimates of trapping efficiency for Falls Lake and other lakes that have residence times similar to Little River Reservoir (Simmons, 1993), it was estimated that Little River Reservoir traps 85 percent of the suspended sediment delivered. By that estimate, 14,900 tons of suspended sediment were delivered to Falls Lake from Little River Reservoir. The unmonitored portion of the Falls Lake Basin transported the largest suspended-sediment load to Falls Lake—118,000 tons from 1989 through 1994. The smallest load (12,300 tons) was contributed by Little Lick Creek from 1989 through 1994. Little Lick Creek was also the smallest tributary monitored.

By normalizing suspended-sediment load to drainage area, transport is expressed as a yield in tons per square mile of drainage area. While load tends to be directly related to drainage basin size, yield tends to be inversely related to drainage basin size (Simmons, 1993). Simmons (1993) reported suspended-sediment yields of 41 to 47 tons/yr for two undisturbed forested basins in the Piedmont Province of North Carolina.

Yields from Little River, Little Lick Creek, and Flat River above Lake Michie (site 15) were similar—between 184 and 223 $tons/mi^2$ (table 10). Suspended-sediment loads appear to have increased slightly compared to yields of 140 and 190 $tons/mi^2$ reported for Little River and Flat River by Simmons (1993) since the period 1970-79. The yield for Eno River near Weaver (site 8) was 95 $tons/mi^2$, about 60 percent of that reported for 1970-79 by Simmons (1993). Ellerbe Creek had an average yield of 347 $tons/mi^2$ for water years 1989 and 1992-94 (table 10).

A summary of suspended-sediment load and yield data for Falls Lake and its tributaries for 1989 and 1992 is shown in figure 16. The 1989 and 1992 water years represent extreme years (wet and dry) and illustrate sediment loads in a range of hydrologic conditions. Ellerbe Creek had the highest yield of any Falls Lake tributary during the wet year and was among the highest in 1992, a dry year. Ellerbe Creek receives effluent from the Durham Northside WWTP that, during this study, comprised about 25 percent of the average daily streamflow. The yield estimate for Ellerbe Creek is based on incomplete data for 1989 and 1994 due to missing discharge record for the period June 1989 through September 1991 and June through August 1994. Based on comparison with other sites, the incomplete record could account for a 15- to 20-percent overestimate of load over the entire period of study because 1989 and 1993 were unusually wet years.

The smallest suspended-sediment yield for the 1989-94 water years was for the Flat River Basin downstream from the Lake Michie dam (site 14) (22 $tons/mi^2$, table 10) as a result of sediment trapping in Lake Michie. An average of about 37,500 tons of suspended sediment was delivered to Lake Michie each year during the 1989-94 water years. Lake Michie trapped from 83 to 93 percent of the sediment load from the Flat River Basin upstream from Lake Michie (table 9). Weaver (1994) estimated, for the period 1983-91, that 89 percent of an average 34,600 tons of suspended sediment delivered to Lake Michie

Table 9. Annual suspended-sediment loads into Falls Lake, Lake Michie, and Little River Reservoir, and out of Lake Michie and Little River Reservoir in the upper Neuse River Basin, water years 1989-94

[Sites are shown in figure 2. —, no data]

Station name or location	Sediment load, in tons per year (percent of total inflow load)						Total load 1989-94	Mean annual load
	1989	1990	1991	1992	1993	1994		
Falls Lake								
Eno River near Weaver (site 8)	21,400 (23)	12,200 (28)	10,600 (31)	8,080 (27)	20,700 (26)	11,300 (28)	84,300	14,000
Little River Reservoir outflow	4,550 (5)	1,860 (4)	2,040 (6)	2,060 (7)	4,440 (6)	1,230 (3)	16,200	2,700
Flat River at Dam near Bahama (site 14)	5,650 (6)	4,010 (9)	2,790 (8)	2,100[a] (7)	4,900[a] (6)	3,100[a] (8)	22,600	3,760
Knap of Reeds Creek near Butner (site 10)	8,780 (10)	6,620 (15)	4,240 (12)	1,980 (7)	7,200 (9)	3,030 (8)	31,800	5,310
Ellerbe Creek near Gorman (site 7)	12,500[b] (14)	—	—	3,100 (10)	9,690 (12)	5,100[c] (13)	—	7,600
Little Lick Creek above Secondary Road 1814 near Oak Grove (site 6)	3,050 (4)	2,090 (5)	1,280 (4)	1,370 (5)	3,120 (4)	1,420 (4)	12,300	2,060
Ungaged drainage area of Falls Lake	32,300 (37)	17,500 (40)	13,700 (40)	10,800 (37)	28,900 (37)	14,500 (37)	118,000	19,600
Total inflow to Falls Lake	88,200	44,200	34,600	29,500	79,000	39,700	315,000	52,500
Lake Michie								
Flat River at Bahama (site 15)	48,900 (89)	20,600 (89)	20,300 (89)	19,900 (89)	64,200 (89)	25,400 (89)	199,000	33,200
Ungaged drainage area of Lake Michie	6,200 (11)	2,630 (11)	2,590 (11)	2,540 (11)	8,190 (11)	3,240 (11)	25,400	4,240
Total inflow to Lake Michie	55,100	23,200	22,900	22,400	72,400	28,600	225,000	37,500
Flat River at Dam near Bahama, Lake Michie outflow (site 14)	5,650 (10)	4,010 (17)	2,790 (12)	2,100[a] (9)	4,900[a] (7)	3,100[a] (11)	22,600	3,760
Little River Reservoir								
Little River at Secondary Road 1461 near Orange Factory (site 12)	24,300 (80)	9,890 (80)	10,900 (80)	11,000 (80)	23,700 (80)	6,560 (80)	86,400	14,400
Ungaged drainage area of Little River Reservoir	6,060 (20)	2,470 (20)	2,720 (20)	2,740 (20)	5,910 (20)	1,640 (20)	21,500	3,590
Total inflow to Little River Reservoir	30,400	12,400	13,600	13,700	29,600	8,200	108,000	18,000
Little River Reservoir outflow[d]	4,550 (15)	1,850 (15)	2,040 (15)	2,060 (15)	4,440 (15)	1,230 (15)	14,900	2,490

[a] Estimate based on average annual tons per total discharge for 1989-91.

[b] Last 5 months of year was estimated based on comparisons with flow at Little Lick Creek.

[c] June, July, and August estimated based on comparisons with flow at Little Lick Creek.

[d] Estimate assumes a retention in the reservoir of 85 percent of the suspended sediment.

Table 10. Suspended-sediment, total nitrogen, and total phosphorus yields for monitoring sites in the upper Neuse River Basin

[Sites are shown in figure 2. Years are water years. —, no data]

Station name or location	Drainage area (square miles)	Average annual yield (tons per square mile)					
		Sediment		Nitrogen		Phosphorus	
		1970-79[a]	1989-94	1983-86[b]	1989-94	1983-86[b]	1989-94
Eno River near Weaver (site 8)	148	160	95	1.2	1.2	0.20	0.11
Little River at Secondary Road 1461 near Orange Factory (site 12)	78.2	140	184	1.4	1.0	.10	.10
Flat River at Bahama (site 15)	149	190	223	—	1.0	—	.09
Flat River at Dam near Bahama, Lake Michie outflow (site 14)	168	—	22	1.0	1.1	.05	.06
Knap of Reeds Creek near Butner (site 10)	43	—	123	2.1	2.2	.50	.53
Ellerbe Creek near Gorman (site 7)	21.9	—	347[a]	13	12[c]	2.8	.47[c]
Little Lick Creek above Secondary Road 1814 near Oak Grove (site 6)	10.1	—	204	2.3	3.5	.50	.28
Neuse River near Falls, Falls Lake outflow (site 1)	771	—	—	1.1	.58	.05	.04

[a] From Simmons (1993).

[b] From Garrett (1990b).

[c] Yield is based on partial record of discharge in 1989 and 1994, and complete record of discharge in 1992 and 1993.

each year was trapped. Weaver used the load-estimation techniques described in Simmons (1993).

Annual sediment loads to Jordan Lake ranged from about 271,000 tons in 1992 to 622,000 tons in 1993 (table 11). The Haw River contributed more than 75 percent of the sediment load to Jordan Lake. Northeast and New Hope Creeks each contributed less than 5 percent. The contribution of each subbasin in the upper Cape Fear River Basin is illustrated in figure 17 for wet (1989) and dry (1992) years. The amount of sediment trapped in Jordan Lake could not be calculated because suspended sediment was not monitored below the dam. Annual sediment loads to the two smaller reservoirs in the upper Cape Fear River Basin (University Lake and Cane Creek Reservoir) averaged about 1,560 and 2,420 tons, respectively (table 11). The trapping efficiency of these reservoirs was not determined because discharge out of these reservoirs was not monitored.

The average annual yields for Northeast Creek and Haw River were similar (252 and 284 tons/mi^2, respectively) despite the large difference in the size of the drainage areas of the two basins (table 12). In this study, sediment yield for the Haw River was more than twice the 140 tons/yr for the Haw River reported by Simmons (1993) for the period 1970-79. The average annual yield for the Morgan Creek Basin (site 29) upstream from University Lake was 52 tons/mi^2. The average annual yield for the Cane Creek Basin upstream from site 27 was 77 tons/mi^2. Simmons

Table 11. Estimates of annual suspended-sediment loads into Jordan Lake, University Lake, and Cane Creek Reservoir in the upper Cape Fear River Basin, water years 1989-94

[Sites are shown in figure 2. —, no data]

Station name or location	Sediment load, in tons per year (percent of total inflow load)						Total load 1989-94	Mean annual load
	1989	1990	1991	1992	1993	1994		
Jordan Lake—Inflows								
New Hope Creek near Blands (site 18)	15,400 (3)	11,300 (2)	15,800 (3)	9,640 (4)	18,800 (3)	8,890 (2)	79,800	13,300
Northeast Creek at Secondary Road 1100 near Genlee (site 19)	7,980 (2)	6,720 (1)	4,630 (1)	4,790 (2)	7,810 (1)	—	—	5,320
Haw River near Bynum (site 24)	406,000 (77)	377,000 (78)	425,000 (78)	206,000 (76)	479,000 (77)	280,000 (78)	2,170,000	362,000
Ungaged drainage area of Jordan Lake	99,200 (19)	91,300 (19)	103,000 (19)	50,900 (19)	117,000 (19)	72,300 (20)	533,000	88,900
Total inflow to Jordan Lake	529,000	486,000	548,000	271,000	622,000	361,000	2,820,000	470,000
University Lake—Inflows								
Morgan Creek near White Cross (site 29)	803 (28)	487 (28)	319 (28)	215 (28)	522 (28)	274 (28)	2,620	437
Ungaged drainage area of University Lake	2,060 (72)	1,250 (72)	820 (72)	553 (72)	1,340 (72)	705 (72)	6,740	1,120
Total inflow to University Lake	2,870	1,740	1,140	768	1,860	979	9,360	1,560
Cane Creek Reservoir—Inflows								
Cane Creek near Orange Grove (site 27)	1,030 (24)	343 (24)	599 (24)	356 (24)	691 (24)	450 (24)	3,470	578
Ungaged drainage area of Cane Creek Reservoir	3,280 (76)	1,090 (76)	1,910 (76)	1,130 (76)	2,200 (76)	1,430 (76)	11,100	1,840
Total inflow to Cane Creek Reservoir	4,310	1,440	2,510	1,490	2,890	1,880	14,500	2,420

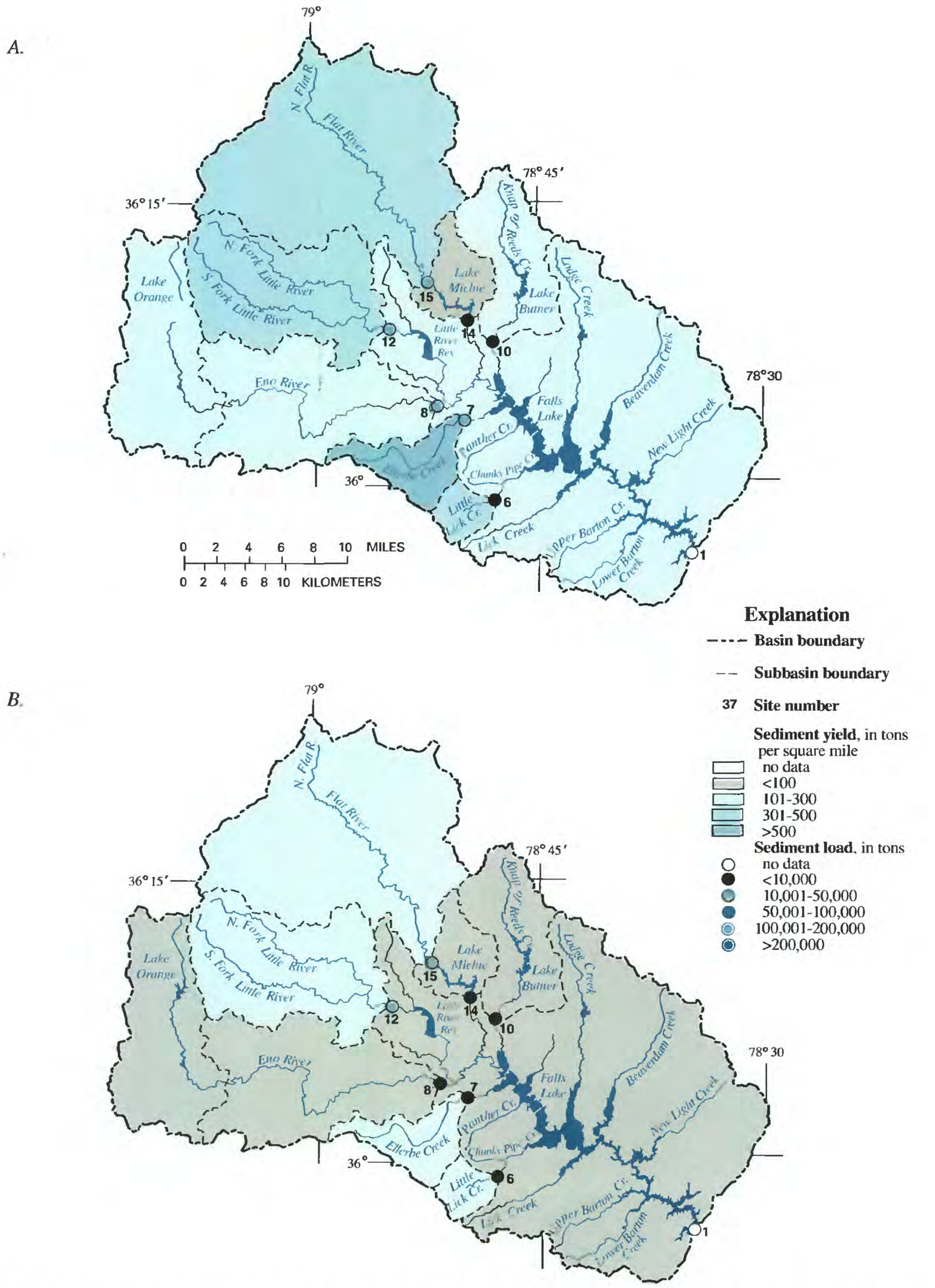

Figure 16. Estimated suspended-sediment yield and load in selected tributaries to Falls Lake, Lake Michie, and Little River Reservoir, (A) 1989 and (B) 1992.

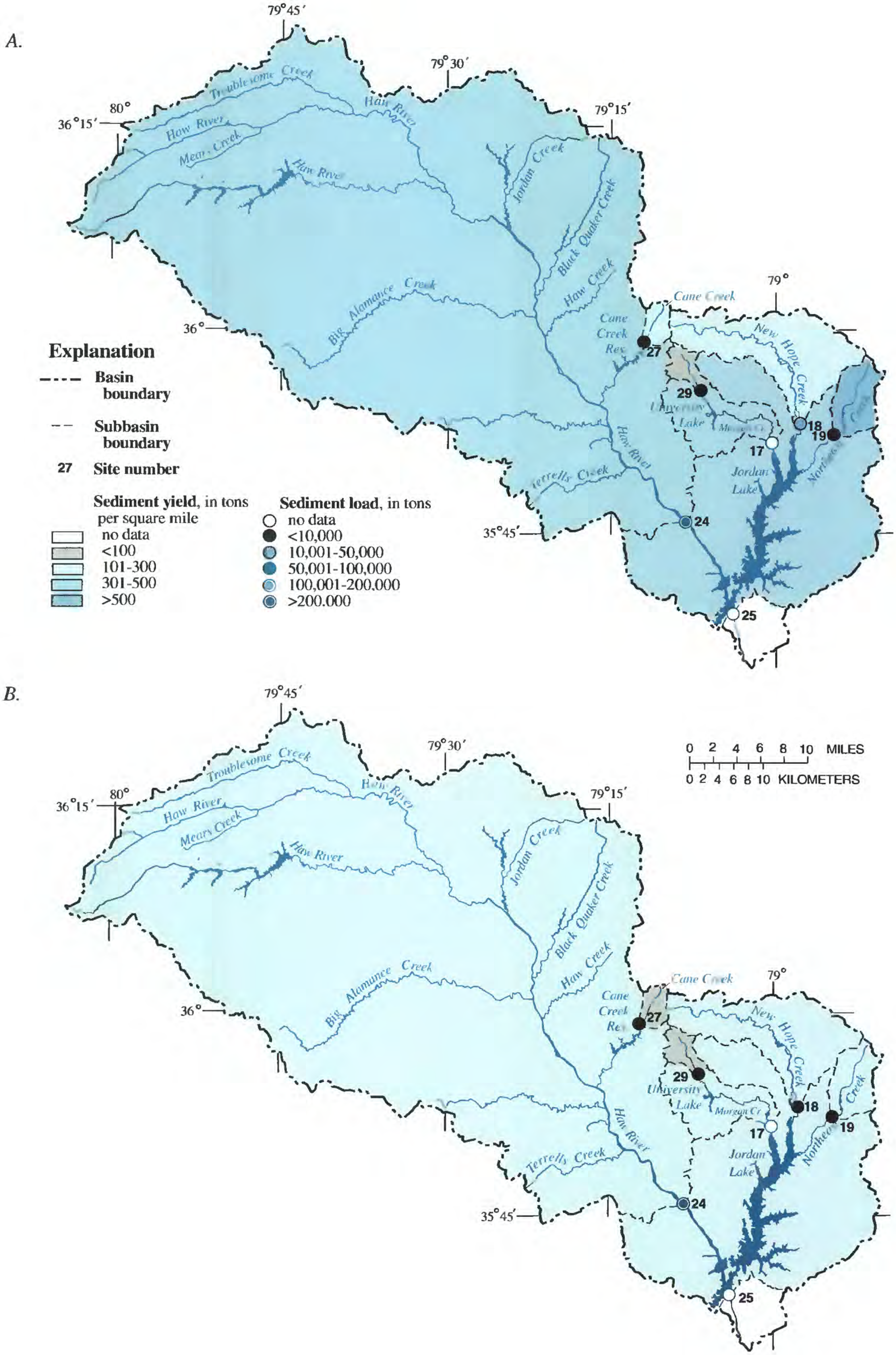

Figure 17. Estimated suspended-sediment yield and load to Cane Creek Reservoir, Jordan Lake, and University Lake, (A) 1989 and (B) 1992.

Table 12. Suspended-sediment, total nitrogen, and total phosphorus yields for monitoring sites in the upper Cape Fear River Basin

[—, no data; years are water years]

Site number (fig. 2)	Station name	Drainage area (square miles)	Average annual yield (tons per square mile)					
			Sediment		Nitrogen		Phosphorus	
			1970-79[a]	1989-94	1983-86[b]	1989-94	1983-86[b]	1989-94
27	Cane Creek near Orange Grove	7.5	47[c]	77	—	1.5	—	0.19
29	Morgan Creek near White Cross	8.4	—	52	—	1.6	—	.26
17	Morgan Creek near Farrington	45.6	—	—	5.8	2.4	1.4	.27
18	New Hope Creek near Blands	75.9	—	175	3.7	4.0	.60	.34
19	Northeast Creek at Secondary Road 1100 near Genlee	21.1	—	252	4.3	5.3	1.0	.45
24	Haw River near Bynum	1,275	140	284	2.2	2.0	.40	.35
25	Haw River below B. Everett Jordan Dam near Moncure	1,689	—	—	1.5	1.3	.20	.15

[a] From Simmons (1993).

[b] From Garrett (1990a).

[c] Cane Creek headwaters.

(1993) reported a yield of 47 tons/mi^2 for 1.1 mi^2 of undisturbed forest in the headwaters of Cane Creek for the period 1970-79. Agricultural activities in the Cane Creek Basin between the headwaters and site 27 probably account for the increased yield.

Yields from the basins upstream from the University and Cane Creek Reservoirs were the lowest in the study area (with the exception of sites downstream from dams). Continued low sediment yields in these basins should extend the life of these reservoirs in terms of both capacity and quality.

Nitrogen and Phosphorus

Annual loads of nitrogen and phosphorus were calculated using regression equations of log instantaneous concentration and log instantaneous discharge (tables S-3 and S-4) and daily mean discharges for each gaged tributary. Nitrogen loads were generally an order of magnitude greater than phosphorus loads.

Annual nitrogen loads to Falls Lake ranged from 780 tons in 1991 to 1,650 tons in 1989 (table 13). The Eno (site 8) and Flat River (site 14) Basins contributed similar nitrogen loads to Falls Lake most years (table 13). Ellerbe Creek Basin contributed about 50 percent more nitrogen than Eno or Flat Rivers, except in the wettest year (1989) when the load was similar to Eno and Flat Rivers (table 13; fig. 18). This is likely because most of the nitrogen load to Ellerbe Creek is from the Durham Northside WWTP that sustains fairly steady flows even in dry years.

Nitrogen loads out of Falls Lake (site 1), an average of 448 tons/yr, accounted for 20 (1992) to 56 (1990) percent of the annual load into the lake. Nitrogen yields out of Falls Lake declined from 1.1 ton/mi^2 (1983-86) to 0.58 ton/mi^2 (1989-94; table 10). However, average annual yields for most Falls Lake tributaries were similar to those reported by Garrett (1990b) for water years 1983 through 1986 (table 10). Little Lick Creek had the only substantial increase in yield (from 2.3 to 3.5 tons/mi^2). Ellerbe Creek had the greatest average annual nitrogen yield of the Falls Lake tributaries during the 1983-86 period (13 tons/mi^2) and during 1989-94 (12 tons/mi^2, table 10). Urban runoff from the city of Durham has a direct affect on the water quality of Ellerbe Creek (North Carolina Department of Environment, Health, and Natural Resources, 1993), and effluent from the Durham Northside WWTP is also a contributor.

Nitrogen loads into Lake Michie (1,010 for 1989-94) were similar to nitrogen loads out of the lake (1,130 for 1989-94; site 14). This may result from underestimation of load from ungaged areas of the basin including Dial Creek which receives drainage from agricultural runoff (Weaver 1994) and because atmospheric inputs of nitrogen were not included. Another factor may be the relatively short hydraulic retention time of Lake Michie—about 45 days—that limits nitrogen removal. Annual nitrogen inflows varied from 94 tons in the driest water year (1992) to 248 tons in the wettest water years (1989 and 1993). The nitrogen yield for Flat River (site 15) was 1.0 tons/mi^2 during 1989-94. No data are available for 1983-86. Below the Lake Michie dam, yields were similar for 1983-86 and 1989-94 water years, 1.0 and 1.1 tons/mi^2, respectively.

Annual nitrogen loads to Little River Reservoir ranged from 55 tons in 1992 to 137 tons in 1989. The nitrogen load out of Little River Reservoir was not monitored. However, Little River Reservoir has a retention time similar to that of Falls Lake (table 2), and retention time is a factor affecting the extent to which chemical and biological processes remove nitrogen from the system. A nitrogen retention rate of 50 percent was estimated for Little River Reservoir based on comparison with Falls Lake data. The nitrogen yield for Little River (site 12) was 1.0 tons/mi^2 during 1989-94 compared to 1.4 tons/mi^2 during 1983-86.

In the upper Cape Fear River Basin, the annual nitrogen load out of Jordan Lake was about 57 percent of the load into the lake. Nitrogen load to Jordan Lake ranged from 2,710 tons in 1992 to 4,410 tons in 1993 (table 14). Haw River contributed most of the annual nitrogen load to Jordan Lake (about 70 percent; fig. 19). Even though Haw River contributes a major share of the load, New Hope and Northeast Creeks produced greater yields—at least double that of Haw River (table 12) and similar to yields produced by Ellerbe and Little Lick Creeks, which also receive WWTP effluent (fig. 19). For Morgan Creek (site 17), average annual nitrogen yields (2.4 tons/mi^2) decreased by 65 percent from the 1983-86 estimate of 5.8 tons/mi^2 (Garrett, 1990a). Nitrogen yield increased by 25 percent from 4.3 to 5.3 tons/mi^2 compared to the 1983-86 period for Northeast Creek.

Table 13. Annual nutrient loads into and out of Falls Lake, Lake Michie, and Little River Reservoir, water years 1989-94

[Sites are shown in figure 2. —, no data]

Station name or location	Nitrogen load, in tons (percent of total inflow load)								Phosphorus load, in tons (percent of total inflow load)							
	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94
Falls Lake																
Eno River near Weaver (site 8)	260 (16)	210 (20)	170 (22)	120 (13)	209 (14)	141 (13)	1,110	185	28 (20)	18 (17)	16 (18)	12 (15)	14 (12)	9 (11)	97	16
Little River Reservoir outflow	69 (4)	49 (5)	41 (5)	28 (3)	66 (4)	31 (3)	283	47	7 (5)	5 (5)	4 (5)	2 (3)	7 (6)	3 (4)	29	4.8
Flat River at Dam near Bahama, Lake Michie outflow (site 14)	270 (16)	210 (20)	140 (18)	105[a] (11)	250[a] (16)	156[a] (15)	1,130	188	15 (10)	11 (10)	8 (9)	6[a] (8)	13[a] (11)	8[a] (10)	61	10
Knap of Reeds Creek near Butner (site 10)	120 (7)	120 (12)	93 (12)	60 (6)	105 (7)	70 (7)	568	95	26 (18)	27 (26)	23 (26)	18 (23)	23 (20)	19 (24)	136	23
Ellerbe Creek near Gorman (site 7)[b]	280[c] (17)	—	—	264 (28)	310 (20)	244[d] (23)	—	274	11 (8)	—	—	9 (12)	12 (10)	9[d] (11)	—	10
Little Lick Creek above Secondary Road 1814 near Oak Grove (site 6)	46 (3)	39 (4)	28 (4)	27 (3)	40 (3)	32 (3)	212	35	4 (3)	3 (3)	2 (2)	2 (3)	4 (4)	2 (2)	17	2.8
Ungaged drainage area of Falls Lake	604 (37)	410 (40)	308 (40)	349 (37)	566 (37)	389 (37)	2,620	437	52 (37)	42 (40)	35 (40)	29 (37)	42 (37)	29 (37)	229	38
Total inflow to Falls Lake	1,650	1,040	780	952	1,540	1,060	7,030	1,170	143	106	88	78	115	79	568	100
Neuse River near Falls, Falls Lake outflow (site 1)	700 (43)	580 (56)	320 (41)	190 (20)	—	—	—	448	55 (38)	41 (39)	21 (24)	11 (14)	—	—	—	32

Table 13. Annual nutrient loads into and out of Falls Lake, Lake Michie, and Little River Reservoir, water years 1989-94 (Continued)

[Sites are shown in figure 2. —, no data]

Station name or location	Nitrogen load, in tons (percent of total inflow load)								Phosphorus load, in tons (percent of total inflow load)							
	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94
Lake Michie																
Flat River at Bahama (site 15)	220 (89)	140 (89)	110 (89)	83 (89)	220 (89)	120 (89)	893	149	21 (89)	13 (89)	10 (89)	8 (89)	21 (89)	11 (89)	84	14
Ungaged drainage area of Lake Michie	28 (11)	18 (11)	14 (11)	11 (11)	28 (11)	15 (11)	114	19	3 (11)	2 (11)	1 (11)	1 (11)	3 (11)	1 (11)	11	1.8
Total inflow to Lake Michie	248	158	124	94	248	135	1,010	168	24	15	11	9	24	12	95	16
Flat River at Dam near Bahama, Lake Michie outflow (site 14)	270 (109)	210 (133)	140 (113)	105[a] (112)	250[a] (101)	156[a] (115)	1,130	188	15 (63)	11 (75)	8 (71)	6[a] (67)	13[a] (55)	8[a] (64)	61	10
Little River Reservoir																
Little River at Secondary Road 1461 near Orange Factory (site 12)	110 (80)	79 (80)	66 (80)	44 (80)	105 (80)	49 (80)	453	76	11 (80)	8 (80)	7 (80)	4 (80)	11 (80)	5 (80)	46	7.7
Ungaged drainage area of Little River Reservoir	27 (20)	20 (20)	16 (20)	11 (20)	26 (20)	12 (20)	113	19	3 (20)	2 (20)	2 (20)	1 (20)	3 (20)	1 (20)	12	1.9
Total inflow to Little River Reservoir	137	99	82	55	131	61	566	94	14	10	9	5	14	6	58	9.6
Estimated Little River Reservoir outflow	69 (50)	99 (50)	83 (50)	55 (50)	132 (50)	61 (50)	283	47	7 (50)	5 (50)	4 (50)	2 (50)	7 (50)	3 (50)	29	4.8

[a] Estimate based on average annual tons per total discharge for 1989-91.

[b] Because discharge data are missing for the 1990 and 1991 water years, loads from Ellerbe Creek were included in the ungaged area for those water years.

[c] Last 5 months of year was estimated based on comparisons of flow at Little Lick Creek.

[d] June, July, and August estimated based on comparison with flow at Little Lick Creek.

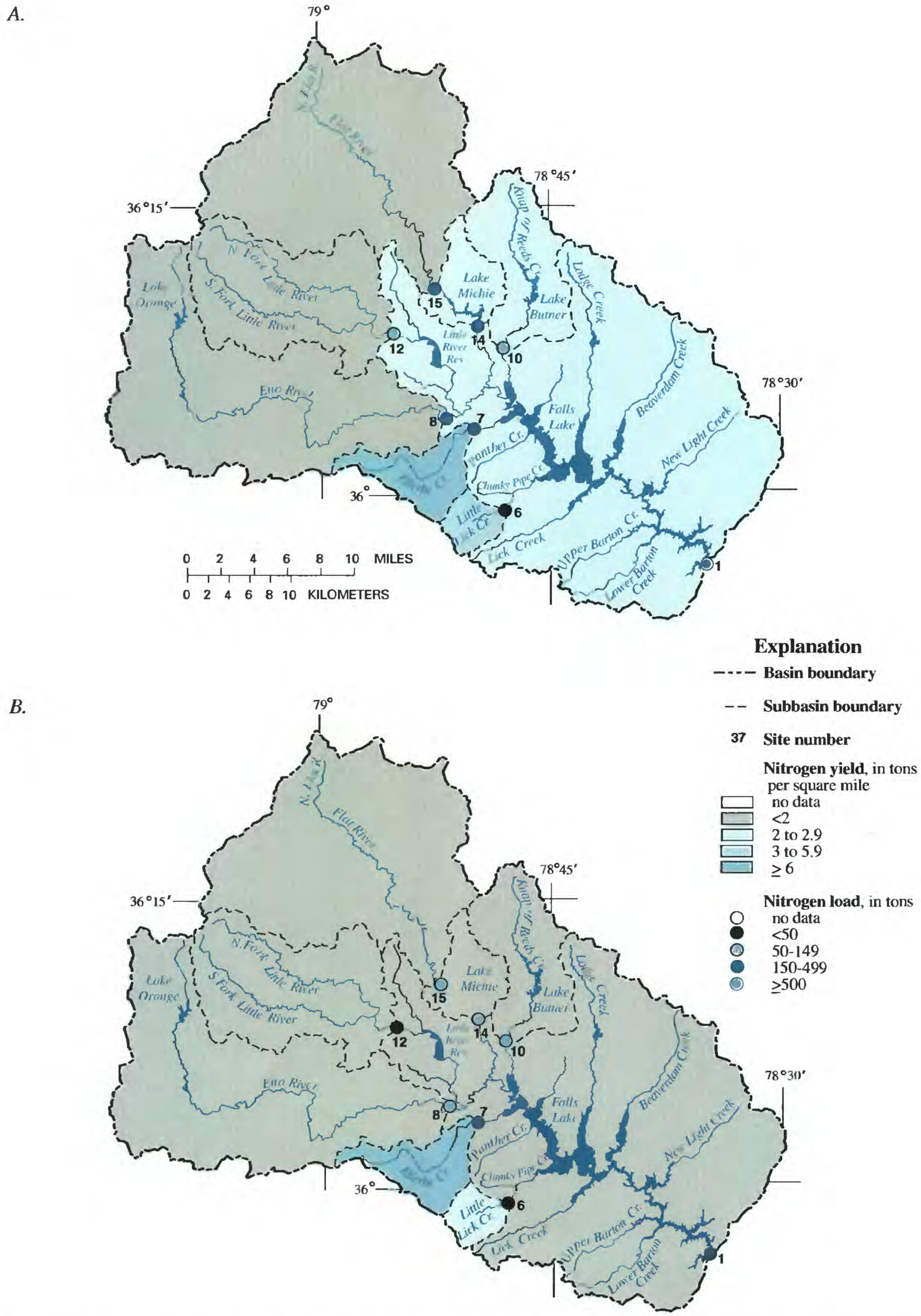

Figure 18. Estimated nitrogen yield and load in selected tributaries to Falls Lake, Lake Michie, and Little River Reservoir, and outflow of nitrogen load from Lake Michie and Falls Lake, (A) 1989 and (B) 1992.

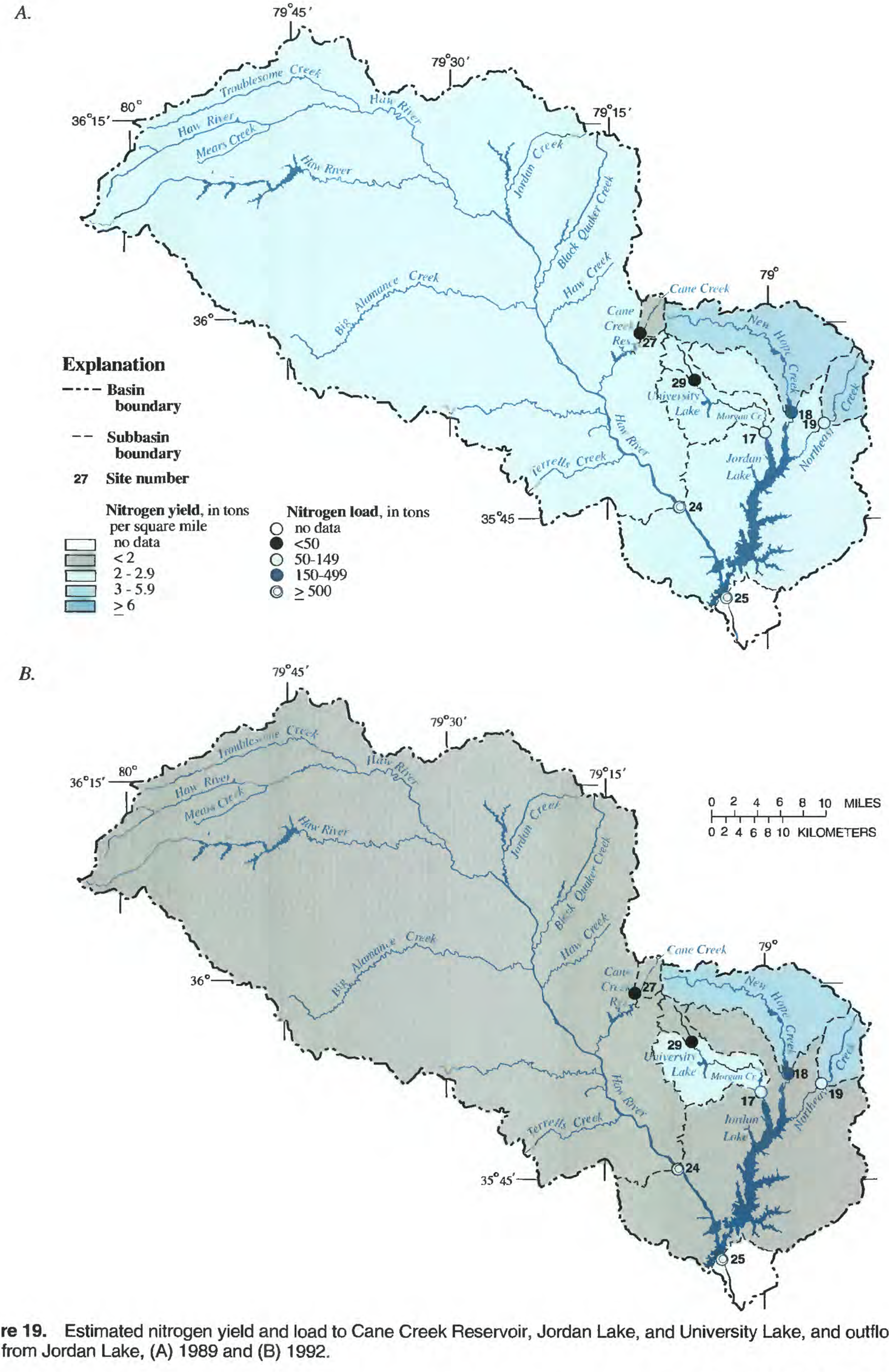

Figure 19. Estimated nitrogen yield and load to Cane Creek Reservoir, Jordan Lake, and University Lake, and outflow of nitrogen load from Jordan Lake, (A) 1989 and (B) 1992.

Table 14. Annual nutrient loads into and out of Jordan Lake, University Lake, and Cane Creek Reservoir, water years 1989-94

[Sites are shown in figure 2. —, no data]

Station name or location	Nitrogen load, in tons (percent of total inflow load)								Phosphorus load, in tons (percent of total inflow load)							
	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94
Jordan Lake																
Morgan Creek near Farrington (site 17)	110 (3)	120 (3)	100 (2.5)	97 (3)	130 (3)	96 (3)	653	110	12 (2)	14 (2)	11 (2)	9 (2)	19 (3)	9 (2)	74	12
New Hope Creek near Blands (site 18)	320 (8)	310 (7)	300 (7)	280 (10)	350 (8)	274 (9)	1,830	306	27 (4)	27 (4)	26 (4)	24 (6)	29 (4)	22 (5)	155	26
Northeast Creek at Secondary Road 1100 near Genlee (site 19)	120 (3)	120 (3)	100 (2.5)	100 (4)	120 (3)	—	560	112	10 (2)	10 (2)	8 (1)	8 (2)	11 (2)	—	—	9.4
Haw River near Bynum (site 24)	2,800 (70)	2,900 (71)	2,900 (71)	1,800 (67)	3,100 (70)	2,100 (70)	15,600	2,600	480 (76)	490 (76)	490 (77)	310 (74)	530 (76)	360 (76)	2,660	440
Ungaged drainage area of Jordan Lake	641 (16)	661 (16)	651 (16)	436 (16)	708 (16)	517 (17)	3,610	602	101 (16)	104 (16)	102 (16)	67 (16)	112 (16)	20 (17)	569	95
Total inflow to Jordan Lake	3,990	4,110	4,050	2,710	4,410	2,990	22,300	3,710	630	645	637	418	701	473	3,500	580
Haw River below Dam near Moncure, Jordan Lake outflow (site 25)	2,400 (60)	2,400 (58)	2,200 (54)	1,500 (55)	3,000 (68)	1,700 (57)	13,200	2,200	270 (43)	280 (43)	250 (39)	160 (38)	340 (48)	190 (40)	1,490	250
University Lake																
Morgan Creek near White Cross (site 29)	18 (28)	19 (28)	12 (28)	9 (28)	14 (28)	11 (28)	83	14	3 (28)	3 (28)	2 (28)	1 (28)	2 (28)	2 (28)	13	2.2
Ungaged drainage area of University Lake	46 (72)	49 (72)	31 (72)	23 (72)	36 (72)	28 (72)	213	36	8 (72)	8 (72)	5 (72)	3 (72)	5 (72)	5 (72)	33	5.6
Total inflow to University Lake	64	68	43	32	50	39	296	49	11	11	7	4	7	7	46	7.7
Cane Creek Reservoir																
Cane Creek near Orange Grove (site 27)	13 (24)	11 (24)	14 (24)	7 (24)	12 (24)	9 (24)	66	11	2 (24)	1 (24)	2 (24)	1 (24)	2 (24)	1 (24)	8	1.4
Ungaged drainage area of Cane Creek Reservoir	41 (76)	35 (76)	45 (76)	22 (76)	38 (76)	29 (76)	210	35	6 (76)	3 (76)	6 (76)	3 (76)	5 (76)	3 (76)	27	4.5
Total inflow to Cane Creek Reservoir	54	46	59	29	50	38	276	46	8	4	8	4	6	4	36	5.9

Annual nitrogen loads to University Lake and Cane Creek Reservoir averaged 49 and 46 tons, respectively. Nitrogen yields were 1.6 tons/mi^2 for Morgan Creek and 1.5 tons/mi^2 for Cane Creek above their reservoirs. These were the lowest yields measured for sites unaffected by reservoirs (fig. 19).

Annual phosphorus loads to Falls Lake averaged about 103 tons for the 6-year study period (table 13). Phosphorus loads and yield were less in 1992, a dry year, than in 1989, a wet year; however, the relative contributions from each tributary remained about the same (fig. 20). Knap of Reeds Creek averaged 23 tons/yr (1989-94), which was the greatest phosphorus contribution of the gaged basins (table 13). Knap of Reeds Creek also had the greatest yield (0.53 tons/mi^2) among gaged basins tributary to Falls Lake (table 10). The yield from Knap of Reeds Creek was essentially unchanged from the 1983-86 period whereas annual phosphorus yields declined by nearly half at Little Lick Creek (site 6) and Eno River (site 8) from the 1983-87 period and declined by 83 percent at Ellerbe Creek (site 7). Declines in phosphorus yields at Little Lick Creek, Ellerbe Creek, and Eno River (site 8) are probably due to improvement in phosphorus removal from wastewater effluents by WWTP's and to the phosphate-detergent ban that became law in January 1988. In 1994, the Little Lick Creek and Eno River WWTP's were closed and effluents re-routed to the Durham Northside WWTP on Ellerbe Creek.

Annual phosphorus loads from Falls Lake averaged 28 percent of the load into the lake, and ranged from 14 percent in water year 1992 to 39 percent in water year 1990. Phosphorus loads from Falls Lake reported by Garrett ranged from 11 percent (1985) to 21 percent (1984) of phosphorus load into the lake.

Phosphorus loads to Lake Michie ranged from 9 tons in 1992 to 24 tons in 1989 and 1993. Phosphorus loads out of the reservoir ranged from 55 percent to 75 percent of the phosphorus load into the lake (table 13). The average annual phosphorus yield in Flat River Basin (site 15), which feeds Lake Michie, for 1989-94 was 0.09 tons/mi^2 (table 10). The yield was 0.06 below Lake Michie (site 14) because of deposition in the lake.

Phosphorus loads to Little River Reservoir ranged from 5 tons in water year 1992 to 14 tons in water years 1989 and 1993. Phosphorus loads out of the reservoir were not measured but were estimated to be 50 percent of inflow loads based on comparison with Falls Lake which has a similar retention time (table 2). The phosphorus yield of Little River Basin was similar to Flat River, 0.10 tons/mi^2.

Annual phosphorus loads to Jordan Lake ranged from 418 tons in 1992 to 701 tons in 1993 (table 14). Haw River accounted for about 75 percent of the phosphorus load to Jordan Lake. Phosphorus load out of Jordan Lake accounted for about 40 percent of the inflow load compared to 28 percent for Falls Lake. The smaller percentage of material trapped by Jordan Lake is probably due, in part, to the unusual morphometry of Jordan Lake. Most of the load to Jordan Lake is from the Haw River (fig. 21); water to the Haw River arm of the lake has a relatively short retention time in the reservoir. Yields of Jordan Lake tributaries ranged from 0.15 to 0.45 tons/mi^2 for the study period (table 12). Average annual phosphorus yields declined at every site compared to yields for 1983-86 (table 12). The greatest decline (81 percent) was recorded at Morgan Creek (site 17). Large declines in phosphorus yield also were observed for New Hope and Northeast Creeks—also located below WWTP's. These declines are probably due to improved phosphorus removal and the phosphate-detergent ban.

Average annual phosphorus load to University Lake was 8 tons and to Cane Creek Reservoir was 6 tons (1989-94). Average annual phosphorus yield was 0.26 tons/mi^2 for Morgan Creek and 0.19 tons/mi^2 for Cane Creek.

Lead and Zinc

Lead and zinc loads were calculated from regression equations of log instantaneous concentration and log instantaneous discharge (table S-5). For some sites, there was no relation between concentration and discharge, and load was calculated from median concentration. For other sites, an insufficient number of concentrations were measured above the laboratory's detection limit, and load could not be calculated. Lead and zinc loads could not be calculated for all the necessary sites required to develop a trace element water budget for every reservoir. Regression analyses for calculating lead and zinc concentrations from discharge produced R^2 values ranging from 0.02 to 0.69 (table S-5).

Average annual lead loads to Falls Lake from tributaries in the upper Neuse River Basin ranged from

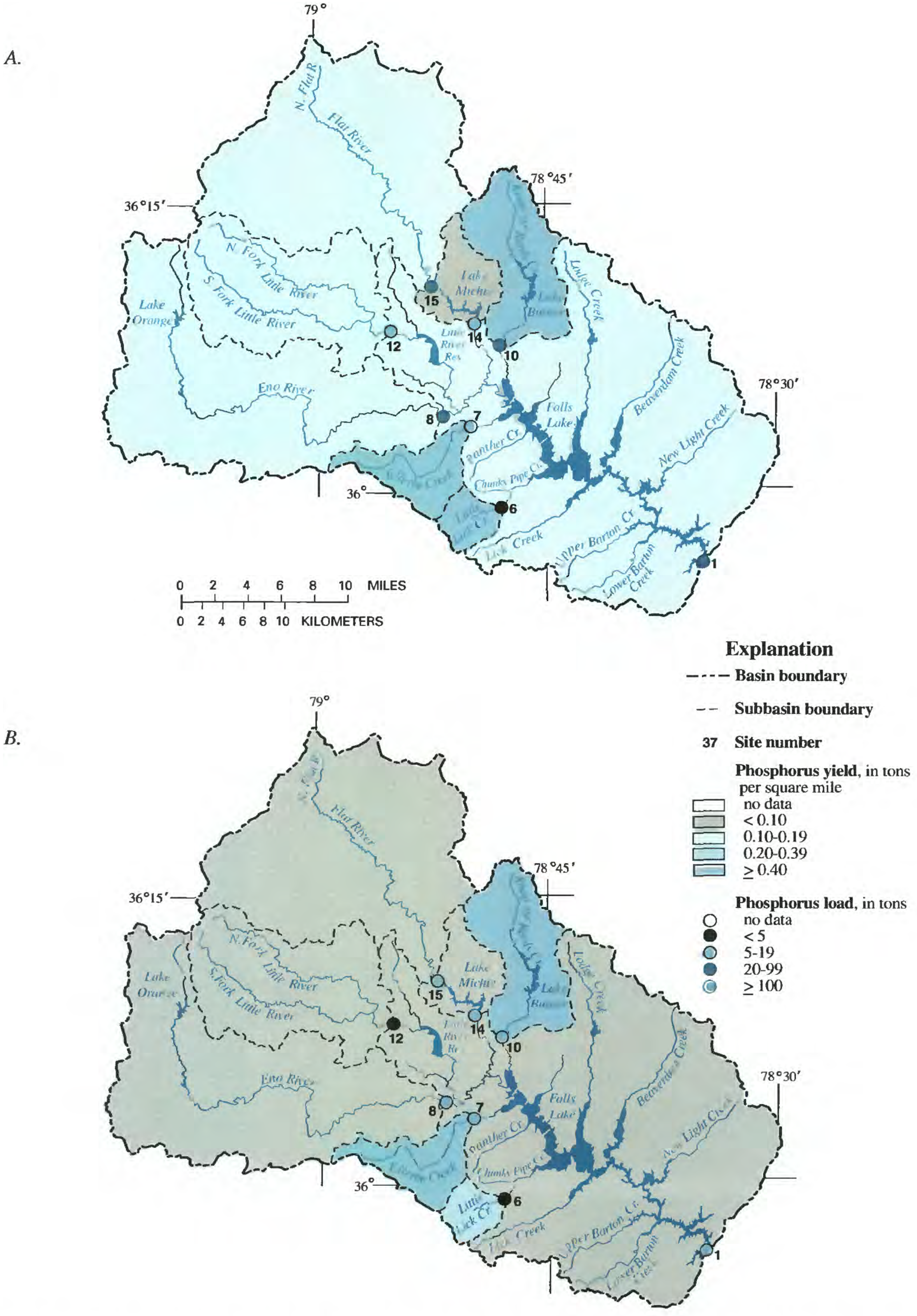

Figure 20. Estimated phosphorus yield and load in selected tributaries to Falls Lake, Lake Michie, and Little River Reservoir, and outflow of phosphorus load from Falls Lake and Lake Michie, (A) 1989 and (B) 1992.

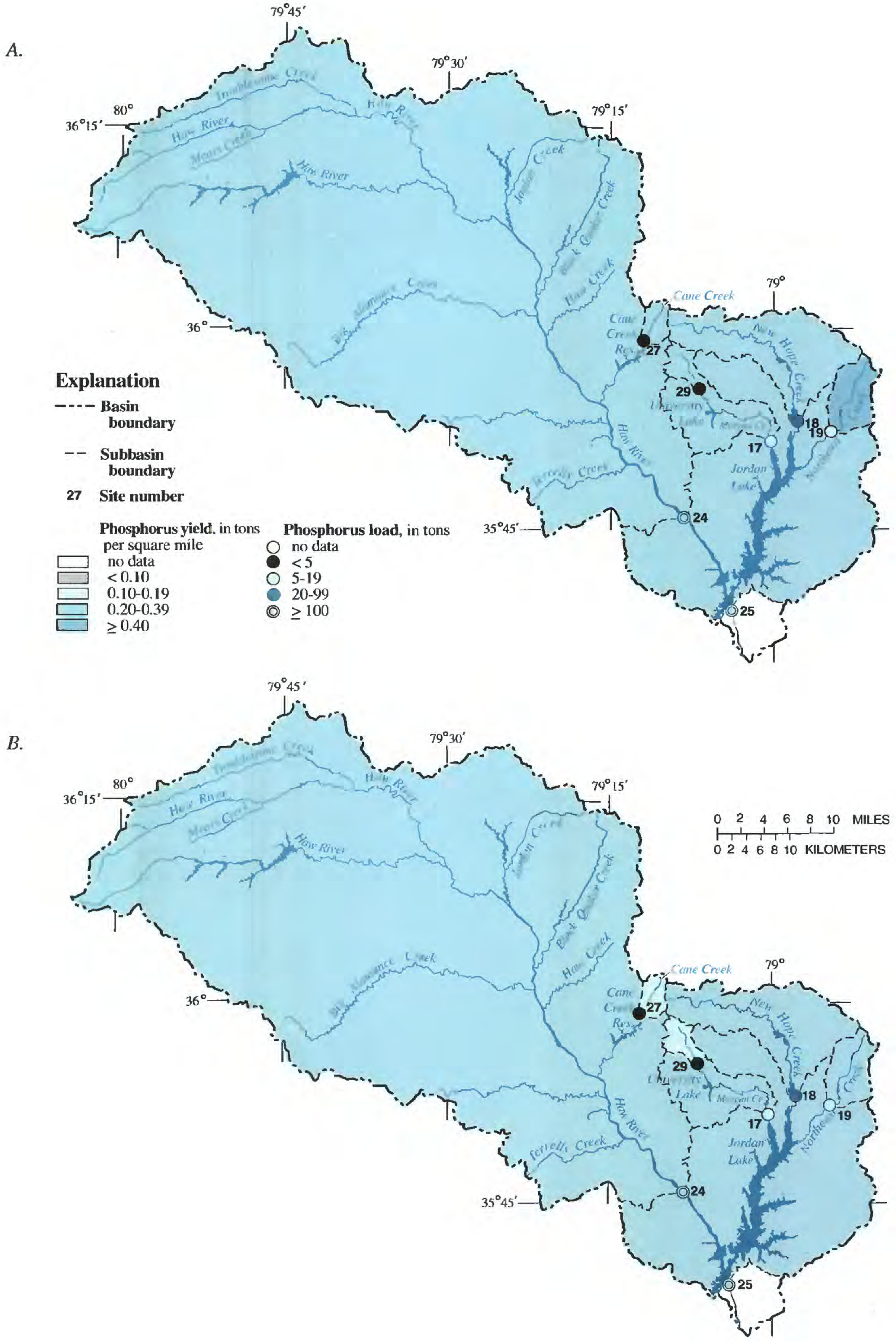

Figure 21. Estimated phosphorus yield and load to Cane Creek Reservoir, Jordan Lake, and University Lake, and outflow of phosphorus load from Jordan Lake, (A) 1989 and (B) 1992.

363 pounds (lbs) from Little Lick Creek (site 6) to 2,300 lbs from Ellerbe Creek (table 15). Lead loads out of Falls Lake ranged from 4,070 lbs in 1992 to 20,000 lbs in 1989 (table 15, fig. 22). Estimated total loads of lead into Falls Lake ranged from 5,860 lbs in 1992 to 15,500 lbs in 1989; that is, about 70 (1992) to 186 (1990) percent of inflows. The reservoir probably acts as a sink for lead; years with loads from the lake exceeding loads to the lake likely indicate an underestimation of input. Discharge data for Ellerbe Creek were unavailable for 1990 and 1991 and that area was included in the ungaged area of the lake. Because Ellerbe Creek accounts for a disproportionately large part of the lead load to Falls Lake, this could account for part of the shortfall especially in 1990 which was a relatively wet year. The lead load at Eno River near Hillsborough (site 26), near the headwaters, averaged 587 pounds per year (lbs/yr). This is 24 percent of the mean lead load in Eno River downstream from Durham (site 8). The lead load in the Neuse River at Smithfield (site 32), located about 35 miles downstream from the Falls Lake dam and downstream from Raleigh, Durham, and Cary, was 25,000 lbs annually, an increase of more than 100 percent.

Average annual lead yield was greatest for Ellerbe Creek (105 pounds per square mile [lbs/mi^2]) and next greatest for Little Lick Creek (36 lbs/mi^2). Smallest yields were recorded for the two headwater streams monitored, Eno River at Hillsborough (site 26, 8.9 lbs/mi^2) and Flat River at Bahama (site 15, 9.4 bs/mi^2) (table 15).

Lead loads to Jordan Lake ranged from 31,700 in 1992 (fig. 23B) to 68,100 in 1993 (table 15). Figure 23A shows the loads and yields of lead during 1989, a year almost as wet as 1993. Average annual inflows of lead to Jordan Lake were estimated at 52,500 lbs for the 6-year data-collection period. Average annual lead loads for tributaries in the upper Cape Fear River Basin ranged from about 667 lbs for Northeast Creek (site 19) to about 40,000 lbs for Haw River near Bynum (site 24, table 15). The contribution from the ungaged portion of the basin was estimated to account for 19 percent of the input. The average annual outflow from Jordan Lake (33,600 lbs for 1989-94) was determined from load calculations at Haw River below the dam (site 25). The lead load out of Jordan Lake ranged from 55 to 73 percent of the loads into the lake (table 15).

Zinc loads to Falls Lake from monitored tributaries ranged from an average of 1,150 lbs/yr from Little Lick Creek to 10,600 lbs/yr from Eno River near Weaver. The zinc load to Falls Lake ranged from 33,300 lbs in 1992 (table 16, fig. 24B) to 60,600 lbs in 1989 (table 16, fig. 24A). The average annual zinc load into Falls Lake was 41,800 lbs. The outflow ranged from 49 percent in 1992 to 152 percent of the inflow in 1990. Average yield for zinc in the upper Neuse River Basin above the Falls Lake dam ranged from 71 to 340 lbs/mi^2. Ellerbe Creek accounted for the maximum yield. The zinc load for the Neuse River at Smithfield (site 32) was about 50 percent more than the load in the Neuse River below Falls Lake.

Table 15. Lead loads and yield from selected tributaries in the upper Neuse River and upper Cape Fear River Basins, water years 1989-94

[Sites are shown in figure 2. lbs/mi^2/yr, pounds per square mile per year; —, no data]

Station name or location	Lead load, in pounds (percent of total inflow load)								Lead yield (lbs/mi^2/yr)
	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94	
Upper Neuse River Basin									
Eno River at Hillsborough (site 26)	776	516	508	456	783	482	3,520	587	8.9
Eno River near Weaver (site 8)	3,480	2,490	2,080	1,420	3,110	1,840	14,400	2,400	16
Knap of Reeds Creek near Butner (site 10)	1,200	1,020	694	351	996	482	4,750	792	18

Table 15. Lead loads and yield from selected tributaries in the upper Neuse River and upper Cape Fear River Basins, water years 1989-94 (Continued)

[Sites are shown in figure 2. lbs/mi^2/yr, pounds per square mile per year; —, no data]

Station name or location	Lead load, in pounds (percent of total inflow load)								Lead yield (lbs/mi^2/yr)
	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94	
Upper Neuse River Basin (Continued)									
Ellerbe Creek near Gorman (site 7)	3,410[a]	—	—	1,210	2,930	1,670[a]	—	2,300	105
Little Lick Creek above Secondary Road 1814 near Oak Grove (site 6)	539	385	239	236	513	264	2,180	363	36
Flat River at Dam near Bahama, Lake Michie outflow (site 14)	1,200	930	633	503[b]	1,135	726[b]	5,130	855	5.1
Ungaged drainage area of Falls Lake	5,680	4,150	3,140	2,890	6,760	3,880	26,500	4,420	16
Total inflow to Falls Lake	15,500	7,970	6,010	5,860	13,700	7,870	56,900	9,490	12
Neuse River near Falls, Falls Lake outflow (site 1)	20,000 (129)	14,800 (186)	7,720 (128)	4,070 (70)	16,600 (121)	7,260 (92)	70,400 (124)	11,700 (124)	15
Neuse River at Smithfield (site 32)	48,400	31,600	17,900	9,630	27,800	14,500	150,000	25,000	21
Lake Michie									
Flat River at Bahama (site 15)	1,830	1,090	889	686	1,950	991	7,440	1,240	8.3
Ungaged drainage area of Lake Michie	223	139	113	87	249	126	948	158	8.3
Total inflow to Lake Michie	2,060	1,230	1,000	773	2200	1120	8,380	1,400	8.3
Flat River at Dam near Bahama, Lake Michie outflow (site 14)	1,200	930	633	503	1,135	726	5,130	855	5.1
Jordan Lake									
New Hope Creek near Blands (site 18)	2,310	1,860	2,250	1,580	2,670	1,420	12,100	2,010	26
Northeast Creek at Secondary Road 1100 near Genlee (site 19)	904	786	557	558	901	298	4,000	667	24
Haw River near Bynum (site 24)	44,400	42,700	46,300	23,600	51,700	31,200	240,000	40,000	31
Ungaged drainage area of Jordan Lake	11,000	10,500	11,300	5,950	12,800	7,600	59,100	9,860	31
Total inflow to Jordan Lake	58,600	55,800	60,400	31,700	68,100	40,600	315,000	52,500	31
Haw River below Dam near Moncure (site 25; Jordan Lake outflow)	37,500 (64)	36,900 (66)	33,500 (55)	19,300 (61)	49,400 (73)	25,200 (62)	202,000 (64)	33,600 (64)	20

[a] June, July, and August estimated based on comparison with flow from Little Lick Creek.

[b] No discharge data available; therefore, outflow assumed to be 65 percent of inflow.

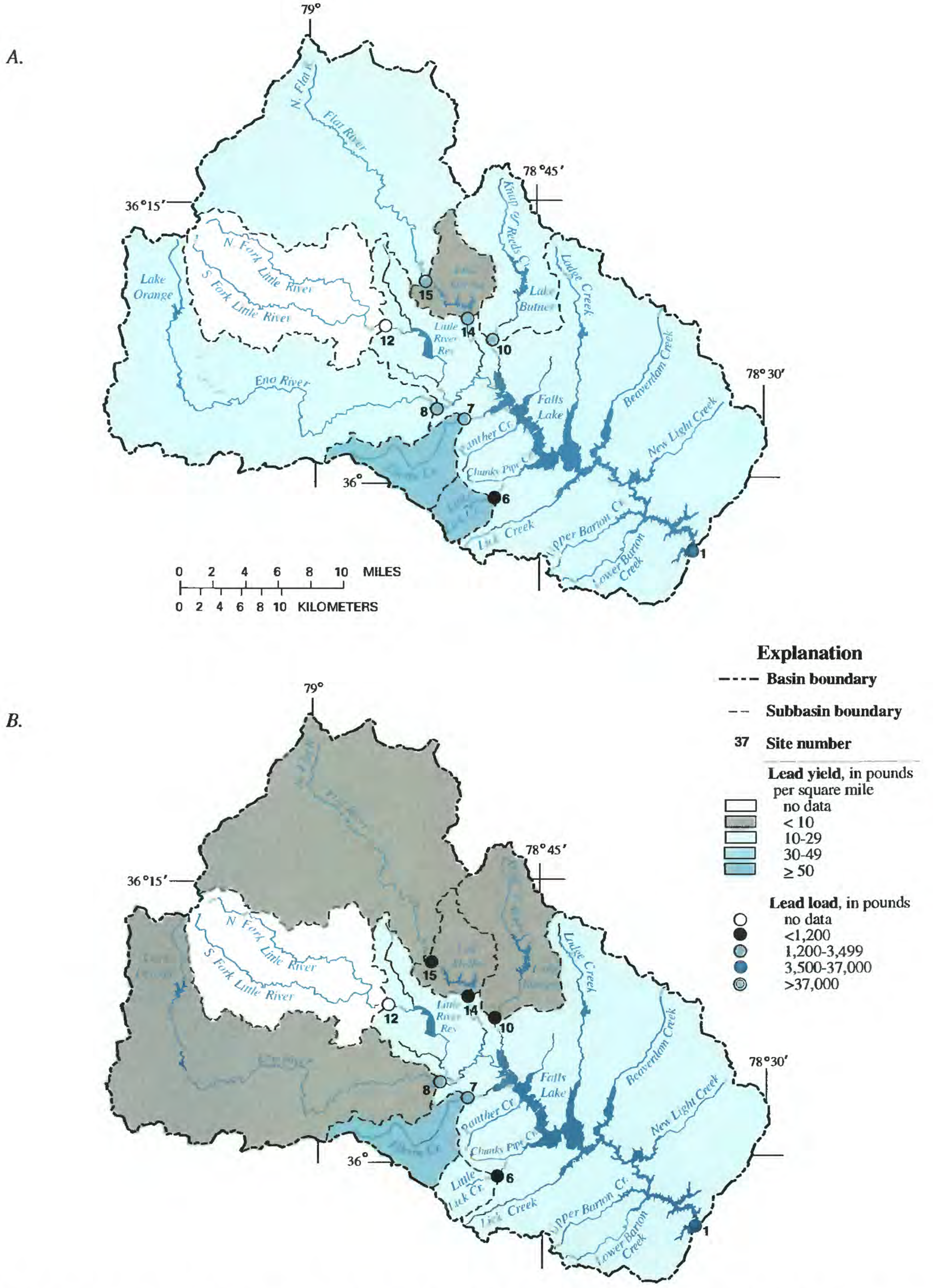

Figure 22. Estimated lead yield and load from selected tributaries to Falls Lake and Lake Michie, and outflow of lead load from Falls Lake, (A) 1989 and (B) 1992.

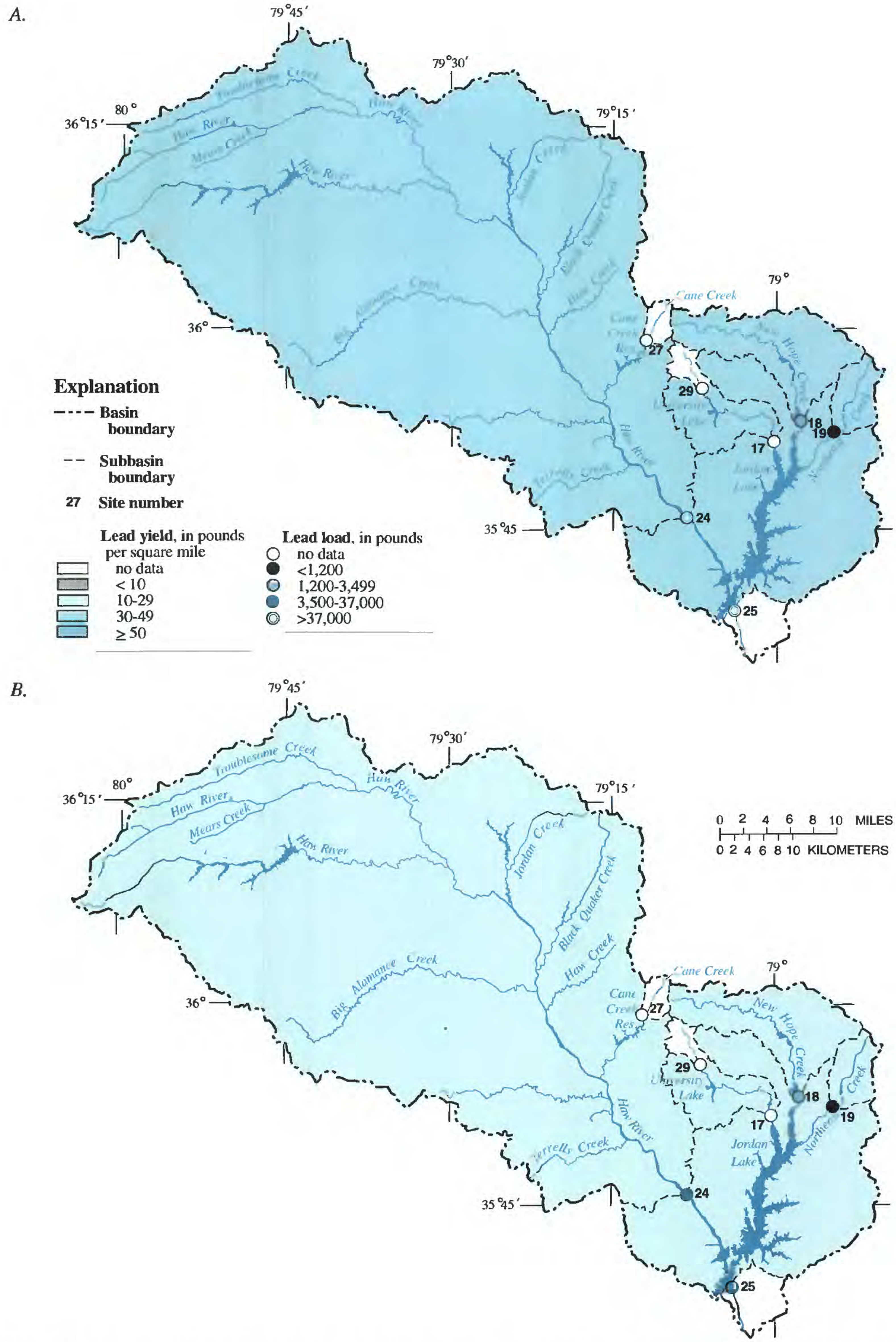

Figure 23. Estimated lead yield and load from selected tributaries to Jordan Lake and University Lake, and outflow of lead load from Jordan Lake, (A) 1989 and (B) 1992.

Table 16. Zinc loads and yield from selected tributaries in the upper Neuse River and upper Cape Fear River Basins, water years 1989-94

[Sites are shown in figure 2. lbs/mi^2/yr, pounds per square mile per year; —, no data]

Station name or location	Zinc load, in pounds (percent of total inflow load)								Zinc yield (lbs/mi^2/yr)
	1989	1990	1991	1992	1993	1994	1989-94	Mean for 1989-94	
Upper Neuse River Basin									
Eno River near Weaver (site 8)	14,800	11,400	9,460	6,330	13,200	8,120	63,400	10,600	71
Knap of Reeds Creek near Butner (site 10)	5,220	4,440	3,010	1,530	4,310	2,090	20,600	3,430	80
Ellerbe Creek near Gorman (site 7)	11,100	—	—	4,660	8,150	5,960	—	7,470	340
Little Lick Creek above Secondary Road 1814 near Oak Grove (site 6)	1,660	1,270	814	761	1,480	920	6,910	1,150	110
Ungaged drainage area of Falls Lake	27,800	18,400	13,900	20,000	24,100	25,500	130,000	21,600	65
Total inflow to Falls Lake	60,600	35,600	27,200	33,300	51,300	42,700	251,000	41,800	54
Neuse River near Falls, Falls Lake outflow (site 1)	69,600 (115)	54,200 (152)	29,200 (107)	16,300 (49)	58,800 (115)	26,849 (63)	255,000 (102)	42,500 (102)	55
Neuse River at Smithfield (site 32)	117,000	81,900	48,200	27,800	71,100	39,300	385,300	64,200	53
Jordan Lake									
New Hope Creek near Blands (site 18)	6,710	5,710	6,400	4,870	7,740	4,440	35,900	6,000	79
Northeast Creek at Secondary Road 1100 near Genlee (site 19)	5,090	4,790	3,740	3,610	5,230	2,600	25,100	4,180	200
Haw River near Bynum (site 24)	110,000	108,000	114,000	60,900	126,000	78,400	597,000	99,600	78
Ungaged drainage area of Jordan Lake	28,100	27,400	28,700	16,000	32,100	19,700	152,000	25,300	80
Total inflow to Jordan Lake	150,000	146,000	153,000	85,400	171,000	105,000	810,000	135,000	80
Haw River at Dam near Moncure, Jordan Lake outflow (site 25)	130,000 (87)	131,000 (90)	118,000 (78)	72,500 (85)	170,000 (99)	90,100 (86)	711,000 (88)	119,000 (88)	70

Zinc loads to Jordan Lake ranged from 85,400 lbs in 1992 (table 16, fig. 25B) to 170,000 lbs in 1993. Figure 25A shows the loads and yields of zinc during 1989. Average annual inflows of zinc (1989-94) to Jordan Lake were about 135,000 lbs from tributaries in the upper Cape Fear River Basin. The ungaged area of the basin accounted for about 19 percent of the inflow. The greatest zinc load to Jordan Lake (75 percent) was from the Haw River (site 24)—the tributary with the largest drainage area. The greatest zinc yield was from Northeast Creek, 200 lbs/mi^2. Zinc loads out of Jordan Lake accounted for 78 to 99 percent of the total inflows of zinc (table 16).

SUMMARY

Water-quality samples were collected from 35 lake and stream sites in the Triangle area of North Carolina from October 1988 through September 1994 by the U.S. Geological Survey (USGS) and the North Carolina Division of Environmental Management (DEM). Samples were analyzed for major ions, nutrients, trace metals, and selected synthetic organic compounds. Data from the two agencies were combined by the USGS for interpretation. In addition to water samples, bed-material samples were collected from 1 to 3 times at selected sites for the analysis of synthetic organic compounds. These data supplement nutrient, major ion, and trace element data collected prior to October 1988 by the USGS and DEM and establish a new database of concentrations of synthetic organic compounds in water and bed material in the study area.

Streams in the upper Neuse and upper Cape Fear River Basins within the study area are generally similar to streams draining relatively pristine basins in the same geochemical zone. The major cations are equally calcium, magnesium, and sodium + potassium, and the major anion is bicarbonate. Streams that receive wastewater effluents or that are downstream from urban areas generally had sodium + potassium as the major cation and sulfate or bicarbonate as the major anion. These waters also had substantially greater total-dissolved solids than the baseline waters.

Stream and lake sites were assigned to one of five site categories according to general site characteristics. Site categories were (1) rivers, (2) large multipurpose reservoirs, (3) small upland water-supply reservoirs, (4) streams below urban areas and WWTP's, and (5) headwater streams. Sites near water-supply intakes were further identified as a sixth category. Concentrations of nitrogen species, phosphorus species, and selected trace metals were compared quantitatively by site category using nonparametric analysis of variance techniques and compared qualitatively (trace metals) using box plots.

Wastewater-treatment plant effluents and urban runoff had a significant effect on water quality compared to reservoirs and headwater streams. Median concentrations of nitrate and total nitrogen were significantly greater for sites below urban areas and WWTP's than for other sites. Total ammonia plus organic nitrogen varied little among site categories, the only significant difference being between headwater streams and streams below urban areas and WWTP's. The median concentration in the latter category was twice that of headwater streams. Organic nitrogen accounted for 80 to 90 percent of total ammonia plus organic nitrogen in all categories. Organic nitrogen was the predominant form of nitrogen at reservoir sites, whereas nitrate was predominant for sites below urban areas and WWTP's. River intake sites had significantly greater concentrations of nitrite plus nitrate than large and small reservoir intake sites. No difference was found between the two categories for ammonia or organic nitrogen.

Median concentrations of total phosphorus were significantly greater for sites below urban areas and WWTP's than for small and large reservoir sites but were not significantly greater than river or headwater sites. The strong association between phosphorus and suspended sediments as well as the importance of point sources as contributors of total phosphorus probably account for the difference in concentrations between reservoirs and streams. Orthophosphate was significantly greater in sites below urban areas and WWTP's than in river or reservoir sites. A marked seasonal pattern was observed for total phosphorus at reservoir sites. Greatest concentrations generally occurred during late summer and fall months and roughly corresponded to peaks in chlorophyll *a*.

Greatest concentrations of metals and trace metals in streams were observed during periods of greater than normal streamflow probably as a result of adsorption to silt, clay, and organic particles. However, most concentrations were below the MRL and below

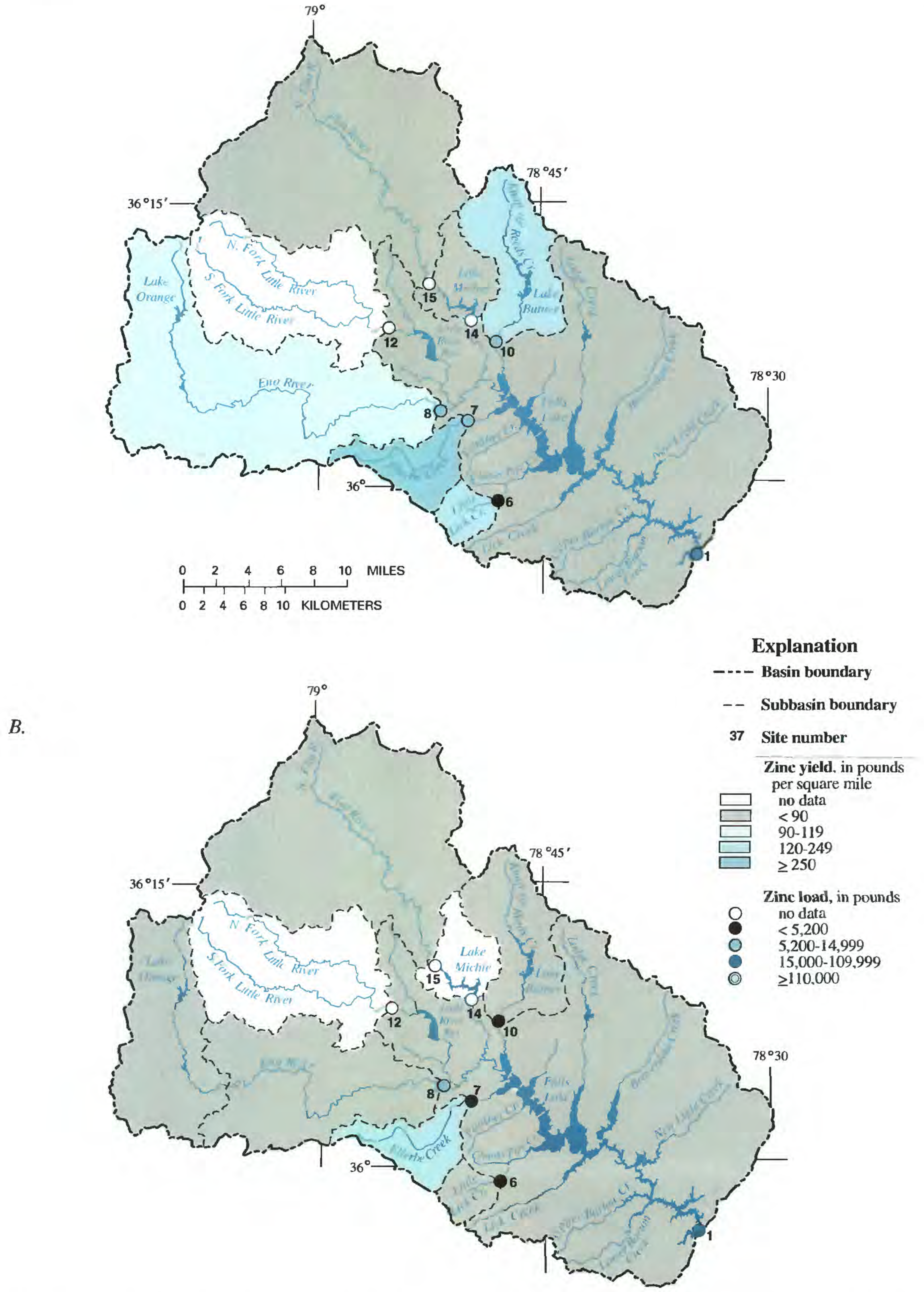

Figure 24. Estimated zinc yield and load from selected tributaries to Falls Lake, and outflow of zinc load from Falls Lake, (A) 1989 and (B) 1992.

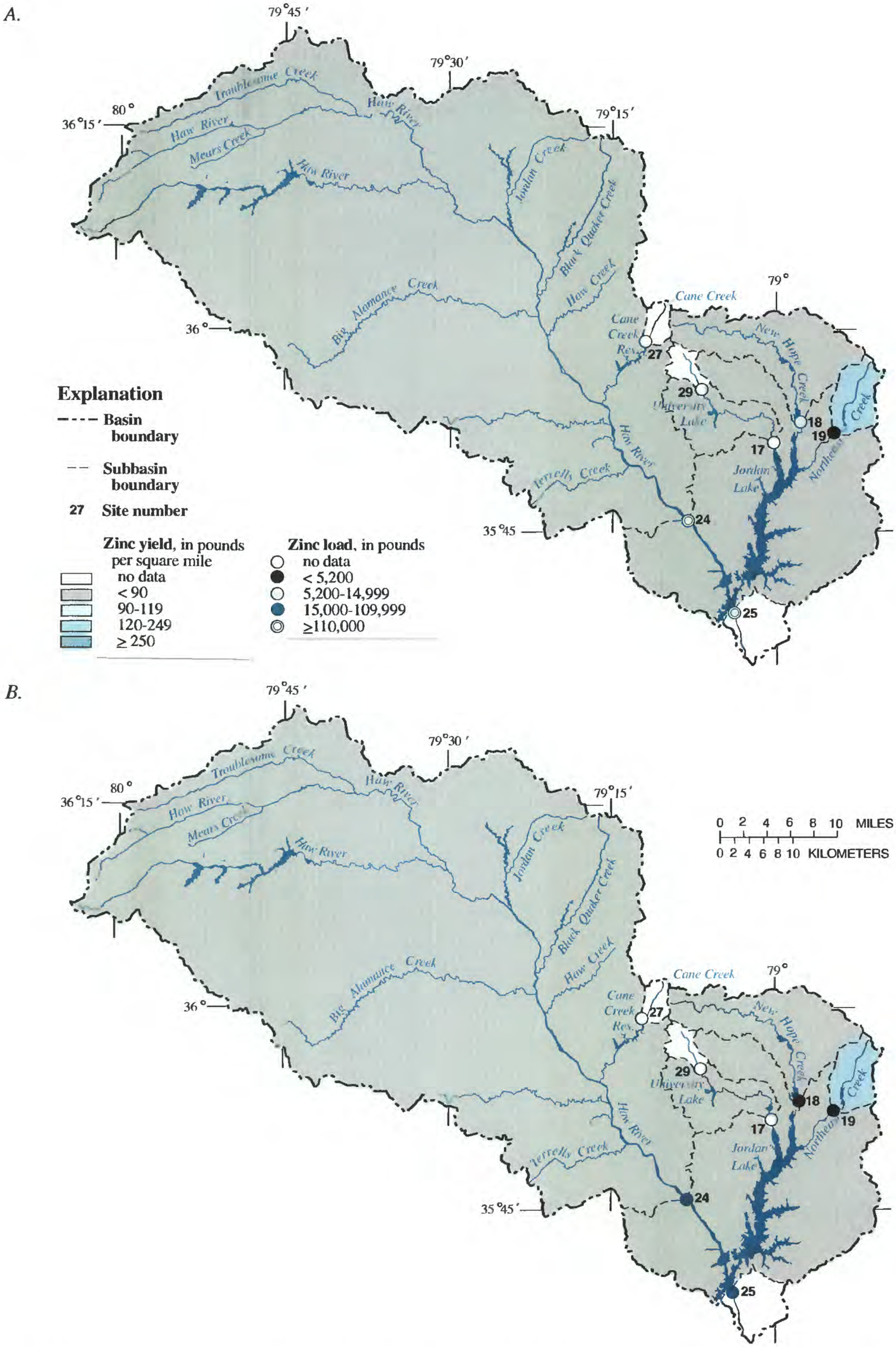

Figure 25. Estimated zinc yield and load from selected tributaries to Jordan Lake, and outflow of zinc load from Jordan Lake, (A) 1989 and (B) 1992.

USEPA drinking-water MCL's. Moreover, exceedences occurred more often at stream sites than at reservoir sites. Only two samples exceeded the State water-quality standard for chromium—Cane Creek and Flat River. Seven samples at Haw River near Bynum and Neuse River at Smithfield exceeded the lead water-quality standard. Median iron and manganese concentrations were near or above the USEPA secondary drinking-water MCL's (1,000 and 50 µg/L, respectively) for stream sites, whereas concentrations at reservoir sites were typically well below the standards.

Samples for volatile organic compounds were collected during the first 3 years of study. Few were detected in concentrations above the MRL. Those detected were one of four trihalomethanes and occurred almost exclusively at sites below urban areas and WWTP's. Trace amounts of other volatile organic compounds, mostly organic solvents such as benzene, dichlorobenzene, tetrachloroethylene, and trichloroethane were found in fewer than 20 percent of the samples collected. No concentrations of volatile organic compounds exceeded USEPA drinking-water MCL's.

Organochlorine and organophosphorus pesticides were also sampled during the first 3 years of study. About 40 percent of the samples analyzed for pesticides contained detectable concentrations of at least one pesticide—most often lindane, dieldrin, diazinon, and heptachlor epoxide. Most detections occurred in samples from tributaries to Falls and Jordan Lakes and Swift Creek. Concentrations were always near the MRL. No concentrations exceeded USEPA drinking-water MCL's; however, some lindane and dieldrin concentrations exceeded the State water-quality standards for the protection of aquatic life.

Selected acetanilide and triazine herbicides were collected in 1992. Most of the samples collected contained detectable concentrations of at least one of these herbicides—chiefly atrazine or simazine. None exceeded the USEPA drinking-water MCL's. These compounds are in widespread use and are more water soluble than organochlorine and organophosphorus pesticides.

Organochlorine, organophosphorus, acetanilide, triazine, carbamate, and chorophenoxy acid pesticides were sampled in the spring of 1993 and 1994 at three sites on streams receiving WWTP effluents to determine the probable source—effluents versus local runoff. Simazine, prometon, 2,4-D, and 2,4-DP were measured at concentrations considerably greater than MRL's but below USEPA drinking-water MCL's. Pesticides detected were present upstream and downstream from WWTP's and in effluents.

Water samples were collected for analysis of 51 semivolatile organic compounds. None were found above MRL's. Most are relatively insoluble in water and, if present, are more likely to reside in bed materials. Samples of bed materials were collected from 24 sites and analyzed for selected semivolatile organic compounds and organochlorine and organophosphorus pesticides. Greatest concentrations of pesticides in bed material were found in the lake-bed materials of the Haw River arm of Jordan Lake, Falls Lake, Lake Michie, and Ellerbe Creek. Lake beds have greater concentrations of organic material and smaller grain size inorganic material than bed materials from streams and this may account for the results from the lakes. Semivolatile organic compounds were not found in concentrations above the MRL.

Most of the stream sites had USGS streamflow gages. Continuous record of streamflow at these sites was used to calculate annual suspended-sediment, total phosphorus, total nitrogen, total lead, and total zinc loads to the reservoirs as well as to calculate drainage basin yields for these constituents. If sufficient water-quality and streamflow data were available, loads of these constituents out of the reservoirs also were calculated to determine the amount of material trapped by the reservoir.

Annual suspended-sediment load into Falls Lake ranged from 29,500 tons to 88,200 tons and varied by water year as a function of streamflow. Flat River is a minor contributor to Falls Lake because Lake Michie traps about 90 percent of the load. Little River also produces a large sediment load that is probably trapped in Little River Reservoir. The trapping rate of Little River Reservoir could not be directly determined because outflow was not monitored. Little River and Flat River above the reservoirs produce yields of about 184 and 223 tons/mi^2. This is an increase compared to yields of 140 and 190 tons reported for 1970-79. Ellerbe Creek produced the largest yield in the Falls Lake Basin (347 tons/mi^2). Undisturbed basins in the Piedmont produce about 45 tons/mi^2.

Annual sediment loads to Jordan Lake ranged from about 271,000 tons in 1992 to 622,000 in 1993.

Haw River contributes about 77 percent of the load to Jordan Lake. New Hope and Northeast Creeks contribute much smaller loads but basin yields are similar to that of Haw River—from 175 to 284 tons/mi^2. The mean annual yields for Morgan and Cane Creeks were 52 and 77 tons/mi^2, respectively. University Lake and Cane Creek Reservoirs probably trap most of the suspended sediment from Morgan and Cane Creeks, respectively, but data were not available to calculate percentage trapped.

Annual nitrogen loads to Falls Lake ranged from 780 tons in 1991 to 1,650 tons in 1989. From 44 to 80 percent of the load to Falls Lake is trapped. Nitrogen loads into Lake Michie were less than nitrogen loads out of the lake. This may be a result of underestimation of load from ungaged portions of the basin including Dial Creek, which receives drainage from agricultural runoff. Another factor may be that the relatively short hydraulic retention time of Lake Michie limits nitrogen removal.

Nitrogen load to Jordan Lake ranged from 2,710 tons in 1992 to 4,100 tons in 1993. From 32 to 46 percent of the nitrogen load to Jordan Lake is trapped. Haw River contributed approximately 70 percent of the nitrogen loads to Jordan Lake; however, New Hope and Northeast Creeks produced greater yields—at least double that of Haw River. Annual nitrogen loads to University Lake and Cane Creek Reservoir averaged 49 and 46 tons, respectively. For Morgan Creek near Farrington, nitrogen yield decreased by 59 percent compared to the 1983-86 period; for Northeast Creek, nitrogen increased by 23 percent. Yields at New Hope, Haw River at Bynum, and Haw River below the dam were unchanged compared to the 1983-86 period. The overall average annual nitrogen yield to Jordan Lake was 2.2 tons/mi^2 compared to 1.5 tons/mi^2 for Falls Lake.

Annual phosphorus loads to Falls Lake ranged from 78 tons (1992) to 143 tons (1989). From 61 to 86 percent of the phosphorus load was trapped in Falls Lake. Only 25 to 45 percent of the phosphorus delivered to Lake Michie was trapped in the reservoir. Knap of Reeds Creek averaged 23 tons/yr (1989-94), which was the greatest phosphorus load of the gaged basins. Annual phosphorus yields declined by at least half at Ellerbe Creek, Little Lick Creek, and Eno River from the 1983-87 period, and remained nearly constant at the other sites tributary to Falls Lake. The decline in phosphorus yield at Little Lick, Ellerbe, and Eno River near Weaver are probably due to improvement in phosphorus removal from wastewater effluents from WWTP's and to the phosphate-detergent ban that became law in January 1988.

Annual phosphorus loads to Jordan Lake ranged from 418 tons in 1992 to 701 tons in 1993. Haw River accounted for about 75 percent of the phosphorus load to Jordan Lake. The average annual phosphorus load to University Lake was 8 tons and to Cane Creek Reservoir was 6 tons. From 52 to 62 percent of the phosphorus load to Jordan Lake was trapped compared to about 70 percent for Falls Lake. The smaller percentage of material trapped by Jordan Lake is due, in part, to the unusual morphometry of Jordan Lake in which most of the flow and load enters near the dam. Average annual phosphorus yields declined at every site compared to yields estimated in an earlier study for 1983-86 probably for the same reason that declines in yields occurred within the upper Neuse River Basin.

Lead and zinc loads were calculated for all sites having sufficient numbers of analyses above the MRL. The lead load to Falls Lake ranged from 5,860 lbs in 1992 to 15,500 lbs in 1989. Ellerbe Creek had the greatest lead yield of monitored tributaries to Falls Lake—105 lbs/mi^2 followed by Little Lick Creek (36 lb/mi^2). The lead load in the Neuse River almost doubled between Falls Lake dam and Smithfield. From 27,200 to 60,600 lbs of zinc were delivered to Falls Lake in 1991 and 1989, respectively. The Neuse River zinc load increased by about 50 percent between the dam and Smithfield.

The lead load to Jordan Lake ranged from 31,700 lbs in 1992 to 68,100 lbs in 1993. The greatest yield was from Haw River—31 lbs/mi^2; however, loads from New Hope and Northeast Creek were similar. About 36 percent of the load to Jordan Lake was trapped. The zinc load to Jordan Lake ranged from 85,400 lbs in 1992 to 171,000 lbs in 1993. The greatest yield (200 lbs/mi^2) was from Northeast Creek and was more than twice the yield from New Hope Creek and the Haw River. About 15 percent of the zinc load was trapped in Jordan Lake.

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SUPPLEMENTARY TABLES

Supplementary Table S-1. Equations describing the suspended-sediment concentration-discharge relation used to calculate loads for sites in the upper Neuse River Basin

[BCF, bias correction factor; R^2, coefficient of determination; ft^3/s, cubic feet per second; S, $\log_{10}$ of suspended-sediment concentration; Q, $\log_{10}$ of discharge; <, less than; >, greater than]

Site number (fig. 2)	Station name	Number of samples	Regression analysis for suspended sediment (S) concentration (milligrams per liter)			
			Log-log regression equation	BCF	R^2	Range of log Q[a] (ft^3/s)
8	Eno River near Weaver	91	$S = 0.745 + 0.207\ Q$	1.67	0.08	<2.5
		25	$S = 0.272 + 0.546\ Q$	1.65	.49	2.5-4.0
		116	$S = 0.27 + 0.546\ Q$	1.72	.49	>4.0
12	Little River at Secondary Road 1461 near Orange Factory	19	$S = 0.288 + 0.496\ Q$	1.54	.46	<2.0
		11	$S = 0.112 + 0.783\ Q$	1.19	.51	2.0-4.0
		25	$S = 0.057 + 0.718\ Q$	1.58	.69	>4.0
14	Flat River at Dam near Bahama	98	$S = 0.92 + 0.12\ Q$	1.25	.23	all
10	Knap of Reeds Creek near Butner	86	$S = 1.36 + 0.152\ Q$	1.99	.06	all
7	Ellerbe Creek near Gorman	74	$S = 0.254 + 0.866\ Q$	1.22	.89	all
6	Little Lick Creek above Secondary Road 1814 near Oak Grove	83	$S = 1.25 + 0.42\ Q$	1.42	.65	all
26	Eno River at Hillsborough	23	$S = 0.811 + 0.023\ Q$	1.16	.00	<1.5
		25	$S = -0.574 + 1.0\ Q$	1.26	.65	1.5-2.9
		33	$S = 0.466 + 0.427\ Q$	1.35	.38	>2.9
32	Neuse River at Smithfield	56	$S = -0.234 + 0.628\ Q$	1.36	.45	all

[a] Range of discharge to which the regression equation applies.

Supplementary Table S-2. Equations describing the suspended-sediment concentration-discharge relation used to calculate loads for sites in the upper Cape Fear River Basin

[BCF, bias correction factor; R^2, coefficient of determination; ft^3/s, cubic feet per second; S, $\log_{10}$ of suspended-sediment concentration; Q, $\log_{10}$ of discharge; <, less than; >, greater than]

Site number (fig. 2)	Station name	Number of samples	Regression analysis for suspended sediment (S) concentration (milligrams per liter)			
			Log-log regression equation	BCF	R^2	Range of log Q^a (ft^3/s)
18	New Hope Creek near Blands	60	S = 1.15 + 0.334 Q	1.43	0.27	all
19	Northeast Creek at Secondary Road 1100 near Genlee	71	S = 1.33 + 0.325 Q	1.67	.29	all
24	Haw River near Bynum	95	S = 0.673 + 0.423 Q	1.76	.28	all
27	Cane Creek near Orange Grove	42	S = 0.752 + 0.054 Q	1.48	.01	<1.1
		23	S = 0.196 + 0.916 Q	1.38	.67	1.1-3.0
		51	S = 0.772 + 0.48 Q	1.94	.45	>3.0
29	Morgan Creek near White Cross	34	S = 0.626 + 0.185 Q	1.42	.05	<0.2
		33	S = 0.259 +0.877 Q	1.44	.57	0.2-2.3
		41	S = 0.55 + 0.55 Q	1.69	.39	>2.3
31	Cape Fear River at State Highway 42 near Brickhaven	39	S = -0.039 + 0.392 Q	1.35	.23	all

[a] Range of discharge to which the regression equation applies.

Supplementary Table S-3. Equations describing the total nitrogen concentration-discharge relation and the total phosphorus concentration-discharge relation used to calculate loads for selected sites in the upper Neuse River Basin

[BCF, bias correction factor; R^2, coefficient of determination; ft^3/s, cubic feet per second; N, $\log_{10}$ of total nitrogen concentration; Q, $\log_{10}$ of discharge; <, less than; P, $\log_{10}$ of total phosphorus concentration; >, greater than]

Site number (fig. 2)	Station name	Number of samples	Regression analysis for nitrogen (N) concentrations (milligrams per liter)				Number of samples	Regression analysis for phosphorus (P) concentrations (milligrams per liter)			
			Log-log regression equation	BCF	R^2	Range of log Q[a] (ft^3/s)		Log-log regression equation	BCF	R^2	Range of log Q[a] (ft^3/s)
8	Eno River near Weaver	125	N = 0.722 - 0.34 Q	1.07	0.50	<2.2	84	P = -0.776 - 0.200 Q	1.27	0.11	<2
		52	N = -0.31 + 0.14 Q	1.11	.18	2.2-4	28	P = -2.11 + 0.42 Q	1.16	.19	2-4
		151	N = 0.46 - 0.156 Q	1.11	.23	>4	93	P = -0.928 - 0.095 Q	1.30	.03	>4
12	Little River at Secondary Road 1461 near Orange Factory	71	N = -0.411 +0.154 Q	1.04	.47	all	64	P = -1.66 + 0.226 Q	1.24	.32	all
14	Flat River at Dam near Bahama	95	N = -0.09 + 0.04 Q	1.07	.10	all	35	P = -1.45 + 0.07 Q	1.11	.17	all
10	Knap of Reeds Creek near Butner	104	N = 1.06 - 0.413 Q	1.20	.52	all	104	P = 0.676 - 0.639 Q	1.64	.51	all
7	Ellerbe Creek near Gorman	67	N = 1.63 - 0.431 Q	1.05	.87	all	28	P = 0.657 - 0.902 Q	1.09	.48	<50
							3	P = -0.696 - 0.013 Q	1.00	.02	>50
6	Little Lick Creek above Secondary Road 1814 near Oak Grove	103	N = 0.894 - 0.35 Q	1.21	.60	all	45	P = -0.872 + 0.057 Q	1.43	.02	all
1	Neuse River near Falls	41	N = -0.257 + 0.024 Q	1.05	.01	all	41	P = -1.97 + 0.192 Q	1.12	.19	all
26	Eno River at Hillsborough	24	N = -0.270 + 0.052 Q	1.04	.04	<1.5	24	P = -1.48 - 0.047 Q	1.14	.01	<1.6
		29	N = -0.595 + 0.29 Q	1.07	.41	1.5-2.9	27	P = -2.10 + 0.395 Q	1.18	.30	1.6-2.9
		35	N = -0.386 + 0.17 Q	1.06	.35	>2.9	35	P = -1.64 + 0.14 Q	1.16	.12	>2.9
9	Eno River near Durham	43	N = -0.231 + 0.027 Q	1.08	.01	all	43	P = -1.32 + 0.057 Q	1.25	.02	all
15	Flat River at Bahama	68	N = -0.454 + 0.157 Q	1.06	.39	all	63	P = -1.60 + 0.187 Q	1.16	.27	all
32	Neuse River at Smithfield	99	N = 1.08 - 0.284 Q	1.03	.61	all	98	P = -0.591 - 0.076 Q	1.12	.03	all

[a] Range of discharge to which the regression equation applies.

Supplementary Table S-4. Equations describing the total nitrogen concentration-discharge relation and the total phosphorus concentration-discharge relation used to calculate loads for selected sites in the upper Cape Fear River Basin

[BCF, bias correction factor; R^2, coefficient of determination; ft^3/s, cubic feet per second; N, $\log_{10}$ of total nitrogen concentration; Q, $\log_{10}$ of discharge; P, $\log_{10}$ of total phosphorus concentration; <, less than; >, greater than]

Site number (fig. 2)	Station name	Number of samples	Regression analysis for nitrogen (N) concentrations (milligrams per liter)				Number of samples	Regression analysis for phosphorus (P) concentrations (milligrams per liter)			
			Log-log regression equation	BCF	R^2	Range of log Q^a (ft^3/s)		Log-log regression equation	BCF	R^2	Range of log Q^a (ft^3/s)
17	Morgan Creek near Farrington	43	N = 1.31 - 0.534 Q	1.06	0.64	all	43	P = -0.555 - 0.069 Q	1.41	0.01	all
18	New Hope Creek near Blands	85	N = 1.49 - 0.475 Q	1.11	.69	all	43	P = 0.347 - 0.453 Q	1.13	.54	all
19	Northeast Creek at Secondary Road 1100 near Genlee	89	N = 1.33 - 0.497 Q	1.15	.65	all	47	P = -0.117 -0.279 Q	1.16	.28	all
24	Haw River near Bynum	88	N = 0.483 - 0.071 Q	1.12	.06	all	88	P = -0.293 - 0.082 Q	1.24	.05	all
27	Cane Creek near Orange Grove	49	N = 0.016 + 0.089 Q	1.08	.13	all	44 5	P = -1.16 - 0.189 Q P = -1.05 + 0.254 Q	1.31 1.18	.13 .12	<1.3 >1.3
29	Morgan Creek near White Cross	11 45 50	N = -0.049 - 0.826 Q N = 0.059 + 0.124 Q N = 0.171 - 0.014 Q	1.05 1.09 1.16	.76 .10 .00	<.06 0.05-2.3 >2.3	29 43 53	P = -0.599 - 0.274 Q P = -0.78 + 0.123 Q P = -0.645 - 0.034 Q	1.17 1.28 1.27	.13 .03 .00	<.20 0.2-2.3 >2.3
25	Haw River below B. Everett Jordan Dam near Moncure	42	N = 0.192 - 0.04 Q	1.03	.03	all	42	P = -0.934 + 0.006 Q	1.07	.00	all
31	Cape Fear River at State Highway 42 near Brickhaven	47	N = 0.282 - 0.048 Q	1.03	.04	all	47	P = -0.715 - 0.085 Q	1.09	.04	all

[a] Range of discharge to which the regression equation applies.

Supplementary Table S-5. Equations describing the lead concentration-discharge relation and zinc concentration-discharge relation used to calculate loads for selected sites in the upper Neuse and upper Cape Fear River Basins

[BCF, bias correction factor; R^2, coefficient of determination; Pb, $\log_{10}$ of total lead concentration; Q, $\log_{10}$ of discharge; Zn, $\log_{10}$ of total zinc concentration; na, not applicable]

Site number (fig. 2)	Station name	Number of samples	Regression analysis for lead (Pb) concentrations (micrograms per liter)			Number of samples	Regression analysis for zinc (Zn) concentrations (micrograms per liter)		
			Log-log regression equation	BCF	R^2		Log -log regression equation	BCF	R^2
			Upper Neuse River Basin sites						
1	Neuse River near Falls	65	$Pb = -0.016 + 0.278 Q$	1.61	0.20	47	$Zn= 0.978 + 0.140 Q$	1.23	0.15
6	Little Lick Creek above Secondary Road 1814 near Oak Grove	42	$Pb = 0.612 + 0.237 Q$	1.29	.45	56	$Zn = 1.60 - 0.003 Q$	1.17	.003
7	Ellerbe Creek near Gorman	39	$Pb = 0.178 + 0.536 Q$	1.44	.69	44	$Zn= 1.66 + 0.134 Q$	1.08	.36
8	Eno River near Weaver	49	$Pb = 0.145 + 0.257 Q$	1.27	.40	53	$Zn= 1.13 + 0.133 Q$	1.26	.18
10	Knap of Reeds Creek near Butner	41	$Pb= 0.952 - 0.052 Q$	1.17	.03	76	$Zn= 1.56 - 0.055 Q$	1.27	.02
15	Flat River at Bahama	13	$Pb = -0.122 + 0.250 Q$	1.12	.55	na	na	na	na
26	Eno River at Hillsborough	12	$Pb= -0.055 + 0.283 Q$	1.07	.51	na	na	na	na
32	Neuse River at Smithfield	26	$Pb= 0.054 + 0.243 Q$	1.42	.08	21	$Zn= 0.953 + 0.124 Q$	1.17	.05
			Upper Cape Fear River Basin sites						
18	New Hope Creek near Blands	32	$Pb= 0.541 + 0.132 Q$	1.40	0.07	na	na	na	na
19	Northeast Creek at Secondary Road 1100 near Genlee	39	$Pb= 0.452 + 0.200 Q$	1.51	.14	59	$Zn= 1.93 - 0.148 Q$	1.45	0.10
24	Haw River near Bynum	52	$Pb= -0.017 + 0.297 Q$	1.38	.38	45	$Zn= 0.804 + 0.200 Q$	1.16	.29
25	Haw River below B. Everett Jordan Dam near Moncure	48	$Pb= 0.194 + 0.176 Q$	1.30	.13	34	$Zn= 1.09 + 0.080 Q$	1.30	.04