Land Use in, and Water Quality of, the Pea Hill Arm of Lake Gaston, Virginia and North Carolina, 1988-90

By MICHAEL D. WOODSIDE

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second
pound, avoirdupois (lb)	0.4536	kilogram
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 18\,(°C) + 32$$

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

Abbreviated water-quality units: Chemical concentrations, water temperature, and specific conductance are given in metric units. Water-quality units are expressed in this report as milligrams per liter (mg/L). Chlorophyll *a* is expressed in micrograms per liter (µg/L). Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). Total and fecal-coliform bacteria are expressed as colonies per 100 milliters of sample water (col/100 mL). The membrane filter pore size is expressed in micrometers (µm).

Land Use in, and Water Quality of, the Pea Hill Arm of Lake Gaston, Virginia and North Carolina, 1988-90

By Michael D. Woodside

Abstract

The City of Virginia Beach currently (1994) supplies water to about 400,000 people in southeastern Virginia. The city plans to withdraw water from the Pea Hill Arm of Lake Gaston to meet projected water needs of the population to the year 2030. The purpose of this report is to (1) describe the temporal and spatial distribution of selected water-quality constituents, (2) document current (1989) land use and land cover in the Pea Hill Arm drainage basin, and (3) discuss relations, if any, between the quality of water in the inlets within the Pea Hill Arm and land uses. The report focuses on water-quality problems in the basin, including changes in concentrations of major ions, nutrients, and algae associated with urban development adjacent to water bodies.

The Pea Hill Arm was classified as mesotrophic on the basis of the range of concentrations of total phosphorus (0.001 to 0.61 milligrams per liter); the range of concentrations of total organic-plus-ammonia nitrogen (0.2 to 1.4 milligrams per liter); and the range of concentrations of chlorophyll *a* (1.4 to 56 micrograms per liter). These water-quality data were collected at 3 feet below the water surface during water years 1989–90.

Thermal stratification in Pea Hill Arm generally began in April and ended in September. Water below a depth of about 25 feet generally became anoxic by June. Destratification generally began in late September and was completed by November. Lake Gaston followed the same general stratification and destratification pattern as Pea Hill Arm, except Lake Gaston was partially destratified during the summer when large amounts of water were released from John H. Kerr Reservoir and Lake Gaston Dams.

During water year 1988, streamflows were 33 percent below the long-term mean-annual streamflows at one of the major streams to Lake Gaston. Low streamflows contributed to elevated specific conductances and concentrations of sodium, calcium, magnesium, and alkalinity from October 1988 to February 1989 at sampling stations in the Pea Hill Arm and Lake Gaston.

About 75 percent of the land use in the Pea Hill Arm is forest land. The remaining 25 percent of the Pea Hill Arm drainage basin is 8 percent pasture/open land, 8 percent open water, 6 percent residential land, and 3 percent cropland. No statistical relations are present between water-quality constituents measured and developed land uses within 11 basins in the Pea Hill Arm Basin, except during periods of stormwater runoff. During a stormwater-runoff event, there was a relation between total nitrite plus nitrate and land use (Kendall's tau correlation coefficient of 0.69). The relation between the developed land use and total nitrite plus nitrate can also be related to the increased ground-water inputs during high base-flow periods.

Spatial differences in water-quality constituents—as determined by Wilcoxon (matched-pairs) signed-rank tests and cluster analyses—were longitudinal and primarily grouped into riverine, transition, and lacustrine zones. These zones were grouped on the basis of flow characteristics and nutrient concentrations.

INTRODUCTION

The City of Virginia Beach currently (1994) supplies water to approximately 400,000 people in southeastern Virginia. To meet projected water needs to the year 2030, the city plans to withdraw up to 60 Mgal/d from the

Pea Hill Arm of Lake Gaston. The water will be conveyed by a 76-mi-long pipeline to raw water facilities in southeastern Virginia.

An increased demand for recreational and retirement waterfront homes has promoted urban development in rural areas adjacent to water bodies, including the Lake Gaston area. Numerous homes and trailer parks have been built in the last 10 years within the primarily forested Pea Hill Arm drainage basin, especially along the shoreline.

Urban development along a shoreline has the potential to rapidly affect water quality. Eutrophic processes can be stimulated by increased sediment and nutrient loads that result from urban development. An increase in the number of septic systems near the shoreline can increase the potential for bacterial contamination and also result in higher nutrient concentrations. In 1988, the U.S. Geological Survey (USGS), in cooperation with the City of Virginia Beach, began an investigation to characterize the quality of water in the Pea Hill Arm of Lake Gaston, and to study the relation between water quality and land-use activities within the Pea Hill Arm drainage basin.

Purpose and Scope

The purpose of this report is to (1) document current (1989) land use and land cover in the Pea Hill Arm drainage basin at a scale of 1:24,000; (2) describe the temporal and spatial distribution of selected water-quality constituents in the Pea Hill Arm; and (3) discuss relations, if any, between water quality in several inlets of the Pea Hill Arm and land-use activities within their respective drainage basins.

Water-quality samples were collected monthly from October 1988 to September 1990 at nine inlet stations in the Pea Hill Arm, one station on the main tributary to the Pea Hill Arm, two lake stations on the mainstem of Pea Hill Arm, and one lake station on the main body of Lake Gaston. The inlet stations were sampled at a depth of 3 ft below the water surface. The remaining sites were sampled at multiple depths. These samples were analyzed for nutrients, organics, inorganics, bacteria, and chlorophyll *a*. Field measurements of dissolved oxygen, pH, specific conductance, temperature, and Secchi-disc transparency were recorded.

Land-use patterns were determined for the Pea Hill Arm drainage basin from aerial photographs taken in February 1989. The following coverages were compiled and entered into the ARC/INFO geographic information system for the Pea Hill Arm Basin: stream network, roads, surface-water stations, point location of houses, and inlet-drainage basins. The following land uses were compiled by use of the classification by Anderson and others (1976): cropland, pasture/open land, forest land, residential land, and ponds.

Acknowledgments

The support and cooperation of Thomas Leahy and Rita Sweet, City of Virginia Beach, is gratefully acknowledged. Appreciation also is extended to Wayne Butler, Virginia Department of Transportation, for taking the aerial photographs.

LOCATION AND DESCRIPTION OF STUDY AREA

Lake Gaston is the second in a series of three reservoirs (John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids) constructed for flood control, low-flow augmentation, recreation, and hydroelectric power along a 45-mi reach of the Roanoke River on the Virginia and North Carolina Stateline (pl. 1). The Lake Gaston Dam was built in 1962; thus, the Pea Hill Arm was formed by inundating the southern Pea Hill Creek drainage basin. The Pea Hill Arm drainage area is located in Brunswick County, Va., and in Northampton and Warren Counties in North Carolina.

Lake Gaston has a surface area of 32 mi^2 and a drainage area of 8,339 mi^2. The normal operating water level in Lake Gaston is approximately 200 ft above mean sea level.

Lake Gaston is classified eutrophic in the Virginia State Water Control Board (1990) report, "Virginia water quality assessment." The upper half of Lake Gaston has had excessive growths of the aquatic weeds *Egeria densa* (Brazilian elodea) and *Hydrilla verticillata* (hydrilla) since 1984. During the winter of 1987, the water level in Lake Gaston was lowered 9 ft to reduce the Brazilian elodea population. The herbicide, dichlobenil, was applied in granular form to the exposed soil in the upper reaches of the reservoir to remove hydrilla. The drawdown was effective in reducing Brazilian elodea;

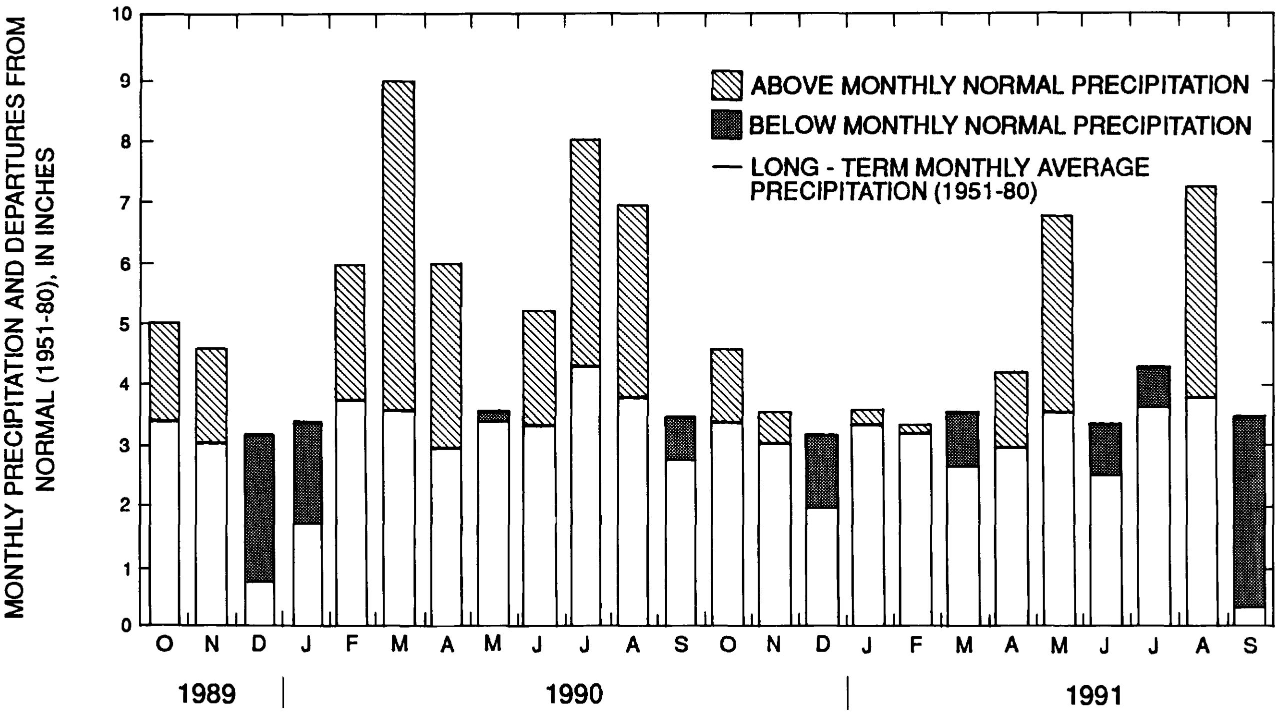


Figure 1. Mean precipitation and departures from normal at John H. Kerr Reservoir, Virginia.

however, hydrilla populations increased rapidly because of the lack of competition (Kay and Bishop, 1988). The herbicide treatment was ineffective in reducing hydrilla populations. Kay (1989) estimated that hydrilla populations will continue to increase and can potentially infest 19 percent of the Lake Gaston surface area.

Geology

The Pea Hill Arm Basin of Lake Gaston lies in the Piedmont Physiographic Province and is underlain by a vast complex of igneous and metamorphic rocks of uncertain age. The Petersburg granite is the predominate igneous rock and consists mainly of biotite granite, and chloritic granodiorite. Gneiss is the predominate metamorphic rock in the basin. The exposed soils in the basin consist of sandy loams and sandy-clay loams that vary in slope from 2 to 15 percent. These deep, well drained soils are moderately permeable with red to yellowish red clay and sandy-clay subsoils.

Climate

The Pea Hill Arm Basin is in a temperate climate zone. Winter storms usually move from the southwest to northeast and often result in steady rainfall that lasts for several days. These low-pressure fronts frequently produce basinwide rainfall. Summer rainfall patterns are dominated by tropical flows of air from the Gulf of Mexico and southwest Atlantic. Summer rainfall events usually are intense, localized thunderstorms, and last only a few hours.

Mean annual precipitation at John H. Kerr Reservoir, located west of the study area, is 41 in. (1951-80 mean) (National Oceanic and Atmospheric Administration, 1990). The long-term (1951-80) monthly average precipitation is evenly distributed throughout the year. During water years 1989-90, the monthly precipitation ranged from 5 in. greater than to 3 in. less than the long-term monthly average precipitation (fig. 1).

Mean monthly air temperatures range from a maximum of 25.5 °C in July to a minimum of 2.8 °C in January (National Oceanic and Atmospheric

Administration, 1990). The first fall frost generally occurs in mid-October; the last spring frost generally occurs in mid-April.

Hydrology

Pea Hill Arm, the largest arm of Lake Gaston, has a drainage area of 27.1 mi^2 and a volume of 8,400 Mgal (Budd, 1987) (table 1). Pea Hill Arm has a hydraulic retention time of 1.5 years, based on average tributary inflows of 23 ft^3/s. Tributary inflows were estimated by calculating the average ratios of discharge to drainage area for gaging stations near the study area.

Table 1. Physical characteristics of the Pea Hill Arm Basin of Lake Gaston, Virginia and North Carolina

Drainage area	27.1	square miles
Surface area	2.2	square miles
Volume[1]	8,400	million gallons
Maximum depth	50	feet
Mean depth[1]	17	feet
Retention time	1.5	years
Average inflow	23	cubic feet per second

[1]Budd, 1987.

Pea Hill Arm is separated from Lake Gaston by a narrow (60 ft), shallow (15 ft) culvert in a road embankment on State route 1214, which prevents rapid mixing of water between Pea Hill Arm and Lake Gaston. Daily flow reversals have been measured at the State route 1214 culvert (Grizzard, 1985). Flow within the Pea Hill Arm also is constricted by similar culverts on State routes 626 and 667, both located in the northern section of the Pea Hill Arm.

Hydrology in the Pea Hill Arm is affected by additional factors, including direct inflows from Pea Hill Creek and intermittent tributaries; water releases from John H. Kerr Reservoir Dam, 37-mi upstream; and releases from Lake Gaston Dam. Intense localized storms occurring only in the Pea Hill Arm Basin can cause water to flow into Lake Gaston. A storm in the upper Roanoke River Basin can cause water in Lake Gaston to flow into the Pea Hill Arm. Daily dam operations at both the John H. Kerr Reservoir and Lake Gaston also affect flow directions and velocities between Pea Hill Arm and Lake Gaston.

METHODS OF STUDY

This section describes station locations, sampling depths, and sampling frequency. Water-quality sampling methods, preservation procedures, and water-quality analyses are listed. Land-use delineation techniques also are discussed.

Location and Description of Sampling Stations

Water samples were collected 3 ft below the water surface at nine inlet stations (table 2 and pl. 1). Inlet stations were located with a depth sounder at the 10-ft bathymetric contour in the center of the inlet channel. The combined drainage areas of the nine inlet stations comprise 45 percent (12.3 mi^2) of the total drainage area of Pea Hill Arm. Water samples also were collected from Pea Hill Creek at State route 665 (station 9880) to represent the quality of water in the largest tributary to Pea Hill Arm. Station numbers and station codes are listed in table 2. The code consists of the last four digits of the full station number, and is used to represent the station number throughout text of this report. Full station numbers are used in figures and tables.

Three lake stations (table 2) were monitored to characterize thermal stratification and destratification processes, and to describe the associated changes in the quality of water during the different stages of the stratification and destratification process. Station 8450 is in the middle of Pea Hill Arm and characterizes water quality near the proposed City of Virginia Beach raw-water intake. Station 8490, near the culvert that connects Pea Hill Arm and Lake Gaston, represents a mixture zone between Lake Gaston and Pea Hill Arm. Station 7950 is in the main body of Lake Gaston and represents water quality in Lake Gaston.

Water samples were collected at Pea Hill Arm stations 8450 and 8490 at depths of 3, 12, and 21 ft below the surface and also at 2 ft above the lake bottom. Stations are located in the old Pea Hill Creek stream channel to maximize sampling depths. Station 7950 in Lake Gaston was sampled at depths of 3, 12, 21, and 39 ft below the water surface and also at 2 ft above the lake bottom. An additional sampling depth at 39 ft was necessary because of the increased water depth in the main body of Lake Gaston. Station 7950 is located in the old Roanoke River stream channel.

Table 2. Water-quality stations in the Pea Hill Arm and Lake Gaston study area, Virginia and North Carolina
[--, data not available]

Station code	Station number	Station name	Drainage area (square miles)
		Inlet stations	
8050	0207988050	Pea Hill Creek above Route 667, near Gasburg, Va.	2.7
8100	0207988100	Pea Hill Creek tributary No. 1, near Gasburg, Va.[1]	1.2
8130	0207988130	Pea Hill Creek tributary No. 2,near Valentines, Va.[1]	1.1
8160	0207988160	Pea Hill Creek tributary No. 3, near Valentines, Va.[1]	1.8
8300	0207988300	Pea Hill Creek tributary No. 4, near Valentines, Va.[1]	1.3
8430	0207988430	Pea Hill Creek tributary No. 4, near Valentines, Va.[1]	1.0
8440	0207988440	Cold Spring Branch, near Gasburg, Va.	1.3
8510	0207988510	Lake Gaston tributary, near Tillans Chapel, near Elams, N.C.	1.4
8550	0207988550	Pea Hill Creek tributary No. 5, near Henrico, N.C.[1]	.5
		Tributary station	
9880	02079880	Pea Hill Creek at Route 665, near Gasburg, Va.	7.2
		Lake stations	
8450	0207988450	Pea Hill Creek above N.C. Stateline, near Gasburg, Va.	7.6
8490	0207988490	Lake Gaston (Pea Hill Creek), near Henrico, N.C.	--
7950	0207987950	Lake Gaston (Little River Channel), near Henrico, N.C.	--

[1]Refers to station description in Water Resources Data, Virginia, Water Year 1989 (Prugh and others, 1990, p. 287-305).

Sampling Procedures

Water samples were collected once a month at nine inlet stations, three lake stations, and one tributary station from October 1988 to September 1990. During the first 12 months of data collection, samples were collected in downstream order (from north to south). The station sampling order was reversed after 1 year of data collection to reduce the potential of differences in water-quality constituents related to changes in temperature or respiration/photosynthesis rates. No samples were collected in December 1989 because of severe weather conditions.

A peristaltic pump connected to 60 ft of weighted tygon tubing was used to obtain multiple-depth lake and inlet samples. The tygon tubing was lowered at each station to a preset sampling depth and flushed several times prior to collecting water samples to eliminate the potential of sample contamination. The sampling order at the lake stations was from the upper to lower depths because the quality of water generally degrades with increasing depths during the summer months. Water samples for dissolved constituents were filtered prior to being exposed to aerobic conditions because some constituents convert from a dissolved to a total phase when exposed to aerobic conditions. An in-line filter press with a 0.45-µm (pore size) membrane filter was connected to the tygon tubing to prevent the water sample from being aerated. Water samples were preserved in the field immediately after collection to prevent the conversion of dissolved and reduced constituents to oxidized precipitates. Grab samples were collected at the tributary station 9880. Bacteria samples were collected manually in sterile bottles at the water surface at all stations to prevent sample contamination.

A multiple-field-parameter water-quality instrument was used to measure pH, water temperature, dissolved oxygen, and specific conductance at all stations. These field parameters were measured at 3- to 5-ft depth intervals at lake stations to characterize vertical profiles. If significant changes occurred in any of the parameters

Table 3. Classes of analyses and sample depths at lake, tributary, and inlet stations, Lake Gaston, Pea Hill Arm, Virginia and North Carolina

Classes of analyses	Lake station[1]		Tributary station[1]	Inlet station[1]
	7950,	8490, 8450	9880	8050, 8100, 8130, 8160, 8300, 8430, 8440, 8510, 8550
Nutrients	A	B	C	E
Inorganics	A	B	C	--
Organics	D	D	C	--
Chlorophyll *a*	A	B	--	E
Bacteria	E	E	C	E
Discharge, instantaneous	--	--	C	--

[1]A, Sample depths of 3, 12, 21, and 39 feet below water surface, and 2 feet above bottom.
B, Sample depths of 3, 12, and 21 feet below water surface, and 2 feet above bottom.
C, Grab sample or discharge measurement.
D, Sampling depth 12 feet below water surface and 2 feet above bottom.
E, Sample depth 1 foot.
--, data not collected

between depth intervals, the instrument was raised to the previous depth and all parameters were measured at 1-ft depth intervals. Detailed vertical profiles aid in the interpretation of the stratification and destratification process.

Sample Preparation and Analysis

The classes of analyses and sample depths at each station are listed in table 3. Water samples were preserved immediately after collection and sent to the USGS laboratory in Arvada, Colo., for analyses. Preparation and preservation of water-quality samples are listed in table 4. Classes of analyses and reporting levels for each constituent are listed in table 5. The methods used for the chemical analysis of samples are presented in table 6.

Bacteria samples and chlorophyll-*a* samples were processed and analyzed by personnel in the Richmond, Va., District office of the USGS. Bacteria samples were processed within 5 hours of collection.

Chlorophyll-*a* samples were filtered through a 47 mm glass-fiber filter and stored in glass vials containing a 90 percent acetone solution. Each vial was wrapped in brown paper to prevent sample degradation caused by exposure to light. Samples were normally analyzed within 24 hours. Samples not analyzed within 24 hours were placed in a freezer for subsequent analysis. Algal enumeration and identification analyses were performed by a contract laboratory.

During the summer, the USGS laboratory recorded the date samples were received and the water temperature on a postcard that was returned to the Richmond office. This information verified that samples arrived at the laboratory chilled and within holding-time limits.

Table 4. Preparation and preservation of water-quality samples from Lake Gaston, Pea Hill Arm, Virginia and North Carolina
[<, less than]

Constituents	Preparation and preservation[1]
Nutrients	Mercuric chloride, chilled
Major cations, iron, and manganese	
Total recoverable	Nitric acid to pH <2
Dissolved	Filtered, nitric acid to pH <2
Major anions and silica	Filtered
Total organic carbon	Glass bottle, chilled
Total recoverable phenols	Glass bottle, copper sulfate and phosphoric acid to pH <2
Chlorophyll *a*	Filter, store filter in 90-percent acetone solution
Algae	Brown plastic bottle with Lugols solution
Bacteria	Sterilized glass bottle

[1]Filtered samples are passed through a 0.45-micrometer membrane filter.

Table 5. Description of classes of analyses and reporting levels for water samples from Lake Gaston, Pea Hill Arm, Virginia and North Carolina

[mg/L, milligrams per liter; µg/L, micrograms per liter; col/100 mL, colonies per 100 milliliter; NTU, nephelometric turbidity units; <, less than]

Constituent	Reporting limit	
Nutrients		
Phosphorus, as P, total	0.001	mg/L
Nitrogen, ammonia plus organic, total	.2	mg/L
Nitrite plus nitrate, as N, total	.01	mg/L
Ammonia, as N, total	.01	mg/L
Inorganics		
Dissolved solids (calculated)	1	mg/L
Alkalinity, as $CaCO_3$	1	mg/L
Calcium	.1	mg/L
Magnesium	.1	mg/L
Sodium	.1	mg/L
Potassium	.1	mg/L
Dissolved silica, as SiO_2	.1	mg/L
Sulfate	.2	mg/L
Fluoride	.1	mg/L
Chloride	.1	mg/L
Total hardness, as $CaCO_3$ (calculated)	1	mg/L
Calcium hardness, as $CaCO_3$ (calculated)	1	mg/L
Turbidity	.1	NTU
Total iron	.01	mg/L
Dissolved iron	.01	mg/L
Total manganese	.01	mg/L
Dissolved manganese	.01	mg/L
Organics		
Organic carbon, total	.1	mg/L
Phenols, total recoverable	1	µg/L
Chlorophyll		
Chlorophyll *a*	.1	µg/L
Phaeo-pigment	.1	µg/L
Bacteria		
Total coliform	<1 to 100,000	col/100 mL
Fecal coliform	<1 to 100,000	col/100 mL

Techniques of Land-Use Delineation

The classification system proposed by Anderson and others (1976) was used to delineate five categories in the Pea Hill Arm drainage basin—forest land, cropland, residential, pasture/open land, and water. Individual structures, such as homes and large outbuildings, also were identified to create a base-line data base for assessing future land-use changes.

Land uses were delineated from aerial photographs taken in February 1989, at a scale of 1:24,000, by the Virginia Department of Transportation. The aerial photography was completed in the winter after deciduous trees dropped their leaves to aid in the identification of structures. Cropland and pasture/open land can be difficult to distinguish in aerial photographs taken during the winter; thus, land uses were field verified during the following summer.

LAND USE IN THE PEA HILL ARM OF LAKE GASTON

Land-use data for the Pea Hill Arm of Lake Gaston were compiled from aerial photographs and entered into a geographic information system at a scale of 1:24,000. The Pea Hill Arm Basin was divided into nine inlet basins, one tributary basin, and one lake basin corresponding to the water-quality sampling stations. Land-use data for each subdrainage basin and the total basin are compiled in table 7 and shown on plate 1.

The Pea Hill Arm Basin is predominately rural with 75 percent of the basin covered by forest land. The majority of the forest land is managed for the production of pine trees. The remaining 25 percent of the Pea Hill Arm drainage basin is 8 percent pasture/open land, 8 percent open water, 6 percent residential, and 3 percent cropland. The 11 basins delineated for this study, range in size from 345 to 4,887 acres. Developed land (crop land, pasture/open land, and residential land) in the 11 basins includes from 7 to 39 percent of the total land use. Although only a small percentage of each of the basins is developed, these land uses can significantly increase nutrient and sediment loads and impair the quality of water in streams and lakes.

Residential land along the 41.5 mi of shoreline in the Pea Hill Arm Basin includes 88 percent of the total residential land in the basin. Many of these homes and mobile homes are used only during the warmer months of the year. Multiple homes often share one septic system. When a majority of the homes are occupied, septic systems can become overloaded and fail to properly treat the wastewater. Septic systems also can fail to properly treat the wastewater because of inadequately sized drain fields or old systems in need of repair. Overloaded and

Table 6. Methods of water-quality analyses for water samples from Lake Gaston, Pea Hill Arm, Virginia and North Carolina

Constituent	Method
Nutrients[1]	
Total phosphorus	Colorimetric, phosphomolybdate method
Total organic nitrogen plus ammonia	Colorimetric, block digestor-salicylate-hypochlorite method
Total nitrite plus nitrate	Colorimetric, cadmium reduction, hydrazine reduction-diazotization method
Total Ammonia	Colorimetric indophenol method
Major cations, iron, and manganese[1]	
Dissolved	Direct atomic absorption spectrometric
Total recoverable	Atomic absorption spectrometric, hydrochloric acid wet digestion
Major anions and silica[1]	
Alkalinity	Electrometric, titration to pH 4.5 endpoint
Chloride	Colorimetric, rerric thiocyanate method
Fluoride	Electrometric, ion-selective electrode
Sulfate	Turbidimetric, barium sulfate method
Silica	Colorimetric, molybdate blue method
Turbidity[1]	Nephelometry
Total organic carbon[2]	Carbon analyzer, potassium persulfate wet digestion
Chlorophyll *a*[3]	Fluorometric, 90-percent acetone extraction
Bacteria[4]	
Total Coliform	Direct count, membrane filter, M-Endo agar
Fecal Coliform	Direct count, membrane filter, M-FC agar
Algae[5]	Membrane filtration

[1]Fishman and Friedman, 1985.
[2]Wershaw and others, 1987.
[3]Strickland and Parsons, 1972.
[4]Britton and Greeson, 1989.
[5]Clesceri and others, 1989.

failing septic systems near the shoreline have the potential to rapidly degrade water quality by increasing nutrient and bacteria concentrations.

The pine forests of the Pea Hill Arm Basin normally are harvested on a 25- to 30-year cycle. After harvesting, a site may be prepared by prescribed burning, drum chopping followed by prescribed burning, and (or) bulldozing. The method of site preparation depends on the amount of undergrowth and density of hardwood species. If a number of hardwood trees and brush remain after harvesting the pine trees, drum chopping can be used to down standing trees and brush, compacting the debris prior to prescribed burning. Prescribed burning generally is done between May and October.

Increased stormflow, peak discharge, and sediment loss have been attributed to removal of protective vegetation by clear-cut harvesting and mechanical site preparation (Blackburn and others, 1990). However, Miller (1984) reported that the effects of harvesting and site preparation on total suspended solids was minimal. Conflicting results are explained by differences in on-site variables, such as soil characteristics, distribution and occurrence of peak stormflows, and site-preparation methods. These different results highlight the importance of customized harvest and site-preparation methods to on-site variables.

Pine seedlings are generally planted after prescribed burning, during the following December to April, leaving sites fallow for less than 1 year. Sites may be inspected 1

Table 7. Land use by subdrainage basins for the Pea Hill Arm of Lake Gaston, Virginia and North Carolina
[--, less than 2 acres; <, less than]

Station Code	Total area	Land use, in acres (percentage of land use in each drainage basin)					
		Cropland	Pasture/open land	Forest	Residential land	Water	Number of structures
				Inlet stations			
8050	1,699	--	99 (6)	1,513 (89)	17 (1)	70 (4)	63
8100	769	52 (7)	187 (24)	455 (59)	61 (8)	14 (2)	101
8130	696	--	125 (18)	556 (80)	7 (1)	8 (1)	21
8160	1,166	107 (9)	172 (14)	853 (73)	21 (2)	13 (1)	46
8300	824	44 (5)	20 (2)	741 (90)	15 (2)	4 (1)	14
8430	656	16 (2)	5 (1)	632 (96)	--	3 (1)	2
8440	820	34 (34)	137 (17)	638 (78)	--	11 (1)	25
8510	882	90 (10)	16 (2)	753 (85)	8 (1)	15 (2)	33
8550	345	--	28 (8)	309 (90)	2 (<1)	6 (2)	11
				Tributary station			
9880	4,591	96 (2)	382 (8)	4,107 (90)	--	6 (<1)	137
				Lake station			
8450	4,887	124 (2)	173 (4)	2,345 (48)	965 (20)	1,280 (26)	943
Total	17,335	563 (3)	1,344 (8)	12,902 (75)	1,096 (6)	1,430 (8)	1,396

to 2 years later to monitor the growth of hardwood species. Hardwoods shade the pine trees, competing with the pines for sunlight. The herbicides glyphosphate and imazapyr are commonly used to selectively retard the growth of the hardwoods (Dennis Gaston, Virginia Department of Forestry, oral commun., 1990).

Glyphosphate is a nonselective, foliar herbicide that is effective against grasses, broadleaf weeds, woody brush, and trees and can be applied during any stage of plant growth. Glyphosphate is absorbed through foliage and translocated throughout the plant. The herbicide interferes with plant amino acid synthesis, thus inhibiting growth. The potential for ground-water contamination is low because glyphosphate is strongly adsorbed to soils (U.S. Environmental Protection Agency, 1990a).

Imazapyr, which is similar to glyphosphate, also is absorbed through foliage and distributed throughout the foliage and roots, and, thereby, interfers with amino acid synthesis. Imazapyr, however, has a moderate leaching potential and can be desorbed from soils. Imazapyr is degraded by photochemical reactions with a half-life of 2.5 to 5.3 days (U.S. Environmental Protection Agency, 1988).

Movement of pesticides in the environment by surface runoff and leaching is affected by the properties of the pesticides and also by the soils to which the pesticides are applied. Properties affecting the movement of pesticides in the environment include the solubility and persistence of the applied pesticide in water, the amount of organic matter in soil, and the soil type. Rainfall immediately following a pesticide application also can increase pesticide concentrations in surface-water runoff.

Pesticide applications also can indirectly affect water quality. Feller (1989) reported significant increases in concentrations of potassium, magnesium, and nitrate in streamwater when vegetative cover was reduced by 40 percent by use of glyphosphate. Feller (1989) also noted that these changes in water quality can persist for 5 or more years following the removal of the vegetative cover.

WATER QUALITY IN THE PEA HILL ARM OF LAKE GASTON

This section is subdivided into two sections to enhance clarity. The first section contains a description of water-quality characteristics and temporal variations. The second section describes spatial differences among stations.

Characteristics

The discussion of water-quality characteristics and temporal variations is further subdivided into three sections—Pea Hill Creek, inlet stations, and lake stations. These sections include discussions of the dominant tributary to the Pea Hill Arm, nine inlets with different shoreline developments and land uses, and three lake stations (two stations within the Pea Hill Arm and one station in Lake Gaston). The section on lake stations includes a discussion of stratification and destratification processes and physiochemical cycles.

Pea Hill Creek

This section briefly describes the general quality of water entering the Pea Hill Arm from Pea Hill Creek. Pea Hill Creek is the largest tributary in the Pea Hill Arm Basin, consisting of 26 percent of the total drainage-basin area upstream from station 9880. The drainage basin at station 9880 is 89 percent forested and 8 percent pasture/open land.

Water samples were collected from October 1988 to September 1990 to assess the water quality during various streamflows. No special attempt was made to collect water samples during a rise or recession of a hydrograph. The maximum instantaneous discharge measured during the monitoring period was 19 ft^3/s on March 14, 1989, the day after a storm, whereas the minimum instantaneous discharge measured was 0.57 ft^3/s on September 5, 1989. The median instantaneous discharge was 2.4 ft^3/s during the monitoring period.

Physical Characteristics

Water temperatures varied seasonally with ambient air temperatures. Extremes in water temperature are buffered by the high specific-heat content of water. The minimum water temperature was 4.5 °C on February 6, 1990, and the maximum water temperature was 24.5 °C on July 31, 1990. The temperature range is well below the maximum water-temperature standard, 32 °C, of the Virginia Department of Environmental Quality (DEQ; formerly, the Virginia Water Control Board) (Commonwealth of Virginia State Water Control Board Regulations, 1988).

Dissolved-oxygen saturation is inversely related to water temperature. The minimum concentration of dissolved oxygen measured (5.2 mg/L), coincided with the maximum water temperature (fig. 2). In contrast, the maximum concentration of dissolved oxygen (11.8 mg/L) was measured in March when the water temperature was 6.5 °C, 2 °C above the minimum water temperature measured. Algal productivity and streamflows may have contributed to the increased concentration of dissolved oxygen in March.

On the basis of the summer (June, July, and August) water temperature range of 16.5 to 24.5 °C, the predicted concentrations of dissolved oxygen are 8.3 to 9.6 mg/L. The concentration range of dissolved oxygen measured during the summer monitoring period was 5.2 to 11.0 mg/L. The water was 63 and 114 percent saturated with dissolved oxygen when the maximum and minimum summer water temperatures were recorded, respectively. Dissolved-oxygen concentrations below saturation levels can be related to organic pollution and algal respiration; however, the minimum recorded concentration of dissolved oxygen is above the minimum dissolved oxygen standard of 4.0 mg/L (Commonwealth of Virginia State Water Control Board Regulations, 1988).

Specific conductance and streamflows were inversely related at station 9880. The Kendall's tau correlation coefficient (Helsel and Hirsh, 1992) is -0.62 with a p value of less than 0.01. The mean specific conductance was 81 µS/cm when the instantaneous discharge was less than or equal to 2.4 ft^3/s and 63 µS/cm when the instantaneous discharge was greater than 2.4 ft^3/s. The elevated ionic concentrations during low streamflows are related to higher ionic concentrations in the ground-water inflow during low streamflows. At higher streamflows, surface-water runoff can dilute the ground-water inflows.

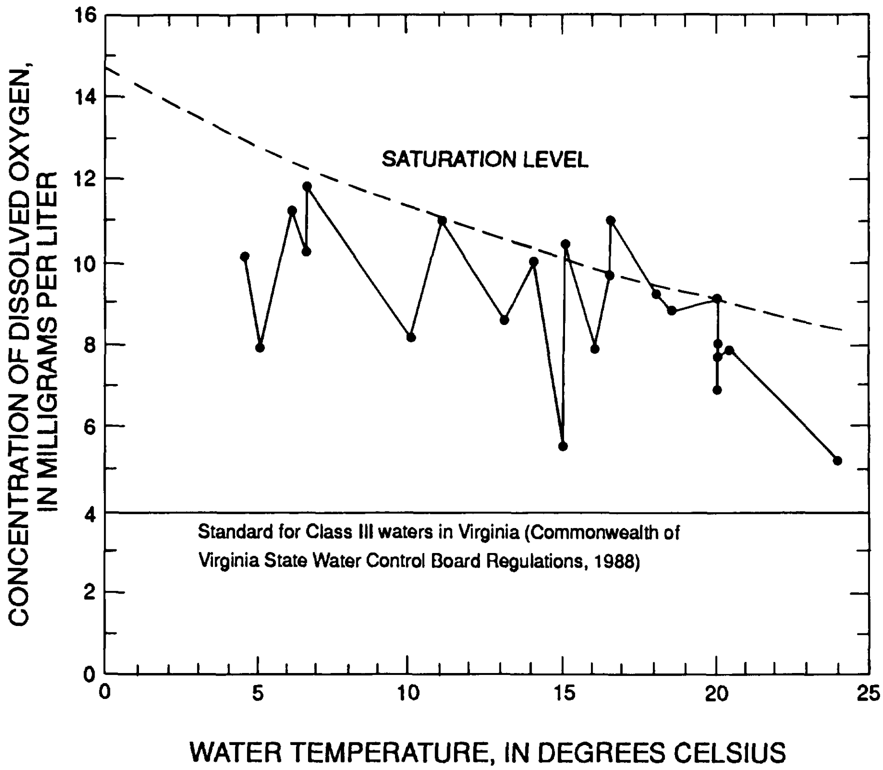


Figure 2. Relation between concentrations of dissolved oxygen and water temperature from the Pea Hill Creek near Gasburg (station 02079880), Virginia, water years 1989-90.

Major Inorganic Constituents

For discussion purposes, major constituents include the following anions, cations, and other dissolved constituents: bicarbonate, calcium, chloride, fluoride, magnesium, manganese, potassium, silica, sodium, sulfate, and iron. Not all of these constituents, however, are discussed for each station.

Information on surficial geology can provide an estimate of general water-quality characteristics. In general, water draining igneous rocks is dilute, with bicarbonate, sodium, and calcium being the dominant ions (Drever, 1988). The water in Pea Hill Creek is no exception; water draining from the chloritic granite in the Pea Hill Arm drainage basin is dilute and classified as a soft water (less than 60 mg/L hardness, as calcium carbonate, Hem, 1985, p. 159). A Piper diagram (Hem, 1985, p. 178) of samples collected at station 9880 during the study period shows that the water is a mixed cation and bicarbonate type (fig. 3).

Seasonal variation in major constituents is related to temperature, flow conditions, and natural weathering processes. Ratios of carbonic-acid weathering reactions are increased during warm, low-streamflow periods, thereby increasing concentrations of calcium, magnesium, and sodium (fig. 4). In contrast, ratios of weathering reactions are decreased during high-streamflow periods resulting in decreased concentrations of calcium, magnesium, and sodium.

Silica is an abundant oxide consisting of 40- to 75-weight percent in most igneous rocks (Hurlbut and Klein, 1977). The mean concentration of silica was 19 mg/L at station 9880. The seasonal pattern of silica (fig. 5) is related to weathering of rocks and streamflows with increased silica concentrations occurring in the summer, corresponding to increased calcium, sodium, and magnesium concentrations.

Concentrations of alkalinity generally decrease during the fall and winter months. The decrease in concentration of alkalinity partially is related to increases in

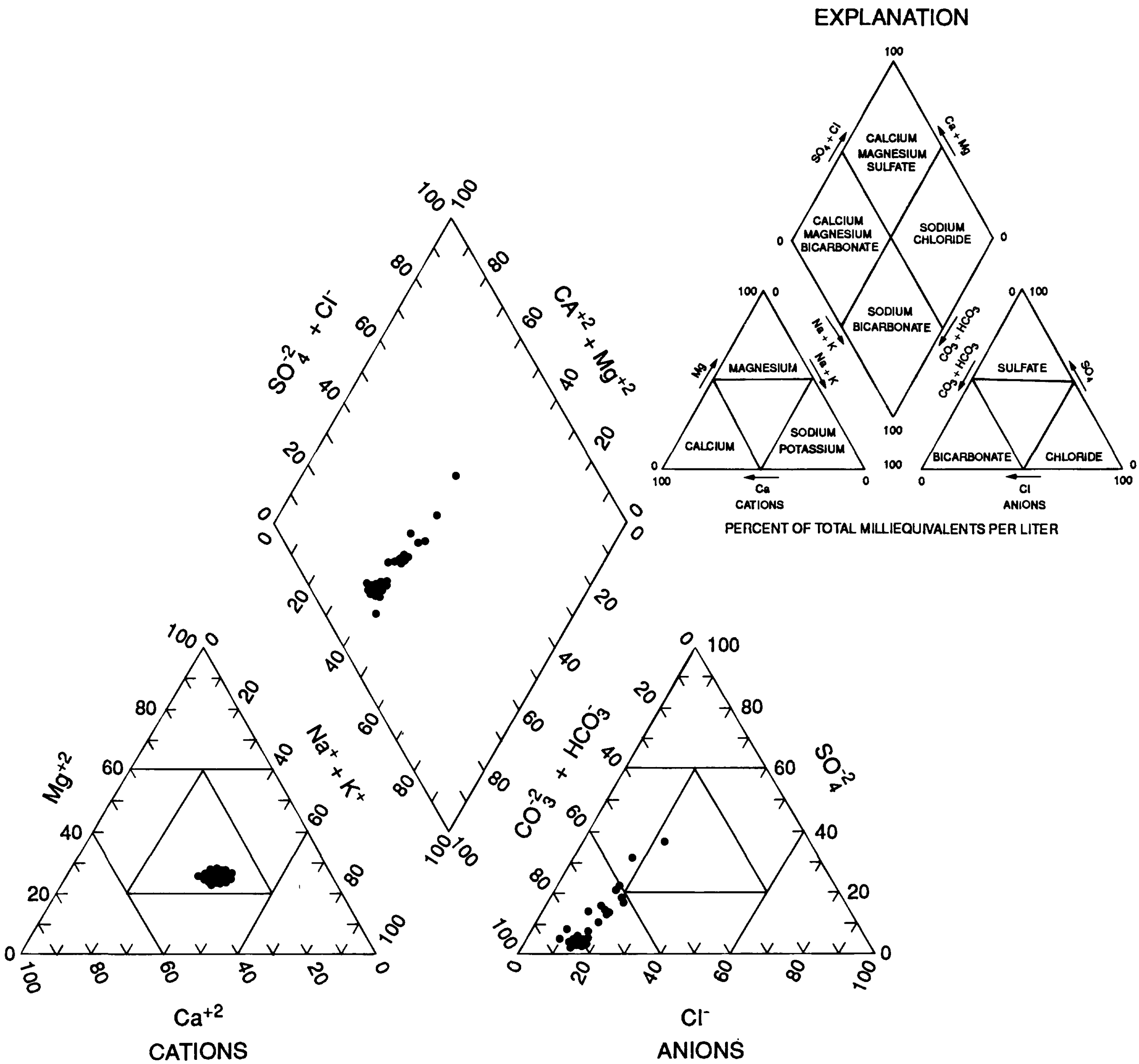


Figure 3. Percentages of major ions in water from the Pea Hill Creek near Gasburg (station 02079880),Virginia, water years 1989-90.

sulfate concentrations during the fall and winter (fig. 5). The secondary maximum contaminant level[1] of sulfate (250 mg/L) (U.S. Environmental Protection Agency, 1990b), was not exceeded during the study period. Sulfate concentrations increase in the fall and winter as organic-bound sulfur is oxidized by the leaching of leaf litter and other organic matter from plants (Wetzel, 1983). The oxidation of organic sulfur produces hydrogen ions that consume bicarbonate, a principal component of alkalinity. The increases of sulfate in the

[1]Secondary Maximum Contaminant Level (SMCL): Contaminants that affect the aesthetic quality of drinking water. At high concentrations or values, health implication, as well as aesthetic degradation can also exist. SMCL's are not Federally enforceable but are guidelines for the States.

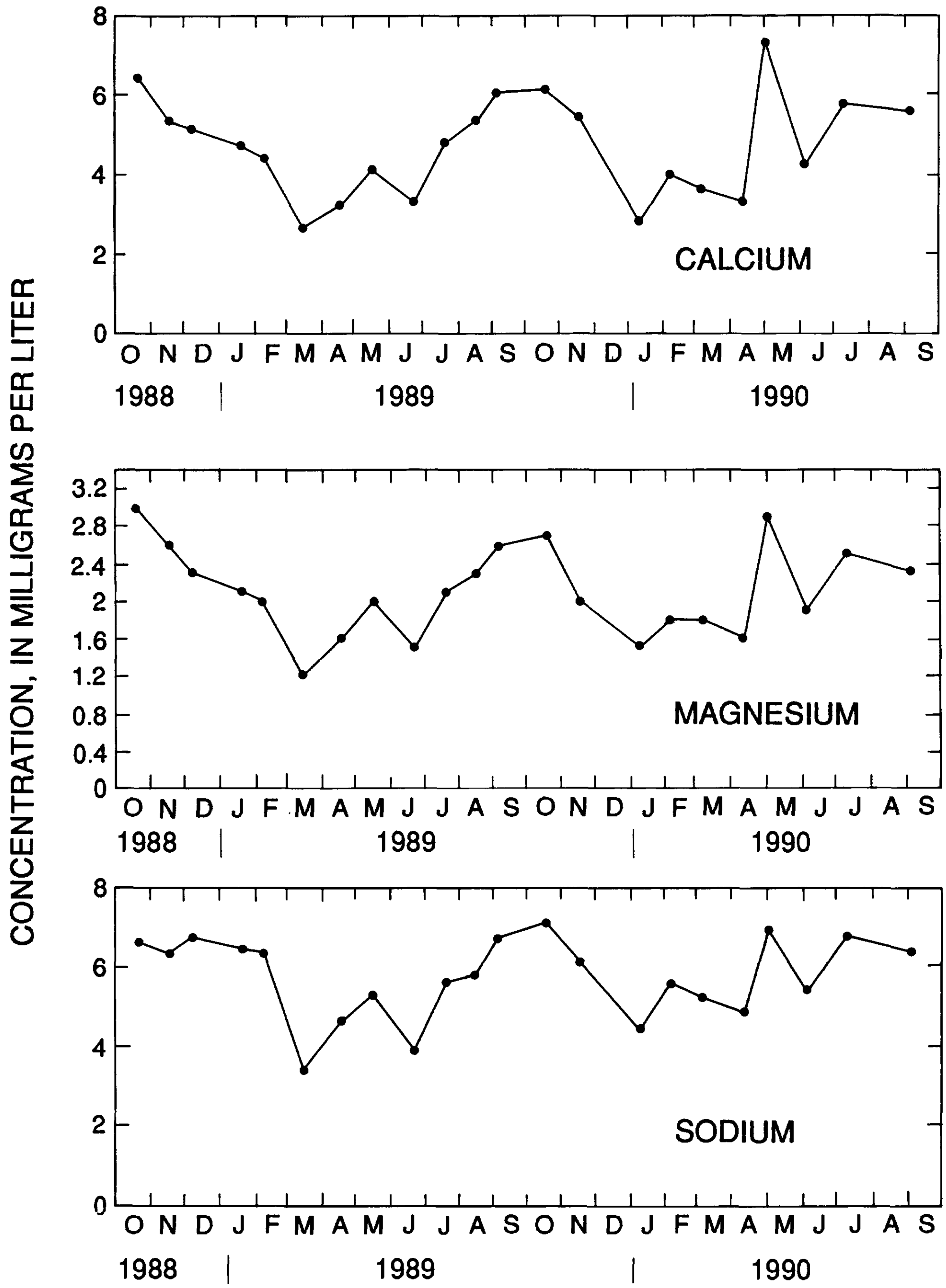


Figure 4. Concentrations of calcium, magnesium, and sodium in water from the Pea Hill Creek near Gasburg (station 02079880), Virginia, water years 1989-90.

fall and winter also can result from precipitation derived sources of sulfate.

The mean concentrations of dissolved iron and manganese were 0.649 and 0.090 mg/L, respectively. Secondary maximum contaminant levels of iron (0.3 mg/L) and manganese (0.05 mg/L) (U.S. Environmental Protection Agency, 1990b) were commonly exceeded. Although these constituents do not pose a health risk, elevated concentrations can create taste and odor problems and stain plumbing fixtures unless the water is treated.

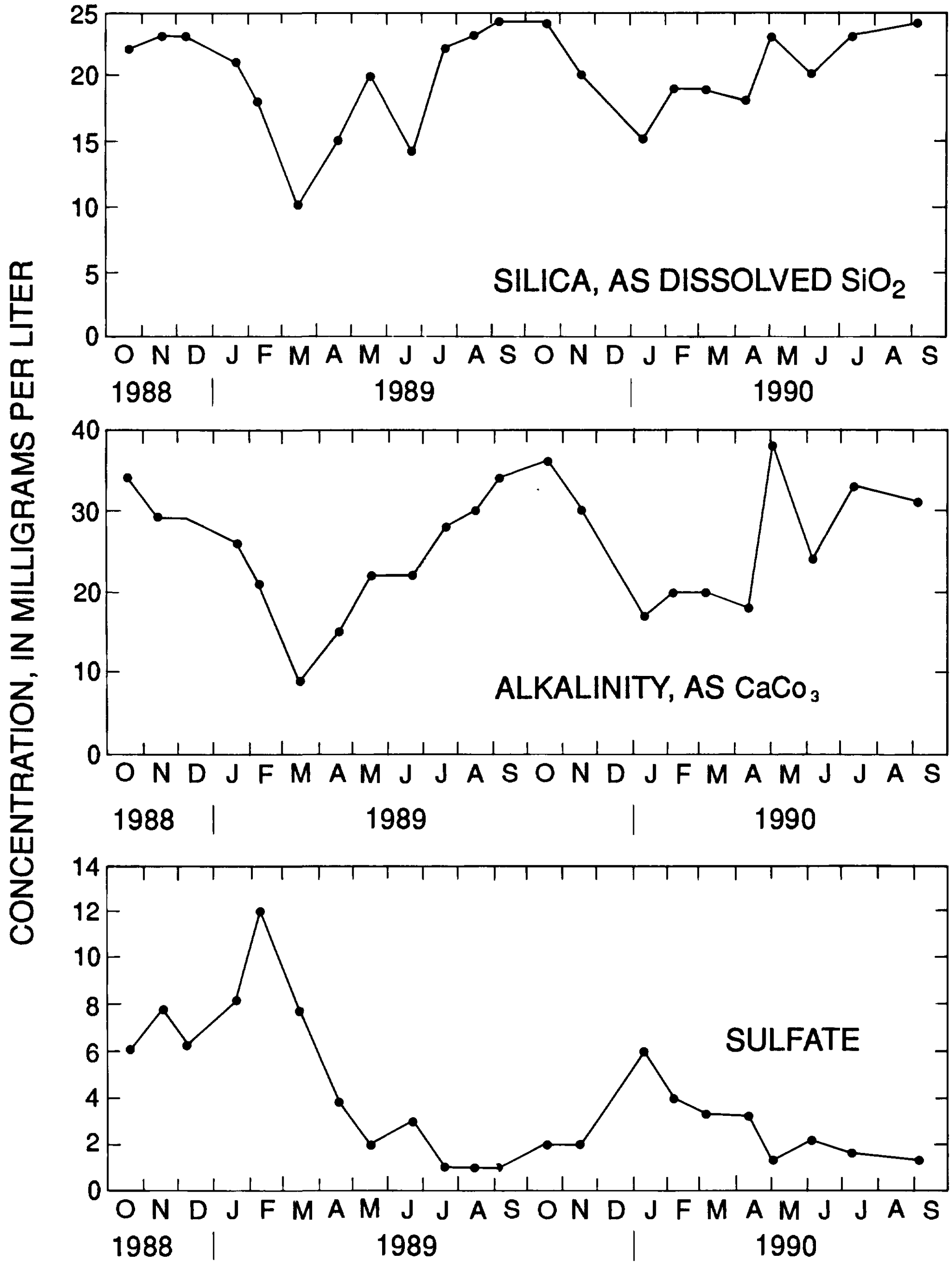


Figure 5. Concentrations of silica, alkalinity, and sulfate in water from the Pea Hill Creek near Gasburg (station 02079880), Virginia, water years, 1989-90.

Nutrients and Organic Carbon

Phosphorus and nitrogen are two essential nutrients required for biological productivity. Phosphorus generally limits biological productivity in fresh waters (Lee and others, 1978; Wetzel, 1983). Increased phosphorus concentrations often stimulate biological productivity, and over time, can cause a lake to become eutrophic.

Concentrations of total phosphorus at station 9880 ranged from 0.011 to 0.061 mg/L during the study period. The mean concentration of total phosphorus was 0.030 mg/L. The maximum concentration was not related to high streamflows; it was recorded on July 10, 1990, when the streamflow was 0.6 ft^3/s. White colloidal material observed throughout the water column,

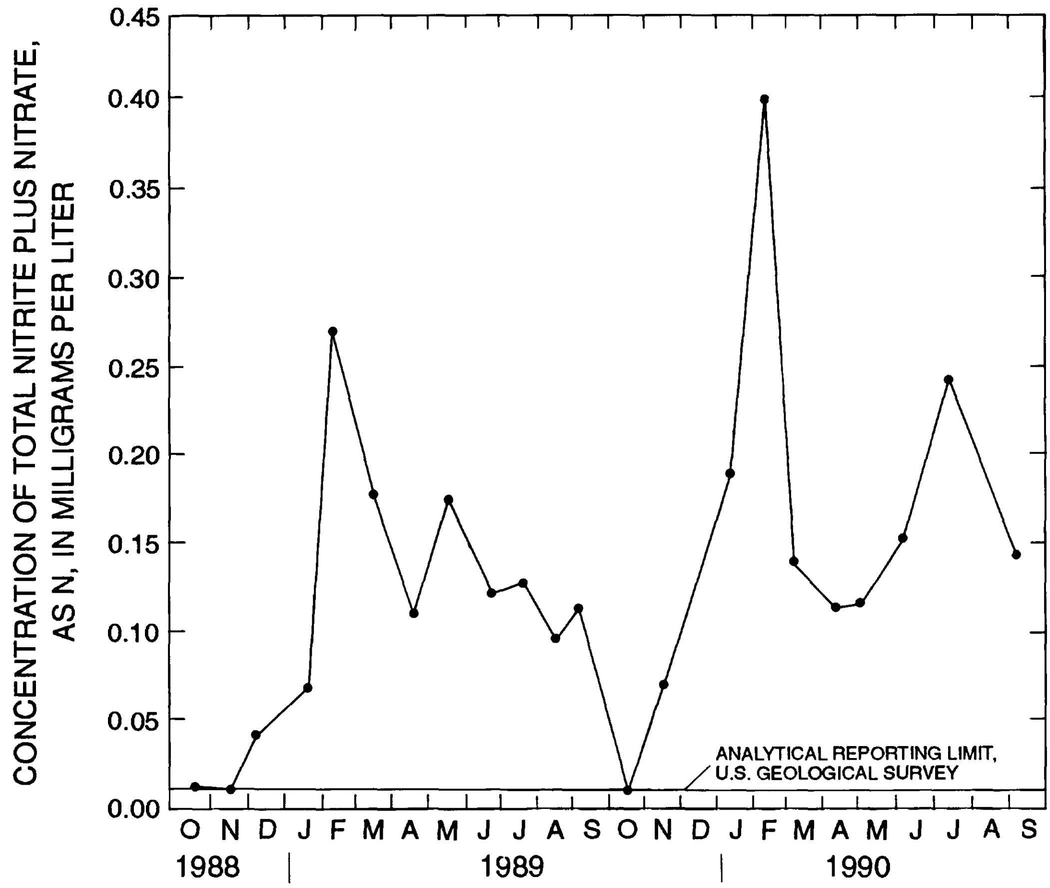


Figure 6. Concentrations of total nitrite plus nitrate in water from the Pea Hill Creek near Gasburg (station 02079880), Virginia, water years, 1989-90.

upstream and downstream from the sampling station could have been the source of the increased phosphorus concentration. The colloidal material was probably not organic because the concentration of total organic carbon on July 10, 1990, was 5.0 mg/L, which was within the normal range of values recorded at station 9880.

Total nitrogen from overland flow generally is in the form of organic nitrogen attached to sediment particles. The mean concentration of total nitrogen (0.5 mg/L) at station 9880 consists of 69 percent organic nitrogen, 25 percent nitrite plus nitrate, and 6 percent ammonia. Concentrations of total organic nitrogen peaked during the winter months when streamflows were high. Peak concentrations of total organic nitrogen, however, did not coincide with peak streamflows. Factors that can account for the lack of relation between streamflow and total organic nitrogen include effects of antecedent streamflows and the lack of samples collected during storms.

Concentrations of nitrite plus nitrate in overland flow generally are low, except when liquid nitrogen fertilizers are applied just before a large storm. The mean concentration of total nitrite plus nitrate was 0.13 mg/L at station 9880. Concentrations of total nitrite plus nitrate generally peaked during the winter months (fig. 6). Increases of nitrates in streams are closely related to water movement in soils, soil type, soil temperature, and available nitrate in the soil (Meybeck, and others 1989). The Kendall's tau correlation coefficient (Helsel and Hirsh, 1992) for total nitrite plus nitrate and streamflows at station 9880 is 0.32 with a *p*-value 0.04, thereby indicating that the two variables are linearly dependent. The seasonal increase during the winter can be related to the increased water movement through the soils, lack of evapotranspiration, and reduced mineralization during the cool, fall and winter months (Legg and Meisinger, 1982).

At station 9880, concentrations of total organic carbon ranged from 3.4 to 11 mg/L during the study period with a mean concentration of 6.0 mg/L and a median concentration of 5.1 mg/L. The Kendall's tau correlation coefficient (Helsel and Hirsch, 1992) for total organic carbon and streamflows at station 9880 is 0.38 with a probability *p* value of 0.02; therefore, concentrations of total organic carbon are related to streamflows at station 9880.

Bacteria

Total coliform and fecal-coliform bacteria are indicators of bacterial contamination. Total coliform bacteria include several coliform subgroups, including groups commonly found in the environment that are not specific to fecal matter. Fecal-coliform bacteria represent specific bacterial indicators of contamination by warm-blooded animals.

The monthly geometric mean for total coliform bacteria was 1,440 col/100 mL. The maximum total-coliform bacteria count (greater than 10,000 col/100 mL) was in a sample collected during a peak streamflow. The density of total coliform bacteria, however, also depends on other factors unrelated to streamflows; thus, no consistent relation between total coliform bacteria and streamflow was detected.

The fecal-coliform bacteria standard for surface waters in Virginia is 1,000 col/100 mL or a geometric mean of 200 col/100 mL for two or more samples collected during a 30-day period (Commonwealth of Virginia State Water Control Board Regulations, 1988). Only one sample exceeded the 1,000 col/100 mL fecal-coliform bacteria standard (February 7, 1989). The geometric monthly mean of fecal-coliform bacteria collected during the study period was 180 col/100 mL. Although the geometric monthly mean is different from the 30-day standard, it does yield information concerning potential contamination.

Inlet Stations

The temporal variability of selected water-quality constituents at nine inlet stations in the Pea Hill Arm of Lake Gaston is discussed in the following sections.

Physical Characteristics

Water temperatures at the inlet stations varied seasonally during the study period. The maximum water temperatures generally occurred in June or July, and the minimum in January.

The saturation of dissolved oxygen in water varies inversely with water temperature. Concentrations of dissolved oxygen at the nine inlet stations ranged from 6.8 to 14.6 mg/L during the winter and early spring and ranged from 5.9 to 10.7 mg/L during the summer. Concentrations of dissolved oxygen peak in the winter and spring because oxygen is more soluble in cold water and decomposition and algal respiration rates are diminished. Lower concentrations of dissolved oxygen in the summer are related to warm-water temperatures, thermal stratification, and increased biological productivity and decomposition. Although water at the inlet stations was frequently undersaturated with dissolved oxygen, concentrations of dissolved oxygen were never below the standard for Class III waters in Virginia (Commonwealth of Virginia State Water Control Board Regulations, 1988) (fig. 7).

Specific conductances ranged from 50 to 120 μS/cm at the inlet stations. Specific conductance noticeably declined after January 1989 at three selected stations shown in figure 8. The other six inlet stations also showed a similar pattern for specific conductance. As discussed earlier, seasonal variability of dissolved ions depends on the mineralogy, flow paths, and streamflows.

The elevated specific conductances at the Pea Hill Arm inlet stations can be partially explained by streamflows into the Pea Hill Arm and Lake Gaston. Streamflows in the Roanoke River Basin were below average during water year 1988 (Prugh and others, 1989). A water year is defined as the period from October 1 through September 30 of the following year. During water year 1988, the annual mean streamflow at a stream-gaging station on the Roanoke River at Randolph, Va., was 36 percent below the long-term mean annual streamflow and 33 percent below the long-term mean annual streamflow at a stream-gaging station on the Dan River at Paces, Va. Both of these stream-gaging stations are just upstream from John H. Kerr Reservoir, and, thus, measure the major inflows into Lake Gaston. The combined drainage area above these two stream-gaging stations constitutes approximately 66 percent of the Lake Gaston drainage area. During periods of low streamflows, ground water generally consists of a large percentage of the total streamflow. In general, dissolved ions are

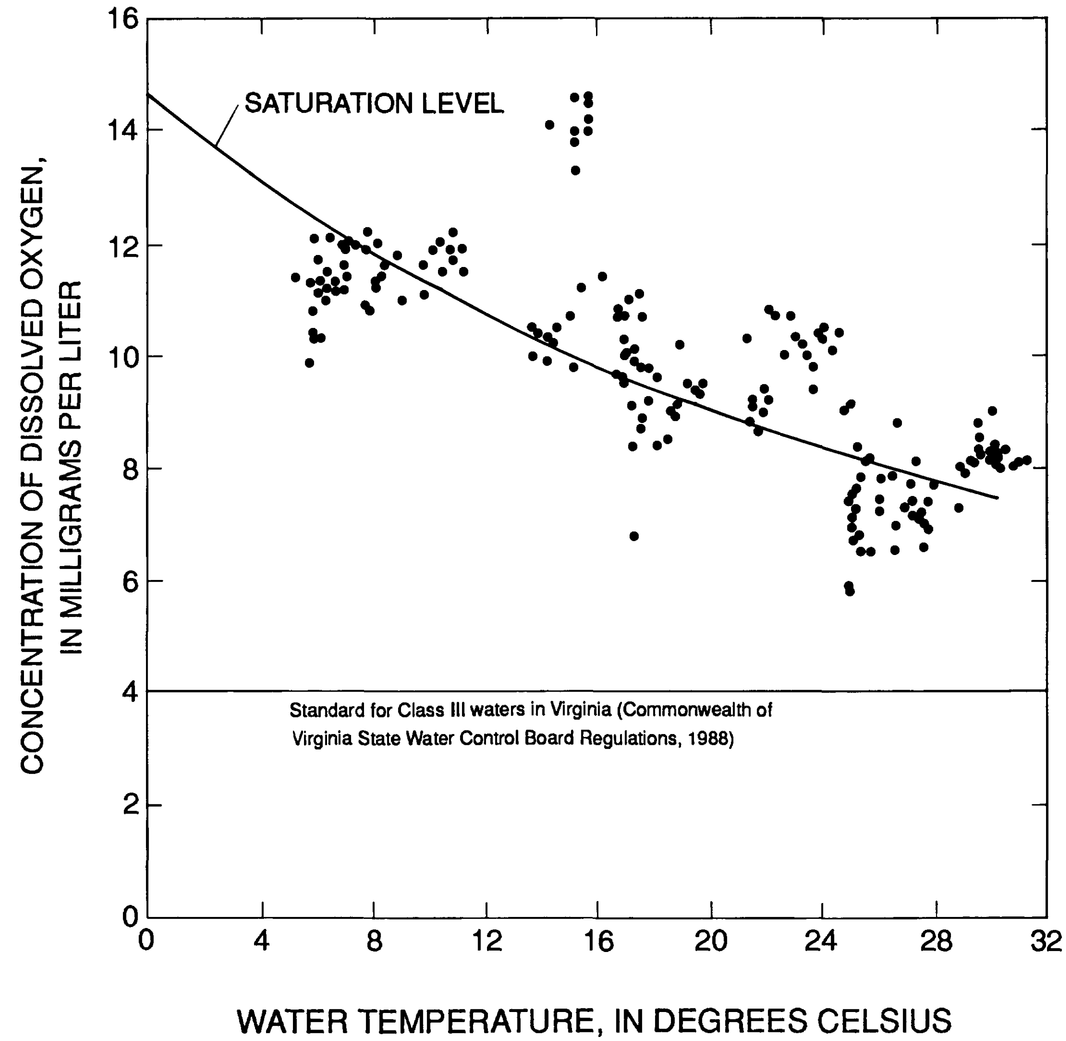


Figure 7. Relation between concentrations of dissolved oxygen in water and water temperature from inlet stations in the Pea Hill Arm of Lake Gaston, Virginia and North Carolina, water years 1989-90.

more concentrated in ground water than in surface water. Thus, the elevated specific conductances recorded in late 1988 at all the inlet stations are partially related to the low streamflows in the major streams flowing into John H. Kerr Reservoir and ultimately into Lake Gaston. The relation between monthly mean discharge and specific conductance for Dan River at Paces, Va., is shown in figure 9. The specific conductance of 270 μS/cm recorded during January 1989 is the maximum value recorded for the period of record (April 1979 to August 1990) at the Dan River at Paces, Va., stream-gaging station.

The decline in specific conductance values at the Pea Hill Arm inlet stations corresponds to increased streamflows in the winter of 1989. The annual mean streamflow at the Roanoke River stream-gaging station was 3 percent above the long-term mean annual streamflow in water year 1989 and 28 percent above the long-term mean annual streamflow in water year 1990. The annual mean streamflow at the Dan River stream-gaging station was 17 percent above the long-term mean annual streamflow in water year 1989 and 43 percent above the long-term mean annual streamflow in 1990.

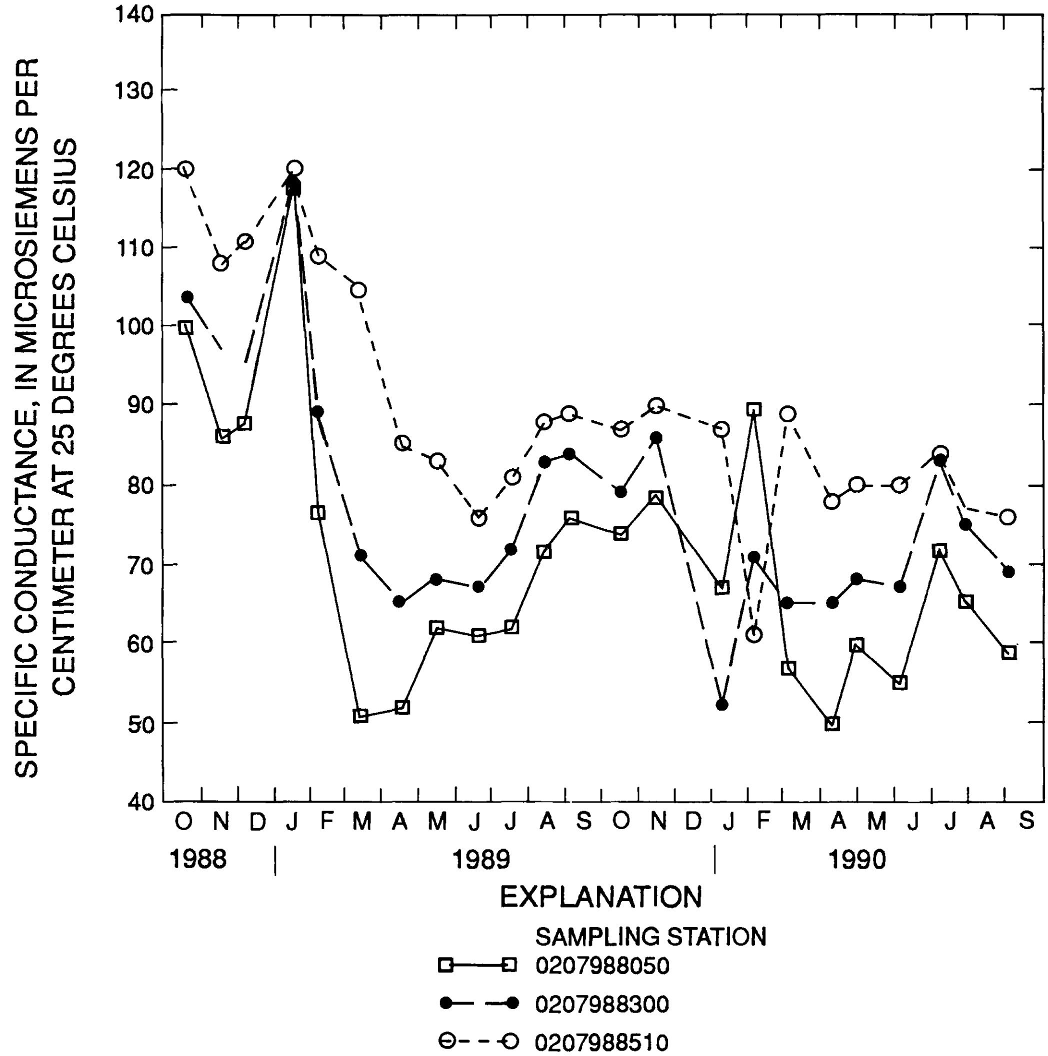


Figure 8. Specific conductance in water at 3 feet below the water surface from selected inlet stations in the Pea Hill Arm of Lake Gaston, Virginia and North Carolina, water years 1989-90.

Nutrients and Organic Carbon

Based on a general trophic classification (Wetzel, 1983), the inlet stations are classified as mesotrophic because mean concentrations of total phosphorus range from 0.011 to 0.024 mg/L at the nine inlet stations. Concentrations of total phosphorus at the nine inlet stations ranged from 0.001 to 0.060 mg/L. Concentrations of total phosphorus were less than 0.030 mg/L on 87 percent of the days sampled. Concentrations of total phosphorus at all nine inlet stations generally were elevated during the spring (March, April, and May) (fig. 10). The median concentration of total phosphorus for the inlet stations was 0.024 mg/L during the spring and less than 0.017 mg/L during the winter, fall, and summer.

Fluctuations of total-phosphorus concentrations were greater at the two inlet stations in the northern part of the Pea Hill Arm than at the other seven inlet stations sampled. Fifty-two percent of the samples with concentrations equal to or greater than 0.030 mg/L were from stations 8050 and 8100 (pl. 1). The combined drainage area of the two northern basin stations is 6,969 acres, whereas the other inlet drainage basins range from 339 to 1,153 acres. The smaller basin sizes, lack of large perennial streams, and interactions with the main body of the

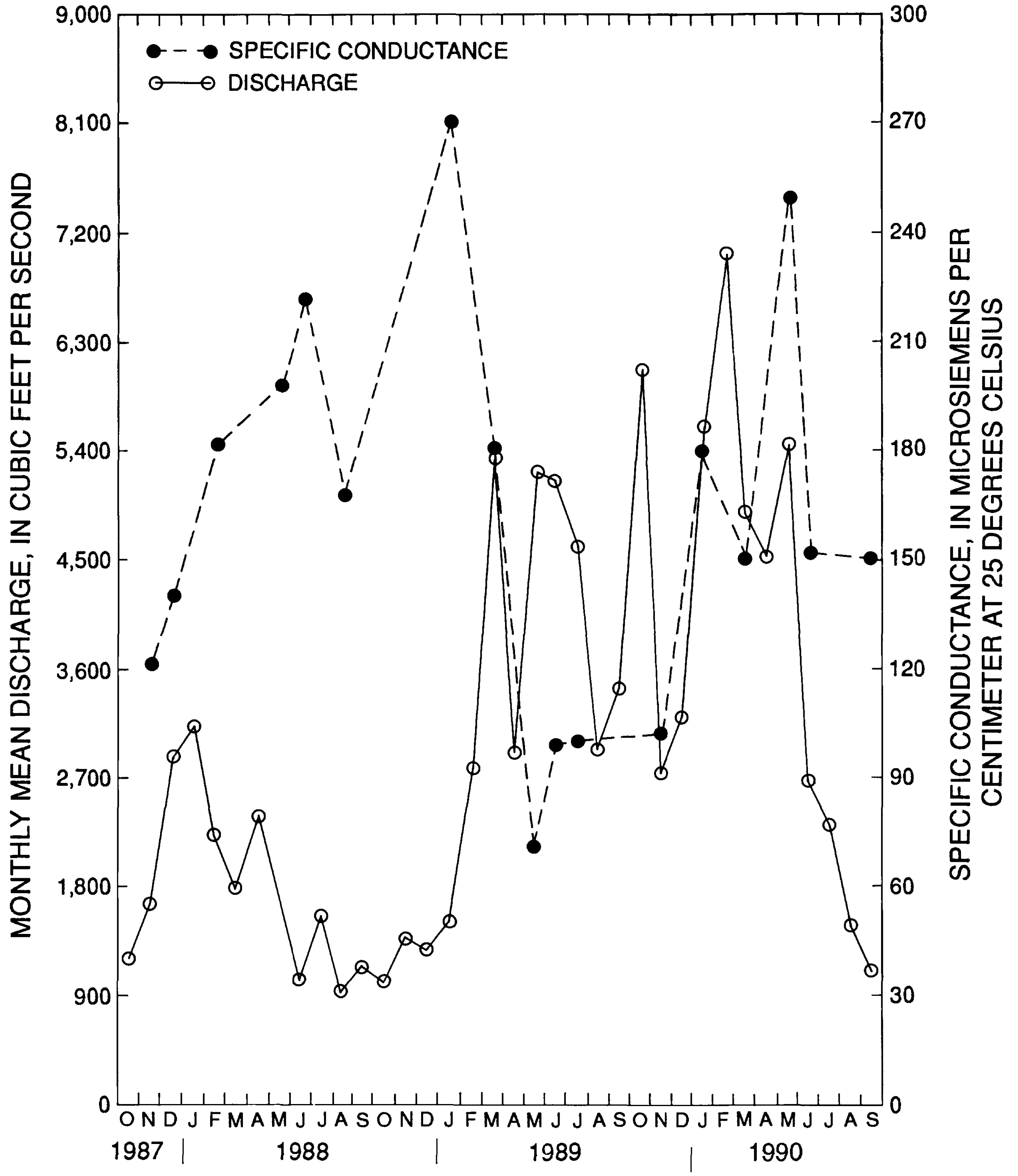


Figure 9. Relation between monthly mean discharge and specific conductance at Dan River at Paces, Virginia, water years 1988-90.

Pea Hill Arm can account for the differences in the peak concentrations of total phosphorus among the northern and southern basin inlet stations.

No seasonal patterns in concentrations of total organic nitrogen plus ammonia are evident at the inlet stations. Mean concentrations of total organic nitrogen plus ammonia at the inlet stations ranged from 0.5 to 0.6 mg/L. Peak concentrations of greater than 1 mg/L were measured at inlet stations 8300, 8430, and 8440. At station 8490, concentrations of total organic nitrogen plus

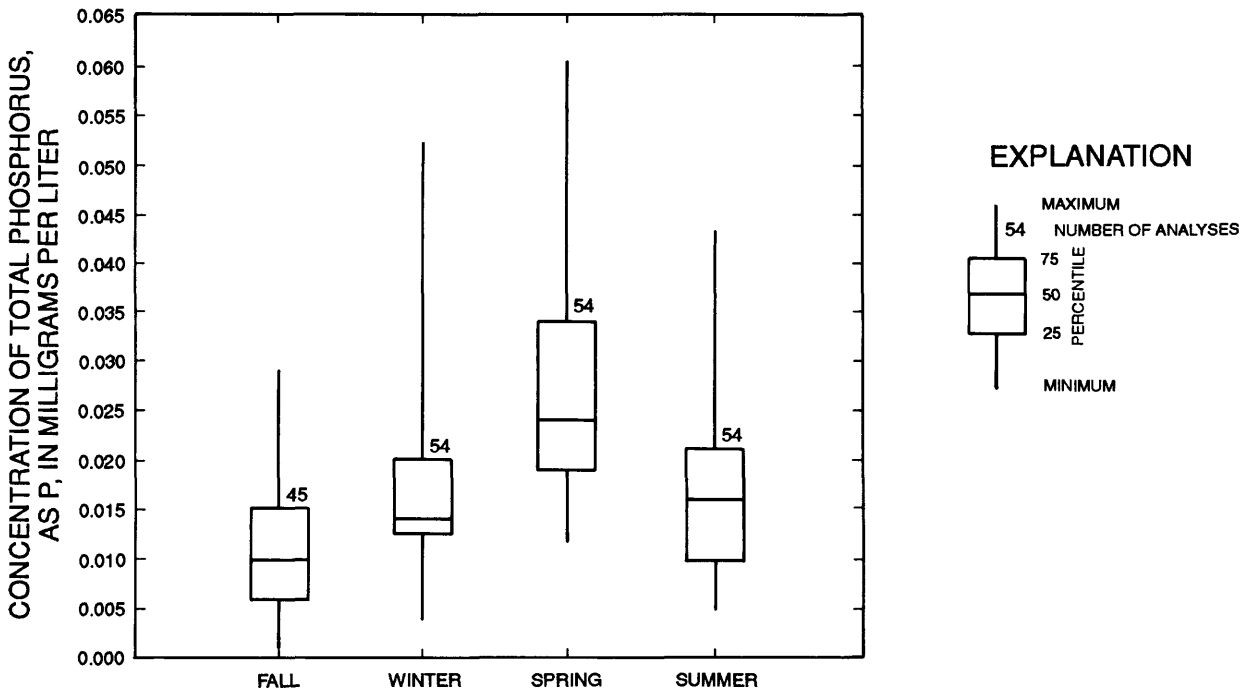


Figure 10. Seasonal concentrations of total phosphorus in water at 3 feet below the water surface from inlet stations in the Pea Hill Arm of Lake Gaston, Virginia and North Carolina, water years 1989-90.

ammonia peaked during the winter. Concentrations at inlet stations 8300 and 8430 peaked in September, during a low-streamflow period.

Similar to the seasonal pattern at station 9880 (fig. 6), concentrations of total nitrite plus nitrate are highest in winter and spring at the inlet stations (fig. 11). Elevated concentrations of total nitrite plus nitrate during the winter (December, January, and February) can be related to the mixing of hypolimnetic water from the deeper sections of Pea Hill Arm with water in the inlets. The hypolimnetic water generally contains elevated concentrations of ammonia by anoxic conditions that result from thermal stratification. As the hypolimnetic water mixes with water containing oxygen, ammonia is converted to nitrate.

Increased inflows of ground water during high base-flow periods also can contribute to the seasonal increase in concentrations of total nitrite plus nitrate at the inlet stations. Additionally, more oxygen can be available in the ground-water system during high base-flow periods, thereby preventing denitrification.

In most lakes and reservoirs, the main nutrients related to an increase in algal productivity are nitrogen and phosphorus. When one of these nutrients is not present in sufficient quantities, algal growth can be limited by that particular nutrient. Nitrogen and phosphorus are typically present in aquatic algae at a ratio of 7 to 1 (by weight), respectively (Wetzel, 1983). If the ratio is greater than 7, algal growth can be limited by phosphorus. When the ratio is less than 7, algal growth can be limited by nitrogen. Algal growth, however, also can be limited by other factors, such as water temperature, light attenuation, residence time, and zooplankton grazing activities.

The mean total-nitrogen to total-phosphorus ratios ranged from 30 to 97 at the inlet stations during the study period. Thus, algal growth at the inlet stations is generally limited by phosphorus. The total-nitrogen to total-phosphorus ratio can also indicate the type of algal species that may be prevalent. For example, when nitrogen is the limiting nutrient, blue-green algae can become the dominant algal type because of their ability to fix nitrogen from the atmosphere. Blue-green algae are a concern to the operators at water-treatment facilities because of the potential to create taste and odor problems in treated drinking water.

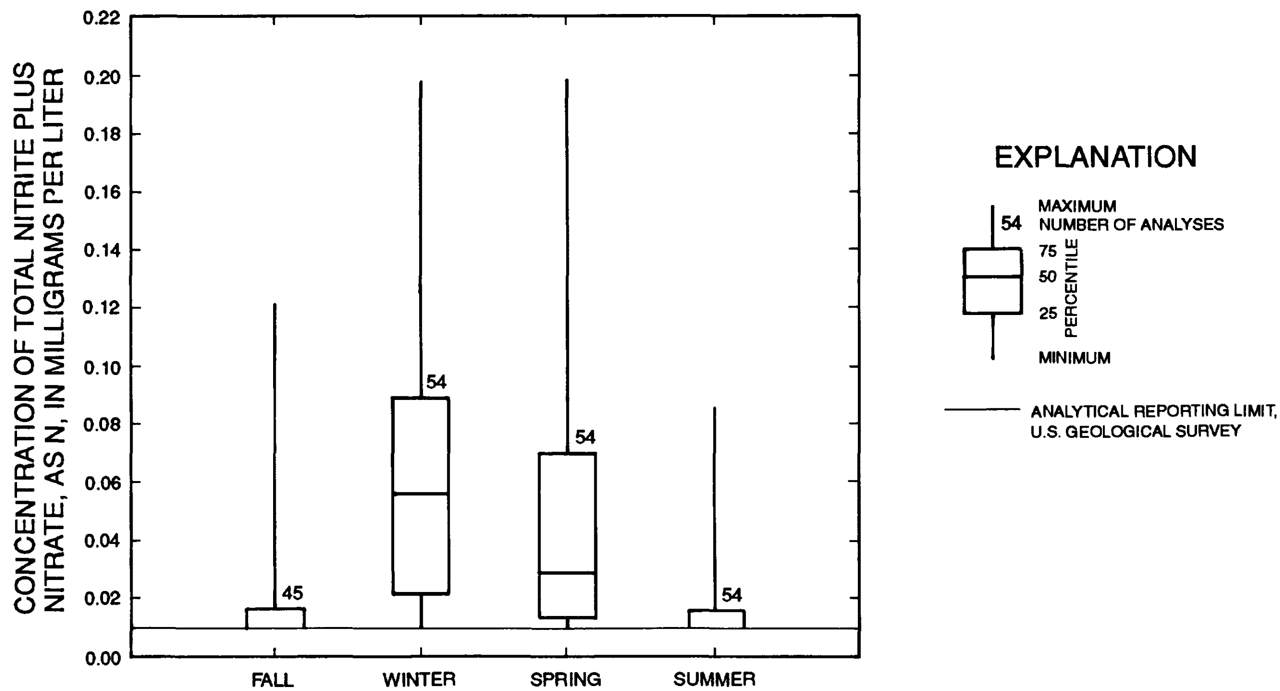


Figure 11. Seasonal concentrations of total nitrite plus nitrate in water at 3 feet below the water surface from inlet stations in the Pea Hill Arm of Lake Gaston, Virginia and North Carolina, water years, 1989-90.

The mean concentration of total organic carbon at all the inlet stations combined was 5.9 mg/L. Concentrations of total organic carbon ranged from 3.2 to 9.4 mg/L. Concentrations were elevated in the spring and summer seasons.

Bacteria

None of the samples collected at the inlet stations exceeded the fecal-coliform bacteria standards for surface waters in Virginia. The maximum number of fecal-coliform colonies recorded at the inlet stations during the study period was 470 col/100 mL at station 8160. Generally, the fecal-coliform colonies were below 20 col/100 mL at the inlet stations. Only 11 of the 203 fecal-coliform bacteria samples collected at all the inlet stations exceeded 100 col/100 mL.

Lake Stations

Three lake stations were monitored during the study period to describe changes in water-quality constituents during the stratification and destratification periods. Station 8450, in the Pea Hill Arm, represents the quality of water near the proposed water intake for the City of Virginia Beach. Station 8490 is near the mouth of the Pea Hill Arm and represents a transition zone with a mixture of water from the Pea Hill Arm and the main body of Lake Gaston. Quality of water at station 7950 represents the quality of water in Lake Gaston near the Pea Hill Arm (pl. 1.).

Physical Characteristics

Water temperature and density stratification in reservoirs control most physiochemical cycles and, thus, affect reservoir productivity. Pea Hill Arm and Lake Gaston are monomictic, undergoing one regular period of circulation each year. Thermal stratification typically begins in May and continues through September (fig. 12). During the summer, three distinct water layers typically exist in monomictic lakes. The upper water layer, termed the epilimnion, is characterized by warm, well-mixed water. The cold and relatively undisturbed lower water layer is the hypolimnion. Separating the epilimnion and the hypolimnion is the metalimnion. The metalimnion is defined as a water layer with a steep thermal gradient, separating relatively isothermal conditions in the epilimnion and the hypolimnion.

In late September, the epilimnion water temperature is lowered by cooler air temperatures and wind-induced mixing. The epilimnion starts to erode or destratify the hypolimnion. The destratification process is referred to as the fall overturn. Pea Hill Arm and Lake Gaston were usually completely mixed by November. Isothermal conditions were prevalent from November until March, as shown by vertical lines in figure 12.

Vertical temperature profiles in figure 13 illustrate the different degrees of stratification at stations 8450, 8490, and 7950 on May 17 and 18, 1989. No stratification was evident at station 7950 on May 18, 1989. The temperature gradient at station 7950 from the water surface to lake bottom was 1.7 °C. At station 8490, the epilimnion was uniformly mixed from 0 to 20 ft below the water surface. An abrupt change in water temperature at 20 to 21 ft marks the top layer of the hypolimnion. On May 18, 1989, there were three distinct temperature zones at station 8450: An epilimnion from 0 to 10 ft below the water surface, a metalimnion from 10 to 25 ft below the water surface, and a hypolimnion from 25 ft to the reservoir bottom.

The stratification process differs at each of the three lake stations. The early formation of stratification at station 8450 can be attributed to the long water-residence time in the northern part of the Pea Hill Arm Basin. Daily flow reversals at the culvert separating the Pea Hill Arm and Lake Gaston can account for the delayed stratification at station 8490, near the culvert. The lack of stratification on May 18, 1989, at station 7950 can be related to hypolimnetic water releases from John H. Kerr Reservoir Dam and from the Lake Gaston Dam. Thus, conditions at station 7950 periodically represent a large river system when large amounts of water are released from the upstream and downstream dams.

The thermal gradient between the epilimnion and the hypolimnion was greatest in July. Vertical temperature plots for July 10 and 11, 1990, are shown in figure 14. Three distinct water temperature layers were evident at station 7950: An epilimnion from 0 to 21 ft below the water surface, a metalimnion from 21 to 30 ft below the water surface, and a hypolimnion from 30 ft below the water surface to the lake bottom. Station 8490 represents a mixture zone of water from Pea Hill Arm and Lake Gaston. The division of the different thermal layers at station 8490 in July was not abrupt like the thermal layers at station 7950. Based on the thermal gradient alone, separation of the hypolimnion and the metalimnion at station 8490 is difficult. Concentrations of dissolved oxygen, however, near zero indicate that the water layer below 20 ft was not mixed with upper-water layers. The thermal gradient at station 8450 was similar to that at station 8490.

The seasonal pattern of dissolved-oxygen concentrations (fig. 15) depends on the mixing patterns in the reservoir, water releases from nearby dams, and thermal stratification. The reservoir begins to thermally stratify in May. During the early stages of thermal stratification, concentrations of dissolved oxygen in the hypolimnion start to decline. As the reservoir thermally stratifies, the hypolimnion becomes anoxic. Anoxic conditions typically last from mid-June to mid-September. The duration of anoxic conditions was shorter in 1989 than in 1990; thus, the anoxic area in the hypolimnion was larger in 1990 than in 1989 (figs. 15 and 16).

The difference in the degrees of stratification during August 1989 and 1990 can be attributed to above normal rainfall during 1989. Monthly rainfall measured at a weather station near John H. Kerr Reservoir was more than 3 in., greater than the long-term monthly means for the months of July and August 1989 (fig. 1). The increased flows in the Lake Gaston drainage basin during July and August 1989 resulted in erosion of the hypolimnion, as shown by the increased concentrations of dissolved oxygen in the hypolimnion and the increase in the depth of isothermal conditions (fig. 16).

Concentrations of dissolved oxygen in the hypolimnion increase as the reservoir thermally destratifies. Dissolved-oxygen concentrations were generally uniform throughout the water column by November.

Similar to the inlet stations, specific conductance was elevated from October 1988 to January 1989 at the lake stations (fig. 17). Specific conductance at 3 ft below the water surface ranged from 105 to 130 μS/cm during October 1988 to January 1989 and from 73 to 119 μS/cm during February 1989 to October 1990. Low streamflows during water year 1988 and applications of road salt in the upper Lake Gaston and Pea Hill Arm drainage basins during December 1988 and January 1989 contributed to the elevated specific conductances at the lake stations. Similar variations in specific conductance also were observed at depths of 12 and 21 ft below the water surface.

Specific conductances near the bottom of the lake ranged from 77 to 130 μS/cm. During the stratified period, physiochemical cycles at the water-sediment interface often result in an increase in specific

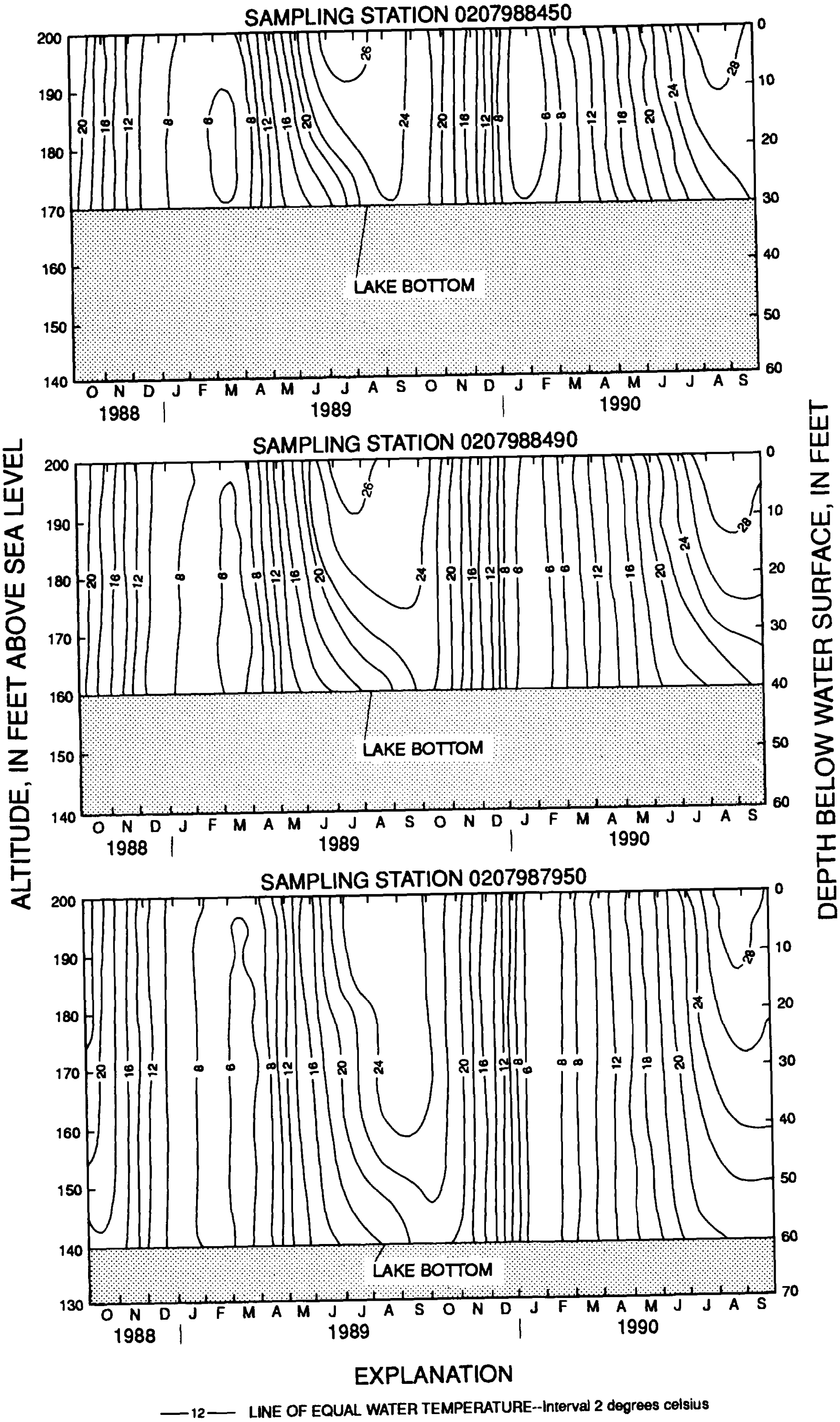


Figure 12. Water temperatures from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

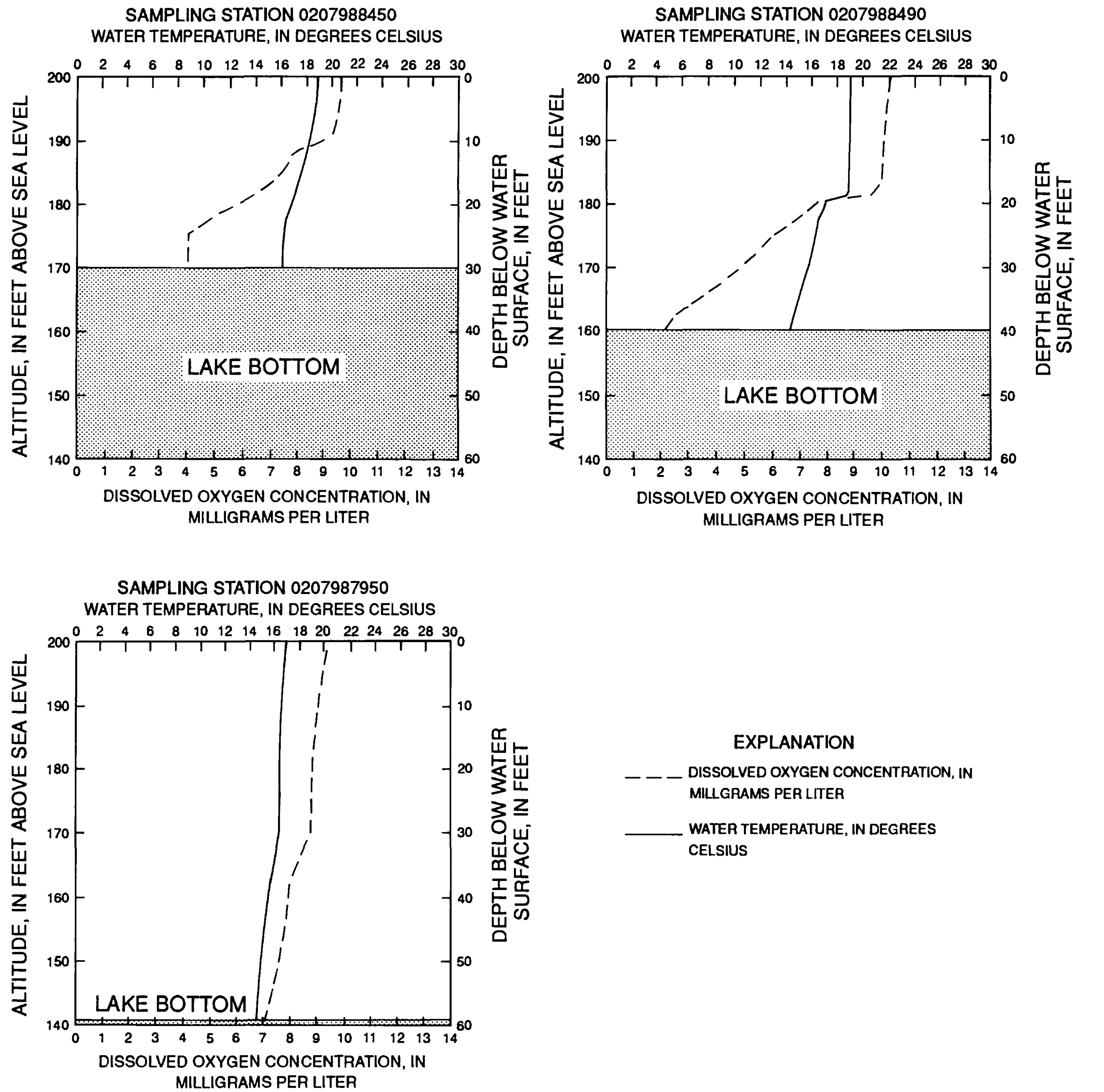


Figure 13. Temperature profiles and concentrations of dissolved oxygen in water from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, May 17-18, 1989.

conductance in the hypolimnion by the release of dissolved iron, manganese, ammonium, and bicarbonate ions. During the stratified period, there was minimum mixing between the warm epilimnion and the dense, colder hypolimnion. Thus, there was little vertical transport of dissolved ions into the epilimnion until the fall overturn.

Major Inorganic Constituents and pH

Although the Pea Hill Arm Basin is entirely within the Piedmont Physiographic Province, the Lake Gaston drainage basin also includes the Valley and Ridge and Blue Ridge Physiographic Provinces. Streams draining the Valley and Ridge Physiographic Province generally have elevated concentrations of dissolved ions because of

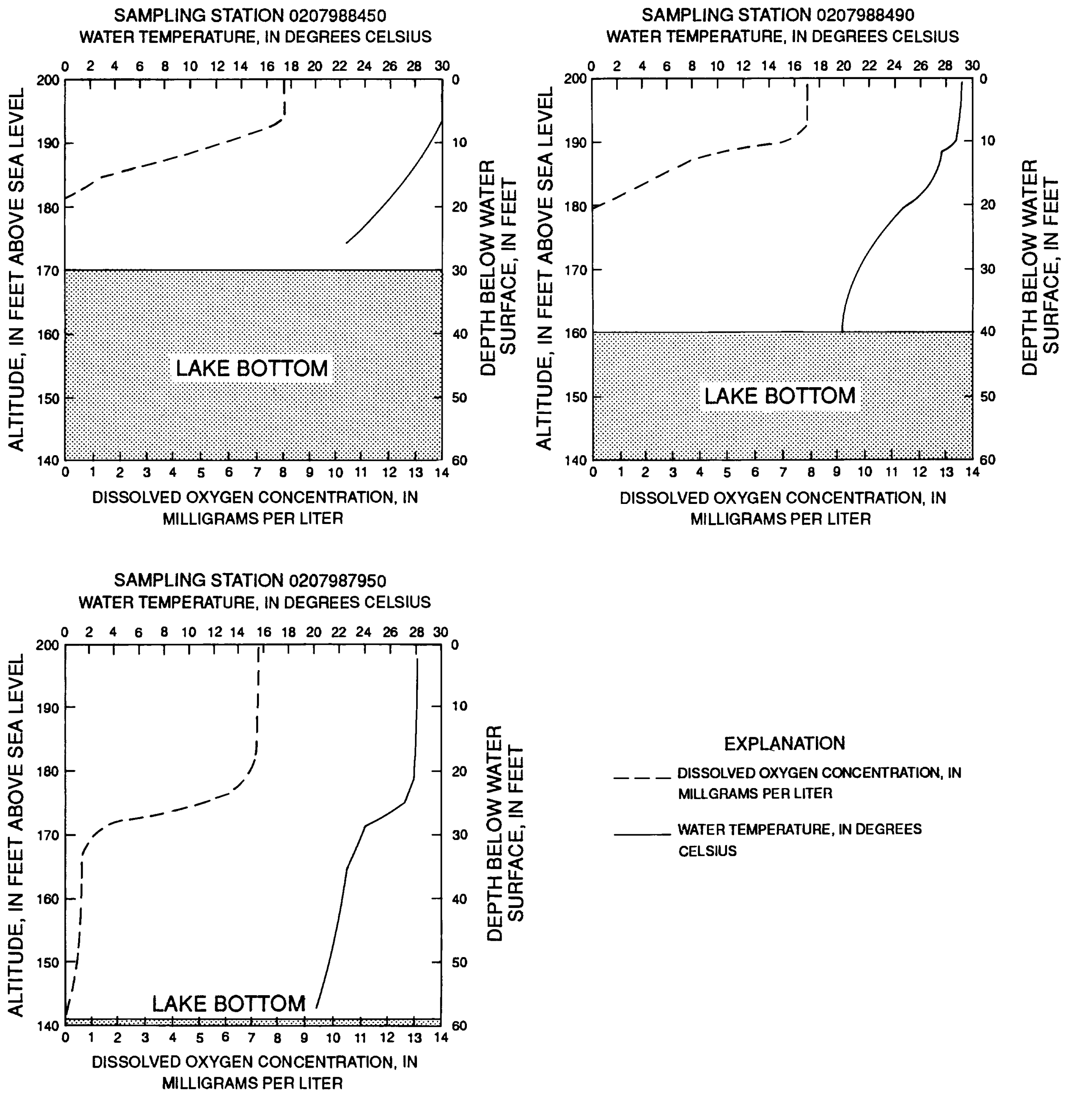


Figure 14. Temperature profiles and concentrations of dissolved oxygen in water from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, July 10-11, 1990.

the abundant dolomite and limestone in that province. Concentrations of major dissolved ions in streams draining the Blue Ridge Physiographic Province vary according to the host rock, which consists of intrusive igneous and metamorphic rocks (Powell and Hamilton, 1988).

The effects of streams draining the Valley and Ridge and Blue Ridge Physiographic Provinces on the quality of water are reflected in the ionic composition of water samples collected at the lake stations at 3 ft below the water surface. Samples from station 7950 generally had higher concentrations of dissolved sodium, calcium,

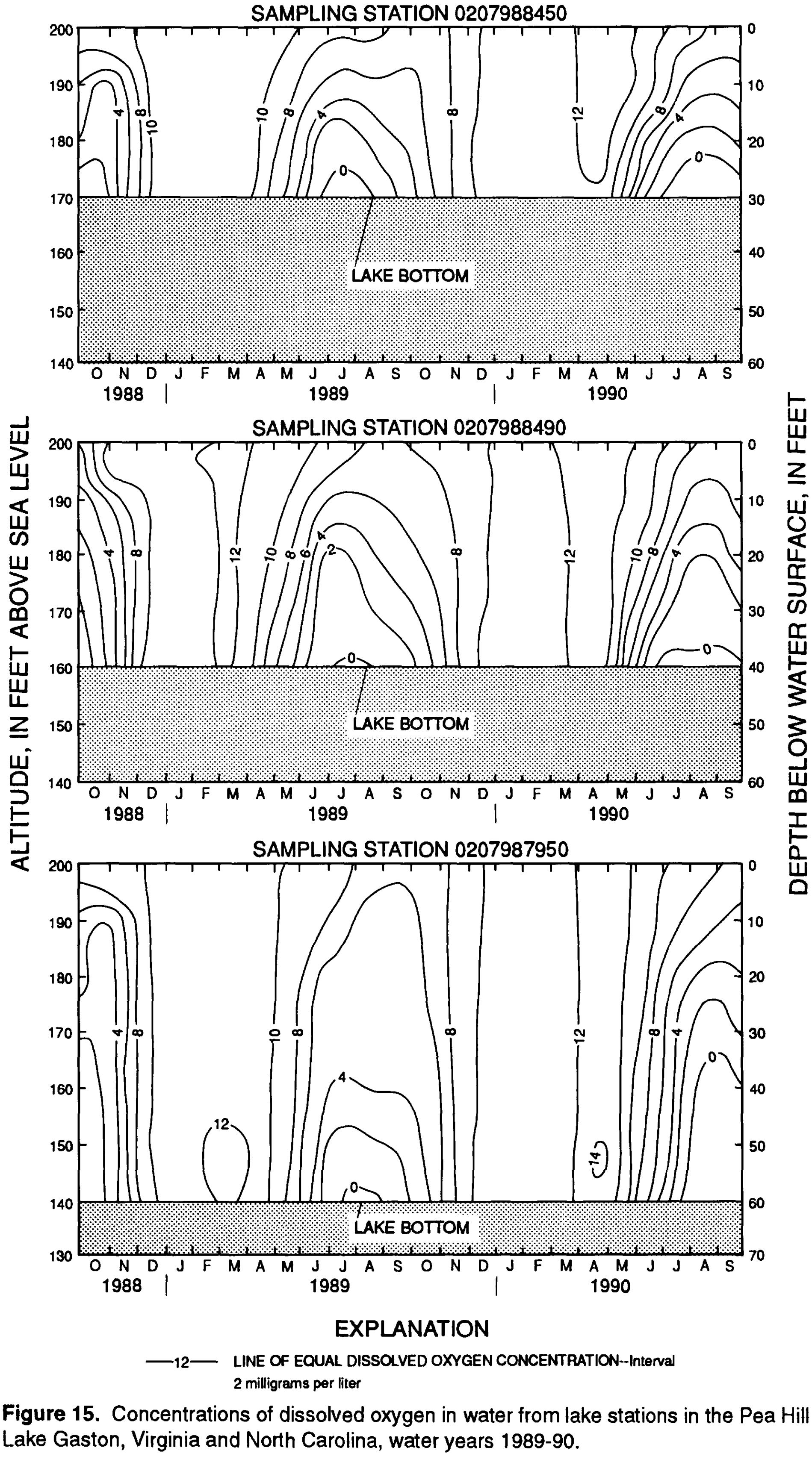


Figure 15. Concentrations of dissolved oxygen in water from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

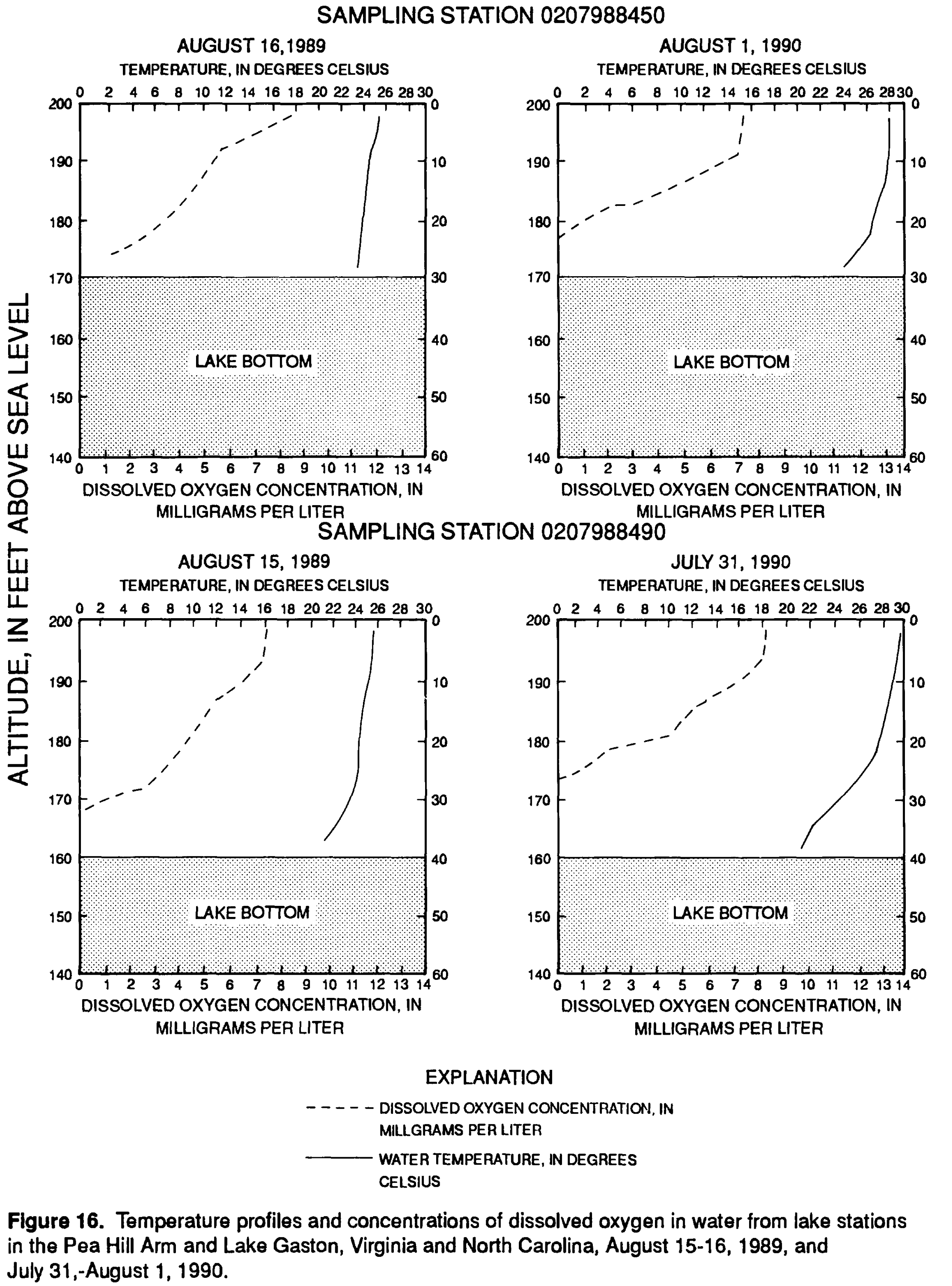


Figure 16. Temperature profiles and concentrations of dissolved oxygen in water from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, August 15-16, 1989, and July 31,-August 1, 1990.

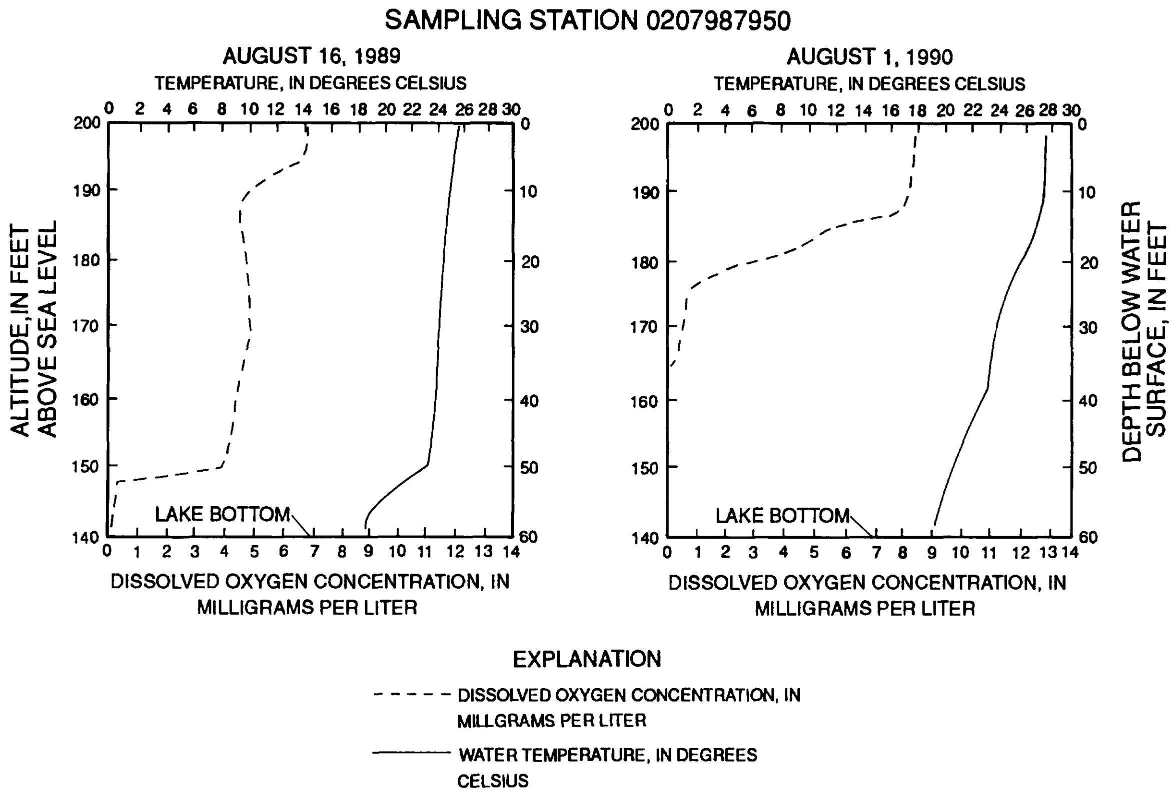


Figure 16. Continued.

magnesium, and alkalinity than samples from the other two lake stations (figs. 18 and 19). Samples from station 8450 generally had the lowest concentrations of major ions of samples from the lake stations.

Elevated ion concentrations during late 1988 and early 1989 may be the result of a combination of the natural factors related to the decreased streamflows and applications of road salt in the upper Lake Gaston drainage basin. Streamflows into Lake Gaston were below average for water year 1988, as discussed earlier. Reduced streamflows contributed to the elevated concentrations of sodium, magnesium, and alkalinity from October 1988 to February 1989 (figs. 18 and 19). Elevated concentrations of sodium, calcium, magnesium, and alkalinity during October and November are probably related to the decreased streamflows, whereas elevated concentrations of sodium, chloride, and alkalinity during January and February can be related to applications of salt to roads throughout the Lake Gaston drainage basin. Snow was recorded at nearby weather stations during December 1988 and January 1989. A comparison of the ionic composition (Stiff, 1951) of water samples collected at the lake stations during January 1989 and 1990 suggests the application of road salt during January 1989 by the elevated levels of sodium and chloride (fig. 20).

Concentrations of sodium and chloride peaked at station 7950 and are diluted with increasing distance from the main body of Lake Gaston. Unlike at the lake stations, chloride concentrations remained stable at tributary station 9880 during the study period. Thus, either the surface runoff containing the road salt was not sampled, road salt was not applied in the Pea Hill Creek drainage basin, or other factors affected the ionic composition of the water in Lake Gaston and Pea Hill Arm.

Fluctuations in concentrations of major ions and in pH are related to weathering processes, temperature, decomposition rates, and lake stratification (figs. 18 and 19). Warm-water temperatures during the summer months increase carbonic-acid weathering reactions, which increase concentrations of calcium and alkalinity. Concentrations of calcium and alkalinity in the epilimnion can remain elevated during the fall and winter months because of the fall overturn. As the reservoir is

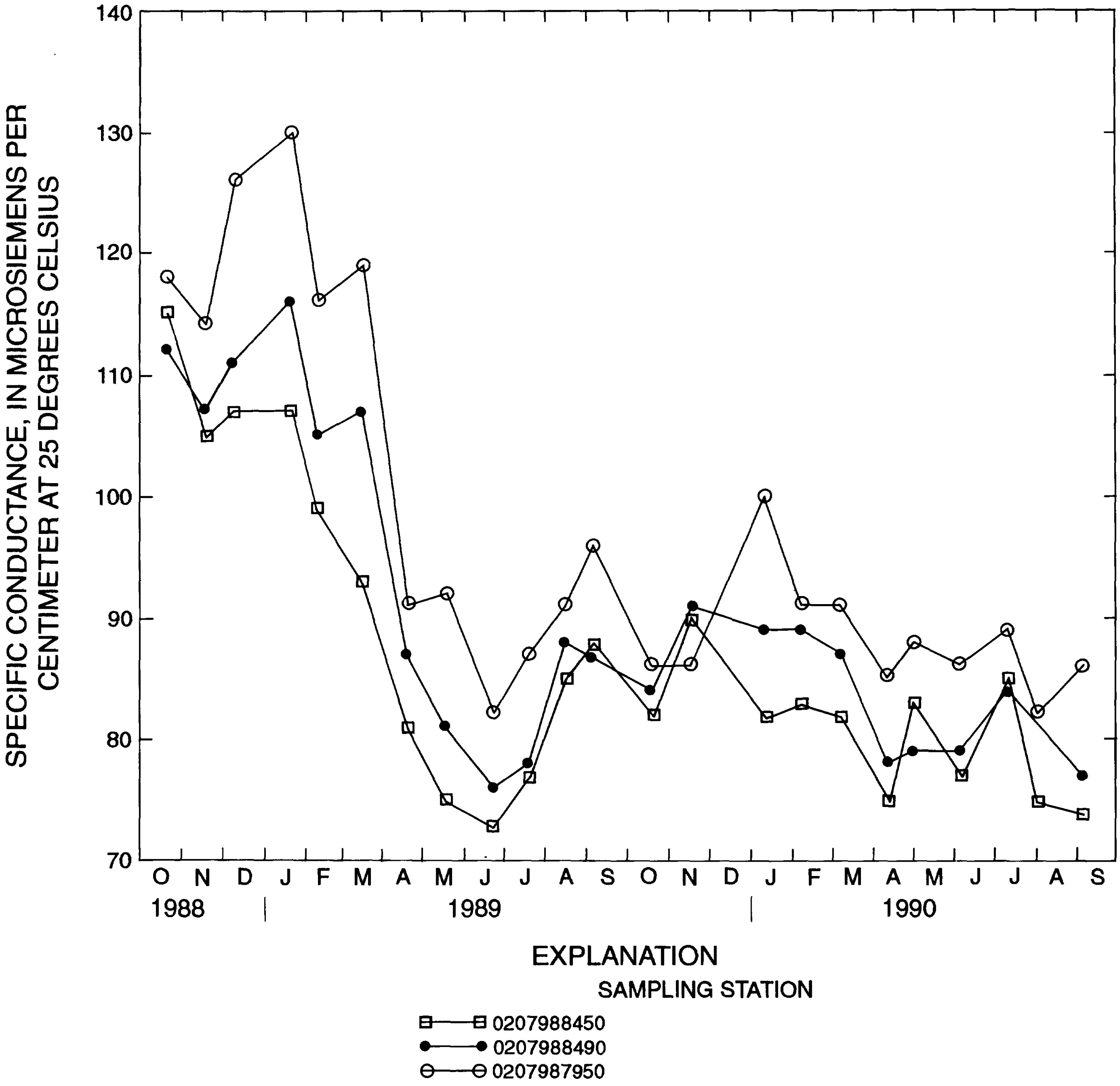


Figure 17. Specific conductance in water 3 feet below the water surface from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years, 1988-90.

mixed, water from the hypolimnion that generally contains elevated concentrations of alkalinity and calcium is mixed with the water in the epilimnion.

Fluctuations in concentrations of calcium and alkalinity in the hypolimnion are related to the decomposition of organic matter and lake stratification. Hypolimnetic oxygen is consumed by the decomposition of organic matter when a lake becomes thermally stratified. Decomposition of organic matter shifts from an aerobic process to an anaerobic process as the hypolimnion becomes anoxic. Alkalinity is released from bottom sediments as iron and manganese oxides are reduced in the oxidation of organic matter (Wetzel, 1983). Dissolution of calcium carbonate also increases alkalinity and calcium concentrations in the hypolimnion (fig. 21).

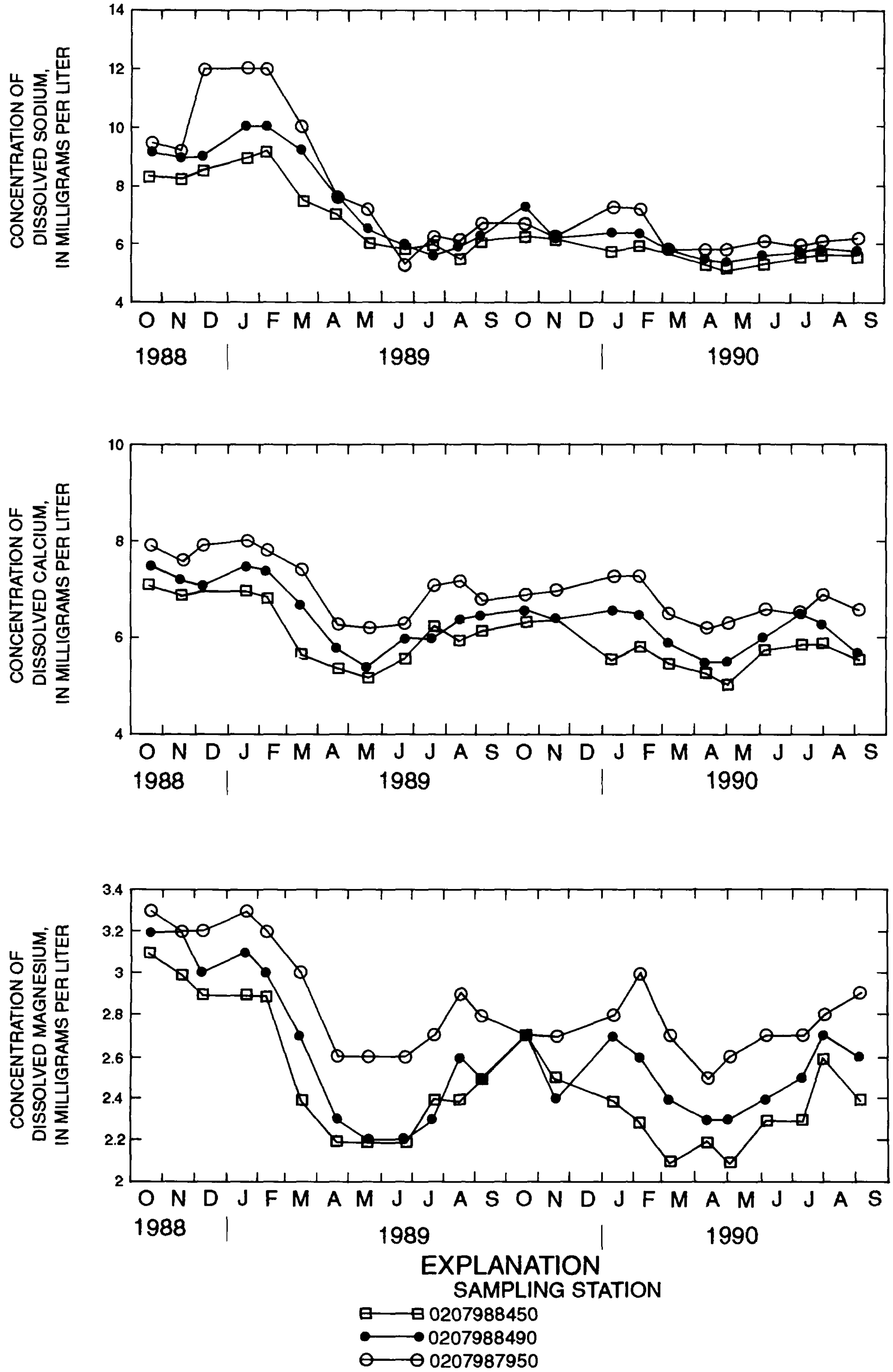


Figure 18. Concentrations of dissolved sodium, calcium, and magnesium in water at 3 feet below the water surface from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

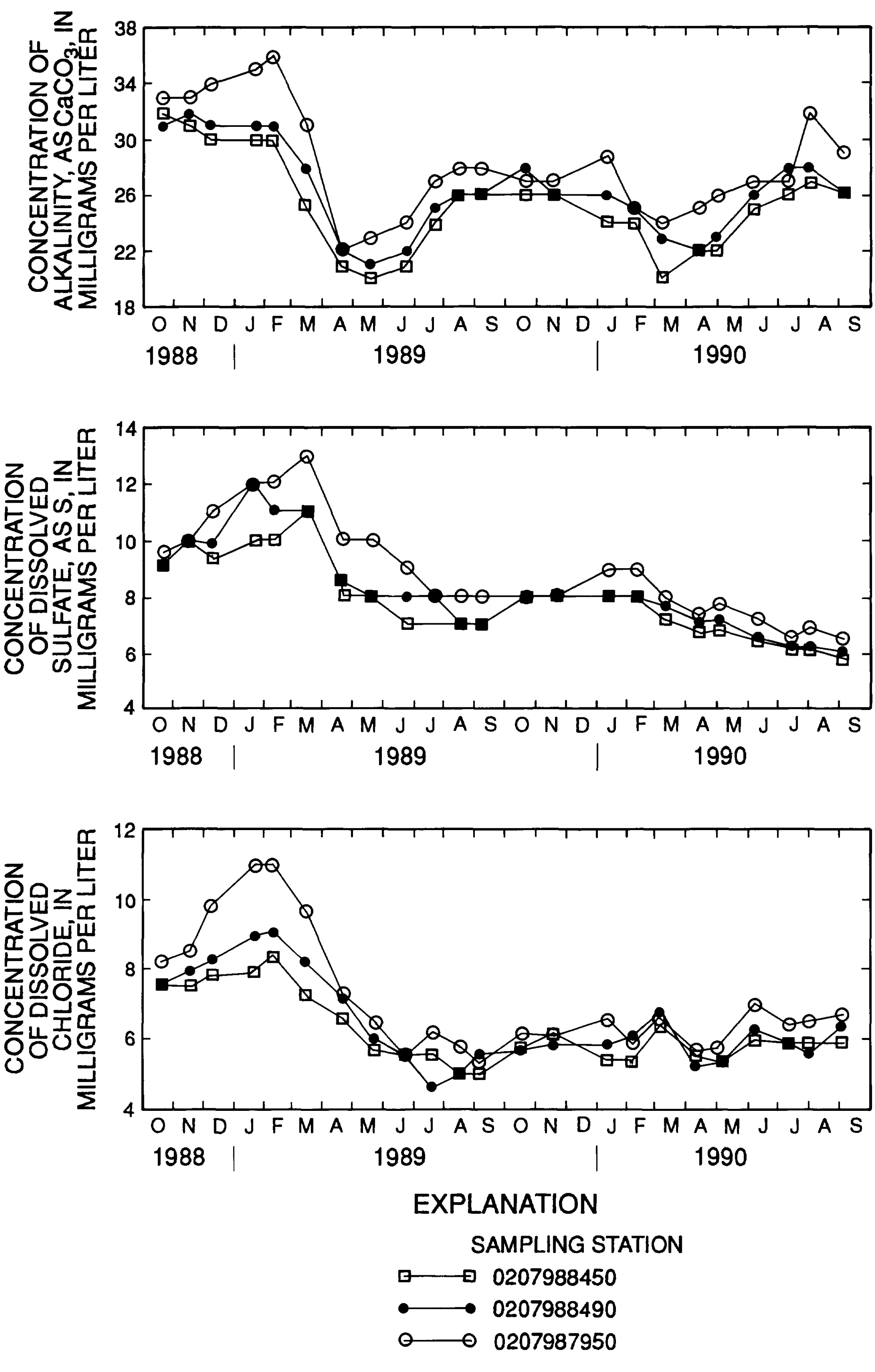


Figure 19. Concentrations of alkalinity, and dissolved sulfate and chloride in water at 3 feet below the water surface from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

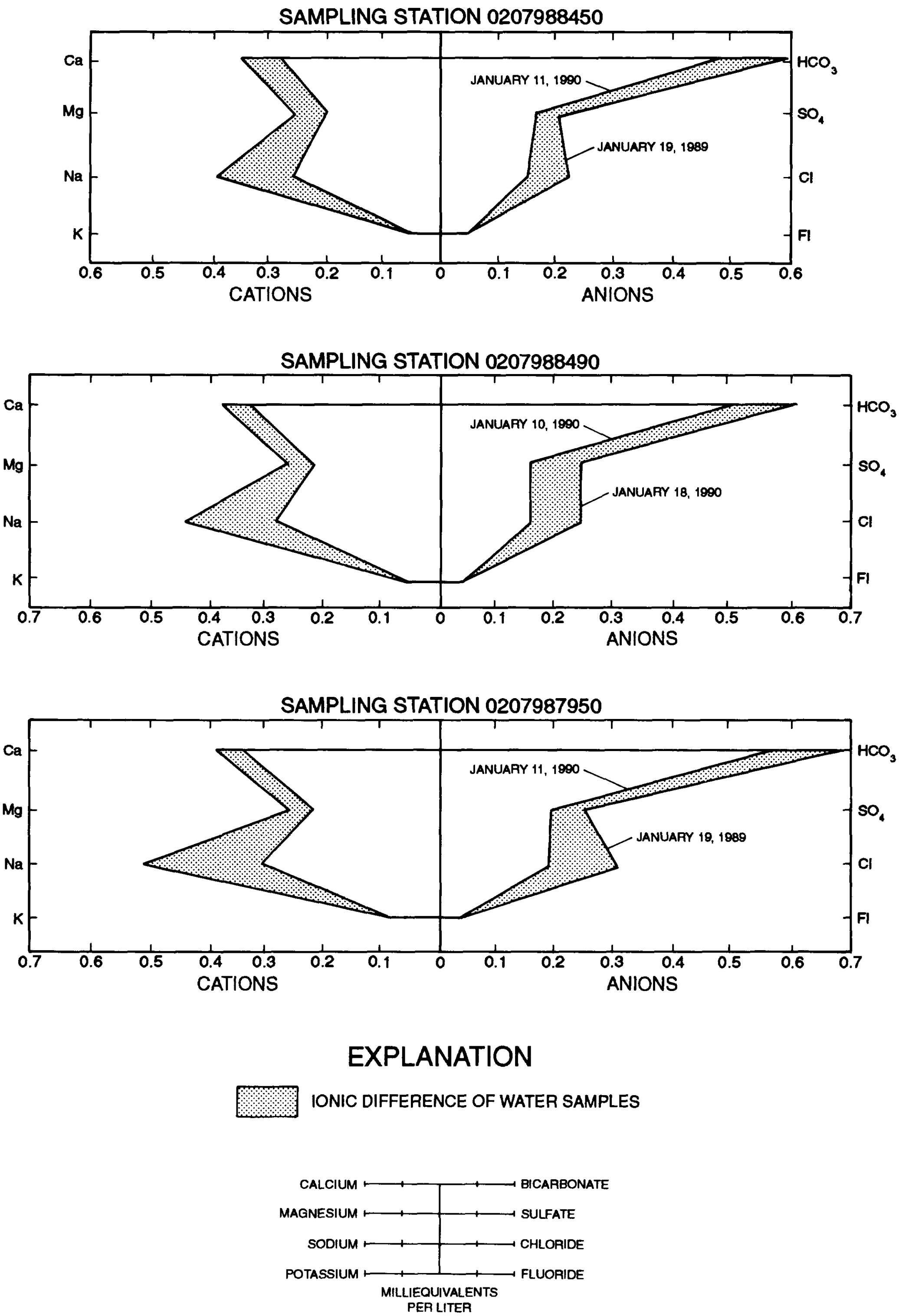


Figure 20. Stiff diagram showing the cation-anion relation of water-quality samples from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, January 1989 and 1990.

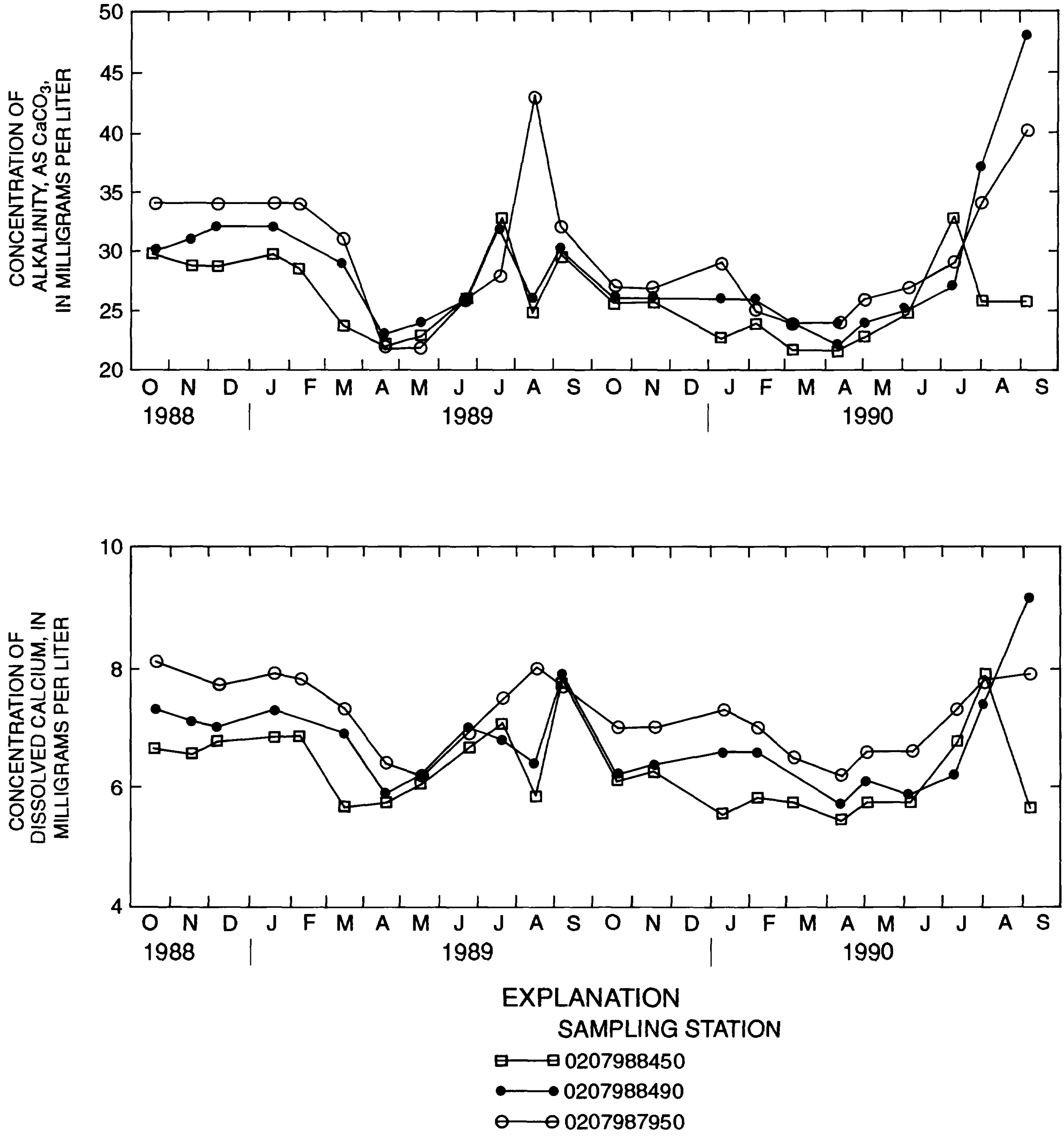


Figure 21. Concentrations of alkalinity and dissolved calcium in water at 2 feet above the lake bottom from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

The pH in the epilimnion ranged from 6.8 to 8.2. Unlike in the epilimnion, the pH varied seasonally in the hypolimnion (fig. 22). The pH in the hypolimnion was generally lower during the summer when the lake was stratified and the hypolimnion was anoxic. The production of CO_2 from the decomposition of organic matter in the hypolimnion generally decreases the pH. The pH near the lake bottom ranged from 6.9 to 8.1.

Concentrations of sulfate in the epilimnion ranged from about 10 to 13 mg/L (fig. 19) from January to

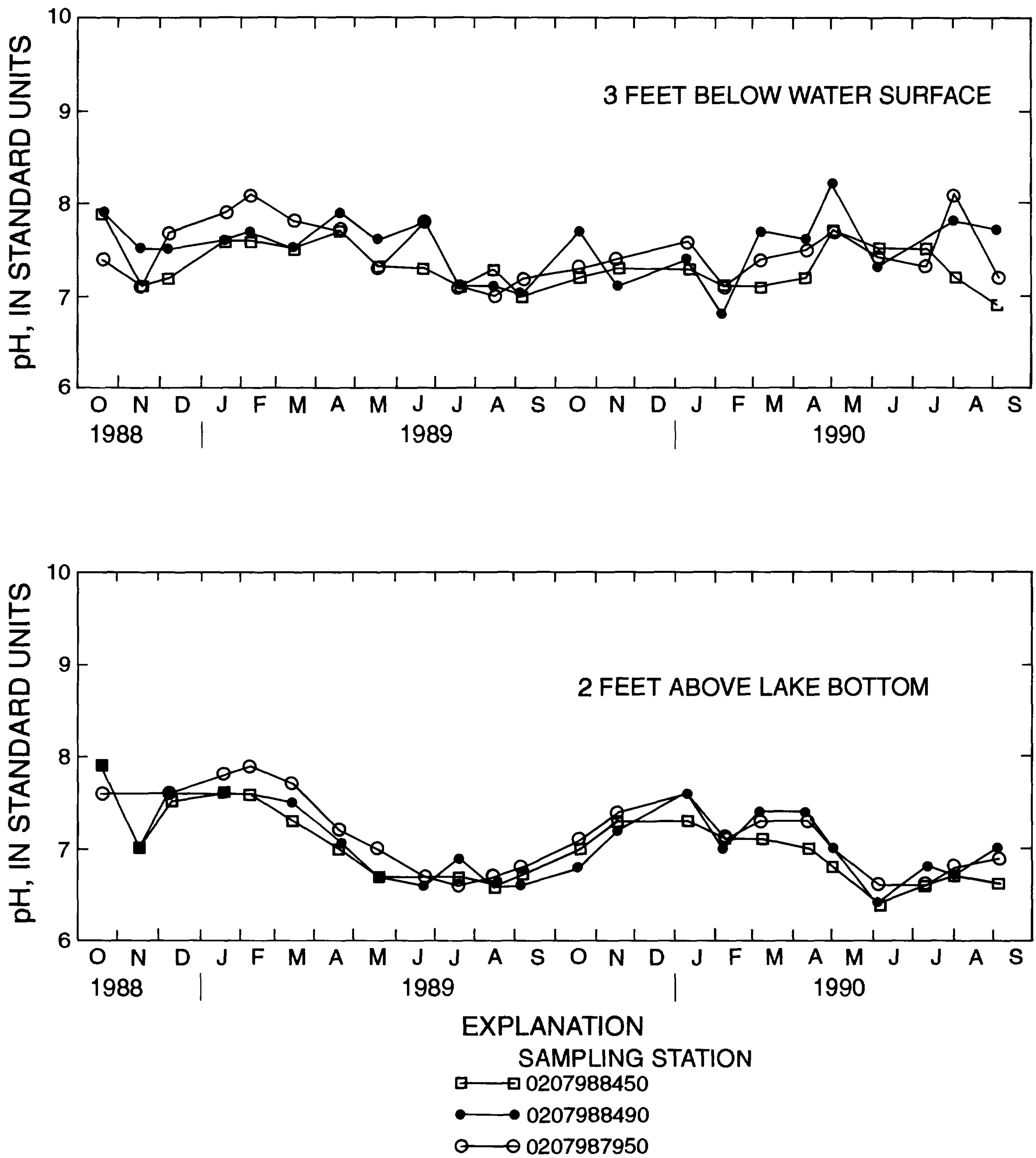


Figure 22. Relation of pH values between water samples at 3 feet below the water surface and 2 feet above the lake bottom from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

March 1989. Low streamflows could have contributed to the elevated concentrations of sulfate during the winter months of 1989. From April 1989 to September 1990, concentrations of sulfate in the epilimnion ranged from 5.7 to 10 mg/L, which is below the secondary maximum contaminant level of 250 mg/L (U.S. Environmental Protection Agency, 1990b).

The biogeochemical cycling of sulfate, along with iron and manganese, is related to the oxidation-reduction conditions in bottom sediments. In an oxidized environment, iron and manganese typically precipitate as carbonates, hydroxides, and sulfides. Concentrations of dissolved oxygen in the hypolimnion decline as oxygen is used by micro-organisms in the oxidation of organic matter. After the hypolimnetic oxygen supply is exhausted, alternate electron acceptors are used sequentially by the micro-organisms, based on the ease of reduction. Generally, nitrate is reduced first, followed by manganese compounds, iron compounds, sulfate, and CO_2. Nitrate cycling is discussed in a subsequent section. The reduction of carbonates and hydroxides typically results in elevated dissolved iron and manganese concentrations.

Concentrations of dissolved manganese near the lake bottom generally were less than 0.040 mg/L when the lake was destratified (fig. 23), whereas the concentrations generally exceeded 1 mg/L when the lake was thermally stratified and the hypolimnion was anoxic. Iron concentrations near the lake bottom also increased from less than 0.200 mg/L during the destratified period to greater than 1 mg/L during the stratified period. Although these concentrations are not a health risk, elevated concentrations of dissolved manganese and iron can increase water-treatment costs.

Concentrations of dissolved iron near the lake bottom at stations 8450 and 8490 declined from near 4 mg/L in July 1989 to less than 0.150 mg/L in August 1989. Above normal rainfall during July and August 1989 could have attributed to the decline in concentrations of dissolved iron in the hypolimnion. The higher streamflows increased concentrations of dissolved oxygen in the hypolimnion; thus, the hypolimnion changed from a reducing environment to an oxidizing environment.

Similar to the decline in concentrations of dissolved iron, concentrations of dissolved manganese also declined during August 1989 at stations 8450 and 8490. However, concentrations of dissolved manganese at station 7950 remained elevated during August 1989. Oxidation rates for manganese are slower than for iron; thus, manganese can exist in the soluble phase longer than iron when the environment changes from reducing to oxidizing. In addition, Burns and Rigler (1976) reported that dissolved manganese will remain soluble if the oxygen saturation is less than about 50 percent. Releases of hypolimnetic water from John H. Kerr Reservoir also could have contributed to the increase in concentrations of dissolved manganese at station 7950 during August 1989.

After iron and manganese compounds are reduced, sulfate is reduced to hydrogen sulfide by the microbial oxidation of organic matter. Sulfate concentrations in the hypolimnion were slightly decreased during the summer (fig. 23). A hydrogen sulfide odor was detected in several samples collected just above the lake sediments from July to September, coinciding with anoxic conditions in the hypolimnion.

Nutrients, Algae, Chlorophyll *a*, and Organic Carbon

Lake Gaston receives direct surface-water runoff from only 7 percent of the total drainage area. Approximately 93 percent of the Lake Gaston drainage area drains into John H. Kerr Reservoir prior to reaching Lake Gaston. John H. Kerr Reservoir, therefore, is a sink for a large percentage of nutrients and sediments.

Lake Gaston and Pea Hill Arm are classified as between oligotrophic and mesotrophic on the basis of total phosphorus concentrations. The mean concentrations of total phosphorus in the upper-water layer (0 to 12 ft below the water surface) at the lake stations ranged from 0.011 to 0.013 mg/L during the study period. Concentrations of total phosphorus in the upper-water layer were elevated during the spring (March, April, and May), primarily as a result of surface-water runoff (fig. 24). A similar seasonal increase in total-phosphorus concentrations also was noted at the inlet stations (fig. 10).

The range of concentrations of total phosphorus in the lower-water layer was similar to the range of concentrations in the upper-water layer. The oxidation of organic matter during anoxic conditions in the hypolimnion typically results in the release of soluble phosphorus from the bottom sediments. As the hypolimnion becomes anoxic, other compounds, such as nitrates and iron and manganese oxides are used by micro-organisms in the oxidation of organic matter. Phosphorus bound to iron, manganese, and other oxides is released in the hypolimnion as these oxides are reduced.

No large release of phosphorus from bottom sediments in Lake Gaston and Pea Hill Arm was measured during the study period (fig. 25). The range of total-phosphorus concentrations near the bottom at the lake stations was from 0.001 to 0.208 mg/L. The peak concentration of 0.208 mg/L observed at station 8450 in September 1989 could have been related to surface-water runoff from above-normal rainfall during July and August 1989. If the peak concentration is omitted, the

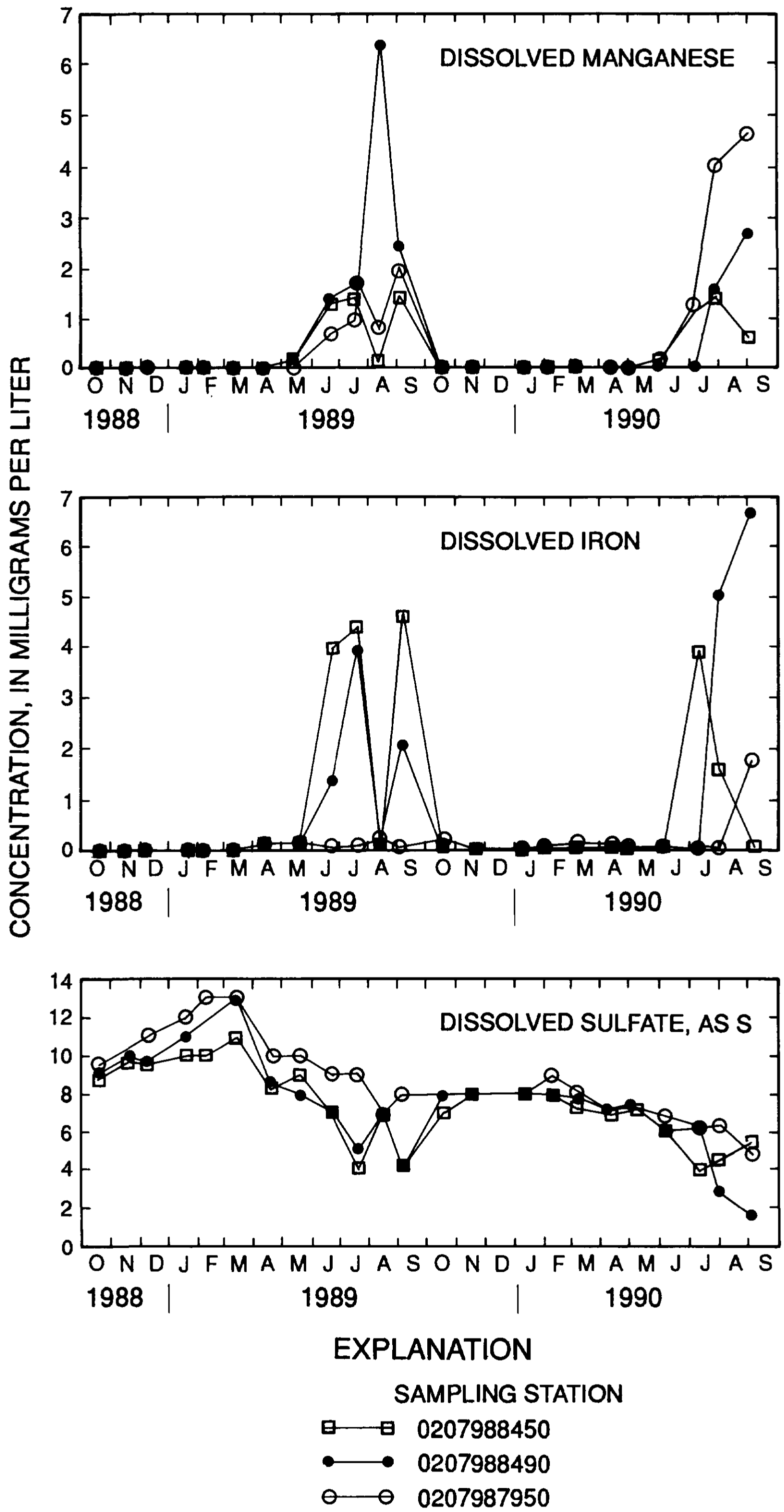


Figure 23. Concentrations of dissolved manganese, iron, and sulfate in water at 2 feet above the lake bottom from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

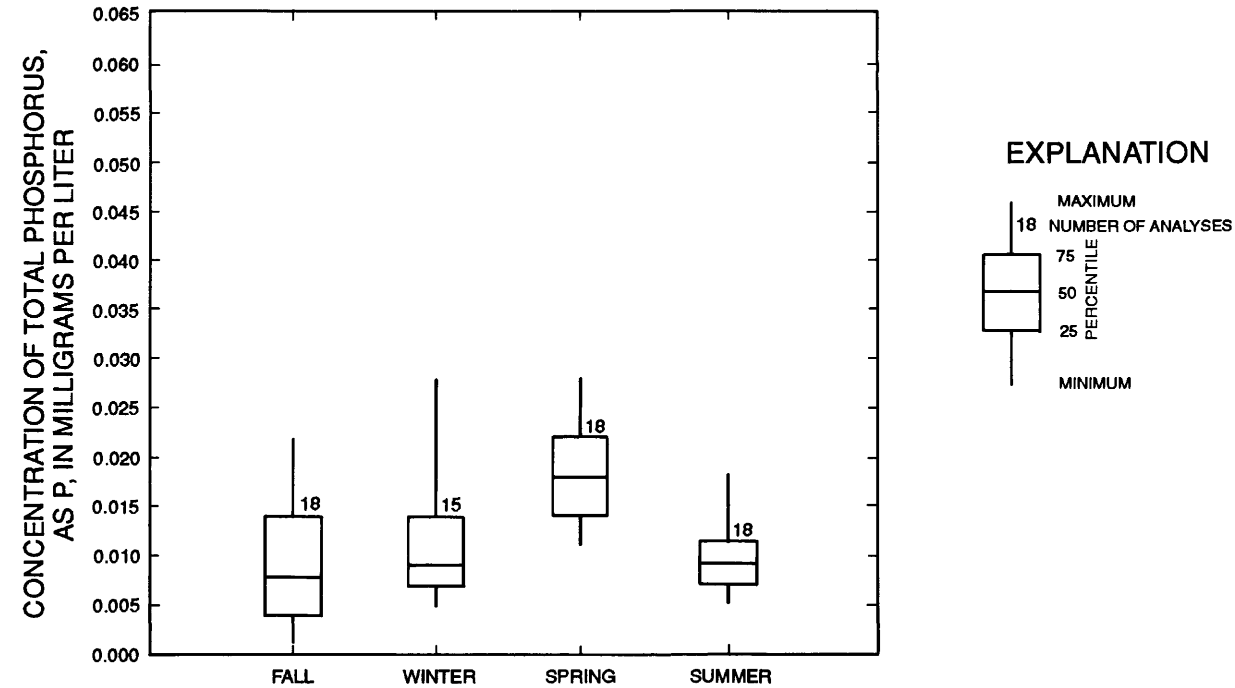


Figure 24. Seasonal concentrations of total phosphorus in water at 3 feet below the water surface from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

concentration range is from 0.001 to 0.036 mg/L. Anoxic conditions, similar to those recorded in September 1989, were recorded on other occasions, but concentrations of total phosphorus remained less than 0.040 mg/L. In addition, the hypolimnion at station 8450 was anoxic for a longer period during the summer of 1990 and no release of phosphorus was measured.

Concentrations of total organic nitrogen-plus-ammonia nitrogen in the reservoir stations varied little with season or depth, with mean concentrations ranging from 0.4 to 0.6 mg/L. During the winter, concentrations of total ammonia increased slightly in the upper-water layer. The small increase could have been related to mixing of the hypolimnetic waters, high in ammonia, with epilimnetic waters.

Concentrations of total ammonia in the hypolimnion generally increased as the reservoir became thermally stratified (figs. 12 and 25). Mean concentrations of total ammonia near the bottom ranged from 0.09 mg/L at station 7950, 0.14 mg/L at station 8450, to 0.18 mg/L at station 8490. Mean concentrations of total ammonia in the hypolimnion during the summer (June, July, and August) were 0.31 mg/L at station 8450, and 0.29 mg/L at station 8490, and 0.14 mg/L at station 7950.

Decomposition of organic matter settling from the epilimnion and the release of ammonia from the bottom sediments during anoxic conditions results in elevated concentrations of ammonia in the hypolimnion while the reservoir is stratified.

Increases in concentrations of total nitrite plus nitrate at 3 ft below the water surface were similar to the total nitrite plus nitrate pattern observed at the inlet stations and at station 9880. Concentrations typically were elevated during December, January, February, and March (fig. 26). During the study period, the mean concentration at 3 ft below the water surface was 0.044 mg/L at station 8450, 0.066 mg/L at station 8490, and 0.161 mg/L at station 7950. During the winter (December, January, and February), the mean concentration at 3 ft below the water surface was 0.071 mg/L at station 8450, 0.106 mg/L at station 8490, and 0.183 mg/L at station 7950. As previously discussed, the increase in concentrations of total nitrite plus nitrate is related to several factors: (1) mixing of hypolimnetic waters containing high ammonia concentrations and the subsequent conversion of ammonia to nitrate, (2) lack of denitrification in ground water during high base-flow periods, and (3) reduced biological activity in the reservoirs during the winter months.

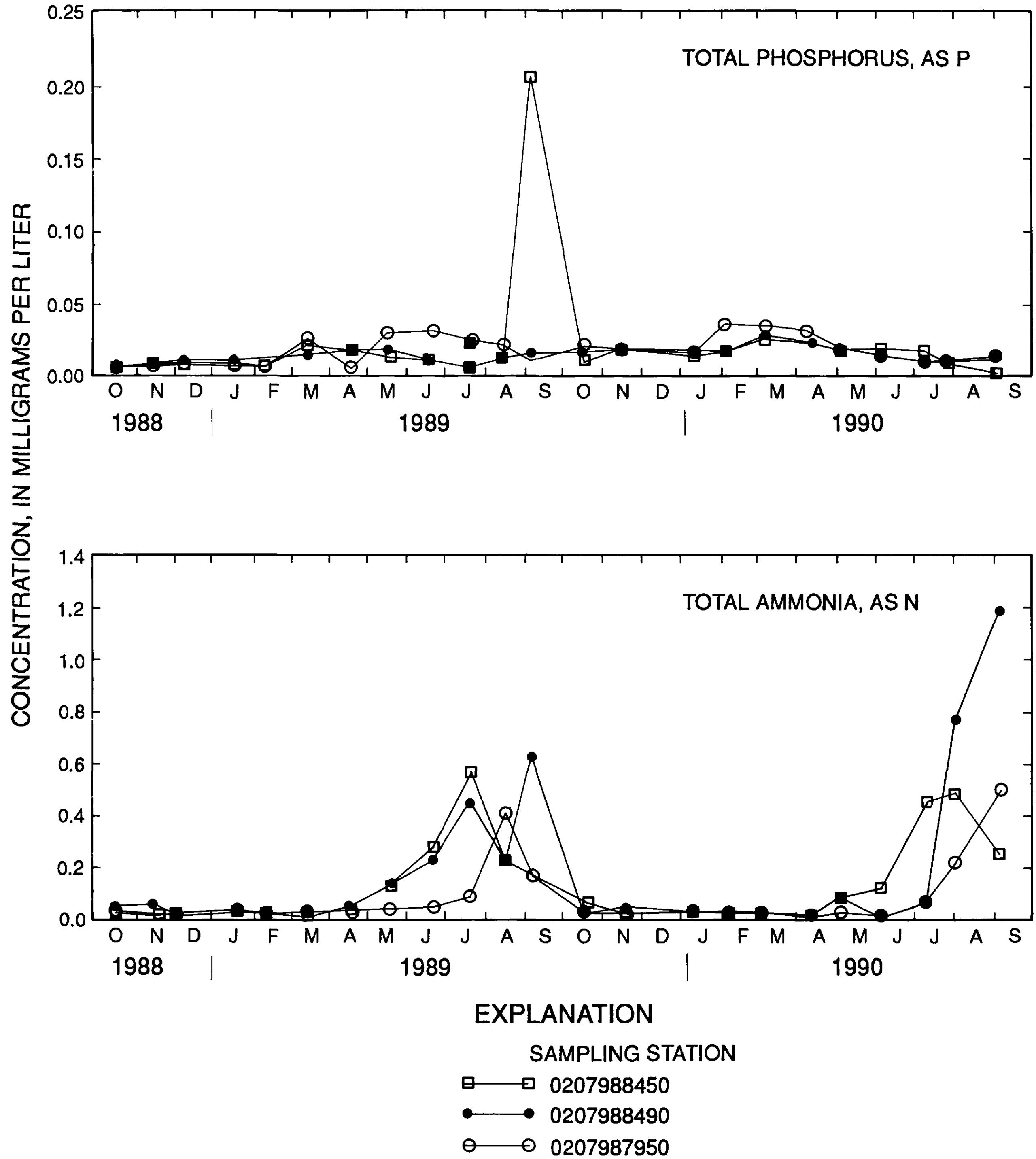


Figure 25. Concentrations of total phosphorus and ammonia in water at 2 feet above the lake bottom from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

During the study period, the mean concentration of total nitrite plus nitrate in the hypolimnion was 0.052 mg/L at station 8450, 0.071 mg/L at station 8490, and 0.186 mg/L at station 7950. Similar to concentrations in the epilimnion, concentrations of total nitrite plus nitrate varied seasonally and were generally elevated during the winter (December, January, and February) (fig. 26). Concentrations of total nitrite plus nitrate in the hypolimnion, however, decreased as the lake thermally stratified.

The disappearance of total nitrite plus nitrate in the hypolimnion coincides with the onset of anoxic conditions in the hypolimnion. Nitrate is used in the oxidation of organic matter in the absence of dissolved oxygen. Concentrations of total nitrite plus nitrate were at or near detection limits during July and August at stations 8450 and 8490.

Total nitrogen to total phosphorus ratios (by weight) for the lake stations at all depths sampled generally exceeded 60, indicating that algal growth in the Pea Hill Arm and Lake Gaston was potentially limited by phosphorus. Algal data support the phosphorus limitation because the algal population was dominated by the diatom species *Cyclotella stelligera*, *Cyclotella kutzingiana*, and *Synedra stelligera* and by *Ankistrodesmus falcatus*, a green alga. Blue-green algae typically become dominant when the total-nitrogen to total-phosphorus ratio is less than seven. Only one blue-green alga, *Aphanizomenon flos-aque*, was present at a percent density greater than or equal to 10 percent of the total-sample density. *Aphanizomenon flos-aque* exceeded 10 percent of the total-sample density only once (August 16, 1989) during the sampling period. Algal species at a percent density greater than or equal to 10 percent of the total-sample density in water from 3 and from 12 ft below the water surface are listed in table 8. All the species identified in samples collected at station 8450 are listed in table 9.

The mean concentrations of chlorophyll *a* at all depths sampled ranged from 3.4 to 15.8 μg/L. Concentrations of chlorophyll *a* were generally less than 30 μg/L, typical of mesotrophic lakes.

Concentrations of total organic carbon ranged from 3.1 to 7.4 mg/L near the lake bottom at the three lake stations. Total-organic carbon concentrations were generally higher at stations 8450 and 8490 than at station 7950 (fig. 27). The longer water-residence times at stations 8450 and 8490 allow the development of increased algal populations, thus the elevated concentrations of total organic carbon. Concentrations of total organic carbon near the bottom of the three lake stations vary seasonally (fig. 27). Concentrations of total organic carbon were elevated in the summer (June, July, and August), coinciding with elevated concentrations of ammonia. The increase in both total organic carbon and ammonia during the summer months indicates that algal matter may be settling from the epilimnion and decomposing in the hypolimnion.

Table 8. Phytoplankton comprising greater than or equal to 10 percent of the total sample density in water at 3 and 12 feet below the water surface from lake station 0207988450 in the Pea Hill Arm, Virginia, water years 1989-90

Water samples collected at 3 feet below the water surface
Cyclotella stelligera
Synedra radians
Ankistrodesmus falcatus
Ochromonas sp.
Rhodomonas minuta
Cyclotella kutzingiana
Cosmarium sp.
Aphanizomenon flos-aquae
Melosira ambigua
Syndera famelica
Water samples collected at 12 feet below the water surface
Cyclotella stelligera
Synedra radians
Ankistrodesmus falcatus
Ochromonas sp.
Cyclotella sp.
Cyclotella kutzingiana
Synedra rumpens
Aphanizomenon flos-aquae
Melosira ambigua

Bacteria

None of the samples collected at the lake stations exceeded the fecal-coliform bacteria standards for surface waters in Virginia. The maximum number of fecal-coliform colonies recorded during the study period was 123 col/100 mL at station 8490. Generally, fecal-coliform bacteria counts were less than 10 col/100 mL.

Table 9. Taxonomic composition of phytoplankton in water at 3 and 12 feet below the water surface from lake station 0207988450 in the Pea Hill Arm, Virginia, water years 1989-90

Phylum Chrysophyta

Anhnanthes exigua
Achnanthes flexella
Achnanthes lenceolata
Achnanthes minutissima
Asterionella formosa
Chromulina sp.
Chrysochromulina sp.
Chrysococcus rufescens
Coscinodiscus sp.
Cyclotella atomus
Cyclotella comta
Cyclotella kutzingian
Cyclotella meneghiniana
Cyclotella sp.
Cyclotella stelligera
Cymbella affinis
Cymbella angustata
Cymbella minuta
Dinobryon bavaricul
Dinobryon sertularia
Dinobryon sp.
Diploneis elliptica
Entomoneis ornata
Fragilaria brevistriata
Fragilaria construens
Fragilaria construens venter
Fragilaria crotonensis
Fragilaria pinnata
Gomphonema olivaceum
Kephyrion sp.
Kephyrion-like
Mallomonas sp.
Melosira ambigua
Melosira distans
Melosira granulata
Melosira italica
Navicula anglica
Navicula cryptocephala
Navicula gregaria
Navicula minima
Navicula minuscula
Navicula pupula
Navicula radiosa
Navicula sp.
Neidium sp.
Nitzschia acicularis
Nitzschia amphibia
Nitzschia capitellata
Nitzschia dissipata
Nitzschia palea
Nitzschia paleacea
Nitzschia sp.

Phylum Chrysophyta—Continued

Ochromonas sp.
Pinnularia sp.
Rhizosolenia eriensis
Stephanodiscus astraea minutula
Stephanodiscus hantzschii
Synedra delicatissima
Synedra famelica
Trachelomonas volvocina
Synedra radians
Synedra rumpens
Synedra sp.
Syndera ulna
Tabellaria fenestrata

Phylum Cyanophyta

Anabaena planctonica
Achnanthes flexella
Achnanthes lenceolata
Achnanthes minutissima
Asterionella formosa
Coscinodiscus sp.
Cyclotella atomus

Phylum Euglenophta

Euglena sp.
Trachelomonas hispida
Trachelomonas sp.
Trachelomonas volvocina

Phylum Chlorophyta

Ankistrodesmus falcatus
Chlamydomonas sp.
Chodatella wratislawiensis
Closteriopsis longissima
Coelastrum microporum
Cosmarium sp.
Crucigenia crucifera
Crucigenia quadrata
Crucigenia tetrapedia
Elakatothrix gelatinosa
Gloeocystis sp.
Nephrocytium sp.
Oocystis parva
Oocystis pusilla
Planktosphaeria gelatinosa
Quadrigula closterioides
Scenedesmus abundans
Scenedesmus denticulatus
Scenedesmus quadricauda
Scenedesmus sp.

Phylum Chlorophyta—Continued

Selenastrum minutum
Sphaerocystis schroeteri
Staurastrum sp.
Tetraedron fenestrata
Tetraedron caudatum
Tetraedron minimum
Tetraedron regulare
Tetraedron sp.
Tetrastrum staurogeniaeforme
Westalla linearis

Phyrrhophyta

Ceratium hirundinella
Cymnodinium sp.
Peridinium cinctum

Phylum Cryptophyta

Cryptomonas erosa
Cryptomonas sp.
Rhodomonas minuta

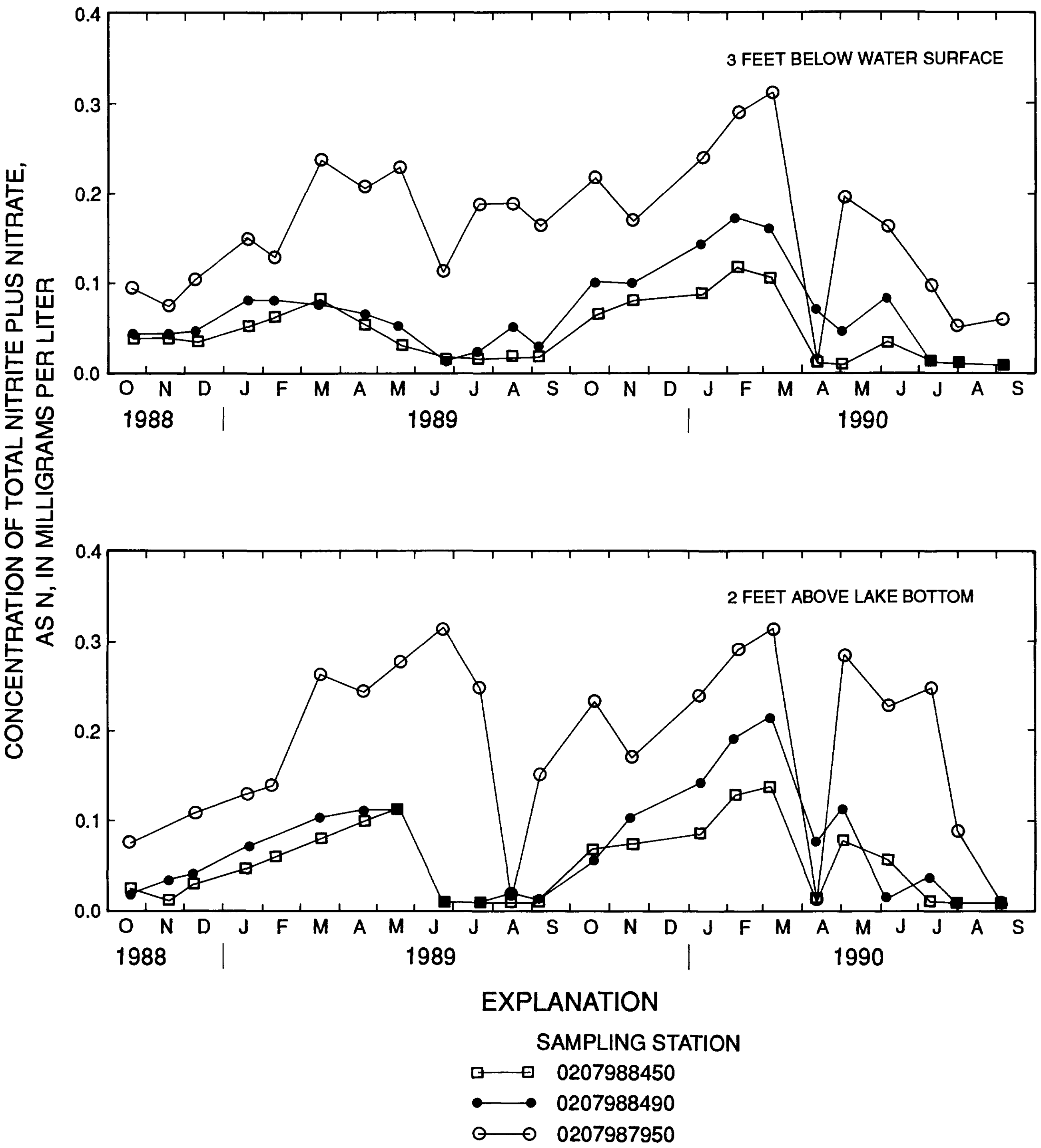


Figure 26. Relation of concentrations of total nitrite plus nitrate in water at 3 feet below the water surface and 2 feet above the lake bottom from lake stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

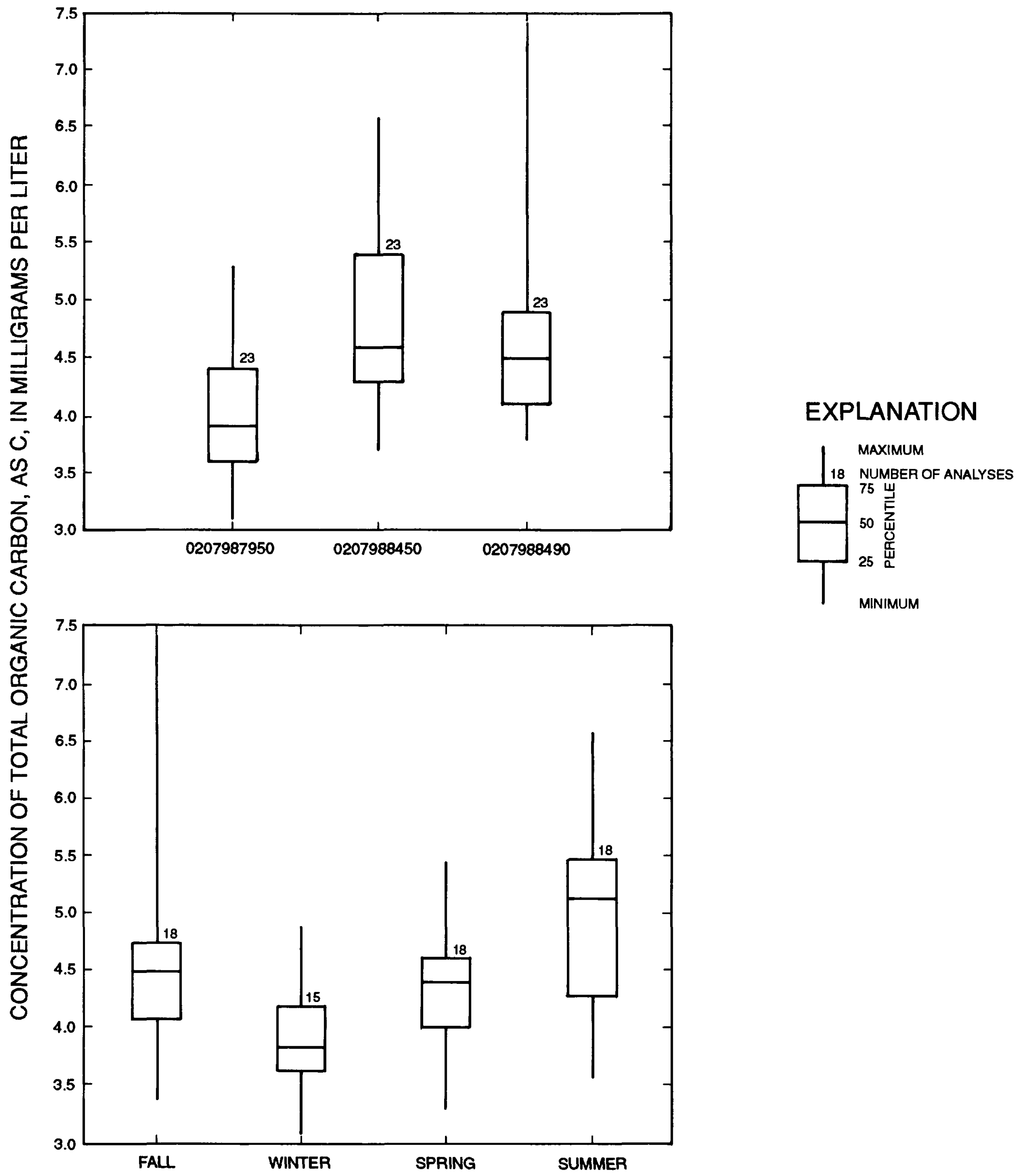


Figure 27. Summary statistics and seasonal variations of concentrations of total organic carbon in water samples collected at 2 feet from the lake bottom at stations 0207987950, 0207988490, and 0207988450 in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water year 1989-90.

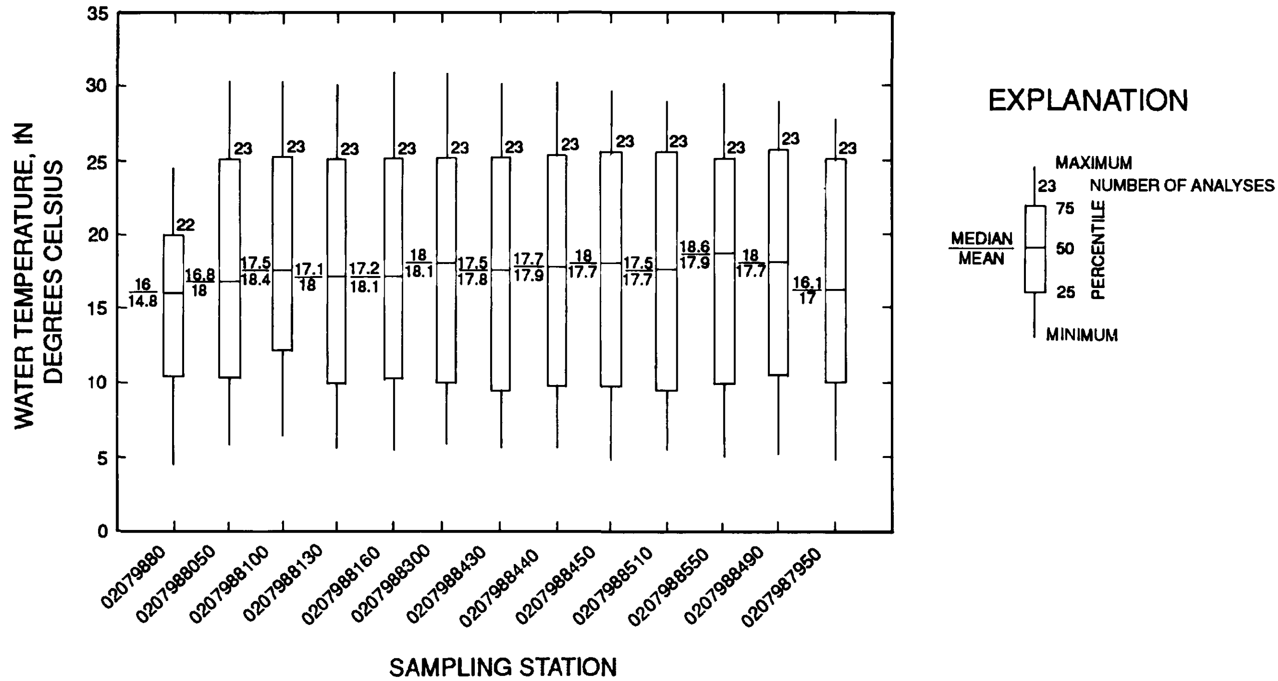


Figure 28. Summary statistics of water temperatures at 3 feet below the water surface at stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

Spatial Variability of Water Quality in the Pea Hill Arm of Lake Gaston

This section describes spatial differences and similarities in selected water-quality constituents in the Pea Hill Arm. The spatial differences are based on land-use data and statistical analysis of water-quality data for one tributary station, nine inlet stations, and three lake stations.

Spatial Differences in Selected Water-Quality Constituents

Spatial differences in water-quality constituents at 3 ft below the water surface were assessed statistically with the Wilcoxon signed-rank test (Helsel and Hirsh, 1992). The Wilcoxon (matched pairs) signed-rank test is a nonparametric test that determines if constituent values at one station differ from constituent values at another station. An alpha value of 0.05 was used to determine if constituent values were statistically different at two stations: *p* values less than 0.05 resulted in rejection of the null hypothesis that there was no difference in concentrations between the two stations tested. A nonparametric test was used because it does not require a normal distribution or equal variance between stations being compared. The matched-pairs version of the Wilcoxon test was used because the samples are hydrologically paired. Each month, water samples were collected during a 2-day period, thus representing the same hydrologic conditions.

The water temperature at the tributary station (9880) was lower than the inlet and lake stations (*p* value less than 0.05). The temperature ranges were similar at all stations, except station 9880 (fig. 28). The median water temperature at station 7950 was lower (*p* value less than 0.05) than at the other stations monitored, except station 9880. The lower water temperature at station 7950 is probably related to the release of cool hypolimnetic water from John H. Kerr Reservoir.

Specific conductance was higher at station 7950 than the other stations monitored in the Pea Hill Arm Basin (*p* value less than 0.05) (fig. 29). Specific conductance generally decreases with distance from the culvert separating the Pea Hill Arm from Lake Gaston (fig. 30). Median specific conductance at stations in the upper Pea Hill Arm (stations 9880, 8050, 8100, 8130, 8160, 8300, and 8430) ranged from 67 to 75 µS/cm, whereas in the southern part of the Pea Hill Arm and

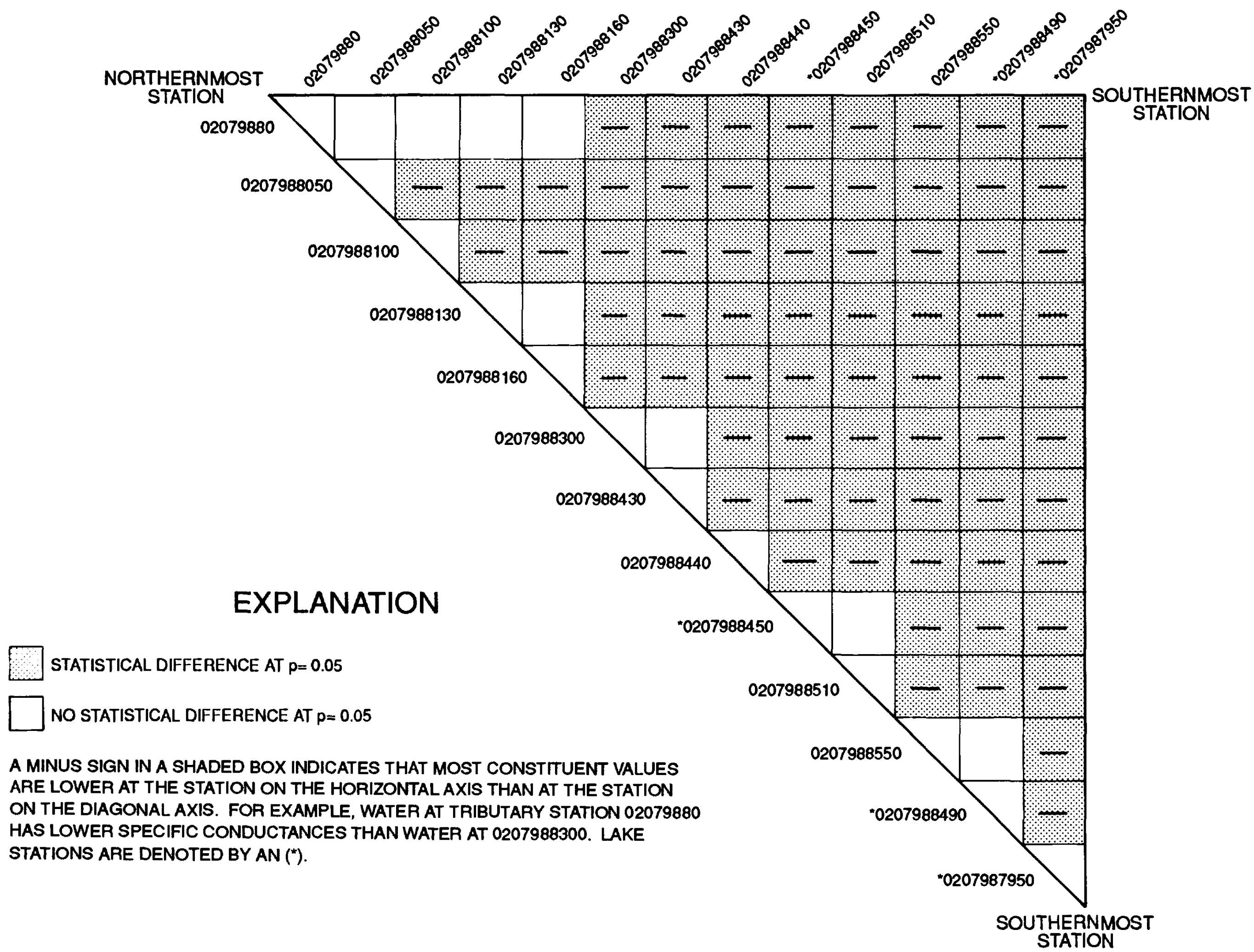


Figure 29. Results of Wilcoxon signed-rank tests for specific conductance at stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

Lake Gaston, median specific conductance ranged from 82 to 91 µS/cm. Differences between physiographic provinces in the drainage areas of Lake Gaston and Pea Hill Arm can explain the decreasing pattern in specific conductance. As discussed earlier, the Pea Hill Arm drainage area is entirely in the Piedmont Physiographic Province, whereas the Lake Gaston drainage area includes parts of the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces.

The decreasing pattern in specific conductance is evident of the mixing characteristics between the main body of Lake Gaston and the Pea Hill Arm. For example, stations 8490 and 8550, located near the culvert separating Pea Hill Arm and the main body of Lake Gaston, frequently mix with water from Lake Gaston; the mixing results in higher specific conductance values compared with values at stations 8160 and 8300, where water infrequently mixes with water from the main body of Lake Gaston (pl. 1).

Median and mean concentrations of total phosphorus were equal to or greater than 0.020 mg/L in the northern basin stations (stations 9880, 8050, and 8100), and less than 0.020 mg/L at the other stations (figs. 31 and 32). The smaller basin sizes, lack of a large perennial stream

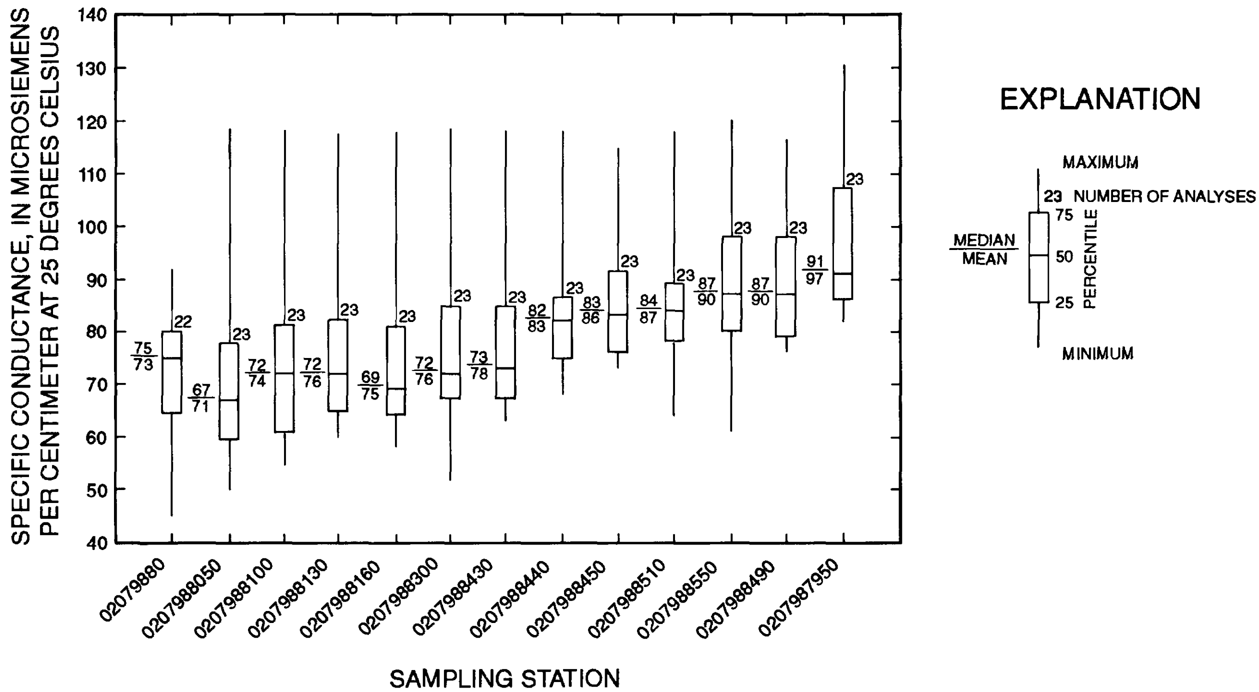


Figure 30. Summary statistics of specific conductance in water at 3 feet below the water surface from stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

like Pea Hill Creek, and interactions with the main body of Pea Hill Arm and Lake Gaston probably account for differences in concentrations in water at the stations in the northern and southern parts of the Pea Hill Arm Basin.

Although concentrations of total nitrite plus nitrate are low (less than 0.4 mg/L) in the Pea Hill Arm Basin and Lake Gaston, there is a concentration gradient (fig. 33). Unlike concentrations of total phosphorus, concentrations of total nitrite plus nitrate were generally higher at the inlet and lake stations in the southern part of the basin (8440, 8450, 8510, 8550, and 7950) (fig. 34) than at the tributary station. The median concentrations of total nitrite plus nitrate are at or near the detection limit (0.01 mg/L) for stations 8050, 8100, 8130, 8160, 8300, and 8430. The median concentrations of total nitrite plus nitrate ranged from 0.27 to 0.53 mg/L for stations 8440, 8450, 8510, and 8550. The elevated median concentrations at stations 8440, 8450, 8510, and 8550 are probably related to the mixing of water in Pea Hill Arm with Lake Gaston, which had a median concentrations of total nitrite plus nitrate of 0.164 mg/L.

The median concentration of total nitrite plus nitrate at station 9880 was different (p value less than 0.05) from all stations except station 7950 (figs. 33 and 34). Thus, conditions at station 7950 are like those of a riverine system during certain flow conditions. The erosion of thermal gradients during the summer at station 7950 indicates a temporary riverine environment. Station 7950 is affected by several land uses and point sources that also may account for the elevated concentrations of total nitrite plus nitrate.

Concentrations of total organic carbon decrease from station 8050 to 7950 (fig. 35). The median concentration of total organic carbon at station 8050 is 6.6 mg/L and at station 7950 is 3.8 mg/L. Prior to reaching Lake Gaston, most of the particulate-organic matter settles in John H. Kerr Reservoir. Low concentrations of total organic carbon at stations in the southern part of the basin are probably the result of the mixing of waters from Pea Hill Arm and Lake Gaston.

Characterization of Similar Water-Quality Zones

A clustering-analysis procedure (SPSS, 1988) was used to identify the presence or absence of longitudinal gradients in water quality. Constituents and properties used in the clustering analysis include water temperature,

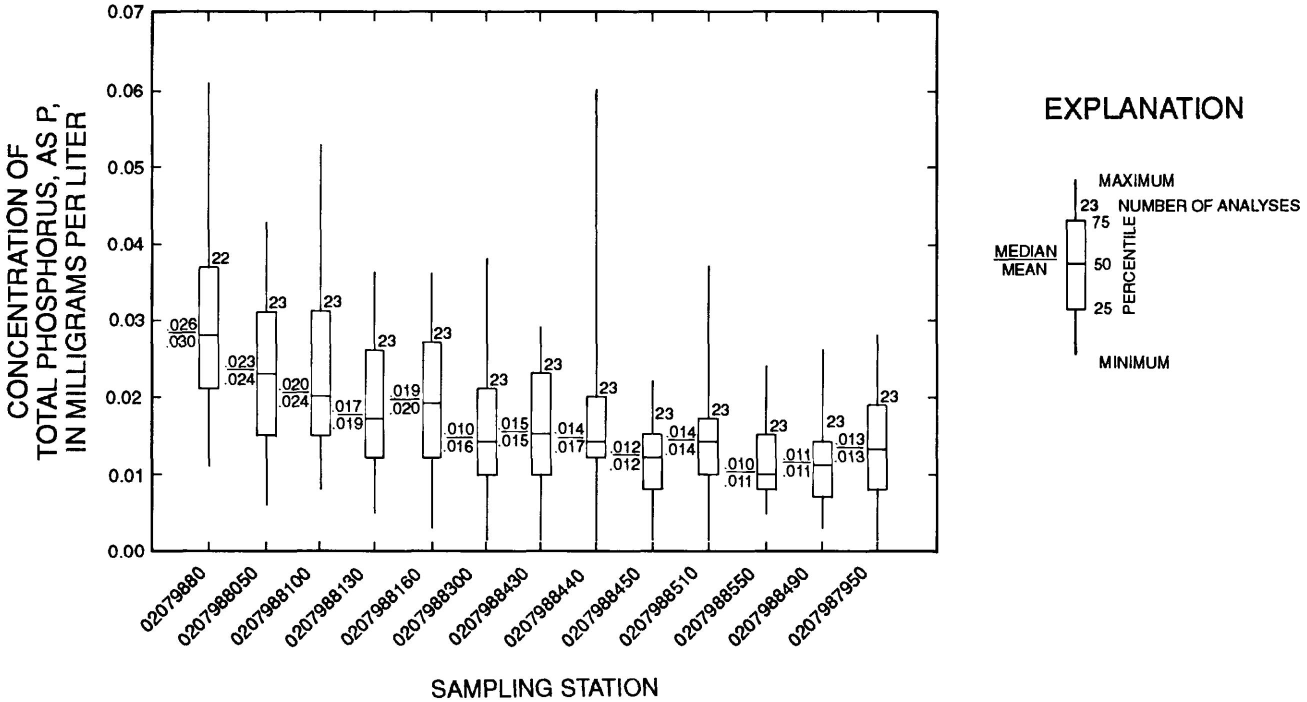


Figure 31. Summary statistics of concentrations of total phosphorus in water at 3 feet below the water surface from stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

specific conductance, dissolved oxygen, pH, total ammonia nitrogen, total organic-plus-ammonia nitrogen, total nitrite-plus-nitrate nitrogen, total phosphorus, total coliform bacteria, and fecal-coliform bacteria.

The station clusters are shown in figure 36. The station clusters roughly follow similar longitudinal variations as described by a heuristic model proposed by Thornton and others (1981). The model describes three distinct zones: riverine, transition, and lacustrine. Each zone typically has unique biological, chemical, and physical properties. A riverine zone is typically well mixed with velocities sufficient to transport fine-grained suspended particles. Sedimentation rates are generally higher in the transition zone. Gradations in light penetration also can be apparent as suspended particles settle to the bottom. The lacustrine zone is characterized by deeper light penetration, low sedimentation rates, and the development of thermal gradients in deeper waters.

Longitudinal gradients in the Pea Hill Arm Basin become apparent after four or five grouping stages. Summary statistics for five cluster groups are listed in table 10. Station 9880 (Group 1) is classified as a riverine zone with elevated concentrations of total phosphorus and total organic carbon. Stations 8050 and 8100 (Group 2) are classified as a transition zone between Pea Hill Creek and the main body of Pea Hill Arm. Stations 8130, 8160, 8300, 8430, 8440, 8450, 8510, and 8550 (Group 3) are classified as a lacustrine zone. Station 8490 (Group 4) represents a mixture of water from the Pea Hill Arm and Lake Gaston, dependent upon flow conditions in Pea Hill Arm and Lake Gaston. Although station 7950 (Group 5) is located in the main body of Lake Gaston, the operations at both the John H. Kerr Reservoir and Lake Gaston Dams can cause station 7950 to resemble a lacustrine zone during low-water release periods and a riverine zone during high-water release periods.

RELATION OF WATER QUALITY TO LAND USE

Land use in the Pea Hill Arm drainage basin is 75 percent forested. The effects of forestry practices on water quality are difficult to assess within a 2-year study because of the 25- to 30-year harvesting cycle. The type of harvesting methods, site preparation, land slope, and

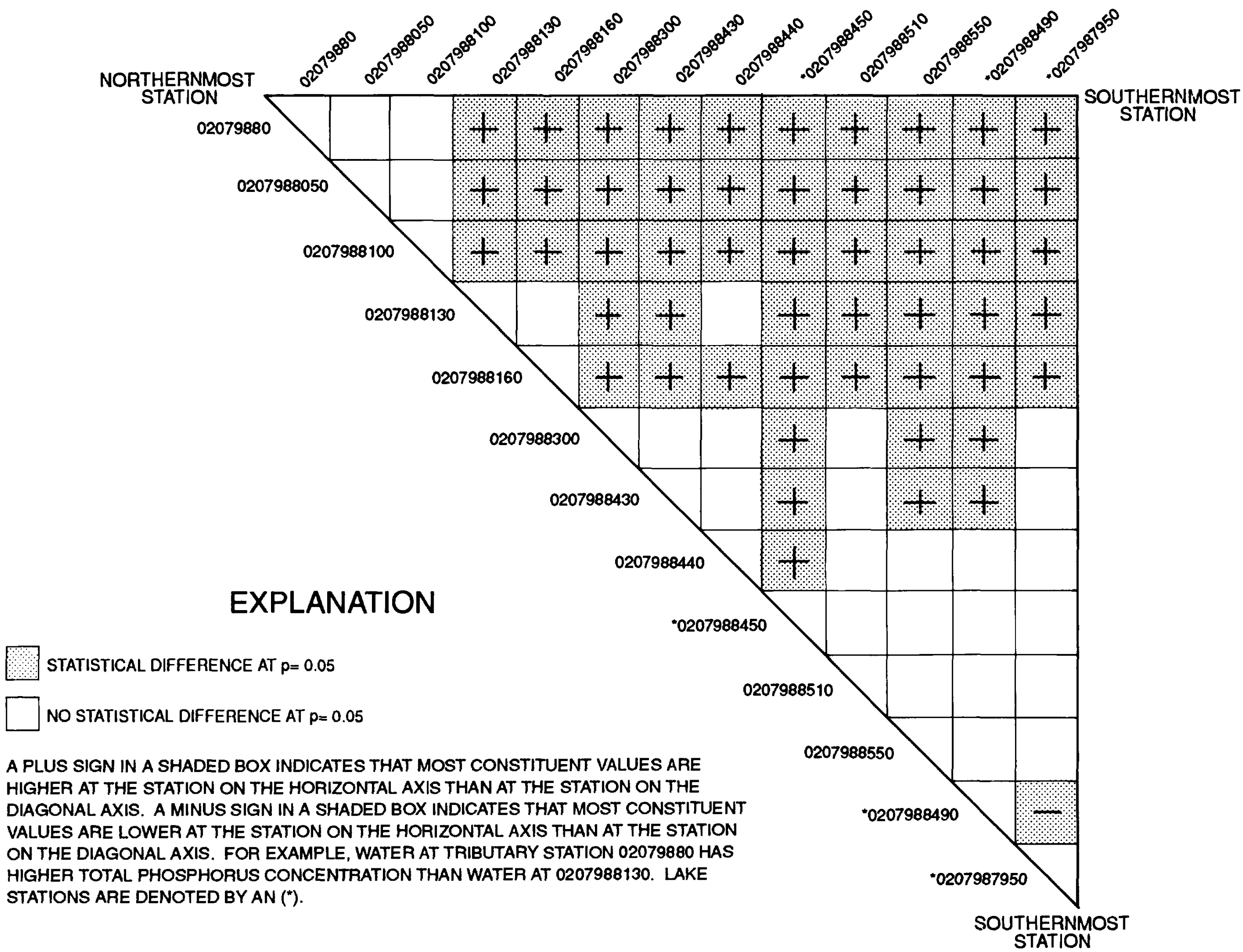


Figure 32. Results of Wilcoxon signed-rank tests for concentrations of total phosphorus at stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

location of the forest in relation to nearby streams or lakes also complicate the relation between forestry practices and water quality.

Drainage basins were delineated for the following 11 stations in the Pea Hill Arm Basin: one tributary station (9880), one lake station (8450), and nine inlet stations (table 7 and fig. 1). The sizes of the drainage basins range from 345 to 4,887 acres. Forest land in the 11 basins comprises 48 to 96 percent of the basins. Cropland, pasture/open land, and residential land were grouped together as developed land to assess potential effects of land use on water quality because of the small sizes of the basins and the small percentage of developed land within each basin.

Kendall's tau coefficients were calculated for the percentage of developed land and each of the water-quality constituents analyzed at the inlet stations (tables 3 and 5). No relation is present between the percentage of developed land and any of the water-quality constituents monitored.

The effects of land use on the quality of water are often exacerbated during high runoff periods. The highest discharge recorded during the sampling period was 19 ft^3/s on March 14, 1989. Thus, the March 14 and 15, 1989, sampling period was selected to represent the

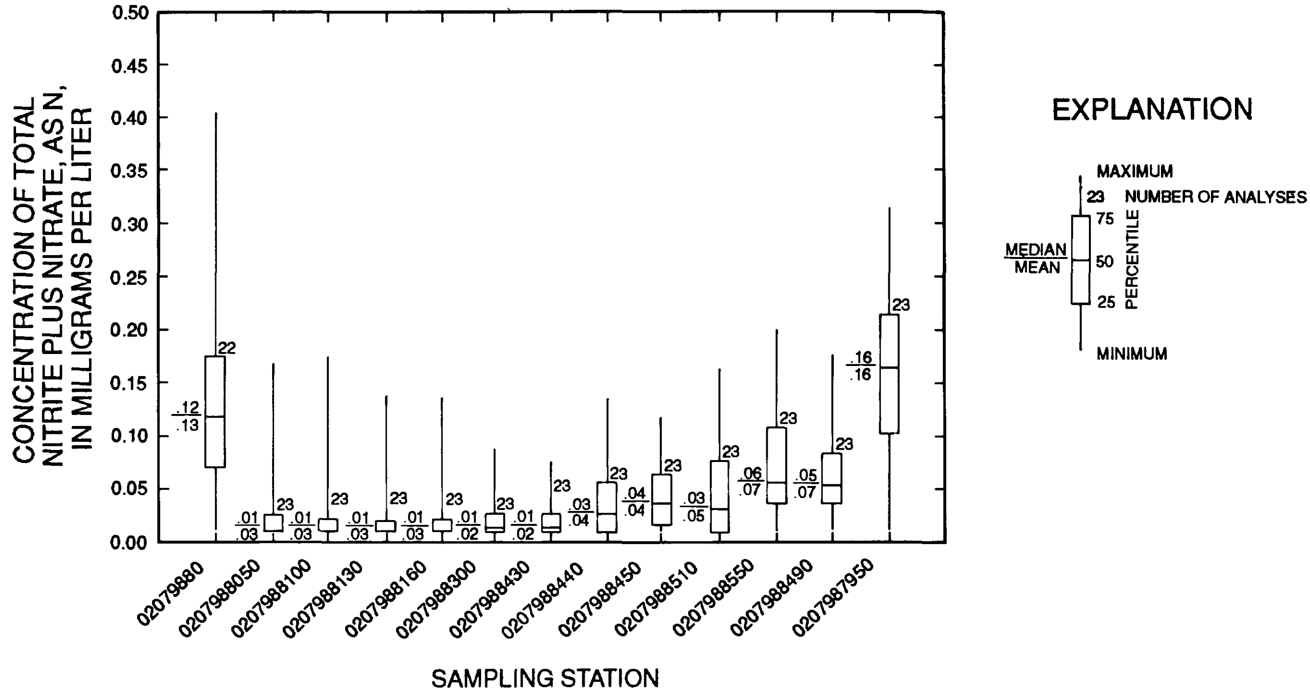


Figure 33. Summary statistics of concentrations of total nitrite plus nitrate in water at 3 feet below the water surface from stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

highest runoff period to determine the effects of land use on the quality of water at the tributary, inlet, and lake stations. Kendall's tau correlation coefficients were recalculated for land use and water-quality constituents. No correlation was evident between the percentage of developed land and water-quality constituents for the 11 basins in Pea Hill Arm during the high runoff period.

If data from stations 9880, 8450, and 8050 are deleted prior to the analysis, a relation is indicated between concentrations of total nitrite plus nitrate and developed land for the remaining stations (fig. 37). The Kendall's tau correlation coefficient for total nitrite plus nitrate is 0.69 with a p value of 0.02. Data from stations 9880, 8450, and 8050 were deleted because drainage characteristics at those stations are different from characteristics of the inlet stations. The remaining eight inlet station drainage basins represent primarily intermittent tributaries and inlet lake water environments. Stations 9880, 8050, and 8450 represent perennial streams, an inlet draining a perennial stream, and a lake environment, respectively.

During the March 1989 sampling period, the highest concentration of total nitrite plus nitrate of the eight inlet stations was at station 8100. The drainage basin for station 8100 also contains the most structures and the largest percentage of pasture/open land and residential land of the eight inlet drainage basins in the Pea Hill Arm. The correlation does not imply causal effects, only a relation between developed land use and total nitrite plus nitrate. As discussed earlier, concentrations of total nitrite plus nitrate were generally elevated at the inlet stations during the winter season. The correlation between the developed land use and total nitrite plus nitrate during the high runoff period in March also can be related to increased ground-water inputs during high base-flow periods.

SUMMARY

The City of Virginia Beach currently supplies water to about 400,000 people in southeastern Virginia. The City of Virginia Beach plans to withdraw 60 Mgal of water a day from the Pea Hill Arm of Lake Gaston to meet projected water needs to the year 2030.

Pea Hill Arm and Lake Gaston are monomictic. Thermal stratification typically began in May and continued through September during the study period. The hypolimnion became anoxic below a water depth of 25 ft

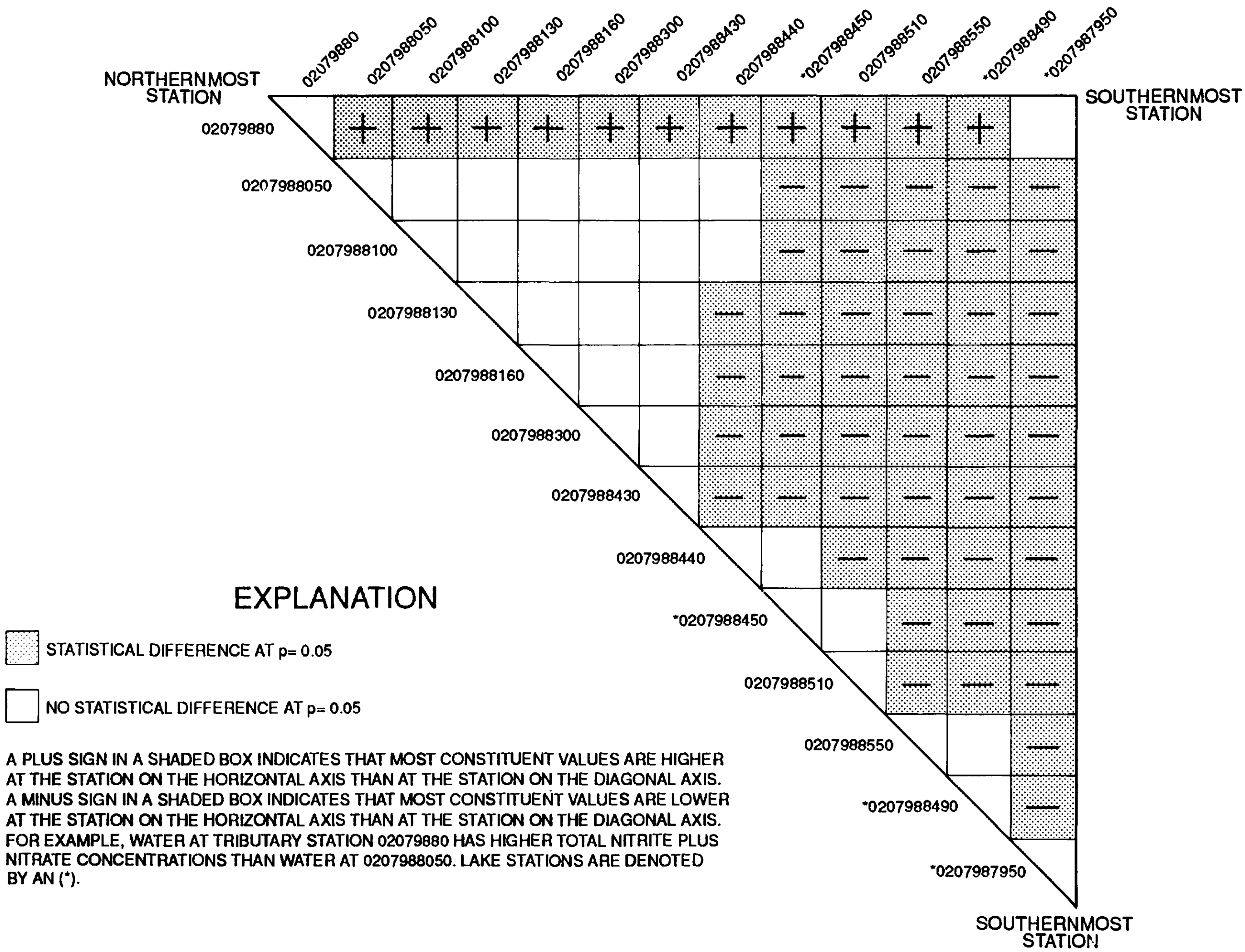


Figure 34. Results of Wilcoxon signed-rank tests for concentrations of total nitrite plus nitrate at stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

by June. Destratification generally began in late September as the epilimnion water temperature was lowered by cool air temperatures and wind-induced mixing. Pea Hill Arm and Lake Gaston are usually completely mixed by November.

The thermal stratification process differed at each of the three lake stations sampled. The culvert separating Pea Hill Arm and Lake Gaston increases the water-residence time in the Pea Hill Arm by preventing the rapid mixing of water between Lake Gaston and Pea Hill Arm. As a result of the increased water-residence time in Pea Hill Arm, water at station 8450 generally stratified earlier than at stations 8490 and 7950. Water at station 8490 represents a mixture of water from Pea Hill Arm and Lake Gaston; therefore, the development of thermal stratification at station 8490 depends on flow directions at the culvert. Thermal stratification of water at station 7950 depends on flows from John H. Kerr Reservoir and Lake Gaston Dams. Station 7950 can resemble a riverine environment when large amounts of water are released from the John H. Kerr Reservoir and Lake Gaston Dams. The release of large amounts of water from the dams during the summer also can erode the depth of thermal stratification.

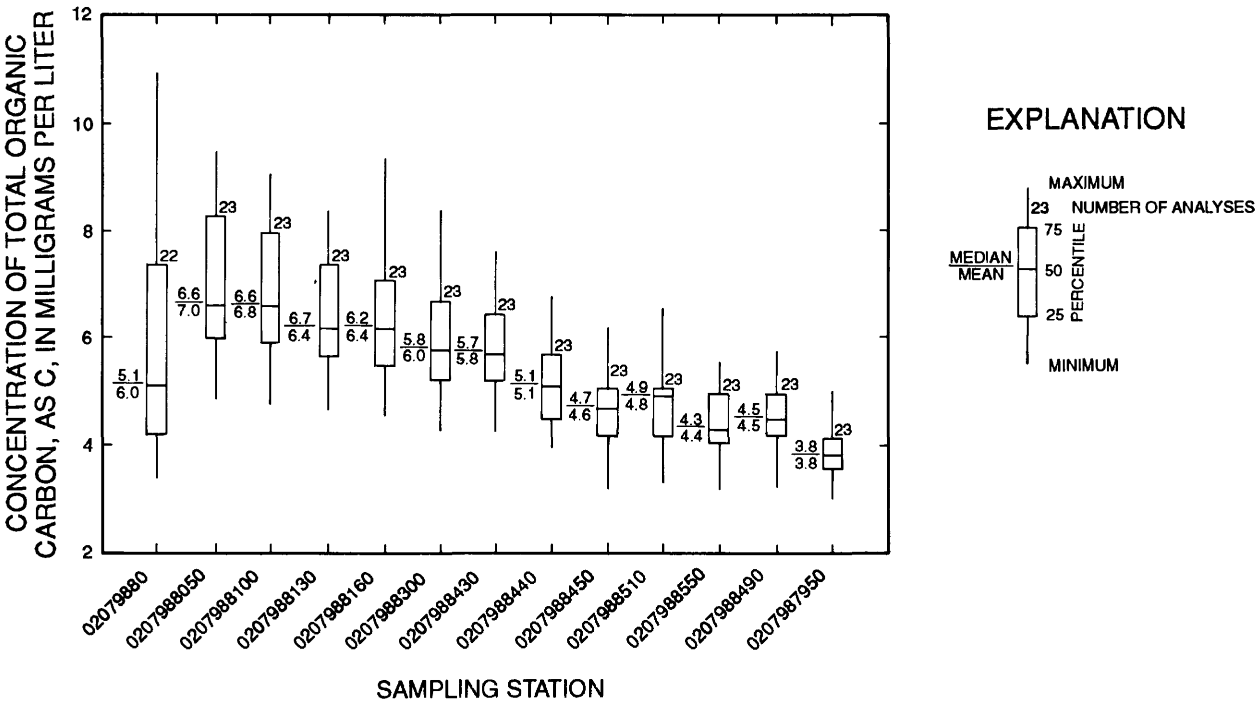


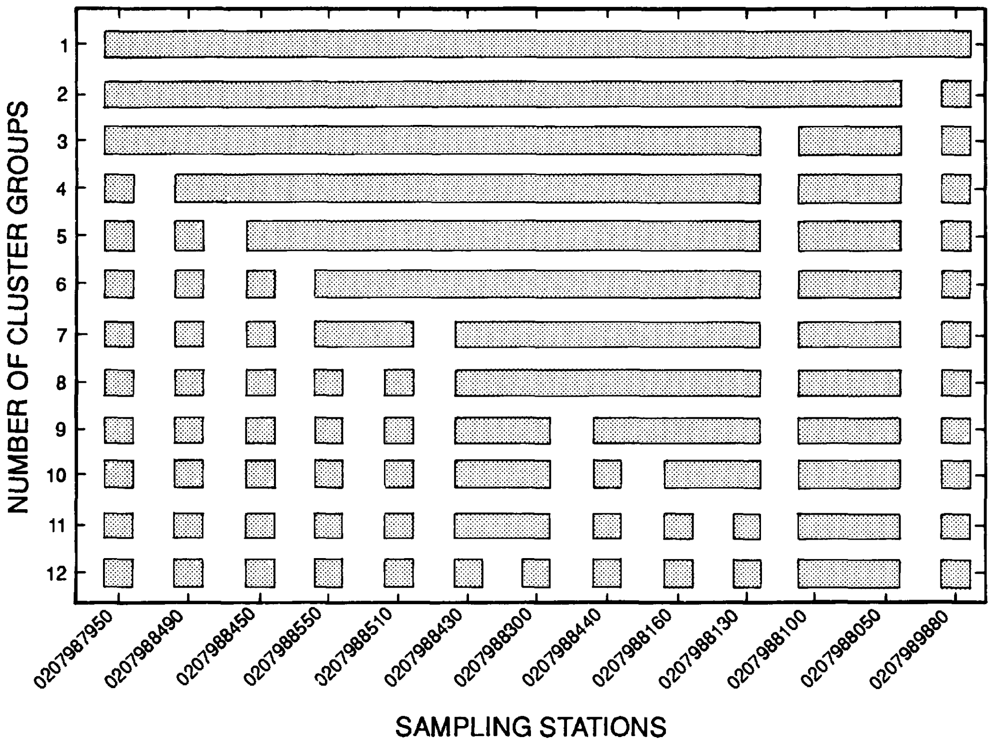
Figure 35. Summary statistics of concentrations of total organic carbon in water at 3 feet below the water surface from stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

Concentrations of dissolved manganese and iron in the hypolimnion commonly exceeded 1 mg/L and 4 mg/L, respectively, when the lake was stratified thermally and the hypolimnion was anoxic. Although these concentrations exceed the U.S. Environmental Protection Agency (1990b) secondary maximum contaminant levels, the concentrations decreased as the lake destratified.

Streamflows into Lake Gaston were below average for water year 1988. In water year 1988, streamflows at a stream-gaging station on the Dan River at Paces, Va., were 33 percent below the long-term mean annual streamflow. A specific conductance of 270 µS/cm recorded January 1989 is the maximum value recorded during the period of record (April 1979 to August 1990) at the Dan River at Paces, Va., sampling station. Low streamflows contributed to elevated specific conductances and elevated concentrations of sodium, calcium, magnesium, and alkalinity at the sampling stations in the Pea Hill Arm and Lake Gaston during October and November 1988. Elevated concentrations of sodium, chloride, and alkalinity during January and February 1989 were probably related to a combination of the natural factors associated with low streamflows and the application of salt to roads throughout the Lake Gaston and Pea Hill Arm drainage basins.

The Pea Hill Arm and Lake Gaston were classified as mesotrophic on the basis of the range of total-phosphorus, total organic-plus-ammonia nitrogen, and chlorophyll-*a* concentrations. Ratios of total nitrogen to total phosphorus (by weight) were typically greater than 7, which indicate that algal growth in the Pea Hill Arm and Lake Gaston are limited by phosphorus. The algal population at station 8450 was dominated by the diatoms *Cyclotella stelligera, Cyclotella kutzingiana,* and *Synedra stelligera* and by *Ankistrodesmus falcatus,* a green alga.

The fecal-coliform bacteria standard for surface waters in Virginia was exceeded only once during the study period, at tributary station 9880. None of the samples collected from the inlet or the lake stations exceeded the fecal-coliform bacteria standard. The maximum fecal-coliform colonies recorded during the study period was 470 col/100 mL at the inlet stations and 120 col/100 mL at the lake stations.



NOTE.-- The number of shaded boxes along each horizontal axis refers to the number of cluster groups. At two cluster groups, all stations are similar except station 0207989880.

Figure 36. Summary of clustering group analysis for stations in the Pea Hill Arm and Lake Gaston, Virginia and North Carolina, water years 1989-90.

No large release of phosphorus from the bottom sediments occurred during anoxic conditions in the hypolimnion in the Pea Hill Arm or Lake Gaston. The lack of a large phosphorus release can be attributed to the sediment and nutrient trapping efficiency of John H. Kerr Reservoir and the lack of a phosphorus source in the bottom sediments on the Pea Hill Arm and Lake Gaston.

The Pea Hill Arm drainage basin is predominately rural with 75 percent of the basin covered by forest land. Most of the forest land is managed for the production of pine trees. Drainage basins were delineated for 11 stations within the Pea Hill Arm Basin. The basins range in size from 345 to 4,887 acres. Forest land in the 11 basins comprises 48 to 96 percent of the basins. The percentage of developed land (cropland, pasture/open land, and residential land) in the 11 basins ranges from 7 to 39 percent. No statistical relations were determined between water-quality constituents and land uses in the Pea Hill Arm drainage basin, except during periods of stormwater runoff. A relation was determined between total nitrite plus nitrate during storms and developed land use among the inlet stations (except 8050). The Kendall's tau correlation coefficient is 0.69 with a p value of 0.02. The relation between the developed land use and total nitrite plus nitrate can be related to the increased ground-water inflows during high base-flow periods.

Differences in water-quality constituents at the tributary, inlet, and lake stations were mainly related to the mixing patterns between Lake Gaston and Pea Hill Arm, releases of water from the John H. Kerr Reservoir and Lake Gaston Dams, and streamflows and nutrients from Pea Hill Creek. Water-quality data were used to cluster similar stations. Five groups of stations were delineated. Station 9880 (group 1) is classified as a riverine zone with higher concentrations of total phosphorus and total organic carbon. Stations 8050 and 8100 (group 2) are classified as a transition zone between Pea Hill Creek and the main body of Pea Hill Arm. Stations 8130, 8160, 8300, 8430, 8440, 8450, 8510, and 8550 (group 3) are classified as a lacustrine zone. Station 8490 (group 4) represents a mixture of water from the Pea Hill Arm and Lake Gaston, dependent on flow conditions in Pea Hill Arm and Lake Gaston. Although station 7950 (group 5) is in the main body of Lake Gaston, the

Table 10. Summary statistics for selected water-quality constituents by cluster group, Lake Gaston, Pea Hill Arm, Virginia, and North Carolina

[°C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; --, no data]

Cluster group[1]	Water temperature (°C)	Specific conductance, (µS/cm)	Dissolved oxygen (mg/L)	pH (standard units)	Total ammonia (mg/L, as N)	Total organic plus ammonia nitrogen (mg/L, as N)	Total nitrite plus nitrate (mg/L, as N)	Total phosphorous (mg/L, as P)	Total coliform (col/100 mL)	Fecal coliform (col/100 mL)
Group 1										
Mean	14.8	73	8.9	--	0.4	0.03	0.13	0.030	2,180	397
Minimum	4.5	45	5.2	6.2	.0	.01	.01	.011	360	1
Maximum	24.5	92	11.8	7.2	1.0	.07	.40	.061	10,000	3,300
Group 2										
Mean	18.2	72	9.7	--	.6	.02	.03	.024	300	22
Minimum	5.8	50	6.9	6.5	.2	.01	.01	.006	8	1
Maximum	30.4	119	13.8	8.2	1.1	.05	.17	.53	2,900	230
Group 3										
Mean	17.9	82	9.7	--	.5	.02	.04	.016	324	20
Minimum	4.8	52	5.5	6.5	.0	.01	.01	.001	2	1
Maximum	30.8	120	14.6	8.0	.9	.10	.20	.060	5,700	470
Group 4										
Mean	17.7	90	9.9	--	.4	.03	.07	.011	140	10
Minimum	5.2	76	6.7	6.8	.2	.01	.01	.003	8	1
Maximum	28.7	116	13.8	8.2	.9	.22	.18	.026	580	123
Group 5										
Mean	17.0	97	9.5	--	.4	.02	.16	.013	144	13
Minimum	4.8	82	5.7	6.9	.1	.01	.01	.001	2	1
Maximum	27.7	130	13.9	8.1	.9	.04	.31	.028	1,300	120

[1]Cluster group 1–station 02079880
Cluster group 2–stations 0207988050 and 0207988100
Cluster group 3–stations 0207988130, 0207988160, 0207988300, 0207988430, 0207988440, 0207988450, 0207988510, and 0207988550
Cluster group 4–station 0207988490
Cluster group 5–station 0207987950

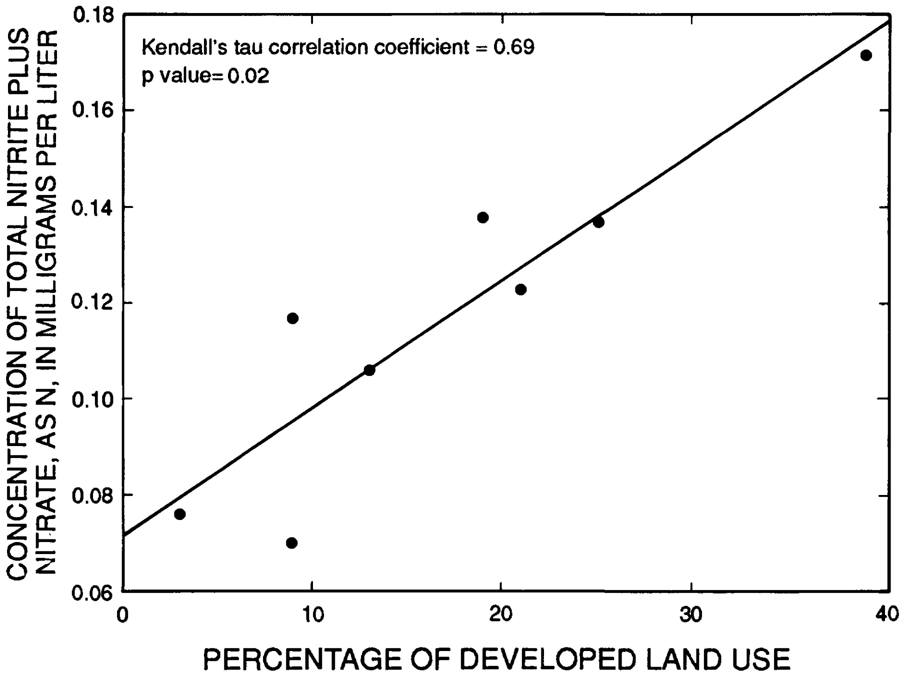


Figure 37. Relation between developed land use (crop land, residential land, and pasture/open land) and concentrations of total nitrite plus nitrate at inlet stations 0207988100, 0207988130, 0207988160, 0207988300, 0207988430, 020798440, 0207988510, and 0207988550, Virginia and North Carolina, during a storm-water runoff event on March 14 and 15, 1989.

operations at the John H. Kerr Reservoir and Lake Gaston Dams can cause station 7950 to resemble a lacustrine zone during low water-release periods and a riverine zone during high water-release periods.

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