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Hydrology and Water Quality of Little Cross Creek, Cumberland County, North Carolina, 1996–98

U.S. Geological Survey
Water-Resources Investigations Report 99-4284

U.S. Department of the Interior
U.S. Geological Survey

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Cover photograph: Terry Middleton, USGS Hydrologic Technician, measuring streamflow at a USGS streamgaging site in Little Cross Creek, Fayetteville, North Carolina. *Photograph taken by M.J. Giorgino.*

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Raleigh, North Carolina
2000

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CONVERSION FACTORS, TEMPERATURE, SEA LEVEL, SPECIFIC CONDUCTANCE, AND ABBREVIATIONS AND ACRONYMS

Multiply	by	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
acre-foot (acre-ft)	1,233	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($[ft^3/s]/mi^2$)	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Temperature may be converted between degrees Celsius (°C) and degrees Fahrenheit (°F) by using the following equations:

$$°C = 5/9\ (°F - 32)$$

$$°F = (1.8 \times °C) + 32$$

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.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C).

Abbreviations and Acronyms used in this report:

amsl	above mean sea level
APHA	American Public Health Association
ASF	automated segmented flow
BCF	bias correction factor
DENR	North Carolina Department of Environment and Natural Resources
EPT	Ephemeroptera, Plecoptera, and Trichoptera
mg/L	milligram per liter
mL	milliliter
mm	millimeter
MRL	minimum reporting level
N	nitrogen
NADP	National Atmospheric Deposition Program
NTU	nephelometric turbidity units
NWQL	U.S. Geological Survey National Water Quality Laboratory
P	phosphorus
PRESS	prediction error sum of squares
PWC	Public Works Commission of the City of Fayetteville
Q	streamflow
(ton/mi^2)/yr	ton per square mile per year
ton/yr	ton per year
USGS	U.S. Geological Survey
WY97	water year 1997

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ABSTRACT

Little Cross Creek is a small stream located in Cumberland County, North Carolina, in the Sand Hills area of the Coastal Plain Province. From August 1996 through August 1998, the U.S. Geological Survey collected streamflow, water-quality, and time-of-travel data at 10 sites in the Little Cross Creek Basin to assess ambient conditions and compute loads of suspended sediment, total nitrogen, total phosphorus, and total organic carbon.

Streamflows in the Little Cross Creek Basin responded to climatic factors and to human activities such as water withdrawals and controlled releases from impoundments. Peak streamflows were observed during the passages of Hurricane Fran in September 1996 and Hurricane Josephine in October 1996. Streamflows generally were lowest during the summer and early fall of 1997, reflecting drought conditions associated with a prevailing El Niño. At most sites, average streamflow per unit drainage area, or yield, was higher than yields reported previously for the Sand Hills. High yields may have resulted from unidentified inputs of water to the study basin or from underestimation of the contributing drainage area.

Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake, four impoundments of Little Cross Creek, notably influence hydrology and water quality in the basin. Streamflow records indicate that these impoundments dampen peak stormflows and delay the downstream release of stormwater. Time of travel also is affected by seasonal stratification in the reservoirs. In general, sites downstream from reservoirs have lower concentrations of suspended sediment, turbidity, and total phosphorus than sites upstream from reservoirs or sites that receive stormwater runoff.

Few water-quality problems were observed in the Little Cross Creek Basin for the constituents that were sampled. However, fecal coliform bacteria commonly exceeded 200 colonies per 100 milliliters at two of the seven monitored sites during the study. Relatively high concentrations of specific conductance, total phosphorus, and total ammonia plus organic nitrogen were observed in Clark Pond Creek, a tributary to Little Cross Creek.

Loads and yields of suspended sediment, total nitrogen, total phosphorus, and total organic carbon were computed for the period from October 1996 through September 1997. The highest suspended-sediment yield (230 tons per square mile per year) occurred upstream from Bonnie Doone Lake, probably because there were no impoundments upstream from this site to intercept sediment. Sediment yields at the remaining Little Cross Creek sites were low relative to yields reported from other urban basins in North Carolina. Downstream from Kornbow Lake, yields of suspended sediment (9.50 tons per square mile per year) and total phosphorus (0.011 ton per square mile per year) were very low. Clark Pond Creek had the highest yields of total phosphorus (0.081 ton per square mile per year) and total organic carbon (11.5 tons per square mile per year). However, total phosphorus yields at all of the Little Cross Creek sites generally were

lower than yields measured in other urban basins in the State.

Comparison of inflow and outflow loads for the four Little Cross Creek reservoirs from October 1996 through September 1997 indicated that Bonnie Doone Lake trapped 92 percent of incoming sediment and 37 percent of incoming total phosphorus. Kornbow Lake trapped 57 percent of incoming sediment and 77 percent of total phosphorus inputs. Nitrogen was not effectively trapped by any of the reservoirs. An influx of sediment, total phosphorus, and total organic carbon was noted at a site downstream from Mintz Pond, and may have resulted from stormwater discharge from the U.S. Highway 401 bypass or from additional, unidentified sources in the watershed downstream from Kornbow Lake.

INTRODUCTION

In 1995, surface water provided 83 percent of the public water supply to residents of Cumberland County, North Carolina (fig. 1; Walters, 1997). The City of Fayetteville, which is the primary municipality and county seat of Cumberland County, obtains about 40 percent of its public drinking water from the Little Cross Creek watershed and the remaining 60 percent from the Cape Fear River. Both of these water-supply sources are located within the Cape Fear River Basin (fig. 1).

Little Cross Creek is a valuable water-supply source for the City of Fayetteville; however, no comprehensive studies of the watershed have been performed. In 1996, the U.S. Geological Survey (USGS) entered into a cooperative agreement with the Public Works Commission (PWC) of the City of Fayetteville to investigate the hydrology and water quality of the Little Cross Creek Basin (fig. 2). This investigation was conducted as part of the USGS Federal-State Cooperative Program, which is designed to collect and disseminate relevant water-resource information and to advance hydrologic science and knowledge. This investigation provides heretofore lacking information regarding hydrology and water quality in an urban setting of the Sand Hills region of North Carolina.

Streamflow, time-of-travel, and water-quality data were collected in the Little Cross Creek Basin from August 1996 through August 1998. Results were analyzed to interpret ambient hydrologic and water-quality conditions in the Little Cross Creek watershed and to assess loads of nutrients and sediment at several locations.

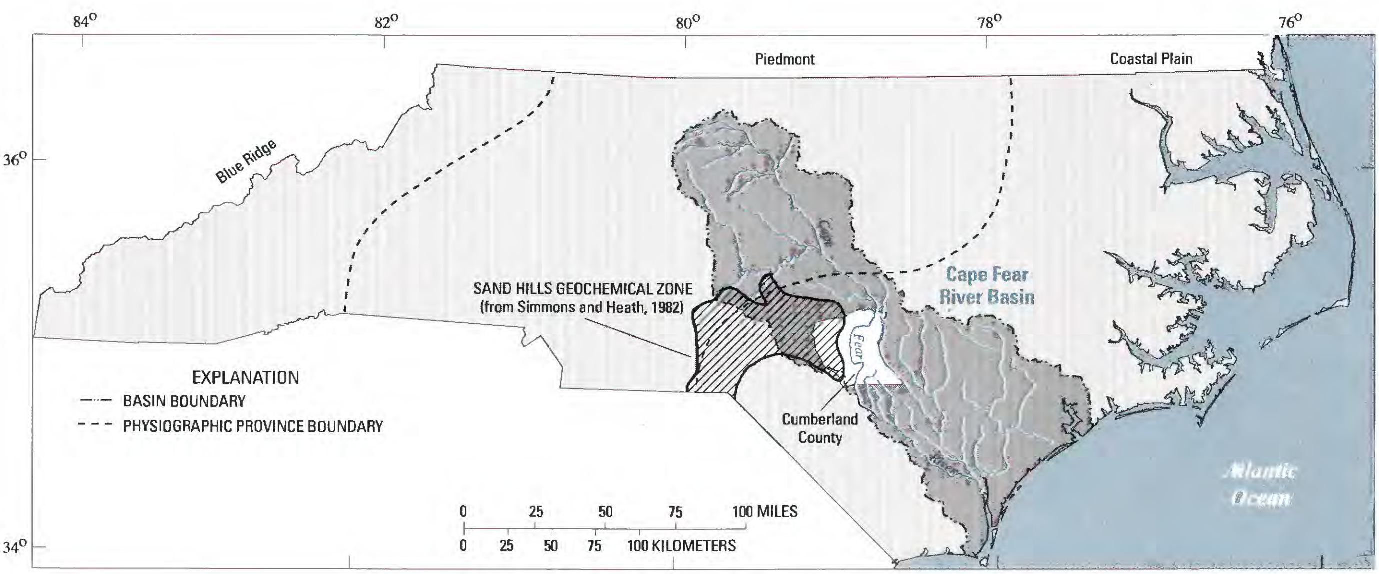

Figure 1. Location of Cumberland County, Sand Hills geochemical zone, Cape Fear River Basin, and physiographic provinces in North Carolina.

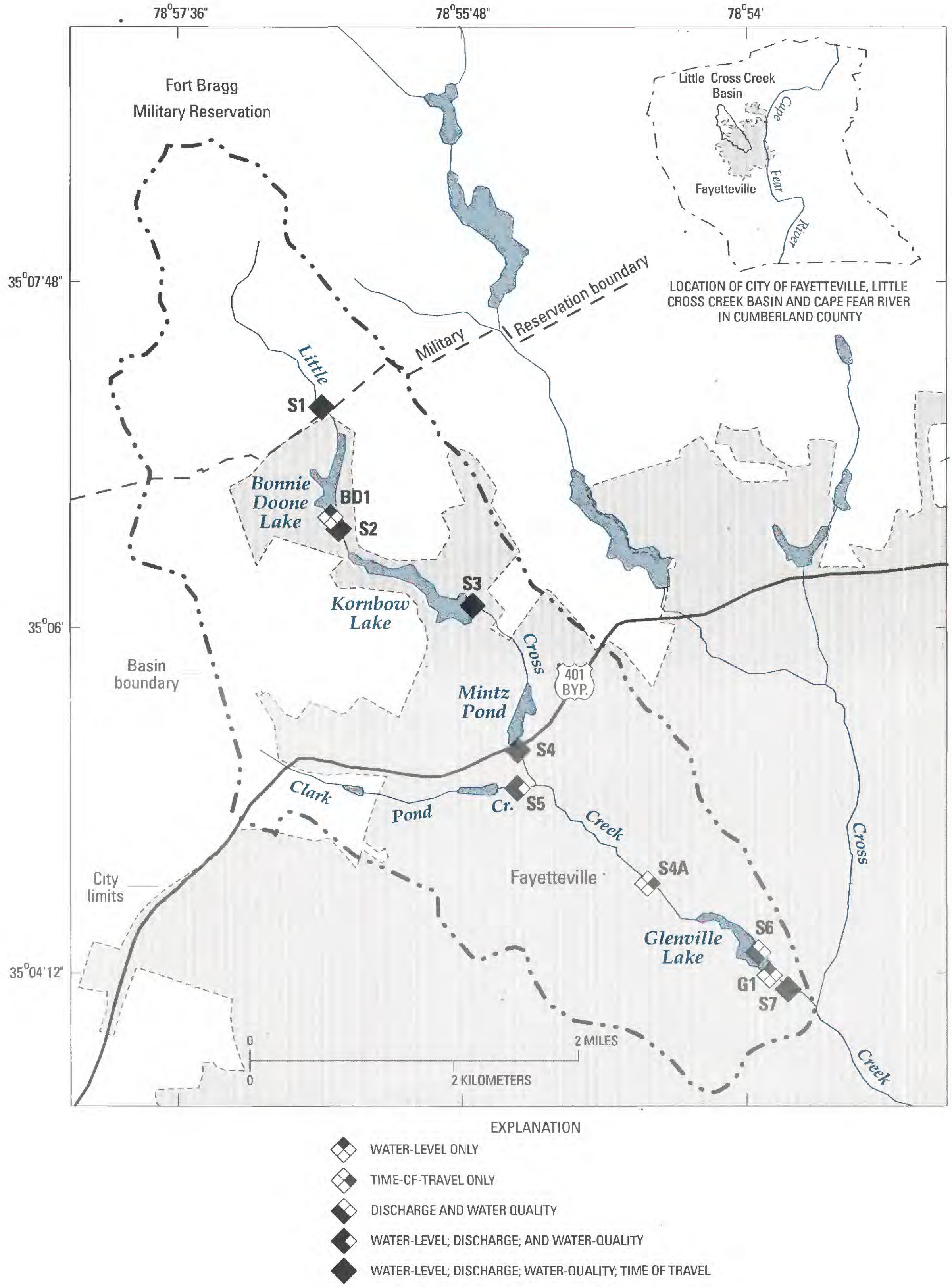

Figure 2. Data-collection sites in the Little Cross Creek Basin in Cumberland County, North Carolina.

Purpose and Scope

This report provides a baseline assessment of hydrology and water quality in the Little Cross Creek Basin in Cumberland County, North Carolina. The report documents data-collection methods, describes ambient hydrologic and water-quality conditions, and presents estimated sediment and nutrient inputs to and outputs from the four Little Cross Creek reservoirs. Time-of-travel characteristics in Little Cross Creek also are discussed. Detailed streamflow and water-quality data collected during the investigation are presented in supplementary tables at the end of the report.

Hydrologic data collected by the USGS include water levels at two reservoir sites and water levels and streamflow at six stream sites for the period from August 1996 through mid-December 1997. Additional records of pumpage into Glenville Lake from Cross Creek and withdrawals from Glenville Lake into the Glenville Water Plant were obtained from the PWC for the same period. Precipitation and evaporation data were obtained from an independently operated National Weather Service site in Fayetteville. Finally, a series of dye-tracer studies was conducted from April 1997 through August 1998 to characterize time of travel in Little Cross Creek under different streamflow conditions.

Water-quality data were collected at seven sites from October 1996 through January 1998. Results are summarized in this report for water temperature, dissolved oxygen, pH, specific conductance, fecal coliform bacteria, turbidity, suspended sediment, nitrogen and phosphorus species, and total organic carbon. Seasonal and spatial patterns of water quality are described and, when applicable, conditions are compared to prevailing water-quality standards. Loads of suspended sediment, nitrogen, phosphorus, and total organic carbon for the period from October 1996 through September 1997 are presented for the seven water-quality sites. Loads from unmonitored areas of the Little Cross Creek Basin also were computed to estimate total inputs to and exports from Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake. Finally, trapping efficiencies of these four reservoirs for sediment, nutrients, and organic carbon are discussed.

Description of Study Area

The study area is located entirely in Cumberland County in southeastern North Carolina (fig. 1). Cumberland County has a surface area of 661 square miles (mi^2). The climate is hot and generally humid during the summer months, with daily average temperatures approaching 80 degrees Fahrenheit (°F). Winters are relatively brief but moderately cold, with average daily temperatures of about 45 °F. Precipitation is evenly distributed throughout the year and averages about 47 inches (in.) per year (National Oceanic and Atmospheric Administration, 1996).

The estimated population of Cumberland County in 1998 was 284,629 (U.S. Bureau of the Census, 1998). The northwestern corner of Cumberland County is part of the U.S. Army Fort Bragg Military Reservation, which was established in 1917. The City of Fayetteville is the largest municipality and the county seat. Fayetteville is a regional trade center that supports a diversified economy including service industries, retail establishments, and manufacturing industries that produce farm chemicals, apparel and other textiles, food products, and wood and fabricated metal products (U.S. Bureau of the Census, 1998).

Little Cross Creek, which is in the Cape Fear River Basin (fig. 1), originates within the Fort Bragg Military Reservation and flows in a southeasterly direction to its confluence with Cross Creek near the center of Fayetteville. Little Cross Creek is impounded in four places—Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake (fig. 2). These reservoirs were constructed between 1909 and 1925, and range in size from about 15 to 47 acres (table 1). A water-intake structure is located in Glenville Lake near the dam. The three upstream reservoirs—Bonnie Doone Lake, Kornbow Lake, and Mintz Pond—provide water storage. Releases from the three upstream reservoirs occasionally are managed to augment withdrawals from Glenville Lake.

Little Cross Creek and its four reservoirs primarily are used for water supply and storage for the City of Fayetteville. The Fayetteville PWC operates the Glenville Water Plant and is the largest public-water supplier in Cumberland County, supplying more that 170,000 customers in 1999 (U.S. Environmental Protection Agency, 1999). Little Cross Creek supplies approximately 40 percent of the drinking water for PWC customers.

Table 1. Morphometric characteristics and estimated retention times of the Little Cross Creek reservoirs

Reservoir name (fig. 2)	Spillway elevation[a] (feet above mean sea level)	Surface area[a] (acres)	Volume[a] (acre-feet)	Theoretical average retention time, October 1996–September 1997[b] (days)
Bonnie Doone Lake	172.8	21.20	149.66	13
Kornbow Lake	159.2	47.09	341.39	81
Mintz Pond	133.8	15.56	53.57	2.5
Glenville Lake	113.1	37.12	230.48	6.6

[a]Source: Giorgino and Strain (1999).

[b]Computed as reservoir volume divided by average outflow; assumes reservoirs are completely mixed.

The Little Cross Creek watershed encompasses less than 10 square miles (mi^2) and drains only 1.5 percent of Cumberland County. It should be noted that this watershed boundary (fig. 2) represents the land-surface divide according to the elevation contours on USGS 7-minute (scale 1:24,000) topographic maps. As discussed later in the report, the actual contributing area for Little Cross Creek probably is larger than indicated by the topographic divide. Land-surface elevations in the watershed range from approximately 300 feet (ft) above mean sea level (amsl) upstream from Bonnie Doone Lake to 100 ft amsl downstream from Glenville Lake.

Little Cross Creek is classified as a WS-IV watershed, which is a classification assigned to water supplies in moderately to highly developed watersheds in North Carolina (North Carolina Department of Environment, Health, and Natural Resources, 1997a). The upper watershed in the proximity of Fort Bragg contains a mixture of forested and cleared areas. Several unpaved roads and numerous industrial facilities are located on the part of Fort Bragg that drains to Bonnie Doone Lake. In the middle and lower watershed downstream from Bonnie Doone Lake, residential and commercial/industrial land uses predominate. No permitted wastewater discharges are located in the Little Cross Creek Basin.

The Little Cross Creek watershed is located in the Sand Hills, which is a subregion of the Coastal Plain Province (Fenneman, 1938; Simmons and Heath, 1982). Sand Hills geology consists of volcanic slate bedrock overlain by multiple layers of unconsolidated sediment (Hudson, 1984). The surficial soil layer consists of highly permeable quartz sand. Because quartz is relatively insoluble, water in the Sand Hills is less mineralized than water from other regions in North Carolina (Simmons and Heath, 1982). In undeveloped areas, infiltration rates are high, and generally little overland flow occurs. Where soils are exposed or disturbed, however, erosion may be severe.

Previous Investigations

Published investigations of hydrology and water quality in the Sand Hills region of North Carolina are sparse, particularly for urban areas. Mason and Caldwell (1992) summarized the effects that a severe storm in September 1989 had on streamflow and flooding in Fayetteville. They noted that the reservoirs on Little Cross Creek and other streams helped to attenuate flooding by reducing peak discharges and delaying the onrush of flood water. Giorgino and Strain (1999) produced bathymetric maps and water-storage estimates for Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake.

Water-quality conditions in Little Cross Creek and its four reservoirs have been evaluated by the North Carolina Department of Environment and Natural Resources (DENR; formerly called the North Carolina Department of Environment, Health, and Natural Resources). DENR biologists have analyzed benthic macroinvertebrates at several stream sites in the basin by using methods and criteria developed for wadeable, flowing waters in North Carolina (North Carolina Department of Environment, Health, and Natural Resources, 1997b). In April 1990, a site upstream from Bonnie Doone Lake was assigned a bioclassification rating of Poor based on the low number of species present in the intolerant groups Ephemeroptera, Plecoptera, and Trichoptera (EPT). This led to the inclusion of Little Cross Creek on North Carolina's 303(d) list of impaired waters (North Carolina Department of Environment, Health, and Natural Resources, 1994). Land use upstream from this site consists of a mixture of forested and developed areas. In March 1998, a site located in an urban area about 250 ft downstream from Glenville Lake dam was sampled and assigned a bioclassification rating of Fair (David Penrose, North Carolina Department of Environment and Natural Resources, written commun., March 13, 1998). This bioclassification was based on EPT taxa richness and biotic indices that considered the pollution tolerance of species in the sample. In September 1998, DENR personnel collected benthic macroinvertebrates from an unnamed tributary to Little Cross Creek located in an undisturbed, forested catchment within Fort Bragg Military Reservation. Bioclassification criteria for small streams in the Piedmont and Coastal Plain have not been developed; therefore, DENR qualitatively evaluated this site by comparing its EPT community composition and biotic-index results with results from other small streams in the Sand Hills (David Penrose, North Carolina Department of Environment and Natural Resources, written commun., December 1, 1998). Results indicated good water-quality conditions.

DEHR also has assessed water-quality conditions in Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake. These investigations, which were limited to summertime sampling, primarily focused on assessing the trophic status of the reservoirs. Sampling conducted in 1998 indicated that Bonnie Doone Lake was oligotrophic, Kornbow Lake was oligo-mesotrophic, Mintz Pond was mesotrophic, and Glenville Lake was eutrophic. DENR personnel noted that nutrient concentrations had decreased and water clarity had increased substantially in Bonnie Doone Lake relative to conditions noted in 1993, and these improvements were attributed to sediment dredging completed in early 1997 (Debra Owen, North Carolina Department of Environment and Natural Resources, oral commun., August 3, 1999).

Water-quality investigations of unpolluted streams near the Little Cross Creek study area are useful for comparative purposes. From 1973 through 1978, the USGS investigated 39 streams with drainage basins that were 90 to 100 percent forested. Results were used to characterize water-quality conditions in relatively undisturbed watersheds and to delineate five geochemical zones within North Carolina (Simmons and Heath, 1982). Although none of these sites were in the Little Cross Creek drainage area, two were located in the Sand Hills geochemical zone. Caldwell (1992) conducted a supplemental investigation of physical, chemical, and biological water quality in nine forested basins, including one in the Sand Hills.

Water-quality conditions and constituent transport in urban areas of North Carolina have been studied by numerous investigators; however, most of these studies have taken place in the Piedmont Province rather than in the Sand Hills. Simmons (1993) analyzed suspended-sediment transport characteristics at 152 sites in North Carolina by using data that were collected from 1970 through 1979. Two sites were in the Sand Hills; however, neither was in an urban setting. Childress and Treece (1996) summarized ambient conditions and loads of suspended sediment, nitrogen, and phosphorus for several sites in the Research Triangle area. Bales and others (1999) presented instream concentrations and loads of suspended sediment, nitrogen, phosphorus, and total organic carbon at nine urban sites in Mecklenburg County. Other studies of sediment and nutrient conditions and(or) transport have been conducted for urban watersheds in Guilford County (Davenport, 1989; 1993); Winston-Salem (Mustard and others, 1987; Driver and Tasker, 1990), and Durham (Colston, 1974).

Acknowledgments

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DATA-COLLECTION METHODS

Data collection began in August 1996 and ended in August 1998. Data were collected from a total of 10 sites located along Little Cross Creek, in one tributary stream, and in two reservoirs (fig. 2; table 2). Sites were located to assess conditions upstream and downstream from each of the four impoundments of Little Cross Creek (fig. 2).

Hydrologic data consisted of water-level measurements at Bonnie Doone Lake and Glenville Lake, and water-level and streamflow measurements at six stream sites (table 2). In addition, six sites in Little Cross Creek were monitored during time-of-travel studies. Water-quality data included in-situ

Table 2. Data-collection sites in the Little Cross Creek study area

[—, data not collected; n/a, not applicable]

Site number (fig. 2)	Site location and USGS downstream order identification number	Drainage area (square miles)	Period of data collection			
			Water level	Streamflow	Time of travel	Water quality
S1	Little Cross Creek upstream from Bonnie Doone Lake, 0210382000	0.938	10/96–12/97	10/96–9/97	2/98, 7/98	10/96–1/98
BD1	Bonnie Doone Lake at dam, 0210382025	2.54	8/96–12/97	—	—	—
S2	Little Cross Creek downstream from Bonnie Doone Lake, 0210382026	2.56	8/96–12/97	8/96–12/97	2/98, 7/98	9/96–1/98
S3	Little Cross Creek downstream from Kornbow Lake, 0210382035	4.25	8/96–12/97	8/96–12/97	2/98, 7/98	9/96–1/98
S4	Little Cross Creek downstream from Mintz Pond, 0210382050	5.61	8/96–12/97	8/96–12/97	4/97, 2/98, 3/98	9/96–1/98
S4A	Little Cross Creek above Glenville Lake near Lyons Road, 0210382080	7.90	—	—	4/97, 2/98, 3/98	—
S5	Clark Pond Creek, 0210382068	.883	8/96–12/97	8/96–12/97	—	9/96–1/98
S6	Outfall from Cross Creek into Glenville Lake, 0210382097 (Flow estimated from pumping records)	n/a	—	11/96–9/97	—	10/96–1/98
G1	Glenville Lake near water-supply intake, 0210382100	9.14	8/96–12/97	—	—	—
S7	Little Cross Creek downstream from Glenville Lake, 0210382103	9.15	8/96–12/97	8/96–12/97	4/97, 3/98	9/96–1/98

measurements and chemical characterization at seven sites—five in Little Cross Creek (sites S1, S2, S3, S4, and S7), one in a tributary to Little Cross Creek (site S5), and one outfall into Glenville Lake (site S6; table 2).

Hydrologic Data

Continuous-record water-level gages were established in August 1996 at sites S2, S3, S4, and S7 in Little Cross Creek, site S5 in Clark Pond Creek, site BD1 in Bonnie Doone Lake, and site G1 in Glenville Lake. In October 1996, another continuous-record gage was established at Little Cross Creek site S1. These gages measured water levels every minute and recorded 15-minute averages. Field personnel visited each stream site about 30 times and documented instantaneous stage and measured streamflow, or discharge, following procedures outlined by Buchanan and Somers (1968) and Rantz and others (1982). Stage-discharge relations subsequently were developed for each stream site, providing estimates of streamflow at 15-minute intervals. Streamflow records were discontinued at all sites in mid-December 1997.

In addition, the USGS investigated time-of-travel characteristics for Little Cross Creek from site S1 upstream from Bonnie Doone Lake to site S7 downstream from Glenville Lake (fig. 2). A series of dye studies was conducted during April 1997, February–March 1998, and July–August 1998, following methods presented by Kilpatrick and Wilson (1989). Time-of-travel procedures are described in greater detail in the "Hydrologic Conditions" section of this report.

Water-Quality Data

Water-quality data collection began in September 1996 and ended in January 1998. Data were collected during at least 19 sampling visits at sites S1, S2, S3, S4, S5, and S7. In order to document water quality across a range of streamflow conditions, sampling visits were timed to coincide with 10 different storms. Site S6 was sampled only when water was discharging from the pipe into Glenville Lake, which occurred during 10 sampling visits.

Water temperature and dissolved oxygen were measured in situ each time samples were collected. At each water-quality site, these measurements were made in mid-channel at a depth of 0.5 ft by using a YSI model-10 dissolved oxygen and temperature meter. Mid-channel water samples were collected and tested immediately for pH by using a Beckman field pH meter, and for specific conductance by using a Hach conductivity meter. Standard calibration and qualityassurance protocols were followed while operating these instruments (Wilde and Radtke, 1998).

Chemical constituents that were sampled at the Little Cross Creek water-quality sites included suspended sediment, total suspended solids, turbidity, fecal coliform bacteria, nitrogen and phosphorus species (total ammonia plus organic nitrogen, dissolved nitrite plus nitrate, dissolved ammonia, total phosphorus, and dissolved orthophosphate), and total organic carbon (table 3). Sample-collection and treatment methods varied depending on the type of site and the constituents to be analyzed.

At each stream site (sites S1, S2, S3, S4, S5, and S7), composite samples were collected for most constituents (table 3). To obtain a composite sample for total suspended solids, turbidity, and nutrients, water was collected from three equally spaced points across the stream channel by using a depth-integrating DH-81 sampler (Edwards and Glysson, 1988). Water collected at each point was transferred to a clean polycarbonate churn splitter, composited, and processed as described by Horowitz and others (1994). Samples for analysis of dissolved constituents were filtered through a 0.45-micron pore-size capsule filter using a peristaltic pump. A DH-48 sampler was used to collect depth- and width-integrated samples for the determination of suspended sediment.

Surface grab samples were collected for fecal coliform bacteria at mid-channel by hand dipping a sterile sample bottle or by using a weighted bottle holder (table 3). Mid-channel grab samples also were collected for the determination of total organic carbon (table 3). Grab-sample collection procedures were used to avoid contact with compositing equipment that could have contaminated the samples. At site S6, all samples were collected directly from the outfall stream.

Numerous quality-control samples were collected to assess the adequacy of equipment-cleaning procedures, the level of contamination in the environment in which samples were collected and processed, and the quality, reliability, and reproducibility of the data generated. Approximately 10 percent of all samples collected during the project were quality-control samples, including equipment blanks, field blanks, split field replicates, and concurrent field replicates.

Equipment and field blanks were analyzed for nutrient species to ensure that the overall sample-collection process did not contaminate the stream samples. An equipment blank is a blank solution subjected to the same collection, processing, preservation, transportation, and laboratory-handling procedures as an environmental sample, but it is processed and shipped from the relatively controlled environment of the District laboratory. Equipment blanks were analyzed twice during the project to ensure that equipment-cleaning procedures were adequate. A field blank is a blank solution subjected to the same collection, processing, preservation, transportation, and laboratory-handling procedures as an environmental sample; it is obtained during the course of collecting and processing environmental samples. A field blank was analyzed once during the study to

Table 3. Sample type, bottles, and treatment procedures for samples collected at the Little Cross Creek water-quality sites, September 1996 through January 1998

[mL, milliliters; °C, degrees Celsius]

Constituent	Sample type	Bottle size	Bottle type	Sample and bottle treatment
Suspended sediment	Composite	1 pint	Glass	None.
Total suspended solids	Composite	500 mL	Polyethylene	Unfiltered; use unfiltered sample to rinse bottle.
Turbidity	Composite	250 mL	Polyethylene	Unfiltered; use unfiltered sample to rinse bottle.
Fecal coliform bacteria	Grab	250 mL	Polypropylene, sterilized	Unfiltered; chill and maintain sample at 4 °C. Deliver to laboratory within 6 hours.
Dissolved nitrite plus nitrate, dissolved ammonia, and dissolved orthophosphate	Composite	125 mL	Brown polyethylene	Filter through a disposable capsule filter with 0.45-micron pore size; use filtered sample to rinse bottle. Chill and maintain sample at 4 °C.
Total ammonia plus organic nitrogen and total phosphorus	Composite	125 mL	Brown polyethylene	Unfiltered; use unfiltered sample to rinse bottle. Chill and maintain sample at 4 °C.
Total organic carbon	Grab	125 mL	Amber glass	Bottle pre-baked at 350 °C. Do not rinse bottle in field. Chill and maintain sample at 4 °C.

assess potential contamination that could occur during sampling and sample processing in the field.

Analytical results of the blank samples indicate that the potential for contamination of the stream samples from the sample-collection process was negligible and does not affect interpretation of the environmental data. Concentrations of nitrite plus nitrate, ammonia, and total ammonia plus organic nitrogen in all blank samples were below laboratory detection levels. A total phosphorus concentration of 0.001 milligram per liter (mg/L) and an orthophosphorus concentration of 0.002 mg/L were reported for one equipment blank. These concentrations were within plus or minus 100 percent of the laboratory detection levels for these constituents (both 0.001 mg/L) and, thus, were within acceptable quality-control limits (Horowitz and others, 1994).

Split field samples provide a measure of laboratory analytical precision for various constituents in a real-world sample matrix. A split sample is an aliquot of an already collected, processed, and preserved sample. During the Little Cross Creek study, split samples were collected three times for nutrient and turbidity analysis. Concurrent field samples are two samples collected as closely together in time and space as possible. Concurrent field samples provide a measure of the maximum imprecision of the data because they are affected by both sampling and analytical variability, as well as by actual heterogeneities in the environment being sampled. During the Little Cross Creek study, concurrent field samples were collected seven times for fecal coliform bacteria, suspended sediment, total suspended solids, and total organic carbon, and four times for nutrient species and turbidity.

In general, the analytical results for field replicate samples indicate excellent data reproducibility for fecal coliform bacteria, turbidity, total suspended solids, nitrogen and phosphorus species, and total organic carbon. Differences between concurrent samples of suspended sediment were more pronounced than for other constituents; however, concentrations in replicate samples were always within the same order of magnitude. In fact, the maximum observed difference between suspended-sediment replicates was 13 mg/L. These differences likely resulted from sampling variability and true heterogeneity in the environment during sample collection. One set of turbidity split samples showed notable disagreement (5.5 versus 12 nephelometric turbidity units [NTU]); all other replicates agreed within 1 NTU. Ammonia concentrations in one set of split samples differed substantially (<0.002 mg/L and 0.15 mg/L). No other ammonia replicates differed by more than 0.005 mg/L.

Analytical Procedures

Water samples were analyzed for turbidity, nutrients, and total organic carbon at the USGS National Water Quality Laboratory in Denver, Colo. (table 4). Turbidity was measured with a turbidimeter, and results were reported in nephelometric turbidity units (Fishman and Friedman, 1989). Nitrogen and phosphorus species were analyzed by automated colorimetric procedures. Low-level nutrient analyses were performed, resulting in minimum reporting levels (MRL) of 0.002 mg/L for dissolved ammonia, 0.005 mg/L for dissolved nitrite plus nitrate, and 0.001 mg/L for total phosphorus and dissolved orthophosphorus (Fishman, 1993). Total organic plus ammonia nitrogen was analyzed by using a micro-Kjeldahl procedure (modified from Fishman and Friedman, 1989). The MRL for total organic plus ammonia nitrogen decreased from 0.20 mg/L to 0.10 mg/L after July 1997. Total organic carbon was determined by wet oxidation with potassium persulfate followed by infrared spectrometry (Wershaw and others, 1987).

Suspended-sediment concentrations were determined in a USGS sediment laboratory in Louisville, Ky., by using gravimetric procedures. Based on the filtration method used during this analysis, suspended sediment is defined as the material residue from a water sample that is retained by a filter with a 1.5-micron pore size. In general terms, suspended sediment includes sand, silt, and medium to coarse clay particles (Guy, 1969). Total suspended solids were measured by the USGS Quality Service Unit in Ocala, Fla., by using gravimetric procedures described by Fishman and Friedman (1989).

Bacteria samples were delivered to the PWC Cross Creek Laboratory in Fayetteville, N.C., within 6 hours of collection, where they were analyzed by using a membrane filtration technique. The membrane filtration method used at the laboratory has been approved by the U.S. Environmental Protection Agency and follows standard, published procedures (American Public Health Association and others, 1995).

Table 4. Analytical procedures and reporting levels for water-quality properties and constituents measured at the Little Cross Creek sites, September 1996 through January 1998

[µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; APHA, American Public Health Association; mg/L, milligrams per liter; USGS, U.S. Geological Survey; NTU, nephelometric turbidity units; NWQL, National Water Quality Laboratory in Denver, Colorado; mL, milliliters; PWC, Public Works Commission of the City of Fayetteville, North Carolina; ASF, automated segmented flow]

Parameter code	Property or chemical constituent	Reporting unit	Minimum reporting level	Analytical method (reference)	Laboratory
00095	Specific conductance, field	µS/cm at 25 °C	1	Electrometric, Wheatstone bridge (Fishman and Friedman, 1989)	Field measurement
00400	pH, field	standard units	0.1	Electrometric, glass electrode (Fishman, 1993)	Field measurement
00010	Water temperature	°C	0.1	Thermometer/thermistor, Standard Methods 2550 B (APHA, 1995)	Field measurement
00300	Oxygen, dissolved	mg/L	0.1	Membrane electrode, Standard Methods 4500-O G (APHA, 1995)	Field measurement
80154	Suspended sediment	mg/L	1	Gravimetric (Guy, 1969)	USGS sediment laboratory, Louisville, Ky.
00530	Solids, total suspended	mg/L	1	Gravimetric (Fishman and Friedman, 1989)	USGS Quality Service Unit, Ocala, Fla.
00076	Turbidity	NTU	1	Nephelometric (Fishman and Friedman, 1989)	USGS NWQL
31616	Fecal coliform bacteria	colonies/100 mL	1	Membrane filtration, Standard Methods 9222 D (APHA, 1995)	PWC Cross Creek Laboratory, Fayetteville, N.C.
00631	Nitrogen, nitrite + nitrate dissolved	mg/L	0.005	Colorimetric, cadmium reduction-diazotization, ASF, low level (Fishman, 1993)	USGS NWQL
00608	Nitrogen, ammonia dissolved	mg/L	0.002	Colorimetric, salicylate-hypochlorite, ASF, low level (Fishman, 1993)	USGS NWQL
00625	Nitrogen, ammonia + organic total	mg/L	0.20[a]	Colorimetric, microblock digestor-salicylate hypochlorite (modified from Fishman and Friedman, 1989)	USGS NWQL
00665	Phosphorus, total	mg/L	0.001	Colorimetric, acid persulfate digestion, phosphomolybdate, ASF, low level (Fishman, 1993)	USGS NWQL
00671	Phosphorus, orthophosphate dissolved	mg/L	0.001	Colorimetric, phosphomolybdate, ASF, low level (Fishman, 1993)	USGS NWQL
00680	Carbon, total organic	mg/L	0.1	Wet oxidation (Wershaw and others, 1987)	USGS NWQL

[a]Minimum reporting level changed to 0.10 mg/L after July 1997.

HYDROLOGIC CONDITIONS

Although the Little Cross Creek watershed is small, the hydrology is complex. Streamflows in the basin are influenced by natural factors such as physiographic location, topography, and seasonal climatic patterns. As would be expected for a predominately urban watershed, Little Cross Creek also is influenced by numerous anthropogenic factors. The most obvious manmade feature is the presence of several impoundments, including the four dams that form Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake. In addition, several smaller impoundments are located on tributaries to Little Cross Creek (fig. 2). Several storm drains discharge urban runoff directly to Little Cross Creek. The hydrology of the stream also is affected by operations of the PWC, including water transfers from another watershed into Glenville Lake, withdrawals at the Glenville Water Plant, and manipulated releases from the impoundments. The following discusses the influence of these factors on conditions observed in the watershed during this study.

Precipitation and Streamflow Characteristics

Long-term average precipitation at Fayetteville, N.C., ranges from 2.86 to 5.61 in. per month with rainfall typically peaking in July and August (fig. 3; National Oceanic and Atmospheric Administration, 1996). Long-term (1961–90) average precipitation equals 46.72 in. per year. During this investigation,

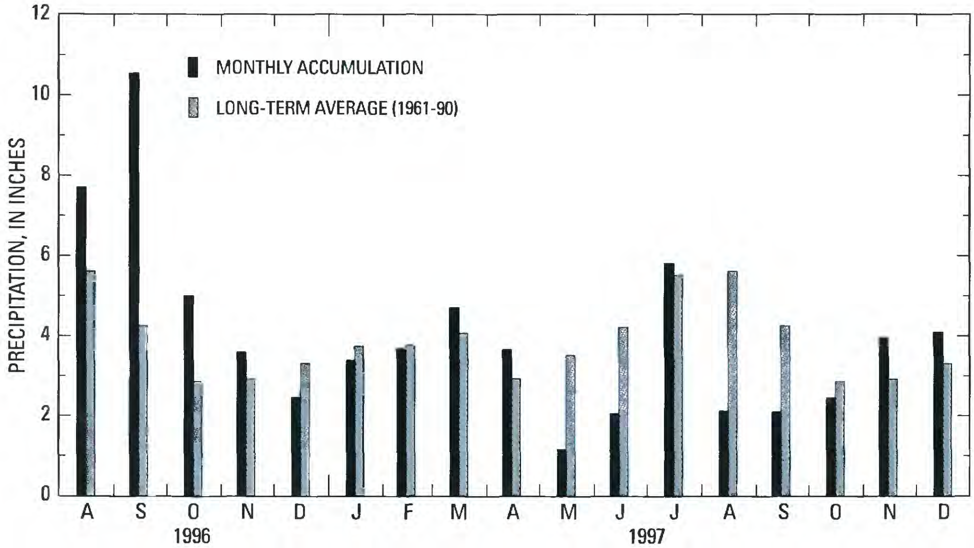

Figure 3. Relation of monthly precipitation from August 1996 through December 1997 with long-term (1961–90) average precipitation, Fayetteville, N.C. (Data provided by the State Climate Office of North Carolina.)

monthly precipitation ranged from 1.16 in. during May 1997 to 10.55 in. during September 1996.

Daily precipitation totals at Fayetteville, N.C., were provided by the State Climate Office of North Carolina at North Carolina State University for the period from August 1996 through December 1997 (Mr. Ryan Boyles, written commun., January 21, 1999). Precipitation was above average during the fall of 1996 (fig. 3), with a maximum daily total of 3.69 in. measured on September 6, 1996, with the passage of Hurricane Fran. An additional 3.40 in. fell on October 8, 1996, with the passage of Hurricane Josephine (fig. 4A; supplementary table ST-1).

Precipitation was below average during the summer and early fall of 1997 (fig. 3). The National Aeronautics and Space Administration (1998) reported that during 1997 and 1998, the largest El Niño in recorded history caused major shifts in global weather patterns. As a result of this phenomenon, the southeastern United States experienced below-average rainfall during the summer and early fall of 1997, and above-average rainfall during the winter of 1997–98. Prevailing meteorologic conditions influenced the data collected during this study; therefore, hydrology and water quality in Little Cross Creek would be expected to vary somewhat in other years.

Daily mean streamflows, or discharge, for all six of the stream-gaging sites in the study area are presented in supplementary tables at the end of this report. Streamflow at site S4 illustrates the response of Little Cross Creek to rainfall and controlled releases from upstream reservoirs. In general, daily mean streamflow mimicked precipitation patterns (fig. 4A and B). At sites S2, S3, S4, S5, and S7, peak flows were observed on September 6 and 17, 1996, following heavy rainfalls (fig. 4A and B; supplementary tables ST-3, ST-4, ST-5, ST-6, and ST-7). The streamflow gage at site S1, which was upstream from Bonnie Doone Lake, was established in early October 1996; peak streamflow was measured at site S1 on October 8, 1996, in response to rainfall from Hurricane Josephine (fig. 4A; supplementary tables ST-1 and ST-2).

Base flows at most Little Cross Creek sites generally were lowest during the summer and early fall of 1997, reflecting the drought conditions associated with El Niño (fig. 4B). In contrast, base flow at site S7 did not vary seasonally because it consisted of a controlled and relatively constant release from the Glenville Lake dam (fig. 4C). Streamflows at site S7 did not vary as much as at other sites following minor rainfall events because withdrawals from Glenville Lake commonly exceeded inputs from precipitation.

Streamflows at sites in the Little Cross Creek Basin also were influenced by operational activities in the watershed. During this study, the PWC periodically manipulated releases at Bonnie Doone Lake, Kornbow Lake, and Mintz Pond to perform inspection and maintenance activities or to augment flows into

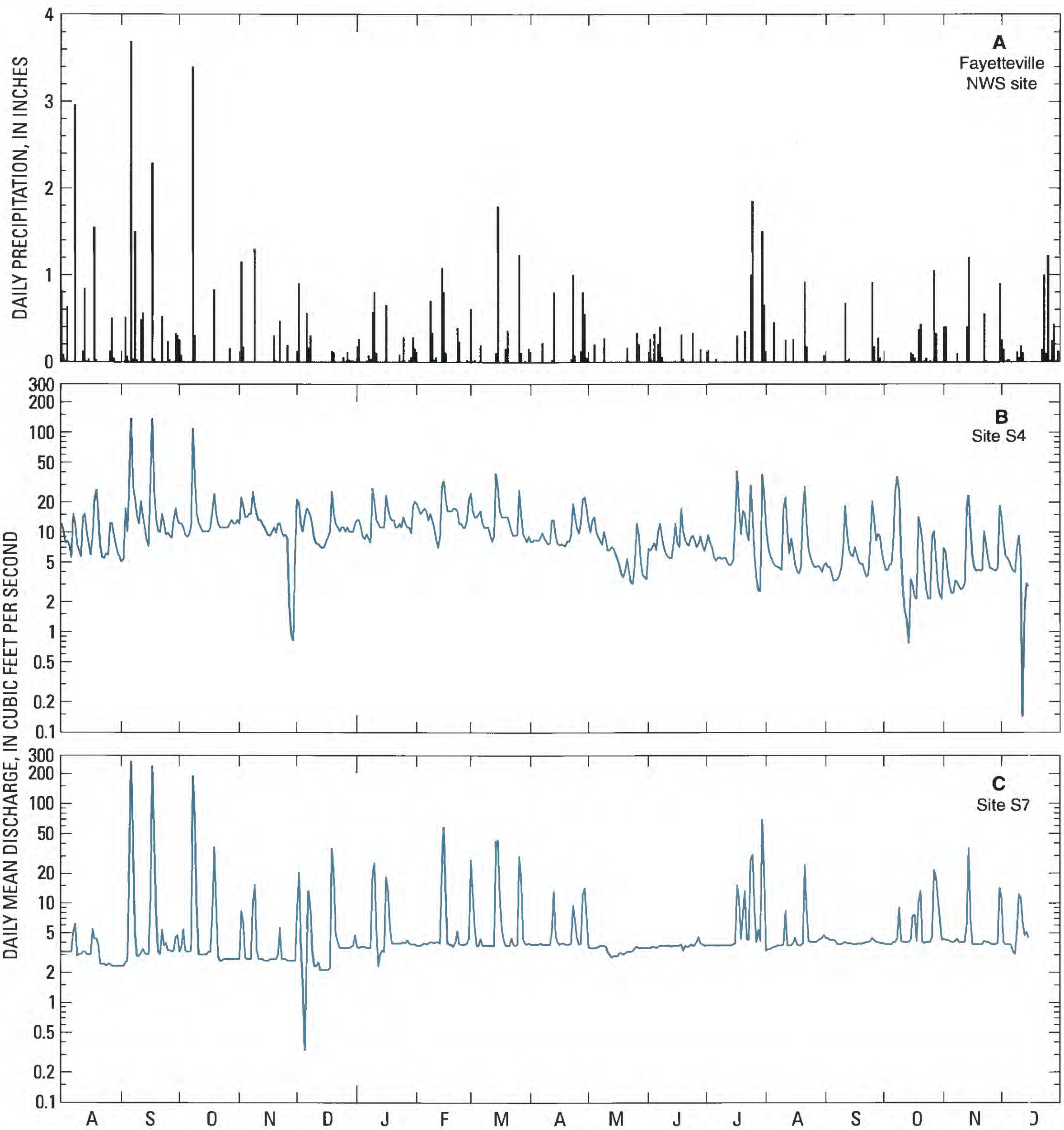

Figure 4. (A) Daily precipitation totals at the Fayetteville National Weather Service (NWS) site and daily mean discharge at Little Cross Creek sites (B) S4 and (C) S7, August 1996 through December 1997. (Precipitation data provided by the State Climate Office of North Carolina.)

Glenville Lake for water supply. The resulting perturbations in streamflow were captured in the stream-gaging record at downstream sites. For example, beginning on October 6, 1997, Bonnie Doone Lake was lowered approximately 4.4 ft (supplementary table ST-8) so that PWC staff could conduct surveys of parts of the lake bed. Streamflows at downstream sites S2, S3, and S4 were elevated for 3 to 4 days following the drawdown and then decreased abruptly (supplementary tables ST-3, ST-4, and ST-5).

Hydrographs (plots of streamflow versus time) for October 7–10, 1996, illustrate how streamflow at the Little Cross Creek sites typically fluctuates in response to rainfall (fig. 5A–G). Upstream from Bonnie Doone Lake at site S1, streamflow both peaked and declined rapidly (fig. 5B). Peak flows at sites S2

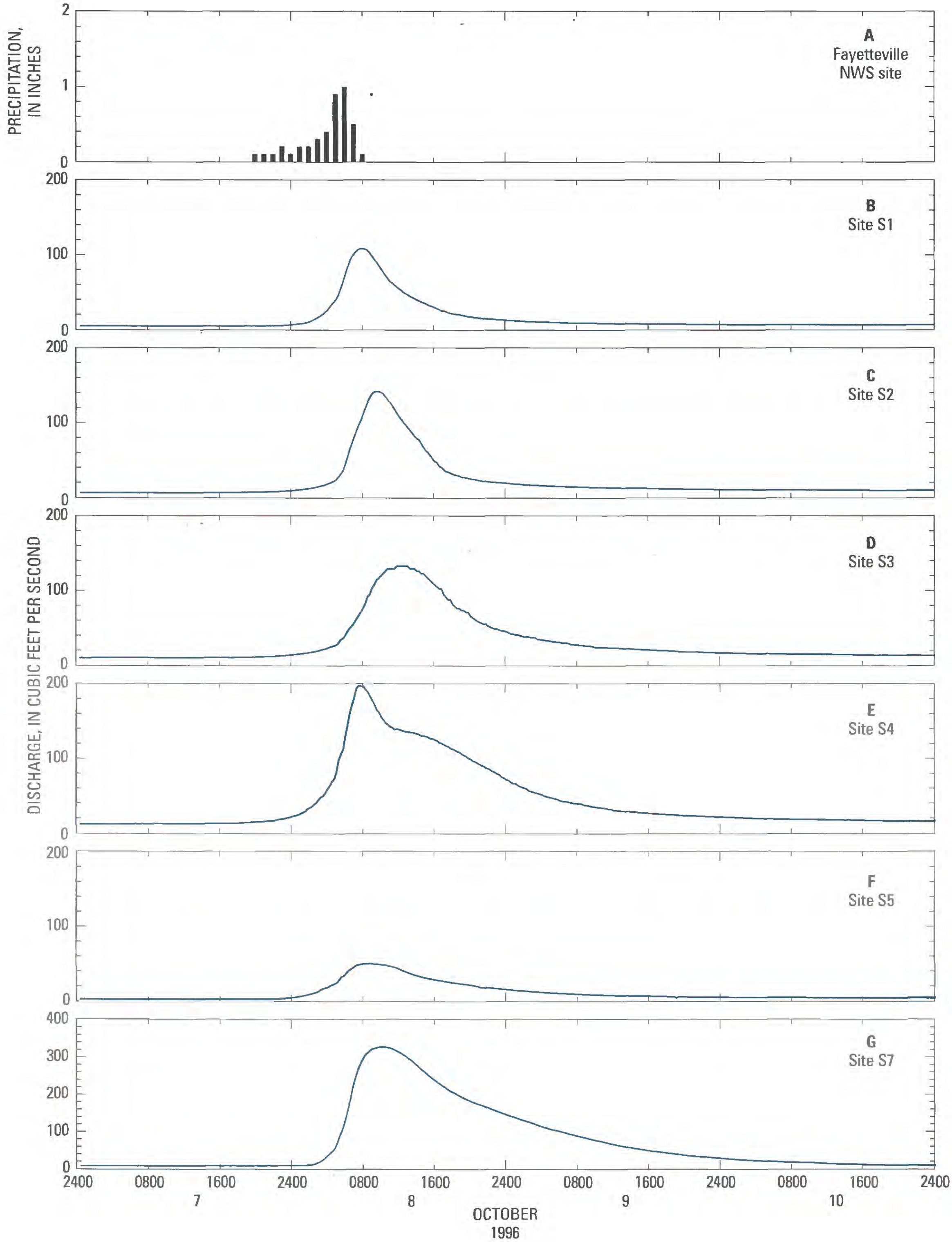

Figure 5. (A) Hourly precipitation totals at the Fayetteville National Weather Service (NWS) site and 15-minute values of discharge at Little Cross Creek sites (B) S1, (C) S2, (D) S3, (E) S4, (F) S5, and (G) S7, October 7–10, 1996.

and S3 were delayed and decreased more gradually than at site S1 because Bonnie Doone Lake and Kornbow Lake attenuated the movement of water downstream (fig. 5C and D). At site S4 downstream from Mintz Pond, a bimodal pattern was observed in the streamflow record (fig. 5E). Storm drains delivered runoff from the U.S. Highway 401 bypass into Little Cross Creek directly upstream from site S4, and probably accounted for the initial rapid pulse of streamflow. A secondary peak occurring several hours after the initial pulse represented water from the rest of the watershed moving downstream through Mintz Pond.

The drainage area for Clark Pond Creek site S5 is small; therefore, streamflow increased quickly at this location following rainfall (fig. 5F). However, a series of small impoundments upstream from site S5 (fig. 2) attenuated the rise and fall of discharge, similar to the way in which the larger impoundments of Bonnie Doone and Kornbow Lakes affected streamflows at site S3.

Peak stormflows were highest at site S7 (fig. 5G). Examination of several storm hydrographs revealed that the peak discharge at site S7 always trailed the initial peaks at sites S4 and S5; however, the relative timing of the peak depended on pre-storm conditions in Glenville Lake. When rainfall began on October 7, 1997, Glenville Lake was above the full-pool elevation of 113.1 ft amsl (supplementary table ST-9), and the peak at S7 occurred approximately 2.5 hours after the peak at S4 (fig. 5E and G). At times when the water-surface elevation of Glenville Lake was below the spillway elevation preceding a storm, the peak streamflow at site S7 was delayed, commonly by several hours, until after Glenville Lake filled and water began flowing over the spillway.

Summary of Conditions for Water Year 1997

Statistics of streamflow were computed and summarized for the period from October 1996 through September 1997 for sites in the Little Cross Creek study area. This time period was chosen because streamflow data were available for all sites and because the period represented a complete annual cycle referred to as water year 1997. Rainfall at the Fayetteville cooperative observer site during this period totaled 39.75 in., which was approximately 6 in. less than the 1961–90 average annual rainfall of 46.72 in.

Average daily mean streamflows at the Little Cross Creek sites ranged from 1.9 to 11 cubic feet per second (ft^3/s) and increased in proportion to drainage area at all sites except site S7, which was downstream from the Glenville Water Plant intake (fig. 2; tables 2, 5). Low streamflows at site S7 resulted from water-supply withdrawals from Glenville Lake, which averaged 11.4 ft^3/s during water year 1997. Likewise, average streamflow per unit drainage area, or yield, ranged from 1.96 to 2.70 $(ft^3/s)/mi^2$ at sites upstream from the Glenville Water Plant, whereas the average yield was 0.67 $(ft^3/s)/mi^2$ at site S7 (table 5).

Average yields at sites S1, S2, S3, S4, and S5 were higher than expected for this area of North Carolina. Based on data collected from 1951 through 1980, Krug and others (1990) predicted an average annual yield of 15 in. or 1.11 $(ft^3/s)/mi^2$ for streams in the vicinity of Little Cross Creek. However, at USGS

Table 5. Summary statistics of discharge recorded at Little Cross Creek sites S1, S2, S3, S4, S5, and S7 for the period from October 1996 through September 1997

[mi^2, square miles; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; in., inches]

Site no. (fig. 2)	Drainage area (mi^2)	Average daily mean discharge (ft^3/s)	Average yield ($[ft^3/s]/mi^2$)	Annual yield (in.)	Minimum daily mean discharge (ft^3/s)	Maximum daily mean discharge (ft^3/s)	Instantaneous peak discharge (ft^3/s)
S1	0.938	2.5	2.70	36.6	0.40	38	106
S2	2.56	5.8	2.26	30.7	2.1	52	139
S3	4.25	8.4	1.97	26.7	.07	71	130
S4	5.61	11	1.96	26.6	.81	107	195
S5	.883	1.9	2.21	30.0	.21	26	48
S7	9.15	6.2	.67[a]	9.09[a]	.33	184	322

[a]Low yield results from water-supply withdrawals.

station 02102908, located at Flat Creek near Inverness and approximately 15 mi northwest of Bonnie Doone Lake, average yield during water year 1997 was 1.62 $(ft^3/s)/mi^2$, and yields averaged 1.66 $(ft^3/s)/mi^2$ from water years 1968 through 1997 (Ragland and others, 1998). Long-term monitoring in the Little Cross Creek watershed would help to determine whether streamflows observed during water year 1997 were typical or anomalous and whether average yield estimates for the Sand Hills should be re-evaluated.

Water year 1997 was not an unusually wet year; thus, the high yields observed in the Little Cross Creek watershed could not be attributed to above-average rainfall. However, several other possible explanations for the high yields exist. First, the contributing drainage area for Little Cross Creek may be larger than that indicated by the land-surface divide. In other words, ground-water flow paths may transport water from areas outside the watershed boundary into Little Cross Creek. Underestimating the contributing area would cause an overestimate of yield, and the effect would be especially pronounced for small catchments such as that for site S1. Determining the ground-water divide was beyond the scope of the present study but could contribute to a better understanding of the hydrology of Little Cross Creek. High streamflow yield also may result from naturally high rates of ground-water discharge within the Little Cross Creek watershed. Finally, water may be entering the Little Cross Creek Basin from unidentified sources, such as sewer or water-line breaks, or from stormwater-collection systems that transport runoff from adjacent watersheds.

Insight into the hydrology of the Little Cross Creek watershed can be furthered by examining the relative magnitude of inputs and outputs to Glenville Lake during October 1996 through September 1997. In water year 1997, estimated inputs totaling 4,650 million gallons (Mgal) included inputs from gaged and ungaged areas of the watershed and from water pumped from Cross Creek to augment the water supply in Glenville Lake (table 6). Inputs measured at sites S4 and S5 accounted for 65.8 percent of the total inflows to Glenville Lake. Inputs from the ungaged area were computed by multiplying the mean of the yields for sites S4 and S5 by the area of the ungaged watershed. Estimated inputs from the ungaged area represented 28.2 percent of the total inflows during water year 1997 (table 6).

From October 1996 through September 1997, water pumped into Glenville Lake from Cross Creek contributed 280 Mgal, or 6 percent of the total inflow, to site S7 (table 6). This value was computed from records of pump operation and flow rates measured in the pipe at site S6 (fig. 2). Pump records for November 1996 through September 1997 were provided by the PWC (Mr. Chris Smith, Public Works Commission, Glenville Water Plant Operator, written commun., February 5, 1999). In order to compute inputs at site S6 for the entire water year, pump usage for October 1996 was estimated to equal the average use from November 1996 through September 1997.

Table 6. Annual water budget for Glenville Lake for the period from October 1996 through September 1997

[Mgal/yr, million gallons per year]

Source or loss	Volume (Mgal/yr)	Percent
Inputs		
Gaged streamflow at site S4 on Little Cross Creek	2,600	55.9
Gaged streamflow at site S5 on Clark Pond Creek	460	9.9
Ungaged area of watershed	1,310[a]	28.2
Water pumped from Cross Creek into Glenville Lake at site S6	280	6.0
Total inputs	4,650	100.0
Outputs		
Withdrawal from Glenville Lake at raw-water intake	2,680	64.5
Gaged streamflow at site S7	1,450	34.9
Evaporation from Glenville Lake	23	.6
Total outputs	4,153	100.0

[a]Computed by multiplying the mean of the average runoff values for sites S4 and S5 (2.08 cubic feet per second per square mile) by the area of the ungaged watershed (2.661 square miles) and converting to million gallons per year.

Although a flow-logging device was installed in the pipe at site S6 during this investigation, numerous problems associated with probe fouling and improper operation occurred. An average flow rate of 1.9 ft^3/s, or 850 gallons per minute (gal/min), was obtained during several probe calibrations and was used to compute inflows at site S6. This flow rate was lower than the 1,000-gal/min rate indicated by the pump performance curve (Mr. Chris Smith, Public Works Commission, Glenville Water Plant Operator, written commun., February 5, 1999).

In water year 1997, estimated outputs totaling 4,153 Mgal included water withdrawals from Glenville Lake to the Glenville Water Plant, gaged streamflow at site S7, and evaporative losses from the surface of Glenville Lake (table 6). Withdrawals of raw water from Glenville Lake for treatment in the Glenville Water Plant averaged 7.352 million gallons per day (Mgal/d) during water year 1997, accounting for about 65 percent of the total outflow (table 6). From October 1996 through September 1997, daily withdrawals ranged from zero to 18.541 Mgal/d (supplementary table ST-10). Withdrawal records for the Glenville Water Plant were provided to the USGS by the PWC (Mr. Chris Smith, Public Works Commission, Glenville Water Plant Operator, written commun., February 3, 1999).

The North Carolina State Climate Office at North Carolina State University computed evaporation rates by using the Penman method (Burman and Pochop, 1991) and meteorologic data collected at the Fayetteville National Weather Service (NWS) site. Total evaporation during water year 1997 equaled 22.8 in., or 57 percent of the total precipitation. Evaporative losses from Glenville Lake were estimated by multiplying the full-pool surface area of the reservoir by the annual evaporation rate and appropriate conversion factors. Evaporative losses accounted for less than 1 percent of the total output from Glenville Lake (table 6).

Total inflows and outflows for Glenville Lake theoretically should have balanced; however, the estimated inflows exceeded the outflows by 497 Mgal, or 11 percent, for water year 1997 (table 6). This imbalance in the water budget for Glenville Lake likely resulted from a combination of unmeasured losses and(or) measurement errors in some of the budget components, especially inputs from the ungaged portion of the watershed.

Ground-water losses due to seepage under the Glenville Lake dam were not measured during this study. However, based on the moderately permeable soils at the dam (Hudson, 1984) and computational methods presented by Arteaga and Hubbard (1975), seepage losses likely would have been less than 10 million gallons per year (Mgal/yr).

The 11-percent imbalance between the inflows and outflows for Glenville Lake could result, in part, from overestimates of streamflow at sites S4 and S5 (table 6). Streamflow measurements with an error of plus or minus 5 percent generally are considered good. If the tributary inflows to Glenville Lake were overestimated by 5 percent and the outflows were underestimated by 5 percent, these measurement errors would account for a 10-percent difference between the total inputs and total outputs. Stage-discharge relations for streams in the Sand Hills region of North Carolina commonly are difficult to establish and must be updated often, because shifting sands in the stream alter the channel morphology over time. Sites in the Little Cross Creek watershed often had low stream velocities, which could have contributed further to measurement error.

Inflows from the ungaged portion of the Glenville Lake watershed may have been overestimated by applying the mean of runoff values from sites S4 and S5. Runoff measured at sites S4 and S5 may not have been representative for the ungaged area because of differences in watershed characteristics. For example, the ungaged portion of the watershed has more undeveloped areas than the drainages for sites S4 and S5, and includes extensive wetlands upstream from the headwaters of Glenville Lake. Representative runoff values for the ungaged area may be more in line with lower values recorded for other, less urbanized sites in the Sand Hills of North Carolina (Krug and others, 1990).

This investigation provides baseline information and a preliminary analysis of the hydrology of Little Cross Creek. Streamflows were measured during periods of both high rainfall and drought, and streamflow responses to climatic and anthropogenic factors were documented. During water year 1997, more than 4,000 Mgal of water flowed through Glenville Lake. Pumped water from Cross Creek made up 6 percent of the total inputs to Glenville Lake during water year 1997; drinking-water withdrawals accounted for 65 percent of the total output from Glenville Lake. Additional information needs were identified and may warrant future investigation of high streamflow yields in the Little Cross Creek Basin, re-examination of regional yield estimates for the Sand Hills, and delineation of ground-water and stormflow paths in the surrounding area.

Time of Travel

Time of travel refers to the time for movement of water or solutes from one point to another in a stream. Time of travel is measured by injecting a neutrally buoyant dye into a stream at a selected location and measuring the concentrations of dye in the resulting dye cloud at other locations downstream (Kilpatrick and Wilson, 1989). Dye studies provide information that is useful to water-resource managers and water users. For example, results can be used to predict the time of arrival and passage of a harmful substance that might be spilled upstream from a water-supply intake and, thus, enable those persons charged with public safety to decide on an appropriate course of action.

Dye studies were conducted in Little Cross Creek from April 1997 through August 1998 to identify travel times between site S1, upstream from Bonnie Doone Lake, and site S7, downstream from Glenville Lake (fig. 2). This section of Little Cross Creek was subdivided into four reaches. Each reach encompassed one of the four reservoirs and was delimited by an upstream and a downstream sampling site. An additional site, S4A, was located in reach 4 approximately midway between sites S4 and S7 (fig. 2; table 7).

At least two dye studies were conducted in each reach—one while streamflows were relatively high and the other during low streamflow conditions. This approach generally allows travel times to be predicted for a broad range of streamflows (Kilpatrick and Wilson, 1989). As discussed below, however, it was not possible to predict ranges of travel times for some reaches in Little Cross Creek.

For comparative purposes, results for all reaches were referenced to streamflow conditions at site S4 (fig. 2; table 7). Flow durations for site S4 were computed based on data collected during water year 1997 and represent the percentage of time that streamflows equaled or exceeded the indicated discharge (fig. 6). For example, 70 percent of the streamflows recorded at site S4 during water year 1997 equaled or exceeded 7.4 ft^3/s (fig. 6). It should be noted that, ideally, flow durations are based on long-term records of streamflow that extend over several years;

Table 7. Summary of time-of-travel data collected during dye studies on Little Cross Creek, April 1997 through August 1998

[Site locations shown in fig. 2]

Reach no.	Reach boundaries in Little Cross Creek	Reach length (miles)	Date of dye injection	Flow duration at index site S4[a] (percent)	Time of travel through the reach (hours)	
					Leading edge of dye	Peak concentration of dye
1	Sites S1 to S2, including Bonnie Doone Lake	0.8	2/23/98	23	23.5	108
			7/20/98	99	23	48
2	Sites S2 to S3, including Kornbow Lake	1.2	2/23/98	23	50	188
			7/20/98	99	47	208
3	Sites S3 to S4, including Mintz Pond	1.1	2/23/98	23	19	25
			7/20/98	99	31	80
4A	Sites S4 to S4A	1.35	2/23/98	8	3	5
			3/3/98	23	4	6
			4/15/97	70	6.1	8.3
4B	Sites S4A to S7, including Glenville Lake	1.15	3/3/98	23	30	50
			4/15/97	70	34.4	51.2

[a]Percentage of time that streamflows were greater than or equal to the discharge at time of dye study.

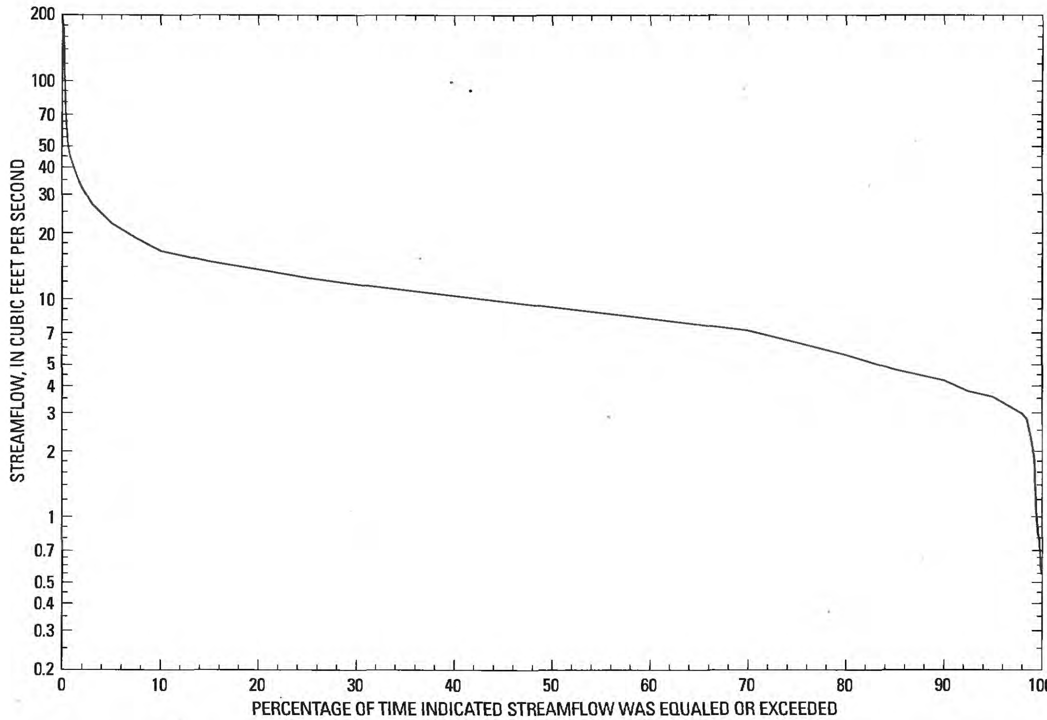

Figure 6. Streamflow-duration curve for Little Cross Creek site S4, October 1996 through September 1997.

however, records representing complete water years for site S4 existed only for 1997. Long-term stream gaging at this site would provide improved measures of flow durations for Little Cross Creek.

During each time-of-travel study, rhodamine dye was injected at the upper end of each reach. Water samples were collected at downstream sites at appropriate time intervals before and during the passage of the dye cloud in order to determine times to the leading edge and the peak concentration of dye (table 7). Concentrations of dye were measured by using a fluorometer outfitted with a 13-millimeter diameter cuvette, which could detect a minimum concentration of 0.01 part per billion. Calibration and operation of the fluorometer followed procedures outlined by Wilson and others (1986) and Turner Designs (1978). Streamflow was measured directly or was obtained from existing stage-discharge ratings at each site while the dye cloud was present.

Dye studies were conducted in reach 1 of Little Cross Creek during periods of high (23-percent flow duration) and low (99-percent flow duration) streamflow (table 7). Results indicate that travel times in this reach were affected by seasonal stratification in Bonnie Doone Lake. One would have expected travel times to have been substantially longer in July 1998 than in February 1998 because July streamflows were much lower; however, the opposite outcome was observed. In July, the peak concentration of dye was observed at site S2 after only 48 hours, whereas, in February, the peak was noted after 108 hours (table 7). During July, Bonnie Doone Lake was, in all likelihood, thermally stratified, which essentially allowed the dye cloud to "short circuit" through the reservoir. In other words, if the reservoir was stratified, as was likely during July, inflowing stream water would tend not to mix vertically throughout the water column, but rather move through the reservoir as a relatively discrete layer. Whether that layer took the form of an overflow, interflow, or underflow would depend on the relative water temperatures in the influent stream and the main body of the reservoir (Kennedy and others, 1985); regardless, the result would be an accelerated passage of the dye cloud through the reservoir.

Similar results were observed in reach 2, where it is presumed that summertime stratification may have limited vertical mixing in Kornbow Lake and accelerated the movement of water from site S2 to site S3 (fig. 2). In reach 2, travel times of the leading edges and peak concentrations were similar during

February and July 1998 even though streamflow conditions were different (table 7). Travel times in July 1998 should have been longer than in February 1998; however, the travel time to the leading edge of dye was slightly faster in July (47 hours) than in February (50 hours; table 7).

These results indicate that patterns of water movement in reaches 1 and 2 varied seasonally; therefore, it would have been inappropriate to compute a single range of travel times for the section of Little Cross Creek upstream from site S3. To compute two ranges of travel times would require conducting an additional high-flow dye study during the summer and an additional low-flow study during the winter. In this manner, travel-time measurements would bracket ranges of flows for periods when the reservoirs were stratified and for periods when the reservoirs were well mixed. These results further indicate that managers should consider the presence or absence of stratification in the reservoirs when making decisions for the Little Cross Creek watershed that involve constituent transport, such as responses to contaminant spills.

Reach 3 extended from site S3 to site S4 and included Mintz Pond (fig. 2). Mintz Pond is shallow, with a mean depth of 3.4 ft (Giorgino and Strain, 1999). Summer stratification probably was not as pronounced in Mintz Pond as in the other reservoirs of Little Cross Creek; no short-circuiting of dye was indicated by the data during July 1998 (table 7). Travel times of both the leading edge and the peak concentration of dye were longer in July 1998 than in February 1998, as was expected based on the different streamflow conditions (table 7). Therefore, ranges of travel times for both the leading edge (table 8) and the peak concentration (table 9) of a solute were computed for this reach following procedures presented by Kilpatrick and Wilson (1989).

Reach 4 consisted of two subreaches: the 1.35-mi free-flowing stretch of Little Cross Creek between site S4 and site S4A, and the 1.15-mi subreach between sites S4A and S7 which included Glenville Lake (fig. 2; table 7). Dye studies were conducted in reach 4 during periods of high (23-percent flow duration) and moderately low (70-percent flow duration) streamflow conditions. One additional

Table 8. Travel times for leading edge of a solute from Little Cross Creek sites S3 through S4A at selected flow durations

Site no. (fig. 2)	Location on Little Cross Creek	Miles upstream from site S7 (fig. 2)	Travel time of leading edge of dye cloud, in hours, for indicated flow duration, in percent[a]										
			10	20	30	40	50	60	70	80	90	95	99
S3	Downstream from Kornbow Lake	4.0	0	0	0	0	0	0	0	0	0	0	0
S4	Downstream from Mintz Pond and U.S. Highway 401 bypass	2.5	19.3	20.9	22.1	23.0	23.9	24.8	25.7	27.2	28.7	29.5	31.2
S4A	Upstream from Glenville Lake near Lyons Drive	1.15	22.5	24.7	26.5	27.7	29.1	30.4	31.8	34.3	37.0	38.6	42.5

[a] Interpolated from travel times measured during dye studies as described by Kilpatrick and Wilson (1989).

Table 9. Travel times for peak concentration of a solute from Little Cross Creek sites S3 through S4A at selected flow durations

Site no. (fig. 2)	Location on Little Cross Creek	Miles upstream from site S7 (fig. 2)	Travel time of peak concentration of dye cloud, in hours, for indicated flow duration, in percent[a]										
			10	20	30	40	50	60	70	80	90	95	99
S3	Downstream from Kornbow Lake	4.0	0	0	0	0	0	0	0	0	0	0	0
S4	Downstream from Mintz Pond and U.S. Highway 401 bypass	2.5	25.5	29.7	33.3	36.2	39.3	42.7	46.3	53.5	62.0	67.3	81.3
S4A	Upstream from Glenville Lake near Lyons Drive	1.15	30.8	35.6	39.8	43.1	46.6	50.4	54.4	62.5	71.8	77.7	92.8

[a] Interpolated from travel times measured during dye studies as described by Kilpatrick and Wilson (1989).

high-flow dye study (8-percent flow duration) was conducted in the subreach between sites S4 and S4A in February 1998 (table 7).

In the subreach between sites S4 and S4A, measured travel times increased as streamflow decreased, which was expected for a typical free-flowing stream (table 7). Therefore, ranges of travel times for both the leading edge and the peak concentration of a solute were computed for this subreach (tables 8 and 9, respectively).

Travel times between sites S4A and S7 seemed to be affected by seasonal stratification in Glenville Lake, similar to results observed in reaches 1 and 2, which were influenced by Bonnie Doone and Kornbow Lakes. Travel times for both the leading edge and the peak concentration of dye were similar during the two dye studies, although flow conditions were markedly different. The data indicated that the dye cloud dispersed less within Glenville Lake in April 1997 than in March 1998, which suggests that thermal stratification had begun to develop in Glenville Lake by mid-April 1997.

Based on the dye-study results, ranges of travel times were estimated for Little Cross Creek in the reaches between site S3 and site S4A (tables 8 and 9). Additional dye studies would be needed to estimate travel times from site S1 to S3 and from S4A to S7, because travel times vary depending on whether Bonnie Doone Lake, Kornbow Lake, and Glenville Lake are stratified or unstratified. During future dye studies, temperature profiles in the reservoirs could be monitored to confirm the presence or absence of stratification.

WATER-QUALITY CONDITIONS

Data for all water-quality constituents were collected at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7 (fig. 2) from October 1996 through January 1998. Additional suspended sediment and total suspended solids samples were collected in September 1996 at sites S2, S3, S4, S5, and S7. Statistical summaries of selected water-quality constituents at all sites are presented in this section. In addition, all water-quality measurements are listed in supplementary tables ST-11 through ST-17 at the end of this report.

These data were analyzed to characterize current conditions in the Little Cross Creek Basin in reference to North Carolina water-quality standards and to interpret spatial, seasonal, and flow-related variations. Results from the Little Cross Creek study area were compared to studies conducted in minimally disturbed streams in the Sand Hills and to studies of urban streams in the Piedmont of North Carolina.

Constituent concentrations were analyzed for spatial (site-to-site), streamflow-related, and seasonal differences. For selected constituents, boxplots illustrate the distribution of observations at each site and also provide a mechanism for visualizing differences between sites. Depending on characteristics of the data, analysis of variance or the nonparametric Kruskal-Wallis W procedure was used to test for site-to-site differences, followed by appropriate multiple-comparison tests. Rank-sum (also known as Mann-Whitney U) tests were used to discern differences between base flow and storm-event samples. Plots of constituent concentrations with time and regression techniques were used to test for seasonality in the data. For all procedures, statistical significance was defined as a p-value or alpha less than or equal to 0.05 for the statistic in use.

Loads of suspended sediment, total nitrogen, total phosphorus, and total organic carbon were computed for each monitored site. Yields, or loads per square mile of drainage area, also were computed and used to compare inputs of sediment and nutrients at various locations in the Little Cross Creek watershed. Finally, loads for unmonitored areas of the watershed were estimated in order to compute total inputs to Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake. Trapping efficiencies for sediment and nutrients were determined by comparing the inflow loads with outflow loads at each of the four reservoirs.

Temperature and Dissolved Oxygen

Water temperatures measured during the study ranged from 4.5 to 29.1 degrees Celsius (°C) (table 10), and followed typical seasonal patterns with lows in January 1996 and highs in July 1997. On any sampling date, water temperatures were similar at all sites. No measurements exceeded the North Carolina State water-quality standard of 32 °C (90 °F) for lower Piedmont and Coastal Plain waters (North Carolina Department of Environment, Health, and Natural Resources, 1997a). It should be noted, however, that no measurements were made during the months of August and September when higher temperatures may have occurred. Also, measurements in July were made during the morning. Continuous records of water

Table 10. Statistical summary of selected water-quality constituents at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, September 1996 through January 1998

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; <, less than; mm, millimeters; --, insufficient data to calculate statistic]

Parameter code	Property or constituent	Descriptive statistics				Percent of samples in which values were less than or equal to those shown		
		Sample size	Maximum	Minimum	Mean	75%	50% (median)	25%
		SITE S1						
00095	Specific conductance (µS/cm at 25 °C)	20	37	16	24	28	24	20
00400	pH, field (standard pH units)	20	6.3	5.2	5.9	6.1	6.0	5.6
00010	Water temperature (°C)	19	24.2	4.5	15.3	20.0	15.0	11.5
00076	Turbidity (NTU)	20	60	1.5	15	23	7.1	3.8
00300	Oxygen, dissolved (mg/L)	19	11.5	5.9	7.9	8.9	7.9	6.8
00301	Oxygen, dissolved (percent of saturation)	19	88	69	78	82	78	75
31616	Fecal coliform bacteria (colonies/100 mL)	17	1,200	<1	38†	220	44	8
00530	Solids, total suspended (mg/L)	20	81	1	19	33	6	3
00631	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	20	.410	.073	.186	.223	.167	.139
00608	Nitrogen, ammonia dissolved (mg/L as N)	20	.088	<.002	.026*	.030	.019	.012
00625	Nitrogen, ammonia + organic total (mg/L as N)	20	.50	<.10	.14*	.12	<.20	<.20
00665	Phosphorous, total (mg/L as P)	20	.066	.003	.024	.042	.019	.006
00671	Phosphorous, orthophosphate dissolved (mg/L as P)	20	.007	<.001	.001*	.002	.001	<.001
00680	Carbon, total organic (mg/L as C)	20	10	1.4	3.5	4.4	2.9	2.2
80154	Suspended sediment (mg/L)	20	395	1	55	60	17	4
70331	Suspended sediment (percent finer than 0.062 mm)	10	96	1	51	88	40	22
		SITE S2						
00095	Specific conductance (µS/cm at 25 °C)	19	30	21	26	28	26	25
00400	pH, field (standard pH units)	19	7.5	5.3	6.1	6.3	6.1	5.7
00010	Water temperature (°C)	19	27.3	8.0	16.9	23.7	16.7	11.0
00076	Turbidity (NTU)	19	19	1.8	6.9	9.4	5.2	3.7
00300	Oxygen, dissolved (mg/L)	18	10.9	5.9	8.4	9.4	8.6	7.3
00301	Oxygen, dissolved (percent of saturation)	18	96	73	86	90	86	81
31616	Fecal coliform bacteria (colonies/100 mL)	18	400	<1	12†	34	15	4
00530	Solids, total suspended (mg/L)	20	16	<1	6*	10	3	2
00631	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	19	.470	.125	.264	.380	.221	.181
00608	Nitrogen, ammonia dissolved (mg/L as N)	19	.148	<.002	.049*	.090	.032	.011
00625	Nitrogen, ammonia + organic total (mg/L as N)	19	.41	<.10	.22*	.30	.20	<.20
00665	Phosphorous, total (mg/L as P)	19	.036	.005	.014	.017	.010	.007
00671	Phosphorous, orthophosphate dissolved (mg/L as P)	19	.003	<.001	.001*	.001	<.001	<.001
00680	Carbon, total organic (mg/L as C)	19	4.8	1.9	3.2	3.6	3.1	2.6
80154	Suspended sediment (mg/L)	20	1,590	2	90	12	8	4
70331	Suspended sediment (percent finer than 0.062 mm)	9	93	1	63	89	75	33
		SITE S3						
00095	Specific conductance (µS/cm at 25 °C)	18	36	27	34	35	34	33
00400	pH, field (standard pH units)	18	6.9	5.6	6.4	6.7	6.4	6.3
00010	Water temperature (°C)	18	28.4	8.0	17.7	24.9	17.4	11.0
00076	Turbidity (NTU)	17	6.8	.45	2.4	3.8	1.8	1.2
00300	Oxygen, dissolved (mg/L)	18	11.4	6.4	9.2	10.6	9.2	7.8
00301	Oxygen, dissolved (percent of saturation)	18	109	83	95	100	94	90
31616	Fecal coliform bacteria (colonies/100 mL)	17	30	<1	5†	10	5	3
00530	Solids, total suspended (mg/L)	19	5	<1	2*	3	2	<1
00631	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	17	.740	.121	.444	.670	.377	.299
00608	Nitrogen, ammonia dissolved (mg/L as N)	17	.028	<.002	.009*	.015	.006	.002
00625	Nitrogen, ammonia + organic total (mg/L as N)	17	.30	<.100	.16*	.17	<.20	<.20
00665	Phosphorous, total (mg/L as P)	17	.012	.001	.006	.008	.006	.004
00671	Phosphorous, orthophosphate dissolved (mg/L as P)	17	.003	<.001	.001*	.001	<.001	<.001
00680	Carbon, total organic (mg/L as C)	17	4.7	2.0	3.1	3.5	3.0	2.6
80154	Suspended sediment (mg/L)	19	24	1	6	8	5	2
70331	Suspended sediment (percent finer than 0.062 mm)	8	86	5	54	68	60	36
		SITE S4						
00095	Specific conductance (µS/cm at 25 °C)	19	52	31	38	39	38	36
00400	pH, field (standard pH units)	19	7.0	5.8	6.6	6.7	6.6	6.5
00010	Water temperature (°C)	19	27.4	5.5	16.5	24.0	16.8	10.0
00076	Turbidity (NTU)	19	12	1.1	3.9	5.0	3.3	2.2
00300	Oxygen, dissolved (mg/L)	19	11.8	5.8	9.0	10.6	9.0	7.7
00301	Oxygen, dissolved (percent of saturation)	19	100	73	90	97	93	81
31616	Fecal coliform bacteria (colonies/100 mL)	18	7,500	1	87†	1,025	83	15
00530	Solids, total suspended (mg/L)	20	11	<1	4*	6	4	2
00631	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	19	.640	.091	.330	.450	.317	.179
00608	Nitrogen, ammonia dissolved (mg/L as N)	19	.236	<.002	.030*	.027	.012	.007
00625	Nitrogen, ammonia + organic total (mg/L as N)	19	.74	<.20	.28*	.34	.27	<.20
00665	Phosphorous, total (mg/L as P)	19	.066	.008	.021	.026	.017	.011
00671	Phosphorous, orthophosphate dissolved (mg/L as P)	19	.024	<.001	.002*	.001	.001	<.001
00680	Carbon, total organic (mg/L as C)	19	6.2	2.8	4.5	5.2	4.3	3.8
80154	Suspended sediment (mg/L)	20	51	1	13	17	8	5
70331	Suspended sediment (percent finer than 0.062 mm)	9	92	18	61	84	74	32

† Geometric mean.

* Value is estimated by using a log-probability regression to predict the values of data below the detection limit.

NOTE: Multiple detection limits during the period of record may result in different values flagged with a "<."

Table 10. Statistical summary of selected water-quality constituents at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, September 1996 through January 1998—Continued

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; <, less than; mm, millimeters; --, insufficient data to calculate statistic]

Parameter code	Property or constituent	Descriptive statistics				Percent of samples in which values were less than or equal to those shown		
		Sample size	Maximum	Minimum	Mean	75%	50% (median)	25%
			SITE S5					
00095	Specific conductance (µS/cm at 25 °C)	18	83	26	60	64	59	56
00400	pH, field (standard pH units)	18	7.4	6.1	6.8	6.9	6.8	6.6
00010	Water temperature (°C)	18	28.9	6.5	17.1	23.8	17.4	10.4
00076	Turbidity (NTU)	18	7.5	2.1	4.1	5.2	3.2	2.7
00300	Oxygen, dissolved (mg/L)	18	11.5	6.0	8.8	10.3	9.0	7.1
00301	Oxygen, dissolved (percent of saturation)	18	103	71	90	95	91	84
31616	Fecal coliform bacteria (colonies/100 mL)	17	390	3	64†	145	100	25
00530	Solids, total suspended (mg/L)	17	12	2	6	7	6	4
00631	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	18	.320	.010	.130	.203	.102	.052
00608	Nitrogen, ammonia dissolved (mg/L as N)	18	.150	<.002	.062*	.093	.056	.015
00625	Nitrogen, ammonia + organic total (mg/L as N)	18	1.1	.20	.49	.58	.44	.30
00665	Phosphorous, total (mg/L as P)	18	.063	.019	.035	.043	.035	.023
00671	Phosphorous, orthophosphate dissolved (mg/L as P)	18	.007	<.001	.002*	.003	.002	.001
00680	Carbon, total organic (mg/L as C)	18	8.0	3.7	5.3	5.9	5.4	4.7
80154	Suspended sediment (mg/L)	19	168	3	34	35	12	8
70331	Suspended sediment (percent finer than 0.062 mm)	8	97	4	49	79	58	8
			SITE S6					
00095	Specific conductance (µS/cm at 25 °C)	10	60	41	50	54	50	46
00400	pH, field (standard pH units)	10	6.8	5.7	6.4	6.7	6.4	6.4
00010	Water temperature (°C)	10	23.0	5.5	15.3	22.2	15.5	9.9
00076	Turbidity (NTU)	10	30	3.1	6.5	4.3	4.0	3.6
00300	Oxygen, dissolved (mg/L)	10	12.9	7.9	9.9	11.0	9.6	8.4
00301	Oxygen, dissolved (percent of saturation)	10	108	90	97	103	97	91
31616	Fecal coliform bacteria (colonies/100 mL)	10	940	30	127†	210	130	58
00530	Solids, total suspended (mg/L)	10	49	2	9	8	4	3
00631	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	10	.490	.141	.280	.314	.252	.240
00608	Nitrogen, ammonia dissolved (mg/L as N)	10	.087	<.002	.050*	.079	.054	.010
00625	Nitrogen, ammonia + organic total (mg/L as N)	10	.37	.20	.28	.33	.30	.20
00665	Phosphorous, total (mg/L as P)	10	.120	.013	.028	.021	.016	.014
00671	Phosphorous, orthophosphate dissolved (mg/L as P)	10	.017	<.001	.005*	.006	.002	<.001
00680	Carbon, total organic (mg/L as C)	10	6.6	1.8	5.0	5.9	5.4	4.4
80154	Suspended sediment (mg/L)	10	44	2	10	12	6	4
70331	Suspended sediment (percent finer than 0.062 mm)	1	84	--	--	--	--	--
			SITE S7					
00095	Specific conductance (µS/cm at 25 °C)	18	55	41	47	50	46	44
00400	pH, field (standard pH units)	18	6.9	5.8	6.5	6.7	6.5	6.4
00010	Water temperature (°C)	18	29.1	6.0	16.1	20.8	16.8	9.8
00076	Turbidity (NTU)	18	7.0	2.1	3.8	4.7	3.7	2.9
00300	Oxygen, dissolved (mg/L)	17	12.2	6.4	9.0	10.5	8.7	7.4
00301	Oxygen, dissolved (percent of saturation)	17	103	78	90	96	91	83
31616	Fecal coliform bacteria (colonies/100 mL)	17	2,000	4	49†	112	35	18
00530	Solids, total suspended (mg/L)	19	16	3	6	6	5	4
00631	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	18	.470	.010	.213	.303	.197	.135
00608	Nitrogen, ammonia dissolved (mg/L as N)	18	.095	<.002	.029*	.039	.014	.009
00625	Nitrogen, ammonia + organic total (mg/L as N)	18	.73	<.20	.33*	.45	.30	.20
00665	Phosphorous, total (mg/L as P)	18	.053	.003	.025	.028	.021	.017
00671	Phosphorous, orthophosphate dissolved (mg/L as P)	18	.006	<.001	.002*	.002	.002	<.001
00680	Carbon, total organic (mg/L as C)	18	7.7	3.6	5.2	6.0	5.0	4.1
80154	Suspended sediment (mg/L)	19	21	3	9	13	8	5
70331	Suspended sediment (percent finer than 0.062 mm)	8	87	33	62	81	68	40

† Geometric mean.
* Value is estimated by using a log-probability regression to predict the values of data below the detection limit.
NOTE: Multiple detection limits during the period of record may result in different values flagged with a "<."

temperatures would be needed to assess conditions relative to water-quality standards.

Dissolved-oxygen concentrations ranged from 5.8 to 12.9 mg/L (table 10). As expected, concentrations at all sites generally were inversely proportional to temperature and, thus, tended to be lower during the summer than during the winter. North Carolina water-quality standards specify 4.0 mg/L as a minimum instantaneous concentration of dissolved oxygen in the State's streams (North Carolina Department of Environment, Health, and Natural Resources, 1997a). This concentration is considered to be the minimum necessary to support a community of tolerant fish species. All concentrations measured at the Little Cross

Creek sites were well above this numerical criterion. As previously noted, however, no measurements were made during August and September when minimal dissolved-oxygen concentrations may have occurred.

Because the solubility of dissolved oxygen in water varies inversely with temperature, it is meaningful to examine dissolved oxygen results in terms of percentage of saturation. The percentage of saturation of dissolved oxygen at all sites in the study area was highest during the winter and generally lowest during the warmer months of May, June, and July 1997. The percentage of saturation at site S1 was lower than at other sites in the study area, ranging from 69 to 88 percent (table 10). The median percentage of saturation increased from 78 percent at site S1 to 86 percent at S2, and median values were 90 percent or greater at sites S3 through S7 (table 10).

pH and Specific Conductance

The pH of surface waters represents an integrated result of a number of chemical equilibria, many of which are altered by sample handling and storage. Therefore, pH was measured immediately after collecting a sample in the field. State water-quality standards recommend a pH range of 6.0 to 9.0 to protect aquatic life, but note that lower values may occur as a result of natural conditions (North Carolina Department of Environment, Health, and Natural Resources, 1997a).

Median pH values at the Little Cross Creek sites were between 6 and 7 standard units, indicating a slight acidity (table 10). Precipitation near Fayetteville also is acidic, with an average pH of 4.6 measured during 1996 and 1997 (National Atmospheric Deposition Program/ National Trends Network, 1999). During the Little Cross Creek study, a minimum pH value of 5.2 was observed at site S1, and a maximum value of 7.5 was observed at site S2 (table 10).

In general, pH values were lowest at site S1, and pH values measured at site S1 were significantly lower during storms than during base-flow conditions. The drainage area for site S1 is dominated by longleaf pine forest, and soil leachate from this type of system tends to be acidic. During a 1986 investigation of several streams in the Sand Hills ecoregion, the North Carolina Division of Water Quality noted that streams with small, undisturbed catchments had pH values averaging 4.3 to 4.9 (David Penrose, North Carolina Division of Water Quality, written commun., December 1, 1998). In pine-dominated ecosystems, acidic conditions are normal, and land-disturbing activities, such as construction and agriculture, are associated with increases in pH (Morgan, 1984).

Specific conductance is a measure of charged ions in solution and, thus, provides a general indication of dissolved-mineral content. Specific conductance in natural waters can range from nearly zero in pure water to 50,000 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C) or more in sea water (Hem, 1985). DENR (1999b) reported that, from September 1993 through September 1997, specific conductance in the Cape Fear River at Fayetteville ranged from 2 to 223 µS/cm with a median of 130 µS/cm. In comparison, specific conductance in the Little Cross Creek watershed ranged from 16 µS/cm at site S1 to 83 µS/cm at site S5 (table 10). Specific conductance tended to increase in a downstream direction at Little Cross Creek sites (S1 through S4 and S7) as drainage area increased and additional dissolved material was added to the stream (fig. 7; tables 2, 10).

The median specific conductance was significantly higher at site S5 in Clark Pond Creek than at all other sites (fig. 7), even though the drainage area for this site was only 0.883 mi^2 (table 2). Further study may be warranted to determine whether the

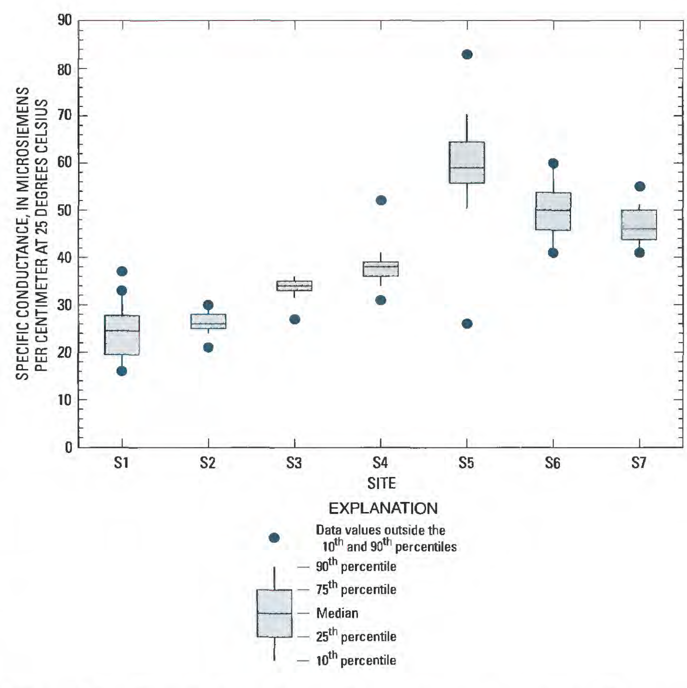

Figure 7. Distribution of specific conductance at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through January 1998.

higher concentrations at this site result from anthropogenic inputs. Specific conductance values showed no seasonality or statistical relation to storms at any of the Little Cross Creek sites.

Fecal Coliform Bacteria

Bacteriological tests are used to assess the sanitary quality of water and the potential public health risks from waterborne diseases. Fecal indicator bacteria, while not typically disease causing, are correlated with the presence of several waterborne pathogens. One of the most widely used indicator bacteria is the fecal coliform group (Myers and Sylvester, 1997). A geometric mean concentration of not more than 200 fecal coliform colonies per 100 milliliters (colonies/100 mL) of water has been established as a safe level for non-potable surface waters (North Carolina Department of Environment, Health, and Natural Resources, 1997a). The North Carolina water-quality standard is based on a geometric mean of at least five samples collected during a 30-day period. During the Little Cross Creek study, samples were not collected with this frequency; therefore, results cannot be said to comply with or violate the standard. However, the numerical criterion of 200 colonies/100 mL is useful for indicating a potential problem with bacterial contamination.

Geometric mean concentrations of fecal coliform bacteria were less than 200 colonies/100 mL at all Little Cross Creek sites (table 10). However, at least one sample exceeded this criterion at every site except site S3. Site S4 had higher concentrations relative to the other sites, with 33 percent of the samples at this site having greater than 200 colonies/100 mL and one sample having a maximum concentration of 7,500 colonies/100 mL (fig. 8; table 10). Twenty-nine percent of the samples collected at site S1 had more than 200 colonies/100 mL.

High concentrations of fecal coliform bacteria are commonly observed following rainfall (North Carolina Department of Environment, Health, and Natural Resources, 1997a). A total of 20 of 114 fecal coliform samples exceeded the 200 colonies/100 mL criterion during the Little Cross Creek study; 18 of these samples were collected during high streamflow. Concentrations at sites S1, S4, and S5 were significantly higher during storms than during base-flow conditions based on a rank-sum statistical test. Densities of fecal coliform bacteria did not follow

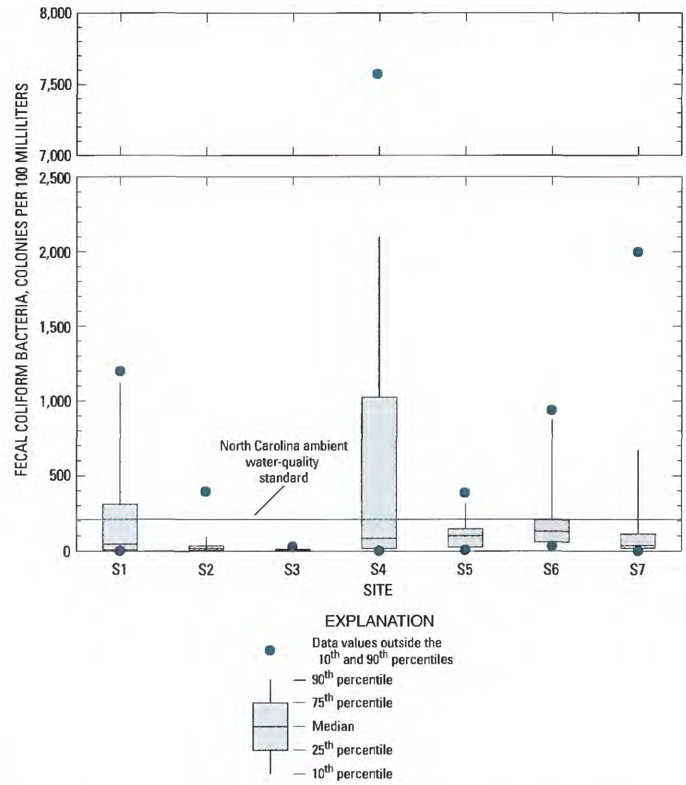

Figure 8. Distribution of concentrations of fecal coliform bacteria at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through January 1998.

apparent seasonal patterns at any of the Little Cross Creek sites.

Turbidity and Suspended Sediment

Turbidity is a measure of water clarity and, therefore, is important to producers of potable drinking water. Water-treatment plants that draw from a surface-water source commonly use fluid-particle separation processes to increase the clarity of their product. The turbidity of the surface-water source is a major determinant of the ease and cost of treatment.

Turbidity is caused by suspended and colloidal matter including silt, clay, microscopic organisms like plankton and zooplankton, and finely divided organic matter in water, and is a measure of how these substances cause light to be scattered and absorbed. Although turbidity generally is proportional to concentrations of suspended sediment, actual correlation is difficult because particle sizes, shapes, and refractive properties all influence the turbidity measurement (American Public Health Association and others, 1995). Turbidity also may be affected by the presence of colored solutes and by the precipitation of dissolved constituents during sample handling and storage (Fishman and Friedman, 1989).

Kruskal-Wallis analysis indicated that turbidity varied significantly between sites in the Little Cross Creek study area (fig. 9A). Site S1 had the highest distribution of turbidity concentrations, including the maximum observed concentration of 60 nephelometric turbidity units (NTU). This observation was the only

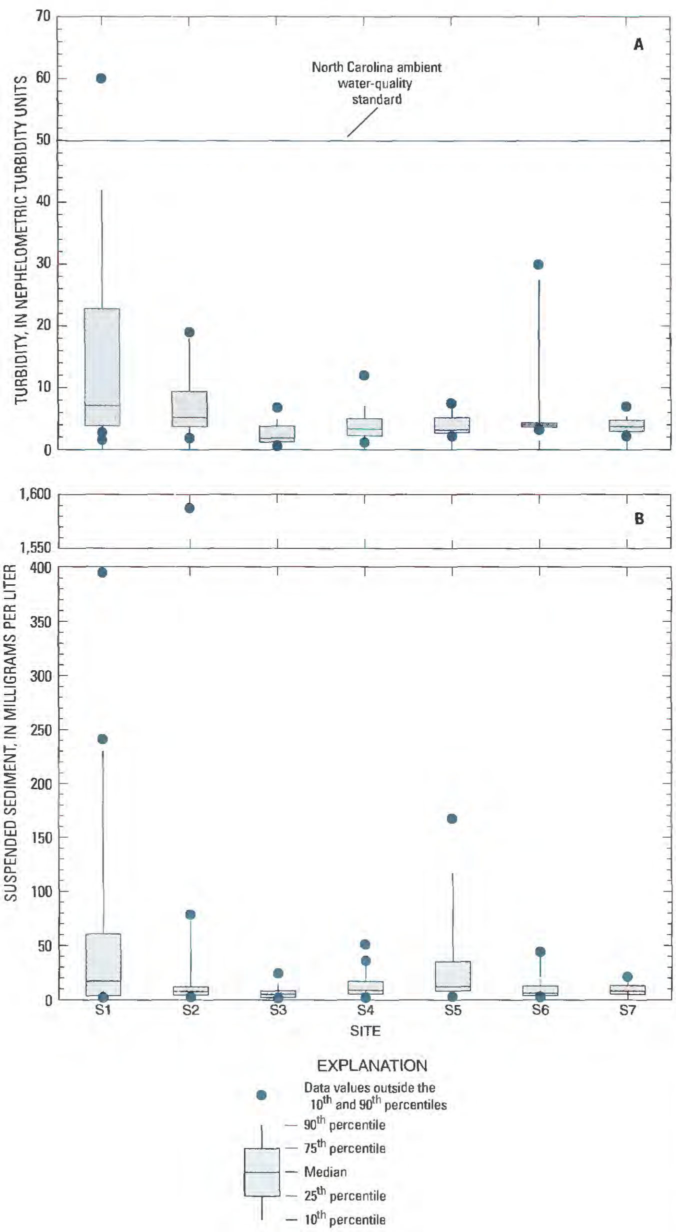

Figure 9. Distribution of concentrations of (A) turbidity, October 1996 through January 1998, and (B) suspended sediment, September 1996 through January 1998, at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7.

sample to exceed the North Carolina State standard for turbidity of 50 NTU (North Carolina Department of Environment, Health, and Natural Resources, 1997a) and occurred during storm-event sampling. Maximum and median turbidity concentrations decreased in a downstream direction from sites S1 to S2 and S3 (fig. 9A; table 10). Despite one high value of 30 NTU at site S6, concentrations of turbidity entering Glenville Lake from sites S4, S5, and S6, and exiting Glenville Lake at site S7 generally were low, with medians of less than 4 NTU (fig. 9A; table 10).

Rank-sum analysis indicated that turbidity was significantly higher at sites S1 and S4 during periods of rainfall than during base flow. These two sites receive direct stormwater runoff. At sites downstream from the reservoirs (sites S2, S3, S5, and S7), rainfall had no significant effect on turbidity, presumably because the impoundments acted as sediment-settling basins. No seasonal patterns were evident in turbidity concentrations at the Little Cross Creek sites.

Fluvial sediment is the leading cause of water-quality impairment in North Carolina rivers and streams (North Carolina Department of Environment and Natural Resources, 1999a). High amounts of stream-borne sediment impair aesthetic quality and reduce the diversity and abundance of aquatic life in streams. Sedimentation also reduces the storage capacity of reservoirs. The primary sources of suspended sediment in streams are stormwater runoff from the watershed and erosion of the stream channel itself (Hem, 1985).

Suspended sediment at the Little Cross Creek sites ranged from a minimum of 1 mg/L at sites S1, S3, and S4 to a maximum of 1,590 mg/L at site S2 on December 19, 1996 (fig. 9B; table 10; supplementary table ST-12). The second highest concentration of 395 mg/L was measured at site S1 on July 30, 1997 (supplementary table ST-11). It is believed that the outlying observation at site S2 may have resulted from inadvertently introducing streambed sand into the bottle during sample collection. Particle-size analysis of this sample showed that 99 percent of the suspended sediment was greater than 0.062 millimeter in diameter and, therefore, classified as sand (supplementary table ST-12). The second highest concentration of suspended sediment measured at site S2 was 79 mg/L. It also should be noted that concentrations of suspended sediment at site S2 may have been elevated slightly during January through March 1997, while Bonnie Doone Lake was being hydraulically dredged. Thus, summary statistics for this site may not be representative of typical conditions.

In general, concentrations of suspended sediment at sites S1, S2, S3, and S4 showed patterns similar to those of turbidity (fig. 9A, B). Median concentrations of suspended sediment decreased in a downstream direction from 17 mg/L at site S1, to 8 mg/L at site S2, to 5 mg/L at site S3, then increased slightly to 8 mg/L at site S4 (table 10). The lowest suspended-sediment concentrations were observed at site S3. These results indicate that Kornbow Lake, in tandem with Bonnie Doone Lake, acts as an effective sediment trap for the upper Little Cross Creek watershed.

Sites S1 and S5 had relatively higher concentrations of suspended sediment than the other Little Cross Creek sites (fig. 9B; table 10). Unlike other sites, site S1 had no upstream impoundment to intercept sediment. Site S5 was situated downstream from a series of small impoundments (fig. 2), but in a highly urbanized setting. Concentrations observed at sites S1 and S5 were consistent with observations from other predominantly urban sites in the North Carolina Coastal Plain (Simmons, 1993) but generally were lower than at urban sites in the Piedmont (Davenport, 1989; Simmons, 1993; Bales and others, 1999). Suspended-sediment concentrations measured at the other Little Cross Creek sites (S2, S3, S4, and S7) were similar to concentrations measured at pristine sites in the Coastal Plain (Simmons, 1993) and probably resulted from sediment trapping in upstream reservoirs.

Suspended-sediment results did not vary seasonally but were related to streamflow at some sites. Similar to turbidity, suspended-sediment concentrations were significantly higher during rainfall periods than during base flow at sites S1 and S4—two sites that receive direct inputs of stormwater runoff. At sites S1 and S4, median concentrations during base-flow conditions were 3 and 8 mg/L, respectively, and median concentrations during storms were 32 and 13 mg/L, respectively.

Nitrogen

Nitrogen (N) and phosphorus (P) are the macronutrients that typically regulate productivity in the aquatic food web (Wetzel, 1983). Sources of nitrogen to surface waters include fertilizers, animal wastes, soil leaching, precipitation, ground-water inputs, decomposition of organic matter, and biological fixation of nitrogen gas (Wetzel, 1983; Hem, 1985).

Nitrogen occurs in numerous forms and oxidation states in natural water. During the investigation of Little Cross Creek, nitrite plus nitrate, ammonia, and total ammonia plus organic nitrogen were measured and reported in terms of equivalent concentrations of elemental nitrogen. As discussed earlier in this report, these three nitrogen species had different laboratory reporting levels that influence interpretation of the results.

Nitrite plus nitrate and ammonia are inorganic species of nitrogen that are readily assimilated by aquatic vegetation. Under well-oxygenated conditions, such as those observed in Little Cross Creek, nitrite concentrations generally are low because nitrite is quickly oxidized to nitrate. Thus, the nitrite plus nitrate component is composed primarily of nitrate. Organic nitrogen, computed by subtracting ammonia from total ammonia plus organic nitrogen, occurs in water as dissolved amino acids and polypeptides, and as living or detrital particulate matter. Total nitrogen concentrations usually are computed by summing total ammonia plus organic nitrogen and nitrite plus nitrate. Because numerous samples collected during the Little Cross Creek study contained total ammonia plus organic nitrogen below the MRL, total nitrogen concentrations are not presented in this report.

Currently, North Carolina State water-quality standards for nutrients have been promulgated only for nitrate in water-supply waters (North Carolina Department of Environment, Health, and Natural Resources, 1997a). However, it is widely accepted that elevated concentrations of nitrogen and phosphorus contribute to water-quality degradation by accelerating eutrophication in lakes and reservoirs. Lake productivities generally correspond to their nitrogen and phosphorus levels (table 11), and concentrations of inorganic nitrogen exceeding 1.5 mg/L commonly are associated with nuisance growths of algae and other undesirable symptoms of overenrichment. Therefore,

Table 11. General relation of lake productivity to average concentrations of inorganic nitrogen and total phosphorus (modified from Wetzel, 1983)

[mg/L, milligrams per liter; <, less than; >, greater than]

Level of lake productivity	Inorganic nitrogen (mg/L)	Total phosphorus (mg/L)
Ultra-oligotrophic	<0.20	<0.005
Oligo-mesotrophic	0.20–0.40	0.005–0.01
Meso-eutrophic	0.30–0.65	0.01–0.03
Eutrophic	0.5–1.5	0.03–0.10
Hypereutrophic	>1.5	>0.10

managers of water-supply impoundments are concerned about high nitrogen concentrations in streams entering those impoundments.

Comparison of the nitrogen species measured at the Little Cross Creek study sites indicates that nitrite plus nitrate was present in higher concentrations than ammonia, and that the relative proportions of the three species varied among sites (fig. 10). For example, at

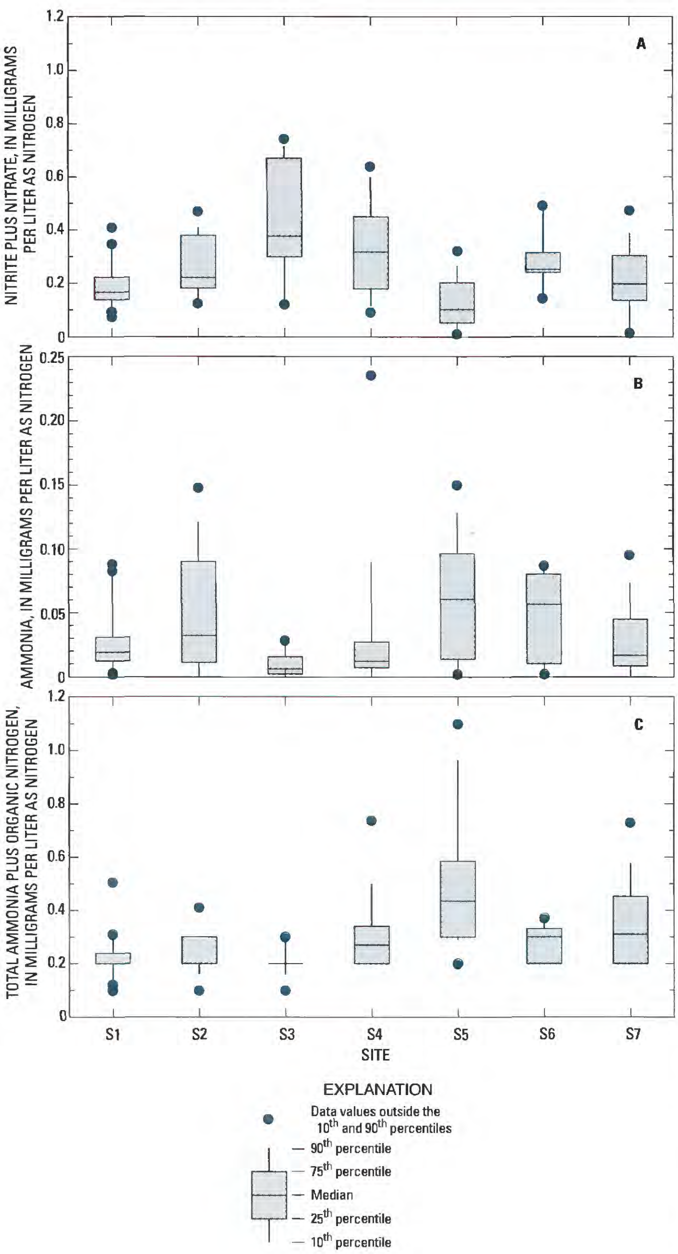

Figure 10. Distribution of concentrations of (A) nitrite plus nitrate, (B) ammonia, and (C) total ammonia plus organic nitrogen at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through January 1998.

Little Cross Creek site S3, nitrite plus nitrate was the predominant form of nitrogen, while ammonia and total ammonia plus organic nitrogen concentrations were low. Conversely, total ammonia plus organic nitrogen predominated at Clark Pond Creek (site S5), and nitrite plus nitrate was low relative to the other sites (fig. 10).

Nitrite plus nitrate concentrations ranged from 0.010 to 0.740 mg/L and generally were highest at site S3 (fig. 10A; table 10). No observations violated the North Carolina State nitrate standard for water supplies of 10 mg/L (North Carolina Department of Environment, Health, and Natural Resources, 1997a). The National Atmospheric Deposition Program (NADP) monitors several constituents in precipitation at sites in Scotland and Sampson Counties, both within 50 miles of the Little Cross Creek study area (National Atmospheric Deposition Program/National Trends Network, 1999). These data indicate that the average concentration of nitrate in precipitation during the Little Cross Creek study was approximately 0.23 mg/L as N, which was within the range of concentrations observed at the Little Cross Creek sites.

Concentrations of nitrite plus nitrate in the Little Cross Creek study area were somewhat higher than concentrations previously reported for unpolluted streams in the same geochemical zone (Simmons and Heath, 1982; Caldwell, 1992). However, concentrations in the Little Cross Creek area were similar to or lower than those observed in urban streams near the Research Triangle area (Garrett and others, 1994), Greensboro (Davenport, 1989), High Point (Davenport, 1993), and Charlotte, N.C. (Robinson and others, 1996, 1998). Concentrations of nitrite plus nitrate did not vary in relation to streamflow at any of the study sites.

Nitrite plus nitrate was the only nutrient species that showed distinct seasonality. At all sites downstream from impoundments (sites S2, S3, S4, S5, and S7), nitrite plus nitrate followed a sinusoidal cycle, with peak concentrations during the winter and minimal concentrations during the summer (fig. 11). Seasonal dynamics of nitrate in the Little Cross Creek reservoirs, although not measured directly, probably are similar to patterns observed in other southeastern reservoirs (Radtke, 1986; Giorgino and Bales, 1997; Bales and Giorgino, 1998). In productive reservoirs, nitrate may be depleted from reservoir surface waters by plankton uptake during the summer growing season. At the same time, reservoir bottom waters tend to become hypoxic. Hypoxic conditions favor denitrification (the bacterial conversion of nitrate to nitrogen gas), which further

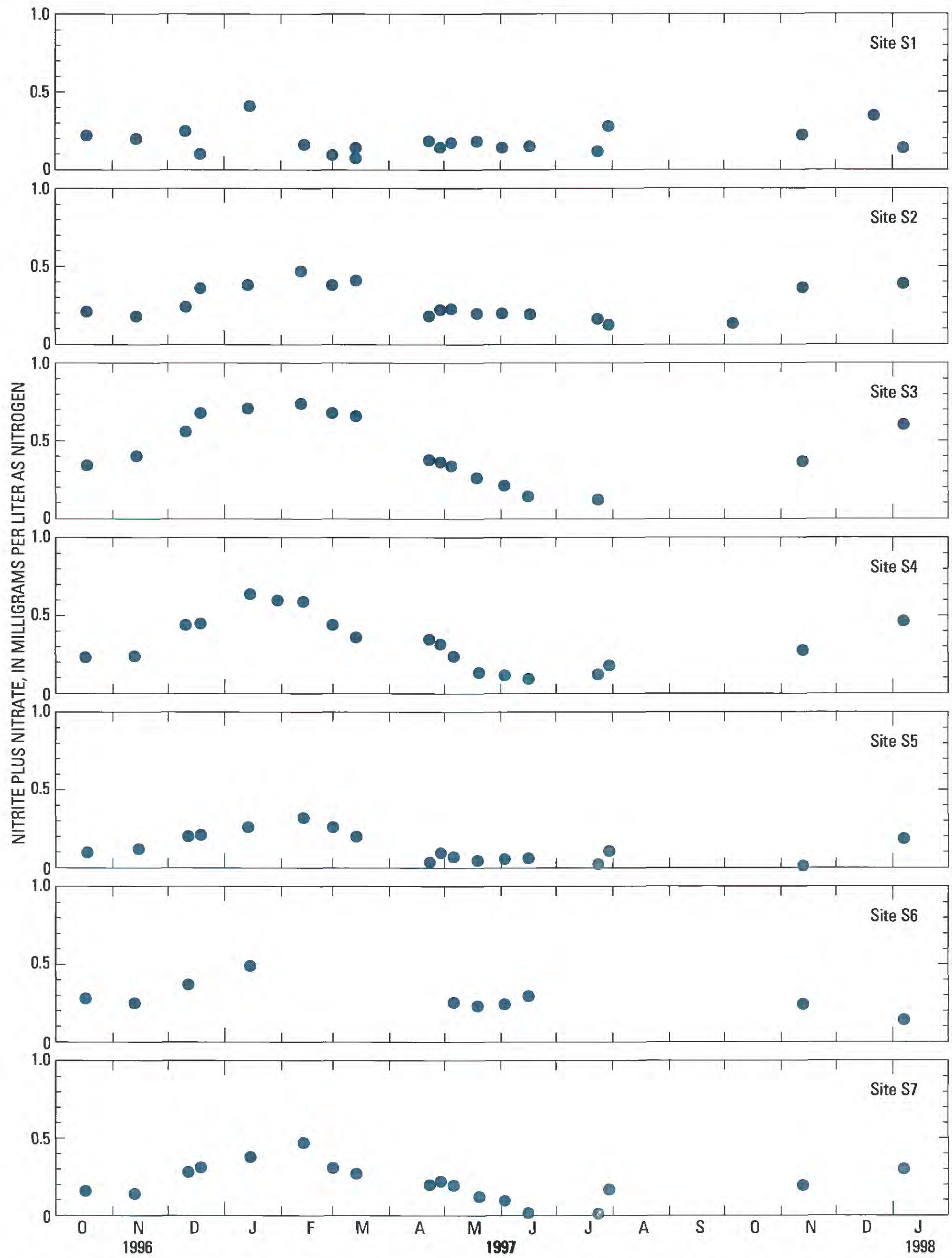

Figure 11. Concentrations of nitrite plus nitrate at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through January 1998.

reduces nitrate concentrations in the reservoir (Wetzel, 1983).

Ammonia concentrations at the Little Cross Creek sites ranged from less than 0.002 to 0.236 mg/L (table 10) and did not vary seasonally at any of the study sites. The maximum concentration was measured at site S4 during a storm; only at this site were median ammonia concentrations significantly higher during storm-related sampling (0.026 mg/L) than during base flow (0.008 mg/L). Even so, ammonia concentrations in Little Cross Creek during storms were lower than those measured in some urban streams in Charlotte and the Research Triangle area (Robinson and others, 1996, 1998; Garrett and others, 1994). During the study, the average ammonia concentration in precipitation was approximately 0.21 mg/L as N, which was higher than most concentrations observed in Little Cross Creek (National Atmospheric Deposition Program/National Trends Network, 1999).

Fifty percent of the ammonia samples collected in the Little Cross Creek watershed contained less than 0.020 mg/L. In well-oxygenated streams, such as those sampled in the Little Cross Creek study, ammonia is rapidly assimilated by aquatic plants or converted to nitrate by bacteria; hence, concentrations generally are low. Overall, the highest median ammonia concentrations were observed at sites S5 and S6, and the lowest concentrations occurred at site S3 (fig. 10B; table 10). Concentrations were within ranges observed in unpolluted streams in the Sand Hills area of North Carolina (Simmons and Heath, 1982; Caldwell, 1992), with no extremely elevated peaks such as those observed in several streams near Durham (Garrett and others, 1994) and Charlotte (Robinson and others, 1996, 1998).

Total ammonia plus organic nitrogen concentrations ranged from less than 0.10 to 1.1 mg/L (table 10) and varied significantly among sites. Site S5 had the highest concentrations, with a median of 0.44 mg/L, and site S3 had the lowest concentrations, with a median of less than 0.20 mg/L (fig. 10C; table 10). Concentrations of total ammonia plus organic nitrogen in 40 of the 121 samples (or 33 percent) analyzed during this investigation were below laboratory reporting levels. Percentages of samples below the MRL at individual sites ranged from 0 percent at sites S5 and S6 to 70 percent at site S1 and 71 percent at site S3. A high proportion of values below reporting levels limited interpretation of these data at some sites.

At site S4, storm-related samples contained significantly more total ammonia plus organic nitrogen than base-flow samples (base-flow median= 0.20 mg/L); however, the median concentration during storms was only 0.33 mg/L. Concentrations observed at the Little Cross Creek sites were similar to those observed in streams near High Point (Davenport, 1993), but were lower than in urban streams in Charlotte and the Research Triangle area of North Carolina (Garrett and others, 1994; Robinson and others, 1996, 1998). Concentrations of total ammonia plus organic nitrogen did not appear to vary seasonally at sites in Little Cross Creek.

Phosphorus

Like nitrogen, phosphorus is an essential plant nutrient. In sufficient amounts, phosphorus can support undesirably high rates of vegetative production in water bodies. Nutrient enrichment, or "eutrophication," can impair water quality by promoting the growth of undesirable organisms and by aggravating hypolimnetic anoxia that, in turn, can lead to excessive concentrations of soluble metals including iron and manganese. Both consequences have negative implications for treating and consuming drinking water.

Phosphorus is naturally present in water as the result of the dissolution of rock minerals in soils and geologic formations; therefore, background concentrations vary geographically. Because phosphorus is an essential element in metabolism, it is always present in animal wastes (both wildlife and domestic) and in human sewage. Phosphorus also may enter surface waters from drainage areas where phosphate fertilizer has been applied.

Phosphorus is present in natural waters in many forms, including dissolved phosphate anions, organic phosphates in biota, colloidal particulates, and complexes with metal oxides, especially ferric hydroxide (Wetzel, 1983; Hem, 1985). As with nitrogen, concentrations of phosphorus have been related to various degrees of lake productivity (table 11). There is general agreement that concentrations of total phosphorus above 0.10 mg/L are associated with nuisance growths of algae and other symptoms of overenrichment in lakes. The National Technical Advisory Committee (1968) lists 0.05 mg/L as a limit for streams entering impoundments.

During the Little Cross Creek investigation, dissolved orthophosphorus and total phosphorus were measured and reported in terms of equivalent concentrations of elemental phosphorus. Orthophosphorus is a dissolved, inorganic species that is readily available for uptake by aquatic plants. Total phosphorus includes both particulate and dissolved, and organic and inorganic phosphorus compounds.

Concentrations of dissolved orthophosphorus ranged from less than 0.001 mg/L at all sites to 0.024 mg/L at site S4 (fig. 12A; table 10). Concentrations of orthophosphorus in 45 percent of all samples collected during the Little Cross Creek study contained less than the MRL of 0.001 mg/L. At individual sites, values below reporting levels made up 22 to 71 percent of the samples. Orthophosphorus

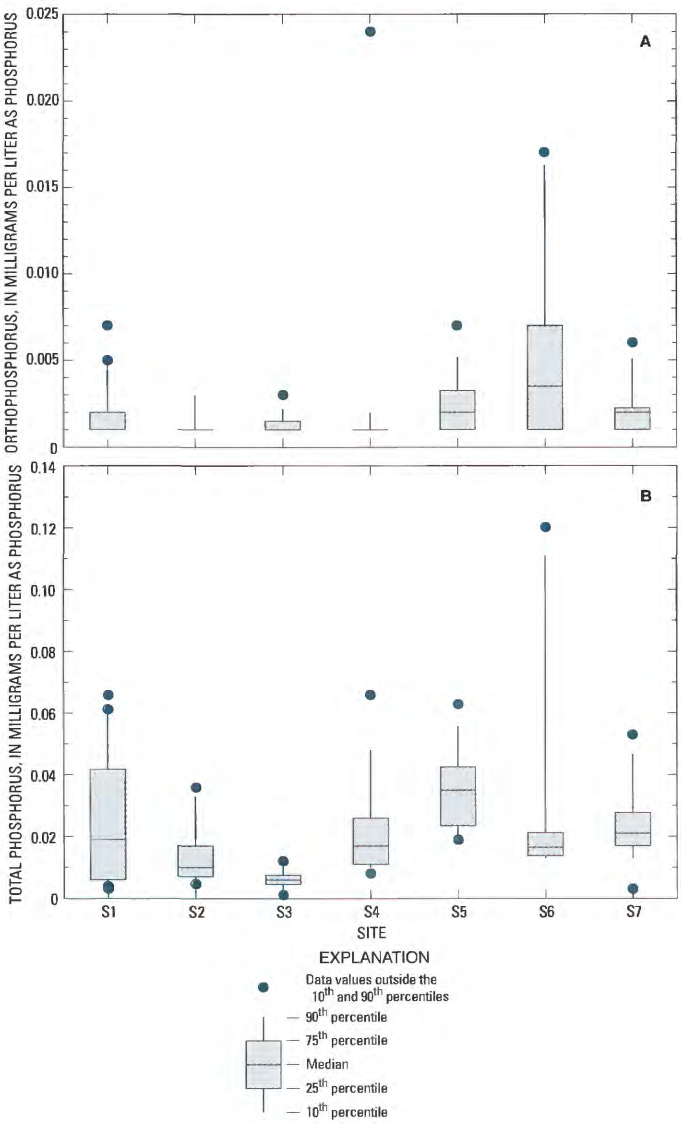

Figure 12. Distribution of concentrations of (A) orthophosphorus and (B) total phosphorus at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through January 1998.

concentrations were not statistically related to streamflow conditions or to seasonal cycles.

The maximum orthophosphorus concentration of 0.024 mg/L was observed on November 13, 1997, during a storm (supplementary table ST-14). All other samples from this site contained orthophosphorus concentrations less than or equal to 0.002 mg/L. Only two additional samples had orthophosphorus concentrations greater than or equal to 0.010 mg/L; these were collected at site S6. The maximum concentration at site S6 (0.017 mg/L) occurred on January 15, 1997, during base-flow conditions. On this date, the PWC was engaged in instream construction work near the pump intake at Cross Creek (the source of water for site S6); this activity also resulted in high turbidity, total suspended solids, suspended sediment, and total phosphorus concentrations in water collected from site S6 (supplementary table ST-16).

Total phosphorus concentrations in the Little Cross Creek study area ranged from 0.001 mg/L at site S3 to 0.120 mg/L at site S6 (fig. 12B; table 10). The maximum concentration at site S6 was measured on January 15, 1997, during conditions described in the preceding paragraph. All other samples collected from the Little Cross Creek study area contained less than 0.07 mg/L, which is much lower than concentrations measured in urban streams near Greensboro (Davenport, 1989), Charlotte (Robinson and others, 1996, 1998), and the Research Triangle area (Garrett and others, 1994). The highest median concentration (0.035 mg/L) was observed at site S5 (table 10).

Distributions of total phosphorus concentrations decreased significantly from site S1 to site S3, indicating that much of the phosphorus from the upper Little Cross Creek watershed was retained in Bonnie Doone Lake and Kornbow Lake (fig. 12B) Concentrations of total phosphorus observed at site S3 were similar to those reported for unpolluted streams in the Sand Hills (Simmons and Heath, 1982; Caldwell, 1992).

At sites S1, S4, and S5, total phosphorus concentrations were significantly higher during high flow than during base flow. Median stormflow concentrations at sites S1, S4, and S5 were 0.034, 0.023, and 0.042 mg/L, respectively, compared to base-flow medians of 0.006, 0.013, and 0.024 mg/L, respectively.

Total Organic Carbon

The composition of organic matter in surface waters is complex, because organic matter represents a mixture of plant and animal products in various stages of decomposition. The organic matter pool includes dissolved organic carbon molecules, such as humic and fulvic acids, as well as living and dead particulate organic carbon. Sources of organic matter to surface waters include both allochthonous materials (of terrestrial origin) and autochthonous matter (from instream production).

Total organic carbon analysis provides a convenient and direct measure of the total organic content of a body of water (American Public Health Association and others, 1995) and provides some indication of organic pollution loads (Hem, 1985). Concentrations of total organic carbon typically range from 1 to 30 mg/L in natural waters; higher concentrations generally occur under polluted conditions (Wetzel, 1983).

In the Little Cross Creek study area, concentrations of total organic carbon ranged from 1.4 to 10 mg/L, with both occurring at site S1 (fig. 13; table 10). The maximum concentration was observed on December 22, 1997, during storm-related sampling (supplementary table ST-11). At site S1 only, storm-related samples contained significantly more total organic carbon than base-flow samples (medians equaled 3.8 and 1.9 mg/L, respectively). Relatively lower concentrations of total organic carbon were detected at sites S1 through S3 in the upper Little Cross Creek watershed than at sites S5 through S7 in the lower watershed. Total organic carbon concentrations at site S4 were in the intermediate value range (fig. 13).

Seasonal variations in total organic carbon were most apparent at sites S3, S4, and S7, where concentrations tended to be higher during summer than winter (fig. 14). The higher summertime concentrations probably reflect increased algal and aquatic plant production in the reservoirs upstream from these sites.

None of the total organic carbon concentrations observed at the Little Cross Creek sites indicated high levels of organic pollution. In comparison, Robinson and others (1998) reported median total organic carbon concentrations of 10 to 19 mg/L at nine urban streams near Charlotte, N.C.; maximum total organic carbon concentrations exceeded 100 mg/L at two of the sites.

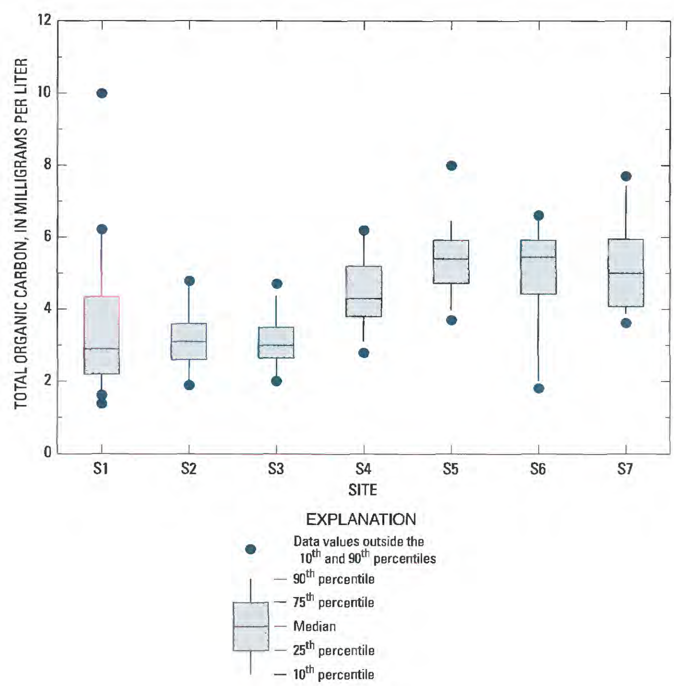

Figure 13. Distribution of concentrations of total organic carbon at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through January 1998.

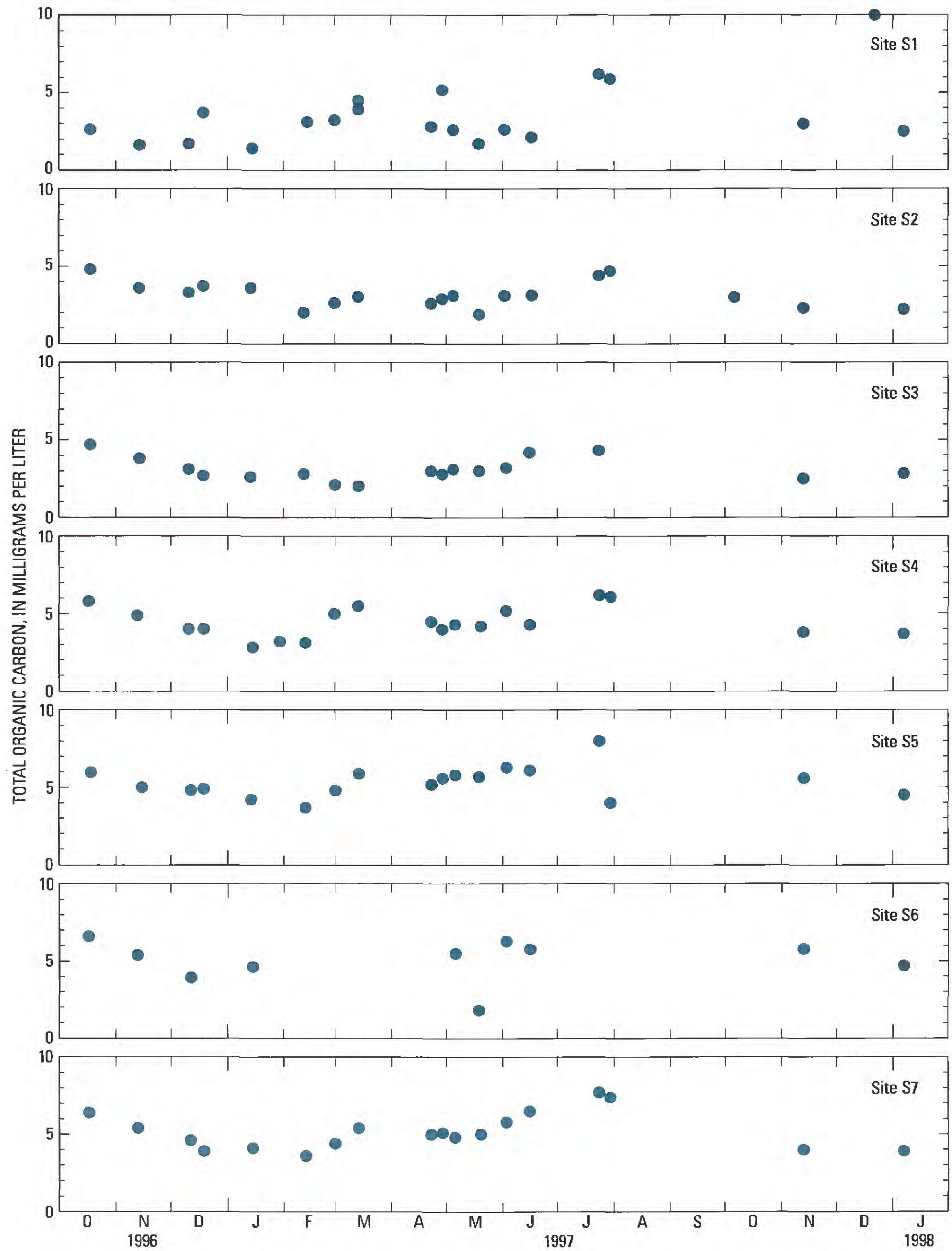

Figure 14. Concentrations of total organic carbon at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through January 1998.

LOADS OF SELECTED WATER-QUALITY CONSTITUENTS

Because the PWC is concerned about sedimentation and nutrient enrichment in the Little Cross Creek Basin, annual loads of suspended sediment, total nitrogen, total phosphorus, and total organic carbon were computed for each site for the 12-month period from October 1996 through September 1997. The computed loads were used to estimate sediment and nutrient inputs to the four Little Cross Creek reservoirs and to evaluate constituent-retention characteristics of the reservoirs during this time period.

Simultaneous measurements of instantaneous streamflow and constituent concentrations collected by the USGS during this investigation were used to develop log-linear regression relations between instantaneous load and discharge. Loads were computed as follows:

$$L = Q \times C \times k, \qquad (1)$$

where

L = load, expressed in mass of constituent per unit time, such as tons per day;

Q = discharge, in cubic feet per second;

C = constituent concentration, in milligrams per liter; and

k = conversion constant (to express load in the desired units).

Instantaneous loads and discharge were transformed to obtain a more linear relation and to achieve uniform variance about the relation throughout the range of data. Loads were transformed by using natural logarithms. Discharge values were transformed by using either natural logarithms or power transformations, depending on the results of preliminary regression analysis. Further regression analysis tested for significant monotonic time trends and seasonality as described by Bales and others (1999). Final load equations were selected based on goodness of fit, realistic predictions of constituent concentrations at discharges both within and outside the sampled range, and examination of regression residuals. In general, predicted concentrations were considered unrealistic if they exceeded concentrations observed in the Little Cross Creek watershed by at least an order of magnitude. Residuals were examined for heteroscedasticity, for normality, and to ensure that remaining explanatory variables were not overlooked.

The selected regression relations (supplementary table ST-18) then were used to compute unit (15-minute interval) loads from the continuous record of discharge collected at each site. Unit loads were summed to produce daily and annual loads for water year 1997.

Negative bias may be introduced when loads are retransformed from a log-space load-discharge equation to the original units (loads are under-predicted). Duan's smearing estimator, which is the mean of the antilog of the residuals from the log-transformed regression equation, effectively corrects for retransformation bias (Duan, 1983; Gilroy and others, 1990). This bias correction factor (BCF) can be equal to or greater than 1.0. A BCF of 1.0 does not alter the load estimate and, thus, is equivalent to applying no correction. In the Little Cross Creek study, calculated BCF's ranged from 1.001 to 1.463 (supplementary table ST-18). Retransformed loads were corrected by multiplying by the BCF. Retransformation bias was not corrected in some earlier studies of constituent loading at other locations; this should be considered when comparing results of the Little Cross Creek investigation with results of other studies.

In certain instances, the 25-percent trimmed mean concentration was used to compute loads for a constituent, rather than using a regression relation. A 25-percent trimmed mean is computed by dropping the highest 25 percent and the lowest 25 percent of the measurements and averaging the rest of the data. By trimming the data, the effects of a few very large (or very small) values on the mean is reduced, and a more reliable measure of the central value of the data is obtained (Helsel and Hirsch, 1992; Ott, 1993). This approach was employed when a regression relation between constituent concentration and flow was biased by an outlier in the data, and the resulting relation predicted unrealistic concentrations at discharges outside of the sampled range. Trimmed means also were used to compute loads for site S6, where no information existed to relate constituent loads to variations in streamflow.

In basins dominated by nonpoint-source inputs, instream concentrations of constituents generally increase with increasing streamflow. In fact, much of the annual instream load may be transported during a few high-flow events. If periodic measurements do not include storm-event samples, estimates of annual loads can be seriously underestimated (Walling and others, 1992). For the Little Cross Creek study, efforts were made to sample a range of discharge conditions, including several storms.

Load estimates are most reliable when constituent concentrations are measured across the entire range of streamflow that occurs at a site. At sites with small catchments, this generally can be accomplished only with the use of automated, flow-activated samplers. During the Little Cross Creek study, water-quality samples were collected manually during high-flow periods, but not at the peak streamflow recorded at each site. However, no more than 0.5 percent of the 15-minute-interval streamflow values recorded during water year 1997 exceeded streamflow maximums associated with water-quality sampling at any of the Little Cross Creek sites (table 12).

Table 12. Comparison of peak instantaneous streamflow recorded from October 1996 through September 1997 with maximum streamflow measured during water-quality sampling at Little Cross Creek sites S1, S2, S3, S4, S5, and S7

[Q, streamflow; WY97, water year 1997; ft^3/s, cubic feet per second]

Site no. (fig. 2)	Peak Q recorded during WY97 (ft^3/s)	Maximum Q during water-quality sampling (ft^3/s)	Percentage of WY97 streamflow values exceeding maximum sampled Q
S1	106	25	0.5
S2	139	66	.1
S3	130	31	.5
S4	195	81	.2
S5	48	26	.2
S7	322	113	.3

For a particular constituent at a site, the percentage of the annual load that was derived from streamflow values exceeding the maximum sampled streamflow depended on the regression relation that was developed. These percentages of extrapolated loads ranged from 1.7 to 77 percent at the Little Cross Creek sites and were highest for all constituents at site S1. The maximum percentage was for suspended sediment. At the remaining sites, extrapolated loads accounted for less than 7 percent of the total annual loads of all constituents (supplementary table ST-18).

Annual loads for the period October 1996 through September 1997 are presented for suspended sediment, total nitrogen, total phosphorus, and total organic carbon at sites S1, S2, S3, S4, S5, S6, and S7 (table 13). During this period, total precipitation in the Little Cross Creek study area was about 6 in. below the annual average of 46.72 in.; therefore, streamflow and load estimates probably under-represent average conditions. Maximum daily loads also are presented; these all occurred during peak flows on October 8, 1996.

Yields (annual load per square mile of drainage area) were computed for sites S1, S2, S3, S4, S5, and S7 (table 13). It should be noted that the hydrologic analysis indicated that the contributing drainage areas for some of these sites may be under-represented. This would cause the constituent yields to be overestimated along with the streamflow yields. In the following sections, estimated loads and yields for the Little Cross Creek sites are discussed in relation to results from other studies of relatively small, urban or developed watersheds in North Carolina.

When interpreting this information, one should consider that load estimates are subject to statistical errors—errors inherent in the discharge and water-quality data as well as errors and bias introduced during load computations. During this study, for example, suspended-sediment concentrations tended to have higher levels of unexplained variance than concentrations of other water-quality constituents; this resulted in relatively weaker load-discharge relations. The weakest regression computed during this study was for suspended-sediment load at site S4, as indicated by the low R^2 value of 0.48 (supplementary table ST-18). In addition, the strength of the load estimates for a single constituent varied among sites. Statistics such as the R^2 and the PRESS (prediction error sum of squares) can be used to compare load regression equations for individual constituents among sites (Helsel and Hirsch, 1992). In general, strong load-discharge regressions have high R^2 values and low PRESS statistics. For example, load equations for nitrogen, phosphorus, and total organic carbon were stronger at site S5 than at site S1 (supplementary table ST-18). Finally, because streamflow values were not adjusted to represent long-term conditions and because the period of water-quality sampling was relatively short, the load estimates presented in this report reflect conditions only during water year 1997.

Suspended Sediment

Suspended-sediment loads do not represent the total sediment load transported by streams. Sediment particles that bounce and roll along the channel bottom compose the bedload portion of the total sediment load. Standard samplers, including those used during this study, cannot accurately measure sediment closer than 2 to 4 in. above the streambed. Because bedload was not measured, only suspended-sediment loads are presented for this investigation (table 13).

Suspended-sediment loads are a function of many watershed factors, including rainfall intensity and streamflow, land-surface slope, land use, soil characteristics, the presence of impoundments, and the implementation of practices to reduce sediment

Table 13. Annual loads of selected constituents at Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, October 1996 through September 1997

[mi^2, square miles; tons/yr, tons per year; ($tons/mi^2$)/yr, tons per square mile per year; —, not computed; %, percent. All maximum daily loads occurred on October 8, 1996]

	Site number (fig. 2)						
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Drainage area (mi^2)	**0.938**	**2.56**	**4.25**	**5.61**	**0.883**	**—**	**9.15**
			Suspended sediment				
Annual load (tons/yr)	200	43.5	40.4	134	26.9	7.31	46.2
Yield ([$tons/mi^2$]/yr)	213	17.0	9.50	23.9	30.5	—	5.04
Maximum daily load (tons)	90.9	1.08	.939	5.20	.982	—	3.79
and percent of annual load	45%	2%	2%	4%	4%		8%
			Total nitrogen[a]				
Annual load (tons/yr)	0.678–997	2.57–2.77	4.21–5.94	6.17–6.54	1.21	0.662	3.22–3.48
Yield ([$tons/mi^2$]/yr)	0.723–1.06	1.00–1.08	0.990–1.40	1.10–1.17	1.38	—	0.352–0.380
Maximum daily load (tons)	0.046–0.047	0.080–0.089	0.118–0.124	0.187–0.202	.057	—	0.288–0.352
and percent of annual load	5–7%	3%	2–3%	3%	5%		9–10%
			Total phosphorus				
Annual load (tons/yr)	0.045	0.077	0.048	0.333	0.072	0.019	0.164
Yield ([$tons/mi^2$]/yr)	.048	.030	.011	.059	.081	—	.018
Maximum daily load (tons)	.005	.004	.001	.008	.005	—	.025
and percent of annual load	11%	5%	2%	2%	7%		15%
			Total organic carbon				
Annual load (tons/yr)	7.93	17.8	27.8	48.7	10.2	6.15	33.3
Yield ([$tons/mi^2$]/yr)	8.46	6.95	6.54	8.68	11.5	—	3.64
Maximum daily load (tons)	.968	139	.723	1.74	.371	—	4.45
and percent of annual load	12%	8%	3%	4%	4%		13%

[a]A range of loads is presented for sites with censored data. See text for additional explanation.

delivery (Simmons, 1993). Yields tend to be highest in areas with high slopes and streamflow velocities, erodible soils, and land-use patterns that disturb or expose the soil surface.

In a survey of suspended-sediment characteristics at 152 sites in North Carolina, Simmons (1993) reported that suspended-sediment yields were minimal in forested basins, intermediate in rural/agricultural basins, and highest in urban areas of the State. Overall, the highest suspended-sediment concentrations and yields in North Carolina were observed at sites in the Piedmont Province.

Yields of suspended sediment ranged from 5.04 to 213 tons per square mile per year ([$tons/mi^2$]/yr) at the Little Cross Creek sites (table 13). The highest yield was observed at site S1, upstream from Bonnie Doone Lake. The basin draining to this site includes forested areas, areas with military/industrial facilities, and cleared areas with numerous unpaved roads. Substantially lower yields at sites S2 and S3 (17.0 and 9.50 ($tons/mi^2$)/yr, respectively) indicate that Bonnie Doone and Kornbow Lakes trap much of the sediment transported by tributaries in the upper Little Cross Creek watershed. At sites S4 and S5, which are located in established residential/commercial areas, suspended-sediment yields were intermediate values (table 13). It should be noted that yields for all constituents at site S7 were relatively low, partly because of constituent trapping in Glenville Lake and partly because of withdrawals into the Glenville Water Plant.

In unimpounded streams, much of the total suspended-sediment load tends to be carried by medium to high streamflows. At site S1 in Little Cross Creek, 45 percent of the total annual suspended-sediment load occurred during 1 day (table 13). Impoundments upstream from sites S2, S3, S4, S5, and S7 lessened the degree of storm-related transport. Maximum daily suspended-sediment loads at these sites ranged from 2 to 8 percent (table 13).

Suspended-sediment characteristics have been studied in several Piedmont streams, but relatively little information has been gathered in the Sand Hills region of North Carolina. Simmons (1993) reported that the average suspended-sediment yield for a site in Flat Creek near Inverness was 60 (tons/mi^2)/yr during the period 1970–79. This site was located at Fort Bragg, in a basin with minor development and some streambank erosion. Caldwell (1992) estimated suspended-sediment yields of 9.8 (tons/mi^2)/yr during a normal streamflow year and 4.8 (tons/mi^2)/yr during a drought year for a minimally disturbed stream in the Sand Hills. Retransformation bias was not corrected in these two studies; therefore, the yields may be underestimated.

With the exception of site S1, sediment yields at the Little Cross Creek sites were relatively low compared to published values for several small (less than 200 mi^2) basins in the North Carolina Piedmont. Sediment yields at nine urban sites in Charlotte ranged from 77 to 4,700 (tons/mi^2)/yr during 1993–98, and were highest in a basin undergoing rapid development (Bales and others, 1999). Residential areas that had been built-out for several years and industrial areas generally had the lowest sediment yields in the Charlotte study. Average suspended-sediment yields of 22 to 347 (tons/mi^2)/yr during 1989–94 were reported for seven basins in the upper Neuse River Basin; yields ranged from 47 to 252 (tons/mi^2)/yr for four watersheds in the upper Cape Fear River Basin (Childress and Treece, 1996). Colston (1974) reported a sediment yield of about 2,100 (tons/mi^2)/yr for an urban basin in Durham, and Mustard and others (1987) reported a yield of 130 (tons/mi^2)/yr for a small urban watershed in Winston-Salem, N.C.

Total Nitrogen

Total nitrogen is typically computed as the sum of nitrite plus nitrate and total ammonia plus organic nitrogen. However, from zero to 71 percent of the total ammonia plus organic nitrogen concentrations measured at the various Little Cross Creek sites were reported as less than the MRL. Consequently, total nitrogen loads were computed in two ways at sites with censored (below-MRL) data. First, minimum total nitrogen loads were computed by assuming that the below-MRL concentrations of total ammonia plus organic nitrogen were zero. Second, maximum total nitrogen loads were computed by assuming that the below-MRL values were equal to the reporting level. Load regression relations were developed independently for minimum and maximum total nitrogen, and the results are presented as a range of total nitrogen loads for sites with censored data (table 13).

Total nitrogen loads ranged from 0.662 ton per year (ton/yr) at site S6 to 6.54 tons/yr at site S4 (table 13). Concentrations of nitrogen at site S6 were similar to concentrations at other sites; thus, the low load resulted from the small quantity of discharge. Yields of total nitrogen at sites in the Little Cross Creek study area ranged from 0.352 (ton/mi^2)/yr at site S7 to 1.40 (tons/mi^2)/yr at site S3 (table 13). Yields at sites S1 through S5, which were not affected by water withdrawals, generally were near the low end of yields reported for other small watersheds in North Carolina. For example, total nitrogen yields for small basins in the upper Neuse and upper Cape Fear River Basins ranged from 1.0 to 13 (tons/mi^2)/yr with a median of 2.2 (tons/mi^2)/yr (Childress and Treece, 1996). At nine urban sites in Charlotte and Mecklenburg County, total nitrogen yields ranged from 1.6 to 6.6 (tons/mi^2)/yr with a median of 2.7 (tons/mi^2)/yr (Bales and others, 1999). Total nitrogen yield for an urban basin in Winston-Salem was 0.77 (ton/mi^2)/yr (Driver and Tasker, 1990).

Total Phosphorus

Yields of total phosphorus at the Little Cross Creek sites ranged from 0.011 (ton/mi^2)/yr at site S3 downstream from Kornbow Lake to 0.081 (ton/mi^2)/yr at site S5 in Clark Pond Creek (table 13). Higher measured concentrations of total phosphorus relative to concentrations at the other Little Cross Creek sites account for the higher yield at site S5, as streamflow yield was similar among most Little Cross Creek sites (table 5; fig. 12B). Total phosphorus yields computed for the Little Cross Creek sites are slightly lower than yields measured in other developed basins in North Carolina.

In comparison, total phosphorus yields ranged from 0.05 to 2.8 (tons/mi^2)/yr in seven small basins in the upper Neuse River Basin and five small basins in the upper Cape Fear River Basin (Childress and Treece, 1996). The median yield at these sites was 0.28 (ton/mi^2)/yr. At nine urban sites near Charlotte, total phosphorus yields ranged from 0.1 to 13.4 (tons/mi^2)/yr; however, eight of these sites had yields less than or equal to 1.3 (tons/mi^2)/yr (Bales and others, 1999). Median yield at the Charlotte sites was 0.6 (ton/mi^2)/yr. For a small urbanized basin in Winston-Salem, a total phosphorus yield of 0.2 (ton/mi^2)/yr was computed (Mustard and others, 1987).

Total Organic Carbon

Total organic carbon loads in the Little Cross Creek study area ranged from 6.15 tons/yr at site S6 to 48.7 tons/yr at site S4 (table 13). Yields were lowest (3.64 [tons/mi^2]/yr) at site S7 below Glenville Lake (table 13), because upstream withdrawals reduced the quantity of streamflow at this location. Total organic carbon yields at Little Cross Creek sites S1 through S5 ranged from 6.54 to 11.5 (tons/mi^2)/yr (table 13). At nine urban sites near Charlotte, total organic carbon yields averaged from 7.1 to 44.6 (tons/mi^2)/yr; average yields at seven of those sites ranged from 13.1 to 27.9 (tons/mi^2)/yr (Bales and others, 1999).

Reservoir Inflows, Outflows, and Constituent Trapping

Constituent loads for monitored sites in the Little Cross Creek study area provide partial estimates of the total loads into and out of Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake during water year 1997. Loads that were contributed to the reservoirs from unmonitored areas of the watersheds also were estimated to provide complete reservoir inflow estimates (table 14). Estimates were based on assumptions that (1) yields for unmonitored areas upstream from Bonnie Doone Lake were similar to yields for site S1, and (2) yields for all other unmonitored areas in the Little Cross Creek Basin were

Table 14. Inflow and outflow loads of selected constituents for the Little Cross Creek reservoirs, October 1996 through September 1997

Source	Load during water year 1997, in tons			
	Suspended sediment	Total nitrogen	Total phosphorus	Total organic carbon
Bonnie Doone Lake				
Gaged inflow load at site S1	200	0.838[a]	0.045	7.93
Inflow load from ungaged drainage area	346	1.45	.078	13.8
Total inflow load	546	2.29	.123	21.7
Total outflow load (Gaged outflow load at site S2) and percent of total inflow load trapped	43.5 92%	2.67[a] -17%	.077 37%	17.8 18%
Kornbow Lake				
Gaged inflow load at site S2	43.5	2.67[a]	0.077	17.8
Inflow load from ungaged drainage area	51.4	2.33	.136	19.4
Total inflow load	94.9	5.00	.213	37.2
Total outflow load (Gaged outflow load at site S3) and percent of total inflow load trapped	40.4 57%	5.08[a] -2%	.048 77%	27.8 25%
Mintz Pond				
Gaged inflow load at site S3	40.4	5.08[a]	0.048	27.8
Inflow load from ungaged drainage area	41.5	1.88	.110	15.6
Total inflow load	81.9	6.96	.158	43.4
Total outflow load (Gaged outflow load at site S4) and percent of total inflow load trapped	134 -64%	6.36[a] 9%	.333 -111%	48.7 -12%
Glenville Lake				
Sum of gaged inflow loads at sites S4, S5, and S6	168	8.23	0.424	65.0
Inflow load from ungaged drainage area	81.2	3.67	.216	30.6
Total inflow load	249	11.9	.640	95.6
Gaged outflow load at site S7	46.2	3.35[a]	.164	33.3
Outflow load in Glenville Water Plant withdrawals	85.0	5.77	.248	56.0
Total outflow load and percent of total inflow load trapped	131 47%	9.12 23%	.412 36%	89.3 7%

[a]Computed as the average of the minimum and maximum total nitrogen loads estimated for this site.

similar to yields from site S5. Most of the unmonitored area upstream from Bonnie Doone Lake has topography, soils, and land uses similar to those of the site S1 drainage area. Land use in the Little Cross Creek Basin downstream from Bonnie Doone Lake is primarily residential and commercial/industrial, similar to the drainage area for site S5. In order to estimate constituent export at the Glenville Water Plant, the total withdrawal during water year 1997 was multiplied by the trimmed mean of constituent concentrations measured at site S7. Inputs from atmospheric deposition and losses via ground-water seepage were not included in this analysis.

During water year 1997, inflow loads of suspended sediment to Bonnie Doone Lake totaled 546 tons (table 14). Outflows accounted for only 8 percent of the inflow load; thus, Bonnie Doone Lake trapped 92 percent of the incoming suspended sediment. Trapping efficiencies for total phosphorus and total organic carbon were less pronounced at 37 and 18 percent, respectively. Comparison of total nitrogen inflows and outflows indicates that a 17-percent gain of total nitrogen occurred within Bonnie Doone Lake (table 14) which did not originate from tributary inflows. Possible sources of additional nitrogen include atmospheric deposition, regeneration of nitrogen in lakebed sediment during dredging, and biological fixation of atmospheric nitrogen. Analysis of NADP nitrogen data for water year 1997 (National Atmospheric Deposition Program/National Trends Network, 1999) showed that atmospheric deposition on the surface of Bonnie Doone Lake accounted for an additional nitrogen load of only 0.01 ton, which was insignificant relative to the total outflow load of 2.67 tons.

Kornbow Lake received about 95 tons of sediment in water year 1997 and retained 57 percent of the inflow load (table 14). Kornbow Lake had the greatest total phosphorus trapping efficiency of all the Little Cross Creek reservoirs, retaining 77 percent of the incoming load. Outflows of total organic carbon represented a 25-percent reduction from inflow loads. No net trapping of total nitrogen occurred in Kornbow Lake (table 14).

Comparison of loads into Mintz Pond and export at site S4 indicate a 64-percent gain for suspended sediment, a 111-percent increase for total phosphorus, and a 12-percent increase for total organic carbon (table 14). It should be noted that, in addition to representing outflow from Mintz Pond, site S4 also receives discharge from storm drains at the U.S. Highway 401 bypass bridge (fig. 2). Because of the location, it cannot be determined whether the increases in sediment, phosphorus, and organic carbon observed at site S4 originate from stormwater runoff or from sources located between site S3 and the Mintz Pond dam. Sources of these constituents upstream from the Highway 401 bridge may include runoff from residential and commercial areas in the Mintz Pond watershed and resuspension of sediment within this shallow reservoir.

Water-plant withdrawals accounted for a large proportion of constituent export from Glenville Lake during water year 1997 (table 14). These export estimates were based on the assumption that concentrations of constituents in withdrawals were equal to average concentrations measured at site S7—an assumption of uncertain validity. Therefore, comparison of loads into and out of Glenville Lake should be interpreted with caution. Load estimates indicate that 47 percent of sediment, 23 percent of total nitrogen, 36 percent of total phosphorus, and 7 percent of total organic carbon entering Glenville Lake was trapped within the reservoir. Glenville Lake had the greatest nitrogen trapping efficiency of the four Little Cross Creek reservoirs. This may have been a result, in part, of denitrification occurring in the extensive wetlands immediately upstream from the lake.

In summary, total nitrogen and total organic carbon loads to the Little Cross Creek reservoirs increased in a downstream direction as drainage area increased (table 14). Loads of suspended sediment decreased from site S1 to site S3 because of particulate trapping in Bonnie Doone and Kornbow Lakes. Load estimates for site S4 indicate an influx of suspended sediment and total phosphorus, which may have resulted from stormwater discharges or unidentified sources between sites S3 and S4. Trapping efficiencies for the various constituents varied widely among reservoirs. Bonnie Doone Lake had the greatest trapping efficiency for suspended sediment (92 percent); phosphorus was trapped most efficiently in Kornbow Lake (77 percent); and the greatest trapping of total nitrogen occurred in Glenville Lake (23 percent).

Sediment and nutrient trapping have been studied in other North Carolina reservoirs; however, these reservoirs are located in the Piedmont and are much larger than the Little Cross Creek impoundments. Weaver (1994) investigated suspended-sediment loading in Lake Michie, a 508-acre reservoir located in Durham County. Comparison of inflow and outflow loads during 1983 through 1991 indicated an average annual suspended-sediment trap efficiency of 89 percent for this reservoir. Similar results were reported for Lake Michie for the period from 1989 through 1994 (Childress and Treece, 1996). Childress and Treece (1996) assessed phosphorus and nitrogen retention in Lake Michie and Jordan Lake from 1989 through 1994, and in Falls Lake from 1989 through 1992. Falls Lake and Jordan Lake are large (12,490 and 14,300 acres, respectively) multipurpose reservoirs located in the Research Triangle area. Average annual trapping efficiencies for phosphorus were 34 percent in Lake Michie, 58 percent in Jordan Lake, and 71 percent in Falls Lake. Jordan Lake and Falls Lake retained an average of 41 and 60 percent, respectively, of annual inflowing nitrogen loads; however, an average annual nitrogen gain of 14 percent was observed in Lake Michie. The greater nitrogen-retention capability of the two large reservoirs was attributed to their longer hydraulic retention times (Childress and Treece, 1996).

SUMMARY

In cooperation with the PWC, the USGS conducted an investigation of Little Cross Creek in Cumberland County, North Carolina, to document ambient hydrologic and water-quality conditions. The USGS collected streamflow, water-quality, and time-of-travel data at several sites in the Little Cross Creek Basin during the period from August 1996 through August 1998. Additional hydrologic and meteorologic records were obtained from the PWC and other public agencies to supplement data collected by the USGS.

The study period included both unusually high and low rainfall conditions, with monthly rainfall accumulations ranging from 1.16 to 10.55 in. Heavy rains occurred during the passage of Hurricanes Fran and Josephine in fall 1996. Drought conditions prevailed during summer and fall 1997, influenced by a persistent El Niño, and total rainfall was about 6 in. below average for the period from October 1996 through September 1997.

Streamflow at the Little Cross Creek gaging sites closely followed precipitation patterns, both seasonally and in response to individual storms. However, comparison of hydrographs at different stream sites showed that impoundments located in the Little Cross Creek Basin dampened peak flows and attenuated the downstream movement of stormwater. Streamflow records at the Little Cross Creek sites also reflected PWC operations in the watershed, such as controlled releases from the reservoirs.

From October 1996 through September 1997, average daily mean streamflows ranged from 1.9 to 11 ft^3/s at sites in the Little Cross Creek study area. Average streamflow per unit drainage area, or yield, ranged from 1.96 to 2.70 $(ft^3/s)/mi^2$ at sites upstream from the Glenville Water Plant. These yields were higher than expected based on previously published information for the Sand Hills of North Carolina, even though rainfall during the 12-month period was about 6 in. below the historical annual average. The contributing drainage area for Little Cross Creek may be larger than the area indicated by the land-surface divide; if so, yields would be overestimated. It is also possible that water may be entering the basin from unidentified sources such as storm-drain networks. Long-term streamflow monitoring and investigation of the ground-water contributing area could improve understanding of the hydrology of the Little Cross Creek Basin.

Immediately downstream from Glenville Lake, average streamflow yield was relatively low (0.67 $[ft^3/s]/mi^2$) during water year 1997 because of drinking-water withdrawals. From October 1996 through September 1997, withdrawals accounted for about 65 percent of the total outflow from Glenville Lake.

Dye-tracer studies were conducted to characterize time of travel in Little Cross Creek from a site upstream from Bonnie Doone Lake to a site downstream from Glenville Lake. Travel times for a range of streamflow conditions were estimated for Little Cross Creek from the Kornbow Lake dam to approximately 1.15 mi upstream from the Glenville Lake dam. Ranges of travel times could not be predicted for remaining sections of Little Cross Creek based on the data that were collected, because travel times were strongly affected by the presence or absence of seasonal stratification in Bonnie Doone, Kornbow, and Glenville Lakes. Additional dye studies or modeling could provide the information needed to predict travel times for all of Little Cross Creek. During future time-of-travel studies, the distribution of temperature and dissolved oxygen in the Little Cross Creek reservoirs should be documented to aid in data interpretation.

Data collected from seven sites indicated that, in general, water quality in Little Cross Creek was satisfactory for its designated use as a drinking-water supply. Published reports of water quality in urban areas of the Sand Hills are relatively scarce; thus, this study provides useful information for future investigations in this region of North Carolina.

Concentrations of suspended sediment at sites downstream from Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake were similar to concentrations observed in minimally disturbed basins in the Sand Hills. At the remaining Little Cross Creek sites, sediment concentrations were similar to those measured at urban sites in the North Carolina Coastal Plain, but generally lower than in urbanized basins in the Piedmont. Concentrations of nitrite plus nitrate and total ammonia plus organic nitrogen were higher at the Little Cross Creek sites than at minimally disturbed sites in the Sand Hills, but lower than in urban Piedmont streams. On the other hand, ammonia concentrations at the Little Cross Creek sites were similar to those reported for minimally developed sites in the Sand Hills. Total phosphorus and total organic carbon concentrations in Little Cross Creek were lower than in urban Piedmont streams. In fact, total phosphorus concentrations downstream from Kornbow Lake were equivalent to those reported for undeveloped streams in the Sand Hills.

Undesirable levels of some water-quality constituents occasionally were observed. Fecal coliform bacteria commonly exceeded 200 colonies/100 mL at site S1 upstream from Bonnie Doone Lake and at site S4 downstream from Mintz Pond. Site S1 also had relatively high concentrations of suspended sediment, turbidity, and total phosphorus compared to other sites in Little Cross Creek. Site S5, located in Clark Pond Creek, had high specific conductance, total phosphorus, and total ammonia plus organic nitrogen relative to other sites.

Spatial differences in water quality that were observed between the Little Cross Creek sites could be attributed, in part, to the presence or absence of upstream reservoirs and to whether sites received direct inputs of stormwater runoff. For example, low concentrations of sediment and total phosphorus generally were observed at sites downstream from Bonnie Doone Lake (site S2) and Kornbow Lake (site S3), indicating that these two reservoirs effectively trapped these constituents. Furthermore, water-quality conditions at these sites did not vary in response to streamflow fluctuations. Conversely, concentrations of suspended sediment, turbidity, total phosphorus, and fecal coliform bacteria were higher during rain events than during base flow at sites S1 and S4. Site S4 received stormwater drainage from the U.S. Highway 401 bypass. Total phosphorus and fecal coliform bacteria also increased during storms at site S5.

Loads of suspended sediment, total nitrogen, total phosphorus, and total organic carbon were computed for the seven Little Cross Creek sites monitored by the USGS for the period from October 1996 through September 1997. Yields, or loads per square mile of drainage area, also were reported. The highest suspended-sediment yield (213 [tons/mi^2]/yr) occurred at site S1. At the remaining Little Cross Creek sites, sediment yields were low relative to yields reported for small urban basins in North Carolina. Suspended-sediment yield at site S3 downstream from Kornbow Lake (9.50 [tons/mi^2]/yr) was comparable to yields at minimally disturbed sites in the Sand Hills, indicating the effectiveness of the upstream reservoirs at retaining particulates. Site S5 had the highest yields of total phosphorus (0.081 [ton/mi^2]/yr) and total organic carbon (11.5 [tons/mi^2]/yr); total nitrogen yield (1.38 [tons/mi^2]/yr) also was slightly higher at site S5 than at the other Little Cross Creek sites.

Total nitrogen yields ranged from 0.352 to 1.40 (tons/mi^2)/yr, near the low end of yields reported for other small urban watersheds in North Carolina. Yields of total phosphorus at all Little Cross Creek sites were lower than yields measured in other developed basins in the State, ranging from 0.011 to 0.081 (ton/mi^2)/yr.

Tributary loads into and out of the Bonnie Doone Lake, Kornbow Lake, Mintz Pond, and Glenville Lake were computed. Loads of total nitrogen and total organic carbon to each of these reservoirs increased in a downstream direction as drainage area increased. Sediment and total phosphorus loads decreased from site S1 to site S3 because of particulate trapping in Bonnie Doone and Kornbow Lakes. An influx of sediment, total phosphorus, and total organic carbon was noted downstream from Mintz Pond, and may have resulted from stormwater discharge from the U.S. Highway 401 bypass or from unidentified sources in the watershed downstream from site S3.

Comparison of inflow and outflow loads indicated that Bonnie Doone Lake trapped 92 percent of incoming suspended sediment and 37 percent of incoming total phosphorus. Kornbow Lake trapped 57 percent of incoming suspended sediment and 77 percent of total phosphorus inputs. Nitrogen was not effectively trapped by any of the reservoirs.

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SUPPLEMENTARY TABLES

Supplementary Table ST-1. Daily precipitation totals for Fayetteville, August 1996 through December 1997

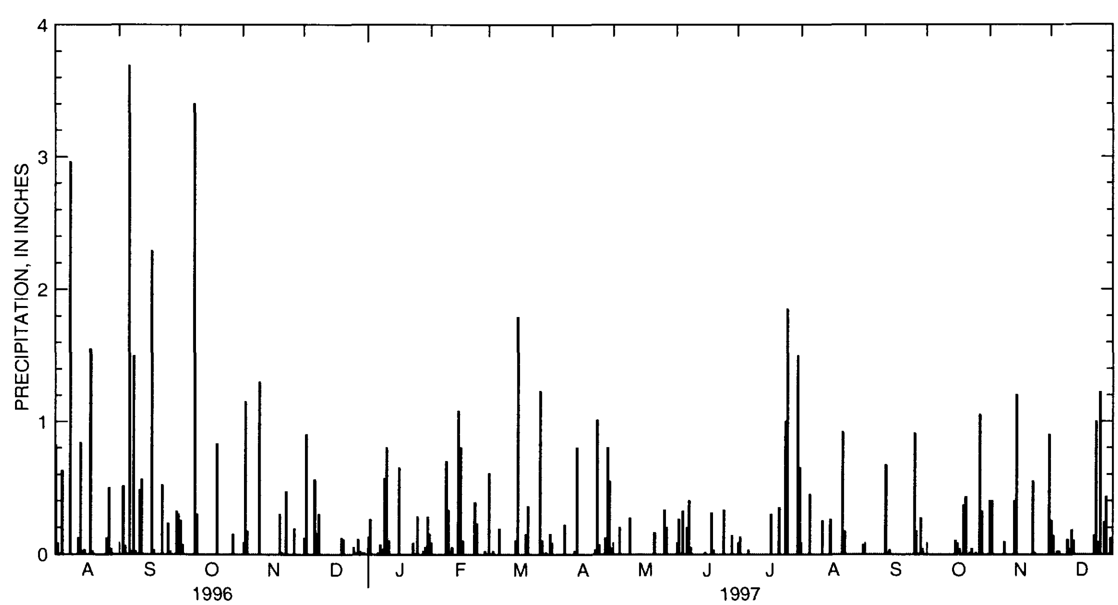
FAYETTEVILLE NATIONAL WEATHER SERVICE COOPERATIVE OBSERVER SITE

[The Fayetteville Cooperative Observer Site is at latitude 35°04', longitude 78°52', Cumberland County. Information was provided by the State Climate Office of North Carolina at North Carolina State University. ---, data not requested or day not in month]

PRECIPITATION, INCHES, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996

DAILY TOTALS

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	0.82	0.00	0.25	0.00	0.12
2	---	---	---	---	---	---	---	0.08	0.00	0.07	1.15	0.90
3	---	---	---	---	---	---	---	0.00	0.51	0.00	0.17	0.00
4	---	---	---	---	---	---	---	0.63	0.06	0.00	0.00	0.00
5	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
6	---	---	---	---	---	---	---	0.00	3.69	0.00	0.00	0.56
7	---	---	---	---	---	---	---	0.00	0.02	0.00	0.00	0.15
8	---	---	---	---	---	---	---	2.96	1.50	3.40	0.00	0.30
9	---	---	---	---	---	---	---	0.00	0.02	0.30	1.30	0.00
10	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
11	---	---	---	---	---	---	---	0.00	0.48	0.00	0.00	0.00
12	---	---	---	---	---	---	---	0.12	0.56	0.00	0.00	0.00
13	---	---	---	---	---	---	---	0.84	0.00	0.00	0.00	0.00
14	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
15	---	---	---	---	---	---	---	0.03	0.00	0.00	0.00	0.00
16	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
17	---	---	---	---	---	---	---	0.00	2.29	0.00	0.00	0.00
18	---	---	---	---	---	---	---	1.55	0.03	0.00	0.00	0.00
19	---	---	---	---	---	---	---	0.02	0.00	0.83	0.30	0.12
20	---	---	---	---	---	---	---	0.00	0.00	0.00	0.01	0.11
21	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
22	---	---	---	---	---	---	---	0.00	0.52	0.00	0.47	0.00
23	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
24	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00
25	---	---	---	---	---	---	---	0.00	0.23	0.00	0.00	0.05
26	---	---	---	---	---	---	---	0.12	0.02	0.00	0.19	0.00
27	---	---	---	---	---	---	---	0.50	0.00	0.15	0.00	0.11
28	---	---	---	---	---	---	---	0.04	0.00	0.00	0.00	0.02
29	---	---	---	---	---	---	---	0.00	0.32	0.00	0.00	0.01
30	---	---	---	---	---	---	---	0.00	0.30	0.00	0.00	0.01
31	---	---	---	---	---	---	---	0.00	---	0.00	---	0.00
TOTAL	---	---	---	---	---	---	---	7.71	10.55	5.00	3.59	2.46



Supplementary Table ST-1. Daily precipitation totals for Fayetteville, August 1996 through December 1997—Continued

FAYETTEVILLE NATIONAL WEATHER SERVICE COOPERATIVE OBSERVER SITE

[The Fayetteville Cooperative Observer Site is at latitude 35°04', longitude 78°52', Cumberland County. Information was provided by the State Climate Office of North Carolina at North Carolina State University. ---, data not requested or day not in month]

PRECIPITATION, INCHES, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997

DAILY TOTALS

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.04	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.25
2	0.26	0.00	0.00	0.00	0.00	0.26	0.13	0.00	0.00	0.00	0.40	0.14
3	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.20	0.32	0.00	0.00	0.00	0.00	0.00	0.02
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.02
6	0.01	0.00	0.19	0.00	0.00	0.20	0.03	0.00	0.00	0.00	0.00	0.00
7	0.07	0.00	0.00	0.22	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00
8	0.03	0.70	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.09	0.00
9	0.57	0.33	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.11
10	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
11	0.10	0.05	0.00	0.00	0.00	0.00	0.00	0.25	0.67	0.00	0.00	0.18
12	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.10
13	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.03	0.00	0.40	0.00
14	0.00	1.08	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00
15	0.00	0.80	1.79	0.00	0.00	0.01	0.00	0.26	0.00	0.10	0.00	0.00
16	0.65	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.04	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.15	0.00	0.00	0.03	0.00	0.00	0.00	0.37	0.00	0.00
20	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00
21	0.00	0.00	0.00	0.00	0.16	0.00	0.35	0.92	0.00	0.00	0.00	0.00
22	0.00	0.39	0.00	0.03	0.00	0.00	0.00	0.17	0.00	0.01	0.55	0.14
23	0.08	0.23	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.04	0.01	1.00
24	0.00	0.00	0.00	0.07	0.00	0.33	1.00	0.00	0.00	0.00	0.00	0.09
25	0.28	0.00	0.00	0.00	0.00	0.00	1.85	0.00	0.91	0.01	0.00	1.22
26	0.00	0.00	1.23	0.00	0.33	0.00	0.00	0.00	0.17	0.00	0.00	0.00
27	0.00	0.02	0.10	0.12	0.20	0.00	0.00	0.00	0.00	1.05	0.00	0.24
28	0.02	0.00	0.00	0.80	0.00	0.14	0.00	0.00	0.27	0.32	0.00	0.43
29	0.05		0.01	0.55	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
30	0.28		0.00	0.04	0.00	0.00	1.50	0.00	0.00	0.00	0.90	0.12
31	0.15		0.15		0.00		0.65	0.07		0.00		0.00
TOTAL	3.39	3.70	4.71	3.66	1.16	2.05	5.81	2.12	2.10	2.45	3.95	4.10

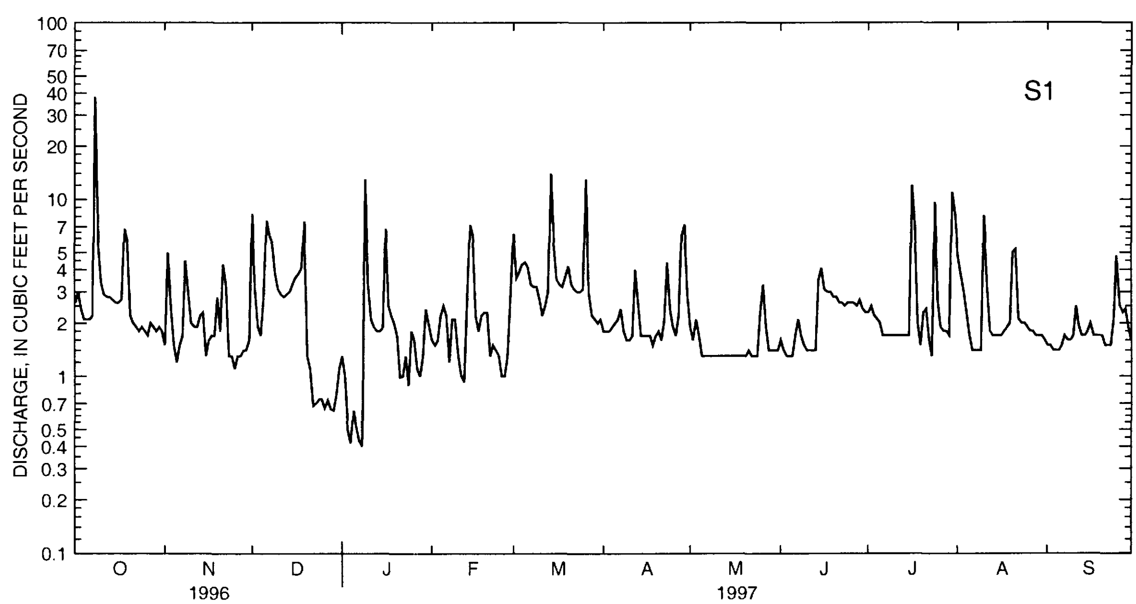
Supplementary Table ST-2. Daily mean values of discharge for Little Cross Creek site S1, October 1996 through September 1997

LITTLE CROSS CREEK ABOVE BONNIE DOONE LAKE NEAR SHAWS, NC

[Site S1 is at latitude 35°07'09", longitude 78°56'45", Cumberland County, U.S. Geological Survey downstream order number 0210382000, Hydrologic Unit 03030004; drainage area is 0.938 square miles; ---, day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, OCTOBER 1996 THROUGH SEPTEMBER 1997
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	e2.6	1.5	8.3	1.3	1.6	6.4	1.8	1.9	1.6	2.3	4.8	1.5
2	e3.0	5.0	3.1	1.0	1.5	3.6	1.8	1.6	1.4	2.5	3.7	1.5
3	e2.4	2.4	1.9	.50	1.6	3.9	1.8	2.1	1.3	2.2	3.0	1.4
4	2.1	1.5	1.7	.42	2.2	4.3	1.9	1.7	1.3	2.1	2.3	1.4
5	2.1	1.2	2.8	.64	2.5	4.4	2.0	1.3	1.3	2.0	1.7	1.4
6	2.1	1.5	7.6	.52	2.2	4.1	2.1	1.3	1.7	1.7	1.4	1.5
7	2.2	1.7	6.2	.43	1.2	3.3	2.4	1.3	2.1	1.7	1.4	1.7
8	38	4.5	5.6	.40	2.1	3.2	1.8	1.3	1.7	1.7	1.4	1.6
9	5.7	3.1	3.8	13	2.1	3.2	1.6	1.3	1.5	1.7	1.4	1.6
10	3.4	2.0	3.1	3.3	1.3	2.7	1.6	1.3	1.4	1.7	8.1	1.7
11	2.9	1.9	2.9	2.1	1.0	2.2	1.7	1.3	1.4	1.7	3.2	2.5
12	2.8	1.9	2.8	1.9	.93	2.5	4.0	1.3	1.4	1.7	1.8	1.9
13	2.8	2.2	2.9	1.8	2.2	3.0	2.7	1.3	1.4	1.7	1.7	1.7
14	2.7	2.3	3.0	1.8	7.2	14	1.7	1.3	3.5	1.7	1.7	1.7
15	2.6	1.3	3.3	1.9	6.2	5.5	1.7	1.3	4.1	1.7	1.7	1.8
16	2.6	1.6	3.6	6.8	2.2	3.5	1.7	1.3	3.1	12	1.7	2.0
17	2.7	1.7	3.8	2.5	1.8	3.3	1.7	1.3	3.0	6.8	1.8	1.7
18	6.8	1.7	4.1	2.2	2.2	3.2	1.5	1.3	3.0	2.0	1.9	1.7
19	5.7	2.8	7.5	2.0	2.3	3.7	1.7	1.3	2.8	1.5	2.0	1.7
20	2.2	1.8	1.3	1.7	2.3	4.2	1.8	1.3	2.8	2.3	5.0	1.7
21	2.0	4.3	1.1	.99	1.3	3.3	1.6	1.4	2.6	2.4	5.2	1.5
22	1.9	3.3	.68	1.0	1.5	3.1	2.1	1.3	2.6	1.6	2.1	1.5
23	1.8	1.3	.70	1.3	1.4	3.0	4.4	1.3	2.5	1.3	2.0	1.5
24	1.9	1.3	.74	.89	1.3	3.0	2.4	1.3	2.6	9.6	2.0	2.1
25	1.8	1.1	.74	1.8	1.0	3.1	1.9	2.3	2.6	2.7	1.9	4.8
26	1.7	1.3	.66	1.6	1.0	13	1.7	3.3	2.6	1.9	1.8	2.5
27	2.0	1.3	.73	1.1	1.3	3.0	2.2	1.9	2.5	1.8	1.8	2.3
28	1.9	1.4	.65	1.0	3.1	2.2	6.3	1.4	2.7	1.8	1.7	2.4
29	1.8	1.4	.64	1.3	---	2.1	7.2	1.4	2.4	1.7	1.7	1.9
30	1.9	1.6	.79	2.4	---	2.0	2.9	1.4	2.3	11	1.7	1.6
31	1.8	---	1.1	2.0	---	2.1	---	1.4	---	8.3	1.6	---
TOTAL	117.9	61.9	87.83	61.59	58.53	124.1	71.7	46.5	67.2	96.8	75.2	55.8
MEAN	3.80	2.06	2.83	1.99	2.09	4.00	2.39	1.50	2.24	3.12	2.43	1.86
MAX	38	5.0	8.3	13	7.2	14	7.2	3.3	4.1	12	8.1	4.8
MIN	1.7	1.1	.64	.40	.93	2.0	1.5	1.3	1.3	1.3	1.4	1.4
CFSM	4.05	2.20	3.02	2.12	2.23	4.27	2.55	1.60	2.39	3.33	2.59	1.98



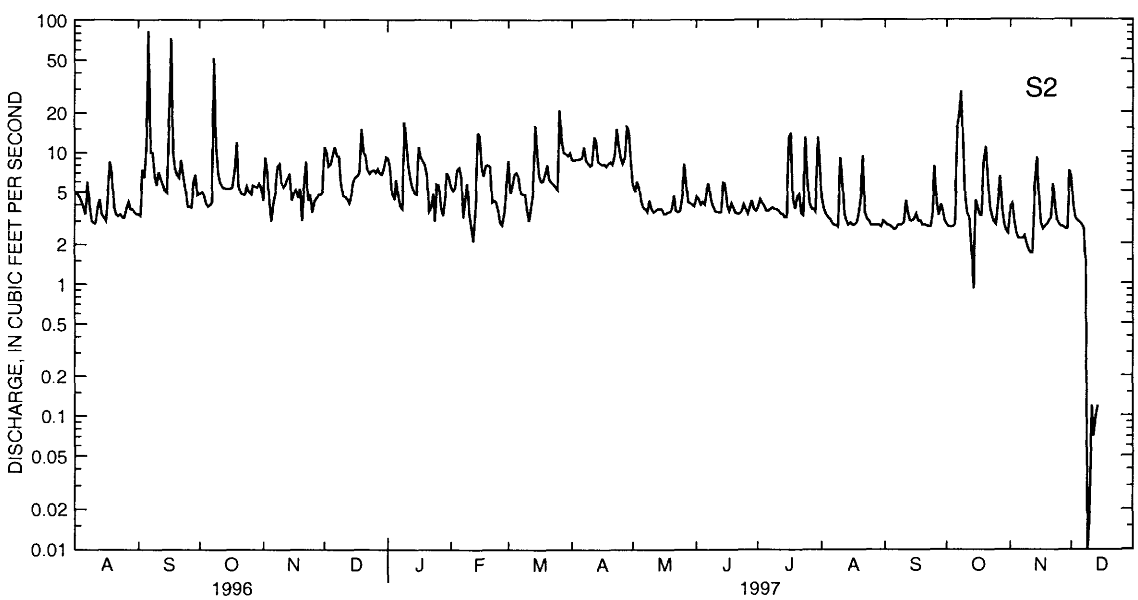
Supplementary Table ST-3. Daily mean values of discharge for Little Cross Creek site S2, August 1996 through December 1997

LITTLE CROSS CREEK BELOW BONNIE DOONE LAKE DAM NEAR SHAWS, NC

[Site S2 is at latitude 35°06'32", longitude 78°56'37", Cumberland County, U.S. Geological Survey downstream order number 0210382026, Hydrologic Unit 03030004; drainage area is 2.56 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	e5.0	3.4	4.9	4.3	11
2	---	---	---	---	---	---	---	e4.8	3.3	5.0	9.2	10
3	---	---	---	---	---	---	---	e4.6	7.4	4.7	7.1	7.8
4	---	---	---	---	---	---	---	e4.2	6.4	4.1	4.1	8.1
5	---	---	---	---	---	---	---	e3.8	12	3.9	3.0	9.7
6	---	---	---	---	---	---	---	e3.4	83	4.0	4.3	11
7	---	---	---	---	---	---	---	e6.0	10	4.2	5.0	9.4
8	---	---	---	---	---	---	---	e4.0	10	52	7.8	9.3
9	---	---	---	---	---	---	---	e3.0	6.6	11	8.2	6.0
10	---	---	---	---	---	---	---	2.9	5.6	6.9	5.9	4.7
11	---	---	---	---	---	---	---	2.9	7.1	5.9	5.4	4.6
12	---	---	---	---	---	---	---	3.9	6.2	5.5	5.7	4.4
13	---	---	---	---	---	---	---	4.4	5.7	5.3	6.3	4.1
14	---	---	---	---	---	---	---	3.4	5.1	5.3	6.9	4.7
15	---	---	---	---	---	---	---	3.2	4.9	5.3	4.3	5.9
16	---	---	---	---	---	---	---	3.0	19	5.3	4.9	6.4
17	---	---	---	---	---	---	---	4.8	73	5.4	5.2	6.6
18	---	---	---	---	---	---	---	8.5	10	7.4	4.5	7.0
19	---	---	---	---	---	---	---	7.0	7.5	12	5.3	15
20	---	---	---	---	---	---	---	3.8	6.7	5.5	3.0	10
21	---	---	---	---	---	---	---	3.4	6.4	4.9	5.3	9.4
22	---	---	---	---	---	---	---	3.3	8.8	4.8	8.5	7.3
23	---	---	---	---	---	---	---	3.4	6.6	4.8	4.3	6.9
24	---	---	---	---	---	---	---	3.2	5.4	5.5	4.8	7.2
25	---	---	---	---	---	---	---	3.2	3.9	5.0	3.5	7.3
26	---	---	---	---	---	---	---	3.7	3.9	4.8	4.3	7.0
27	--	---	---	---	---	---	---	4.2	3.8	5.6	4.5	7.5
28	---	---	---	---	---	---	---	3.7	6.0	5.5	4.8	6.9
29	---	---	---	---	---	---	---	3.7	6.8	5.4	4.8	6.8
30	---	---	---	---	---	---	---	3.5	4.8	5.8	5.1	7.5
31	---	---	---	---	---	---	---	3.4	---	5.4	---	9.2
TOTAL	--	---	---	---	---	---	---	125.3	349.3	221.1	160.3	238.7
MEAN	---	---	---	---	---	---	---	4.04	11.6	7.13	5.34	7.70
MAX	---	---	---	---	---	---	---	8.5	83	52	9.2	15
MIN	--	---	---	---	---	---	---	2.9	3.3	3.9	3.0	4.1
CFSM	--	---	---	---	---	---	---	1.58	4.54	2.78	2.08	3.00



Supplementary Table ST-3. Daily mean values of discharge for Little Cross Creek site S2, August 1996 through December 1997—Continued

LITTLE CROSS CREEK BELOW BONNIE DOONE LAKE DAM NEAR SHAWS, NC

[Site S2 is at latitude 35°06'32", longitude 78°56'37", Cumberland County, U.S. Geological Survey downstream order number 0210382026, Hydrologic Unit 03030004; drainage area is 2.56 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	9.0	5.5	8.7	8.8	5.7	4.6	3.8	4.5	2.9	2.8	3.9	6.4
2	7.9	5.1	4.9	8.7	5.0	4.4	4.4	3.7	2.8	2.7	4.1	3.9
3	4.8	5.3	5.5	8.8	6.0	4.0	4.1	3.4	2.8	2.7	3.0	3.1
4	4.4	7.3	6.8	8.8	5.4	4.2	3.9	3.2	2.7	2.7	2.4	3.0
5	6.2	7.6	7.0	8.9	4.2	4.0	3.6	3.1	2.6	2.8	2.2	2.9
6	4.7	6.6	6.4	9.0	3.8	5.1	3.6	2.9	2.6	15	2.2	2.8
7	3.9	3.2	4.9	11	3.7	5.8	3.7	2.8	2.8	19	2.2	2.6
8	3.7	4.7	4.8	8.6	3.5	4.4	3.8	2.8	2.8	29	2.3	1.4
9	17	5.8	4.8	8.3	4.3	3.9	3.7	2.7	2.8	12	2.0	.01
10	12	3.4	3.7	7.9	3.7	3.6	3.7	9.1	2.9	4.5	1.8	.02
11	7.8	2.6	3.0	8.0	3.5	3.5	3.6	6.4	4.3	3.4	1.7	.12
12	6.2	2.1	3.8	13	3.6	3.5	3.4	3.4	3.4	3.1	1.7	.07
13	5.4	4.0	4.9	12	3.7	3.5	3.4	3.0	3.0	1.8	5.4	.10
14	4.9	14	16	8.5	3.7	5.9	3.2	2.8	3.0	.91	9.1	.12
15	4.8	13	10	8.2	3.7	5.8	3.2	2.9	3.1	4.3	4.7	---
16	11	7.5	6.6	8.0	3.4	3.9	13	2.8	3.4	3.8	2.9	---
17	9.2	6.6	6.0	8.1	3.4	3.6	14	2.8	3.0	3.3	2.6	---
18	8.5	7.9	6.0	7.8	3.5	4.1	4.4	2.9	3.0	3.3	2.7	---
19	8.1	8.0	6.9	8.2	3.5	3.8	3.7	3.4	2.8	8.3	2.8	---
20	6.7	7.8	8.0	8.4	3.7	3.5	4.6	4.7	2.8	11	3.0	---
21	3.6	4.2	6.2	8.0	4.7	3.4	4.8	9.4	2.8	6.0	3.1	---
22	3.8	4.3	5.9	9.5	3.6	3.4	3.4	3.5	2.7	3.8	5.7	---
23	4.9	4.2	5.7	15	3.5	3.5	3.3	3.1	2.7	3.3	3.8	---
24	3.0	3.6	5.4	11	3.6	4.0	13	3.0	3.3	2.9	3.0	---
25	5.7	2.9	5.2	9.0	4.7	3.7	6.3	2.8	7.9	2.8	2.8	---
26	5.6	2.8	21	8.2	8.2	3.4	4.1	2.8	4.1	4.3	2.7	---
27	3.8	3.5	12	9.1	5.8	3.8	3.7	2.8	3.3	6.6	2.7	---
28	3.3	6.0	10	16	4.2	4.3	3.7	2.8	4.0	3.7	2.6	---
29	4.5	---	9.8	14	4.1	3.7	3.5	2.8	3.6	2.8	2.6	---
30	7.0	---	9.4	8.2	4.0	3.6	13	2.7	3.0	2.5	7.2	---
31	6.4	---	10	---	3.9	---	8.6	3.0	---	2.4	---	---
TOTAL	197.8	159.5	229.3	287.0	131.3	121.9	162.2	112.0	96.9	177.51	98.9	---
MEAN	6.38	5.70	7.40	9.57	4.24	4.06	5.23	3.61	3.23	5.73	3.30	---
MAX	17	14	21	16	8.2	5.9	14	9.4	7.9	29	9.1	---
MIN	3.0	2.1	3.0	7.8	3.4	3.4	3.2	2.7	2.6	.91	1.7	---
CFSM	2.49	2.22	2.89	3.73	1.65	1.59	2.04	1.41	1.26	2.23	1.29	---

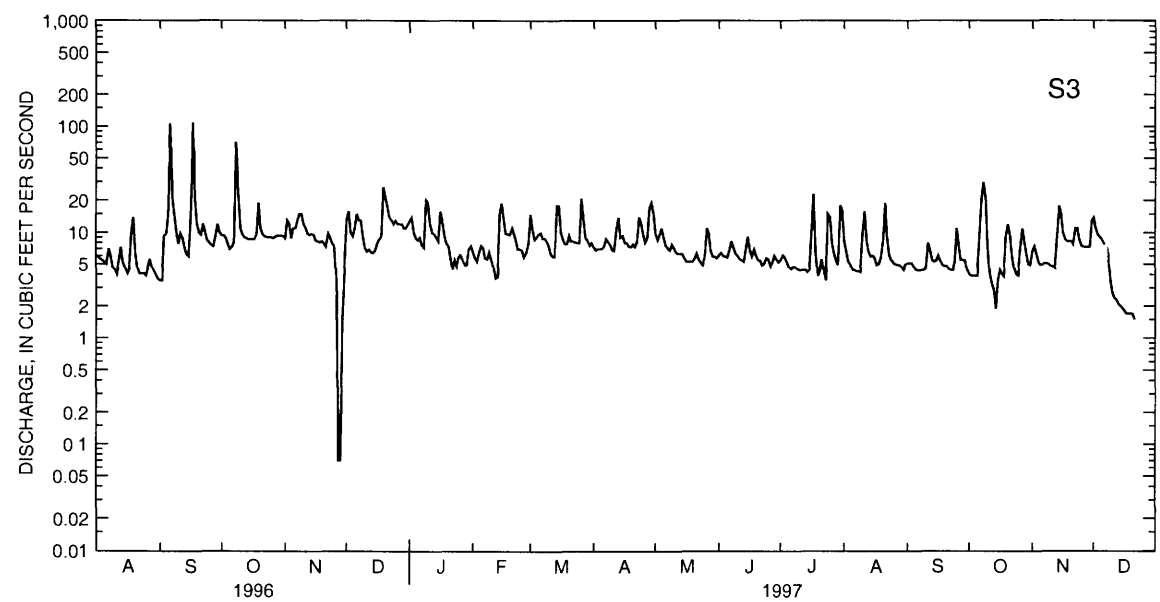
Supplementary Table ST-4. Daily mean values of discharge for Little Cross Creek site S3, August 1996 through December 1997

LITTLE CROSS CREEK BELOW KORNBOW LAKE DAM NEAR SHAWS, NC

[Site S3 is at latitude 35°06'04", longitude 78°55'42", Cumberland County, U.S. Geological Survey downstream order number 0210382035, Hydrologic Unit 03030004; drainage area is 4.25 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	e6.0	3.5	9.4	8.8	13
2	---	---	---	---	---	---	---	e5.8	3.5	9.3	13	16
3	---	---	---	---	---	---	---	e5.6	9.4	8.8	12	10
4	---	---	---	---	---	---	---	e5.4	9.7	7.7	8.9	9.2
5	---	---	---	---	---	---	---	e5.2	15	7.0	11	11
6	---	---	---	---	---	---	---	e5.0	107	7.3	11	15
7	---	---	---	---	---	---	---	e7.0	21	8.1	13	13
8	---	---	---	---	---	---	---	e6.0	15	71	15	13
9	---	---	---	---	---	---	---	4.6	9.8	23	15	9.3
10	---	---	---	---	---	---	---	4.4	7.8	11	12	7.1
11	---	---	---	---	---	---	---	4.0	9.8	9.6	11	6.6
12	---	---	---	---	---	---	---	5.5	8.8	9.0	9.8	6.9
13	---	---	---	---	---	---	---	7.3	7.2	8.8	9.5	6.5
14	---	---	---	---	---	---	---	5.2	6.2	8.6	9.7	6.4
15	---	---	---	---	---	---	---	4.6	5.9	8.6	9.5	6.8
16	---	---	---	---	---	---	---	4.1	15	8.6	8.4	7.8
17	---	---	---	---	---	---	---	4.5	109	8.6	8.3	8.6
18	---	---	---	---	---	---	---	10	20	9.8	8.1	9.3
19	---	---	---	---	---	---	---	14	12	19	8.2	27
20	---	---	---	---	---	---	---	6.4	10	11	7.8	21
21	---	---	---	---	---	---	---	4.6	9.5	9.6	7.3	17
22	---	---	---	---	---	---	---	4.1	12	9.2	9.8	14
23	---	---	---	---	---	---	---	4.1	10	9.1	9.1	13
24	---	---	---	---	---	---	---	4.1	8.4	9.1	7.9	12
25	---	---	---	---	---	---	---	3.9	7.9	9.1	7.4	13
26	---	---	---	---	---	---	---	4.6	7.6	8.9	3.3	12
27	---	---	---	---	---	---	---	5.6	7.4	9.1	.07	12
28	---	---	---	---	---	---	---	4.7	9.4	9.4	.07	12
29	---	---	---	---	---	---	---	4.3	e12	9.3	1.6	11
30	---	---	---	---	---	---	---	3.9	e10	9.3	5.4	11
31	---	---	---	---	---	---	---	3.6	---	9.3	---	12
TOTAL	---	---	---	---	---	---	---	168.1	499.8	365.6	261.94	362.5
MEAN	---	---	---	---	---	---	---	5.42	16.7	11.8	8.73	11.7
MAX	---	---	---	---	---	---	---	14	109	71	15	27
MIN	---	---	---	---	---	---	---	3.6	3.5	7.0	.07	6.4
CFSM	---	---	---	---	---	---	---	1.28	3.92	2.78	2.06	2.75



Supplementary Table ST-4. Daily mean values of discharge for Little Cross Creek site S3, August 1996 through December 1997—Continued

LITTLE CROSS CREEK BELOW KORNBOW LAKE DAM NEAR SHAWS, NC

[Site S3 is at latitude 35°06'04", longitude 78°55'42", Cumberland County, U.S. Geological Survey downstream order number 0210382035, Hydrologic Unit 03030004; drainage area is 4.25 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	13	6.6	15	7.2	9.8	6.1	5.5	8.4	5.1	4.0	6.7	14
2	14	5.8	11	6.8	8.5	6.4	6.1	6.5	5.1	3.9	7.4	11
3	10	5.3	8.6	7.0	9.6	6.0	5.8	5.3	5.1	3.9	6.3	9.5
4	8.3	6.4	9.1	7.0	11	5.9	5.2	4.9	4.7	3.9	5.2	9.1
5	8.5	7.5	9.7	7.0	8.8	5.8	4.7	4.4	4.4	3.9	4.9	8.6
6	9.0	7.2	10	7.3	7.5	6.8	4.5	4.4	4.4	9.7	4.9	7.8
7	7.6	5.7	8.8	8.7	7.1	8.3	4.7	4.3	4.4	21	5.1	7.7
8	7.2	5.6	8.8	8.1	6.8	7.1	4.7	4.3	4.4	30	5.1	6.5
9	20	6.5	8.2	7.6	7.7	6.3	4.5	4.2	4.4	21	5.0	3.6
10	19	5.6	7.5	6.8	7.0	6.0	4.4	10	4.7	7.6	4.8	2.7
11	12	4.7	6.2	6.7	6.5	5.6	4.4	16	8.0	4.2	4.8	2.4
12	10	3.7	5.9	11	6.3	5.5	4.4	8.3	6.7	3.3	4.6	2.3
13	9.7	3.8	5.9	14	6.3	5.3	4.4	6.5	5.5	2.8	8.5	2.1
14	9.1	15	18	9.0	6.2	6.9	4.2	5.9	5.3	1.9	18	2.0
15	8.3	19	18	9.3	5.7	9.2	4.4	6.0	5.4	3.6	15	1.9
16	16	13	10	8.0	5.3	6.7	9.5	5.7	6.0	4.4	10	1.8
17	13	9.8	8.6	8.0	5.3	5.9	23	4.9	5.4	4.0	8.6	1.7
18	9.1	9.7	7.8	7.4	5.3	6.9	6.5	5.0	4.9	3.8	8.3	1.7
19	7.9	9.6	7.8	7.3	5.3	6.0	3.9	5.7	4.8	9.0	8.3	1.7
20	7.4	11	9.4	7.7	5.6	5.5	4.4	8.4	4.8	12	8.3	1.7
21	5.3	9.7	8.3	7.3	6.3	5.4	5.6	19	4.5	9.3	7.7	1.5
22	4.5	8.4	8.3	8.2	5.6	4.9	4.2	9.2	4.4	6.1	11	---
23	5.5	7.0	8.1	14	5.2	5.0	3.5	6.1	4.4	4.6	11	---
24	4.3	7.0	8.0	12	4.9	5.7	15	5.5	5.2	4.0	8.6	---
25	5.8	6.8	8.0	9.5	6.1	5.6	14	5.2	11	3.9	7.5	---
26	6.1	5.9	21	8.1	11	4.8	8.0	5.0	7.3	6.8	7.3	---
27	5.5	6.5	13	9.0	9.8	5.2	6.2	4.9	5.5	11	7.3	---
28	4.9	7.9	8.9	17	6.7	6.0	5.4	4.9	5.5	8.5	7.3	---
29	4.9	---	8.4	19	5.9	5.5	4.9	4.7	5.5	6.2	7.3	---
30	7.0	---	7.5	15	5.9	5.2	18	4.4	4.4	5.0	13	---
31	7.5	---	7.9	---	5.7	---	16	5.0	---	4.9	---	---
TOTAL	282.2	220.7	301.7	281.0	214.7	181.5	220.0	203.0	161.2	228.2	237.8	---
MEAN	9.10	7.88	9.73	9.37	6.93	6.05	7.10	6.55	5.37	7.36	7.93	---
MAX	20	19	21	19	11	9.2	23	19	11	30	18	---
MIN	4.5	3.7	5.9	6.7	4.9	4.8	3.5	4.2	4.4	1.9	4.6	---
CFSM	2.14	1.86	2.29	2.20	1.63	1.42	1.67	1.54	1.26	1.73	1.87	---

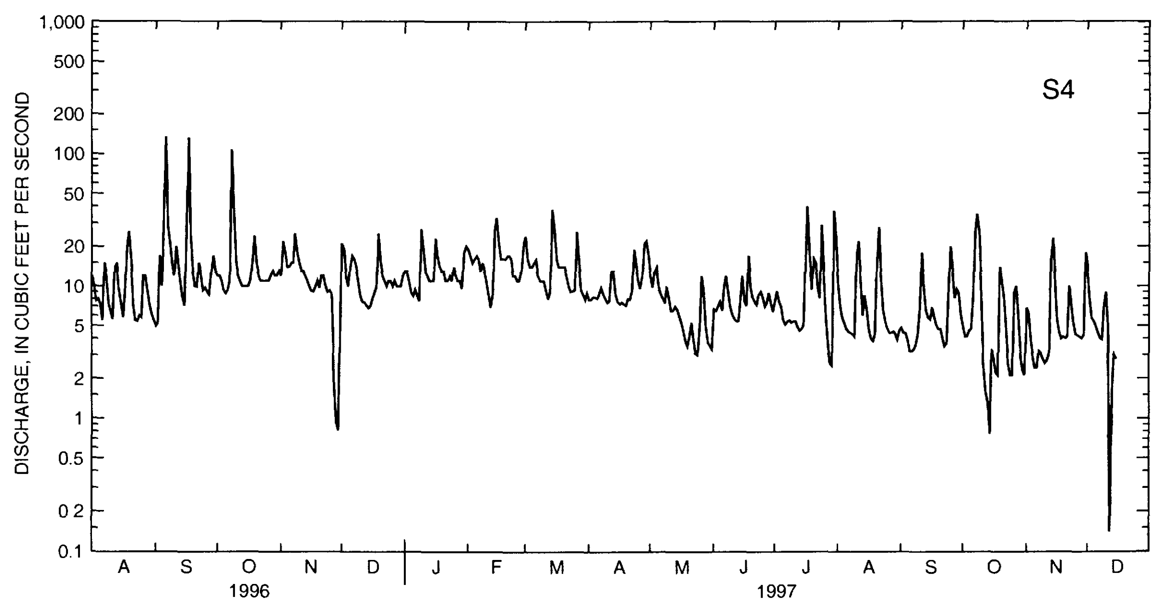
Supplementary Table ST-5. Daily mean values of discharge for Little Cross Creek site S4, August 1996 through December 1997

LITTLE CROSS CREEK BELOW MINTZ POND NEAR BONNIE DOONE, NC

[Site S4 is at latitude 35°05'19", longitude 78°55'27", Cumberland County, U.S. Geological Survey downstream order number 0210382050, Hydrologic Unit 03030004; drainage area is 5.61 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	e12	5.0	12	12	21
2	---	---	---	---	---	---	---	e10	5.3	12	22	19
3	---	---	---	---	---	---	---	7.7	17	11	18	12
4	---	---	---	---	---	---	---	8.0	10	9.3	14	10
5	---	---	---	---	---	---	---	7.2	30	8.8	14	14
6	---	---	---	---	---	---	---	5.5	134	9.4	15	17
7	---	---	---	---	---	---	---	15	28	11	15	16
8	---	---	---	---	---	---	---	12	21	107	25	14
9	---	---	---	---	---	---	---	7.3	14	33	18	11
10	---	---	---	---	---	---	---	6.4	12	15	15	8.5
11	---	---	---	---	---	---	---	5.6	20	12	13	7.6
12	---	---	---	---	---	---	---	14	14	11	13	7.5
13	---	---	---	---	---	---	---	15	11	10	12	7.1
14	---	---	---	---	---	---	---	9.7	8.3	10	11	6.8
15	---	---	---	---	---	---	---	7.5	7.1	10	10	7.0
16	---	---	---	---	---	---	---	5.8	34	10	9.2	8.0
17	---	---	---	---	---	---	---	9.2	132	11	9.1	8.8
18	---	---	---	---	---	---	---	20	24	16	10	9.9
19	---	---	---	---	---	---	---	26	13	24	11	25
20	---	---	---	---	---	---	---	15	10	15	9.7	15
21	---	---	---	---	---	---	---	7.2	9.9	12	12	12
22	---	---	---	---	---	---	---	5.5	15	11	12	11
23	---	---	---	---	---	---	---	5.4	12	11	10	10
24	---	---	---	---	---	---	---	6.0	9.3	11	9.0	11
25	---	---	---	---	---	---	---	5.8	9.7	11	9.3	11
26	---	---	---	---	---	---	---	12	9.0	11	8.5	10
27	---	---	---	---	---	---	---	12	8.6	12	1.9	11
28	---	---	---	---	---	---	---	9.2	13	13	.95	10
29	---	---	---	---	---	---	---	7.3	17	12	.81	10
30	---	---	---	---	---	---	---	6.1	13	12	6.5	10
31	---	---	---	---	---	---	---	5.5	---	13	---	12
TOTAL	---	---	---	---	---	---	---	300.9	666.2	486.5	346.96	363.2
MEAN	---	---	---	---	---	---	---	9.71	22.2	15.7	11.6	11.7
MAX	---	---	---	---	---	---	---	26	134	107	25	25
MIN	---	---	---	---	---	---	---	5.4	5.0	8.8	.81	6.8
CFSM	---	---	---	---	---	---	---	1.73	3.96	2.80	2.06	2.09



Supplementary Table ST-5. Daily mean values of discharge for Little Cross Creek site S4, August 1996 through December 1997—Continued

LITTLE CROSS CREEK BELOW MINTZ POND NEAR BONNIE DOONE, NC

[Site S4 is at latitude 35°05'19", longitude 78°55'27", Cumberland County, U.S. Geological Survey downstream order number 0210382050, Hydrologic Unit 03030004; drainage area is 5.61 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	13	19	24	7.9	12	6.7	7.5	11	4.8	4.9	6.8	14
2	13	17	16	7.9	9.8	6.5	9.2	7.1	4.4	4.1	6.2	8.2
3	11	15	14	8.3	13	7.0	7.7	5.8	4.4	4.1	3.9	5.7
4	8.9	16	14	8.2	14	7.6	6.9	5.2	3.8	4.6	2.9	5.4
5	8.4	17	15	8.1	10	6.5	5.5	4.7	3.2	4.7	2.4	5.0
6	9.4	16	16	8.7	8.8	10	5.1	4.5	3.2	8.5	2.4	4.4
7	8.5	13	12	9.7	8.1	12	5.4	4.4	3.3	26	3.2	4.0
8	7.7	15	11	8.6	7.4	8.8	5.5	4.3	3.6	35	3.1	3.9
9	27	13	11	8.0	10	6.9	5.3	4.1	4.3	25	2.8	6.9
10	20	11	11	7.5	8.1	6.0	5.4	17	6.8	6.5	2.6	9.0
11	13	8.5	9.2	7.7	6.5	5.6	5.4	22	18	2.6	2.7	4.9
12	12	6.9	8.0	13	6.5	5.4	4.9	10	9.5	1.6	3.0	.14
13	11	8.7	9.0	13	7.0	5.4	4.6	6.0	6.5	1.3	16	1.6
14	11	27	38	8.9	6.7	7.7	4.7	8.5	5.8	.76	23	3.0
15	11	33	28	7.6	6.0	12	5.1	6.6	5.6	3.3	11	2.8
16	23	21	16	7.3	5.3	7.7	13	4.7	6.9	2.9	5.7	---
17	17	16	14	7.5	4.6	7.0	40	4.0	5.9	2.2	4.4	---
18	14	16	14	7.3	3.8	17	17	3.8	5.0	2.1	4.0	---
19	13	16	14	7.1	3.5	10	9.4	4.3	4.7	14	4.1	---
20	13	17	14	8.0	4.1	8.2	16	16	4.7	11	4.0	---
21	11	17	12	7.9	5.3	7.5	15	28	4.0	7.8	4.1	---
22	11	16	10	9.2	3.9	7.2	9.7	12	3.5	4.3	10	---
23	12	12	9.1	19	3.1	8.6	8.1	6.5	3.7	2.6	7.2	---
24	11	12	9.2	14	3.0	9.1	29	5.5	7.8	2.1	5.3	---
25	14	11	9.3	11	5.1	8.2	14	4.8	20	2.1	4.3	---
26	12	11	26	9.6	12	7.0	5.7	4.4	13	8.9	4.2	---
27	11	13	15	12	9.4	7.5	3.4	4.4	8.1	10	4.1	---
28	11	21	9.4	21	5.0	8.9	2.6	4.5	9.4	5.3	4.0	---
29	9.6	---	8.7	22	3.7	7.3	2.5	4.3	8.8	2.9	4.3	---
30	18	---	7.9	17	3.5	6.4	37	3.9	6.1	2.3	18	---
31	20	---	8.9	---	3.3	---	23	4.6	---	2.1	---	---
TOTAL	405.5	435.1	433.7	313.0	212.5	241.7	333.6	236.9	198.8	215.56	179.7	---
MEAN	13.1	15.5	14.0	10.4	6.85	8.06	10.8	7.64	6.63	6.95	5.99	---
MAX	27	33	38	22	14	17	40	28	20	35	23	---
MIN	7.7	6.9	7.9	7.1	3.0	5.4	2.5	3.8	3.2	.76	2.4	---
CFSM	2.33	2.77	2.49	1.86	1.22	1.44	1.92	1.36	1.18	1.24	1.07	---

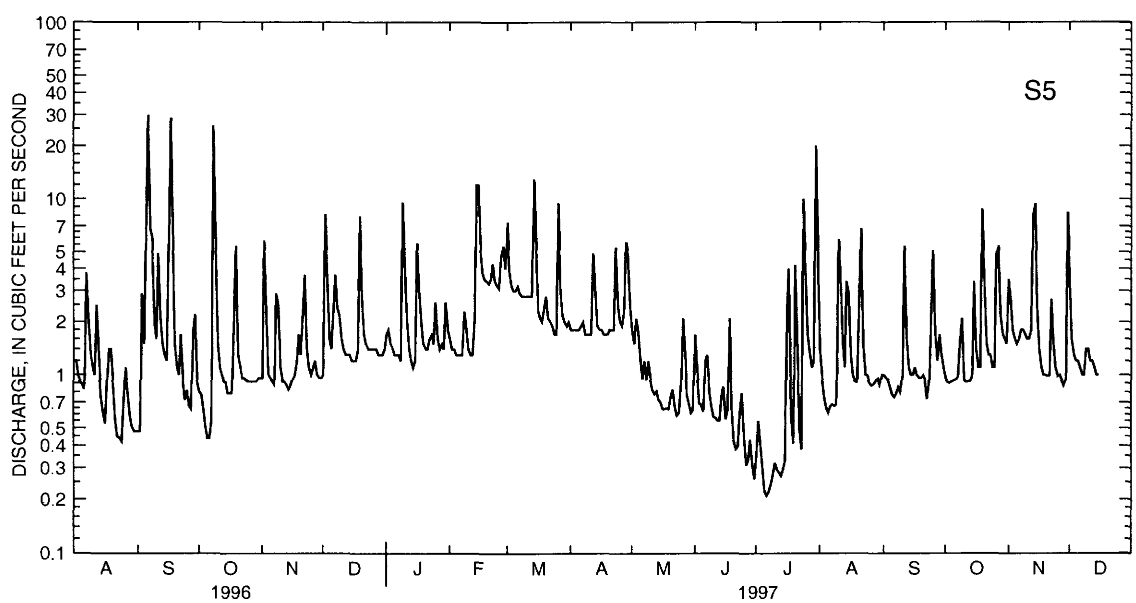
Supplementary Table ST-6. Daily mean values of discharge for Clark Pond Creek site S5, August 1996 through December 1997

CLARK POND CREEK BELOW DAM NEAR BONNIE DOONE, NC

[Site S5 is at latitude 35°05'07", longitude 78°55'24", Cumberland County, U.S. Geological Survey downstream order number 0210382068, Hydrologic Unit 03030004; drainage area is 0.883 square mile; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	e1.2	.48	.80	.96	1.0
2	---	---	---	---	---	---	---	e1.2	.48	.77	5.8	8.2
3	---	---	---	---	---	---	---	.98	2.9	.64	1.9	4.3
4	---	---	---	---	---	---	---	.91	1.5	.51	1.0	1.6
5	---	---	---	---	---	---	---	.88	6.3	.44	.96	1.4
6	---	---	---	---	---	---	---	.83	30	.44	.92	2.2
7	---	---	---	---	---	---	---	3.8	6.7	.55	.88	3.7
8	---	---	---	---	---	---	---	2.1	e6.0	26	2.9	2.4
9	---	---	---	---	---	---	---	1.3	e2.0	5.5	2.5	2.2
10	---	---	---	---	---	---	---	1.1	e1.6	1.5	1.1	1.6
11	---	---	---	---	---	---	---	1.0	4.9	1.1	.92	1.4
12	---	---	---	---	---	---	---	2.5	2.1	1.0	.92	1.3
13	---	---	---	---	---	---	---	1.3	1.5	.92	.88	1.3
14	---	---	---	---	---	---	---	.77	1.3	.91	.83	1.3
15	---	---	---	---	---	---	---	.62	1.2	.79	.87	1.2
16	---	---	---	---	---	---	---	.53	7.9	.79	.94	1.2
17	---	---	---	---	---	---	---	.94	29	.79	1.0	1.2
18	---	---	---	---	---	---	---	1.4	4.3	2.5	1.2	1.4
19	---	---	---	---	---	---	---	1.4	1.5	5.4	1.7	8.0
20	---	---	---	---	---	---	---	.81	1.1	1.3	1.3	2.7
21	---	---	---	---	---	---	---	.56	1.0	1.1	2.2	1.7
22	---	---	---	---	---	---	---	.45	1.7	.96	3.7	1.5
23	---	---	---	---	---	---	---	.44	.93	.96	1.4	1.4
24	---	---	---	---	---	---	---	.42	.72	.94	e1.1	1.4
25	---	---	---	---	---	---	---	.73	.82	.92	e1.0	1.4
26	---	---	---	---	---	---	---	1.1	.67	.92	1.1	1.4
27	---	---	---	---	---	---	---	.79	.64	.92	1.2	1.4
28	---	---	---	---	---	---	---	.60	1.8	.92	1.0	1.3
29	---	---	---	---	---	---	---	.51	2.2	.92	.96	1.3
30	---	---	---	---	---	---	---	.48	.93	.96	.96	1.3
31	---	---	---	---	---	---	---	.48	---	.96	---	1.4
TOTAL	---	---	---	---	---	---	---	32.13	124.17	63.13	44.10	65.1
MEAN	---	---	---	---	---	---	---	1.04	4.14	2.04	1.47	2.10
MAX	---	---	---	---	---	---	---	3.8	30	26	5.8	8.2
MIN	---	---	---	---	---	---	---	.42	.48	.44	.83	1.0
CFSM	---	---	---	---	---	---	---	1.17	4.69	2.31	1.66	2.38



Supplementary Table ST-6. Daily mean values of discharge for Clark Pond Creek site S5, August 1996 through December 1997—Continued

CLARK POND CREEK BELOW DAM NEAR BONNIE DOONE, NC

[Site S5 is at latitude 35°05'07", longitude 78°55'24", Cumberland County, U.S. Geological Survey downstream order number 0210382068, Hydrologic Unit 03030004; drainage area is 0.883 square mile; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1.7	1.6	7.4	1.8	1.8	1.7	.34	1.4	.99	.95	3.5	3.0
2	1.8	1.4	3.9	1.8	1.5	1.0	.55	.96	.96	.91	2.7	1.6
3	1.5	1.4	3.2	1.8	2.1	.69	.39	.76	.94	.90	1.8	1.3
4	1.4	1.3	3.0	1.8	1.8	.68	.28	.65	.85	.92	1.6	1.2
5	1.3	1.3	3.0	1.8	1.2	.62	.22	.61	.77	.93	1.5	1.2
6	1.3	1.3	3.2	1.9	.95	1.2	.21	.66	.75	.94	1.6	1.1
7	1.3	1.3	2.9	2.0	1.2	1.3	.22	.68	.79	.98	1.8	1.0
8	1.2	2.3	2.8	1.7	.94	.80	.24	.67	.85	1.5	1.8	1.0
9	9.6	1.9	2.8	1.7	1.2	.67	.27	.68	.80	2.1	1.7	1.4
10	4.6	1.4	2.8	1.7	.94	.58	.32	5.9	.99	.94	1.6	1.4
11	2.1	1.3	2.8	1.7	.82	.57	.29	3.9	5.4	.91	1.6	1.2
12	e1.4	1.3	2.8	4.9	.78	.55	.28	1.5	1.6	.92	1.8	1.2
13	e1.2	2.1	2.8	3.2	.81	.55	.27	1.1	1.1	.92	8.1	1.1
14	e1.1	12	13	1.9	.72	.75	.29	3.4	1.0	1.0	9.4	1.0
15	1.2	12	4.9	1.8	.70	.86	.33	2.9	1.0	3.4	2.4	1.0
16	5.6	5.0	2.3	1.8	.64	.56	2.2	1.3	1.1	1.4	1.4	---
17	3.2	3.8	2.1	1.7	.64	.63	4.0	.99	.99	1.1	1.1	---
18	2.0	3.5	2.0	1.7	.65	2.1	.60	.92	.96	1.1	1.0	---
19	1.5	3.4	2.4	1.7	.64	.64	.41	.91	.96	8.8	1.0	---
20	1.4	3.3	2.8	1.8	.74	.42	4.2	3.4	.99	3.9	.98	---
21	1.4	3.5	2.1	1.8	.83	.38	1.9	6.8	.93	1.5	.99	---
22	1.6	4.3	2.0	1.8	.67	.39	.49	1.5	.73	1.3	2.7	---
23	1.7	3.4	1.9	5.3	.59	.60	.38	1.0	.90	1.3	1.5	---
24	1.5	3.2	1.7	2.5	.61	.79	10	.99	2.0	1.1	1.1	---
25	2.6	3.1	1.7	2.0	.91	.46	4.5	.90	5.1	1.1	.98	---
26	1.6	4.6	9.5	1.9	2.1	.31	1.7	.87	1.7	4.8	1.0	---
27	1.4	5.4	3.1	2.3	1.4	.33	1.3	.89	1.2	5.4	.94	---
28	1.5	4.0	2.2	5.7	.77	.43	1.1	.93	1.7	2.2	.87	---
29	1.4	---	2.0	5.0	.68	.31	1.2	.95	1.3	1.7	.94	---
30	2.6	---	1.9	2.5	.61	.26	20	.88	1.1	1.6	8.4	---
31	1.8	---	2.0	---	.63	---	4.2	1.0	---	1.5	---	---
TOTAL	65.5	94.4	103.0	71.0	30.57	21.13	62.68	50.00	40.45	58.02	67.80	---
MEAN	2.11	3.37	3.32	2.37	.99	.70	2.02	1.61	1.35	1.87	2.26	---
MAX	9.6	12	13	5.7	2.1	2.1	20	6.8	5.4	8.8	9.4	---
MIN	1.1	1.3	1.7	1.7	.59	.26	.21	.61	.73	.90	.87	---
CFSM	2.39	3.82	3.76	2.68	1.12	.80	2.29	1.83	1.53	2.12	2.56	---

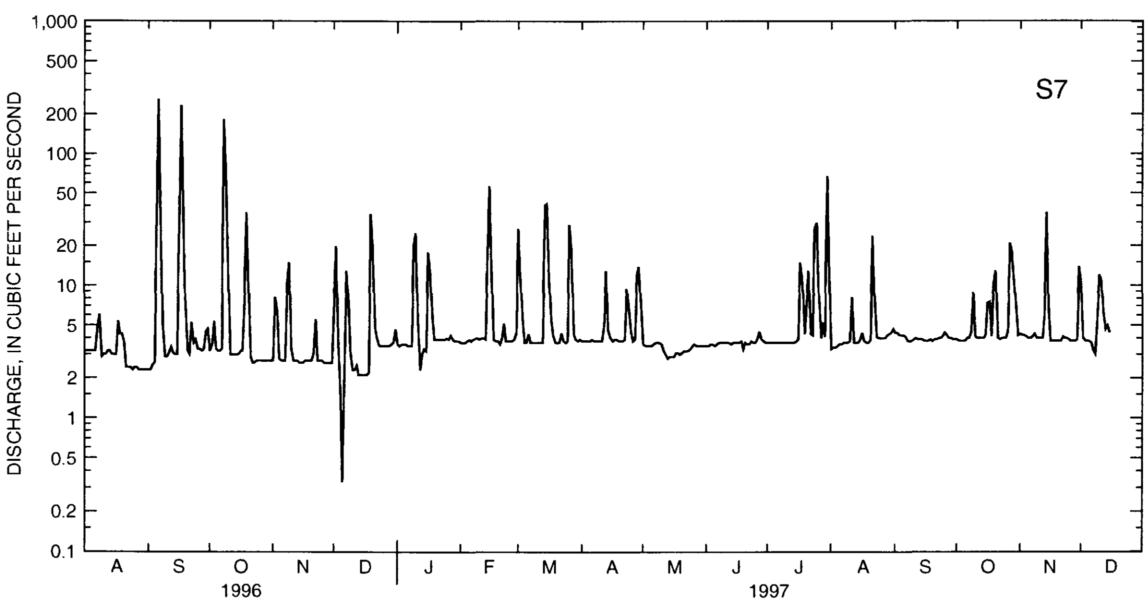
Supplementary Table ST-7. Daily mean values of discharge for Little Cross Creek site S7, August 1996 through December 1997

LITTLE CROSS CREEK BELOW GLENVILLE LAKE DAM AT FAYETTEVILLE, NC

[Site S7 is at latitude 35°04'07", longitude 78°53'47", Cumberland County, U.S. Geological Survey downstream order number 0210382103, Hydrologic Unit 03030004; drainage area is 9.15 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	e3.2	2.3	3.2	2.7	8.5
2	---	---	---	---	---	---	---	e3.2	2.3	3.6	8.2	20
3	---	---	---	---	---	---	---	3.2	2.5	5.4	6.3	3.9
4	---	---	---	---	---	---	---	3.2	2.6	3.3	2.8	1.6
5	---	---	---	---	---	---	---	3.2	24	3.2	2.7	.33
6	---	---	---	---	---	---	---	3.2	259	3.2	2.7	3.4
7	---	---	---	---	---	---	---	5.0	e40	3.3	2.7	13
8	---	---	---	---	---	---	---	6.1	e5.0	184	9.9	8.2
9	---	---	---	---	---	---	---	2.9	e2.9	67	15	3.2
10	---	---	---	---	---	---	---	3.0	2.9	9.3	3.3	2.3
11	---	---	---	---	---	---	---	3.0	3.1	3.0	2.7	2.3
12	---	---	---	---	---	---	---	3.2	3.4	3.0	2.7	2.5
13	---	---	---	---	---	---	---	3.2	3.1	3.0	2.7	2.1
14	---	---	---	---	---	---	---	3.0	3.0	3.0	2.6	2.1
15	---	---	---	---	---	---	---	3.0	3.0	3.0	2.6	2.1
16	---	---	---	---	---	---	---	3.0	11	3.2	2.6	2.1
17	---	---	---	---	---	---	---	5.4	232	3.2	2.7	2.1
18	---	---	---	---	---	---	---	4.3	41	7.9	2.7	2.2
19	---	---	---	---	---	---	---	4.3	7.8	36	2.7	35
20	---	---	---	---	---	---	---	3.7	3.2	9.0	2.7	19
21	---	---	---	---	---	---	---	2.4	3.0	2.9	3.0	4.8
22	---	---	---	---	---	---	---	2.4	5.3	2.6	5.6	4.0
23	---	---	---	---	---	---	---	2.4	3.7	2.6	2.7	3.5
24	---	---	---	---	---	---	---	2.3	3.9	2.7	2.7	3.5
25	---	---	---	---	---	---	---	2.4	3.3	2.7	2.7	3.5
26	---	---	---	---	---	---	---	2.4	3.3	2.7	2.6	3.5
27	---	---	---	---	---	---	---	2.3	3.2	2.7	2.6	3.5
28	---	---	---	---	---	---	---	2.3	3.3	2.7	2.6	3.5
29	---	---	---	---	---	---	---	2.3	4.5	2.7	2.6	3.6
30	---	---	---	---	---	---	---	2.3	4.7	2.7	2.6	3.7
31	---	---	---	---	---	---	---	2.3	---	2.7	---	4.7
TOTAL	---	---	---	---	---	---	---	98.1	692.3	389.5	112.7	177.73
MEAN	---	---	---	---	---	---	---	3.16	23.1	12.6	3.76	5.73
MAX	---	---	---	---	---	---	---	6.1	259	184	15	35
MIN	--	---	---	---	---	---	---	2.3	2.3	2.6	2.6	.33
CFSM	---	---	---	---	---	---	---	.35	2.52	1.37	.41	.63



Supplementary Table ST-7. Daily mean values of discharge for Little Cross Creek site S7, August 1996 through December 1997—Continued

LITTLE CROSS CREEK BELOW GLENVILLE LAKE DAM AT FAYETTEVILLE, NC

[Site S7 is at latitude 35°04'07", longitude 78°53'47", Cumberland County, U.S. Geological Survey downstream order number 0210382103, Hydrologic Unit 03030004; drainage area is 9.15 square miles; ---, no data or day not in month; e, estimated; MAX, maximum; MIN, minimum; CFSM, mean cubic feet per second per square mile]

DISCHARGE, CUBIC FEET PER SECOND, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	3.6	3.7	27	3.8	3.6	3.5	3.7	3.3	4.4	3.9	4.3	11
2	3.5	3.7	12	3.8	3.5	3.5	3.7	3.4	4.4	3.8	4.2	4.0
3	3.6	3.7	5.6	3.8	3.5	3.6	3.7	3.4	4.2	3.8	4.2	3.8
4	3.6	3.8	3.7	3.8	3.5	3.6	3.7	3.5	4.2	3.8	4.1	3.8
5	3.6	3.9	3.7	3.8	3.5	3.5	3.7	3.6	4.2	3.8	4.0	3.8
6	3.5	3.8	4.3	3.9	3.6	3.6	3.7	3.6	4.1	4.0	4.0	3.7
7	3.5	3.9	3.7	3.8	3.7	3.7	3.7	3.7	3.8	4.0	4.1	3.2
8	3.5	4.0	3.7	3.8	3.7	3.7	3.7	3.7	3.8	4.4	4.3	3.0
9	20	4.0	3.7	3.8	3.7	3.7	3.7	3.7	3.8	8.9	4.0	5.1
10	25	3.9	3.7	3.8	3.6	3.7	3.7	3.8	3.9	4.1	4.0	12
11	5.2	4.0	3.7	3.8	3.2	3.7	3.7	8.2	4.0	4.0	4.0	11
12	2.3	4.0	3.7	5.1	3.0	3.7	3.7	3.7	3.9	4.0	4.0	6.3
13	3.0	3.9	3.7	13	2.8	3.6	3.7	3.7	3.9	4.0	6.1	4.7
14	3.3	22	41	4.6	2.9	3.7	3.7	3.7	3.9	4.0	36	5.0
15	3.2	57	42	4.0	2.9	3.7	3.8	3.9	3.8	4.2	6.8	4.4
16	18	13	11	3.8	2.9	3.7	3.9	4.4	3.8	7.4	3.8	---
17	13	3.9	5.5	3.9	3.1	3.7	15	3.8	3.8	7.5	3.8	---
18	5.7	3.8	4.2	3.9	3.1	3.8	11	3.7	3.9	4.1	3.8	---
19	3.9	3.8	3.7	3.8	3.0	3.3	4.3	3.7	3.8	10	3.8	---
20	3.9	3.6	3.7	3.8	3.1	3.7	7.4	3.9	3.9	13	3.8	---
21	3.9	4.0	3.7	3.8	3.2	3.6	13	24	3.9	4.0	3.8	---
22	3.9	5.2	4.4	3.9	3.2	3.6	4.3	8.7	4.0	3.9	4.1	---
23	3.9	3.8	3.8	9.5	3.2	3.8	4.2	4.1	4.0	4.0	4.0	---
24	3.9	3.8	3.7	6.6	3.3	3.7	27	4.0	4.1	4.0	4.0	---
25	4.0	3.8	3.8	4.5	3.5	3.7	30	4.0	4.4	4.0	3.9	---
26	3.9	3.8	29	3.8	3.6	4.0	8.6	4.0	4.2	4.5	3.8	---
27	4.2	3.9	18	3.9	3.5	4.5	4.0	4.0	4.0	21	3.8	---
28	3.9	4.4	4.3	12	3.5	3.9	5.3	4.2	4.0	18	3.8	---
29	3.8	---	3.9	14	3.5	3.8	4.1	4.3	3.9	11	3.9	---
30	3.8	---	3.8	7.1	3.5	3.7	68	4.4	3.9	7.1	14	---
31	e3.8	---	3.9	---	3.5	---	18	4.7	---	4.2	---	---
TOTAL	177.9	190.1	275.6	156.9	103.4	111.0	283.7	148.8	119.9	192.4	166.2	---
MEAN	5.74	6.79	8.89	5.23	3.34	3.70	9.15	4.80	4.00	6.21	5.54	---
MAX	25	57	42	14	3.7	4.5	68	24	4.4	21	36	---
MIN	2.3	3.6	3.7	3.8	2.8	3.3	3.7	3.3	3.8	3.8	3.8	---
CFSM	.63	.74	.97	.57	.36	.40	1.00	.52	.44	.68	.61	---

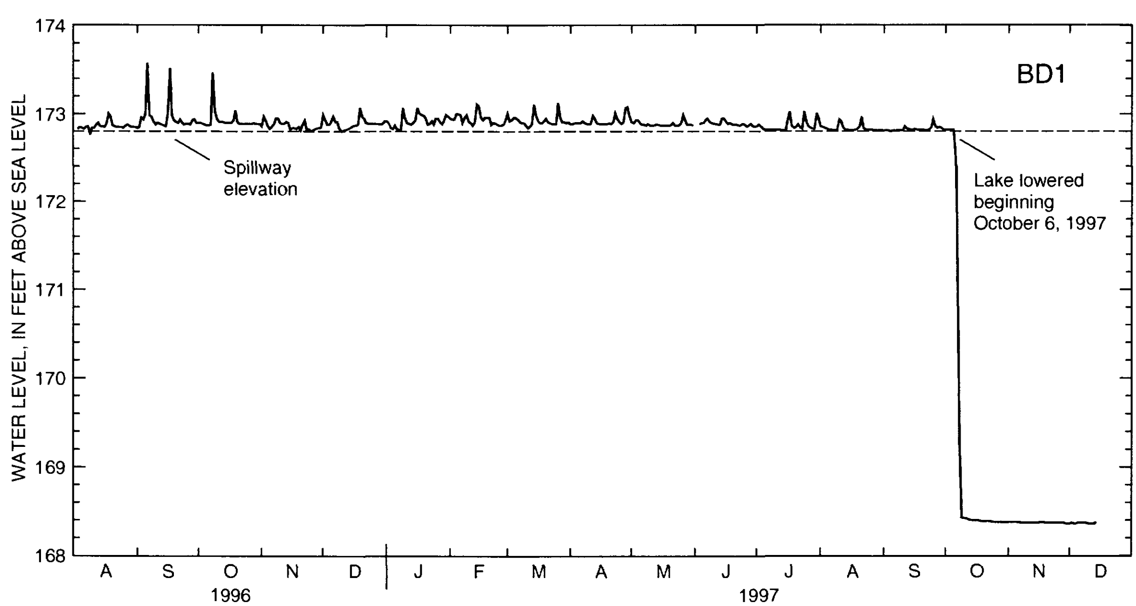
Supplementary Table ST-8. Daily mean water levels for Bonnie Doone Lake site BD1, August 1996 through December 1997

BONNIE DOONE LAKE AT DAM NEAR BONNIE DOONE, NC

[Site BD1 is at latitude 35°06'35", longitude 78°56'40", Cumberland County, U.S. Geological Survey downstream order number 0210382025, Hydrologic Unit 03030004; drainage area is 2.54 square miles; spillway elevation is 172.8 feet above mean sea level; ---, no data or day not in month; MAX, maximum; MIN, minimum]

WATER LEVEL, IN FEET ABOVE SEA LEVEL, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	---	172.84	172.90	172.86	172.99
2	---	---	---	---	---	---	---	---	172.85	172.90	172.97	172.93
3	---	---	---	---	---	---	---	172.83	172.96	172.89	172.92	172.88
4	---	---	---	---	---	---	---	172.85	172.94	172.88	172.86	172.88
5	---	---	---	---	---	---	---	172.84	173.00	172.87	172.83	172.92
6	---	---	---	---	---	---	---	172.83	173.58	172.87	172.86	172.97
7	---	---	---	---	---	---	---	172.85	172.98	172.88	172.88	172.91
8	---	---	---	---	---	---	---	172.86	172.97	173.47	172.95	172.91
9	---	---	---	---	---	---	---	172.76	172.91	173.03	172.95	172.83
10	---	---	---	---	---	---	---	172.84	172.88	172.94	172.90	172.80
11	---	---	---	---	---	---	---	172.84	172.90	172.91	172.89	172.81
12	---	---	---	---	---	---	---	172.88	172.89	172.91	172.89	172.82
13	---	---	---	---	---	---	---	172.90	172.88	172.91	172.91	172.83
14	---	---	---	---	---	---	---	172.86	172.87	172.90	172.90	172.84
15	---	---	---	---	---	---	---	172.86	172.86	172.90	172.82	172.86
16	---	---	---	---	---	---	---	172.85	173.01	172.90	172.84	172.87
17	---	---	---	---	---	---	---	172.90	173.52	172.90	172.84	172.87
18	---	---	---	---	---	---	---	173.00	172.98	172.93	172.83	172.88
19	---	---	---	---	---	---	---	172.97	172.93	173.04	172.85	173.07
20	---	---	---	---	---	---	---	172.87	172.91	172.91	172.81	172.97
21	---	---	---	---	---	---	---	172.86	172.90	172.89	172.88	172.95
22	---	---	---	---	---	---	---	172.85	172.94	172.89	172.93	172.90
23	---	---	---	---	---	---	---	172.85	172.90	172.89	172.82	172.89
24	---	---	---	---	---	---	---	172.85	172.88	172.89	172.83	172.89
25	---	---	---	---	---	---	---	172.84	172.89	172.89	172.80	172.89
26	---	---	---	---	---	---	---	172.86	172.89	172.89	172.82	172.89
27	---	---	---	---	---	---	---	172.88	172.88	172.89	172.83	172.89
28	---	---	---	---	---	---	---	172.87	172.93	172.90	172.84	172.89
29	---	---	---	---	---	---	---	172.85	172.94	172.89	172.84	172.88
30	---	---	---	---	---	---	---	172.85	172.90	172.89	172.85	172.89
31	---	---	---	---	---	---	---	172.85	---	172.89	---	172.92
MEAN	---	---	---	---	---	---	---	---	172.96	172.92	172.87	172.89
MAX	---	---	---	---	---	---	---	---	173.58	173.47	172.97	173.07
MIN	---	---	---	---	---	---	---	---	172.84	172.87	172.80	172.80



Supplementary Table ST-8. Daily mean water levels for Bonnie Doone Lake site BD1, August 1996 through December 1997—Continued

BONNIE DOONE LAKE AT DAM NEAR BONNIE DOONE, NC

[Site BD1 is at latitude 35°06'35", longitude 78°56'40", Cumberland County, U.S. Geological Survey downstream order number 0210382025, Hydrologic Unit 03030004; drainage area is 2.54 square miles; spillway elevation is 172.8 feet above mean sea level; ---, no data or day not in month; MAX, maximum; MIN, minimum]

WATER LEVEL, IN FEET ABOVE SEA LEVEL, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	172.92	172.95	173.01	172.89	172.91	---	172.86	172.86	172.81	172.82	168.38	168.36
2	172.90	172.94	172.92	172.89	172.90	---	172.88	172.85	172.81	172.82	168.38	168.37
3	172.84	172.94	172.93	172.90	172.93	172.89	172.86	172.84	172.81	172.82	168.38	168.36
4	172.83	173.00	172.96	172.90	172.93	172.90	172.83	172.83	172.80	172.82	168.38	168.36
5	172.87	173.00	172.96	172.90	172.90	172.90	172.82	172.82	172.81	172.82	168.38	168.37
6	172.83	172.99	172.94	172.90	172.88	172.93	172.82	172.82	172.81	172.48	168.38	168.37
7	172.82	172.90	172.91	172.92	172.88	172.95	172.82	172.81	172.81	171.13	168.37	168.37
8	172.82	172.96	172.90	172.90	172.87	172.91	172.82	172.81	172.81	169.27	168.37	168.37
9	173.07	172.99	172.90	172.89	172.89	172.90	172.82	172.81	172.81	168.43	168.37	168.37
10	172.96	172.92	172.87	172.89	172.87	172.89	172.82	172.94	172.81	168.42	168.37	168.36
11	172.90	172.90	172.84	172.89	172.87	172.89	172.82	172.92	172.86	168.42	168.37	168.36
12	172.89	172.87	172.86	172.98	172.87	172.88	172.82	172.84	172.83	168.41	168.37	168.36
13	172.88	172.91	172.89	172.95	172.88	172.88	172.81	172.82	172.83	168.40	168.37	168.36
14	172.90	173.11	173.11	172.90	172.88	172.95	172.81	172.82	172.82	168.40	168.37	168.38
15	172.93	173.09	172.99	172.89	172.87	172.95	172.81	172.81	172.81	168.40	168.37	---
16	173.07	172.96	172.92	172.89	172.87	172.91	172.94	172.81	172.83	168.40	168.37	---
17	173.01	172.93	172.90	172.89	172.87	172.89	173.03	172.81	172.82	168.40	168.38	---
18	172.99	172.96	172.90	172.89	172.87	172.90	172.86	172.82	172.82	168.39	168.38	---
19	172.98	172.96	172.92	172.89	172.87	172.88	172.84	172.83	172.82	168.39	168.37	---
20	172.95	172.96	172.95	172.90	172.87	172.88	172.85	172.86	172.82	168.39	168.37	---
21	172.88	172.88	172.91	172.89	172.90	172.88	172.88	172.97	172.81	168.39	168.37	---
22	172.89	172.90	172.90	172.91	172.87	172.87	172.84	172.84	172.81	168.39	168.37	---
23	172.92	172.90	172.89	173.01	172.87	172.87	172.83	172.82	172.82	168.39	168.37	---
24	172.88	172.88	172.89	172.94	172.87	172.89	173.03	172.82	172.84	168.38	168.37	---
25	172.95	172.87	172.89	172.91	172.90	172.88	172.91	172.82	172.94	168.38	168.37	---
26	172.95	172.87	173.13	172.89	172.99	172.86	172.86	172.82	172.86	168.38	168.37	---
27	172.91	172.88	172.96	172.91	172.93	172.87	172.84	172.81	172.84	168.38	168.37	---
28	172.89	172.94	172.91	173.07	172.88	172.89	172.83	172.81	172.85	168.38	168.37	---
29	172.93	---	172.91	173.08	172.88	172.86	172.83	172.81	172.84	168.38	168.36	---
30	172.99	---	172.90	172.97	172.88	172.86	173.01	172.81	172.82	168.38	168.36	---
31	172.97	---	172.91	---	172.87	---	172.95	172.81	---	168.38	---	---
MEAN	172.92	172.94	172.93	172.92	172.89	---	172.86	172.83	172.83	169.36	168.37	---
MAX	173.07	173.11	173.13	173.08	172.99	---	173.03	172.97	172.94	172.82	168.38	---
MIN	172.82	172.87	172.84	172.89	172.87	---	172.81	172.81	172.80	168.38	168.36	---

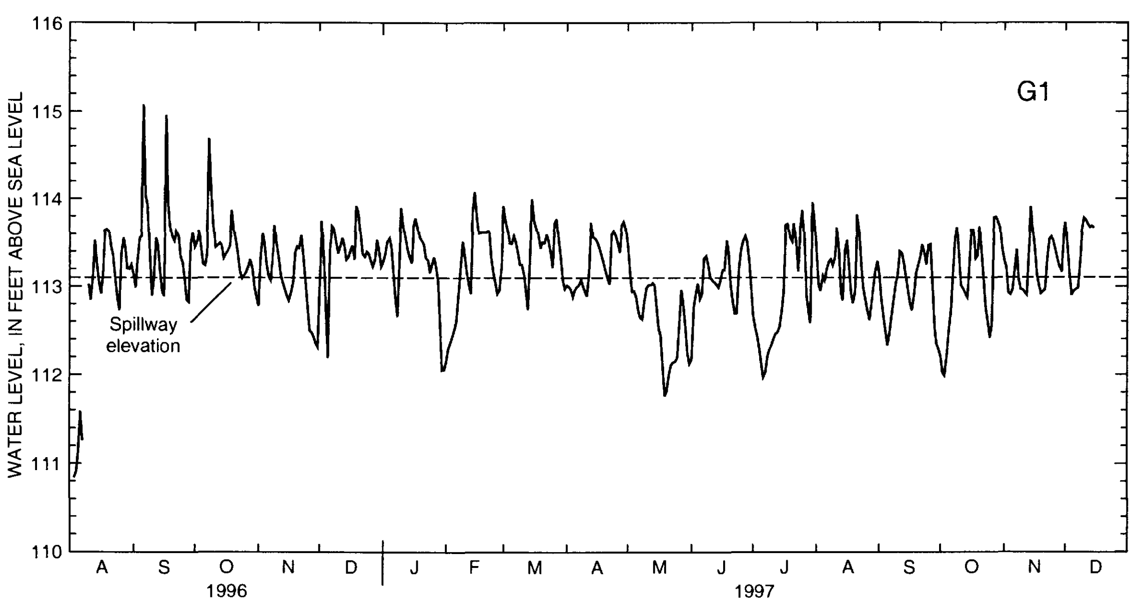
Supplementary Table ST-9. Daily mean water levels for Glenville Lake site G1, August 1996 through December 1997

LITTLE CROSS CREEK (GLENVILLE LAKE) AT WATER-SUPPLY INTAKE AT FAYETTEVILLE, NC

[Site G1 is at latitude 35°04'08", longitude 78°53'50", Cumberland County, U.S. Geological Survey downstream order number 0210382100, Hydrologic Unit 03030004; drainage area is 9.14 square miles; spillway elevation is 113.1 feet above mean sea level; ---, no data or day not in month; MAX, maximum; MIN, minimum]

WATER LEVEL, IN FEET ABOVE SEA LEVEL, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	---	113.13	113.46	112.78	113.02
2	---	---	---	---	---	---	---	---	112.99	113.52	113.31	113.75
3	---	---	---	---	---	---	---	110.84	113.31	113.64	113.61	113.36
4	---	---	---	---	---	---	---	110.91	113.56	113.46	113.48	112.67
5	---	---	---	---	---	---	---	111.15	113.58	113.26	113.26	112.19
6	---	---	---	---	---	---	---	111.59	115.08	113.24	113.11	113.41
7	---	---	---	---	---	---	---	111.26	114.04	113.38	113.07	113.69
8	---	---	---	---	---	---	---	---	113.93	114.69	113.31	113.66
9	---	---	---	---	---	---	---	---	113.45	114.11	113.70	113.52
10	---	---	---	---	---	---	---	113.03	112.90	113.71	113.49	113.38
11	---	---	---	---	---	---	---	112.85	113.08	113.45	113.33	113.46
12	---	---	---	---	---	---	---	113.11	113.56	113.47	113.14	113.56
13	---	---	---	---	---	---	---	113.53	113.47	113.50	113.05	113.47
14	---	---	---	---	---	---	---	113.28	113.19	113.47	112.97	113.31
15	---	---	---	---	---	---	---	113.05	112.94	113.33	112.89	113.34
16	---	---	---	---	---	---	---	112.92	112.89	113.38	112.84	113.41
17	---	---	---	---	---	---	---	113.15	114.96	113.41	112.93	113.47
18	---	---	---	---	---	---	---	113.64	113.97	113.47	113.06	113.31
19	---	---	---	---	---	---	---	113.65	113.70	113.87	113.39	113.92
20	---	---	---	---	---	---	---	113.63	113.57	113.65	113.46	113.84
21	---	---	---	---	---	---	---	113.46	113.52	113.51	113.44	113.60
22	---	---	---	---	---	---	---	113.36	113.63	113.36	113.59	113.37
23	---	---	---	---	---	---	---	113.09	113.58	113.17	113.36	113.34
24	---	---	---	---	---	---	---	112.86	113.35	113.10	113.07	113.40
25	---	---	---	---	---	---	---	112.73	113.27	113.13	112.76	113.38
26	---	---	---	---	---	---	---	113.37	113.09	113.17	112.50	113.29
27	---	---	---	---	---	---	---	113.56	112.85	113.23	112.48	113.23
28	---	---	---	---	---	---	---	113.44	112.82	113.31	112.43	113.31
29	---	---	---	---	---	---	---	113.21	113.49	113.21	112.35	113.54
30	---	---	---	---	---	---	---	113.20	113.62	113.00	112.31	113.42
31	---	---	---	---	---	---	---	113.25	---	112.89	---	113.23
MEAN	---	---	---	---	---	---	---	---	113.48	113.44	113.08	113.38
MAX	---	---	---	---	---	---	---	---	115.08	114.69	113.70	113.92
MIN	---	---	---	---	---	---	---	---	112.82	112.89	112.31	112.19



Supplementary Table ST-9. Daily mean water levels for Glenville Lake site G1, August 1996 through December 1997—Continued

LITTLE CROSS CREEK (GLENVILLE LAKE) AT WATER-SUPPLY INTAKE AT FAYETTEVILLE, NC

[Site G1 is at latitude 35°04'08", longitude 78°53'50", Cumberland County, U.S. Geological Survey downstream order number 0210382100, Hydrologic Unit 03030004; drainage area is 9.14 square miles; spillway elevation is 113.1 feet above mean sea level; ---, no data or day not in month; MAX, maximum; MIN, minimum]

WATER LEVEL, IN FEET ABOVE SEA LEVEL, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY MEAN VALUES

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	113.28	112.15	113.92	113.02	113.46	112.18	112.68	113.38	113.15	112.20	113.29	113.73
2	113.36	112.29	113.77	113.00	113.14	112.78	112.53	113.01	112.87	112.02	113.21	113.47
3	113.52	112.36	113.65	112.97	112.94	112.92	112.44	112.95	112.68	111.99	112.93	113.11
4	113.56	112.43	113.50	112.88	112.95	113.04	112.29	113.12	112.48	112.22	112.91	112.90
5	113.45	112.52	113.49	112.96	112.88	112.86	112.12	113.07	112.33	112.49	112.96	112.95
6	113.15	112.62	113.58	113.00	112.74	112.91	111.97	113.19	112.46	112.74	113.21	112.97
7	112.88	112.92	113.51	113.02	112.65	113.32	112.03	113.28	112.65	113.18	113.42	112.98
8	112.66	113.23	113.38	113.08	112.63	113.35	112.20	113.31	112.83	113.56	113.08	113.25
9	113.38	113.52	113.25	113.00	112.83	113.25	112.28	113.24	113.02	113.67	112.97	113.62
10	113.90	113.37	113.25	112.94	112.99	113.10	112.34	113.33	113.15	113.34	112.96	113.78
11	113.69	113.16	113.14	112.89	113.02	113.07	112.41	113.67	113.40	113.01	112.93	113.76
12	113.54	113.03	112.94	113.18	113.02	113.05	112.46	113.40	113.38	112.97	112.90	113.71
13	113.42	112.92	112.74	113.73	113.04	113.02	112.48	112.93	113.26	112.91	113.29	113.67
14	113.34	113.86	113.53	113.57	113.01	112.99	112.54	112.84	113.12	112.87	113.91	113.69
15	113.27	114.08	114.00	113.55	112.78	113.07	112.72	113.42	112.96	113.27	113.64	113.66
16	113.69	113.80	113.75	113.50	112.52	113.19	112.95	113.53	112.81	113.64	113.43	---
17	113.78	113.61	113.67	113.44	112.44	113.19	113.70	113.23	112.73	113.64	113.12	---
18	113.66	113.62	113.60	113.36	112.05	113.53	113.71	112.92	112.91	113.32	113.01	---
19	113.56	113.62	113.44	113.27	111.76	113.38	113.55	112.81	113.15	113.35	112.92	---
20	113.52	113.62	113.51	113.18	111.82	113.03	113.51	112.95	113.25	113.68	112.94	---
21	113.48	113.63	113.50	113.10	112.01	112.83	113.72	113.82	113.34	113.37	112.97	---
22	113.33	113.63	113.60	113.03	112.11	112.69	113.47	113.66	113.48	113.05	113.32	---
23	113.30	113.34	113.52	113.60	112.14	112.69	113.17	113.24	113.38	112.75	113.54	---
24	113.16	113.16	113.38	113.63	112.15	113.21	113.62	112.99	113.25	112.59	113.57	---
25	113.25	113.05	113.22	113.58	112.20	113.41	113.87	112.87	113.47	112.42	113.51	---
26	113.34	112.92	113.71	113.50	112.64	113.53	113.59	112.73	113.48	112.56	113.42	---
27	113.23	112.96	113.77	113.39	112.97	113.58	112.90	112.62	113.05	113.78	113.32	---
28	113.05	113.23	113.54	113.70	112.80	113.51	112.72	112.79	112.54	113.79	113.22	---
29	112.52	---	113.35	113.74	112.53	113.28	112.58	112.99	112.34	113.73	113.16	---
30	112.05	---	113.08	113.65	112.24	112.98	113.96	113.17	112.29	113.66	113.59	---
31	112.06	---	112.98	---	112.13	---	113.77	113.29	---	113.43	---	---
MEAN	113.27	113.17	113.46	113.28	112.60	113.10	112.91	113.15	112.97	113.07	113.22	---
MAX	113.90	114.08	114.00	113.74	113.46	113.58	113.96	113.82	113.48	113.79	113.91	---
MIN	112.05	112.15	112.74	112.88	111.76	112.18	111.97	112.62	112.29	111.99	112.90	---

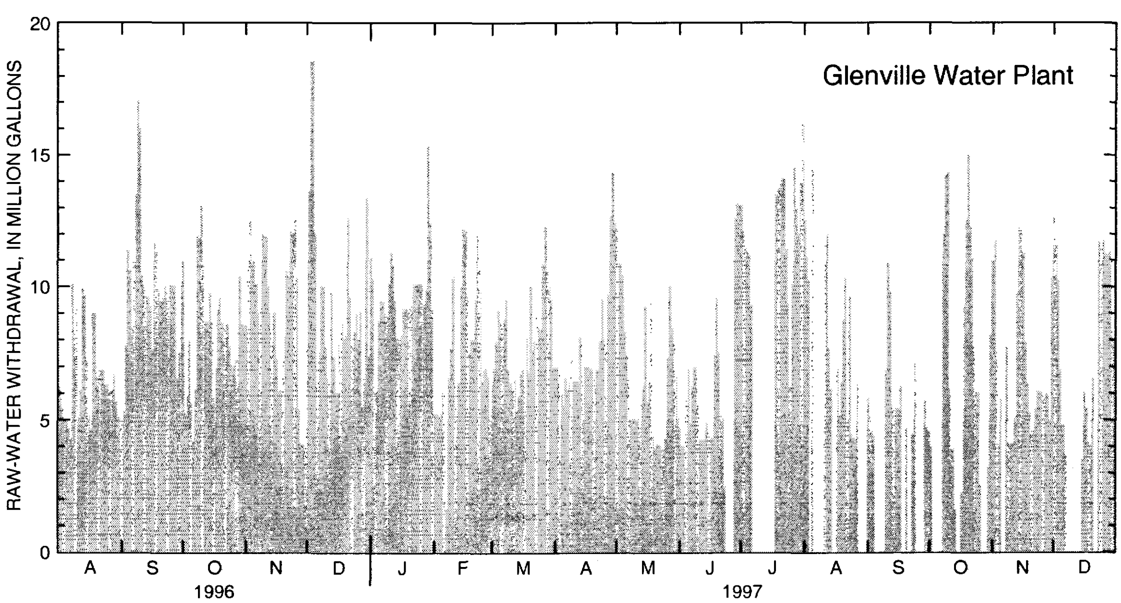
Supplementary Table ST-10. Daily withdrawals from Glenville Lake site G1 into Glenville Water Plant, August 1996 through December 1997

LITTLE CROSS CREEK (GLENVILLE LAKE) AT WATER-SUPPLY INTAKE AT FAYETTEVILLE, NC

[Site G1 is at latitude 35°04'08", longitude 78°53'50", Cumberland County, U.S. Geological Survey downstream order number 0210382100, Hydrologic Unit 03030004; drainage area is 9.14 square miles; ---, no data or day not in month; MAX, maximum; MIN, minimum]

WITHDRAWAL, IN MILLION GALLONS, CALENDAR YEAR JANUARY THROUGH DECEMBER 1996
DAILY TOTALS

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	---	---	---	---	---	---	---	11.581	5.041	10.957	8.491	7.908
2	---	---	---	---	---	---	---	6.259	5.310	5.236	10.975	13.593
3	---	---	---	---	---	---	---	5.461	7.732	5.848	12.679	18.521
4	---	---	---	---	---	---	---	4.949	11.316	7.920	10.898	18.541
5	---	---	---	---	---	---	---	4.916	10.601	5.634	10.944	12.036
6	---	---	---	---	---	---	---	4.691	8.415	4.178	10.069	7.071
7	---	---	---	---	---	---	---	4.251	10.916	6.144	8.976	7.522
8	---	---	---	---	---	---	---	10.060	13.466	11.906	9.474	9.992
9	---	---	---	---	---	---	---	8.341	17.027	11.815	11.982	9.977
10	---	---	---	---	---	---	---	9.176	16.002	13.123	11.892	7.726
11	---	---	---	---	---	---	---	5.049	10.401	10.803	11.870	6.512
12	---	---	---	---	---	---	---	6.099	10.004	8.681	9.979	6.517
13	---	---	---	---	---	---	---	9.899	9.581	8.678	9.012	9.748
14	---	---	---	---	---	---	---	9.630	9.572	9.746	9.006	7.365
15	---	---	---	---	---	---	---	7.218	9.224	8.612	8.996	6.010
16	---	---	---	---	---	---	---	5.122	7.646	5.792	7.259	6.012
17	---	---	---	---	---	---	---	4.644	11.609	6.965	6.045	7.804
18	---	---	---	---	---	---	---	8.965	11.265	9.112	6.084	8.562
19	---	---	---	---	---	---	---	8.965	9.877	9.528	7.102	8.045
20	---	---	---	---	---	---	---	6.589	9.452	8.602	8.090	8.138
21	---	---	---	---	---	---	---	6.862	9.557	8.588	10.538	12.605
22	---	---	---	---	---	---	---	6.853	9.994	8.563	10.370	9.559
23	---	---	---	---	---	---	---	6.831	9.852	8.556	12.077	8.032
24	---	---	---	---	---	---	---	6.310	9.968	7.734	12.030	8.265
25	---	---	---	---	---	---	---	6.310	10.018	7.020	12.630	8.978
26	---	---	---	---	---	---	---	6.048	10.021	7.020	10.317	7.993
27	---	---	---	---	---	---	---	6.086	10.035	7.288	5.362	9.025
28	---	---	---	---	---	---	---	6.668	6.533	8.505	4.083	5.482
29	---	---	---	---	---	---	---	5.674	7.504	10.360	4.076	6.560
30	---	---	---	---	---	---	---	5.085	10.074	8.535	4.017	13.335
31	---	---	---	---	---	---	---	5.071		8.492		7.379
TOTAL	---	---	---	---	---	---	---	209.663	298.013	259.941	275.323	284.813
MEAN	---	---	---	---	---	---	---	6.763	9.934	8.385	9.177	9.188
MAX	---	---	---	---	---	---	---	11.581	17.027	13.123	12.679	18.541
MIN	---	---	---	---	---	---	---	4.251	5.041	4.178	4.017	5.482



Supplementary Table ST-10. Daily withdrawals from Glenville Lake site G1 into Glenville Water Plant, August 1996 through December 1997—Continued

LITTLE CROSS CREEK (GLENVILLE LAKE) AT WATER-SUPPLY INTAKE AT FAYETTEVILLE, NC

[Site G1 is at latitude 35°04'08", longitude 78°53'50", Cumberland County, U.S. Geological Survey downstream order number 0210382100, Hydrologic Unit 03030004; drainage area is 9.14 square miles; ---, no data or day not in month; MAX, maximum; MIN, minimum]

WITHDRAWAL, IN MILLION GALLONS, CALENDAR YEAR JANUARY THROUGH DECEMBER 1997
DAILY TOTALS

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	11.072	5.207	6.346	6.952	12.180	4.694	13.070	12.480	5.781	4.539	10.934	12.636
2	10.244	5.215	6.899	6.952	10.859	4.011	12.124	11.079	5.151	3.958	11.724	11.583
3	6.124	5.143	7.947	6.905	10.847	4.016	11.460	10.198	4.600	0.000	7.619	10.210
4	6.095	5.218	9.074	5.936	10.409	5.985	11.298	0.000	4.380	0.000	4.057	6.843
5	8.681	6.019	8.635	5.525	8.298	6.877	11.176	14.387	0.000	0.000	5.766	4.778
6	9.439	5.951	8.684	6.554	7.387	4.844	9.269	0.000	0.000	0.000	0.000	4.770
7	9.387	1.585	8.757	6.125	6.547	6.242	0.000	0.000	0.000	0.000	0.000	3.705
8	8.970	6.554	9.480	6.424	4.995	6.941	0.000	0.000	0.000	11.966	7.715	0.000
9	8.923	7.630	6.859	7.751	5.008	6.938	0.000	0.000	0.000	14.206	4.084	0.000
10	10.095	10.383	6.399	6.434	5.014	5.558	0.000	0.000	6.824	14.358	4.084	0.000
11	11.260	6.590	6.106	6.434	4.998	4.229	0.000	11.644	10.868	6.148	4.077	0.000
12	10.782	6.397	6.489	6.452	5.016	4.234	0.000	11.981	9.797	3.904	5.109	0.000
13	9.464	6.372	5.370	8.091	5.679	4.232	0.000	7.642	5.491	3.888	9.720	0.000
14	8.056	9.992	5.902	7.930	6.266	4.856	0.000	6.163	5.469	1.601	12.422	0.000
15	8.013	12.153	6.710	6.984	9.221	4.850	0.000	0.000	5.436	0.000	12.987	3.460
16	8.158	12.103	6.877	6.970	5.651	4.323	0.000	0.000	5.423	0.000	11.227	5.996
17	9.155	9.636	6.297	6.970	6.410	4.313	0.000	6.899	6.252	2.245	7.898	5.400
18	9.156	7.452	8.053	6.905	10.043	7.417	13.452	5.136	0.000	9.273	6.341	4.135
19	9.116	7.986	6.797	6.851	4.363	9.548	13.697	6.388	0.000	12.486	5.249	4.033
20	9.196	7.988	10.000	6.849	3.936	7.488	13.858	8.699	4.683	15.028	4.541	6.521
21	9.301	9.484	7.560	6.845	4.044	5.205	14.134	10.291	0.000	12.260	4.536	0.000
22	10.067	12.011	7.925	6.850	4.028	5.025	14.058	5.007	0.000	11.058	5.436	0.000
23	10.059	10.663	8.899	7.914	3.982	2.462	11.400	9.569	4.454	7.740	6.031	11.660
24	10.063	6.420	8.407	9.480	3.926	0.000	9.324	4.451	7.229	6.012	6.031	11.516
25	10.148	6.840	8.385	8.013	4.275	0.000	6.327	4.280	0.000	5.993	6.012	11.733
26	10.147	6.929	10.858	7.997	7.305	0.000	10.085	4.243	0.000	2.512	5.980	11.241
27	9.292	6.604	12.255	9.664	10.003	0.000	14.480	6.280	0.000	0.000	5.957	11.172
28	9.862	5.090	10.550	12.667	8.437	12.580	12.920	0.000	0.000	0.000	5.906	11.270
29	15.329		9.966	14.281	8.049	13.128	12.013	0.000	5.727	0.000	4.977	10.772
30	12.418		9.498	12.390	6.635	13.064	13.930	0.000	4.696	3.180	10.291	8.053
31	9.130		6.955		5.025		16.538	0.000		8.193		7.062
TOTAL	297.202	209.615	248.939	232.095	208.836	163.060	244.613	156.817	102.261	160.548	196.711	178.549
MEAN	9.587	7.486	8.030	7.737	6.737	5.435	7.891	5.059	3.409	5.179	6.557	5.760
MAX	15.329	12.153	12.255	14.281	12.180	13.128	16.538	14.387	10.868	15.028	12.987	12.636
MIN	6.095	1.585	5.370	5.525	3.926	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table ST-11. Water-quality field measurements and sample analyses at Little Cross Creek site S1, October 1996 through January 1998

LITTLE CROSS CREEK ABOVE BONNIE DOONE LAKE NEAR SHAWS, NC

[Site S1 is at latitude 35°07'09", longitude 78°56'45", Cumberland County, U.S. Geological Survey downstream order number 0210382000; ft^3/s, cubic foot per second; μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Discharge, inst. (ft^3/s) (00061)	Specific conductance (μS/cm) (00095)	pH, field (standard units) (00400)	Water temperature (°C) (00010)	Turbidity (NTU) (00076)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Fecal coliform bacteria (colonies/ 100 mL) (31616)	Total suspended solids (mg/L) (00530)
					1996					
Oct. 17	1305	2.8	---	---	---	---	---	---	K27	---
18	1605	2.7	28	6.1	20.0	2.9	6.9	76	---	4
Nov. 13	1310	2.1	---	---	---	---	---	---	44	---
14	1130	2.7	28	6.1	9.5	3.9	9.0	78	---	3
Dec. 11	0820	3.4	---	---	---	---	---	---	K2	---
11	1615	2.4	24	6.0	11.5	3.8	9.0	83	---	2
19	0900	11	18	5.8	9.0	23	8.9	78	220	21
					1997					
Jan. 14	1015	1.8	---	---	---	---	---	---	<1	---
15	0945	1.8	26	6.3	4.5	2.7	11.5	88	---	1
Feb. 12	0940	1.2	---	---	---	---	---	---	K2	---
14	1015	2.1	21	6.1	---	22	---	---	---	14
Mar. 1	0910	6.0	21	6.0	16.2	14	7.8	79	K53	8
14	0945	14	16	5.2	14.4	25	8.5	84	820	55
14	1525	14	16	5.6	16.0	42	8.4	86	---	37
Apr. 23	1420	3.5	22	5.8	13.9	12	7.7	77	---	12
29	1000	11	17	5.7	15.0	60	8.1	82	400	57
May 5	0930	1.3	---	---	---	---	---	---	K8	---
5	1200	1.3	24	6.1	15.5	4.8	7.9	79	---	1
19	0920	1.3	---	---	---	---	---	---	K9	---
19	1230	1.5	25	6.0	19.9	3.1	6.8	75	---	5
June 2	1235	1.5	---	---	---	---	---	---	K16	---
2	1500	1.8	25	6.2	21.9	4.7	5.9	69	---	1
16	1010	3.0	---	---	---	---	---	---	54	---
17	1045	2.7	25	5.9	20.0	4.9	6.8	75	---	4
July 24	1030	23	19	5.2	24.2	42	6.2	74	K1,100	44
30	0945	22	33	5.2	23.2	7.5	6.3	73	1,200	12
Nov. 13	1115	6.8	37	6.3	12.5	1.5	8.1	76	100	5
Dec. 22	1300	25	31	6.3	9.0	20	9.4	81	---	81
					1998					
Jan. 7	0900	2.5	---	---	---	---	---	---	K4	---
7	1200	3.7	27	5.2	14.6	6.7	7.8	77	---	5

Supplementary Table ST-11. Water-quality field measurements and sample analyses at Little Cross Creek site S1, October 1996 through January 1998—Continued

LITTLE CROSS CREEK ABOVE BONNIE DOONE LAKE NEAR SHAWS, NC

[Site S1 is at latitude 35°07'09", longitude 78°56'45", Cumberland County, U.S. Geological Survey downstream order number 0210382000; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Dissolved nitrite + nitrate (mg/L as N) (00631)	Dissolved ammonia (mg/L as N) (00608)	Total ammonia + organic nitrogen (mg/L as N) (00625)	Total phos-phorus (mg/L as P) (00665)	Dissolved phos-phorus ortho, (mg/L as P) (00671)	Total organic carbon (mg/L as C) (00680)	Suspended sediment (mg/L) (80154)	Suspended sediment (percent finer than 0.062 mm) (70331)
				1996					
Oct. 17	1305	---	---	---	---	---	---	---	---
18	1605	0.220	<0.002	<0.20	0.006	<0.001	2.6	6	---
Nov. 13	1310	---	---	---	---	---	---	---	---
14	1130	.200	.033	<.20	.004	.001	1.6	3	---
Dec. 11	0820	---	---	---	---	---	---	---	---
11	1615	.250	.030	<.20	.005	<.001	1.7	1	---
19	0900	.100	.010	<.20	.049	<.001	3.7	70	30
				1997					
Jan. 14	1015	---	---	---	---	---	---	---	---
15	0945	.410	.088	<.20	.003	<.001	1.4	3	---
Feb. 12	0940	---	---	---	---	---	---	---	---
14	1015	.160	.083	<.20	.029	<.001	3.1	30	---
Mar. 1	0910	.093	.012	<.20	.019	<.001	3.2	25	49
14	0945	.140	.017	.50	.043	<.001	3.9	70	81
14	1525	.073	.013	<.20	.052	<.001	4.5	32	95
Apr. 23	1420	.184	.031	<.20	.019	.007	2.8	12	86
29	1000	.143	.019	.25	.061	.002	5.2	132	31
May 5	0930	---	---	---	---	---	---	---	---
5	1200	.173	.023	<.20	.006	.001	2.6	3	---
19	0920	---	---	---	---	---	---	---	---
19	1230	.181	.028	<.20	.006	.002	1.7	8	---
June 2	1235	---	---	---	---	---	---	---	---
2	1500	.140	.017	<.20	.007	.001	2.6	5	---
16	1010	---	---	---	---	---	---	---	---
17	1045	.150	.019	<.20	.007	.001	2.1	2	---
July 24	1030	.118	.003	.26	.066	.001	6.2	32	96
30	0945	.280	.030	.25	.029	.002	5.9	395	1
Nov. 13	1115	.224	.010	.12	.019	.003	3.0	22	22
Dec. 22	1300	.347	.037	.31	.038	.001	10	241	21
				1998					
Jan. 7	0900	---	---	---	---	---	---	---	---
7	1200	.138	.013	<.10	.013	.005	2.5	5	---

Supplementary Table ST-12. Water-quality field measurements and sample analyses at Little Cross Creek site S2, September 1996 through January 1998

LITTLE CROSS CREEK BELOW BONNIE DOONE LAKE DAM NEAR SHAWS, NC

[Site S2 is at latitude 35°06'32", longitude 78°56'37", Cumberland County, U.S. Geological Survey downstream order number 0210382026; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Discharge, inst. (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	pH, field (standard units) (00400)	Water temperature (°C) (00010)	Turbidity (NTU) (00076)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Fecal coliform bacteria (colonies/ 100 mL) (31616)	Total suspended solids (mg/L) (00530)
					1996					
Sept. 5	1845	6.5	---	---	---	---	---	---	---	3
Oct. 17	1320	5.5	---	---	---	---	---	---	K4	---
18	1430	5.8	21	5.8	18.5	6.2	7.3	77	---	4
Nov. 13	1320	6.3	---	---	---	---	---	---	28	---
14	1400	7.2	30	5.5	11.0	9.4	8.8	79	---	8
Dec. 11	0840	5.3	---	---	---	---	---	---	K7	---
11	1515	2.6	27	5.8	9.5	5.5	9.2	81	---	12
19	1000	19	26	5.9	9.0	18	9.9	86	K4	14
					1997					
Jan. 14	1030	4.8	---	---	---	---	---	---	38	---
14	1530	4.8	25	6.1	8.0	15	10.6	89	---	15
Feb. 12	1000	2.5	---	---	---	---	---	---	<1	---
12	1430	1.3	29	5.6	11.0	6.8	9.4	85	---	7
Mar. 1	1015	7.9	26	5.7	15.4	19	9.6	96	<1	16
14	1035	14	27	5.7	15.2	5.9	8.5	86	K15	<1
Apr. 23	1100	10	25	6.3	16.7	3.0	9.0	95	---	2
29	1100	18	24	6.2	16.8	4.0	8.4	88	34	1
May 5	0950	4.2	---	---	---	---	---	---	K18	---
5	1445	4.4	25	6.5	21.2	4.9	8.2	92	---	3
19	0940	3.5	---	---	---	---	---	---	K1	---
19	1345	4.7	26	6.4	23.7	2.0	7.2	86	---	4
June 2	1250	4.4	---	---	---	---	---	---	K5	---
2	1630	4.0	26	6.3	25.4	1.8	6.8	84	---	1
16	1030	4.1	---	---	---	---	---	---	59	---
17	1000	3.5	26	6.2	23.7	2.5	7.4	88	---	2
July 24	1130	29	28	5.8	26.2	5.2	5.9	73	33	<1
30	1030	16	27	6.2	27.3	3.7	6.3	80	32	3
Oct. 6	1130	66	27	6.3	21.7	10	---	---	400	10
Nov. 13	1215	8.6	29	7.5	12.0	4.8	8.7	81	61	10
					1998					
Jan. 7	0910	5.0	---	---	---	---	---	---	K3	---
7	1345	3.9	29	5.3	9.1	3.9	10.9	95	---	2

Supplementary Table ST-12. Water-quality field measurements and sample analyses at Little Cross Creek site S2, September 1996 through January 1998—Continued

LITTLE CROSS CREEK BELOW BONNIE DOONE LAKE DAM NEAR SHAWS, NC

[Site S2 is at latitude 35°06'32", longitude 78°56'37", Cumberland County, U.S. Geological Survey downstream order number 0210382026; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Dissolved nitrite + nitrate (mg/L as N) (00631)	Dissolved ammonia (mg/L as N) (00608)	Total ammonia + organic nitrogen (mg/L as N) (00625)	Total phosphorus (mg/L as P) (00665)	Dissolved phosphorus ortho, (mg/L as P) (00671)	Total organic carbon (mg/L as C) (00680)	Suspended sediment (mg/L) (80154)	Suspended sediment (percent finer than 0.062 mm) (70331)
				1996					
Sept. 5	1845	---	---	---	---	---	---	8	---
Oct. 17	1320	---	---	---	---	---	---	---	---
18	1430	0.210	<0.002	0.20	0.016	<0.001	4.8	8	---
Nov. 13	1320	---	---	---	---	---	---	---	---
14	1400	.180	.073	.20	.014	<.001	3.6	6	---
Dec. 11	0840	---	---	---	---	---	---	---	---
11	1515	.240	.148	.30	.017	<.001	3.3	11	---
19	1000	.360	.098	.20	.036	<.001	3.7	1,590	1
				1997					
Jan. 14	1030	---	---	---	---	---	---	---	---
14	1530	.380	.058	.30	.033	<.001	3.6	21	---
Feb. 12	1000	---	---	---	---	---	---	---	---
12	1430	.470	.121	<.20	.006	<.001	2.0	9	---
Mar. 1	1015	.380	.099	.30	.026	<.001	2.6	14	93
14	1035	.410	.090	.30	.012	<.001	3.0	7	86
Apr. 23	1100	.181	.016	.20	.007	.001	2.6	6	74
29	1100	.221	.017	<.20	.006	.003	2.9	3	92
May 5	0950	---	---	---	---	---	---	---	---
5	1445	.227	.011	<.20	.009	.001	3.1	9	---
19	0940	---	---	---	---	---	---	---	---
19	1345	.199	.012	<.20	.008	.002	1.9	7	---
June 2	1250	---	---	---	---	---	---	---	---
2	1630	.197	<.002	<.20	.005	<.001	3.1	5	---
16	1030	---	---	---	---	---	---	---	---
17	1000	.192	.006	.22	.006	<.001	3.1	3	---
July 24	1130	.163	.054	.27	.014	<.001	4.4	4	60
30	1030	.125	.032	.24	.010	<.001	4.7	2	75
Oct. 6	1130	.133	.032	.41	.020	<.001	3.0	79	6
Nov. 13	1215	.363	.046	.16	.010	.003	2.3	12	83
				1998					
Jan. 7	0910	---	---	---	---	---	---	---	---
7	1345	.389	<.002	<.10	.009	.001	2.2	2	---

Supplementary Table ST-13. Water-quality field measurements and sample analyses at Little Cross Creek site S3, September 1996 through January 1998

LITTLE CROSS CREEK BELOW KORNBOW LAKE DAM NEAR SHAWS, NC

[Site S3 is at latitude 35°06'04", longitude 78°55'42", Cumberland County, U.S. Geological Survey downstream order number 0210382035; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Discharge, inst. (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	pH, field (standard units) (00400)	Water temperature (°C) (00010)	Turbidity (NTU) (00076)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Fecal coliform bacteria (colonies/ 100 mL) (31616)	Total suspended solids (mg/L) (00530)
					1996					
Sept. 5	1800	12	---	---	---	---	---	---	---	1
Oct. 17	1335	8.6	---	---	---	---	---	---	K3	---
18	1245	18	27	6.3	21.0	3.7	7.9	88	---	3
Nov. 13	1335	9.4	---	---	---	---	---	---	K12	---
14	1615	10	35	5.6	12.0	4.4	10.5	97	---	3
Dec. 11	0855	6.3	---	---	---	---	---	---	K8	---
11	1330	6.8	33	6.4	10.0	6.8	10.6	94	---	2
19	1030	31	34	6.5	9.5	3.8	10.8	95	K11	2
					1997					
Jan. 14	1042	9.4	---	---	---	---	---	---	K5	---
14	1415	8.4	34	6.4	8.0	3.4	11.1	93	---	5
Feb. 12	1015	4.2	---	---	---	---	---	---	<1	---
12	1215	4.1	34	6.3	9.7	3.8	11.4	100	---	2
Mar. 1	1115	15	33	6.2	17.7	2.7	9.7	102	K9	1
14	1105	22	33	6.4	15.7	2.3	10.0	102	K2	<1
Apr. 23	1215	13	34	6.7	17.2	.60	9.2	99	---	3
29	1200	22	32	6.7	17.5	1.8	8.8	93	K8	3
May 5	1010	9.4	---	---	---	---	---	---	K4	---
5	1600	7.6	32	6.8	22.1	1.2	8.2	94	---	<1
19	0955	5.3	---	---	---	---	---	---	K1	---
19	1515	5.2	34	6.8	25.3	.65	7.4	91	---	<1
June 2	1300	6.3	---	---	---	---	---	---	K3	---
3	1200	5.7	34	6.8	24.8	.45	9.0	109	---	<1
16	1040	6.8	---	---	---	---	---	---	K10	---
16	1615	5.8	34	6.9	26.6	1.2	7.1	90	---	1
July 24	1230	19	35	6.4	28.2	1.4	6.4	83	30	5
30	1130	20	35	6.6	28.4	---	6.6	85	K16	<1
Nov. 13	1300	10	36	6.0	13.0	1.3	9.1	87	K5	3
					1998					
Jan. 7	0925	10.0	---	---	---	---	---	---	K4	---
7	1515	8.7	36	5.8	11.3	1.7	11.2	103	---	1

Supplementary Table ST-13. Water-quality field measurements and sample analyses at Little Cross Creek site S3, September 1996 through January 1998—Continued

LITTLE CROSS CREEK BELOW KORNBOW LAKE DAM NEAR SHAWS, NC

[Site S3 is at latitude 35°06'04", longitude 78°55'42", Cumberland County, U.S. Geological Survey downstream order number 0210382035; ft^3/s, cubic foot per second; μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Dissolved nitrite + nitrate (mg/L as N) (00631)	Dissolved ammonia (mg/L as N) (00608)	Total ammonia + organic nitrogen (mg/L as N) (00625)	Total phosphorus (mg/L as P) (00665)	Dissolved phosphorus ortho, (mg/L as P) (00671)	Total organic carbon (mg/L as C) (00680)	Suspended sediment (mg/L) (80154)	Suspended sediment (percent finer than 0.062 mm) (70331)
1996									
Sept. 5	1800	---	---	---	---	---	---	8	---
Oct. 17	1335	---	---	---	---	---	---	---	---
18	1245	0.340	<0.002	0.30	0.012	<0.001	4.7	6	---
Nov. 13	1335	---	---	---	---	---	---	---	---
14	1615	.400	.015	.20	.002	<.001	3.8	3	---
Dec. 11	0855	---	---	---	---	---	---	---	---
11	1330	.560	.013	<.20	.010	<.001	3.1	3	---
19	1030	.680	.010	<.20	.008	<.001	2.7	5	63
1997									
Jan. 14	1042	---	---	---	---	---	---	---	---
14	1415	.710	.004	<.20	.008	<.001	2.6	13	---
Feb. 12	1015	---	---	---	---	---	---	---	---
12	1215	.740	<.002	<.20	.006	<.001	2.8	8	---
Mar. 1	1115	.680	.019	<.20	.002	<.001	2.1	2	63
14	1105	.660	.006	<.20	.005	<.001	2.0	2	86
Apr. 23	1215	.377	.004	<.20	.006	.001	3.0	3	70
29	1200	.363	.003	<.20	.001	.003	2.8	2	57
May 5	1010	---	---	---	---	---	---	---	---
5	1600	.338	.006	<.20	.005	.002	3.1	10	---
19	0955	---	---	---	---	---	---	---	---
19	1515	.260	.016	<.20	.004	.002	3.0	15	---
June 2	1300	---	---	---	---	---	---	---	---
3	1200	.213	.002	<.20	.006	<.001	3.2	3	---
16	1040	---	---	---	---	---	---	---	---
16	1615	.143	<.002	.28	.007	<.001	4.2	8	---
July 24	1230	.121	.027	.22	.007	<.001	4.3	24	5
30	1130	---	---	---	---	---	---	2	29
Nov. 13	1300	.364	.028	.17	.005	.002	2.5	5	58
1998									
Jan. 7	0925	---	---	---	---	---	---	---	---
7	1515	.604	<.002	<.10	.005	<.001	2.8	1	---

Supplementary Table ST-14. Water-quality field measurements and sample analyses at Little Cross Creek site S4, September 1996 through January 1998

LITTLE CROSS CREEK BELOW MINTZ POND NEAR BONNIE DOONE, NC

[Site S4 is at latitude 35°05'19", longitude 78°55'27", Cumberland County, U.S. Geological Survey downstream order number 0210382050; ft^3/s, cubic foot per second; μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count; >, greater than]

Date	Time	Discharge, inst. (ft^3/s) (00061)	Specific conductance (μS/cm) (00095)	pH, field (standard units) (00400)	Water temperature (°C) (00010)	Turbidity (NTU) (00076)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Fecal coliform bacteria (colonies/ 100 mL) (31616)	Total suspended solids (mg/L) (00530)
					1996					
Sept. 5	1730	18	---	---	---	---	---	---	---	7
Oct. 17	1300	11	---	---	---	---	---	---	25	---
17	1615	11	31	6.4	20.5	3.1	8.4	92	---	5
Nov. 13	1115	12	39	7.0	10.0	3.3	11.2	97	K15	3
Dec. 11	0910	7.1	---	---	---	---	---	---	K8	---
11	1130	7.5	38	6.5	8.0	4.7	10.6	90	---	4
19	1200	31	35	6.5	10.0	5.1	10.5	94	K320	4
					1997					
Jan. 14	1059	11	---	---	---	---	---	---	K6	---
15	1300	12	37	6.6	5.5	2.2	11.8	93	---	4
30	1400	81	39	6.6	8.0	5.0	11.4	96	K14	6
Feb. 12	1040	7.1	---	---	---	---	---	---	K1	---
13	1145	5.7	40	6.5	8.6	3.8	11.4	97	---	2
Mar. 1	1245	25	36	6.4	17.5	12	9.3	97	1,100	11
14	1300	62	34	6.6	16.1	7.1	9.4	97	>1,200	10
Apr. 23	1335	19	39	6.7	16.8	3.3	8.4	88	---	6
29	1330	24	37	6.6	17.7	2.6	8.4	89	120	1
May 5	1030	10	---	---	---	---	---	---	46	---
6	1200	8.8	36	6.9	19.7	2.2	9.0	99	---	<1
19	1015	3.7	---	---	---	---	---	---	K15	---
20	0830	6.2	38	6.9	24.0	1.1	7.7	93	---	2
June 2	1320	6.3	---	---	---	---	---	---	1,000	---
3	1515	6.9	36	6.6	24.2	2.2	6.7	81	---	3
16	1055	7.8	---	---	---	---	---	---	30	---
16	1515	7.4	38	6.6	26.3	2.3	6.0	75	---	3
July 24	1430	25	37	6.5	27.4	4.5	5.8	73	K7,500	<1
30	1315	42	38	7.0	26.9	3.0	6.1	76	K200	4
Nov. 13	1415	28	52	6.7	12.5	1.2	8.5	80	1,500	2
					1998					
Jan. 7	0940	50	---	---	---	---	---	---	K140	---
7	1750	7.9	41	5.8	12.9	5.0	10.5	100	---	10

Supplementary Table ST-14. Water-quality field measurements and sample analyses at Little Cross Creek site S4, September 1996 through January 1998—Continued

LITTLE CROSS CREEK BELOW MINTZ POND NEAR BONNIE DOONE, NC

[Site S4 is at latitude 35°05'19", longitude 78°55'27", Cumberland County, U.S. Geological Survey downstream order number 0210382050; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count; >, greater than]

Date	Time	Dissolved nitrite + nitrate (mg/L as N) (00631)	Dissolved ammonia (mg/L as N) (00608)	Total ammonia + organic nitrogen (mg/L as N) (00625)	Total phosphorus (mg/L as P) (00665)	Dissolved phosphorus ortho, (mg/L as P) (00671)	Total organic carbon (mg/L as C) (00680)	Suspended sediment (mg/L) (80154)	Suspended sediment (percent finer than 0.062 mm) (70331)
				1996					
Sept. 5	1730	---	---	---	---	---	---	36	---
Oct. 17	1300	---	---	---	---	---	---	---	---
17	1615	0.230	<0.002	0.20	0.017	<0.001	5.8	2	---
Nov. 13	1115	.240	.010	.30	.011	<.001	4.9	5	---
Dec. 11	0910	---	---	---	---	---	---	---	---
11	1130	.440	<.002	.20	.011	<.001	4.0	10	---
19	1200	.450	.012	<.20	.019	<.001	4.0	13	60
				1997					
Jan. 14	1059	---	---	---	---	---	---	---	---
15	1300	.640	.008	<.20	.010	<.001	2.8	1	---
30	1400	.600	.006	<.20	.012	<.001	3.2	5	85
Feb. 12	1040	---	---	---	---	---	---	---	---
13	1145	.590	.005	<.20	.008	<.001	3.1	13	---
Mar. 1	1245	.440	.024	.40	.026	<.001	5.0	51	34
14	1300	.360	.042	.50	.048	.001	5.5	21	76
Apr. 23	1335	.348	.090	.38	.017	.002	4.5	6	92
29	1330	.317	.036	.27	.010	.002	4.0	7	30
May 5	1030	---	---	---	---	---	---	---	---
6	1200	.237	.007	<.20	.013	.001	4.3	8	---
19	1015	---	---	---	---	---	---	---	---
20	0830	.134	.016	.24	.014	.002	4.2	9	---
June 2	1320	---	---	---	---	---	---	---	---
3	1515	.114	.014	.30	.017	<.001	5.2	13	---
16	1055	---	---	---	---	---	---	---	---
16	1515	.091	.009	.34	.015	.001	4.3	4	---
July 24	1430	.120	.027	.33	.031	.001	6.2	7	83
30	1315	.179	.024	.33	.031	.001	6.1	6	74
Nov. 13	1415	.277	.236	.74	.066	.024	3.8	22	18
				1998					
Jan. 7	0940	---	---	---	---	---	---	---	---
7	1750	.464	.009	.20	.020	.001	3.7	18	---

Supplementary Table ST-15. Water-quality field measurements and sample analyses at Clark Pond Creek site S5, September 1996 through January 1998

CLARK POND CREEK BELOW DAM NEAR BONNIE DOONE, NC

[Site S5 is at latitude 35°05'07", longitude 78°55'24", Cumberland County, U.S. Geological Survey downstream order number 0210382068; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Discharge, inst. (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	pH, field (standard units) (00400)	Water temperature (°C) (00010)	Turbidity (NTU) (00076)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Fecal coliform bacteria (colonies/ 100 mL) (31616)	Total suspended solids (mg/L) (00530)
					1996					
Sept. 5	1100	1.3	---	---	---	---	---	---	---	---
Oct. 17	1245	.79	---	---	---	---	---	---	K12	---
18	1015	.70	26	6.4	19.5	7.4	7.7	83	---	---
Nov. 13	1145	.92	---	---	---	---	---	---	K8	---
15	1030	.84	57	6.9	10.0	3.0	9.7	84	---	5
Dec. 11	0905	1.4	---	---	---	---	---	---	K8	---
12	1230	1.4	56	6.7	10.5	5.1	11.1	99	---	5
19	1130	9.7	57	6.8	9.5	3.3	10.6	94	290	2
					1997					
Jan. 14	1055	---	---	---	---	---	---	---	140	---
14	1300	1.1	60	6.8	6.5	5.3	11.5	92	---	6
Feb. 12	1030	1.3	---	---	---	---	---	---	K3	---
13	1015	1.1	63	6.9	8.5	5.0	11.1	94	---	3
Mar. 1	1205	7.0	56	6.6	17.7	7.5	9.8	103	K300	5
14	1200	22	55	6.6	16.4	4.9	9.6	99	140	12
Apr. 23	1300	5.1	83	6.9	17.4	2.4	8.5	91	---	7
29	1245	5.8	63	6.9	17.5	2.9	8.6	91	54	6
May 5	1020	1.1	---	---	---	---	---	---	96	---
6	1045	.86	64	6.9	17.6	3.0	7.8	82	---	7
19	1010	.64	---	---	---	---	---	---	130	---
19	1600	.42	66	6.9	24.9	2.5	6.6	80	---	6
June 2	1315	.92	---	---	---	---	---	---	150	---
3	1345	.61	69	6.7	23.5	2.1	6.0	71	---	4
16	1050	.57	---	---	---	---	---	---	K72	---
16	1430	.51	68	6.8	25.0	2.6	7.1	86	---	4
July 24	1330	17	63	6.9	28.9	2.8	6.8	88	K390	12
30	1245	26	54	7.4	27.7	7.0	7.1	89	K100	6
Nov. 13	1345	10	53	6.5	13.5	2.7	9.5	92	120	11
					1998					
Jan. 7	0935	4.1	---	---	---	---	---	---	38	---
7	1720	2.3	58	6.1	12.9	3.6	10.2	97	---	4

Supplementary Table ST-15. Water-quality field measurements and sample analyses at Clark Pond Creek site S5, September 1996 through January 1998—Continued

CLARK POND CREEK BELOW DAM NEAR BONNIE DOONE, NC

[Site S5 is at latitude 35°05'07", longitude 78°55'24", Cumberland County, U.S. Geological Survey downstream order number 0210382068; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Dissolved nitrite + nitrate (mg/L as N) (00631)	Dissolved ammonia (mg/L as N) (00608)	Total ammonia + organic nitrogen (mg/L as N) (00625)	Total phos-phorus (mg/L as P) (00665)	Dissolved phos-phorus ortho, (mg/L as P) (00671)	Total organic carbon (mg/L as C) (00680)	Suspended sediment (mg/L) (80154)	Suspended sediment (percent finer than 0.062 mm) (70331)
				1996					
Sept. 5	1100	---	---	---	---	---	---	28	---
Oct. 17	1245	---	---	---	---	---	---	---	---
18	1015	0.097	<0.002	0.40	0.041	<0.001	6.0	8	---
Nov. 13	1145	---	---	---	---	---	---	---	---
15	1030	.120	.080	.60	.037	.002	5.0	12	---
Dec. 11	0905	---	---	---	---	---	---	---	---
12	1230	.200	.015	.30	.026	.003	4.8	4	---
19	1130	.210	.004	.30	.039	<.001	4.9	117	4
				1997					
Jan. 14	1055	---	---	---	---	---	---	---	---
14	1300	.260	.056	.30	.033	.003	4.2	8	---
Feb. 12	1030	---	---	---	---	---	---	---	---
13	1015	.320	.041	.20	.020	<.001	3.7	15	---
Mar. 1	1205	.260	.039	.30	.029	<.001	4.8	8	97
14	1200	.200	.010	.50	.044	.001	5.9	17	50
Apr. 23	1300	.034	.065	1.1	.041	.007	5.2	35	17
29	1245	.094	.093	.46	.028	.004	5.6	168	5
May 5	1020	---	---	---	---	---	---	---	---
6	1045	.070	.085	.32	.022	.005	5.8	11	---
19	1010	---	---	---	---	---	---	---	---
19	1600	.045	.119	.38	.019	.004	5.7	54	---
June 2	1315	---	---	---	---	---	---	---	---
3	1345	.054	.150	.57	.024	.001	6.3	117	---
16	1050	---	---	---	---	---	---	---	---
16	1430	.059	.106	.45	.020	.001	6.1	4	---
July 24	1330	.022	.025	.95	.063	.002	8.0	3	67
30	1245	.106	.088	.73	.054	.002	4.0	17	70
Nov. 13	1345	.010	.003	.58	.055	.003	5.6	10	82
				1998					
Jan. 7	0935	---	---	---	---	---	---	---	---
7	1720	.186	.126	.42	.042	.002	4.5	4	---

Supplementary Table ST-16. Water-quality field measurements and sample analyses at Little Cross Creek site S6, October 1996 through January 1998

OUTFALL FROM CROSS CREEK INTO GLENVILLE LAKE AT FAYETTEVILLE, NC

[Site S6 is at latitude 35°04'11", longitude 78°53'50", Cumberland County, U.S. Geological Survey downstream order number 0210382097; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Discharge, inst. (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	pH, field (standard units) (00400)	Water temperature (°C) (00010)	Turbidity (NTU) (00076)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Fecal coliform bacteria (colonies/ 100 mL) (31616)	Total suspended solids (mg/L) (00530)
					1996					
Oct. 17	1100	1.6	41	6.2	18.5	3.9	9.1	96	300	6
Nov. 13	1211	---	49	6.4	10.0	4.1	12.4	108	51	4
Dec. 11	0920	---	---	---	---	---	---	---	60	---
12	0930	---	46	6.4	10.5	4.5	10.2	91	---	5
					1997					
Jan. 14	1112	---	---	---	---	---	---	---	30	---
15	1445	---	60	6.5	5.5	30	12.9	102	---	49
May 5	1035	---	---	---	---	---	---	---	92	---
6	1345	---	45	6.5	18.6	3.6	8.4	90	---	4
19	1025	---	---	---	---	---	---	---	140	2
19	1700	---	52	6.8	23.0	3.6	8.4	98	---	---
June 2	1325	---	---	---	---	---	---	---	150	---
3	1100	---	56	6.7	22.3	4.0	7.9	91	---	3
16	1110	---	---	---	---	---	---	---	180	3
16	1330	---	53	6.7	22.2	3.6	9.1	105	---	14
Nov. 13	1530	---	50	6.4	12.5	4.2	10.4	98	940	---
					1998					
Jan. 7	0955	---	---	---	---	---	---	---	120	---
7	1600	---	50	5.7	9.5	3.1	10.5	92	---	2

Date	Time	Dissolved nitrite + nitrate (mg/L as N) (00631)	Dissolved ammonia (mg/L as N) (00608)	Total ammonia + organic nitrogen (mg/L as N) (00625)	Total phosphorus (mg/L as P) (00665)	Dissolved phosphorus ortho, (mg/L as P) (00671)	Total organic carbon (mg/L as C) (00680)	Suspended sediment (mg/L) (80154)	Suspended sediment (percent finer than 0.062 mm) (70331)
				1996					
Oct. 17	1100	0.280	<0.002	0.30	0.016	<0.001	6.6	11	---
Nov. 13	1211	.250	.054	.30	.013	<.001	5.4	5	---
Dec. 11	0920	---	---	---	---	---	---	---	---
12	0930	.370	.047	.20	.013	<.001	3.9	7	---
				1997					
Jan. 14	1112	---	---	---	---	---	---	---	---
15	1445	.490	.059	.20	.120	.017	4.6	44	---
May 5	1035	---	---	---	---	---	---	---	---
6	1345	.253	.083	.22	.016	.005	5.5	7	---
19	1025	---	---	---	---	---	---	---	---
19	1700	.232	.087	.36	.017	.005	1.8	4	---
June 2	1325	---	---	---	---	---	---	---	---
3	1100	.243	.066	.32	.018	.002	6.3	4	---
16	1110	---	---	---	---	---	---	---	---
16	1330	.295	.079	.37	.018	.002	5.8	3	---
Nov. 13	1530	.244	.010	.32	.031	.006	5.8	17	84
				1998					
Jan. 7	0955	---	---	---	---	---	---	---	---
7	1600	.141	.010	.20	.014	.010	4.7	2	---

Supplementary Table ST-17. Water-quality field measurements and sample analyses at Little Cross Creek site S7, September 1996 through January 1998

LITTLE CROSS CREEK BELOW GLENVILLE LAKE DAM AT FAYETTEVILLE, NC

[Site S7 is at latitude 35°04'07", longitude 78°53'47", Cumberland County, U.S. Geological Survey downstream order number 0210382103; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Discharge, inst. (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	pH, field (standard units) (00400)	Water temperature (°C) (00010)	Turbidity (NTU) (00076)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent saturation) (00301)	Fecal coliform bacteria (colonies/ 100 mL) (31616)	Total suspended solids (mg/L) (00530)
					1996					
Sept. 5	1535	2.8	---	---	---	---	---	---	---	10
Oct. 17	1200	3.1	43	6.3	18.0	4.2	9.5	99	29	5
Nov. 13	1200	2.7	---	---	---	---	---	---	64	---
13	1545	2.6	44	6.4	10.5	3.7	10.3	91	---	4
Dec. 11	0925	2.3	---	---	---	---	---	---	32	---
12	1045	2.6	46	6.4	9.0	4.8	10.7	92	---	6
19	1330	55	45	6.5	10.0	3.0	10.8	99	35	3
					1997					
Jan. 14	1108	3.3	---	---	---	---	---	---	160	---
15	1130	3.4	46	6.7	6.0	3.7	12.2	97	---	5
Feb. 12	1045	3.8	---	---	---	---	---	---	K14	---
13	1400	3.7	50	6.5	8.7	4.7	---	---	---	4
Mar. 1	1330	30	45	6.6	17.2	5.2	10.0	103	K260	5
14	1335	31	42	6.9	16.0	4.9	9.4	96	K10	8
Apr. 23	1500	14	48	6.7	16.7	2.6	8.7	92	---	4
29	1415	14	43	6.8	17.0	3.0	8.5	88	42	6
May 5	1045	3.5	---	---	---	---	---	---	56	---
6	1530	3.5	46	6.5	18.4	3.9	8.6	91	---	5
19	1030	3.2	---	---	---	---	---	---	K14	---
20	0930	2.8	48	6.8	20.4	2.1	7.0	78	---	6
June 2	1335	3.7	---	---	---	---	---	---	21	---
3	0815	3.6	50	6.4	22.4	2.6	6.7	78	---	3
16	1115	3.7	---	---	---	---	---	---	58	---
16	1300	3.7	51	6.5	22.2	7.0	7.7	88	---	16
July 24	1545	34	47	6.6	29.1	3.3	6.4	83	2,000	6
30	1400	113	41	6.9	26.9	4.5	6.7	83	K340	11
Nov. 13	1515	3.9	55	6.5	12.5	2.2	8.5	80	35	5
					1998					
Jan. 7	0945	2.7	---	---	---	---	---	---	K4	---
7	1700	3.4	51	5.8	9.1	3.0	10.8	94	---	3

Supplementary Table ST-17. Water-quality field measurements and sample analyses at Little Cross Creek site S7, September 1996 through January 1998—Continued

LITTLE CROSS CREEK BELOW GLENVILLE LAKE DAM AT FAYETTEVILLE, NC

[Site S7 is at latitude 35°04'07", longitude 78°53'47", Cumberland County, U.S. Geological Survey downstream order number 0210382103; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters; mm, millimeter; <, less than; ---, no data; K, results based on nonideal colony count]

Date	Time	Dissolved nitrite + nitrate (mg/L as N) (00631)	Dissolved ammonia (mg/L as N) (00608)	Total ammonia + organic nitrogen (mg/L as N) (00625)	Total phosphorus (mg/L as P) (00665)	Dissolved phosphorus ortho, (mg/L as P) (00671)	Total organic carbon (mg/L as C) (00680)	Suspended sediment (mg/L) (80154)	Suspended sediment (percent finer than 0.062 mm) (70331)
					1996				
Sept. 5	1535	---	---	---	---	---	---	14	---
Oct. 17	1200	0.160	<0.002	0.40	0.027	<0.001	6.4	9	---
Nov. 13	1200	---	---	---	---	---	---	---	---
13	1545	.140	.019	.20	.014	<.001	5.4	8	---
Dec. 11	0925	---	---	---	---	---	---	---	---
12	1045	.280	.004	.20	.021	<.001	4.6	3	---
19	1330	.310	<.002	<.20	.017	<.001	3.9	5	87
					1997				
Jan. 14	1108	---	---	---	---	---	---	---	---
15	1130	.380	.014	<.20	.021	.002	4.1	21	---
Feb. 12	1045	---	---	---	---	---	---	---	---
13	1400	.470	.011	<.20	.003	.003	3.6	8	---
Mar. 1	1330	.310	.006	.20	.016	<.001	4.4	5	75
14	1335	.270	.009	.30	.025	<.001	5.4	19	45
Apr. 23	1500	.198	.039	.32	.020	.002	5.0	5	82
29	1415	.221	.070	.45	.017	.003	5.1	4	78
May 5	1045	---	---	---	---	---	---	---	---
6	1530	.196	.095	.27	.020	.002	4.8	5	---
19	1030	---	---	---	---	---	---	---	---
20	0930	.122	.062	.37	.030	.006	5.0	7	---
June 2	1335	---	---	---	---	---	---	---	---
3	0815	.095	.072	.51	.025	.001	5.8	11	---
16	1115	---	---	---	---	---	---	---	---
16	1300	.015	.034	.46	.044	.001	6.5	13	---
July 24	1545	.010	.010	.73	.053	.002	7.7	10	62
30	1400	.168	.037	.56	.046	.002	7.4	5	38
Nov. 13	1515	.196	.025	.36	.026	.005	4.0	18	33
					1998				
Jan. 7	0945	---	---	---	---	---	---	---	---
7	1700	.301	.009	.20	.020	.002	3.9	3	---

Supplementary Table ST-18. Equations used to compute unit loads of suspended sediment, total nitrogen, total phosphorus, and total organic carbon for Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, water year 1997

[BCF, bias correction factor; Adj. R^2, coefficient of determination or fraction of the variance explained by regression, adjusted for the model degrees of freedom; PRESS, prediction error sum of squares; Q, discharge, in cubic feet per second; L, constituent load in tons per day; exp, inverse natural log; ln, natural log; dectime, date expressed in decimal format; sint, sine(2 x pi x dectime); cost, cosine(2 x pi x dectime); SE, standard error of the 25-percent trimmed mean in milligrams per liter; n/a, not applicable]

Constituent	Number of samples	Load equation for load-discharge relation	BCF	Adj. R^2	PRESS	Percent of load above sampled Q
		Site S1—Little Cross Creek above Bonnie Doone Lake				
Suspended sediment	20	L = exp [-5.437 + 2.412 (ln Q)] (1.463)	1.463	0.87	19.7	77
Minimum total nitrogen	20	L = exp [-7.630 + 1.196 (ln Q)] (1.142)	1.142	.81	7.40	14
Maximum total nitrogen	20	L = exp [-6.939 + 1.053 (ln Q)] (1.035)	1.035	.94	1.71	9.6
Total phosphorus	20	L = exp [7.058 - 18.965 ($Q^{-0.125}$) + 0.510 (sint)] (1.099)	1.099	.95	4.40	32
Total organic carbon	20	L = exp [-5.507 + 1.447 (ln Q)] (1.030)	1.030	.97	1.47	24
		Site S2—Little Cross Creek below Bonnie Doone Lake				
Suspended sediment	20	L = †7.6 (Q) (*0.0027); SE = 0.56	n/a	n/a	n/a	1.7
Minimum total nitrogen	19	L = exp [-7.037 + 1.108 (ln Q) + 0.378 (cost)] (1.038)	1.038	0.92	2.01	2.2
Maximum total nitrogen	19	L = exp [-12.923 + 6.380 ($Q^{0.125}$) + 0.171 (sint) + 0.234 (cost)] (1.007)	1.007	.98	.431	2.5
Total phosphorus	19	L = exp [-11.021 + 1.303 (ln Q) + 0.527 (cost)] (1.074)	1.074	.89	3.77	3.7
Total organic carbon	19	L = exp [-5.020 + 1.108 (ln Q)] (1.029)	1.029	.94	1.38	2.3
		Site S3—Little Cross Creek below Kornbow Lake				
Suspended sediment	19	L = †4.9 (Q) (*0.0027); SE = 0.70	n/a	n/a	n/a	3.3
Minimum total nitrogen	17	L = exp [-6.911 + 1.096 (ln Q) + 0.420 (cost)] (1.015)	1.015	0.94	0.812	3.9
Maximum total nitrogen	17	L = exp [468.911 + 1.035 (ln Q) - 0.238 (dectime) + 0.244 (sint) + 0.376 (cost)] (1.001)	1.001	.99	.101	3.1
Total phosphorus	17	L = †0.0058 (Q) (*0.0027); SE = 0.0003	n/a	n/a	n/a	3.3
Total organic carbon	17	L = exp [-4.581 + 0.939 (ln Q) -0.288 (sint) - 0.199 (cost)] (1.007)	1.007	.95	.415	3.5
		Site S4—Little Cross Creek below Mintz Pond				
Suspended sediment	20	L = exp [-4.209 + 1.171 (ln Q)] (1.434)	1.434	0.48	19.0	3.7
Minimum total nitrogen	19	L = exp [5.697 - 13.310 ($Q^{-0.125}$) + 0.214 (cost)] (1.029)	1.029	.93	1.54	2.8
Maximum total nitrogen	19	L = exp [-6.865 + 1.141 (ln Q) + 0.144 (sint) + 0.281 (cost)] (1.012)	1.012	.97	.710	2.9
Total phosphorus	19	L = exp [-1754.480 - 11.255 ($Q^{-0.25}$) + 0.878 (dectime)] (1.065)	1.065	.89	3.60	2.5
Total organic carbon	19	L = exp [-4.609 + 1.076 (ln Q) - 0.144 (sint) - 0.194 (cost)] (1.011)	1.011	.96	.713	3.4

† 25-percent trimmed mean concentration, in milligrams per liter.
* Conversion constant used to express load in tons per day.

Supplementary Table ST-18. Equations used to compute unit loads of suspended sediment, total nitrogen, total phosphorus, and total organic carbon for Little Cross Creek sites S1, S2, S3, S4, S5, S6, and S7, water year 1997—Continued

[BCF, bias correction factor; Adj. R^2, coefficient of determination or fraction of the variance explained by regression, adjusted for the model degrees of freedom; PRESS, prediction error sum of squares; Q, discharge, in cubic feet per second; L, constituent load in tons per day; exp, inverse natural log; ln, natural log; dectime, date expressed in decimal format; sint, sine(2 x pi x dectime); cost, cosine(2 x pi x dectime); SE, standard error of the 25-percent trimmed mean in milligrams per liter; n/a, not applicable]

Constituent	Number of samples	Load equation for load-discharge relation	BCF	Adj. R^2	PRESS	Percent of load above sampled Q
		Site S5—Clark Pond Creek				
Suspended sediment	19	L = †14 (Q) (*0.0027); SE = 2.1	n/a	n/a	n/a	3.4
Total nitrogen	18	L = exp [-6.536 + 1.112 (ln Q)] (1.026)	1.026	0.98	1.05	4.4
Total phosphorus	18	L = exp [-9.463 + 1.194 (ln Q) - 0.287 (sint)] (1.013)	1.013	.99	.632	6.8
Total organic carbon	18	L = exp [-4.250 + 1.003 (ln Q) - 0.131 (cost)] (1.011)	1.011	.99	.698	3.5
		Site S6—Glenville Lake inflow pipe from Cross Creek				
Suspended sediment	10	L = †6.3 (Q) (*0.0027); SE = 1.1	n/a	n/a	n/a	n/a
Total nitrogen	10	L = †0.5698 (Q) (*0.0027); SE = 0.0060	n/a	n/a	n/a	n/a
Total phosphorus	10	L = †0.0165 (Q) (*0.0027); SE = 0.0006	n/a	n/a	n/a	n/a
Total organic carbon	10	L = †5.3 (Q) (*0.0027); SE = 0.22	n/a	n/a	n/a	n/a
		Site S7—Little Cross Creek below Glenville Lake				
Suspended sediment	19	L = †7.6 (Q) (*0.0027); SE = 0.75	n/a	n/a	n/a	8.7
Minimum total nitrogen	18	L = exp [-6.656 + 1.037 (ln Q) - 0.164 (cost)] (1.015)	1.015	0.98	0.916	9.5
Maximum total nitrogen	18	L = exp [-6.672 + 1.073 (ln Q)] (1.012)	1.012	.98	.581	11
Total phosphorus	18	L = exp [-15.804 + 6.215 ($Q^{0.125}$) - 0.402 (cost)] (1.093)	1.093	.88	5.49	16
Total organic carbon	18	L = exp [-9.975 + 5.922 ($Q^{0.125}$) - 0.206 (cost)] (1.009)	1.009	.99	.475	14

† 25-percent trimmed mean concentration, in milligrams per liter.
* Conversion constant used to express load in tons per day.