# SELECTED WATER-QUALITY AND BIOLOGICAL CHARACTERISTICS OF STREAMS IN SOME FORESTED BASINS OF NORTH CAROLINA, 1985-88

By William S. Caldwell

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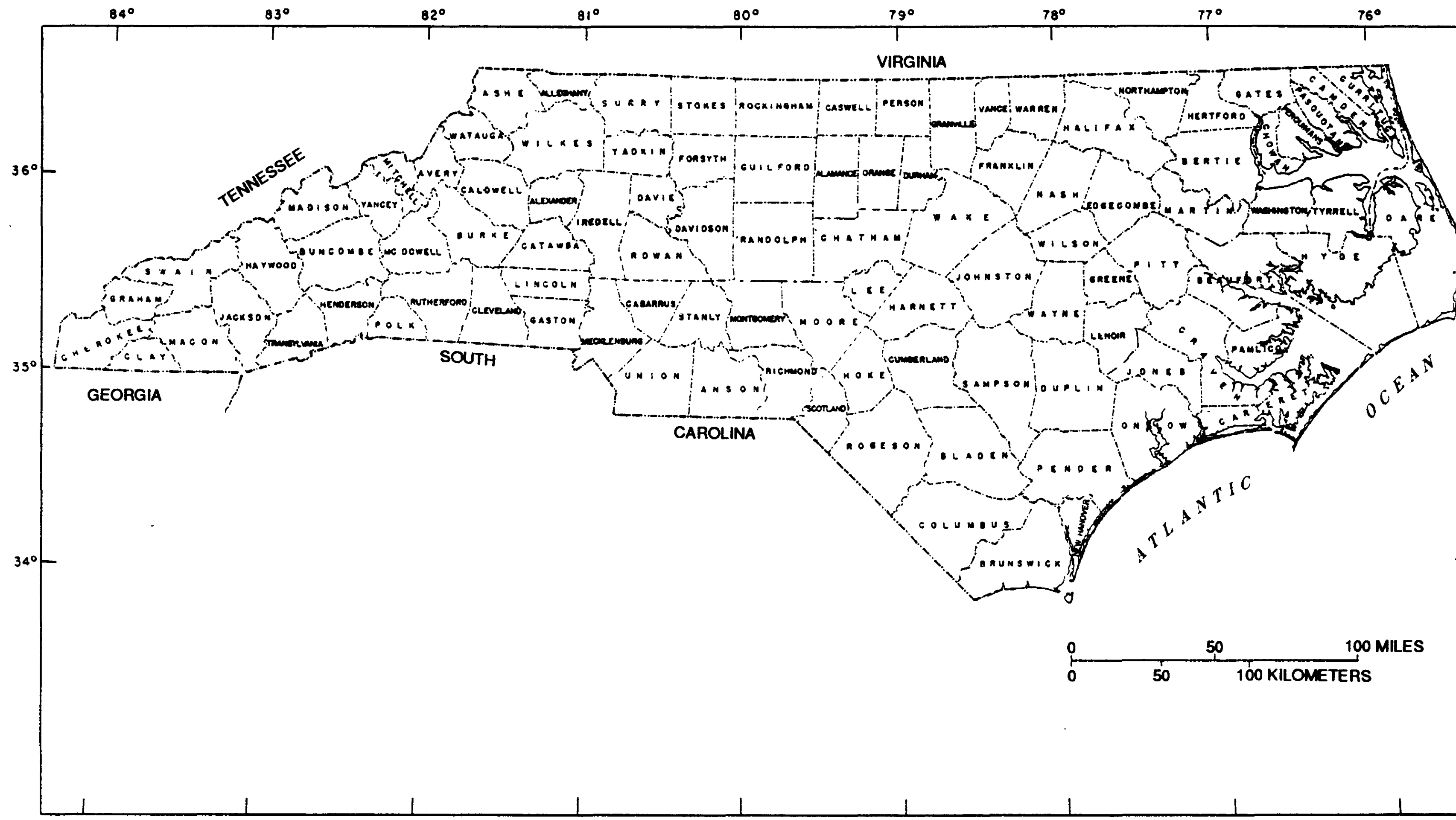
## CONVERSION FACTORS AND VERTICAL DATUM

| 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*** | |
| gallon (gal) | 3.785 | liter |
| | ***Flow*** | |
| foot per second (ft/s) | 0.3048 | meter per second |
| 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 |
| | ***Gradient*** | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer |
| | ***Mass*** | |
| ounce, avoirdupois (oz) | 28.35 | gram |
| pound, avoirdupois (lb) | 0.4536 | kilogram |
| ton, short (2,000 lb) | 0.9072 | megagram |
| | ***Mass per unit area*** | |
| ton, short per square mile ($ton/mi^2$) | 0.3503 | megagram per square kilometer |

***Temperature:*** In this report temperature is given in degrees Celsius ($^{\circ}C$), which can be converted to degrees Fahrenheit ($^{\circ}F$) by the following equation:

$$^{\circ}F = 1.8\ (^{\circ}C) + 32$$

***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 the United States and Canada, formerly called Sea Level Datum of 1929.




Counties in North Carolina

# SELECTED WATER-QUALITY AND BIOLOGICAL CHARACTERISTICS OF STREAMS IN SOME FORESTED BASINS OF NORTH CAROLINA, 1985-88

**By William S. Caldwell**

## ABSTRACT

A study was conducted by the U.S. Geological Survey in cooperation with the North Carolina Department of Environment, Health, and Natural Resources from July 1985 through September 1988 to characterize selected physical, chemical, and biological components of streams draining undeveloped, forested basins in North Carolina. Nine sampling sites were established on streams that drain forested basins ranging in size from 0.67 to 11.2 square miles. The basins were selected to represent drainage from each of five geochemical zones across the State.

Samples for water-quality analyses were taken during low-flow and stormflow conditions and compared with precipitation analyses and streamflow analyses from an earlier study. The water analyses included specific conductance, dissolved oxygen, water temperature, suspended sediment, pH, major dissolved constituents, nutrients, minor constituents, organochlorine insecticides, and biochemical oxygen demand. Biological characteristics included sampling for fish tissue analyses for minor constituents and synthetic organic compounds, fish community structure, and benthic macroinvertebrates.

Stream-water quality in undeveloped, forested basins is largely influenced by the quality of precipitation, soil and rocks, and the intensity of runoff. Precipitation is the source of about 10 to 40 percent of the chloride concentration in stormflows and constituted a greater percentage in the eastern half of the State. Mean concentrations of sulfate in precipitation commonly ranged between 20 and 30 percent of mean concentrations of sulfate in stormflow with no geographic distribution preference. Soil and rocks were the major source of the other major dissolved constituents and minor constituents.

Mean total nitrogen concentrations ranged from 0.16 milligrams per liter during low-flow conditions to 1.2 milligrams per liter during stormflow. Organic nitrogen accounted for 60 to 85 percent of the total

nitrogen concentration. The ratios of mean concentrations of total nitrogen to total phosphorus ranged from 11:1 to 110:1 indicating that phosphorus is the limiting nutrient factor in stream water from forested basins.

Stream water was free of organochlorine insecticides; but DDD, DDE, DDT, Lindane, and Mirex were detected in 18 of 60 samples of streambed material. Concentrations ranged from 0.1 to 3.3 micrograms per kilogram.

About 35 percent of the fish tissue analyses showed detectable concentrations of copper, lead, mercury, and nickel. Compared with the North Carolina ambient fish tissue data base, two fish samples contained relatively high concentrations of mercury (0.34 and 0.30 milligram per kilogram), and one fish sample contained a relatively high lead concentration of 1.2 milligrams per kilogram. Synthetic organic chemicals were not detected in fish tissue.

The fish community structure data were scored and rated using Karr's Index of Biotic Integrity as modified for North Carolina. The streams draining forested basins rated from poor to good primarily because of natural stresses on fish communities resulting from low-flow and no-flow conditions and from low nutrient conditions in these headwater streams. Other than nutrients, water quality was not a factor in these low ratings.

Data from benthic macroinvertebrate surveys were used to rate the study sites using taxa richness and biotic indexes developed for bioclassification of streams in forested basins. Beetree Creek, North Harper Creek, Dutchmans Creek, New Hope River tributary, and Suck Creek tributary were rated excellent and are representative of natural conditions in their respective basins. The benthic taxa in Chinkapin Creek tributary and W.P. Brice Creek are representative of naturally stressed communities in swampy Coastal Plain basins adapting to low pH and dissolved-oxygen concentrations, and, hence, these sites received bioclassification ratings of good and good to fair, respectively.

## INTRODUCTION

The chemical constituents of North Carolina streams are derived from natural and manmade sources. The primary natural sources include dissolved, particulate, and gaseous constituents in atmospheric deposition, leachates from the weathering of rocks and soils, and the breakdown and decay of forest litter and other plant life. Manmade sources include point sources, such as outfalls from industrial and municipal waste-treatment facilities, nonpoint sources, such as runoff from agricultural and urban areas, and atmospheric deposition. A previous study by the North Carolina Department of Natural Resources and Community Development (1979a), currently known as the North Carolina Department of Environment, Health, and Natural Resources (EHNR), has shown that water quality in more than 7 percent of the State's streams is severely degraded and the quality of a greater percentage is impaired to some degree. Because many constituents that naturally occur in stream water may also be indicative of possible pollution, it is necessary to identify, insofar as possible, naturally occurring levels of these constituents in order to accurately evaluate the effects of man-induced activities in forested stream basins.

Publications on colonial North Carolina indicate that as early as 1700, only a few percent of the State's forests had been cleared, and that at least 95 percent of the State's 53,000 $mi^2$ area was then covered by shrubs or forests (Burney, 1975). This is in contrast to the highways, railroads, urban developments, industrial complexes, farms, and other human-related activities that have reduced forests to less than 65 percent of the State's land area by the last half of the 20th century (North Carolina Department of Natural Resources and Community Development, 1979b). During colonial days and earlier, physical and chemical characteristics of the State's streams were determined almost totally by natural processes, whereas today, the chemistry of most streams reflects manmade influences.

Several investigations on stream quality and land-management practices in forested basins have been conducted in North Carolina. These programs have contributed data about the chemical characteristics of the State's streams in locations where the influence of man is minimal. For example, studies have been conducted at Coweeta Hydrologic Laboratory located about 70 mi southwest of Asheville since the mid-1930's (Swank and Crossley, 1988). Stream-quality and other hydrologic data have been collected from undisturbed, forested basins for comparison with data from basins undergoing clearcutting, road building, reforestation, and other changes. The 50-plus years of research at Coweeta Hydrologic Laboratory represent the longest continuous environmental study on any landscape in North America (Swank and Crossley, 1988); however, the studies are restricted to a 3.4 $mi^2$ mountainous watershed. Also during the mid-1930's, the Tennessee Valley Authority began sampling suspended sediment to define transport rates from various stream basins in western North Carolina, including several that were almost totally forested. The information was vital in estimating the useful life of the reservoir network.

In 1962, the U.S. Geological Survey (USGS) established a Hydrologic Benchmark site on Cataloochee Creek near Cataloochee, Haywood County. The Hydrologic Benchmark Network, composed of 57 stations in 37 states, was specifically developed to define water quality in the natural environment; thus, most stations are located in catchments least affected by man, such as national and state parks, wilderness areas, and areas set aside for scientific study (Cobb and Biesecker, 1971).

From late 1973 through 1978, the USGS, in cooperation with the North Carolina Department of Environment, Health, and Natural Resources, conducted the first statewide investigation to identify and quantify water-quality constituents derived from background sources (Simmons and Heath, 1982). This study evaluated data collected from 39 streams draining undeveloped or minimally developed, forested catchments and delineated five geochemical zones (fig. 1). The 1973-78 investigation provided the State's most comprehensive data base on natural stream quality at that time.

During the 1970's and early 1980's when North Carolina experienced unprecedented growth and development of its industrial and land resources, the number of forested catchments containing no manmade development in the State was reduced. In 1985, the USGS and EHNR jointly undertook an intensive investigation to address stream water, precipitation, and biological characteristics not covered in the initial Simmons and Heath (1982) study. Data, such as sediment chemistry, organic compounds, precipitation chemistry, fish tissue chemistry, and other biological characteristics, were included in the study in addition to monitoring streamflow continuously at all sample sites.

## Purpose and Scope

This report describes selected water-quality and certain biological characteristics of streams draining forested catchments in largely undeveloped basins. The data provide a basis by which background conditions may be defined for streams whose basins are 100 percent forested. This information can then be used by State regulatory agencies for evaluating water-quality standards and criteria in the State of North Carolina.

From July 1985 through September 1988, periodic water-quality and biological sampling was conducted at nine stream sites located within totally forested basins (fig. 1). Streamflow was also continuously monitored. The basins were selected to be free of highways, railroads, agricultural and grazing activities, residential areas, and other nonpoint sources of contamination and ranged in size from 0.67 to 11.2 $mi^2$. Geographic distribution was selected to provide representative coverage of North Carolina's soils, geology, and physiography.

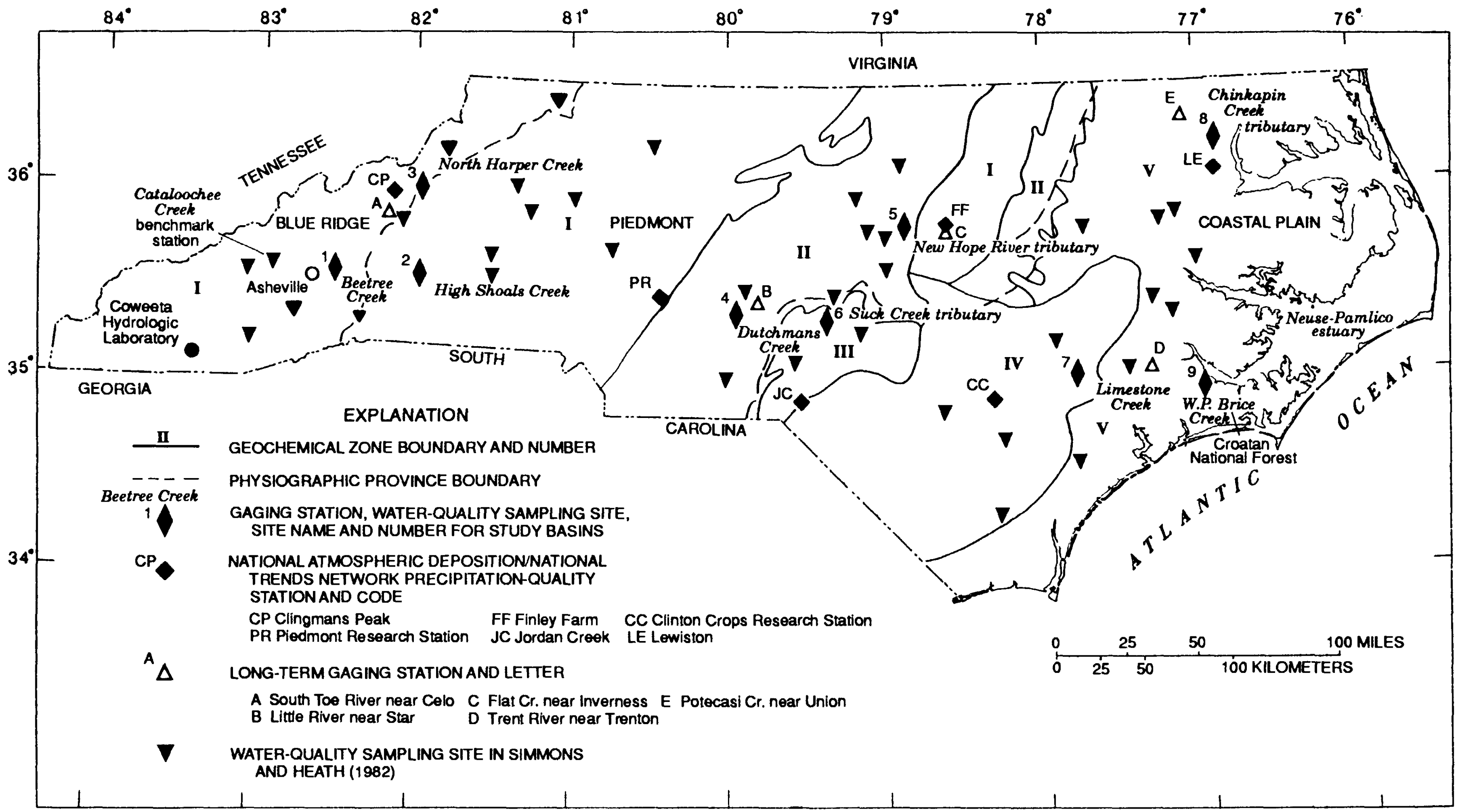



Figure 1.--Location of study basins, precipitation-quality stations, and geochemical zones in North Carolina (modified from Simmons and Heath, 1982).

The study builds on and supplements the earlier work of Simmons and Heath (1982) by increasing the number of chemical constituents analyzed and the frequency of sampling, and by including analyses of precipitation and biological data. Comparisons are made with some of the water-quality data in geochemical zones of the earlier report. Fish tissue analyses for minor constituents are compared with results of the EHNR ambient fish tissue monitoring network. Fish and benthic macroinvertebrate community structures are given ratings to assess the species present and the relations between the number of species at each study site. Macroinvertebrates are given a bioclassification rating based on the taxa richness and biotic index values at each location.


### Acknowledgments

The author wishes to recognize and thank personnel of EHNR who assisted with selecting network data sites, collecting water-quality and biological samples, and performing all taxonomic identifications. The author also wishes to recognize and thank the laboratory staff of EHNR who performed all chemical and biological analyses of samples collected by EHNR personnel. Special recognition is due V.P. Schneider and D.L. Penrose of EHNR for preparation of the section, "Selected Biological Characteristics of Streams," in this report.

The author extends his appreciation to C.E. Simmons (USGS, retired) for sharing his expertise in sediment transport mechanisms and for his contributions in reviewing this report. A special thanks is extended to private land owners for permitting the USGS to construct and operate stream-monitoring stations on their property. Without their generous cooperation, this investigation would not have been possible because of the scarcity of sizeable forested basins meeting the site-selection criteria.


## MAJOR FACTORS AFFECTING WATER-QUALITY AND BIOLOGICAL CHARACTERISTICS

The chemical quality of water in streams draining forested basins is primarily dependent upon the chemical quality of precipitation and the composition of rocks and soils underlying the basins through which water percolates before discharging to streams. The resultant chemical composition of the water, along with certain physical characteristics such as water temperature, dissolved-oxygen concentrations, and flow conditions, influence stream biology.

## Precipitation

Precipitation is the ultimate source of water in North Carolina's streams and contains chemical constituents derived from local and distant sources. During rainless periods, atmospheric dryfall of particulate matter and aerosols is also sources of chemicals. According to various recent studies, dryfall can be a major source of chemical loading (Linberg and others, 1986; Swank and Waide, 1988). Bulk precipitation samples collected at the Coweeta Hydrologic Laboratory in western North Carolina indicate that, for this area of the State, (1) precipitation is an indirect source of major chemical constituents, minor constituents, and nutrients; (2) much of the chloride and sodium, and 40 percent of the magnesium in precipitation are of marine origin; and (3) the nutrients, nitrate and ammonia, are terrestrial in origin (Swank and Waide, 1988).

The terrestrial origin of nutrients in the Coweeta Hydrologic Laboratory precipitation samples substantiates the Gambell and Fisher (1966) study that shows increased concentration of nutrients in precipitation in a westward direction across the State away from the Atlantic Ocean. Kuenzler and others (1977) reported weighted-mean concentrations of 0.36 and 0.06 milligram per liter (mg/L), respectively, for total nitrogen and phosphorus in bulk precipitation in eastern North Carolina. Other studies have demonstrated that concentrations of nitrogen and phosphorus were often greater in precipitation than in streams draining forested basins (Joyner, 1974; Ellis and others, 1978). Simmons and Heath (1982, p. 28-29) showed that bulk precipitation could be the major source of calcium and sulfate in streams draining forested basins. Peters (1984), in a study of environmental factors affecting stream chemistry in the United States, presented average values of atmospherically derived constituents in stream yields. Using data from 56 basins across the United States, Peters (p. 18) estimated that averages of 30 percent of the sodium and 60 percent of the sulfate in stream yields were contributed by atmospheric deposition.

Little information is available for the State documenting the effects of plant foliage on precipitation quality and quantity during the process of throughfall. According to Linberg and others (1986), forest canopies can interact with anthropogenically generated airborne particles and vapors to produce significant fluxes in dryfall deposition. Precipitation is enriched in dissolved constituents as it passes through the plant foliage before reaching the ground (Likens and others, 1977).

## Soils and Geology

The geology of North Carolina is complex and is characterized by a wide variety of rock types (fig. 2). Rock types range from relatively insoluble crystalline rocks such as granitic intrusives, metamorphosed sedimentary and volcanic rocks, schist, and slate, which underlie the Blue Ridge and Piedmont Provinces, to relatively soluble beds of limestone that underlie parts of the Coastal Plain (Stuckey, 1965).

The elements and minerals that compose the many varieties of rocks and sediments in North Carolina are not uniformly distributed and may be abundant in one region and absent in another. The same is true in regard to soils derived through the weathering of rocks; thus, in the Blue Ridge and Piedmont Provinces, the mineral composition of the underlying rocks controls the physical and chemical characteristics of the soils. In contrast, soils of the Coastal Plain Province were derived largely from previously weathered sediments and organic material deposited in ancient lagoons, sounds, rivers, and beaches; therefore, underlying crystalline rocks, which may be thousands of feet below the surface, are geologically and mineralogically unrelated to the Coastal Plain deposits.

The effects of soils and geology on natural stream quality are complex and begin with precipitation. Before precipitation reaches the Earth's surface, it absorbs gases in the atmosphere, primarily carbon dioxide and sulfur dioxide, causing it to become acidic. Water percolating through the upper soil zone also dissolves additional carbon dioxide produced by root respiration and bacterial decay of plant debris. When this acidic solution comes in contact with soils and rocks, it dissolves certain constituents in these materials and transports them in solution to streams.

Water flowing across and percolating through these soils and rocks is affected by their chemical and mineralogical content. For instance, concentrations of solutes in streamflow during low-flow conditions are generally lower in those basins underlain by weather-resistant quartzite but are greater in basins underlain by more soluble rocks, such as dolomite or limestone. Hem (1985) also suggests that the severity of chemical attack in the weathering process ranges widely and is related to the availability of soluble minerals in the soils and rocks.

In their study of water-quality characteristics of streams in forested basins, Simmons and Heath (1982) divided the State into five geochemical zones based on similarities of major geologic units and chemical composition of streamflows in those zones (fig. 1). Comparisons and contrasts of

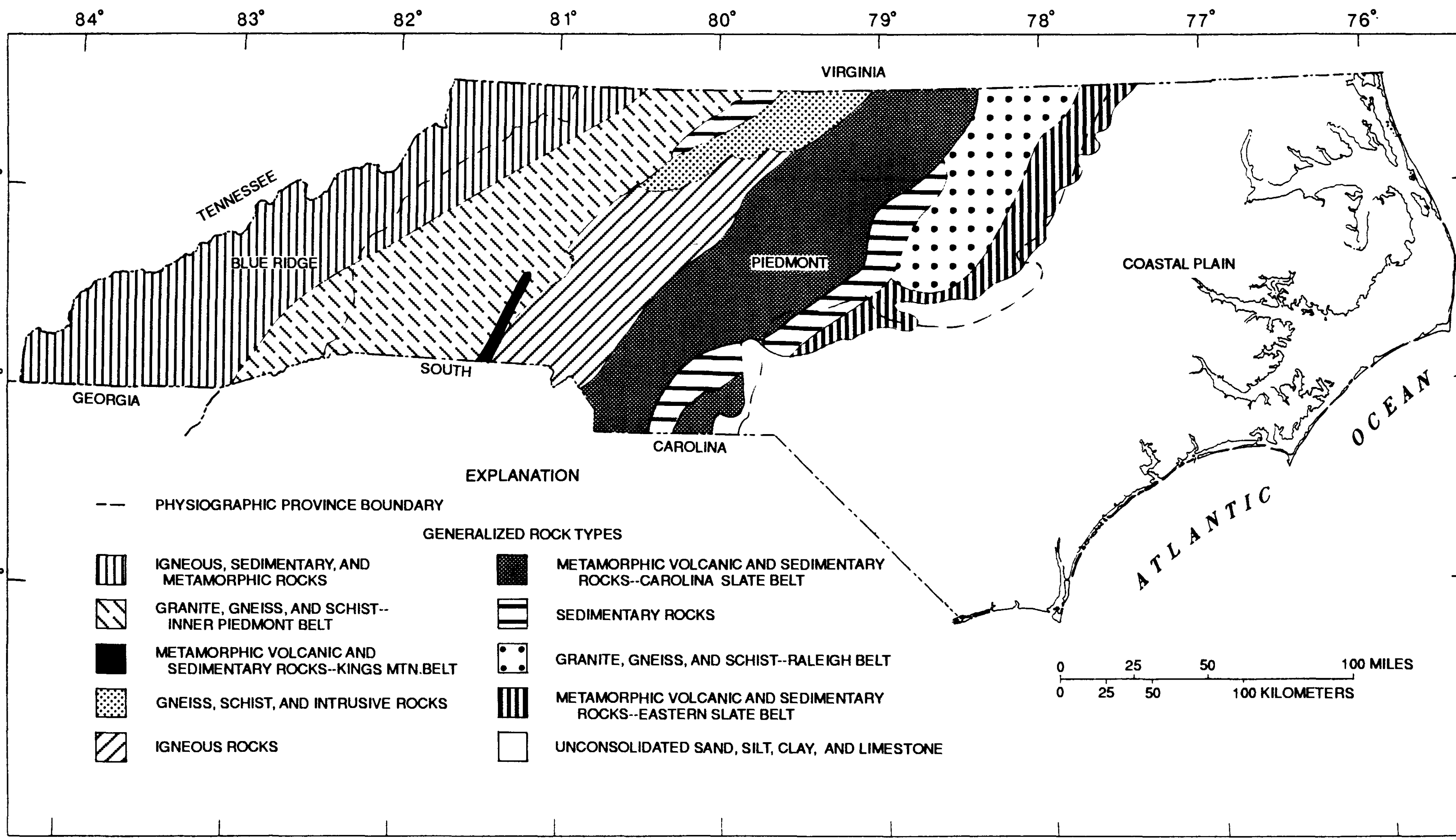



Figure 2.--Generalized rock types in North Carolina (modified from North Carolina Department of Environment, Health, and Natural Resources, 1991).

stream-water quality in each basin with the results for corresponding geochemical zones of the Simmons and Heath (1982) investigation are discussed in later sections of this report.

## Streamflow and Channel Characteristics

Streamflow characteristics of volume, source, velocity, and depth, in conjunction with channel features, such as size of bed materials, gradients, and channel geomorphology, have an effect on the physical, chemical, and biological characteristics of a stream. Many authors, including Simmons and Heath (1982, p. 27), have shown that during storm runoff, concentrations of various dissolved inorganic constituents in stream water were at maximum levels prior to the storm, decreased to minimal levels near the peak flow, and increased to pre-storm levels as flows receded. They attributed the decreased constituent levels to dilution effects of the less mineralized rainfall.

Other constituents, especially those that sorb or cling to sediments, may increase in concentration in streams during storm runoff. Dissolved-oxygen concentrations are also expected to increase during storm runoff, but this is attributed to increased aeration caused by turbulent flow.

Channel depth may affect stream chemistry, especially in the eastern part of North Carolina. For instance, deeply incised channels can intercept deeper ground water that may be more mineralized than shallow ground water especially during periods of low flow. When a stream's geometry has been changed by excavating and straightening its channel (channelization), stream-water chemistry, biological habitats, and flow regimes are altered, which have significant effects on stream biota.

## Runoff Conditions

Conditions under which runoff occurs in the Blue Ridge and Piedmont Provinces are different from those in the Coastal Plain Province. Both the westernmost provinces are underlain by bedrock that has been broken along an intricate network of fractures (fig. 3A). The bedrock is overlain, except where exposed at the surface, by soil and disintegrated (weathered) rock referred to as residuum, which may be tens of feet thick. The upper few feet of residuum contains the soil zone.

The soil zone of wooded areas in the Blue Ridge and Piedmont Provinces is covered by several inches of forest litter, which is capable of holding

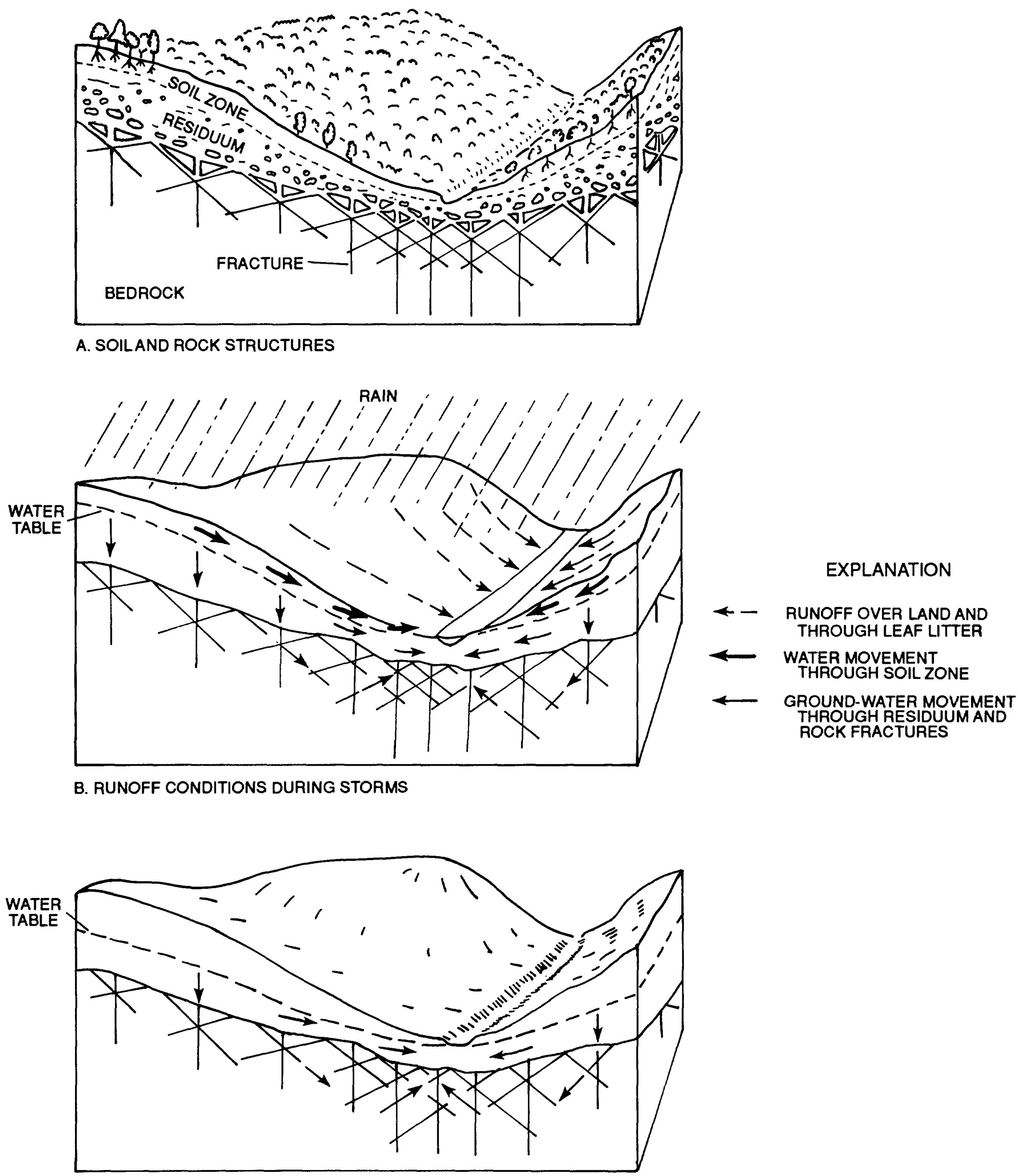



Figure 3.--Diagrams showing (A) soil and rock structures, (B) runoff conditions during storms, and (C) runoff conditions during base flow in a forested basin in the Blue Ridge or Piedmont Province (modified from Simmons and Heath, 1982).

water. Helvey and Patric (1965) reported that as much as 13 percent of total annual rainfall is retained by the wetting of foliage and forest floor litter and, therefore, is not available as runoff. Rainfall not intercepted by vegetation and organic litter moves quickly downslope to discharge into the nearest stream (fig. 3B).

According to Fisher and Katz (1988, p. 2), when rainfall contacts the land surface, it might follow several paths. They show that a small part of rainfall becomes storm runoff; a larger part infiltrates into deeper soil zones, becomes ground water, and discharges into streams following the storm; and some is retained as temporary storage. Although a rare occurrence in forested watersheds, intense rains of long duration can also produce large amounts of overland runoff.

During dry periods, water in the soil zone is depleted, the lateral movement of water through this zone ceases, and water reaching the streams is ground water that has moved through the deeper residuum and bedrock (fig. 3C). Because streamflow in these small, forested basins is derived totally from ground water during droughts, the basins' bedrock mineralogy should have maximum effect on stream-water chemistry at that time.

Runoff conditions in the Coastal Plain Province vary somewhat from those in the Blue Ridge and Piedmont Provinces primarily because of differences in topography and soils. The relatively flat surface of the Coastal Plain results in the slower movement of water on the surface and underground. Where the soils of the Coastal Plain Province are sandy and porous, rainfall rapidly percolates, and occurrences of overland runoff in forested areas are few. Clay soils allow greater runoff than sandy soils because of reduced infiltration capacity, although ponding occurs in flat flood plains where many Coastal Plain forests grow regardless of soil type. In general, however, most of the hydrologic processes in streams of the Piedmont and Blue Ridge Provinces are also characteristic of Coastal Plain streams (Simmons and Heath, 1982, p. 18).

## Other Factors

Certain natural processes may cause temporary changes in stream-water chemistry that could be misinterpreted as man-related. For instance, fires caused by lightning can destroy forest cover and litter in a basin, resulting in accelerated erosion and increased sediment and nutrient influx to streams until the vegetative cover is reestablished. Although rare in North Carolina, discharge of natural mineral springs sometimes produces constituent levels in streams many times greater than those in streams that receive municipal and industrial discharge (Pratt, 1908). The cessation of flow during rainless periods also produces unusual changes in a stream's physical, chemical, and biological characteristics. During a prolonged drought, water temperatures generally increase and dissolved-oxygen levels decrease; the concentration of some chemical constituents may increase because of evaporation, while others, such as those associated with sediment, may decrease. Gases, such as methane, increase as organic materials in the streambed deposits decompose under anaerobic conditions. Diminishing levels of oxygen in standing pools may result in the death of fish and other aquatic life; channel desiccation results in mortality of many organisms or changes in behavioral or physiological responses.

## DATA COLLECTION AND ANALYSIS

Basins selected for this study were totally forested and barren of highways, houses, farmlands, channelized streams, and other man-related activities. Those that were near paper mills, coal-fired powerplants, large cities, and other major sources of air pollution were rejected. Because of the need for the collection of biological data and continuous stream-discharge data, data-collection sites were limited to those streams that had flow all year or, at least, most of the year.

More than 200 candidate catchments were inspected by USGS and EHNR scientists, including the basins used by Simmons and Heath (1982). Based on that reconnaissance and on the results of preliminary chemical and biological analyses, nine basins qualified and were selected for this investigation. Location and other site information are provided in table 1 for the selected study basins. The selected basins are believed to be as good a representation of geologic and geographic conditions across the State as the site-selection criteria would permit (fig. 1).

### Precipitation

Precipitation-quantity and quality data from six stations are used in this report. These data were collected and provided by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). The precipitation station nearest each study basin was chosen to represent the quality of precipitation at that basin (fig. 1). A list of the precipitation collection sites used in this report and their associated study basin stations is given in table 2.

Table 1.--*Station names, locations, drainage areas, and water-quality sampling periods at study sites*

[mi², square mile; mi, mile; ft, foot; SR, secondary road; NC, North Carolina State highway]

| Site number (fig. 1) | USGS station number | USGS station name | Gage location: Latitude | Gage location: Longitude | Gage location: Description | Drainage area (mi²) | Geo-chemical zone | Physio-graphic province | Water-quality sampling period |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 03450000 | Beetree Creek near Swannanoa | 35°39'11" | 82°24'20" | On left bank 0.5 mi downstream from Wolfe Branch, 0.8 mi upstream from Beetree Reservoir Dam, 3.8 mi north of Swannanoa, and 4.8 mi above mouth, Buncombe County | 5.46 | I | Blue Ridge | May 1986-September 1988 |
| 2 | 0213875850 | High Shoals Creek near Dysartsville | 35°35'57" | 81°54'19" | On left bank 0.5 mi above mouth, and 1.9 mi west of Dysartsville, McDowell County | 2.38 | I | Piedmont | May 1986-January 1987 |
| 3 | 0214042720 | North Harper Creek near Kawana | 36°00'31" | 81°51'13" | On right bank 100 ft upstream U.S. Forest Service Road 58, and 3.4 mi northwest of Kawana, Avery County | 1.25 | I | Blue Ridge | May 1986-September 1988 |
| 4 | 02123567 | Dutchmans Creek near Uwharrie | 35°22'05" | 80°01'49" | Near midstream at upstream end of two 6-ft corrugated metal pipe culverts on SR 1150, 1.0 mi upstream from mouth, and 3.0 mi southwest of Uwharrie, Montgomery County | 3.44 | II | Piedmont | March 1986-September 1988 |
| 5 | 0209782150 | New Hope River tributary at SR 1716 near Farrington | 35°45'50" | 79°03'08" | At downstream side of culvert on SR 1716, 3.3 mi southwest of Farrington, Chatham County | 2.05 | II | Piedmont | March 1986-September 1988 |
| 6 | 0210108450 | Suck Creek tributary near Zion Grove | 35°20'17" | 79°33'57" | On left bank 300 ft from mouth, 0.8 mi south of SR 1261, and 2.0 mi east of Zion Grove, Moore County | .67 | III | Coastal Plain | April 1986-September 1988 |
| 7 | 0210797940 | Limestone Creek at SR 24 near Hadley | 34°54'55" | 77°41'35" | At downstream side of culvert on NC 24, 1.2 mi east of Hadley, Duplin County | 1.61 | IV | Coastal Plain | April 1986-September 1988 |
| 8 | 0205356401 | Chinkapin Creek tributary at SR 1432 near Harrelsville | 36°15'35" | 76°51'23" | On left bank 10 ft downstream from culvert on SR 1423, 4.5 mi southwest of Harrelsville, Hertford County | .76 | V | Coastal Plain | April 1986-September 1988 |
| 9 | 0209257120 | W.P. Brice Creek below SR 1101 near Riverdale | 34°58'09" | 77°02'55" | On left bank on downstream side of bridge on road 170, 2.7 mi below SR 1101, and 4.2 mi southwest of Riverdale, Craven County | 11.2 | V | Coastal Plain | April 1986-September 1988 |

Table 2.--*Study basins and associated National Atmospheric Deposition Program/National Trends Network (NADP/NTN) precipitation-quality stations*

| Site number (fig. 1) | Name of study basin | Associated precipitation-quality station (fig. 1) |
|---|---|---|
| 1 | Beetree Creek | Clingmans Peak |
| 2 | High Shoals Creek | Clingmans Peak |
| 3 | North Harper Creek | Clingmans Peak |
| 4 | Dutchmans Creek | Piedmont Research Station |
| 5 | New Hope River tributary | Finley Farm |
| 6 | Suck Creek tributary | Jordan Creek |
| 7 | Limestone Creek | Clinton Crops Research Station |
| 8 | Chinkapin Creek tributary | Lewiston |
| 9 | W.P. Brice Creek | Clinton Crops Research Station |

## Sampling

The USGS and EHNR shared responsibility for sample collection according to the type of data and sampling frequency (table 3). USGS personnel collected water samples only during storm runoff periods, whereas EHNR field personnel collected water samples on a routine, monthly basis regardless of flow conditions. The USGS sampling program was designed for stream samples to be collected during one or two storms per year at each site. This method is described by Wilder and Simmons (1982) and is used to quantify any changes in constituent levels as discharge increases, peaks, and decreases during a single storm period. Automatic pumping samplers were installed at four sites (Beetree Creek, site 1; High Shoals Creek, site 2; North Harper Creek, site 3; and Dutchmans Creek, site 4) to collect storm runoff samples.

Personnel from both agencies used the sampling techniques and depth-integrating samples described by Guy and Norman (1970). The techniques and procedures used in obtaining suspended sediment, dissolved constituents, minor elements, and nutrient samples are outlined by Simmons and Heath (1982, p. 14); procedures used in collecting and shipping organic samples are described by Wershaw and others (1987).

Streambed material was collected and analyzed for selected nutrients, minor elements, and selected organochlorine constituents, hereafter referred to as organics. Using a 32-oz glass jar as a scooping tool, a sample of at least 300 grams of bottom material was collected from an area approximately 6 to 8 in. in length and 2 in. deep. Where the streambed was rocky, a stainless steel spoon cleaned with acetone or methanol was used to collect material between the rocks.

Table 3.--*Types of data available and frequency of collection at study sites*

[USGS, U.S. Geological Survey; EHNR, North Carolina Department of Environment, Health, and Natural Resources; C, continuous; NS, did not sample; E, selected event; M, monthly; Q, quarterly; A, annually; S, semi-annually; O, one sample]

| Data type | Frequency of collection | |
|---|---|---|
| | USGS | EHNR |
| Water discharge | C | NS |
| Suspended sediment | E | NS |
| Major constituents (dissolved) | E | M |
| Major constituents (total) | E | M |
| Nutrients (total) | E | M |
| Minor elements (total) | E | Q |
| Selected organic constituents | E | A |
| Biochemical oxygen demand (BOD) | NS | M |
| Bottom material | NS | S |
| Biological (fish) | NS | O |
| Biological (benthic organisms) | NS | O |

Fish were collected for tissue and community structure analyses by EHNR personnel. A representative 400-ft section of each stream was isolated using block nets placed at each end of the section. Fish in most stream segments were collected using a backpack electroshocker and a seine (a net on which the bottom was weighted with sinkers and the top supported by floats). Several areas of the stream were reshocked to ensure completeness of sampling effort. The riffle areas were disturbed by kicking up the bottom substrate and a small seine was placed downstream to collect the fish. Hoop nets were used to collect fish at W.P. Brice Creek (site 9) because this site was too deep to use an electroshocker and too narrow for a boat.

Fish collected for community structure analyses were identified by species level, and the length range and total weight of each species were recorded. Fish collected for tissue analyses were individually measured (weight and length); however, on composite samples, the mean weight and the mean length were reported.

Fish used for tissue analyses were wrapped in aluminum foil, placed on ice, and frozen. Fish were later thawed and prepared for analyses by scaling each whole fish then homogenizing the whole fish sample in a blender following standard operating procedures established by the North Carolina Division of Environmental Management (North Carolina Department of Natural Resources and Community Development, 1987). Samples were refrozen until analyzed.

Benthic macroinvertebrates were collected using a qualitative sampling method (North Carolina Department of Environment, Health, and Natural Resources, 1990). This collection technique consists of two kick-net samples, three dip-net samples (sweeps), one leaf-pack sample, two fine-mesh rock and(or) log wash samples, one sand sample, and visual observations. Invertebrates were separated from the rest of the sample in the field, using forceps and white plastic trays, and preserved in glass vials containing 95 percent ethanol. Organisms were picked roughly in proportion to their abundance, but no attempt was made to remove all organisms.

## Laboratory Analysis

Water and fish tissue samples collected by EHNR personnel were sent to the EHNR laboratory in Cary, North Carolina. Samples collected by USGS personnel were sent to the USGS National Water-Quality Laboratory in Arvada, Colorado. Concentrations of suspended sediment were determined at the USGS District sediment laboratory in Raleigh, North Carolina, using the methods described by Guy (1969, p. 46). Joint training sessions were conducted to ensure that all sampling devices and techniques conformed with USGS standards and policy. Because of differences in laboratory equipment of the two agencies, however, detection limits for several constituents were different. The levels of detection limits for the laboratories, and State and U.S. Environmental Protection Agency (EPA) criteria are presented in table 4.

## Data Analysis

Data collected by the USGS during the course of this investigation are stored in the USGS computerized data system, WATSTORE (National Water Data Storage and Retrieval System), and are available upon request. Daily values of stream discharge, laboratory analyses, and field analyses are published in annual data reports (Ragland and others, 1987, 1989, and 1990). Biological and stream chemistry data collected by EHNR personnel are in various files maintained by that agency. Laboratory analytical data from EHNR were combined with USGS data in a computer file to facilitate analyses and interpretation of data.

Although considerable effort was made to maintain uniform data-collection and laboratory techniques between cooperating agencies, some inconsistencies, such as those with laboratory detection limits, did occur. Most problems were recognized and corrected promptly. Statistical

Table 4.--*Laboratory detection limits and criteria for selected constituents*

[USGS, U.S. Geological Survey; EHNR, North Carolina Department of Environment, Health, and Natural Resources; mg/L, milligrams per liter; --, not analyzed or no criterion; SMCL[1,2], secondary maximum contaminant level; MCL[3], maximum contaminant level; °C, degrees Celsius; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; *, North Carolina standard for all freshwaters (North Carolina Environmental Management Commission, 1986)]

| Constituent | USGS detection limit | EHNR detection limit | Federal criteria | North Carolina criteria[4] |
|---|---|---|---|---|
| Dissolved constituents (mg/L) | | | | |
| Calcium | 0.1 | -- | -- | -- |
| Magnesium | .1 | -- | -- | -- |
| Potassium | .1 | -- | -- | -- |
| Sodium | .1 | -- | -- | -- |
| Chloride | .1 | 1.0 | SMCL: 250 | Aquatic life: 230 |
| Fluoride | .1 | -- | MCL: 4 | Aquatic life: 1.8 |
| Solids, residue at 180 °C | 1 | -- | -- | -- |
| Silica | .1 | -- | -- | -- |
| Sulfate | .2 | 5 | SMCL: 250 | -- |
| Total nutrients (mg/L) | | | | |
| Nitrite plus nitrate (as N) | 0.1 | 0.01 | MCL: 10 | -- |
| Ammonia (as N) | .01 | .01 | -- | -- |
| Ammonia plus organic nitrogen (as N) | .2 | .1 | -- | -- |
| Orthophosphorus (as P) | .01 | .01 | -- | -- |
| Phosphorus (as P) | .01 | .01 | -- | -- |
| Total recoverable minor constituents (µg/L) | | | | |
| Aluminum | 10 | 50 | SMCL: 50-200 | -- |
| Cadmium | 1 | [5]2 | MCL: 5 | [6]*2 |
| Arsenic | 1 | 10 | MCL: 50 | *50 |
| Chromium | 1 | 25 | MCL: 50 | *50 |
| Cobalt | 1 | 50 | -- | *1,000 |
| Copper | 1 | 10 | SMCL: 1,000 | [7]*15 |
| Iron | 10 | 50 | SMCL: 300 | [7]*1,000 |
| Lead | 5 | [8]10 | MCL: 50 | [9]*25 |
| Manganese | 10 | 25 | SMCL: 50 | -- |
| Mercury | .1 | .2 | MCL: 2 | *0.2; Aquatic life: 0.012 |
| Selenium | 1 | 5 | MCL: 50 | [10]*10 |
| Zinc | 10 | 10 | SMCL: 5,000 | [7]*50 |
| Nickel | 1 | 50 | -- | [9]*50 |

[1]U.S. Environmental Protection Agency, 1991b.

[2]Secondary MCL's are established for contaminants that can adversely affect the odor or appearance of water. They are nonenforceable and aesthetically based.

[3]U.S. Environmental Protection Agency, 1991a.

[4]North Carolina Department of Natural Resources and Community Development, 1989.

[5]Detection limit for cadmium was lowered from 10 to 2 µg/L in January 1988.

[6]Designated trout waters have cadmium limit of 0.4 µg/L.

[7]Value represents action levels as specified in Administrative Code Section 15 NCAC 2B .0211 (b) (North Carolina Division of Environmental Management Commission, 1976) for unfiltered water supplies.

[8]Detection limit for lead was lowered from 50 to 10 µg/L in January 1988.

[9]If a more stringent criteria is needed, then 0.01 of the 96-hour LC50 (American Public Health Association, 1976) for aquatic life is the standard.

[10]The limit for lakes, ponds, and reservoirs is 5 µg/L.

calculations for streamflow, precipitation, and water-quality constituents were performed using the statistical software package P-STAT[1] (Buhler and others, 1983). A procedure developed by Helsel and Cohn (1988) was used to calculate means, standard deviations, and other statistics for those constituents with a significant number of values reported to be less than the detection limit. This procedure calculates substitute values using an adjusted maximum likelihood log-normal distribution based upon the distribution of data above the detection limit (Cohn, 1988).

## REVIEW OF 1986-88 HYDROLOGIC CONDITIONS

Although some biological samples were collected in 1985, all hydrologic samples were collected between 1986 and 1988. During the 1986-88 study period, annual precipitation was generally below normal in 1986 and 1988 (National Oceanic and Atmospheric Administration, 1988a) and near normal to slightly above normal in 1987 (fig. 4). During mid and late summer of 1986, western and central North Carolina experienced a severe drought. The average monthly precipitation during the sampling period was 0.16 to 1.27 in. below normal for seven of the nine study sites (National Oceanic and Atmospheric Administration, 1986, 1987, and 1988b). At W.P. Brice and North Harper Creeks, monthly precipitation was 0.12 and 0.38 in. above normal, respectively, during the sampling period. The precipitation was compared with the long-term median for 1951-80 provided by the National Oceanic and Atmospheric Administration (1981).

Compared with long-term records, flows at most gaging stations across North Carolina were below normal (daily median discharge) during 1986 and 1988 and near normal in 1987. Drought conditions during the period of this study are reflected in the streamflow hydrographs for selected long-term gaging stations across the State (fig. 5). The percent of days from 1986 to 1988 having mean daily discharge below the median for these stations ranged from 71 percent at Little River near Star to 83 percent at Flat Creek near Inverness (fig. 5). These low-flow conditions reduced opportunities to collect the number of water samples during stormflow conditions needed to define stream-water chemistry throughout the full range of discharge, resulting in a bias toward low-flow conditions during the study.

The base period used to determine daily median discharge at the selected long-term gaging stations was 1959-88, except Flat Creek near

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[1]Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

Inverness for which the base period was 1969-88. Each station was selected using criteria which included a location closest to a study basin, a long period of record, nonregulated flow, and catchment size.

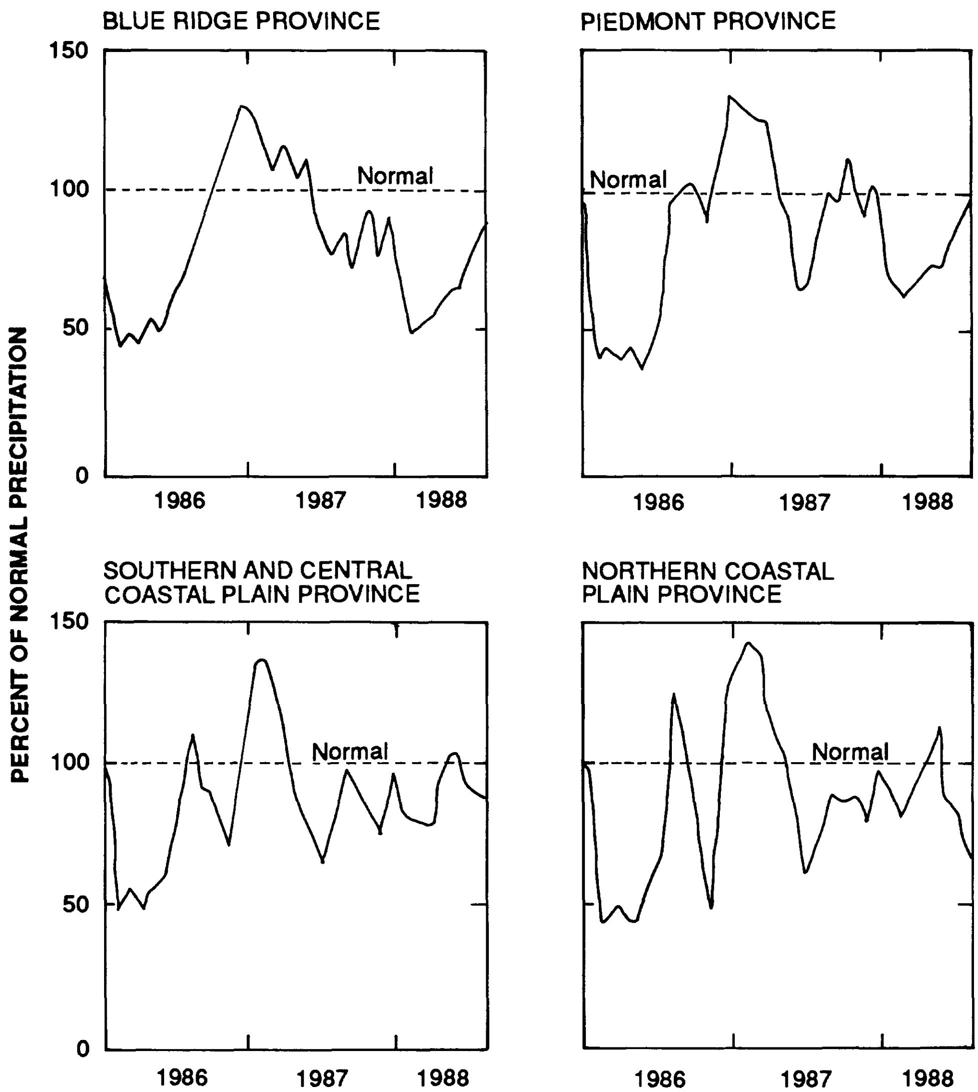


Figure 4.--Percent of normal precipitation (1951-80) in North Carolina from January 1986-September 1988 (modified from National Oceanic and Atmospheric Administration, 1988a).

## DESCRIPTION OF FORESTED BASINS

Descriptions of the forested basins studied are presented in this section and include drainage area, general range of land-surface elevation, soil types, geology, nature of the stream channel and flow, and major tree species composing the forest. The basin sites are shown in figure 1. Because of the complex nature of geology in North Carolina, the geologic

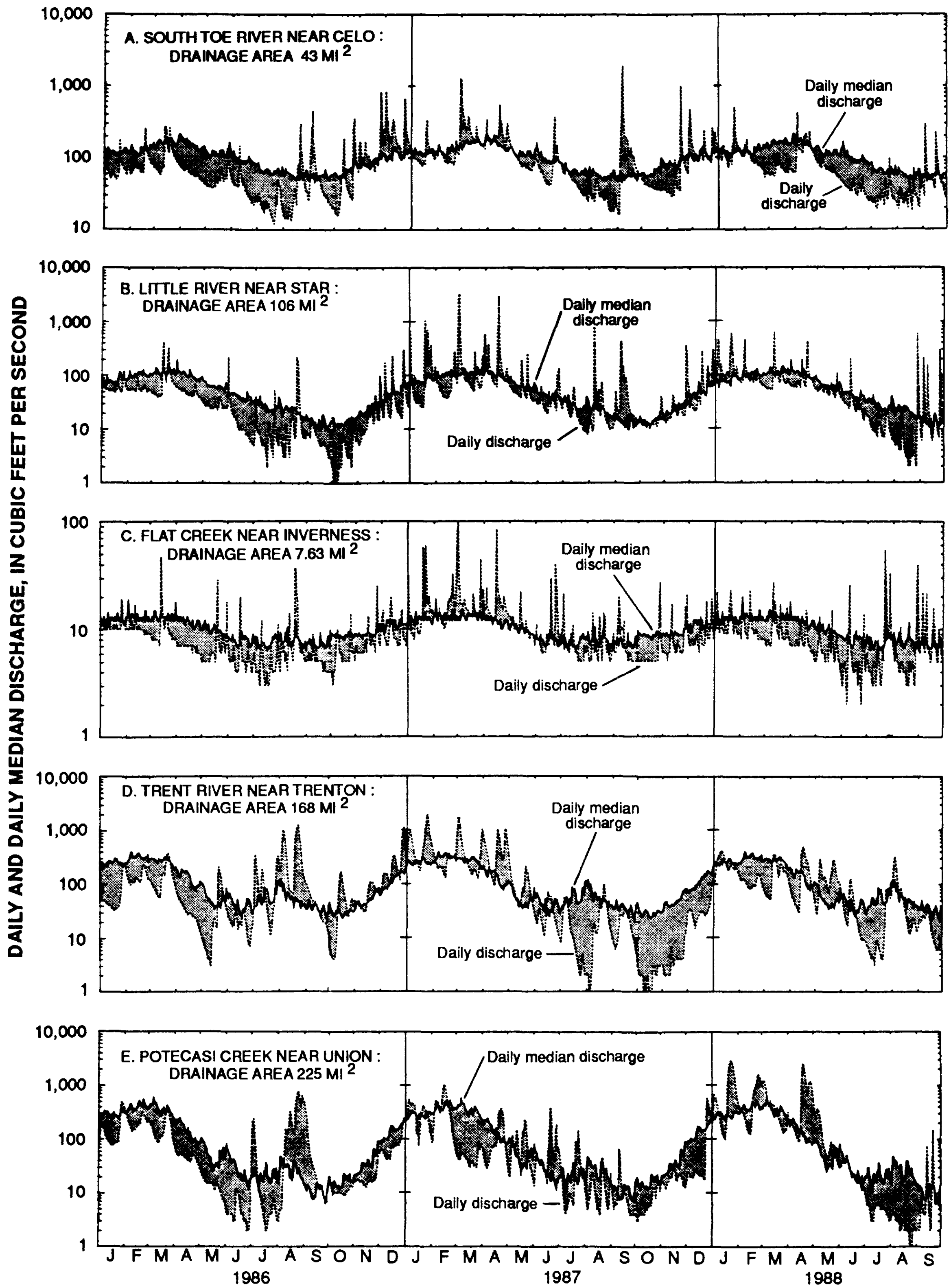


Figure 5.--Daily discharge and daily median discharge for selected long-term gaging stations in North Carolina, January 1986-September 1988. Locations of stations are shown in figure 1.

descriptions are from a generalized geologic map (North Carolina Department of Environment, Health, and Natural Resources, 1991). Additional data on streamflow, channel, and other characteristics are given in table 5.

Beetree Creek (site 1) near Swannanoa has a 5.46-$mi^2$ drainage area in Buncombe County in the eastern Blue Ridge Province (fig. 1). The basin is extremely steep and rugged with elevations ranging from 2,760 to 5,680 ft. This is a protected catchment and serves as part of the water supply for the city of Asheville. Soils are mostly sandy loams ranging in color from light yellow to orange, but browns and grays also occur (Daniels and others, 1984). The underlying rocks, characteristic of geochemical zone I, are clastic metasedimentary and mafic and felsic metavolcanic rocks consisting of gneiss, schist, metagraywacke, amphibolite, and calc-silicate granofels. The stream channel at site 1 is well defined, and bed materials range from coarse sands to cobbles and large boulders. Mean daily flow during the study period was about 6 $ft^3/s$. Major tree species in the basin are spruce and fir at higher elevations and beech, ash, oak, and poplar at lower elevations.

High Shoals Creek (site 2) near Dysartsville, McDowell County, has a 2.38-$mi^2$ drainage area characterized by steeply rolling topography with elevations ranging from 1,200 to 2,243 ft. The basin is in the western Piedmont Province (fig. 1). Soils are relatively thin and are mostly red to yellowish-red clay loam containing numerous rock fragments (Daniels and others, 1984). The basin is underlain by metamorphosed granitic gneiss, including quartz diorite, biotite gneiss, and amphibolite of geochemical zone I. The steep slopes and high water table account for many springs and seeps in the basin. Stream channels are well defined with steep banks and contain silt, coarse sand, large cobbles, and boulders; mean daily flow in the channel during the study period was about 2 $ft^3/s$. Major tree species include oak, ash, maple, beech, and pine. This site was discontinued from the study on January 19, 1987, when abnormal sediment concentrations in stream water were observed due to the start of mining operations in the basin.

North Harper Creek (site 3) near Kawana has a 1.25-$mi^2$ drainage area and is in Avery County in the northeastern Blue Ridge Province (fig. 1). The basin's landscape is steep and rugged with elevations ranging from 3,160 to 3,970 ft. Soils are shallow (generally less than 1 to 2 ft), contain many rock fragments, and range from coarse loams to clay loams. Underlying these soils are metamorphosed felsic gneiss rocks derived from sedimentary and igneous rocks, and the area is part of geochemical zone I. Stream channels are well defined and contain silt, coarse sand, and boulders.

Table 5.--*Selected streamflow, channel, and other characteristics at study sites, 1986-88*

[$ft^3/s$, cubic foot per second; >, greater than]

| Site number (fig. 1) | Study basin | Characteristic | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean daily flow ($ft^3/s$) | Maximum mean daily flow ($ft^3/s$) | Minimum mean daily flow ($ft^3/s$) | Zero-flow days (percent) | Channel definition | Stream width (feet) | Rapids and falls | Stability of channel banks | Bed material | Average depth to bedrock (feet) | Water color |
| 1 | Beetree Creek | 6.66 | 60 | 0.71 | 0 | Good | 39 | Numerous | Good | Sand to boulders | 0-3 | Clear |
| 2 | High Shoals Creek | 2.02 | 14 | .60 | 0 | Good | 13 | Numerous | Good | Silt to boulders | 0-3 | Clear |
| 3 | North Harper Creek | 1.81 | 16 | .32 | 0 | Good | 10 | Numerous | Good | Silt to boulders | 0-3 | Clear |
| 4 | Dutchmans Creek | 2.27 | 127 | .01 | 0 | Good | 6 | Some | Good | Sand to boulders | 0-15 | Clear |
| 5 | New Hope River tributary | .58 | 51 | 0 | 55 | Good | 6 | Some | Good | Silt to boulders | 0-15 | Clear |
| 6 | Suck Creek tributary | .26 | 6.7 | 0 | 5 | Fair | 6 | Rare | Fair | Silt to boulders | >20 | Clear to light tea |
| 7 | Limestone Creek | 3.18 | 65 | 0 | 26 | Fair to poor | 10 | None | Poor | Silt to sand | 1,000 | Dark tea |
| 8 | Chinkapin Creek tributary | .45 | 33 | 0 | 71 | Fair | 5 | None | Poor | Silt to gravel | 1,000 | Dark tea |
| 9 | W.P. Brice Creek | 18.7 | 470 | .12 | 0 | Poor | 23 | None | Poor | Silt to sand | 1,000 | Dark tea |

Streamflow during the study period was continuous and daily flow averaged about 1.8 $ft^3/s$. Major species of trees growing in this catchment are fir, spruce, beech, ash, and oak.

Dutchmans Creek (site 4) near Uwharrie has a 3.44-$mi^2$ drainage area in Montgomery County in the central Piedmont Province (fig. 1). The topography of the basin is characterized by sharp ridges, low peaks, steep slopes, and rough terrain with elevations ranging from 360 to 840 ft. Most soils in the basin are silty with very fine sand, are generally less than 3 ft thick, and have low permeability (Daniels and others, 1984, p. 38). The basin is underlain by metasedimentary rocks of the Carolina Slate Belt, which is composed mostly of metamudstone, argillite, and epiclastic rock that characterize geochemical zone II. The stream channel is well defined, and bed material ranges in composition from coarse sand to cobbles and small boulders. Bedrock is exposed in many reaches of the channel. Mean daily streamflow during the study was more than 2 $ft^3/s$. Major tree species growing in the basin are oak, ash, maple, beech, and pine.

New Hope River tributary (site 5) near Farrington is an eastern Piedmont Province basin in Chatham County (fig. 1). The drainage area of this basin is 2.05 $mi^2$ with land-surface elevations ranging from 240 to 600 ft; hills are moderately rounded and valley walls are less steep than to the west. Basin soils are comprised of two groups: (1) the "red-clay lands," which have scattered and embedded quartz and slate fragments and contain clay high in potash; and (2) a nameless soil group characterized by a stony-silt loam containing slate and quartz fragments and a heavy plastic clay matrix (Daniels and others, 1984). These soils may be less than 3 ft thick in some areas. The basin is underlain by sedimentary rocks composed of conglomerate, sandstone, and mudstone, which also form part of geochemical zone II. The stream channel at site 5 is well defined and contains bed material ranging in size from silt to boulders. Mean daily flow in New Hope River tributary was low, 0.58 $ft^3/s$, and flow ceased for more than half the days of the study period. Major tree species present are mostly hardwoods, including oaks, ash, poplar, maples, and gum. Pines are also scattered throughout the basin.

Suck Creek tributary (site 6) near Zion Grove is in the Coastal Plain Province of Moore County (fig. 1). This 0.67-$mi^2$ basin is characterized by a rolling topography with elevations that range from 410 to 620 ft. Soils are composed of fine- to medium-quartz sand with minor amounts of quartz pebbles, mica flakes, and clay. These permeable soils are underlain by unconsolidated sand and clay of the Middendorf Formation. The stream channel is fairly well defined and contains bed material ranging in size from silt to boulders. Streamflow was very low, but steady; mean daily flow was 0.26 $ft^3/s$ during the study, but ceased only 5 percent of the time. Major tree species present in the basin are long-leaf pine, oak, and maple.

Limestone Creek (site 7) near Hadley is in Duplin County in the southern Coastal Plain Province (fig. 1). The basin drainage area is 1.61 $mi^2$ and has swamp-like characteristics with low topography, low relief, and elevations ranging from 22 to 28 ft. The basin soils are generally sandy and are composed of reworked siliceous Coastal Plain sediments. The generally sandy nature of the soils are a principal characteristic of geochemical zone IV. The soils are underlain by the Peedee Formation, which consists of layered sand, clayey sand, and clay. The channel is defined as fair to poor and contains bed material that is mostly silt and fine sand. The mean daily flow in Limestone Creek was slightly more than 3 $ft^3/s$, but flow could not be detected about 25 percent of the days during the study. Major tree species growing in this basin are long-leaf pine, oak, poplar, and cypress. A swine farm was located upstream of the gaging station; however, water-quality and bottom-material samples were collected at an established location upstream from this facility.

Chinkapin Creek tributary (site 8) near Harrelsville is in Hertford County in the northern Coastal Plain Province (fig. 1). This gently sloping basin has a drainage area of 0.76 $mi^2$ with land-surface elevations that range from 10 to 40 ft. The basin, which is in geochemical zone V, contains soils that are a mixture of sand, silt, and clay in about equal proportions and are generally characterized as fine, sandy loam to well-drained silty clay. The soils in this basin, derived from Coastal Plain sediments, are strongly acidic and siliceous (U.S. Department of Agriculture, 1984). Underlying the surficial materials is the Yorktown Formation, which consists of fine sand, fossiliferous clay, and shell beds. The stream channel is fairly well defined, and bed materials range in size from silt to gravel. During the study period, there was no flow detected in Chinkapin Creek tributary nearly three-fourths of the time. Daily mean flow for the remainder of the time was 0.45 $ft^3/s$. Major tree species present in the basin are pine, poplar, cypress, and oak.

W.P. Brice Creek (site 9) near Riverdale is in the Croatan National Forest in Craven County (fig. 1). This eastern Coastal Plain basin has the largest drainage area of the selected study basins, approximately 11.2 $mi^2$. Land-surface elevations in the basin range from 25 to 40 ft. The soils in this basin are derived from reworked Coastal Plain sediments and are composed of sand and clay, but in and near streams and swamps, the soils contain a large percentage of organic matter; most are strongly acidic. As at site 8, this basin is in geochemical zone V and is underlain by sand and clay of the Yorktown Formation. Because of the basin's low topography, heavy rains can cause extensive flooding of lowlands, and sluggish flows often cause flood conditions to persist for a week or more. The stream channel is poorly defined; bed material consists of silt and sand mixed with organic debris. W.P. Brice Creek had a mean daily flow of about 19 $ft^3/s$ and did not cease flowing during the study. Major tree species growing in this basin are yellow pine, cypress, gum, oak, and poplar.

## SELECTED PHYSICAL AND CHEMICAL CHARACTERISTICS OF WATER IN STREAMS

The results of sampling for selected physical and chemical characteristics of stream water and precipitation in forested basins are presented in this section, along with the results of the sampling of streambed material for some of these characteristics. The selected physical characteristics include specific conductance, dissolved oxygen, temperature, and suspended sediment. Selected chemical characteristics include pH, major dissolved constituents, nutrients, minor constituents, organochlorine insecticides, and biochemical oxygen demand.

Precipitation was analyzed for major dissolved constituents, pH, and nutrients. Streambed material was analyzed for nutrients, minor constituents, and organochlorine insecticides. The analytical results for precipitation and streambed material are discussed with the results for stream water under the appropriate constituent headings.

Water-quality sampling sites were chosen to best assure that the samples represented natural conditions. These sites were not always at the gaging station location on a given stream (table 1). A summary of these locations is provided in table 6.

### Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electrical current and is presented as microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C). Values of specific conductance are indicators of the quantities of dissolved ions in water. Concentrations of most major dissolved materials in stream water are diluted by precipitation and(or) high flows (increased water volume), thus specific conductance is expected to vary inversely with discharge.

Table 6.--*Summary of water-quality sampling locations*

[ft, foot; mi, mile]

| Site number (fig. 1) | Study basin | Description of water-quality sampling site |
|---|---|---|
| 1 | Beetree Creek | Low-flow samples taken about 25 ft upstream of stream gage; stormflow samples taken at gage. |
| 2 | High Shoals Creek | All samples taken at stream gage. |
| 3 | North Harper Creek | All samples taken at stream gage. |
| 4 | Dutchmans Creek | All samples taken at stream gage. |
| 5 | New Hope River tributary | All samples taken about 1/4 mi upstream of stream gage. |
| 6 | Suck Creek tributary | All samples taken about 100 ft downstream from stream gage. |
| 7 | Limestone Creek | All samples taken about 1/4 mi upstream of stream gage and upstream of swine farm. |
| 8 | Chinkapin Creek tributary | All samples taken about 50 ft upstream of stream gage on upstream side of culvert. |
| 9 | W.P. Brice Creek | All samples taken about 25 ft upstream of stream gage on upstream side of culvert. |

The mean specific conductance values during low-flow periods ranged from 17 µS/cm at 25 $^{\circ}C$ at North Harper Creek in geochemical zone I to 65 µS/cm at 25 $^{\circ}C$ at New Hope River tributary in geochemical zone II (table 7). The mean specific conductance at Limestone Creek in geochemical zone IV was marginally higher during stormflow conditions, but this may reflect the small number of samples collected during low-flow periods rather than a true relation.

Because low-flow conditions largely represent ground-water contributions to streamflow, specific conductance values during these flow conditions are reflective of the types of rocks through which the ground water flows and the velocity with which it moves toward streams. The longer the contact time the ground water has with available soluble minerals, the greater its dissolved-ion content will be, resulting in a higher specific conductance in the resultant discharge to streams.

Table 7.--*Statistical summary of specific conductance by basin and flow condition*

[μS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; N, number of analyses; SD, standard deviation]

| Site number (fig. 1) | Study basin | Geo-chemical zone | Flow condition | Specific conductance (μS/cm at 25 °C) N | Mean | Median | Range of values | SD |
|---|---|---|---|---|---|---|---|---|
| 1 | Beetree Creek | I | Stormflow | 6 | 21 | 20 | 17-25 | 3.3 |
| | | | Low flow | 27 | 21 | 22 | 11-33 | 5.9 |
| 2 | High Shoals Creek | I | Stormflow | 4 | 26 | 28 | 11-34 | 8.8 |
| | | | Low flow | 2 | 34 | 34 | 33-34 | .7 |
| 3 | North Harper Creek | I | Stormflow | 8 | 17 | 13 | 12-36 | 7.5 |
| | | | Low flow | 26 | 17 | 15 | 8-32 | 6.4 |
| 4 | Dutchmans Creek | II | Stormflow | 16 | 39 | 40 | 27-51 | 6.2 |
| | | | Low flow | 31 | 49 | 49 | 33-67 | 9.5 |
| 5 | New Hope River tributary | II | Stormflow | 10 | 39 | 36 | 28-56 | 8.8 |
| | | | Low flow | 17 | 65 | 62 | 30-120 | 23 |
| 6 | Suck Creek tributary | III | Stormflow | 4 | 22 | 22 | 20-24 | 1.5 |
| | | | Low flow | 37 | 25 | 24 | 12-50 | 6.7 |
| 7 | Limestone Creek | IV | Stormflow | 6 | 52 | 52 | 36-68 | 12 |
| | | | Low flow | 2 | 50 | 50 | 48-52 | 2.8 |
| 8 | Chinkapin Creek tributary | V | Stormflow | 8 | 46 | 42 | 23-60 | 12 |
| | | | Low flow | 10 | 49 | 44 | 37-75 | 12 |
| 9 | W.P. Brice Creek | V | Stormflow | 13 | 54 | 55 | 36-76 | 11 |
| | | | Low flow | 26 | 59 | 60 | 29-84 | 12 |

In general, differences of mean specific conductance between stormflow and low-flow conditions are relatively small in a given basin compared to differences of mean values at low-flow conditions between some basins. This also indicates the influence of geology on water chemistry between basins.

## Dissolved Oxygen and Water Temperature

Biological, chemical, and physical variables acting simultaneously determine the amount of dissolved oxygen present in a stream at the time of sampling. Dissolved oxygen is required for the respiration of aerobic organisms such as fish, macroinvertebrates, bacteria, and plants. Biological and chemical processes including the decomposition of dissolved, suspended, or precipitated organic matter can deplete a stream of its oxygen supply. The capacity of water to contain dissolved oxygen is directly related to temperature. Dissolved-oxygen concentrations in stream water tend to be less during the warmer months; however, dissolved-oxygen concentrations above equilibrium conditions (supersaturation) can be observed during the summer in streams containing elevated photosynthetic activity (Hem, 1985).

The temperature of stream water generally is directly related to air temperature but tends to lag behind sudden changes in air temperature. This delay is due to the slower heating and cooling rate of water. The mean water temperature for samples collected during the summer months (June, July, and August) of 1986-88 ranged from 17 $^{\circ}$C in the streams sampled in the mountains to 22 $^{\circ}$C in the streams sampled nearest the coast. All samples were collected during daylight hours.

The relation between dissolved-oxygen concentration and water temperature varies across the State. Three study basins were selected to illustrate these relations, Beetree Creek (site 1), Dutchmans Creek (site 4), and W.P. Brice Creek (site 9) (fig. 6). At Beetree Creek, dissolved-oxygen concentrations were close to the predicted saturation concentrations using the method of Skougstad and others (1979) at prevailing water temperatures. Some dissolved-oxygen concentrations were above the predicted saturation concentration, indicating that aeration may be the contributing factor, as water flows turbulently over rocks at this site. The mean summer dissolved-oxygen concentration for 1986-88 was also close to the saturation concentration at the mean summer water temperature (fig. 6A).

Stream water in Dutchmans Creek in the Piedmont Province of North Carolina also contained dissolved-oxygen concentrations near saturation values (fig. 6B). However, there were fewer values observed greater than saturation, and the mean summer dissolved-oxygen concentration was less than at Beetree Creek with respect to saturation at the mean summer water temperature. Observed dissolved-oxygen concentrations at Dutchmans Creek and at Beetree Creek were above minimum concentrations recommended by the EPA (1976) for fish.

Natural streamflow conditions in the Coastal Plain Province appear to be more conducive to fish stress, especially in summertime. At W.P. Brice Creek, dissolved-oxygen concentrations were all significantly less than saturation values (fig. 6C). A number of observations, including a plot of the mean summer dissolved-oxygen concentration at the mean summer water temperature, were below the recommended limit for fish (U.S. Environmental Protection Agency, 1976). This is attributed to reduced stream turbulence during sluggish summertime streamflow, especially where flows decrease to

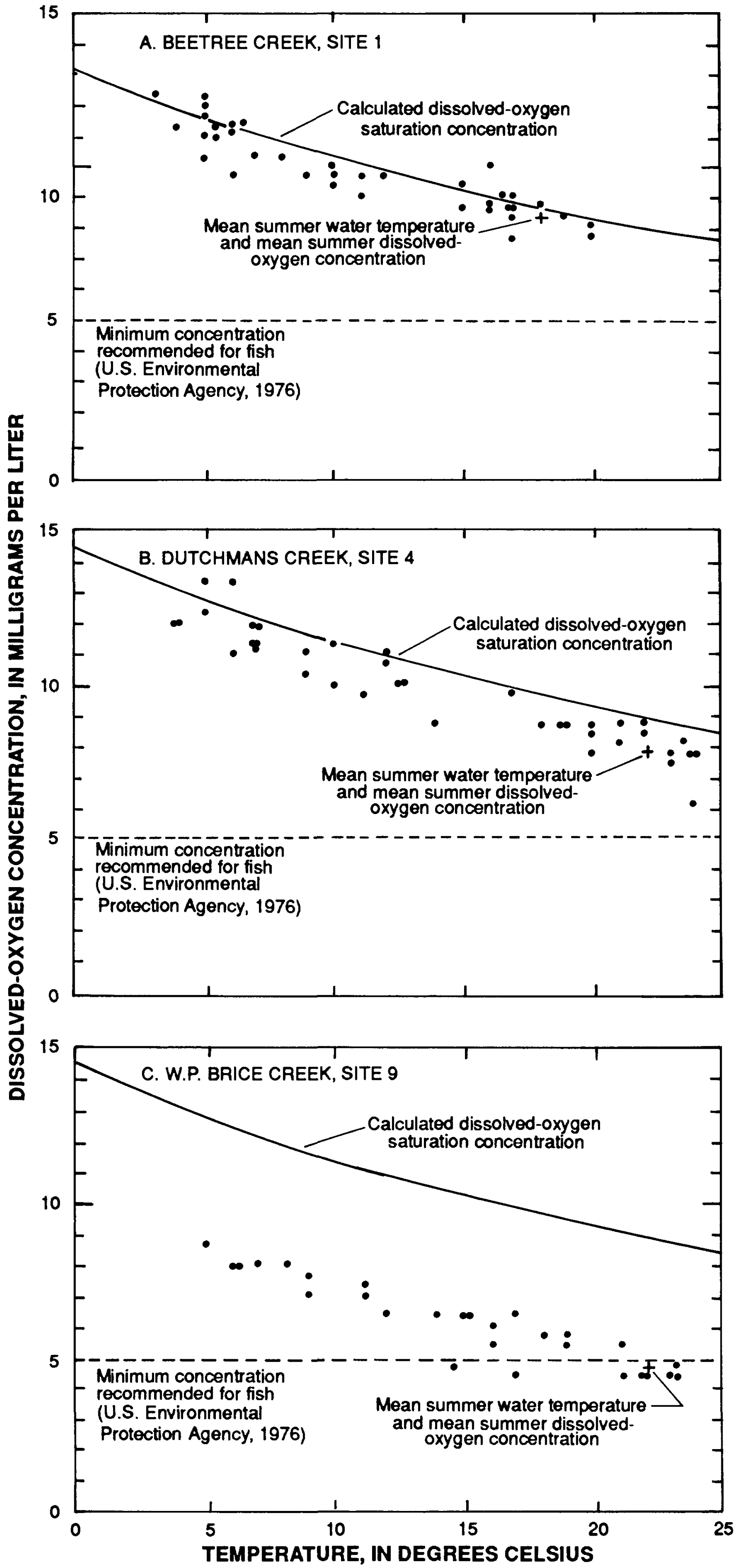


Figure 6.--Relation of dissolved-oxygen concentration and water temperature, 1986-88, at (A) Beetree Creek, (B) Dutchmans Creek, and (C) W.P. Brice Creek, with dissolved-oxygen saturation curves calculated from Skougstad and others (1979).

less than 1 $ft^3/s$ and often cease. Chemical and(or) biological oxygen demand due to decaying organic matter could rapidly deplete dissolved oxygen in a slow-moving stream.

## Suspended Sediment and Transport

Fluvial sediment in forested-basin streams is derived primarily from channel scour, bank caving, and forest litter. Clay and organic material also may be washed into streams from the soil surface and shallow soil zone during heavy rains (Simmons, 1988, p. 37). The primary factors that affect the rate of erosion and sediment transport are soil type, surface cover, rainfall intensity, surface slope, and drainage. Concentrations of suspended sediment vary considerably from one basin to another as these and other factors change. Because runoff velocity and associated turbulence determine the size and quantity of materials transported, maximum concentrations of suspended sediment usually occur during storm runoff. The intensity of the storm is also critical; for example, a gentle 3-in. rainfall spread over several days may produce far less sediment transport than an intense 3-in. rain that falls in a few hours.

Continuous streamflow data permits the computation of fluvial sediment discharge for this investigation. Using sediment-concentration data collected at low, medium, and high flows and historic data, sediment-transport curves for each site were prepared to show the relation between suspended-sediment discharge and water discharge. Hourly values of water discharge and corresponding sediment discharge were determined from each site curve. These values were summed to provide estimates of annual sediment discharge and yield (table 8). This method of computation used hourly values because it was necessary to compute time increments considerably less than a day in order to account for quickly rising and falling storm hydrographs that are characteristic of the small watersheds in this study. For instance, some storm periods shown on hydrographs were as brief as a few hours. Sediment transport values were not computed for Limestone and High Shoals Creeks because data were not sufficient to define sediment-transport curves.

Values in table 8 represent only suspended sediment transported in the stream water. An unknown and unmeasured amount of sediment also was transported along the stream bottom as the bedload discharge and is considered to be a minor component of the total sediment discharge.

Table 8.--*Estimated suspended-sediment discharge and yield for study basins, 1987-88 water years*[1]

[$ft^3/s$, cubic feet per second; t, tons; $t/mi^2/yr$, tons per square mile per year; n, number of samples; *r*, correlation coefficient; --, no data]

| Site no. (fig. 1) | Study basin | Geo-chemical zone | 1987 water year: Mean water discharge ($ft^3/s$) | 1987 water year: Estimated suspended-sediment discharge (t) | 1987 water year: Estimated suspended-sediment yield ($t/mi^2/yr$) | 1988 water year: Mean water discharge ($ft^3/s$) | 1988 water year: Estimated suspended-sediment discharge (t) | 1988 water year: Estimated suspended-sediment yield ($t/mi^2/yr$) | [2]n | [3]*r* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Beetree Creek | I | -- | -- | -- | 6.25 | 26 | 4.9 | 58 | 0.88 |
| 3 | North Harper Creek | I | 4.14 | 210 | 170 | 1.80 | 23 | 18 | 49 | .55 |
| 4 | Dutchmans Creek | II | 3.08 | 320 | 93 | 1.60 | 71 | 21 | 55 | .66 |
| 5 | New Hope River tributary | II | 1.28 | 17 | 8.3 | .45 | 2.8 | 1.4 | 13 | .86 |
| 6 | Suck Creek tributary | III | .64 | 6.6 | 9.8 | .31 | 3.2 | 4.8 | 18 | .96 |
| 8 | Chinkapin Creek tributary | V | .89 | 7.7 | 10 | .07 | .7 | .9 | 25 | .85 |
| 9 | W.P. Brice Creek | V | 19.5 | 63 | 5.6 | 18.9 | 58 | 5.2 | 26 | .81 |

[1]Period October 1 through September 30 for which analyses were made.
[2]Number of samples used to define sediment-transport curve.
[3]Correlation coefficient of estimated sediment discharge and actual sediment discharge.

Naturally occurring sediment discharge in streams draining forested basins is highly variable across the State and tends to be greatest in those study sites located in the Blue Ridge and western Piedmont Provinces. For example, during 1987, annual sediment yield at the North Harper Creek site was 170 tons per square mile (tons/mi$^2$) as compared with 5.6 tons/mi$^2$ and 10 tons/mi$^2$ at the W.P. Brice Creek and Chinkapin Creek tributary sites (table 8). Climatological effects are also somewhat variable. Estimated sediment yields during water year 1987, when precipitation was above normal, ranged from 1.1 to 11 times greater than those of water year 1988, when widespread drought conditions prevailed (table 8). Suspended-sediment discharge at the W.P. Brice Creek site, however, was relatively unaffected by the drought, as evidenced by a slightly lower annual sediment yield for the 1988 water year.

## pH

The level of pH in a stream is important to its aquatic life. Current research indicates that the major sources of acidity in forested, headwater basins are direct input from acidic precipitation and from organic acidity that results from the decay of vegetation (U.S. Environmental Protection Agency, 1988). Contact with soils and rocks in a basin can also change the pH of precipitation before the water reaches the stream as surface runoff or ground-water discharge.

The pH of precipitation tends to be uniform throughout the State. Stensland and Semonin (1982) have noted no significant changes in pH values less than 5.0 for the entire eastern half of the United States since the early 1950's. During this study, the annual mean pH values of precipitation collected at stations nearest the forested basins (fig. 1 and table 2) ranged from 4.36 to 4.60 (National Atmospheric Deposition Program, 1987 and 1988).

The mean pH of stream water at the study sites in geochemical zones I, II, and III ranged from 1.5 to 2 pH units higher than the annual mean pH of rainfall (fig. 7). This indicates that soil, rocks, or other conditions in these basins were sufficient to raise the pH of streamflow. At study sites in geochemical zones IV and V, the mean pH of stream water was near or below the annual mean pH of rainfall. The presence of acidic soil conditions, as well as the presence of abundant decaying organic material, in these forested Coastal Plain basins could account for the low pH values of the stream water.

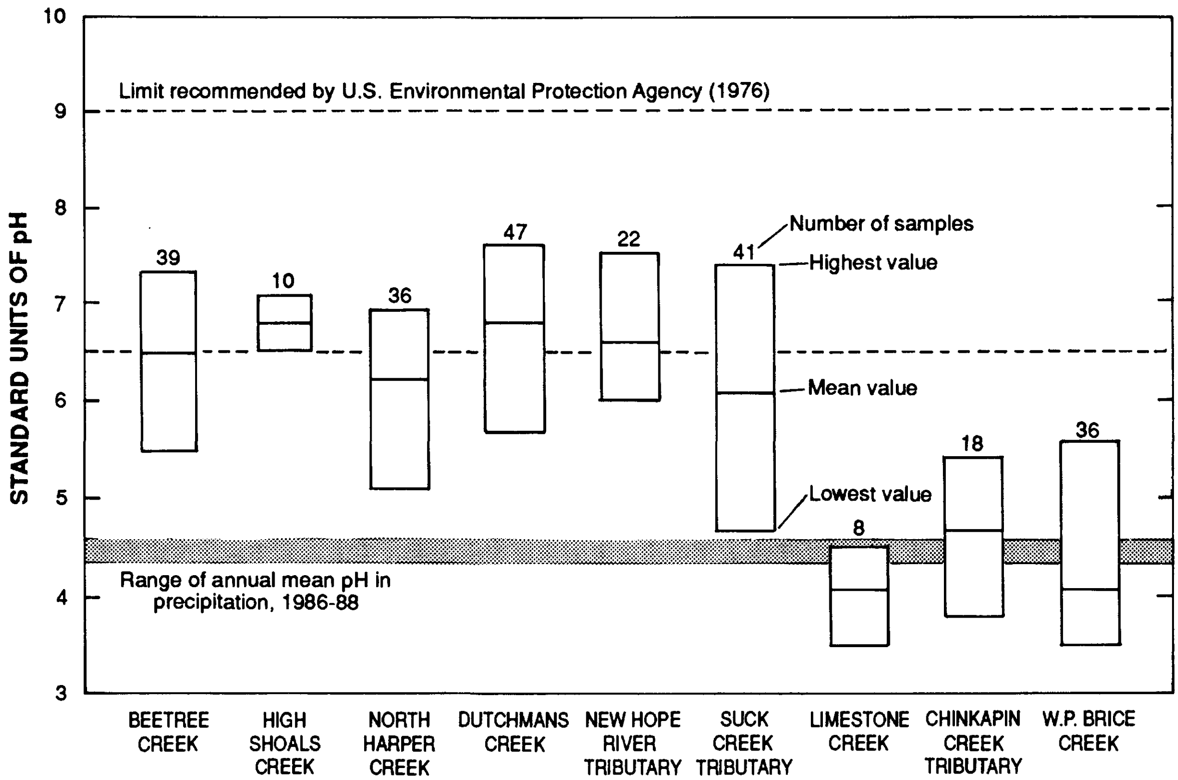


Figure 7.--Variation of daytime pH in stream water at study sites, 1986-88.

Data collected during this study show little to no variation in stream water pH due to flow conditions; however, seasonal fluctuations up to nearly 3 pH units were observed, with the highest pH values observed during the summer months. Hem (1985) reports that seasonal and diurnal fluctuations of stream pH are often influenced by photosynthesizing organisms with the highest pH values occurring during summer days when these processes are at their peak, and lower values occurring at night when photosynthetic activity is decreased. All pH values in this study were obtained during the daytime.

The mean pH values for the North Harper Creek and Suck Creek tributary sites also do not meet the minimum limit recommended by the EPA (1976) to support freshwater fish and plant life (fig. 7). The mean pH values for the Limestone Creek, Chinkapin Creek tributary, and W.P. Brice Creek sites were below pH 5.5, at which fish reproduction may be affected, and the mean values for the Limestone Creek and W.P. Brice Creek sites were below pH 4.5, which can be fatal to various species of adult fish. Whether or not these low pH values in the stream water in these basins would be significantly changed by changes in the pH of precipitation is not known.

## Major Dissolved Constituents

The major dissolved constituents commonly present in natural waters in concentrations exceeding 1.0 mg/L include calcium, magnesium, potassium, sodium, silica, dissolved solids (sum of major ions), chloride, fluoride, sulfate, and nitrate. Nitrate is discussed in the nutrients section. Data for these constituents are presented with respect to flow conditions in the streams (table 9). Discussion of the major dissolved constituents is limited to those for which significant observations may be made or for which comparisons with data collected by Simmons and Heath (1982) are pertinent.

Precipitation is generally a minor source of major dissolved constituents to a stream. Concentrations of dissolved constituents such as calcium, sodium, chloride, and sulfate observed in precipitation are nominal compared with the total concentrations that ultimately reach the stream according to Likens and others (1977). Summary statistics of selected dissolved constituents in precipitation collected nearest each study site (table 10) show that median concentrations of calcium, magnesium, potassium, and sodium are no more than 9 percent of the stormflow concentrations of these constituents (table 9). Chloride and sulfate, however, may be responsible for a larger percentage of these ions in stormflow. Statewide, precipitation may account for about 20 percent of the mean concentration of chloride, and rainfall may account for approximately 25 percent of the mean concentration of sulfate in stormflow.

As precipitation falls through the forest canopy and leaf litter, its constituent concentration may increase 2 to 10 times before it reaches the soil surface (Likens and others, 1977). This may be due, in part, to (1) washoff of evaporated salts from previous rainfall, (2) washoff of atmospheric dryfall, and (3) leaching of the decayed leaf litter.

Mean concentrations of calcium in streamflow were highest in New Hope River tributary and Dutchmans Creek in geochemical zone II. Metavolcanic rocks in this geochemical zone typically contain significant calcium in their composition, especially where parent rocks were basic. Simmons and Heath (1982) also reported calcite as a common fracture-filling mineral in the rocks of geochemical zone II. This could explain the elevated calcium concentrations in low flow and stormflow from these basins. Calcium contributions to stormflow from precipitation are relatively small and fairly uniform across the State (fig. 8A).

The presence of metamorphosed volcanic rocks in the basins of New Hope River tributary and Dutchmans Creek may also explain the elevated mean

Table 9.--*Statistical summary of concentrations of major dissolved constituents by study basin and flow condition, 1986-88, and ranges from previous study*

[N, number of analyses; SD, standard deviation; mg/L, milligrams per liter; --, not determined; sum, sum of major ions; *, no data; <, less than]

| Study basin | Geo-chemical zone | Flow condition | N | Mean | Me-dian | Range | SD | Range previous study[1] | N | Mean | Me-dian | Range | SD | Range previous study[1] | N | Mean | Me-dian | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Calcium, in mg/L | | | | | | Magnesium, in mg/L | | | | | | Potassium, in mg/L | | | | | |
| Beetree Creek | I | Stormflow | 9 | 1.2 | 1.2 | 0.91-1.5 | 0.24 | 0.5-3.0 | 9 | 0.55 | 0.53 | 0.42-0.70 | 0.10 | 0.3-0.9 | 9 | 0.98 | 0.70 | 0.40-1.8 | 0.56 | 0.4-0.9 |
| | | Low flow | 4 | 1.1 | 1.1 | 1.0-1.2 | .08 | .7-2.1 | 4 | .53 | .55 | .40-.60 | .09 | .3-.9 | 4 | .57 | .55 | .40-.80 | .17 | .3-1.9 |
| High Shoals Creek | I | Stormflow | -- | -- | -- | -- | -- | .5-3.0 | -- | -- | -- | -- | -- | .3-.9 | -- | -- | -- | -- | -- | .4-.9 |
| | | Low flow | -- | -- | -- | -- | -- | .7-2.1 | -- | -- | -- | -- | -- | .3-.9 | -- | -- | -- | -- | -- | .3-1.9 |
| North Harper Creek | I | Stormflow | 5 | .93 | .95 | .81-1.1 | .11 | .5-3.0 | 5 | .23 | .22 | .20-.28 | .03 | .3-.9 | 5 | .56 | .50 | .40-1.0 | .25 | .4-.9 |
| | | Low flow | 2 | .70 | .70 | .60-.80 | .14 | .7-2.1 | 2 | .15 | .15 | .10-.20 | .07 | .3-.9 | 2 | .25 | .25 | .20-.30 | .07 | .3-1.9 |
| Dutchmans Creek | II | Stormflow | 9 | 2.0 | 2.1 | 1.5-2.5 | .34 | 2.1-3.2 | 9 | .99 | 1.0 | .74-1.2 | .16 | .7-1.1 | 9 | 1.4 | 1.4 | 1.0-2.0 | .31 | .3-1.8 |
| | | Low flow | 1 | 2.7 | 2.7 | -- | -- | 2.9-10 | 1 | 1.1 | 1.1 | -- | -- | 1.1-4.1 | 1 | 1.7 | 1.7 | -- | -- | .3-1.8 |
| New Hope River tributary | II | Stormflow | 5 | 2.9 | 3.1 | 2.0-4.0 | .83 | 2.1-3.2 | 5 | 1.5 | 1.6 | 1.1-2.1 | .40 | .7-1.1 | 5 | .38 | .40 | .30-.40 | .04 | .3-1.8 |
| | | Low flow | 2 | 5.3 | 5.3 | 5.1-5.5 | .28 | 2.9-10 | 2 | 3.0 | 3.0 | 2.8-3.1 | .21 | 1.1-4.1 | 2 | .55 | .55 | .40-.70 | .21 | .3-1.8 |
| Suck Creek tributary | III | Stormflow | 3 | .62 | .60 | .59-.64 | .02 | .1-.8 | 3 | .67 | .60 | .63-.70 | .04 | .3-.5 | 3 | .83 | .80 | .80-.90 | .06 | .1-.2 |
| | | Low flow | 7 | .78 | .70 | .56-1.1 | .17 | .5-.6 | 7 | .71 | .66 | .50-1.0 | .16 | .3-.4 | 7 | .80 | .80 | .50-1.1 | .18 | .5 |
| Limestone Creek | IV | Stormflow | 3 | 1.5 | 1.3 | 1.2-1.9 | .38 | 1.1-1.9 | 3 | .70 | .72 | .55-.83 | .14 | .3-.6 | 3 | .67 | .70 | .50-.80 | .15 | .4-.7 |
| | | Low flow | 4 | 1.7 | 1.6 | 1.5-2.2 | .33 | .4-.7 | 4 | .78 | .76 | .59-1.0 | .17 | .3-.8 | 4 | 1.1 | .95 | .60-1.9 | .56 | .1-1.0 |
| Chinkapin Creek tributary | V | Stormflow | 2 | 1.5 | 1.5 | 1.4-1.6 | .14 | .4-3.7 | 2 | 1.0 | 1.0 | .84-1.2 | .25 | .5-.7 | 2 | 1.6 | 1.6 | 1.5-1.6 | .07 | .1-1.1 |
| | | Low flow | 4 | 1.8 | 1.8 | 1.4-2.2 | .34 | .2-4.0 | 4 | 1.3 | 1.2 | 1.0-1.8 | .36 | .3-1.5 | 4 | 1.6 | 1.70 | 1.0-2.1 | .49 | .4-1.9 |
| W.P. Brice Creek | V | Stormflow | 3 | 1.5 | 1.5 | 1.4-1.7 | .15 | .4-3.7 | 3 | .40 | .38 | .34-.47 | .07 | .5-.7 | 3 | .20 | .20 | .20-.20 | 0 | .1-1.1 |
| | | Low flow | 2 | 1.4 | 1.4 | 1.3-1.5 | .14 | .2-4.0 | 2 | .40 | .40 | .40-.40 | 0 | .3-1.5 | 2 | .30 | .30 | .30-.30 | 0 | .4-1.9 |

[1]Range for geochemical zone.

Table 9.--*Statistical summary of concentrations of major dissolved constituents by study basin and flow condition, 1986-88, and ranges from previous study*--Continued

[N, number of analyses; SD, standard deviation; mg/L, milligrams per liter; --, not determined; sum, sum of major ions; *, no data; <, less than]

| Study basin | Geo-chemical zone | Flow condition | N | Mean | Me-dian | Range | SD | Range previous study[1] | N | Mean | Me-dian | Range | SD | Range previous study[1] | N | Mean | Me-dian | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sodium, in mg/L | | | | | | Silica, in mg/L | | | | | | Dissolved solids (sum), in mg/L | | | | | |
| Beetree Creek | I | Stormflow | 9 | 1.1 | 1.1 | 1.0-1.4 | 0.14 | 0.4-1.3 | 9 | 5.9 | 5.9 | 5.3-6.7 | 0.46 | 3.6-8.6 | 9 | 18 | 17 | 15-22 | 2.8 | 12-18 |
| | | Low flow | 4 | 1.2 | 1.2 | 1.1-1.3 | .12 | 1.0-2.2 | 4 | 7.4 | 7.4 | 6.6-7.9 | .58 | 5.9-9.5 | * | * | * | * | * | 16-22 |
| High Shoals Creek | I | Stormflow | -- | -- | -- | -- | -- | .4-1.3 | -- | -- | -- | -- | -- | 3.6-8.6 | * | * | * | * | * | 12-18 |
| | | Low flow | -- | -- | -- | -- | -- | 1.0-2.2 | -- | -- | -- | -- | -- | 5.9-9.5 | * | * | * | * | * | 16-22 |
| North Harper Creek | I | Stormflow | 5 | .94 | 1.0 | .70-1.3 | .25 | .4-1.3 | 5 | 4.3 | 4.5 | 3.5-5.1 | .66 | 3.6-8.6 | 5 | 18 | 18 | 16-19 | 1.2 | 12-18 |
| | | Low flow | 2 | .95 | .95 | .90-1.0 | .07 | 1.0-2.2 | 2 | 5.2 | 5.2 | 4.8-5.5 | .49 | 5.9-9.5 | * | * | * | * | * | 16-22 |
| Dutchmans Creek | II | Stormflow | 9 | 2.9 | 2.9 | 1.6-3.9 | .73 | 1.3-2.5 | 9 | 12 | 13 | 6.1-17 | 3.5 | 3.1-8.8 | 9 | 41 | 43 | 28-51 | 7.3 | 22-28 |
| | | Low flow | 1 | 3.6 | 3.6 | -- | -- | 4.7-7.3 | 1 | 17 | 17 | -- | -- | 12-29 | * | * | * | * | * | 48-78 |
| New Hope River tributary | II | Stormflow | 5 | 2.4 | 2.6 | 1.6-3.5 | .78 | 1.3-2.5 | 5 | 9.6 | 10 | 6.9-13 | 2.6 | 3.1-8.8 | 5 | 36 | 38 | 28-47 | 8.1 | 22-28 |
| | | Low flow | 1 | 5.8 | 5.8 | -- | -- | 4.7-7.3 | 2 | 16 | 16 | 15-16 | .71 | 12-29 | * | * | * | * | * | 48-78 |
| Suck Creek tributary | III | Stormflow | 3 | 1.1 | 1.1 | 1.0-1.1 | .06 | .8-1.0 | 3 | 4.2 | 4.1 | 4.1-4.4 | .17 | 4.5-4.6 | 3 | 17 | 17 | 17-18 | .6 | 12-13 |
| | | Low flow | 6 | 1.6 | 1.6 | 1.4-1.9 | .18 | 1.0-1.5 | 7 | 7.4 | 7.3 | 6.2-9.5 | 1.1 | 4.5-5.1 | * | * | * | * | * | * |
| Limestone Creek | IV | Stormflow | 3 | 2.9 | 3.1 | 2.5-3.2 | .38 | 2.1-2.5 | 3 | 5.7 | 5.6 | 4.1-7.4 | 1.6 | 1.6-8.7 | 3 | 33 | 36 | 28-36 | 4.6 | 22-25 |
| | | Low flow | 4 | 2.9 | 2.9 | 2.4-3.4 | .44 | 2.0-2.5 | 4 | 3.6 | 3.5 | 2.4-4.9 | 1.0 | 1.9-9.0 | * | * | * | * | * | 17-25 |
| Chinkapin Creek tributary | V | Stormflow | 2 | 2.0 | 2.0 | 1.7-2.3 | .42 | 1.8-2.7 | 1 | 7.2 | 7.2 | 7.2 | 0 | 3.5-5.6 | 1 | 30 | 30 | -- | -- | 17-28 |
| | | Low flow | 4 | 2.9 | 2.95 | 2.6-3.1 | .22 | 2.8-4.8 | 4 | 9.3 | 9.5 | 8.3-10 | .73 | 5.2-11 | * | * | * | * | * | 24-38 |
| W.P. Brice Creek | V | Stormflow | 3 | 2.7 | 2.7 | 2.4-2.9 | .25 | 1.8-2.7 | 3 | 4.3 | 4.2 | 4.0-4.7 | .36 | 3.5-5.6 | 2 | 41 | 41 | 39-43 | 2.8 | 17-28 |
| | | Low flow | 2 | 3.0 | 3.0 | 2.8-3.2 | .28 | 2.8-4.8 | 2 | 5.1 | 5.1 | 5.1-5.1 | 0 | 5.2-11 | * | * | * | * | * | 24-38 |

[1]Range for geochemical zone.

Table 9.--*Statistical summary of concentrations of major dissolved constituents by study basin and flow condition, 1986-88, and ranges from previous study*--Continued

[N, number of analyses; SD, standard deviation; mg/L, milligrams per liter; --, not determined; sum, sum of major ions; *, no data; <, less than]

| Study basin | Geo-chemical zone | Flow condition | N | Mean | Me-dian | Range | SD | Range previous study[1] | N | Mean | Me-dian | Range | SD | Range previous study[1] | N | Mean | Me-dian | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Chloride, in mg/L | | | | | | Fluoride, in mg/L | | | | | | Sulfate, in mg/L | | | | | |
| Beetree Creek | I | Stormflow | 9 | 0.96 | 0.60 | 0.50-1.6 | 0.49 | 0.0-1.9 | 9 | -- | 0.10 | <0.10-0.10 | -- | 0.0-0.5 | 9 | 5.3 | 4.8 | 3.9-6.9 | 1.1 | 0.8-5.7 |
| | | Low flow | 31 | .90 | .90 | .70-2.0 | .20 | .1-2.0 | 4 | <.10 | <.10 | <.10-.10 | -- | .05-.15 | 30 | 4.5 | 4.5 | 3.9-7.0 | .60 | 1.0-3.9 |
| High Shoals Creek | I | Stormflow | 4 | 1.0 | 1.0 | 1.0-1.0 | 0 | .0-1.9 | -- | -- | -- | -- | -- | .0-.5 | 5 | -- | <5.0 | <5.0-5.0 | -- | .8-5.7 |
| | | Low flow | 2 | 1.0 | 1.0 | 1.0-1.0 | 0 | .1-2.0 | -- | -- | -- | -- | -- | .05-.15 | 1 | <5.0 | <5.0 | -- | -- | 1.0-3.9 |
| North Harper Creek | I | Stormflow | 6 | 1.2 | 1.1 | <1.0-2.3 | .61 | .0-1.9 | 5 | .10 | .10 | .10-.10 | 0 | .0-.5 | 5 | 8.1 | 7.8 | 6.1-10 | 1.9 | .8-5.7 |
| | | Low flow | 26 | .80 | .80 | .60-1.0 | .20 | .1-2.0 | 2 | .10 | .10 | .10-.10 | 0 | .05-.15 | 28 | 3.8 | 3.5 | 3.5-8.0 | 1.4 | 1.0-3.9 |
| Dutchmans Creek | II | Stormflow | 10 | 2.1 | 2.2 | 1.3-2.8 | .46 | 1.4-2.9 | 10 | -- | .10 | <.10-.10 | -- | 0-.2 | 10 | 14 | 14 | 12-17 | 1.8 | 5.5-8.1 |
| | | Low flow | 32 | 2.9 | 3.0 | 2.0-5.0 | .70 | 3.1-10 | 1 | .10 | .10 | -- | -- | 0-.1 | 30 | 5.8 | 5.0 | <2.0-26 | 3.7 | 1.2-8.2 |
| New Hope River tributary | II | Stormflow | 6 | 2.0 | 2.0 | .90-3.0 | .73 | 1.4-2.9 | 5 | <.10 | <.10 | <.10-<.10 | 0 | 0-.2 | 6 | 12 | 12 | 8.0-13 | 1.9 | 5.5-8.1 |
| | | Low flow | 13 | 6.0 | 6.0 | 3.0-12 | 2.5 | 3.1-10 | 2 | .10 | .10 | .10-.10 | 0 | 0-.1 | 9 | 10 | 11 | 6.0-17 | 3.4 | 1.2-8.2 |
| Suck Creek tributary | III | Stormflow | 3 | 1.1 | 1.1 | 1.0-1.2 | .10 | 1.5-2.5 | 3 | <.10 | <.10 | <.10-<.10 | 0 | .1-.3 | 3 | 7.5 | 7.6 | 7.2-7.8 | .30 | 2.6-3.4 |
| | | Low flow | 38 | 2.9 | 3.0 | 1.0-13 | 1.9 | 1.1-1.8 | 7 | .07 | .06 | .03-.10 | .0 | 0-.1 | 38 | 5.3 | 5.6 | 1.6-11 | 2.4 | 2.0-2.5 |
| Limestone Creek | IV | Stormflow | 3 | 5.9 | 6.5 | 4.4-6.8 | 1.3 | 3.1-5.4 | 3 | -- | .10 | <.10-.10 | -- | .1-.3 | 3 | 16 | 15 | 14-18 | 2.1 | 7.8-8.8 |
| | | Low flow | 4 | 6.8 | 7.6 | 3.8-8.3 | 2.0 | 2.7-4.2 | 4 | .10 | .10 | .10-.20 | .0 | 0-.1 | 4 | 20 | 21 | 17-23 | 2.5 | 5.2-12 |
| Chinkapin Creek tributary | V | Stormflow | 3 | 3.3 | 3.4 | 2.0-4.5 | 1.2 | 1.9-5.3 | 1 | <.10 | <.10 | -- | -- | 0-.5 | 3 | 8.7 | 8.0 | 6.0-12 | 3.1 | 5.7-12 |
| | | Low flow | 8 | 4.5 | 4.8 | 3.5-5.3 | .70 | 3.6-7.6 | 4 | .10 | .10 | .10-.20 | .0 | 0-.2 | 8 | 11 | 10 | <5.0-19 | 6.5 | 5.6-12 |
| W.P. Brice Creek | V | Stormflow | 6 | 6.4 | 6.5 | 4.5-8.6 | 1.6 | 1.9-5.3 | 3 | -- | .10 | <.10-.10 | -- | 0-.5 | 5 | -- | <5.0 | <5.0-25 | -- | 5.7-12 |
| | | Low flow | 26 | 6.4 | 6.2 | 2.0-10 | 1.6 | 3.6-7.6 | 2 | <.10 | <.10 | <.10-.10 | -- | 0-.2 | 28 | 2.4 | .40 | <5.0-29 | 7.4 | 5.6-12 |

[1]Range for geochemical zone.

Table 10.--*Statistical summary of concentrations of selected major constituents in precipitation at National Atmospheric Deposition Program/National Trends Network stations nearest study basins, January 1986-February 1988*[1]

[N, number of samples; SD, standard deviation; mg/L, milligrams per liter]

| Study basin | Geochemical zone | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Calcium, in mg/L | | | | | Chloride, in mg/L | | | | | Magnesium, in mg/L | | | | |
| Beetree Creek | I | 61 | 0.10 | 0.04 | 0.01-1.3 | 0.20 | 61 | 0.20 | 0.09 | 0.03-1.9 | 0.30 | 61 | 0.03 | 0.01 | 0.003-0.20 | 0.05 |
| High Shoals Creek | I | 61 | .10 | .04 | .01-1.3 | .20 | 61 | .20 | .09 | .03-1.9 | .30 | 61 | .03 | .01 | .003-.20 | .05 |
| North Harper Creek | I | 61 | .10 | .04 | .01-1.3 | .20 | 61 | .20 | .09 | .03-1.9 | .30 | 61 | .03 | .01 | .003-.20 | .05 |
| Dutchmans Creek | II | 81 | .14 | .08 | .01-1.6 | .22 | 81 | .41 | .24 | .03-7.9 | .90 | 81 | .04 | .03 | .004-.52 | .06 |
| New Hope River tributary | II | 73 | .13 | .08 | .01-.71 | .14 | 73 | .65 | .35 | .06-4.7 | .91 | 73 | .06 | .03 | .004-.31 | .06 |
| Suck Creek tributary | III | 75 | .11 | .06 | .01-.91 | .14 | 75 | .49 | .26 | .03-4.1 | .66 | 75 | .05 | .03 | .003-.35 | .06 |
| Limestone Creek | IV | 75 | .20 | .08 | .01-3.0 | .40 | 75 | .60 | .40 | .03-4.2 | .80 | 75 | .07 | .04 | .003-1.2 | .10 |
| Chinkapin Creek tributary | V | 91 | .11 | .07 | .01-.75 | .12 | 91 | .64 | .28 | .06-7.9 | 1.0 | 91 | .05 | .03 | .004-.54 | .07 |
| W.P. Brice Creek | V | 75 | .20 | .08 | .01-3.0 | .40 | 75 | .60 | .40 | .03-4.2 | .80 | 75 | .07 | .04 | .003-1.2 | .10 |
| | | Potassium, in mg/L | | | | | Sodium, in mg/L | | | | | Sulfate, in mg/L | | | | |
| Beetree Creek | I | 61 | 0.02 | 0.01 | 0.003-0.20 | 0.04 | 61 | 0.10 | 0.10 | 0.01-1.0 | 0.20 | 61 | 2.1 | 1.5 | 0.30-9.2 | 1.8 |
| High Shoals Creek | I | 61 | .02 | .01 | .003-.20 | .04 | 61 | .10 | .10 | .01-1.0 | .20 | 61 | 2.1 | 1.5 | .30-9.2 | 1.8 |
| North Harper Creek | I | 61 | .02 | .01 | .003-.20 | .04 | 61 | .10 | .10 | .01-1.0 | .20 | 61 | 2.1 | 1.5 | .30-9.2 | 1.8 |
| Dutchmans Creek | II | 81 | .05 | .02 | .003-.53 | .10 | 81 | .24 | .13 | .02-4.1 | .48 | 81 | 3.0 | 2.6 | .28-11 | 2.1 |
| New Hope River tributary | II | 73 | .05 | .03 | .003-.62 | .09 | 73 | .37 | .19 | .03-2.6 | .52 | 73 | 2.7 | 2.1 | .40-10 | 2.1 |
| Suck Creek tributary | III | 75 | .03 | .02 | .003-.21 | .04 | 75 | .31 | .16 | .02-2.3 | .42 | 75 | 2.2 | 1.8 | .16-11 | 1.8 |
| Limestone Creek | IV | 75 | .06 | .03 | .003-.70 | .10 | 75 | .40 | .20 | .02-2.5 | .50 | 75 | 3.0 | 1.7 | .30-36 | 4.6 |
| Chinkapin Creek tributary | V | 91 | .04 | .02 | .003-.38 | .06 | 91 | .37 | .17 | .02-4.5 | .58 | 91 | 2.2 | 1.6 | .26-11 | 1.7 |
| W.P. Brice Creek | V | 75 | .06 | .03 | .003-.70 | .10 | 75 | .40 | .20 | .02-2.5 | .50 | 75 | 3.0 | 1.7 | .30-36 | 4.6 |

[1]Gwendolyn Scott, National Atmospheric Deposition Program/National Trends Network, written commun., 1988.

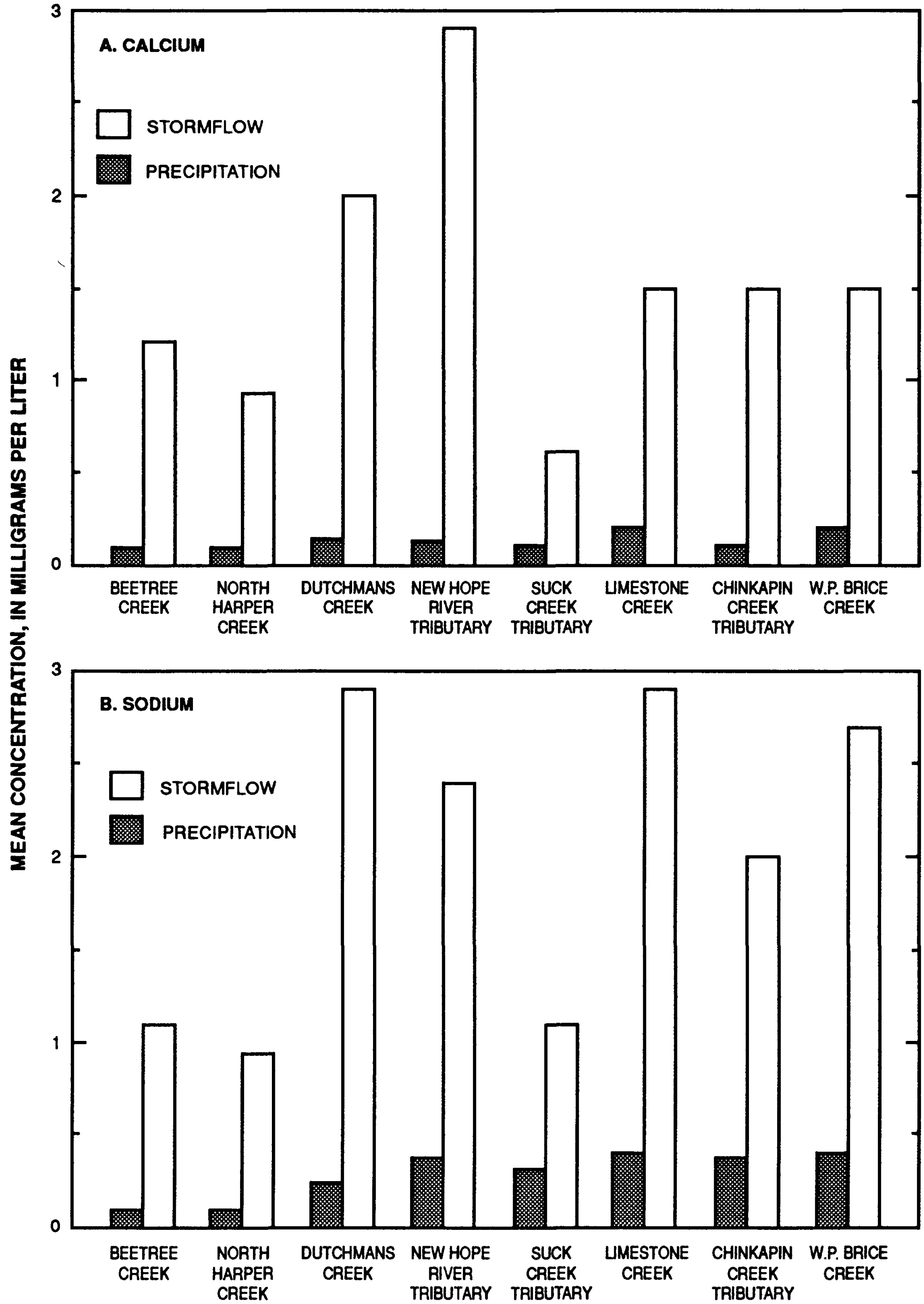


Figure 8.--Mean concentration of (A) calcium and (B) sodium in stormflow and precipitation at the study sites, 1986-88.

concentrations of sodium in these streams because these rocks are also relatively sodium rich (fig. 8B). However, Limestone and W.P. Brice Creeks and Chinkapin Creek tributary also contain elevated mean sodium concentrations in their streamflows. Abundant clay in these Coastal Plain basins could account for these elevated values because sodium is attracted to clay with strong cation-exchange capacity (Hem, 1985). Precipitation contains slightly elevated mean concentrations of sodium in the eastern half of the State, but this does not appear sufficient to account for the higher mean concentrations of sodium observed in the stormflows (fig. 8B).

Mean chloride concentrations in precipitation ranged from 10 to 44 percent of the mean concentrations of this constituent observed in stormflows during the study period. Chloride concentrations in precipitation tend to be greater in the eastern part of the State because of the prevalence of storms bearing seawater aerosols (Junge and Werby, 1958). Gambell and Fisher (1966) reported mean chloride concentrations in precipitation from 16 mg/L along the North Carolina coast to 0.5 mg/L about 100 miles inland. Observed mean chloride concentrations in precipitation in the eastern part of the State during this study ranged from 0.60 to 0.64 mg/L (table 10). The mean chloride concentrations during stormflow were highest in Limestone Creek, Chinkapin Creek tributary, and W.P. Brice Creek (table 9), the three easternmost streams in this study.

Mean concentrations of chloride are generally greater during low flows, except in the basins of geochemical zone I where stormflows have slightly greater mean concentrations of this ion. These observations are in agreement with the findings of Simmons and Heath (1982) for streams in geochemical zone I. Because mean concentrations of chloride are lowest in streamflows in the basins of geochemical zone I, the slightly higher chloride values during stormflow might be attributed to a greater influence of chloride from precipitation plus contributions from the forest canopy and leaf litter.

Mean concentrations of sulfate in precipitation commonly ranged between 20 and 30 percent of mean concentrations of sulfate in stormflow at the study sites across the State, an indication that precipitation contributes a significant proportion of this ion to streamflow. During this study, sulfate concentrations tended to increase during stormflow. The relation between sulfate concentration and unit-area discharge for Dutchmans Creek (site 4) and New Hope River tributary (site 5), for example, shows that sulfate concentrations during stormflow are approximately 3 times greater than during low flow (fig. 9).

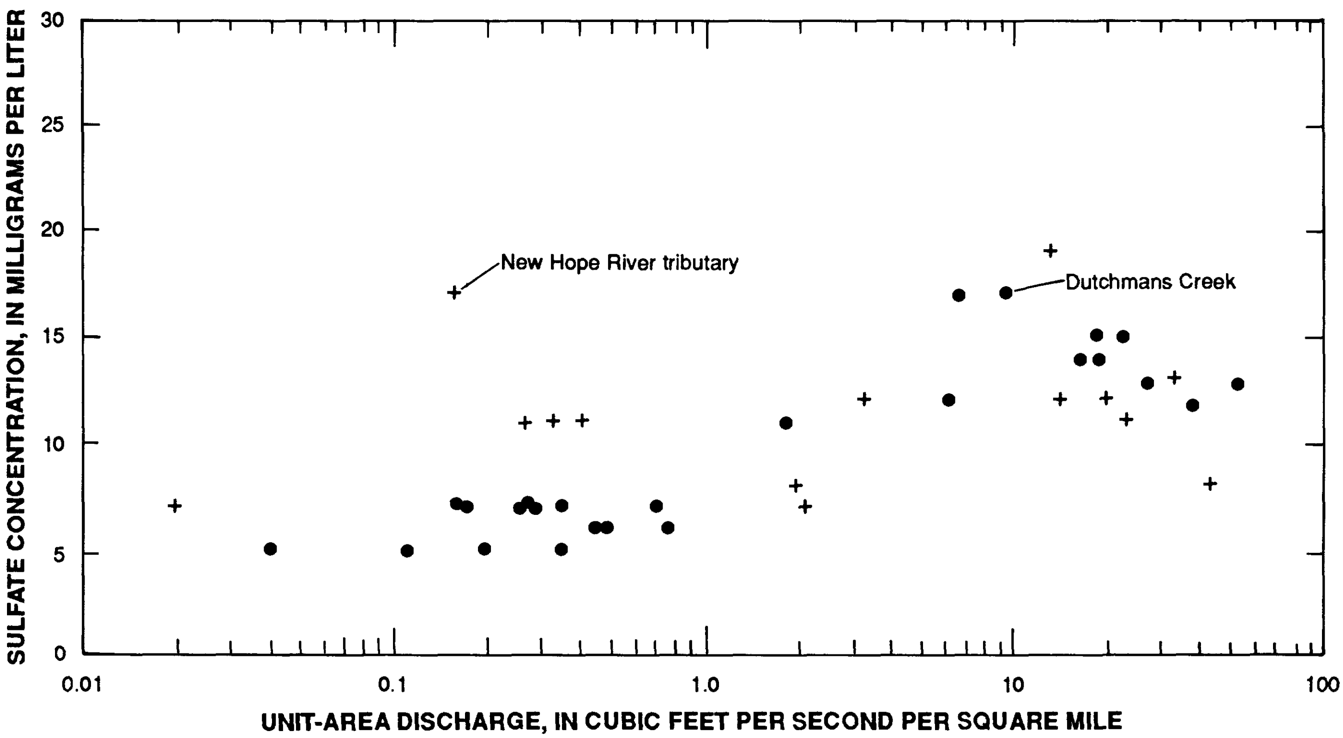


Figure 9.--Relation of unit-area water discharge to sulfate concentration in Dutchmans Creek and New Hope River tributary, 1986-88.

Low flow in Dutchmans Creek and New Hope River tributary also contained some of the higher mean concentrations of sulfate among the study sites. The rocks of these basins are mostly metamorphosed volcanic units (geochemical zone II). Basic metavolcanic rocks may contain significant amounts of sulfur-bearing minerals such as pyrite that could contribute to elevated concentrations of sulfate in streamflow.

In general, the sulfate concentrations observed in this study were higher than those reported in Simmons and Heath (1982). This may be due to a systematic laboratory correction error during the period October 1982 through July 1989 (D.A. Rickert, U.S. Geological Survey, written commun., 1989).

Individual dissolved-constituent concentrations often vary with discharge, as discussed earlier. These variations are usually most pronounced during a rapid change in stage, as during a storm. Changes in stream discharge and concentrations of selected constituents and specific conductance were observed at Dutchmans Creek during a rise in stage on April 19, 1988 (fig. 10). Concentrations were at their highest levels prior to the flood peak and then declined rapidly to their lowest levels about an hour after discharge reached its maximum; shortly thereafter, concentrations

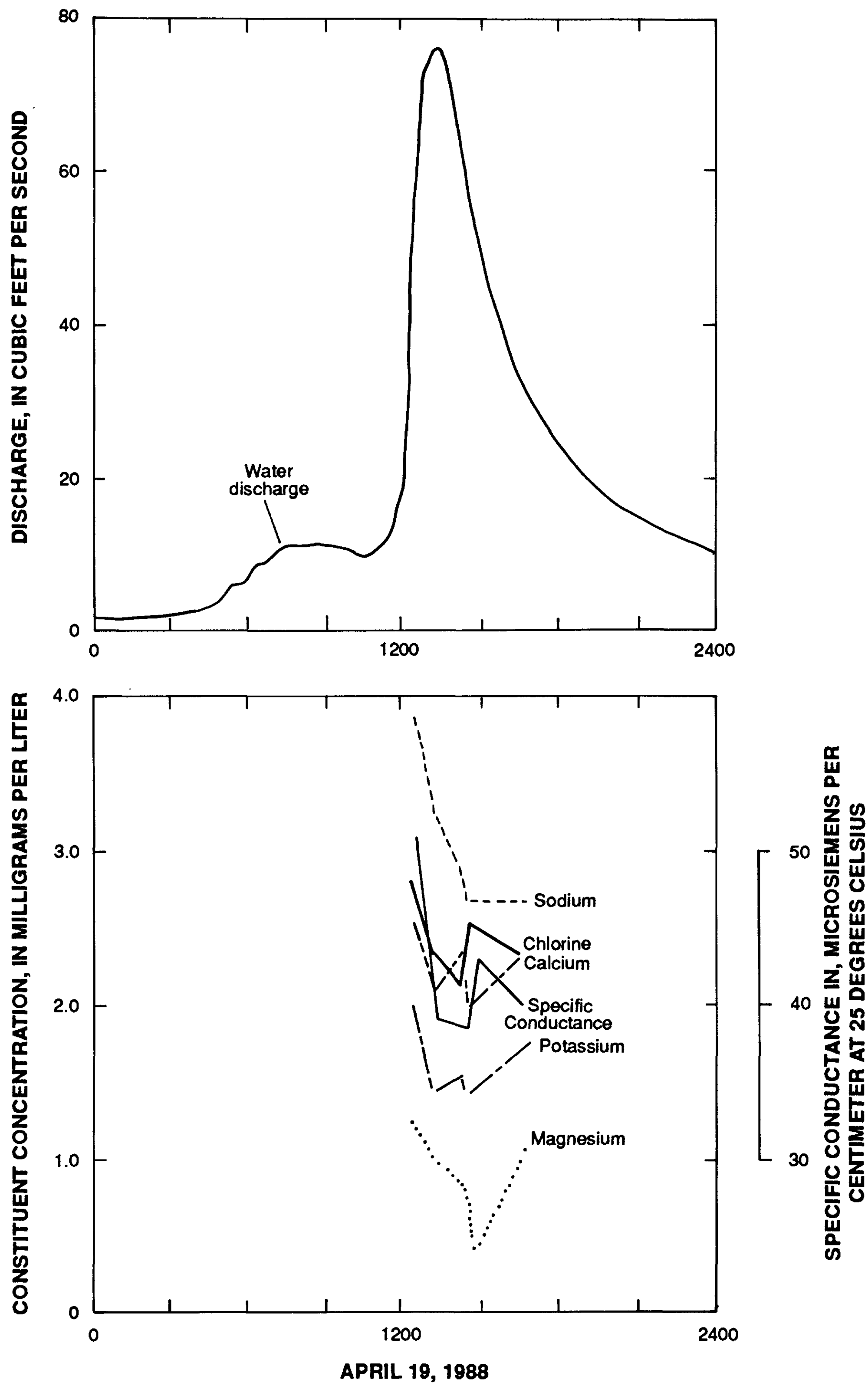


Figure 10.--Concentrations of selected major dissolved constituents and specific conductance during peak flow in Dutchmans Creek, April 19, 1988.

of dissolved constituents began to increase again. The greatest decrease in a constituent concentration during this event was observed for sodium, which declined by 31 percent in a 2-hour period.

Mean concentrations of selected major dissolved constituents grouped by geochemical zone and by flow condition show generally good agreement with ranges of values reported by Simmons and Heath (1982). About 73 percent of the mean values are within the ranges reported by Simmons and Heath (1982), or fall just outside a given range by no more than 20 percent (table 11). Mean values for many major dissolved constituents in Suck Creek tributary and Limestone Creek were greater than the ranges for geochemical zones III and IV, respectively, by more than 20 percent. This may be a function of comparing data from a single representative basin in a geochemical zone to data grouped from several basins in a geochemical zone.

Table 11.--*Mean concentrations of major dissolved constituents, 1986-88, by geochemical zone and flow condition as compared with data by Simmons and Heath (1982)*

[Sum, sum of major ions. Comparison with data by Simmons and Heath (1982): *, in same range; ND, not determined: +, greater than; -, less than]

| Geochemical zone | Flow condition | Calcium | Magnesium | Potassium | Sodium | Silica | Dissolved solids (sum) | Chloride | Sulfate |
|---|---|---|---|---|---|---|---|---|---|
| I | Stormflow | * | * | * | * | * | * | * | * |
| | Low flow | * | * | * | * | * | ND | * | + |
| II | Stormflow | * | + | * | + | + | + | * | + |
| | Low flow | * | * | * | * | * | ND | * | * |
| III | Stormflow | * | + | + | + | * | + | * | + |
| | Low flow | + | + | ND | + | + | ND | + | + |
| IV | Stormflow | * | + | * | + | * | + | + | + |
| | Low flow | + | * | + | + | * | ND | + | + |
| V | Stormflow | * | * | * | * | * | + | - | * |
| | Low flow | * | * | * | * | * | ND | * | - |

## Nutrients

Water and bottom-material samples were collected in order to quantify concentrations of selected nutrients consisting of various combinations of nitrogen compounds and total phosphorus, which are essential for the growth of aquatic plant life. The sources of these constituents in forested basins are diverse. Nitrogen occurs in rocks in very small amounts. Bacteria in the soil and algae and other biota in water convert nitrogen into nitrate, which is a form available for plant growth (Hem, 1985, p. 124). Considerable amounts of nitrogen are also supplied in precipitation.

Phosphorus is more abundant than nitrogen in rocks, although rocks are not usually a major source of this nutrient because of its low solubility. Precipitation is the primary source of phosphorus in forested basins.

Recent studies of forested basins, such as that by Swank and Waide (1988), conclude that annual inputs of nitrate and phosphate to catchments are considerably greater than outputs. In forested catchments, the highly organic surface soils and leaf litter serve as vast nutrient pools and often contain reserves of nitrogen and phosphorus equivalent to several years' uptake by living vegetation in the basins (Monk and Day, 1988).

Summaries of nutrient data collected for this study and ranges for corresponding data by geochemical zone in Simmons and Heath (1982) are presented in table 12. The nutrient constituents reported in this study include nitrite plus nitrate nitrogen, ammonia nitrogen, ammonia plus organic nitrogen, organic nitrogen, total nitrogen, and total phosphorus.

Concentrations of nitrite plus nitrate nitrogen are well below recommended limits for nitrate in drinking water established by the EPA (1976). The maximum observed concentration was 0.44 mg/L during low flow in New Hope River tributary (site 5). However, mean concentrations of ammonia nitrogen at all study sites equalled or exceeded the suggested limit of 0.02 mg/L for waters to be suitable for fish reproduction (U.S. Environmental Protection Agency, 1976), except at Beetree Creek (site 1) during low-flow conditions (table 12). Mean concentrations of nitrogen as ammonia in precipitation (table 13) exceeded mean concentrations of ammonia nitrogen in stream water at all study sites in all flow conditions.

Several studies have noted that total nitrogen concentrations in surface water greater than 0.3 mg/L indicate the potential for nuisance growth of algae (Sawyer, 1947; Sakamoto, 1966; Vollenweider, 1971). During low-flow conditions, mean concentrations of total nitrogen exceeded this value at High Shoals Creek; and at the three easternmost study sites, Limestone and W.P. Brice Creeks and Chinkapin Creek tributary, the highest mean concentration was 0.79 mg/L at Limestone Creek.

Water samples collected during stormflows commonly contain mean concentrations of total nitrogen about twice those in samples collected during low flows. There is no geographic pattern for concentrations of total nitrogen in water in streams during periods of stormflow, but during low flow, water in streams in the eastern part of the State contains slightly greater mean concentrations of total nitrogen than water in streams in other areas.

Table 12.--*Statistical summary of concentrations of nutrients by study basin and flow condition, 1986-88, and ranges from previous study*

[N, number of analyses; SD, standard deviation; mg/L, milligrams per liter; <, less than; --, not determined]

| Study basin | Geo-chemical zone | Flow condition | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Nitrite plus nitrate nitrogen, in mg/L | | | | | | Ammonia nitrogen, in mg/L | | | | | | Ammonia plus organic nitrogen, in mg/L | | | | | |
| Beetree Creek | I | Stormflow | 10 | 0.24 | 0.20 | 0.20-0.40 | 0.07 | 0.01-0.62 | 10 | 0.01 | 0.01 | <0.01-0.02 | 0.01 | 0.00-0.01 | 10 | 0.89 | 0.80 | <0.20-2.6 | 0.78 | -- |
| | | Low flow | 31 | .19 | .17 | <.01-.37 | .07 | .00-.17 | 31 | .02 | .02 | <.01-.14 | .02 | .00-.01 | 31 | .09 | .07 | <.10-.30 | .08 | -- |
| High Shoals Creek | I | Stormflow | 5 | .04 | .01 | <.01-.07 | .07 | .01-.62 | 5 | .03 | .03 | .01-.05 | .01 | .00-.01 | 5 | .12 | .10 | <.10-.20 | .04 | -- |
| | | Low flow | 2 | <.02 | <.02 | <.01-.03 | -- | .00-.17 | 2 | .07 | .07 | .04-.10 | .03 | .00-.01 | 2 | .30 | .30 | .10-.50 | .20 | -- |
| North Harper Creek | I | Stormflow | 8 | -- | <.10 | <.10-1.9 | -- | .01-.62 | 8 | .02 | .02 | <.01-.04 | .02 | .00-.01 | 8 | .83 | .55 | <.20-1.9 | 1.2 | -- |
| | | Low flow | 31 | .05 | .04 | <.01-.20 | .05 | .00-.17 | 31 | .02 | .02 | <.01-.06 | .01 | .00-.01 | 31 | .13 | .10 | <.10-.50 | .08 | -- |
| Dutchmans Creek | II | Stormflow | 10 | <.10 | <.10 | <.10-<.10 | 0 | .00-.26 | 10 | .05 | .05 | .01-.10 | .03 | .01-.02 | 10 | .75 | .75 | .30-1.4 | .40 | -- |
| | | Low flow | 32 | .04 | .02 | <.01-.17 | .07 | .00-1.0 | 31 | .02 | .01 | <.01-.05 | .01 | .00-.07 | 32 | .24 | .20 | <.01-1.2 | .21 | -- |
| New Hope River tributary | II | Stormflow | 10 | -- | <.10 | <.01-<.10 | -- | .00-.26 | 10 | .03 | .03 | <.01-.08 | .03 | .01-.02 | 10 | .70 | .65 | .20-1.3 | .30 | -- |
| | | Low flow | 19 | .03 | .01 | <.01-.44 | .06 | .00-1.0 | 19 | .02 | .01 | <.01-.04 | .01 | .00-.07 | 19 | .18 | .20 | <.10-.32 | .09 | -- |
| Suck Creek tributary | III | Stormflow | 5 | .12 | .10 | <.10-.20 | .04 | .04-.05 | 5 | -- | <.01 | <.01-.03 | -- | .00-.01 | 5 | .64 | .26 | .30-1.0 | .26 | -- |
| | | Low flow | 37 | .03 | .02 | <.01-.25 | .04 | .04-.19 | 37 | .02 | .01 | <.01-.18 | .01 | .00-.01 | 37 | .21 | .10 | <.01-1.2 | .20 | -- |
| Limestone Creek | IV | Stormflow | 7 | .26 | .22 | .06-.42 | .13 | .01-.07 | 7 | .05 | .04 | <.01-.09 | .04 | .01-.02 | 7 | .81 | .80 | .30-1.5 | .42 | -- |
| | | Low flow | 5 | .11 | .09 | .06-.30 | .08 | -- | 5 | .04 | .04 | .02-.07 | .02 | -- | 5 | .66 | .61 | .40-1.0 | .22 | -- |
| Chinkapin Creek tributary | V | Stormflow | 8 | -- | <.10 | .01-<.10 | -- | .00-.15 | 8 | .03 | .03 | <.01-.08 | .03 | .01-.04 | 8 | .70 | .75 | .20-1.2 | .32 | -- |
| | | Low flow | 10 | .05 | .01 | <.01-.20 | .12 | .00-.05 | 10 | .05 | .04 | .01-.14 | .04 | .00-.06 | 10 | .58 | .55 | .20-1.5 | .38 | -- |
| W.P. Brice Creek | V | Stormflow | 11 | .02 | .02 | <.01-<.10 | .01 | .00-.15 | 11 | .03 | .03 | <.01-.07 | .02 | .01-.04 | 11 | .64 | .50 | .30-1.1 | .24 | -- |
| | | Low flow | 29 | .02 | .01 | <.01-.10 | .01 | .00-.05 | 29 | .04 | .02 | .01-.27 | .05 | .00-.06 | 29 | .50 | .50 | .20-1.4 | .23 | -- |

[1]Range for geochemical zone.

Table 12.--*Statistical summary of concentrations of nutrients by study basin and flow condition, 1986-88, and ranges from previous study*--Continued

[N, number of analyses; SD, standard deviation; mg/L, milligrams per liter; <, less than; --, not determined]

| Study basin | Geo-chemical zone | Flow condition | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic nitrogen, in mg/L | | | | | | Total nitrogen, in mg/L | | | | | | Total phosphorus, in mg/L | | | | | |
| Beetree Creek | I | Stormflow | 10 | 0.88 | 0.79 | <0.19-2.6 | 0.78 | 0.02-0.29 | 10 | 1.1 | 1.1 | <0.40-2.8 | 0.91 | 0.14-0.92 | 10 | 0.01 | 0.01 | <0.01-0.04 | 0.01 | 0.00-0.03 |
| | | Low flow | 31 | .08 | .06 | <.06-.28 | .06 | .00-.27 | 31 | .24 | .20 | <.11-.58 | .19 | .00-.36 | 31 | .01 | .01 | <.01-<.10 | .01 | .00-.02 |
| High Shoals Creek | I | Stormflow | 5 | .08 | .07 | .05-.17 | .04 | .02-.29 | 5 | .14 | .11 | <.11-.27 | .06 | .14-.92 | 5 | .01 | .01 | <.01-.02 | .00 | .00-.03 |
| | | Low flow | 2 | .23 | .23 | 0-.46 | .23 | .00-.27 | 2 | .32 | .32 | .11-.53 | .21 | .00-.36 | 1 | .02 | .02 | -- | -- | .00-.02 |
| North Harper Creek | I | Stormflow | 8 | .83 | .52 | <.19-1.9 | 1.2 | .02-.29 | 8 | 1.2 | .75 | <.30-2.5 | 1.6 | .14-.92 | 8 | .04 | .02 | .01-.24 | .08 | .00-.03 |
| | | Low flow | 31 | .11 | .08 | .04-.46 | .09 | .00-.27 | 31 | .16 | .15 | .11-<.60 | .07 | .00-.36 | 31 | .01 | .01 | <.01-.08 | .01 | .00-.02 |
| Dutchmans Creek | II | Stormflow | 10 | .69 | .68 | .27-1.3 | .37 | .37-.69 | 10 | .85 | .85 | .40-1.5 | .40 | .34-.73 | 10 | .03 | .02 | .01-.09 | .02 | .03-.04 |
| | | Low flow | 31 | .20 | .18 | 0-1.2 | .21 | .07-.51 | 32 | .28 | .22 | <.02-1.3 | .21 | .07-1.5 | 31 | .02 | .02 | <.01-.05 | .01 | .01-.05 |
| New Hope River tributary | II | Stormflow | 10 | .64 | .57 | .19-1.3 | .30 | .37-.69 | 10 | .77 | .75 | .21-1.4 | .29 | .34-.73 | 10 | .04 | .04 | <.01-.11 | .04 | .03-.04 |
| | | Low flow | 19 | .14 | .11 | .08-.29 | .09 | .07-.51 | 19 | .22 | .18 | <.11-.76 | .14 | .07-1.5 | 19 | .02 | .02 | .01-.07 | .02 | .01-.05 |
| Suck Creek tributary | III | Stormflow | 5 | -- | <.69 | .27-<.99 | -- | .31-.38 | 5 | .76 | .80 | .40-1.1 | .24 | .37-.43 | 5 | .01 | .01 | <.01-.04 | .01 | .00-.01 |
| | | Low flow | 37 | .21 | .08 | 0-<1.2 | .47 | .20-.24 | 37 | .24 | .19 | <.05-1.3 | .19 | .28-.40 | 37 | .01 | .01 | <.01-.10 | .01 | .00-.01 |
| Limestone Creek | IV | Stormflow | 7 | .76 | .71 | <.29-1.4 | .49 | .23-.66 | 7 | 1.1 | 1.0 | .71-1.8 | .37 | .30-.69 | 7 | .03 | .02 | .01-.08 | .02 | .01-.03 |
| | | Low flow | 5 | .62 | .59 | .37-.95 | .21 | .15-.51 | 5 | .79 | .70 | .67-1.1 | .16 | .21-.51 | 5 | .03 | .02 | .02-.07 | .02 | .01-.03 |
| Chinkapin Creek tributary | V | Stormflow | 8 | .66 | .71 | .19-1.1 | .29 | .34-.99 | 8 | .78 | .85 | .21-1.3 | .33 | .49-1.2 | 8 | .02 | .02 | .01-.03 | .01 | .02-.04 |
| | | Low flow | 10 | .53 | .51 | .11-1.4 | .36 | .15-.72 | 10 | .66 | .50 | .21-1.6 | .40 | .15-.72 | 10 | .03 | .02 | .01-.09 | .02 | .01-.02 |
| W.P. Brice Creek | V | Stormflow | 11 | .61 | .49 | <.29-1.1 | .25 | .34-.99 | 11 | .70 | .50 | .31-1.2 | .24 | .49-1.2 | 11 | .02 | .02 | <.01-.03 | .01 | .02-.04 |
| | | Low flow | 29 | .45 | .45 | .13-1.3 | .22 | .15-.72 | 29 | .52 | .51 | .21-1.4 | .23 | .15-.72 | 29 | .02 | .02 | <.01-.04 | .01 | .01-.02 |

[1]Range for geochemical zone.

Table 13.--*Statistical summary of concentrations of selected nutrients and pH values in precipitation near study basins, January 1986-February 1988*[1]

[N, number of analyses; SD, standard deviation; mg/L, milligrams per liter]

| Study basin | Geochemical zone | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Nitrogen as ammonia, in mg/L | | | | | Nitrogen as nitrate, in mg/L | | | | |
| Beetree Creek | I | 61 | 0.22 | 0.12 | 0.02-1.3 | 0.28 | 61 | 0.95 | 0.64 | 0.03-6.0 | 0.98 |
| High Shoals Creek | I | 61 | .22 | .12 | .02-1.3 | .28 | 61 | .95 | .64 | .03-6.0 | .98 |
| North Harper Creek | I | 61 | .22 | .12 | .02-1.3 | .28 | 61 | .95 | .64 | .03-6.0 | .98 |
| Dutchmans Creek | II | 81 | .43 | .24 | .02-3.7 | .57 | 81 | 2.0 | 1.5 | .17-7.2 | 1.6 |
| New Hope River tributary | II | 73 | .44 | .26 | .02-3.2 | .48 | 73 | 1.8 | 1.3 | .31-9.0 | 1.7 |
| Suck Creek tributary | III | 75 | .19 | .10 | .02-2.2 | .30 | 75 | 1.5 | 1.1 | .14-8.5 | 1.1 |
| Limestone Creek | IV | 75 | .47 | .18 | .02-12 | 1.4 | 75 | 1.6 | .93 | .11-19 | 2.3 |
| Chinkapin Creek tributary | V | 91 | .23 | .15 | .02-1.3 | .25 | 91 | 1.3 | 1.0 | .03-5.4 | .98 |
| W.P. Brice Creek | V | 75 | .47 | .18 | .02-12 | 1.4 | 75 | 1.6 | .93 | .11-19 | 2.3 |
| | | Phosphorus as orthophosphate, in mg/L | | | | | pH, in pH units | | | | |
| Beetree Creek | I | 61 | 0.04 | 0.01 | 0.01-0.83 | 0.14 | 54 | 4.5 | 4.5 | 3.8-5.1 | 0.28 |
| High Shoals Creek | I | 61 | .04 | .01 | .01-.83 | .14 | 54 | 4.5 | 4.5 | 3.8-5.1 | .28 |
| North Harper Creek | I | 61 | .04 | .01 | .01-.83 | .14 | 54 | 4.5 | 4.5 | 3.8-5.1 | .28 |
| Dutchmans Creek | II | 81 | .02 | .01 | .01-.36 | .05 | 72 | 4.3 | 4.3 | 3.7-6.7 | .40 |
| New Hope River tributary | II | 73 | .06 | .01 | .01-1.8 | .24 | 69 | 4.5 | 4.4 | 3.7-5.7 | .39 |
| Suck Creek tributary | III | 75 | .02 | .01 | .01-.12 | .01 | 71 | 4.4 | 4.4 | 3.7-5.1 | .29 |
| Limestone Creek | IV | 75 | .04 | .01 | .01-.79 | .12 | 60 | 4.5 | 4.4 | 3.7-5.4 | .34 |
| Chinkapin Creek tributary | V | 91 | .02 | .01 | .01-.40 | .04 | 42 | 4.2 | 4.3 | 3.2-5.4 | .42 |
| W.P. Brice Creek | V | 75 | .04 | .01 | .01-.79 | .12 | 60 | 4.5 | 4.4 | 3.7-5.4 | .34 |

[1] Gwendolyn Scott, National Atmospheric Deposition Program/National Trends Network, written commun., 1988.

Organic nitrogen constitutes the greatest percentage of total nitrogen in stream water at all study sites. On average, more than 70 percent of the total nitrogen observed at each site was organic nitrogen. The primary source of organic nitrogen was decaying leaf litter from the nutrient pool and aquatic vegetation, although there was significant nitrogen input from precipitation in the forms of ammonia and nitrate (table 13). A comparison of the ratios of values of organic nitrogen to total nitrogen by month indicates little or no seasonal trend, which indicates that leaf litter is a constant source of this nutrient.

Phosphorus is an essential nutrient for aquatic life and is reported in this study as total phosphorus in stream water and as orthophosphate in precipitation. A concentration of total phosphorus should not exceed 0.1 mg/L as suggested by the EPA (1976) to prevent nuisance growth of algal blooms in streams. During low-flow conditions, mean concentrations of total phosphorus in stream water at all sites met this criterion. The highest mean total phosphorus concentration was 0.03 mg/L at Limestone Creek and Chinkapin Creek tributary during low-flow conditions.

Total phosphorus concentrations in stream water are generally slightly greater during stormflow than during low flow. When phosphorus is dissolved, most of it is absorbed into iron and aluminum hydroxides and oxides (Crawford, 1985) and, thus, may be transported in greater amounts with sediments during high flows. The greatest mean concentration for total phosphorus was 0.04 mg/L in North Harper Creek and New Hope River tributary during stormflow conditions, but is below the limit suggested for streams entering impoundments (National Technical Advisory Committee, 1968). There are no geologic or geographic factors that bear upon the presence of total phosphorus concentrations in stream water at any of the study sites.

The nutrient pool from leaf litter and organic soils seems to be the likely source of phosphorus in streams of the study basins; however, precipitation also contributes a significant input of phosphorus to the basins (table 13). The dominant source under given streamflow conditions and the role of seasonal influence are contributing factors to the occurrence of phosphorus in streams and are not well understood.

The ratio of nitrogen to phosphorus can be used as an indicator of the potential for excess algae growth. The National Technical Advisory Committee to the Secretary of the Interior (1968) indicates that a ratio of concentrations of total nitrogen to total phosphorus near 10:1 appears to be a good guideline for indicating normal conditions in natural waters. A low ratio of nitrogen to phosphorus (less than 10:1) suggests there is enough phosphorus available for plants, such as algae, to metabolize all of the available nitrogen for growth. Conversely, a high ratio (greater than 10:1) indicates there is not a sufficient supply of phosphorus to metabolize all of the available nitrogen. Therefore, phosphorus is the limiting nutrient factor controlling excessive algal growth in streams.

The ratio of mean concentrations of total nitrogen to total phosphorus from nutrient data collected in this study ranges from 11:1 to 110:1. This indicates that phosphorus is the limiting nutrient factor in all of the study streams. New Hope River tributary had the lowest ratios of 11:1 during low flow and 19:1 during stormflow, so there may be times during which phosphorus may not be the limiting nutrient factor at this study site. Precipitation near this study basin also contained the highest mean concentration of phosphorus (as orthophosphate) (table 13), which may indicate that rainfall has a greater influence on the phosphorus content of streamflow here than in the other study basins.

Mean concentrations of nutrients in stream water at the study sites lie mostly within the ranges of values reported by Simmons and Heath (1982) for corresponding geochemical zones and flow conditions (table 14). Mean concentrations for some constituents determined in this study are slightly higher than the ranges of values for the earlier study and consistently higher in geochemical zone IV and for ammonia nitrogen. Flow condition does not appear to be a contributory factor.

Table 14.--*Mean concentrations of nutrients, 1986-88, by geochemical zone and flow condition as compared with data by Simmons and Heath (1982)*

[Comparison with data by Simmons and Heath (1982): *, in same range; +, greater than; ND, not determined; -, less than]

| Geochemical zone | Flow condition | Nitrite plus nitrate ammonia | Ammonia nitrogen | Organic nitrogen | Total nitrogen | Total phosphorus |
|---|---|---|---|---|---|---|
| I | Stormflow | * | + | + | * | * |
| | Low flow | * | + | * | * | * |
| II | Stormflow | ND | + | * | + | * |
| | Low flow | * | * | * | * | * |
| III | Stormflow | + | ND | ND | + | * |
| | Low flow | - | + | * | - | * |
| IV | Stormflow | + | + | + | + | * |
| | Low flow | ND | ND | + | + | * |
| V | Stormflow | * | * | * | * | * |
| | Low flow | * | * | * | * | * |

Analysis of water samples from streams provides data on water quality at a specific time, whereas analysis of streambed samples reflects those constituents that are adsorbed by, or otherwise associated with, streambed sediments deposited over a period of time. In the case of nutrients, the relation between concentrations in stream water and concentrations associated with bottom sediments is not well understood.

A summary of selected nutrient concentrations in bottom material indicates that nearly all of the total nitrogen in these samples is organic nitrogen (table 15) compared with 70 percent organic nitrogen in stream water. Although a limited number of streambed samples were taken, Limestone Creek, New Hope River tributary, and Beetree Creek had significantly greater mean total nitrogen concentrations (that is, organic nitrogen content) than the other sites. The reason for this is not clear, although there may be some relation between these values and higher mean values of total nitrogen in stormflows at these sites (table 12).

As with mean total nitrogen concentrations, Beetree Creek and New Hope River tributary also had the highest mean concentrations of orthophosphate in streambed materials; however, Limestone Creek had the lowest mean concentration. There were large differences in mean concentrations of orthophosphate at the study sites, but the small number of samples taken did not permit analysis of this relation.

## Minor Constituents

Samples of water and streambed material were collected at each study site in order to quantify concentrations of selected minor constituents, including aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, and zinc. Minor constituents are those present in water with concentrations typically less than 1,000 μg/L (micrograms per liter); however, iron, aluminum, and manganese can often attain concentrations greater than this (table 16).

Iron most often appears in the greatest concentrations in water and, next to aluminum, is the second most common metal in the Earth's crust. Mean total iron concentrations during stormflow and low-flow conditions at most study sites exceeded the recommended secondary maximum contaminant level of 300 μg/L for drinking water set by the EPA (1991a) (table 4). Beetree and North Harper Creeks had mean total iron concentrations below this limit during low-flow conditions (table 16). For the three streams in geochemical zone I, 22 percent of the water samples contained total iron

Table 15.--*Statistical summary of concentrations of selected nutrients in streambed material in study basins, 1986-88*

[N, number of samples; SD, standard deviation; mg/kg, milligrams per kilogram; --, not determined]

| Study basin | Geo-chemical zone | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ammonia nitrogen, in mg/kg | | | | | Ammonia plus organic nitrogen, in mg/kg | | | | | Nitrite plus nitrate nitrogen, in mg/kg | | | | |
| Beetree Creek | I | 6 | 0.65 | 0.70 | 0.40-0.90 | 0.21 | 6 | 313 | 200 | 9.1-940 | 327 | 6 | 2.1 | 1.8 | 1.1-3.8 | 1.1 |
| High Shoals Creek | I | 5 | .82 | 1.1 | .40-1.1 | .38 | 5 | 150 | 170 | 9.2-250 | 92 | 5 | 1.3 | 1.5 | .40-1.9 | .61 |
| North Harper Creek | I | 5 | .66 | .40 | .30-1.6 | .55 | 5 | 114 | 130 | 9.5-180 | 64 | 5 | 1.8 | 1.7 | 1.1-2.8 | .70 |
| Dutchmans Creek | II | 2 | .55 | .55 | .40-.70 | .21 | 2 | 85 | 85 | 9.2-160 | 107 | 2 | .70 | .70 | .70-.70 | 0 |
| New Hope River tributary | II | 1 | .70 | .70 | -- | -- | 1 | 380 | 380 | -- | -- | 1 | .40 | .40 | -- | -- |
| Suck Creek tributary | III | 2 | .40 | .40 | .40-.40 | -- | 2 | 70 | 70 | 9.0-130 | 86 | 2 | .95 | .95 | .70-1.2 | .35 |
| Limestone Creek | IV | 3 | 2.1 | .80 | .30-5.3 | 2.8 | 3 | 439 | 500 | 8.0-810 | 404 | 3 | .33 | .30 | .30-.40 | .06 |
| Chinkapin Creek tributary | V | 1 | 2.5 | 2.5 | -- | -- | 1 | 8.8 | 8.8 | -- | -- | 1 | .40 | .40 | -- | -- |
| W.P. Brice Creek | V | 1 | .40 | .40 | -- | -- | 1 | 70 | 70 | -- | -- | 1 | .40 | .40 | -- | -- |
| | | Total nitrogen, in mg/kg | | | | | Organic nitrogen, in mg/kg | | | | | Orthophosphate, in mg/kg | | | | |
| Beetree Creek | I | 6 | 315 | 203 | 11-943 | 299 | 6 | 312 | 199 | 8.4-939 | 298 | 6 | 157 | 160 | 110-210 | 33 |
| High Shoals Creek | I | 5 | 151 | 172 | 11-250 | 82 | 5 | 149 | 169 | 8.1-250 | 82 | 5 | 31 | 31 | 22-46 | 9.3 |
| North Harper Creek | I | 5 | 116 | 132 | 11-181 | 57 | 5 | 113 | 130 | 7.9-180 | 57 | 5 | 65 | 48 | 42-110 | 30 |
| Dutchmans Creek | II | 2 | 85 | 85 | 9.9-161 | 75 | 2 | 84 | 84 | 8.8-159 | 75 | 2 | 35 | 35 | 26-44 | 13 |
| New Hope River tributary | II | 1 | 380 | 380 | -- | -- | 1 | 379 | 379 | -- | -- | 1 | 110 | 110 | -- | -- |
| Suck Creek tributary | III | 2 | 70 | 70 | 9.7-131 | 61 | 2 | 69 | 69 | 8.6-130 | 60 | 2 | 19 | 19 | 15-23 | 5.7 |
| Limestone Creek | IV | 3 | 440 | 500 | 8.3-810 | 330 | 3 | 437 | 495 | 7.7-809 | 330 | 3 | 6.7 | 3.8 | .30-16 | 8.2 |
| Chinkapin Creek tributary | V | 1 | 9.2 | 9.2 | -- | -- | 1 | 6.3 | 6.3 | -- | -- | 1 | 53 | 53 | -- | -- |
| W.P. Brice Creek | V | 1 | 70 | 70 | -- | -- | 1 | 70 | 70 | -- | -- | 1 | 61 | 61 | -- | -- |

Table 16.--*Statistical summary of minor constituent concentrations by study basin and flow condition, 1986-88, and ranges from previous study*

[N, number of analyses; SD, standard deviation; µg/L, micrograms per liter; --, not determined; <, less than. Statistical procedures using values preceded by the < symbol developed by Helsel and Cohn, 1988]

| Study basin | Geo-chem-ical zone | Flow condition | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total aluminum, in µg/L | | | | | | Total arsenic, in µg/L | | | | | | Total cadmium, in µg/L | | | | | |
| Beetree Creek | I | Stormflow | 8 | 1,426 | 815 | 60-4,100 | 1,417 | -- | 8 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 8 | <1.0 | <1.0 | <1.0-1.0 | -- | -- |
| | | Low flow | 31 | 92 | 50 | 30-800 | 120 | -- | 18 | -- | <10 | <1.0-<10 | -- | 0-1 | 19 | -- | <10 | <1.0-<10 | -- | -- |
| High Shoals Creek | I | Stormflow | 5 | 280 | 50 | 50-750 | 327 | -- | 3 | <10 | <10 | <10-<10 | 0 | 0 | 5 | <10 | <10 | <10-<10 | 0 | -- |
| | | Low flow | 2 | 200 | 200 | 150-250 | 71 | -- | 2 | <10 | <10 | <10-<10 | 0 | 0-1 | 2 | <10 | <10 | <10-<10 | 0 | -- |
| North Harper Creek | I | Stormflow | 5 | 1,692 | 1,200 | 200-4,900 | 1,927 | -- | 5 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 5 | -- | <1.0 | <1.0-1.0 | -- | -- |
| | | Low flow | 31 | 106 | 70 | <50-700 | 85 | -- | 18 | -- | <10 | <1.0-<10 | -- | 0-1 | 20 | -- | <10 | <1.0-<10 | -- | -- |
| Dutchmans Creek | II | Stormflow | 11 | 946 | 910 | <10-2,200 | 701 | -- | 12 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0-3 | 10 | -- | <1.0 | <1.0-2.0 | -- | -- |
| | | Low flow | 29 | 170 | 100 | <50-850 | 158 | -- | 13 | -- | <10 | <1.0-<10 | -- | 0-2 | 14 | -- | <10 | <1.0-<10 | -- | -- |
| New Hope River tributary | II | Stormflow | 9 | 846 | 770 | 460-1,900 | 442 | -- | 9 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0-3 | 8 | <1.0 | <1.0 | <1.0-<1.0 | 0 | -- |
| | | Low flow | 18 | 609 | 535 | 200-1,300 | 322 | -- | 11 | -- | <1.0 | <1.0-<10 | -- | 0-2 | 12 | -- | 1.0 | <1.0-<10 | -- | -- |
| Suck Creek tributary | III | Stormflow | 5 | 630 | 720 | 270-910 | 274 | -- | 4 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0-1 | 5 | <1.0 | <1.0 | <1.0-<1.0 | 0 | -- |
| | | Low flow | 37 | 158 | 100 | <50-830 | 130 | -- | 17 | -- | <10 | <1.0-<10 | -- | 0 | 18 | -- | <6.0 | <1.0-<10 | -- | -- |
| Limestone Creek | IV | Stormflow | 7 | 1,271 | 1,300 | 1,000-1,700 | 236 | -- | 7 | -- | <1.0 | <1.0-<10 | -- | 0-1 | 7 | -- | <1.0 | <1.0-<2.0 | -- | -- |
| | | Low flow | 5 | 1,008 | 990 | 750-1,300 | 208 | -- | 5 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 5 | -- | <1.0 | <1.0-2.0 | -- | -- |
| Chinkapin Creek tributary | V | Stormflow | 8 | 682 | 695 | 370-990 | 213 | -- | 7 | <2.3 | <1.0 | <1.0-<10 | 3.4 | 0-2 | 7 | <2.0 | <1.0 | <1.0-<10 | 3.6 | -- |
| | | Low flow | 10 | 883 | 725 | 300-2,900 | 736 | -- | 8 | -- | <1.0 | <1.0-<10 | -- | 0-1 | 8 | -- | <1.0 | <1.0-<10 | -- | -- |
| W.P. Brice Creek | V | Stormflow | 11 | 1,424 | 630 | 500-9,200 | 2,580 | -- | 9 | <1.8 | <1.0 | <1.0-<10 | 3.2 | 0-2 | 10 | -- | <1.0 | <1.0-<10 | -- | -- |
| | | Low flow | 29 | 749 | 630 | 330-4,700 | 768 | -- | 10 | -- | <10 | <1.0-<10 | -- | 0-1 | 11 | -- | <10 | <1.0-<10 | -- | -- |

[1]Range for geochemical zone.

Table 16.--*Statistical summary of minor constituent concentrations by study basin and flow condition, 1986-88, and ranges from previous study*--Continued

[N, number of analyses; SD, standard deviation; µg/L, micrograms per liter; --, not determined; <, less than. Statistical procedures using values preceded by the < symbol developed by Helsel and Cohn, 1988]

| Study basin | Geo-chem-ical zone | Flow condition | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total chromium, in µg/L | | | | | | Total cobalt, in µg/L | | | | | | Total copper, in µg/L | | | | | |
| Beetree Creek | I | Stormflow | 8 | 3.0 | 2.5 | <1.0-10 | 2.8 | 10-20 | 8 | 1.8 | 1.5 | <1.0-4.0 | 1.3 | -- | 8 | 3.8 | 3.0 | <1.0-9.0 | 3.4 | 1.5-12 |
| | | Low flow | 20 | -- | <25 | <1.0-<25 | -- | 10-20 | 11 | -- | <50 | <1.0-<50 | -- | -- | 19 | 11 | 2.1 | 1.0-120 | 11 | 0-9 |
| High Shoals Creek | I | Stormflow | 5 | <25 | <25 | <25-<25 | 0 | 10-20 | 3 | <50 | <50 | <50-<50 | 0 | -- | 5 | <10 | <10 | <10-<10 | 0 | 1.5-12 |
| | | Low flow | 2 | <25 | <25 | <25-<25 | 0 | 10-20 | 1 | <50 | <50 | -- | -- | -- | 2 | <10 | <10 | <10-<10 | 0 | 0-9 |
| North Harper Creek | I | Stormflow | 5 | 1.8 | 2.0 | <1.0-3.0 | .97 | 10-20 | 5 | 1.4 | 1.0 | <1.0-3.0 | 1.0 | -- | 5 | 5.4 | 3.0 | 2.0-11 | 3.9 | 1.5-12 |
| | | Low flow | 20 | 1.2 | 1.0 | <1.0-<25 | .90 | 10-20 | 15 | -- | <50 | <1.0-<50 | -- | -- | 20 | -- | <10 | <1.0-<10 | -- | 0-9 |
| Dutchmans Creek | II | Stormflow | 10 | 2.7 | 1.2 | <1.0-6.0 | 4.0 | 10-20 | 10 | 2.1 | 2.0 | <1.0-4.0 | 1.1 | -- | 10 | 4.1 | 2.5 | 1.0-11 | 3.2 | 2-11 |
| | | Low flow | 14 | -- | <25 | <1.0-<25 | -- | 10-20 | 13 | -- | <50 | 1.0-<50 | -- | -- | 14 | -- | <10 | 1.0-<10 | -- | 0-10 |
| New Hope River tributary | II | Stormflow | 8 | 4.1 | 4.5 | <1.0-6.0 | 5.4 | 10-20 | 8 | .92 | .34 | <1.0-3.0 | 1.6 | -- | 8 | 4.1 | 4.0 | 3.0-6.0 | 1.1 | 2-11 |
| | | Low flow | 12 | 3.3 | 2.6 | 1.0-<25 | 2.6 | 10-20 | 10 | -- | <1.0 | <1.0-<50 | -- | -- | 12 | 2.3 | 1.3 | <1.0-11 | 2.8 | 0-10 |
| Suck Creek tributary | III | Stormflow | 5 | -- | <1.0 | <1.0-5.0 | -- | 10 | 5 | 3.0 | 3.0 | 2.0-5.0 | 1.2 | -- | 5 | 4.2 | 4.0 | 3.0-6.0 | 1.1 | 1 |
| | | Low flow | 18 | 2.8 | 2.2 | 1.0-<25 | 2.2 | 10-20 | 18 | 2.3 | 1.1 | <1.0-<50 | 3.6 | -- | 18 | 2.6 | 2.2 | 1.0-<10 | 1.7 | 0-4 |
| Limestone Creek | IV | Stormflow | 7 | 2.3 | 1.1 | <1.0-<25 | 3.3 | 10 | 7 | -- | <1.0 | <1.0-<50 | -- | -- | 7 | 2.3 | 2.0 | 1.0-<10 | 1.4 | 1-2 |
| | | Low flow | 5 | -- | <1.0 | <1.0-6.0 | -- | 10-20 | 5 | -- | <1.0 | <1.0-1.0 | -- | -- | 5 | 2.1 | 1.0 | <1.0-4.0 | 3.1 | 3-5 |
| Chinkapin Creek tributary | V | Stormflow | 7 | -- | <1.0 | <1.0-<25 | -- | 10 | 7 | 2.0 | 1.7 | <1.0-<50 | 1.2 | -- | 7 | 3.9 | 3.0 | <1.0-<10 | 3.0 | 0-5 |
| | | Low flow | 8 | 5.4 | 4.5 | 2.0-<25 | 3.8 | 10-15 | 8 | 4.7 | 3.3 | 1.0-<50 | 4.4 | -- | 8 | 2.3 | 1.8 | <1.0-<10 | 1.6 | 1-4 |
| W.P. Brice Creek | V | Stormflow | 10 | 3.6 | 2.0 | <1.0-<25 | 4.6 | 10 | 9 | -- | <1.0 | <1.0-<50 | -- | -- | 10 | 1.6 | .97 | <1.0-<10 | 2.0 | 0-5 |
| | | Low flow | 11 | -- | <25 | <1.0-<25 | -- | 10-15 | 10 | -- | <50 | <1.0-<50 | -- | -- | 11 | -- | <10 | 1.0-<10 | -- | 1-4 |

[1] Range for geochemical zone.

Table 16.--*Statistical summary of minor constituent concentrations by study basin and flow condition, 1986-88, and ranges from previous study*--Continued

[N, number of analyses; SD, standard deviation; µg/L, micrograms per liter; --, not determined; <, less than. Statistical procedures using values preceded by the < symbol developed by Helsel and Cohn, 1988]

| Study basin | Geochemical zone | Flow condition | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total iron, in µg/L | | | | | | Total lead, in µg/L | | | | | | Total manganese, in µg/L | | | | | |
| Beetree Creek | I | Stormflow | 8 | 1,570 | 890 | <10-4,400 | 1,574 | 20-3,600 | 8 | <5.0 | <5.0 | -- | 0 | 2-25 | 8 | 116 | 45 | <10-290 | 193 | -- |
| | | Low flow | 27 | 120 | 35 | <10-1,000 | 290 | 60-3,000 | 19 | -- | <50 | <5.0-<50 | -- | 0-16 | 30 | 20 | 3.1 | <10-370 | 67 | -- |
| High Shoals Creek | I | Stormflow | 3 | 1,533 | 1,600 | 1,200-1,800 | 306 | 20-3,600 | 5 | <50 | <50 | -- | 0 | 2-25 | 5 | -- | <25 | <25-65 | -- | -- |
| | | Low flow | 1 | 580 | 580 | -- | -- | 60-3,000 | 2 | <50 | <50 | -- | 0 | 0-16 | 1 | 30 | 30 | -- | -- | -- |
| North Harper Creek | I | Stormflow | 5 | 674 | 320 | 110-1,700 | 700 | 20-3,600 | 5 | 4.8 | 5.0 | <5.0-6.0 | 1.1 | 2-25 | 5 | 92 | 50 | <10-230 | 136 | -- |
| | | Low flow | 27 | 71 | 50 | <10-490 | 77 | 60-3,000 | 20 | -- | <50 | <5.0-64 | -- | 0-16 | 27 | -- | <25 | <10-80 | -- | -- |
| Dutchmans Creek | II | Stormflow | 10 | 1,430 | 1,300 | 250-3,400 | 953 | 770-13,000 | 10 | <5.0 | <5.0 | <5.0-5.0 | -- | 4-10 | 10 | 164 | 100 | <10-380 | 297 | -- |
| | | Low flow | 31 | 411 | 400 | 170-950 | 169 | 160-2,100 | 14 | -- | <50 | <5.0-50 | -- | 4-11 | 30 | 37 | 21 | 20-240 | 47 | -- |
| New Hope River tributary | II | Stormflow | 9 | 1,088 | 710 | 460-3,100 | 849 | 770-13,000 | 9 | -- | <5.0 | <5.0-<50 | -- | 4-10 | 9 | 61 | 30 | <25-280 | 60 | -- |
| | | Low flow | 17 | 604 | 520 | 160-1,400 | 352 | 160-2,100 | 12 | -- | <5.0 | <5.0-<10 | -- | 4-11 | 16 | 13 | 12 | <10-30 | 7.5 | -- |
| Suck Creek tributary | III | Stormflow | 5 | 616 | 480 | 160-1,100 | 384 | 7-9 | 5 | -- | <5.0 | <5.0-6.0 | -- | 7-8 | 5 | 70 | 70 | 10-120 | 46 | -- |
| | | Low flow | 37 | 404 | 250 | <10-1,200 | 647 | 420-590 | 18 | -- | <30 | <5.0-<50 | -- | 1-8 | 37 | 36 | 23 | 10-230 | 40 | -- |
| Limestone Creek | IV | Stormflow | 7 | 428 | 250 | 150-1,100 | 354 | 250 | 7 | <5.7 | <5.0 | <5.0-<10 | 1.9 | 5-6 | 7 | 13 | 13 | 10-<25 | 4.6 | -- |
| | | Low flow | 5 | 660 | 640 | 390-1,000 | 223 | 80-1,200 | 5 | <5.0 | <5.0 | -- | 0 | 1-7 | 5 | 17 | 10 | <10-40 | 12 | -- |
| Chinkapin Creek tributary | V | Stormflow | 8 | 455 | 405 | 340-780 | 152 | 130-2,000 | 7 | -- | <5.0 | <5.0-<50 | -- | 0-11 | 8 | 105 | 100 | 40-170 | 40 | -- |
| | | Low flow | 10 | 1,841 | 820 | 390-8,900 | 2,606 | 200-1,000 | 8 | -- | <5.0 | <5.0-<50 | -- | 4-14 | 10 | 131 | 105 | 90-220 | 46 | -- |
| W.P. Brice Creek | V | Stormflow | 11 | 575 | 540 | 240-1,100 | 306 | 130-2,000 | 10 | -- | <5.0 | <5.0-<50 | -- | 0-11 | 11 | 20 | 7.0 | <10-190 | 36 | -- |
| | | Low flow | 28 | 533 | 485 | 240-1,000 | 221 | 200-1,000 | 11 | -- | <50 | <5.0-<50 | -- | 4-14 | 29 | -- | <25 | <10-<25 | -- | -- |

[1]Range for geochemical zone.

Table 16.--*Statistical summary of minor constituent concentrations by study basin and flow condition, 1986-88, and ranges from previous study*--Continued

[N, number of analyses; SD, standard deviation; µg/L, micrograms per liter; --, not determined; <, less than. Statistical procedures using values preceded by the < symbol developed by Helsel and Cohn, 1988]

| Study basin | Geochemical zone | Flow condition | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mercury, in µg/L | | | | | | Nickel, in µg/L | | | | | |
| Beetree Creek | I | Stormflow | 8 | <0.10 | <0.10 | <0.10-0.10 | -- | 0.3-.5 | 8 | 5.4 | 4.0 | <1.0-15 | 8.5 | -- |
| | | Low flow | 19 | -- | <.20 | <.10-<.20 | -- | 0-.5 | 19 | -- | <50 | <1.0-<50 | -- | -- |
| High Shoals Creek | I | Stormflow | 4 | <.20 | <.20 | <.20-<.20 | 0 | .3-.5 | 5 | <50 | <50 | <50-<50 | 0 | -- |
| | | Low flow | 2 | <.20 | <.20 | <.20-<.20 | 0 | 0-.5 | 2 | <50 | <50 | <50-<50 | 0 | -- |
| North Harper Creek | I | Stormflow | 5 | -- | <.10 | <.10-.10 | -- | .3-.5 | 5 | -- | <1.0 | <1.0-2.0 | -- | -- |
| | | Low flow | 19 | -- | <.20 | <.10-<.20 | -- | 0-.5 | 20 | -- | <50 | <1.0-<50 | -- | -- |
| Dutchmans Creek | II | Stormflow | 12 | -- | <.10 | <.10-.70 | -- | 0-.5 | 10 | 4.2 | 3.5 | <1.0-7.0 | 2.9 | -- |
| | | Low flow | 13 | -- | <.20 | <.10-.20 | -- | 0 | 14 | -- | <50 | 1.0-50 | -- | -- |
| New Hope River tributary | II | Stormflow | 9 | .23 | .10 | <.10-.70 | .25 | 0-.5 | 6 | 3.5 | 3.5 | 1.0-6.0 | 1.9 | -- |
| | | Low flow | 11 | .10 | .10 | <.10-.20 | .0 | 0 | 12 | 3.2 | 2.6 | 1.0-<50 | 2.3 | -- |
| Suck Creek tributary | III | Stormflow | 5 | -- | <.10 | <.10-1.0 | -- | 0 | 5 | 2.6 | 3.0 | 1.0-3.0 | .89 | -- |
| | | Low flow | 17 | .10 | .05 | <.10-.60 | .20 | 0-.1 | 16 | 5.6 | 4.9 | 3.0-<50 | 3.8 | -- |
| Limestone Creek | IV | Stormflow | 7 | -- | <.10 | <.10-<.30 | -- | 0-.3 | 7 | 3.0 | 2.6 | <1.0-<50 | 2.0 | -- |
| | | Low flow | 4 | -- | <.25 | <.10-.70 | -- | .1-.5 | 5 | 2.1 | 2.0 | <1.0-4.0 | 1.9 | -- |
| Chinkapin Creek tributary | V | Stormflow | 6 | -- | <.10 | <.10-<.20 | -- | 0-.5 | 7 | 5.0 | 3.8 | <1.0-<50 | 4.2 | -- |
| | | Low flow | 6 | -- | .10 | <.10-<.20 | -- | .3-.5 | 7 | 4.0 | 3.7 | 2.0-<50 | 1.7 | -- |
| W.P. Brice Creek | V | Stormflow | 9 | -- | <.10 | <.10-.20 | -- | 0-.5 | 10 | 4.2 | 2.7 | <1.0-<50 | 4.6 | -- |
| | | Low flow | 11 | -- | <.20 | <.10-.60 | -- | .3-.5 | 11 | -- | <50 | <1.0-<50 | -- | -- |

[1]Range for geochemical zone.

Table 16.--*Statistical summary of minor constituent concentrations by study basin and flow condition, 1986-88, and ranges from previous study*--Continued

[N, number of analyses; SD, standard deviation; mg/L, micrograms per liter; --, not determined; <, less than. Statistical procedures using values preceded by the < symbol developed by Helsel and Cohn, 1988]

| Study basin | Geochemical zone | Flow condition | N | Mean | Median | Range | SD | Range previous study[1] | N | Mean | Median | Range | SD | Range previous study[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Selenium, in µg/L | | | | | | Zinc, in µg/L | | | | | |
| Beetree Creek | I | Stormflow | 8 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 8 | -- | <10 | <10-10 | -- | 0-30 |
| | | Low flow | 16 | -- | <5.0 | <1.0-<5.0 | -- | 0 | 20 | -- | <10 | <10-13 | -- | 0-30 |
| High Shoals Creek | I | Stormflow | 4 | <5.0 | <5.0 | <5.0-<5.0 | 0 | 0 | 5 | -- | <10 | <10-56 | -- | 0-30 |
| | | Low flow | 2 | -- | <8.0 | <5.0-<10 | -- | 0 | 1 | <10 | <10 | -- | -- | 0-30 |
| North Harper Creek | I | Stormflow | 5 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 5 | -- | <10 | <10-30 | -- | 0-30 |
| | | Low flow | 17 | -- | <5.0 | <1.0-<5.0 | -- | 0 | 20 | -- | <10 | <10-13 | -- | 0-30 |
| Dutchmans Creek | II | Stormflow | 12 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 10 | 10 | 6.2 | <10-30 | 12 | 10-15 |
| | | Low flow | 13 | -- | <5.0 | <1.0-<10 | -- | 0 | 14 | -- | <10 | <10-10 | -- | 0-10 |
| New Hope River tributary | II | Stormflow | 9 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 8 | -- | <10 | <10-120 | -- | 10-15 |
| | | Low flow | 11 | -- | <1.0 | <1.0-<5.0 | -- | 0 | 12 | -- | <10 | <10-10 | -- | 0-10 |
| Suck Creek tributar | III | Stormflow | 4 | <1.0 | <1.0 | <1.0-<1.0 | 0 | 0 | 5 | <10 | <10 | <10-<10 | 0 | 0-20 |
| | | Low flow | 17 | -- | <5.0 | <1.0-<5.0 | -- | 0 | 18 | -- | <10 | <10-20 | -- | 10-20 |
| Limestone Creek | IV | Stormflow | 7 | <1.6 | <1.0 | <1.0-<5.0 | 1.5 | 0 | 7 | 13 | 10 | <10-20 | 7.5 | 10 |
| | | Low flow | 5 | -- | <1.0 | <1.0-1.0 | -- | 0 | 5 | -- | <10 | <10-130 | -- | 10 |
| Chinkapin Creek tributary | V | Stormflow | 7 | <1.6 | <1.0 | <1.0-<5.0 | 1.5 | 0 | 7 | -- | <10 | <10-30 | -- | 0-20 |
| | | Low flow | 8 | -- | <1.0 | <1.0-<5.0 | -- | 0 | 7 | 19 | 16 | <10-50 | 13 | 5-20 |
| W.P. Brice Creek | V | Stormflow | 9 | <1.4 | <1.0 | <1.0-<5.0 | 1.3 | 0 | 10 | -- | <10 | <10-140 | -- | 0-20 |
| | | Low flow | 11 | -- | <5.0 | <1.0-<10 | -- | 0 | 11 | -- | <10 | <10-14 | -- | 5-20 |

[1]Range for geochemical zone.

concentrations that exceeded 300 µg/L, whereas 87 percent of the water samples from the two streams in geochemical zone V exceeded this concentration. Thirteen percent of all the samples collected across the State exceeded the maximum concentration of 1,000 µg/L total iron that is established by the North Carolina Environmental Management Commission (1986) as a water-quality standard for protecting aquatic life (table 4).

Mean total iron concentrations appear to vary directly with changes in streamflow conditions at some of the study sites, with maximum concentrations occurring during stormflow (table 16). However, this relation was reversed at Limestone Creek and Chinkapin Creek tributary. Individual total iron concentrations were plotted against unit-area discharge by geochemical zone to further explore this relation (fig. 11). The best relation appears in Beetree and North Harper Creeks in geochemical zone I (fig. 11A). A less distinct relation occurs in Dutchmans Creek and New Hope River tributary in geochemical zone II (fig. 11B), and there seems to be no relation at sites in the other geochemical zones (fig. 11C). The strength of the relation between increasing total iron concentration and increasing unit-area discharge decreases from west to east across the State.

Iron in stream water usually occurs as an oxide coating on eroded materials and(or) as finely dispersed particles and is of terrestrial origin because it is a common constituent in hundreds of mineral species. The total iron concentrations in the streams of study sites in geochemical zones I and II and from Simmons and Heath (1982) appear to be directly related to suspended-sediment concentrations (fig. 12), although the details of the transport mechanism were not investigated.

Because clay minerals are hydrated silicates of aluminum and iron, it is expected that concentrations of aluminum in streams are related to concentrations of iron and suspended sediment, as well as showing a general relation to discharge. Mean concentrations of total aluminum are lower during low-flow conditions than during stormflow at all study sites except at Chinkapin Creek tributary (table 16). A plot of total aluminum and total iron concentrations for six study sites shows a 95-percent correlation (fig. 13).

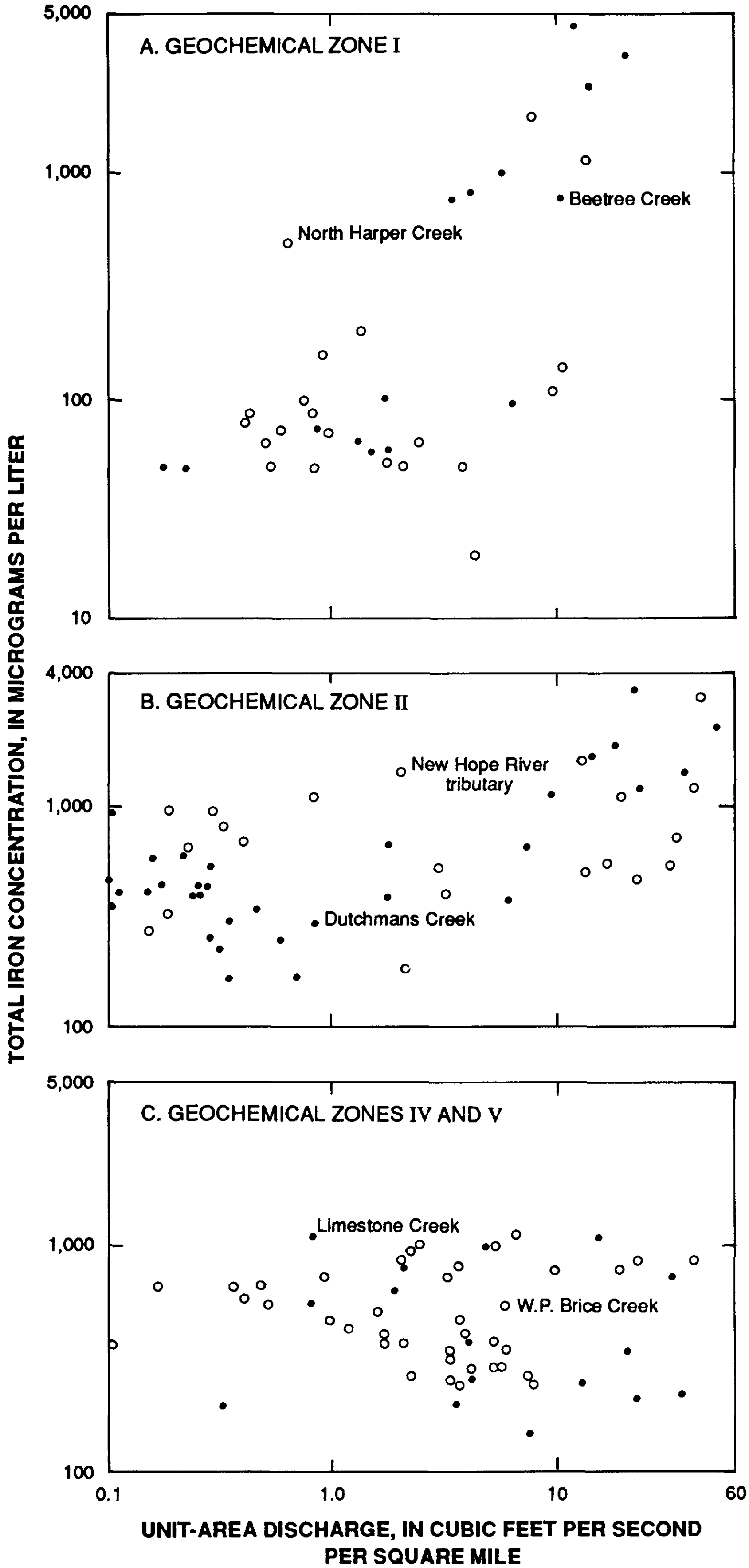


Figure 11.--Relation between unit-area water discharge and total iron concentration in stream water at study sites in geochemical zones (A) I, (B) II, (C) IV and V, 1986-88.

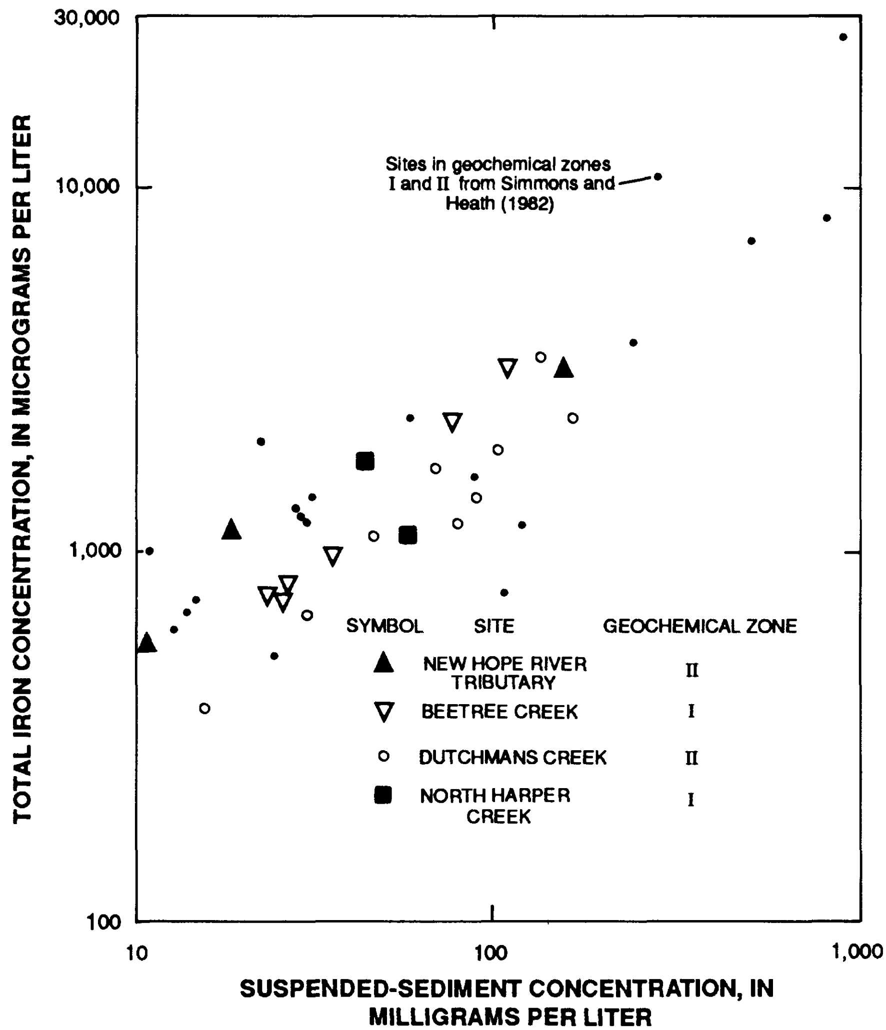


Figure 12.--Relation of total iron concentration and suspended-sediment concentration in stormflow at study sites in geochemical zones I and II, 1986-88.

Manganese is usually widely dispersed in most rocks and only rarely occurs in large quantities. It is, however, often attached to various clay minerals as an oxide coating (Horowitz, 1985); therefore, manganese should be similarly related to discharge and sediment as are iron and aluminum. Mean total manganese concentrations were greater during stormflow than during low-flow conditions, except at Chinkapin Creek tributary and Limestone Creek. Observed concentrations ranged from less than 10 to 380 µg/L; however, at Limestone Creek no manganese concentration was greater than 40 µg/L (table 16). As in the case of iron and aluminum, these data indicate manganese concentrations are somewhat flow-related, with greater concentrations usually occurring during storm runoff.

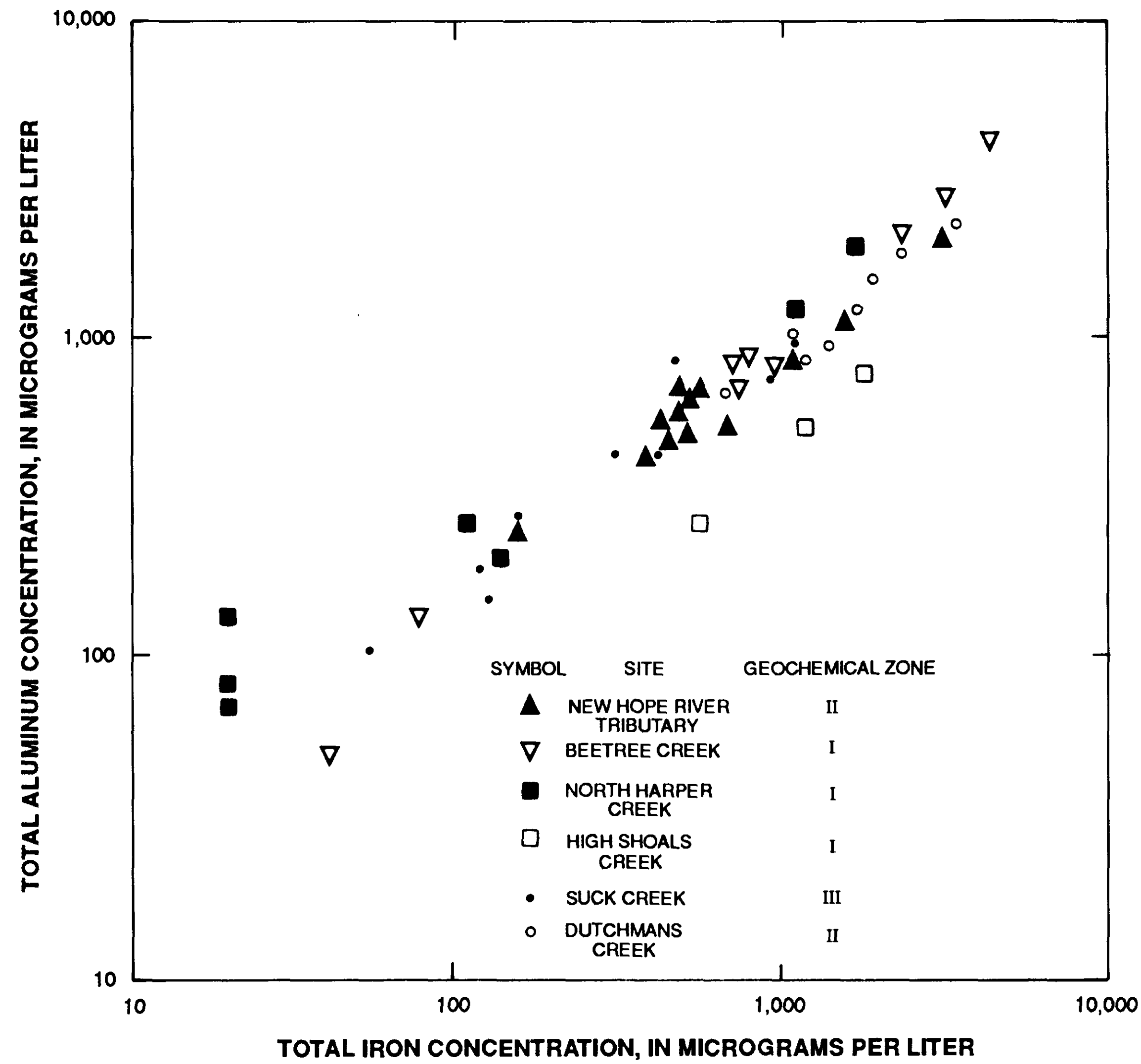


Figure 13.--Relation of total aluminum concentration and total iron concentration in stream water at study sites in geochemical zones I, II, and III, 1986-88.

The relation between concentrations of total manganese and total iron for samples collected during stormflow from sites in geochemical zones I and II (fig. 14) indicates the ratios of manganese to iron in stream water ranges from 1:15 to 1:40. This contrasts with a ratio of 1:50 for most rocks (Hem, 1985). Slack and Feltz (1968) report that the amount of manganese released during the decomposition of fallen leaves might be significant, especially for headwater streams draining forested basins. Aquatic plants as a source of manganese to streams is also suggested by Hem (1985); however, the importance of these plants as a source of this constituent at the study sites is unknown.

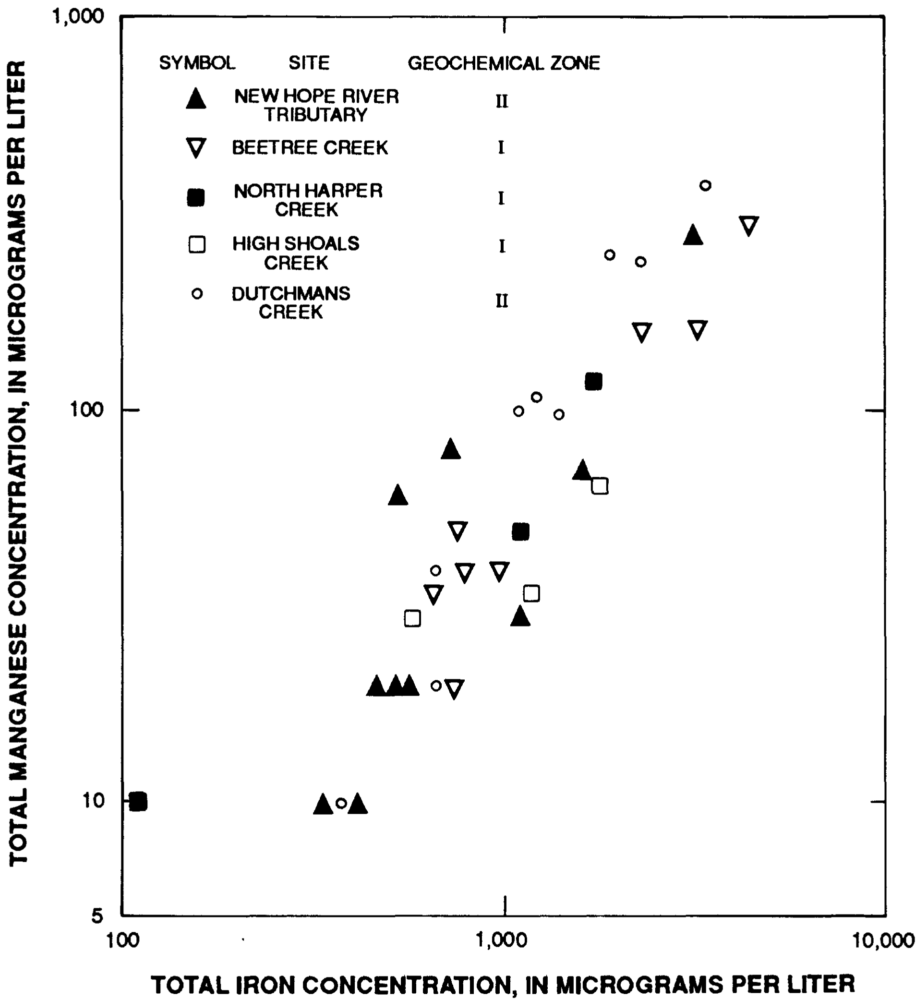


Figure 14.--Relation of total manganese concentration and total iron concentration in stormflow at study sites in geochemical zones I and II, 1986-88.

Although total zinc concentrations exceeded 100 µg/L in several samples collected from New Hope River tributary, Limestone Creek, and W.P. Brice Creek, mean or median concentrations at all sampling sites and for both flow conditions were less than 20 µg/L (table 16). However, at least one sample was obtained from each of five study sites that equalled or exceeded the North Carolina standard of 50 µg/L (table 4) for freshwater aquatic life: Chinkapin Creek tributary (50 µg/L), W.P. Brice Creek (140 µg/L), New Hope River tributary (120 µg/L), Limestone Creek (130 µg/L), and High Shoals Creek (56 µg/L).

Maximum concentrations of total zinc were evenly distributed between stormflow and low flows, and there was no significant relation between concentrations of total zinc, water discharge, or suspended sediment. As reported by Simmons and Heath (1982), the maximum observed concentration of total zinc from 95 samples was 30 µg/L. These findings indicate that zinc is a widespread constituent, but its concentration in stream water from forested basins is usually less than 10 µg/L.

Arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, and selenium occurred in very low concentrations, generally on the order of 10 µg/L or less (table 16). Analyses of these constituents at low concentrations by the USGS and EHNR laboratories, using equipment having different detection-limit capabilities, presented difficulties in the interpretation of the results. Inferences about distribution by geochemical zone or flow condition are difficult to make, and discussion is restricted to possible sources of these constituents based on the relatively few values above detection limits.

The highest detected concentration of total chromium was 10 µg/L during stormflow in Beetree Creek (table 16). The highest mean concentration was 5.4 µg/L during low flow in Chinkapin Creek tributary. These values are well below the standard of 50 µg/L for all freshwaters in North Carolina (table 4).

Mean or median concentrations of total arsenic, total cadmium, and total selenium at all study sites were less than 10 µg/L. The highest detected concentration of these constituents was 2 µg/L of total cadmium during stormflow at Dutchmans Creek and during low flow at Limestone Creek (table 16). These constituents occur in small amounts in the rocks and soils in the study site basins, but they may also be transported in the atmosphere from sources such as stack emissions and deposited in the streams by dryfall. It is possible that some arsenic may also be a component of airborne pesticides and herbicides.

Mean total cobalt concentrations ranged from 0.92 to 4.7 µg/L. The maximum single detectable concentration of total cobalt was 5 µg/L in Suck Creek tributary (table 16).

Mean concentrations of total copper, total lead, and total nickel were below 10 µg/L, except for a mean of 11 µg/L observed for total copper during low flow in Beetree Creek. One low-flow sample at North Harper Creek contained 64 µg/L total lead, which was the highest detected concentration of these constituents (table 16). The primary source of these constituents is from rocks and soils; however, at least part of the lead could be from atmospheric sources such as exhausts from gasoline engines (Alexander and Smith, 1988).

Of the minor constituents discussed thus far, mercury is considered to be one of the most toxic. Accordingly, the EPA has proposed a maximum contaminant level of 2.0 µg/L for domestic water supplies (U.S. Environmental Protection Agency, 1976). Of the 167 samples analyzed, the greatest concentration observed was 0.7 µg/L in Dutchmans Creek, New Hope River tributary, and Limestone Creek.

From the late 1700's to the discovery of gold in California in 1849, North Carolina was the leading gold producer in the United States, and numerous mining and panning operations continued through the early 1900's. Mercury was used by many miners throughout the Piedmont and Blue Ridge Provinces as an accumulator to capture the gold. There is growing speculation that some of the mercury occurring in stream water in North Carolina today is not native, but the remnants of a once-thriving mining industry (Albert Carpenter, North Carolina Geological Survey, oral commun., 1988).

Comparisons of mean concentrations of selected minor constituents were made with data in Simmons and Heath (1982), and grouped by geochemical zone and flow condition (table 17). In general, there were few differences between the observed data from the two studies. Mean concentrations of total chromium observed in this study were slightly less than the ranges of values reported in Simmons and Heath (1982).

Table 17.--*Mean concentrations of selected minor constituents 1986-88, by geochemical zone and flow condition as compared with data by Simmons and Heath (1982)*

[Comparison with data by Simmons and Heath (1982): -, less than; *, in same range; ND, not determined; +, greater than]

| Geochemical zone | Flow condition | Chromium | Copper | Iron | Mercury | Zinc |
|---|---|---|---|---|---|---|
| I | Stormflow | - | * | * | ND | * |
| | Low flow | - | * | * | * | * |
| II | Stormflow | - | * | * | * | - |
| | Low flow | - | * | * | + | * |
| III | Stormflow | ND | + | + | ND | * |
| | Low flow | - | * | - | * | ND |
| IV | Stormflow | - | * | + | ND | + |
| | Low flow | ND | - | * | ND | ND |
| V | Stormflow | - | * | * | ND | * |
| | Low flow | - | * | * | - | * |

According to Horowitz (1985), streambed sediments often serve as sinks or reservoirs for minor constituents. Approximately 35 samples of streambed material were collected and analyzed for aluminum, cadmium, chromium, copper, lead, mercury, nickel, and zinc (table 18). The highest observed concentrations of most minor constituents occur in the streambed sediments of Beetree Creek and New Hope River tributary. The reason or reasons for this are not understood at this time, but may be related to the limited number of samples taken.

Because there are no standards or criteria for concentrations of minor constituents in streambed material, a classification scheme developed by Kelly and Hite (1984) for Illinois is used in modified form to assess the significance of some of the minor constituents in this material (table 19). The classification scheme uses the following adjective ratings to describe the concentrations of these constituents in streambed sediments: "non-elevated," "slightly elevated," "elevated," "highly elevated," and "extremely elevated." Aluminum and nickel are not given adjective ratings in this classification.

Mean concentrations of total copper, total lead, and total zinc in streambed material at all sites are non-elevated, as are the maximum observed concentrations of these constituents. One of four samples taken at Chinkapin Creek tributary was slightly elevated with respect to total cadmium concentration. At Beetree Creek, one sample had a slightly elevated total chromium concentration, but the two samples at New Hope River tributary were highly elevated and extremely elevated in chromium content. One streambed sample at High Shoals Creek was classified as extremely elevated in total mercury concentration. Additional samples will be needed to determine whether these elevated values are significant.

Recent investigations confirm that atmospheric deposition is an important source of some minor constituents to lakes and streams. Dillon and Evans (1982) and Thomas and others (1984) described a major contribution of lead, zinc, and cadmium from the atmosphere. The atmospheric transport of mercury might also be significant according to Windom and others (1975). An indepth review of sources and characteristics of minor constituents in surface waters was prepared by Elder (1988) who emphasized that the atmosphere is the most likely source of most of these constituents, which are observed in uniform concentrations over a widespread area. Soil samples from the 0 to 5 centimeter soil horizon collected at the Coweeta Hydrologic Laboratory forested sites during 1981-84 showed that lead and cadmium concentrations were greater in the upper few centimeters of soil, also indicating deposition from aerial sources (Ragsdale and Berish, 1988).

Table 18.--*Statistical summary of concentrations of minor constituents in streambed material in study basins, 1986-88*

[N, number of analyses; SD, standard deviation; mg/kg, milligrams per kilogram; --, not determined]

| Study basin | Geochemical zone | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total aluminum, in mg/kg | | | | | Total cadmium, in mg/kg | | | | | Total chromium, in mg/kg | | | | |
| Beetree Creek | I | 6 | 6,293 | 7,850 | 130-13,000 | 5,147 | 6 | 0.10 | 0.10 | 0.10-0.10 | 0 | 6 | 16 | 16 | 13-18 | 2.4 |
| High Shoals Creek | I | 5 | 4,100 | 3,800 | 3,500-5,400 | 775 | 5 | .10 | .10 | .10-.10 | 0 | 5 | 4.2 | 4.2 | 3.4-4.9 | .57 |
| North Harper Creek | I | 5 | 2,360 | 2,200 | 1,500-3,700 | 882 | 5 | .10 | .10 | .10-.10 | 0 | 5 | .91 | .80 | .59-1.6 | .39 |
| Dutchmans Creek | II | 2 | 2,550 | 2,550 | 1,700-3,400 | 1,202 | 4 | .10 | .10 | .10-.10 | 0 | 4 | 10 | 9.4 | 8.0-13 | 2.2 |
| New Hope River tributary | II | 1 | 13,000 | 13,000 | -- | -- | 2 | .10 | .10 | .10-.10 | 0 | 2 | 57 | 57 | 46-68 | 16 |
| Suck Creek tributary | III | 2 | 1,005 | 1,005 | 810-1,200 | 276 | 4 | .10 | .10 | .10-.10 | 0 | 4 | 1.8 | 1.8 | 1.0-2.7 | .83 |
| Limestone Creek | IV | 3 | 1,660 | 1,500 | 580-2,900 | 1,168 | 3 | .10 | .10 | .10-.10 | 0 | 3 | 1.4 | 1.2 | .60-2.5 | .97 |
| Chinkapin Creek tributary | V | 1 | 2,000 | 2,000 | -- | -- | 4 | .32 | .10 | .10-1.0 | .45 | 4 | 8.1 | 8.4 | 3.6-12 | 4.0 |
| W.P. Brice Creek | V | 2 | 815 | 815 | 640-990 | 247 | 3 | .10 | .10 | .10-.10 | 0 | 3 | 1.4 | 1.3 | .90-2.1 | .61 |
| | | Total copper, in mg/kg | | | | | Total lead, in mg/kg | | | | | Total mercury, in mg/kg | | | | |
| Beetree Creek | I | 4 | 13 | 14 | 9.2-16 | 2.9 | 6 | 2.5 | 2.3 | 1.5-4.3 | 1.0 | 6 | 0.03 | 0.02 | 0.02-0.06 | 0.02 |
| High Shoals Creek | I | 5 | 3.5 | 3.7 | 2.3-4.6 | .87 | 5 | 2.5 | 2.6 | 1.7-3.1 | .56 | 5 | .09 | .04 | .02-.32 | .13 |
| North Harper Creek | I | 5 | .51 | .50 | .04-1.1 | .38 | 5 | 3.4 | 3.0 | 2.5-4.9 | .93 | 4 | .02 | .02 | .02-.02 | 0 |
| Dutchmans Creek | II | 4 | 2.1 | 2.0 | 1.9-2.7 | .39 | 4 | 3.7 | 3.6 | 3.1-4.5 | .59 | 4 | .02 | .02 | .02-.02 | 0 |
| New Hope River tributary | II | 1 | 9.5 | 9.5 | -- | -- | 2 | 14 | 14 | 12-17 | 3.5 | 2 | .03 | .03 | .02-.04 | .01 |
| Suck Creek tributary | III | 4 | 1.5 | 1.4 | .93-2.1 | .51 | 4 | 1.9 | 1.8 | 1.0-3.0 | .84 | 4 | .02 | .02 | .02-.02 | 0 |
| Limestone Creek | IV | 1 | .18 | .18 | -- | -- | 3 | 1.5 | .99 | .93-2.5 | .89 | 3 | .02 | .02 | .02-.02 | 0 |
| Chinkapin Creek tributary | V | 3 | 3.2 | 3.5 | 2.4-3.6 | .67 | 4 | 6.2 | 6.3 | 2.2-9.9 | 4.2 | 4 | .02 | .02 | .02-.03 | .00 |
| W.P. Brice Creek | V | 3 | .23 | .28 | .11-.30 | .10 | 3 | 1.5 | 1.5 | 1.1-2.0 | .45 | 3 | .02 | .02 | .02-.02 | 0 |

Table 18.--*Statistical summary of concentrations of minor constituents in streambed material in study basins, 1986-88*--Continued

[N, number of analyses; SD, standard deviation; mg/kg, milligrams per kilogram; --, not determined]

| Study basin | Geochemical zone | N | Mean | Median | Range | SD | N | Mean | Median | Range | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total nickel, in mg/kg | | | | | Total zinc, in mg/kg | | | | |
| Beetree Creek | I | 6 | 10 | 10 | 6.4-15 | 3.7 | 6 | 36 | 36 | 28-42 | 6.4 |
| High Shoals Creek | I | 5 | 1.3 | 1.3 | .85-1.7 | .32 | 5 | 22 | 9.9 | 7.0-70 | 27 |
| North Harper Creek | I | 5 | .60 | .50 | .50-1.0 | .22 | 5 | 6.9 | 6.3 | 3.3-13 | 3.6 |
| Dutchmans Creek | II | 4 | 2.2 | 2.2 | 1.3-2.9 | .69 | 4 | 13 | 9.2 | 9.1-23 | 6.9 |
| New Hope River tributary | II | 2 | 6.6 | 6.6 | 5.2-7.9 | 1.9 | 2 | 34 | 34 | 33-35 | 1.4 |
| Suck Creek tributary | III | 4 | 1.8 | 1.6 | .70-3.2 | 1.1 | 4 | 4.6 | 4.2 | 2.1-7.9 | 2.5 |
| Limestone Creek | IV | 3 | .50 | .50 | .50-.50 | 0 | 3 | .54 | .44 | .19-1.0 | .41 |
| Chinkapin Creek tributary | V | 4 | 2.1 | 2.3 | .90-2.8 | .91 | 4 | 14 | 14 | 8.2-17 | 4.0 |
| W.P. Brice Creek | V | 3 | .50 | .50 | .50-.50 | 0 | 4 | 4.0 | 2.1 | .73-11 | 4.7 |

Table 19.--*Classification scheme for evaluation of concentrations of selected minor constituents in streambed sediments (modified from Kelly and Hite, 1984)*

[Results in milligrams per kilogram of sediment; <, less than; >, greater than]

| Constituent | Non-elevated | Slightly elevated | Elevated | Highly elevated | Extremely elevated |
|---|---|---|---|---|---|
| Cadmium | <0.5 | >0.5 | >1 | >2 | >20 |
| Chromium | <16 | >16 | >23 | >38 | >60 |
| Copper | <38 | >38 | >60 | >100 | >200 |
| Lead | <28 | >28 | >38 | >60 | >100 |
| Mercury | <.07 | >.07 | >.10 | >.17 | >.30 |
| Zinc | <80 | >80 | >100 | >170 | >300 |

## Organochlorine Insecticides

The sampling of both water and streambed materials for organic compounds in this study was conducted to quantify the selected organic constituents that may have been introduced into the system from any nonpoint sources such as surface runoff or atmospheric deposition. The samples were analyzed exclusively for the following organochlorine insecticides:

| | | |
|---|---|---|
| Aldrin | Endrin | Methoxychlor |
| Chlordane | Ethion | Methylparathion |
| DDD | Gross PCB's | Methyltrithion |
| DDE | Gross PCN's | Mirex |
| DDT | Hept Epox | Parathion |
| Diazinon | Heptachlor | Perthane |
| Dieldrin | Lindane | Toxaphene |
| Endosulfan | Malathion | Trithion |

Stream waters in the forested basins of the study sites were free of organochlorine insecticides at the time of sampling. At several sites, the streambed materials showed some signs of past or accumulative presence of 5 insecticides (table 20). A total of 60 streambed samples were analyzed during this study and insecticides were detected in 18 samples collected from North Harper Creek, Limestone Creek, Chinkapin Creek tributary, and W.P. Brice Creek. Concentrations of insecticides ranged from 0.1 to 3.3 micrograms per kilogram (µg/kg).

Although DDT was banned in 1973, it is highly persistent in natural conditions. As with many other insecticides, DDT was applied in a variety of ways ranging from wet aerosol sprays to dry "dusting" from crop planes. Used worldwide for 30 to 40 years, DDT and its degradation products (DDD and DDE) occur in most soils and stream sediments throughout the United States

Table 20.--*Detected organochlorine insecticide concentrations in streambed material by study site, 1986-88*

[N1, number of samples collected; N2, number of samples above detection limit; µg/kg, micrograms per kilogram; NS, no samples above detection limit]

| Constituent | Detection limit (µg/kg) | North Harper Creek | | | Limestone Creek | | | Chinkapin Creek tributary | | | W.P. Brice Creek | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N1 | N2 | Range[1] (µg/kg) | N1 | N2 | Range[1] (µg/kg) | N1 | N2 | Range (µg/kg) | N1 | N2 | Range[1] (µg/kg) |
| DDD | 0.1 | 3 | 1 | 0.1 | 3 | 1 | 0.2 | 3 | 2 | 1.7-3.3 | 3 | 1 | 0.7 |
| DDE | .1 | 3 | 1 | 1.1 | 3 | 1 | .1 | 3 | 3 | .2-1.8 | 3 | 1 | .3 |
| DDT | .1 | 3 | 1 | 2.0 | 3 | 1 | .1 | 3 | 2 | .3-1.7 | 3 | 1 | .1 |
| Lindane | .1 | 3 | 1 | .1 | 3 | 0 | NS | 3 | 0 | NS | 3 | 0 | NS |
| Mirex | .1 | 3 | 1 | .9 | 3 | 0 | NS | 3 | 0 | NS | 3 | 0 | NS |

[1]A single value is the only detected value.

as a result of atmospheric transport and deposition. Stamer and others (1985) state that streambed-sediment concentrations of DDT between 0 and 4 μg/kg represent slight enrichment over natural conditions, 4 to 23 μg/kg represent moderate enrichment, and concentrations greater than 23 μg/kg represent gross enrichment. The data collected during the course of this study thus indicate that the streambed materials in the selected forested basins are only slightly enriched with respect to DDT.

Lindane and Mirex were used as soil insecticides in North Carolina and were subsequently restricted by the EPA because of their persistence in the environment. Two streambed samples at North Harper Creek contained less than 1.0 μg/kg of each insecticide. The presence of these two insecticides was not detected in analyses of streambed samples from any of the other study sites.

### Biochemical Oxygen Demand

Biological and chemical processes can consume oxygen vital to the health of biota in a stream. Uptake of oxygen by organisms for metabolic processes can be measured by determining the 5-day biochemical oxygen demand (BOD). The results are usually expressed in terms of the weight of oxygen required for metabolic processes per unit volume of the sample in milligrams per liter. The 5-day BOD range commonly observed for moderately contaminated streams is 1 to 8 mg/L (Nemerow, 1974).

The mean BOD observed in the forested basins ranges from 0.35 mg/L in Beetree Creek to 1.0 mg/L in Limestone Creek, Chinkapin Creek tributary, and W.P. Brice Creek. The data indicate a general increase in BOD eastward across the State (fig. 15). The values of BOD indicate the absence of large quantities of oxygen-consuming material in these streams, although nearly every stream exceeded 1.0 mg/L BOD at times.

## SELECTED BIOLOGICAL CHARACTERISTICS OF STREAMS

The biological characteristics selected for study in this investigation include fish tissue analyses for minor constituents and synthetic organic chemicals, fish community structure ratings, and benthic macroinvertebrate taxa richness indicators. Because of the diverse nature of the biological components in streams, sampling results for each biological characteristic are given by study site. Integration and discussion of all the biological sampling results are presented at the end of this section.

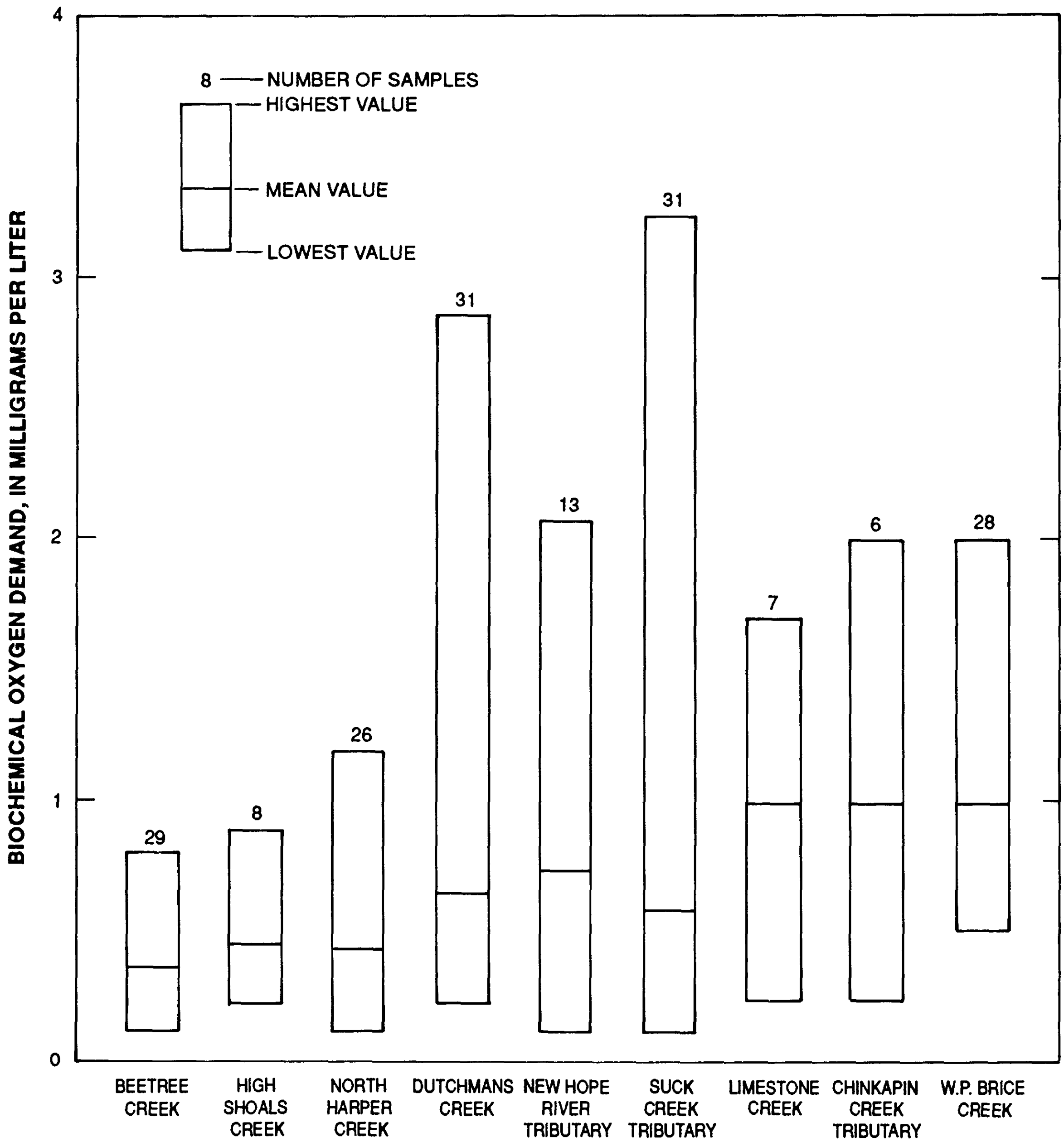


Figure 15.--Biochemical oxygen demand concentration at study basin sites, 1986-88.

The North Carolina Department of Environment, Health, and Natural Resources has maintained an ambient fish tissue monitoring network since 1981 and the benthic macroinvertebrate ambient network since 1982. These two monitoring programs supplement an ongoing ambient water-quality monitoring program maintained by nine regional offices. Many of these ambient monitoring locations were selected as reference locations for the State of North Carolina. However, little biological information has been collected from small forested catchments, such as those of this study.

The statewide ambient fish tissue monitoring network has 1,225 observations for each of 6 minor constituents: cadmium, chromium, copper, lead, mercury, and nickel. The observations consist of 750 fillet or muscle tissue samples and 475 whole fish samples. This data base will be referred to in the interpretation of fish tissue analyses. Fish community structure and benthic macroinvertebrate taxa richness are evaluated in this study by means of biotic indexes, and each study site is given a numerical or adjective rating for these two characteristics.

## Fish Tissue

Fish samples were collected from 1986 to 1988 at all study basin streams except at Chinkapin Creek tributary site where the stream was dry each time tissue sampling was attempted. Fish tissue was analyzed for 6 minor constituents and 18 synthetic organic chemicals (table 21). A visual inspection of each fish was made to eliminate from the sample any fish that appeared to have disease. This ensured the data base to be representative of healthy fish.

Analyses for selected minor constituents in fish tissue showed that 35 percent of the samples contained detectable concentrations of copper, lead, mercury, and nickel. About 38 percent of these detected concentrations were greater than concentrations reported in the monitoring network ambient fish tissue data base (table 22). Concentrations of cadmium and chromium in fish tissue were below the laboratory detection limits for all samples.

At the Beetree Creek site, a whole bluegill, *Lepomis macrochirus*, and two composited samples consisting of two and five whole northern hogsuckers, *Hypentelium nigricans*, were analyzed for selected minor constituents. Cadmium, chromium, and lead concentrations were below detection limits in these tissue samples. In the bluegill sample, concentrations of 0.55 milligram per kilogram (mg/kg) copper and 0.06 mg/kg mercury were detected.

The copper result is average and the mercury result is low when compared with mean values for copper and mercury reported in the ambient fish tissue data base for bluegill whole fish samples (table 22).

Table 21.--*Detection limits for selected minor constituents and synthetic organic chemicals in fish tissue as analyzed by the North Carolina Department of Environment, Health, and Natural Resources laboratory*

[mg/kg, milligrams per kilogram; µg/g, micrograms per gram]

| Constituent | Detection limit | Constituent | Detection limit |
|---|---|---|---|
| **Minor constituents (in mg/kg)** | | | |
| Cadmium | 0.10 | Chromium | 0.25 |
| Copper | .10 | Lead | .50 |
| Mercury | .02 | Nickel | .50 |
| **Synthetic organic chemicals (in µg/g)** | | | |
| Aldrin | 0.01 | Dieldrin | 0.02 |
| o,p'DDD | .02 | p,p'DDD | .04 |
| o,p'DDE | .02 | p,p'DDE | .02 |
| Total DDT | .09 | o,p'DDT | .02 |
| p,p'DDT | .07 | Chlordane, cis | .06 |
| Chlordane, trans | .06 | Nonachlor, trans | .02 |
| Methoxychlor | .08 | Endrin | .04 |
| Hexachlorobenzene | .01 | alpha-BHC | .01 |
| gamma-BHC | .01 | PCB | .40 |

The results for the northern hogsucker composited samples showed copper concentrations of 0.72 mg/kg and 0.59 mg/kg, and mean concentrations of 0.10 mg/kg and 0.11 mg/kg for mercury. When compared with the ambient fish tissue data base for northern hogsucker whole samples, these results are near average. A nickel concentration of 0.53 mg/kg was detected in one of the two northern hogsucker composites. All nickel concentrations for northern hogsuckers whole fish samples in the ambient fish tissue data base were below the detection limit.

The analyses of two composited samples of five whole bluehead chubs, *Nocomis leptocephalus*, from High Shoals Creek showed that concentrations of lead and nickel in the tissue were below detection limits. Copper concentrations of 0.56 mg/kg and 0.77 mg/kg in these samples were low compared to mean concentrations for whole bluehead chub in the ambient fish tissue data base (table 22). Concentrations of 0.05 mg/kg and 0.11 mg/kg indicated detectable, but low, mercury values when compared to results in the ambient fish tissue data base. However, the fish tissue samples were collected 9 months after mining activities were observed in the basin, and the data may not reflect natural stream conditions.

Table 22.--*Physical properties of fish and concentrations of selected minor constituents in fish tissue in study basins, 1986-88*

[Results are reported in milligrams per kilogram (mg/kg) wet weight; mm, millimeter; W, whole fish; <, less than; F, fillet]

| Site number (fig. 1) | Study basin | Date | Species common name | Number of fish in sample | Sample type | Mean weight (grams) | Mean length (mm) | Cadmium (mg/kg) | Chromium (mg/kg) | Copper (mg/kg) | Ambient fish tissue data base[1] for copper (mg/kg) | Lead (mg/kg) | Mercury (mg/kg) | Ambient fish tissue data base[1] for mercury (mg/kg) | Nickel (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Beetree Creek | 10/20/87 | Bluegill | 1 | W | 62 | 143 | <0.10 | <0.25 | 0.55 | 0.57 | <0.50 | 0.06 | 0.13 | <0.50 |
| 1 | Beetree Creek | 10/20/87 | Northern hogsucker | 2 | W | 71 | 179 | <.10 | <.25 | .72 | .54 | <.50 | .10 | .08 | .53 |
| 1 | Beetree Creek | 10/20/87 | Northern hogsucker | 5 | W | 79 | 185 | <.10 | <.25 | .59 | .54 | <.50 | .11 | .08 | <.50 |
| 2 | High Shoals Creek[2] | 10/21/87 | Bluehead chub | 5 | W | 18 | 105 | <.10 | <.25 | .56 | .91 | <.50 | .05 | .14 | <.50 |
| 2 | High Shoals Creek[2] | 10/21/87 | Bluehead chub | 5 | W | 49 | 147 | <.10 | <.25 | .77 | .91 | <.50 | .11 | .14 | <.50 |
| 3 | North Harper Creek | 10/21/87 | Brown trout | 3 | W | 246 | 307 | <.10 | <.25 | 1.70 | 1.51 | <.50 | .17 | .06 | <.50 |
| 3 | North Harper Creek | 10/21/87 | Brown trout | 3 | W | 262 | 270 | <.10 | <.25 | 1.50 | 1.51 | <.50 | .06 | .06 | <.50 |
| 4 | Dutchmans Creek | 09/15/87 | Smallmouth bass | 3 | W | 109 | 202 | <.10 | <.25 | .32 | .32 | <.50 | .34 | .05 | <.50 |
| 4 | Dutchmans Creek | 09/15/87 | Redbreast sunfish | 4 | W | 47 | 132 | <.10 | <.25 | .42 | .63 | <.50 | .08 | .15 | <.50 |
| 4 | Dutchmans Creek | 09/15/87 | Redbreast sunfish | 2 | W | 92 | 170 | <.10 | <.25 | .27 | .63 | <.50 | .30 | .15 | <.50 |
| 5 | New Hope River tributary | 04/14/86 | Chain pickerel | 1 | F | 263 | 377 | <.10 | <.25 | .18 | .33 | <.50 | .18 | .35 | <.50 |
| 5 | New Hope River tributary | 04/14/86 | Green sunfish | 2 | W | 56 | 146 | <.10 | <.25 | .41 | .41 | <.50 | .08 | .12 | <.50 |
| 5 | New Hope River tributary | 04/14/86 | Green sunfish | 2 | W | 53 | 143 | <.10 | <.25 | .33 | .41 | <.50 | .06 | .12 | <.50 |
| 5 | New Hope River tributary | 04/14/86 | Green sunfish | 2 | W | 31 | 124 | <.10 | <.25 | .36 | .41 | <.50 | .05 | .12 | <.50 |
| 5 | New Hope River tributary | 09/04/87 | Green sunfish | 6 | W | 72 | 162 | <.10 | <.25 | .53 | .41 | <.50 | .18 | .12 | <.50 |
| 6 | Suck Creek tributary | 09/15/87 | Creek chubsucker | 3 | W | 27 | 135 | <.10 | <.25 | .62 | .11 | <.50 | .17 | .13 | <.50 |
| 6 | Suck Creek tributary | 09/15/87 | Redbreast sunfish | 4 | W | 12 | 86 | <.10 | <.25 | .37 | .63 | <.50 | .12 | .15 | <.50 |
| 7 | Limestone Creek[3] | 08/27/87 | Yellow bullhead | 3 | W | 37 | 145 | <.10 | <.25 | .41 | .51 | <.50 | .23 | .23 | <.50 |
| 7 | Limestone Creek[3] | 08/27/87 | Redfin pickerel | 3 | W | 38 | 169 | <.10 | <.25 | .40 | .51 | <.50 | .25 | .21 | <.50 |
| 9 | W.P. Brice Creek | 03/03/88 | Warmouth | 1 | W | 99 | 170 | <.10 | <.25 | .49 | 1.0 | 1.20 | .28 | .19 | <.50 |

[1] Mean concentrations from North Carolina Department of Environment, Health, and Natural Resources ambient fish tissue monitoring network data used for comparisons.
[2] Data for High Shoals Creek may not reflect natural conditions.
[3] Data for Limestone Creek do not necessarily reflect natural conditions.

At the North Harper Creek site, two composited samples of three whole brown trout, *Salmo trutta*, were analyzed for selected minor constituents. Results indicated that concentrations of lead and nickel in the tissue were below detection limits. Copper concentrations of 1.50 and 1.70 mg/kg were observed, which were near average when compared to whole brown trout results in the ambient fish tissue data base (table 22).

A mercury concentration of 0.17 mg/kg was detected in tissue from one composited sample of brown trout, which was slightly elevated compared with the ambient fish tissue data base for this species. Mercury concentration in the other composited sample of trout was equal to the mean mercury concentration of 0.06 mg/kg in the data base.

Three composited fish samples taken from Dutchmans Creek were analyzed for selected minor constituents. These consisted of (1) three whole smallmouth bass, *Micropterus dolomieui*, (2) four whole redbreast sunfish, *Lepomis auritus*, and (3) two whole redbreast sunfish. Concentrations of lead and nickel in these fish were below detection limits. The smallmouth bass tissue sample contained an average copper concentration of 0.32 mg/kg, but its mercury level of 0.34 mg/kg was elevated when compared to the mean mercury concentration of 0.05 mg/kg in the ambient fish tissue data base for this species (table 22).

The results for both the redbreast sunfish composited samples showed copper concentrations of 0.27 and 0.42 mg/kg, which were low compared to the ambient data base. One redbreast sunfish composited sample contained 0.30 mg/kg mercury concentration that was higher than the ambient fish tissue data base mean value, but the other sample contained a much lower mercury concentration (0.08 mg/kg).

At the New Hope River tributary site, one fillet of chain pickerel, *Esox niger*, and four whole fish composites of green sunfish, *Lepomis cyanellus*, a total of five samples, were analyzed for selected minor constituents. Analyses showed that concentrations of lead and nickel in all fish tissue samples were below detection limits. In the chain pickerel tissue sample, copper and mercury concentrations of 0.18 mg/kg were detected, which were low when compared to the mean values for copper and mercury in the ambient fish tissue data base for chain pickerel fillets (table 22).

Copper and mercury concentrations in the three composited green sunfish samples collected in April 1986 were at or slightly less than the mean values in the ambient fish tissue data base. However, the sample of green sunfish taken in September 1987 contained copper and mercury concentrations slightly elevated with respect to the data base.

At the Suck Creek tributary site, a composited sample of three whole creek chubsuckers, *Erimyzon oblongus*, and a composited sample of four whole redbreast sunfish, *Lepomis auritus*, were analyzed for selected minor constituents. Concentrations of lead and nickel were below detection limits in both tissue samples. In the creek chubsucker sample, a copper concentration of 0.62 mg/kg and a mercury concentration of 0.17 mg/kg were detected (table 22). The result for copper was well above average when compared to the mean value of copper in the ambient fish tissue data base for creek chubsucker whole fish samples. Mercury in the chubsucker tissue sample was slightly above the mean value for mercury in the species.

The results for the composited redbreast sunfish tissue sample showed a copper concentration of 0.37 mg/kg and a mercury concentration of 0.12 mg/kg. These values were below mean compared to the ambient fish tissue data-base values for copper and mercury in redbreast sunfish.

Sampling at the established water-quality site at Limestone Creek, upstream of a swine farm, yielded only one redfin pickerel, *Esox americanus*, and was not used in the analysis. The limited sample was probably a result of the extremely small size of the creek at this location, which becomes dry during low-flow periods. Limestone Creek was also sampled downstream from the swine farm, and a composited sample of three whole yellow bullheads, *Ameiurus natalis*, and a composited sample of three whole redfin pickerel, *Esox americanus*, were analyzed for selected minor constituents. Concentrations of cadmium, chromium, lead, and nickel were all below standard detection levels. In the composited yellow bullhead tissue sample, a copper concentration of 0.41 mg/kg and a mercury concentration of 0.23 mg/kg were detected, which were below average and average, respectively, when compared to the ambient fish tissue data base for yellow bullhead whole fish samples. Copper and mercury concentrations in the redfin pickerel sample were also near mean concentrations of these minor constituents in the ambient fish tissue data base. Although the concentrations of these minor constituents in fish tissue were nominal with respect to the ambient fish tissue data base, these data do not represent natural conditions at this study site because the samples were collected in proximity to a road and downstream from a swine farm.

Chinkapin Creek tributary was the only site at which no fish tissue samples were collected. The stream was dry each time this site was visited to collect tissue samples. However, fish were collected at this site on

June 25, 1987, for analysis of fish community structure. The use of formaldehyde to preserve the specimens precluded the use of these samples for tissue analysis.

At W.P. Brice Creek, one warmouth, *Lepomis gulosus*, was analyzed as a whole fish tissue sample for selected minor constituents. The concentration of nickel was below the detection limit. A copper concentration of 0.49 mg/kg was detected, which was low when compared to the mean value for whole warmouth tissue results in the ambient fish tissue data base. A mercury concentration of 0.28 mg/kg also was detected in this tissue, which was slightly elevated when compared to the data base for this species.

A lead concentration of 1.20 mg/kg in this sample was the only time lead was detected in fish tissue in this study. The ambient fish tissue data-base results for lead in warmouth were below the detection limit.

All results for the analyses of 18 synthetic organic chemicals in fish tissue samples were below the laboratory detection limits for each of these chemicals (table 21). The fish samples for analysis of synthetic organic chemicals at some study sites contained species different from those used for the analysis of minor constituents (table 23). Although the analyses for synthetic organic chemicals were below laboratory detection limits, these results do not necessarily represent natural conditions at High Shoals and Limestone Creeks for the reasons discussed earlier.

Table 23.--*Physical properties of fish sampled for analysis of synthetic organic chemicals in fish tissue at study basins, 1987-88*

[mm, millimeter]

| Site number (fig. 1) | Study basin | Date | Species common name | Number of fish in sample | Mean weight (grams) | Mean length (mm) |
|---|---|---|---|---|---|---|
| 1 | Beetree Creek | 10/20/87 | Northern hogsucker | 5 | 79 | 185 |
| 2 | High Shoals Creek | 10/21/87 | Bluehead chub | 5 | 49 | 147 |
| 3 | High Shoals Creek | 10/21/87 | Brown trout | 3 | 246 | 307 |
| 4 | North Harper Creek | 10/21/87 | Brown trout | 3 | 262 | 270 |
| 5 | Dutchmans Creek | 09/15/87 | Smallmouth bass | 3 | 109 | 202 |
| 6 | New Hope River tributary | 09/04/87 | Green sunfish | 6 | 72 | 162 |
| 7 | Suck Creek tributary | 09/15/87 | Yellow bullhead | 4 | 39 | 151 |
| 8 | Limestone Creek | 08/27/87 | Creek chubsucker | 5 | 30 | 127 |
| 9 | W.P. Brice Creek | 03/03/88 | Brown bullhead | 2 | 200 | 244 |

## Fish Community Structure

A fish community is simply described as all the fish inhabiting a section of a stream. The method used to analyze fish community structure in this study was to count all fish species in a section of a stream and use the Index of Biotic Integrity (IBI) rating (Karr and others, 1986) to evaluate the various species present, the relations between the numbers of each species, and their general health. The IBI, which rates streams from poor to excellent, relies on a number of different factors that include:

| | |
|---|---|
| Number of species | Percentage of green sunfish |
| Number of individuals | Percentage of insectivores |
| Number of darter species | Percentage of omnivores |
| Number of sunfish species | Percentage of piscivores |
| Number of sucker species | Percentage of hybrids |
| Number of intolerant species | Percentage of diseased individuals |

Each factor is evaluated on a 1-3-5 scale, with a score of 1 equal to worst case and a score of 5 equal to best case. The scores of each factor are added and compared to an adjective rating as follows:

| Rating | Score |
|---|---|
| Excellent | 58-60 |
| Good-Excellent | 53-57 |
| Good | 48-52 |
| Fair-Good | 45-47 |
| Fair | 40-44 |
| Poor-Fair | 35-39 |
| Poor | 28-34 |
| Very Poor-Poor | 23-27 |
| Very Poor | 12-22 |
| No Fish | -- |

Each factor based on a percentage is standard, that is, not variable depending on stream size or order. The factors that rely on number can be modified to more closely represent what numbers and kinds of species would be expected to occur within the particular river basin and stream order. A fish community with an excellent rating is "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" as defined by Karr and Dudley (1981).

The fish community is dependent upon habitat availability and water quality. Increases in sediment deposition, for example, will decrease the available habitat for some species and, thus, cause a decline in their numbers as well as alter the numbers and kinds of other fish in the stream. Similarly, water-quality contamination has, in most cases, a generally negative effect upon the fish community structure. The IBI can be a useful biological monitoring tool for assessing the water quality of a stream because the different factors can be related to the amount of stress exerted upon the fish community by various sources of contamination.

Some stresses that affect the fish community in small headwater streams may not be water-quality related. The fact that a number of the streams of the basins selected for this study had periods of no flow in addition to low nutrient levels will tend to skew the IBI results toward the low end of the index and, thus, their rating may not be due to the water quality of the streams, but rather to variability in stream hydrology, habitat stress, or nutrient availability.

The IBI factors were modified for North Carolina streams by replacing percentage of green sunfish with percentage of tolerant indicator species (Karr and others, 1986). The numbers, species, lengths, and weights of the fish used in the community structure analysis are shown in table 24, and the results of the IBI analysis are presented in table 25. Unless otherwise indicated, community sampling occurred during normal flow conditions.

Beetree Creek contained 6 species and a total of 30 individuals. The dominant species was the rainbow trout, *Oncorhynchus mykiss*. This stream had relatively high percentages of omnivores and piscivores (table 25), but the number of species, individuals, darter, sucker, and sunfish species were lower than expected for a mountain stream. However, Beetree Creek is typical of a managed trout stream.

High Shoals Creek contained 6 species and a total of 96 individuals. The dominant species was the rosyside dace, *Clinostomus funduloides*, composing 61 percent of the total population. This stream was almost completely dominated by cyprinids (92 percent) with five cyprinid species and one sucker species present. Relatively high percentages of insectivores and omnivores were represented in the sample. Darter, sunfish, intolerant species, and piscivores were absent. The absence of sunfish in this stream may suggest a limited availability of pool habitat in this stream.

The sample at North Harper Creek contained eight individuals of brown trout, *Salmo trutta*, which was the only species present. Data collected by the North Carolina Division of Inland Fisheries in 1968 indicated that only

Table 24.--*Fish community structure data at each study site, 1986-87*

| Family<br>*Species*<br>Common name | Number of fish | Length range[1] (millimeter) | Total weight (grams) |
|---|---|---|---|
| **Beetree Creek (site 1), June 30, 1987** | | | |
| Salmonidae | | | |
| *Oncorhynchus mykiss* | | | |
| Rainbow trout | 11 | 42-201 | 284 |
| Cyprinidae | | | |
| *Rhinichthys atratulus* | | | |
| Blacknose dace | 8 | 51-87 | 26.8 |
| *Rhinichthys cataractae* | | | |
| Longnose dace | 2 | 87-94 | 16.8 |
| Catostomidae | | | |
| *Hypentelium nigricans* | | | |
| Northern hogsucker | 7 | 163-223 | 537 |
| Centrarchidae | | | |
| *Lepomis auritus* | | | |
| Redbreast sunfish | 1 | 143 | 62 |
| Cottidae | | | |
| *Cottus bairdi* | | | |
| Mottled sculpin | 1 | 87 | 6.7 |
| **High Shoals Creek (site 2), June 30, 1987** | | | |
| Cyprinidae | | | |
| *Campostoma anomalum* | | | |
| Stoneroller | 1 | 74 | 3.5 |
| *Clinostomus funduloides* | | | |
| Rosyside dace | 59 | 40-86 | 157 |
| *Nocomis leptocephalus* | | | |
| Bluehead chub | 3 | 67-148 | 51.3 |
| *Notropis chlorocephalus* | | | |
| Greenhead shiner | 11 | 46-58 | 16.1 |
| *Semotilus atromaculatus* | | | |
| Creek chub | 14 | 40-142 | 179 |
| Catostomidae | | | |
| *Catostomus commersoni* | | | |
| White sucker | 8 | 88-127 | 124 |
| **North Harper Creek (site 3), July 1, 1987** | | | |
| Salmonidae | | | |
| *Salmo trutta* | | | |
| Brown trout | 8 | 142-330 | 1,633 |

[1]A single value represents the length of a single fish.

Table 24.--*Fish community structure data at each study site, 1986-87*--Continued

| Family<br>*Species*<br>Common name | Number of fish | Length range[1] (millimeter) | Total weight (grams) |
|---|---|---|---|
| **Dutchmans Creek (site 4), April 6, 1987** | | | |
| Cyprinidae | | | |
| *Nocomis leptocephalus* | | | |
| Bluehead chub | 3 | 63-136 | 52 |
| *Semotilus atromaculatus* | | | |
| Creek chub | 2 | 38-61 | 34 |
| Catostomidae | | | |
| *Erimyzon oblongus* | | | |
| Creek chubsucker | 2 | 75-77 | 10.6 |
| Ictaluridae | | | |
| *Noturus insignis* | | | |
| Margined madtom | 2 | 86-87 | 3.9 |
| Aphredoderidae | | | |
| *Aphredoderus sayanus* | | | |
| Pirate perch | 2 | 76-89 | 16.7 |
| Centrarchidae | | | |
| *Lepomis auritus* | | | |
| Redbreast sunfish | 10 | 60-170 | 474 |
| *Micropterus dolomieui* | | | |
| Smallmouth bass | 12 | 51-233 | 399 |
| **New Hope River tributary (site 5), April 14, 1986** | | | |
| Esocidae | | | |
| *Esox americanus* | | | |
| Redfin pickerel | 3 | 90-112 | 170 |
| Cyprinidae | | | |
| *Cyprinella analostana* | | | |
| Satinfin shiner | 1 | 66 | 3.5 |
| Ictaluridae | | | |
| *Ameiurus natalis* | | | |
| Yellow bullhead | 1 | 78 | 7 |
| *Ameiurus platycephalus* | | | |
| Flat bullhead | 1 | 90 | 10 |
| Centrarchidae | | | |
| *Lepomis auritus* | | | |
| Redbreast sunfish | 3 | 58-97 | 30 |
| *Lepomis cyanellus* | | | |
| Green sunfish | 47 | 60-185 | 1,724 |
| *Lepomis gibbosus* | | | |
| Pumpkinseed | 13 | 53-117 | 115 |
| *Lepomis macrochirus* | | | |
| Bluegill | 1 | 73 | 7 |

[1]A single value represents the length of a single fish.

Table 24.--*Fish community structure data at each study site, 1986-87*--Continued

| Family<br>*Species*<br>Common name | Number of fish | Length range[1] (millimeter) | Total weight (grams) |
|---|---|---|---|
| **Suck Creek tributary (site 6), September 15, 1987** | | | |
| Cyprinidae | | | |
| *Semotilus atromaculatus* | | | |
| Creek chub | 21 | 75-148 | 222 |
| Ictaluridae | | | |
| *Ameiurus natilis* | | | |
| Yellow bullhead | 8 | 90-171 | 246 |
| Centrarchidae | | | |
| *Lepomis auritus* | | | |
| Redbreast sunfish | 5 | 80-95 | 57 |
| *Lepomis macrochirus* | | | |
| Bluegill | 6 | 50-82 | 38 |
| **Limestone Creek (site 7), April 23, 1987** | | | |
| Anguillidae | | | |
| *Anguilla rostrata* | | | |
| American eel | 1 | 115 | 2.7 |
| Esocidae | | | |
| *Esox americanus* | | | |
| Redfin pickerel | 10 | 111-212 | 275 |
| Catostomidae | | | |
| *Erimyzon oblongus* | | | |
| Creek chubsucker | 1 | 131 | 33 |
| *Erimyzon sucetta* | | | |
| Lake chubsucker | 9 | 77-152 | 302 |
| Ictaluridae | | | |
| *Ameiurus natalis* | | | |
| Yellow bullhead | 5 | 52-147 | 127 |
| Aphradoderidae | | | |
| *Aphredoderus sayanus* | | | |
| Pirate perch | 1 | 85 | 9 |
| Cyprinodontidae | | | |
| *Fundulus lineolatus* | | | |
| Lined top-minnow | 7 | 36-65 | 9.4 |
| Poeciliidae | | | |
| *Gambusia affinis* | | | |
| Mosquitofish | 2 | 43-44 | 1.9 |
| Centrarchidae | | | |
| *Centrarchus macropterus* | | | |
| Flier | 1 | 77 | 10.2 |
| *Enneacanthus gloriosus* | | | |
| Bluespotted sunfish | 8 | 38-90 | 65.5 |
| *Enneacanthus obesus* | | | |
| Banded sunfish | 10 | 35-82 | 35.3 |

[1]A single value represents the length of a single fish.

Table 24.--*Fish community structure data at each study site, 1986-87*--Continued

| Family<br>*Species*<br>Common name | Number of fish | Length range[1] (millimeter) | Total weight (grams) |
|---|---|---|---|
| Chinkapin Creek tributary (site 8), June 25, 1987 | | | |
| Umbridae | | | |
| *Umbra pygmaea* | | | |
| Eastern Mudminnow | 1 | 75 | 6.4 |
| Esocidae | | | |
| *Esox americanus* | | | |
| Redfin pickerel | 1 | 117 | 11.2 |
| Aphredoderidae | | | |
| *Aphredoderus sayanus* | | | |
| Pirate perch | 1 | 120 | 26.8 |
| Centrarchidae | | | |
| *Acantharchus pomotis* | | | |
| Mud Sunfish | 1 | 147 | 73.6 |
| *Centrarchus macropterus* | | | |
| Flier | 6 | 74-86 | 60 |
| W.P. Brice Creek (site 9), August 4, 1987 | | | |
| Anguillidae | | | |
| *Anguilla rostrata* | | | |
| American eel | 3 | 225-275 | 86 |
| Esocidae | | | |
| *Esox americanus* | | | |
| Redfin pickerel | 7 | 113-240 | 456 |
| Ictaluridae | | | |
| *Ameiurus natalis* | | | |
| Yellow bullhead | 4 | 175-340 | 926 |
| Aphredoderidae | | | |
| *Aphredoderus sayanus* | | | |
| Pirate perch | 9 | 53-73 | 29.2 |
| Centrarchidae | | | |
| *Centrarchus macropterus* | | | |
| Flier | 1 | 145 | 57 |
| *Enneacanthus gloriosus* | | | |
| Bluespotted sunfish | 5 | 43-73 | 49 |

[1]A single value represents the length of a single fish.

Table 25.--*Index of Biotic Integrity (IBI) ratings for fish community structure for each study site, 1986-87*

[IBI factor scores are shown in parentheses]

| IBI factor | Beetree Creek | High Shoals Creek | North Harper Creek | Dutchmans Creek | New Hope River tributary | Suck Creek tributary | Limestone Creek | Chinkapin Creek tributary | W.P. Brice Creek |
|---|---|---|---|---|---|---|---|---|---|
| Number of species | 6 (3) | 6 (3) | 1 (1) | 7 (3) | 8 (3) | 4 (1) | 11 (5) | 5 (3) | 6 (3) |
| Number of individuals | 30 (3) | 96 (5) | 8 (1) | 33 (3) | 70 (5) | 40 (3) | 55 (5) | 10 (1) | 29 (3) |
| Number of darter species | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) |
| Number of sunfish species | 1 (3) | 0 (1) | 0 (1) | 1 (3) | 4 (5) | 2 (3) | 3 (3) | 2 (3) | 2 (3) |
| Number of sucker species | 1 (3) | 1 (3) | 0 (1) | 1 (3) | 0 (1) | 0 (1) | 2 (5) | 0 (1) | 0 (1) |
| Number of intolerant species | 1 (3) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) | 0 (1) |
| Percent insectivores | 57 (3) | 81 (5) | 0 (1) | 42 (3) | 94 (5) | 47 (1) | 80 (5) | 90 (5) | 75 (3) |
| Percent omnivores | 6 (5) | 18 (5) | 0 (5) | 21 (3) | 0 (5) | 53 (1) | 1.8 (5) | 0 (5) | 0 (5) |
| Percent piscivores | 37 (5) | 0 (1) | 100 (5) | 37 (5) | 6 (5) | 0 (1) | 18.2 (5) | 10 (5) | 24 (5) |
| Percent tolerant indicator species | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 67 (1) | 0 (5) | 20 (3) | 10 (5) | 31 (3) |
| Percent hybrids | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) |
| Percent diseased | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) | 0 (5) |
| Score total | (44) | (40) | (32) | (40) | (42) | (28) | (48) | (40) | (38) |
| Rating | Fair | Fair | Poor | Fair | Fair | Poor | Good | Fair | Poor-fair |
| Relative presence of aufwuchs | None | Moderate | None | None | Moderate | Abundant | None | Abundant | Moderate |

brook trout, *Salvelinus fontinalis*, were present in this stream (Jim Borowa, North Carolina Division of Inland Fisheries, oral commun., 1988). It is likely that non-native brown trout were introduced into this stream and were able to out-compete and replace the native brook trout. The high slope of this stream, which probably contains several natural fish barriers, would make recruitment by other species difficult.

Dutchmans Creek contained 7 species and a total of 33 individuals. The dominant species were the redbreast sunfish, *Lepomis auritus*, and the smallmouth bass, *Micropterus dolomieui*. There was a high percentage (37 percent) of piscivores at this site (table 25). The percentage of omnivores and insectivores was fair, as were the numbers of species, individuals, sucker, and sunfish species. Darter and intolerant species were absent. The smallmouth bass population at this location was introduced through stocking, which probably gave this species an advantage over the native species and is a limiting factor in this stream. Although Dutchmans Creek was sampled during normal flow conditions, flow data show that this stream has severely reduced flow during prolonged dry summer months.

The sampling for fish community structure in New Hope River tributary was performed downstream of the culvert at Secondary Road 1716 because a 2-ft drop from the culvert acts as a barrier to upstream fish movement. There were no fish at the designated water-quality sampling site upstream of the road. This stream contained 8 species with a total of 70 individuals, the dominant species of which was the green sunfish, *Lepomis cyanellus*. There were relatively large numbers of total individuals, sunfish species, piscivores, and insectivores. Absent were darter, sucker, and intolerant species.

Because of the numbers of sunfish and because the sampling site was downstream from a road, the fish community structure there does not represent natural stream conditions for the New Hope River tributary study basin. The green sunfish is a very pollution-tolerant species, and its presence in high numbers can be indicative of fish community stress (Lemley, 1985). The most probable source of stress to the fish community was that this stream went dry for extended periods. The sampling site was also very close to B. Everett Jordan Reservoir, which would limit recruitment primarily to sunfish. Dominance of the fish community by lake species was observed at this site, which had over 91 percent sunfish. The stream at the sampling site likely experienced its greatest stress when the Jordan Reservoir was constructed, changing this stream from a fishery standpoint into an extension of the lake.

Suck Creek tributary was sampled after a long period of no flow and contained 4 species with a total of 40 individuals. The dominant species was the creek chub, *Semotilus atromaculatus*. This species is an omnivore, and its abundant presence, 53 percent of the total fish community, is indicative of a fish community out of the normal trophic balance. The abundance of varied aquatic organisms, including algae, that adhere to and form a surface coating on streambed material (aufwuchs) observed at this site would favor omnivorous species. The sample also had a low percentage (less than 50 percent) of insectivores and no piscivores; absent were darter, sucker, and intolerant species.

The sampling site was just above a small pond, and the fish community probably experiences stress as a result of low-flow and no-flow conditions. The presence of the pond also would limit the recruitment of many species, especially minnows and darters, which would be expected to exist in streams in this area.

The Limestone Creek fish community samples contained 11 species and a total of 55 individuals. The dominant species were banded sunfish, *Enneacanthus obesus*, and redfin pickerel, *Esox americanus*. There was a relatively large number of sucker species and a relatively high percentage of omnivores, insectivores, and piscivores. The number of sunfish species for this area and for this size stream are usually higher than observed (Menhinick, 1991). The species *Lepomis* was absent, possibly due to the lack of a pooling habitat and rooty vegetation which this species prefers. Also absent at this site were darters and intolerant species.

Chinkapin Creek tributary had 5 species but only 10 individuals. This tributary is an ephemeral stream that is often dry 100 ft below the sampling site. The only recruitment to this site would be from a swamp upstream and from Chinkapin Creek when it is flooded.

W.P. Brice Creek is a blackwater stream that contained 6 species with a total of 29 individuals. The dominant species were pirate perch, *Aphredoderus sayanus*, and redfin pickerel, *Esox americanus*. There was a relatively high percentage of piscivores and total insectivores. Absent in this sample were darters, suckers, and intolerant species.

Fish communities in blackwater streams are difficult to assess because of natural stresses, such as low dissolved-oxygen concentration (fig. 6C) and low pH (fig. 7). The low total number of fish and the low diversity of fish species at this site were probably the result of these natural stresses and the sampling methodology employed in this study. This site was sampled with hoop nets which are very selective in the type of species and size of fish captured.

## Benthic Macroinvertebrates

Benthic macroinvertebrates were collected one time at each study site to quantify the benthic organisms, or benthos, living in these small streams. These data are used to quantify some characteristics of the benthic community and to assign a bioclassification rating to the study site. The bioclassification ratings are based on the taxa richness and biotic index values at each location. These values are compared with criteria developed by the Biological Assessment Group for the several major ecoregions in North Carolina (North Carolina Department of Environment, Health, and Natural Resources, 1990), and each site in this study was given a bioclassification adjective rating. The taxa richness of the benthic macroinvertebrates and bioclassification of the sites selected for this study are summarized in table 26, and a species list of all organisms collected is listed in the appendix.

Total taxa richness ($S_T$) and taxa richness for the sum of Ephemeroptera, Plecoptera, and Trichoptera taxa ($S_{EPT}$) are calculated and are used to assign a bioclassification to each station (Excellent, Good, Good to Fair, Fair, or Poor). Bioclassifications were determined based on two metrics: (1) taxa richness totals, where emphasis is placed on the intolerant taxa in the Ephemeroptera, Plecoptera, and Trichoptera, and (2) biotic indexes, which summarize the pollution tolerance values of each taxa (EPT biotic indexes included) collected in the sample, weighted by their abundance. In addition to taxa richness, the data summaries also include the calculation of a biotic index for each sample (table 26). Tolerance values for the taxa vary from 0 (most intolerant) to 5 (most tolerant).

Flow conditions during the sampling for the benthos are summarized in table 27, as well as some site characteristics that may be pertinent to the interpretation of the data. In some cases, benthos were collected before stream gages were installed (Suck Creek tributary and Dutchmans Creek), or less than 30 days after a stream gage was installed (Chinkapin Creek tributary, W.P. Brice Creek, and Limestone Creek). Flow data relative to benthos sampling are limited or not available at these sites.

Benthic samples from Beetree Creek were collected March 17, 1986, during swift flow conditions. The streambed at this site consists of large boulders and cobble riffles. The benthic community at this location is dominated by intolerant taxa, including several mayflies: *Leucrocuta aphrodite*, *Epeorus pleuralis*, and *Epeorus dispar*, *Paraleptophlebia* spp., and *Baetis flavistriga;* stoneflies: *Allocapnia* spp. and *Tallaperla* spp.; and caddisflies: *Diplectrona modesta* and *Rhyacophila carolina*. Taxa richness

Table 26.--*Benthic macroinvertebrate taxa richness for major taxonomic groups, biotic indexes, and bioclassification by study basin*

| Taxa | Number of individuals at study basins | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Beetree Creek | High Shoals Creek | North Harper Creek | Dutchmans Creek | New Hope River tributary | Suck Creek tributary | Limestone Creek | Chinkapin Creek tributary | W.P. Brice Creek |
| Ephemeroptera | 18 | 13 | 15 | 12 | 13 | 4 | 1 | 0 | 3 |
| Plecoptera | 8 | 5 | 9 | 2 | 6 | 6 | 0 | 1 | 1 |
| Trichoptera | 13 | 14 | 19 | 10 | 10 | 11 | 0 | 0 | 9 |
| Coleoptera | 3 | 8 | 5 | 12 | 6 | 3 | 6 | 3 | 3 |
| Odonata | 1 | 5 | 3 | 3 | 3 | 2 | 3 | 1 | 5 |
| Megaloptera | 0 | 2 | 1 | 3 | 2 | 3 | 0 | 0 | 2 |
| Diptera | 15 | 17 | 24 | 9 | 19 | 23 | 12 | 12 | 15 |
| Miscellaneous diptera | 8 | 6 | 7 | 5 | 10 | 7 | 2 | 8 | 3 |
| Oligocheata | 3 | 3 | 2 | 2 | 4 | 2 | 6 | 6 | 5 |
| Crustacea | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 |
| Mollusca | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| Other | 1 | 1 | 3 | 0 | 1 | 0 | 2 | 2 | 3 |
| Total taxa richness | 72 | 76 | 90 | 60 | 76 | 63 | 35 | 36 | 53 |
| EPT[1] richness | 39 | 32 | 43 | 24 | 29 | 21 | 1 | 1 | 13 |
| EPT abundance[2] | 161 | 107 | 172 | 99 | 163 | 89 | 10 | 1 | 66 |
| Biotic index | 1.93 | 2.24 | 1.96 | 2.13 | 2.48 | 2.51 | 3.54 | 3.62 | 3.11 |
| EPT biotic index | 1.59 | 1.64 | 1.33 | 1.67 | 2.09 | 1.54 | 3.30 | 3.30 | 2.12 |
| Bioclassification | Excellent | Good | Excellent | Excellent | Excellent | Excellent | Poor | Poor | Good-fair |

[1]EPT indicates sum of Ephemeroptera, Plecoptera, and Trichoptera.

[2]Sum of subjective evaluation of relative abundances of species composing the EPT taxa, where rare=1, common=3, and abundant=10.

Table 27.--*Flow conditions and selected site characteristics at study basin sampling sites for benthic macroinvertebrates*

[7Q10, annual lowest streamflow over a 7 consecutive day period that would occur on an average of once every 10 years; NA, not available]

| Study basin | Collection date | Flow description during sampling | Discharge (cubic feet per second) | | | Estimated streambed composition (percent) | | | | | Relative bank erosion | Canopy (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | At collection date | Mean flow 30 days prior to collection | During 7Q10 (low-flow) periods | Boulder | Cobble | Gravel | Sand | Silt | | |
| Beetree Creek | 3/17/86 | Swift | 63.0 | 35.0 | 0.71 | 60 | 20 | 10 | 10 | 0 | None | 90 |
| High Shoals Creek | 7/22/86 | Moderate | .90 | 1.27 | .9 | 10 | 40 | 10 | 30 | 10 | None | 100 |
| North Harper Creek | 8/06/86 | Moderate | .47 | .69 | .4 | 40 | 20 | 10 | 20 | 10 | None | 100 |
| Dutchmans Creek | 7/31/85 | Moderate | NA | NA | .45 | 20 | 50 | 10 | 20 | 0 | None | 100 |
| New Hope River tributary | 4/01/86 | Moderate | .54 | 4.4 | .00 | 30 | 40 | 20 | 10 | Trace | Moderate | 90 |
| Suck Creek tributary | 3/06/86 | Moderate | NA | NA | .00 | 40 | 30 | 10 | 10 | 10 | Moderate | 90 |
| Limestone Creek | 4/23/86 | Low | .42 | [1].82 | .00 | 0 | 0 | 0 | 10 | 90 | None | 90 |
| Chinkapin Creek tributary | 4/03/86 | None | .0 | NA | .00 | 0 | 0 | Trace | 15 | 85 | Moderate | 95 |
| W.P. Brice Creek | 4/22/86 | Moderate | 6.7 | [1]14.7 | .00 | 0 | 0 | 0 | Trace | 100 | None | 90 |

[1]Mean flow based on less than 30 days record prior to sampling.

values were very high ($S_T$=72 and $S_{EPT}$=39) but within the good bioclassification category. However, the biotic index of 1.93 (table 26) was within an excellent rating, which permitted an overall excellent bioclassification for Beetree Creek.

High Shoals Creek has perennial flow at the sampling site, and the streambed material is dominated by cobble and sand (table 27). Many intolerant taxa were present; however, abundance (or density) appeared to be reduced when compared to other mountain streams. The sum of Ephemeroptera, Plecoptera, and Trichoptera (EPT) abundance at this site was 107, which, compared with EPT abundance values at North Harper and Beetree Creeks, was significantly lower (table 26). For example, *Isonychia* spp., *Tallaperla* spp., *Diplectrona modesta*, and *Glossosoma* spp., all of which are generally abundant in many mountain streams, were all present in High Shoals Creek but were rare to common in the collection. As a result, taxa richness and biotic index values for High Shoals Creek were within the good bioclassification for mountain stream systems (North Carolina Department of Environment, Health, and Natural Resources, 1990).

North Harper Creek is also a perennial stream whose streambed is dominated by boulders, cobble, and sand, with several deep pools in the sampling area. The benthic macroinvertebrate community here contained a very diverse assemblage of intolerant taxa with taxa richness values of $S_T$=90 and $S_{EPT}$=43 (table 26). Many of the abundant taxa included those that are typically found in clean mountain stream systems (mayflies: *Drunella conestee* and *Heptagenia marginalis*; the dragonfly: *Lanthus vernalis*; stoneflies: *Tallaperla* spp. and *Allocapnia* spp.; and caddisflies: *Diplectrona modesta* and *Rhyacophila nigrita*). The biotic indexes were also low. These data indicate that North Harper Creek is a good example of a natural mountain stream system showing little effect from human activities. Both taxa richness and biotic index values indicate an excellent bioclassification at this location according to criteria developed for mountain streams (North Carolina Department of Environment, Health, and Natural Resources, 1990).

Dutchmans Creek typically has reduced flow during prolonged summer periods with little rainfall. Minimum flows often are less than 1.0 $ft^3/s$ for extended periods (table 5). The streambed is composed mostly of cobbles, boulders, and sand. Benthos samples were collected July 31, 1985, which was prior to the installation of the stream gage; the streamflow condition during sampling was moderate (table 27). Many taxa collected from this location were those that are typically collected in mountain streams, especially *Epeorus* spp. and *Dolophilodes* spp., and several intolerant taxa were also abundant. Taxa richness and biotic index values were slightly lower at this site than those recorded from New Hope River tributary, which is in the same geochemical zone. However, the bioclassification of the stream was rated as excellent.

The streambed at the New Hope River tributary site is dominated by boulders and cobble riffles. Flow data from this location indicated that there is little or no flow for extended periods of time. However, winter and spring months are high-flow periods with several large runoff events occurring each year. The benthos sample was collected on April 1, 1986, after a continuous-flow period averaging more than 4 $ft^3/s$ in the preceding 30 days (table 27).

Taxa richness values were high for New Hope River tributary with $S_T$ and $S_{EPT}$ values of 76 and 29, respectively (table 26). Taxa richness totals and biotic index values indicate an excellent bioclassification for this stream (table 26). Several intolerant taxa were abundant and include many mayfly (*Ameletus lineatus*, *Eurylophella bicolor*, and *Paraleptophlebia* spp.) and stonefly (*Amphinemura* spp. and *Clioperla clio*) species. Several other intolerant taxa were common (*Haploperla brevis*, *Dolophilodes* spp., and *Rhyacophila carolina*). Life cycle strategies of these taxa probably included diapause (a period of reduced activity) and(or) over-summering as eggs buried within the substrate. High taxa richness values and the presence of the intolerant taxa indicate that this stream may be considered typical of a small undisturbed forested basin in geochemical zone II.

Suck Creek tributary is the smallest of the forested catchments in this investigation. Benthos samples were collected on March 6, 1986, prior to the installation of a stream gage but during moderate streamflow conditions (table 27). The benthos collection site has mostly a boulder and cobble streambed, which is unusual for streams in geochemical zone III.

Taxa richness values were high ($S_T$=63 and $S_{EPT}$=21) but not quite within the excellent category; however, the biotic index value of 2.51 is classed as excellent. Many of the benthos were intolerant and included *Habrophlebia vibrans*, *Eccoptura xanthenes*, *Strophopteryx* spp., *Diplectrona modesta*, *Wormaldia* spp., and *Anisocentropus pyraloides*. Although the small size of this catchment tends to decrease taxa richness, the overall bioclassification of the stream is excellent and may be considered representative of benthic communities in undisturbed forested basins in geochemical zone III.

The Limestone Creek streambed is composed almost entirely of silt and sand. Hydrologic records indicate that this site has no measurable flow sporadically during most summer and fall months. Benthos were collected April 23, 1986, during streamflow conditions described as low (table 27), and many benthic taxa were collected from snag habitats.

Dominant taxa included the amphipod, *Crangonyx* spp.; the isopod, *Asellus* spp., and the chironomid, *Cricotopus/Orthocladius* sp. 52. Taxa richness and biotic index values give this site a bioclassification rating of poor (table 26). The presence of a swine farm immediately upstream of the macroinvertebrate collection site likely affects the benthic macroinvertebrate community, and the benthos collection is not considered typical for undisturbed catchments in geochemical zone IV.

Chinkapin Creek tributary has a sandy silt streambed and consists of a braided channel at the collection site above the road, and a somewhat more confined channel below the road. The swamp-like characteristics of the catchment are typical of small streams in geochemical zone V. There was no measurable flow on the collection date. Periods of no flow occur for several months each year, but mean flow for the 30 days prior to the collection date is unknown.

The benthic community at this site was difficult to assess because the swamp-like conditions of the catchment naturally stress the fauna due to low dissolved oxygen and high organic loadings. The dominant taxa at this site were amphipods (*Crangonyx* spp.) and isopods (*Asellus* spp.), two groups which have several over-summering strategies, and Chironomidae (mostly *Cricotopus/Orthocladius* sp. 10), which have short life cycles. Taxa richness values were very low and the biotic index values were very high (table 26), indicating a bioclassification rating of poor; nevertheless, the benthos represent a natural macroinvertebrate community in undisturbed swampy watersheds in geochemical zone V.

W.P. Brice Creek has the largest catchment area of any of the sites selected for this study. The creek has a braided channel with a streambed dominated by silt. The water is clear but is brownish in color due to humic substances in the water, which is characteristic of drainage from a swampy catchment. Although zero flow may occur in W.P. Brice Creek occasionally, the stream did not dry up during the study period. The average flow 30 days prior to benthic collection was about 15 $ft^3/s$.

Most benthic taxa were collected from snag habitats such as submerged branches. Taxa richness values were higher at this site than at Chinkapin Creek tributary, reflecting a more permanent aquatic habitat. Although many intolerant taxa were collected from this location, including mayflies (*Eurylophella temporalis* and *Leptophlebia* spp.) and caddisflies

(*Heteroplectron americanum*, *Triaenodes abus*, and *Molanna blenda*), the bioclassification rating is only good-fair. The benthic community as collected here probably reflects natural conditions in a highly acidic stream.

## Discussion

The biological analyses were intended to supplement the water-quality data by providing background information about specific biological characteristics of streams whose basins consist of undisturbed forest land. Observations regarding the results of the biological sampling effort are presented in this section.

Fish tissue analyses might be expected to show minimal concentrations of minor constituents, possibly related to the geology of the basin, and show only traces of synthetic organic compounds that might be transported by the atmosphere. In the case of synthetic organic compounds, these expectations were met because none of the 18 synthetic organic compounds were detected in tissue samples. This is also supported by the water-quality data that indicated no presence of detectable organochlorine insecticides in stream water and very minor amounts in streambed samples.

Copper and mercury were the only minor constituents detected in fish tissue at all study sites. About one-third of these observations were greater than mean concentrations of these constituents in comparable fish tissue in the ambient fish data base.

At Beetree Creek two of the three tissue samples exceeded the mean concentrations of copper in the ambient fish tissue data base. These results may relate to the water-quality data at Beetree Creek that show the greatest mean total copper concentration during low-flow conditions (table 16). The results may also relate to the high value for total copper in streambed material at Beetree Creek (table 18).

Most of the fish tissue samples contained concentrations of mercury equal to or less than mean concentrations in the ambient fish tissue data base. Mercury concentrations in fish tissue collected during this study apparently are not related to the varied distribution of mercury in stream water and streambed material.

The single observation of lead in fish tissue at W.P. Brice Creek was more than twice the detection limit. This positive value for lead, plus the slightly elevated mercury concentration in the fish tissue, may be due to this stream's low pH values (fig. 7), which tend to increase the bioavailability of these constituents. Two tissue samples from Limestone Creek, which also contains low pH water, showed no detectable concentration of lead. However, the fish tissue analyses from Limestone Creek do not represent natural conditions because of the location of the sampling site.

Fish tissue samples were collected in High Shoals Creek after mining activities began in the basin. The results of minor constituent and synthetic organic compound analyses of the two samples of fish taken there do not represent natural conditions at this study site.

At New Hope River tributary, there were no fish at the designated sampling site upstream of the gaging station, and fish samples had to be collected downstream of a road culvert. The results of fish tissue analyses at this study site are not representative of natural conditions, although the analyses are comparable to results at the other study sites.

Because the streams at the study sites drain undisturbed forested basins, it might be expected that they should receive an excellent IBI rating for fish community structure and an excellent bioclassification rating for the benthic community composition. A stream that receives a rating other than excellent is indicative that some stress has been placed on its biological component. Such stress could result from natural or manmade conditions or a combination of both.

Stress in mid- to high-order perennial streams commonly is exerted upon the biological communities by various sources of contamination. However, stress to a biological community can also be achieved by naturally occurring drastic changes in hydrology or habitat. Naturally occurring stresses in the low-order streams observed in this study are streamflow intermittency, low pH, or low nutrient availability.

Four of the streams selected for this investigation had prolonged periods of no flow: New Hope River tributary, Suck Creek tributary, Limestone Creek, and Chinkapin Creek tributary (table 5); flow in Dutchmans Creek approached no-flow conditions at times. This stress limits the number of biological species that can survive. Williams (1987) suggests that survival of benthic macroinvertebrate species depends on the length of the dry period, and survivors range from facultative species (physiologically tolerant taxa with flexible life cycles) to obligate species restricted to temporary waters. Also, the number of individual fish is limited in these types of streams due to the inability to recruit from higher order downstream waters.

Fish community and benthic macroinvertebrate samples were to be collected at the same designated sampling location as the water-quality samples so that natural stream conditions would be represented as closely as possible. However, due to the small drainage area, intermittent flow characteristics, and the required fish sample size, collection sites were relocated downstream at New Hope River tributary and Limestone Creek, where the stream conditions were likely to be more affected by some development. High Shoals Creek fish samples were collected after the site was discontinued from this study due to mining activities in the basin. Limestone Creek was the only site at which the benthic macroinvertebrate samples were collected at a location known to be subject to the effects of upstream development.

The benthic macroinvertebrate collections indicated that Beetree Creek, North Harper Creek, Dutchmans Creek, New Hope River tributary, and Suck Creek tributary had bioclassification ratings of excellent, which indicates natural stream conditions exist at each of these sites with respect to their benthic communities. However, the fish community IBI ratings of these streams range from poor to fair. Natural stresses on the fish communities may include low nutrients at all these sites and intermittent flows at New Hope River tributary and Suck Creek tributary. The fish community samples collected at New Hope River tributary are not representative of natural stream conditions due to the sampling location downstream from a road.

Benthic macroinvertebrate samples were collected in High Shoals Creek prior to the detection of increased sediment in water-quality samples and the subsequent discontinuation of this site from the study. High Shoals Creek had a bioclassification rating of good, but this rating could be indicative of the addition of contaminated sediment to the stream that was not observed in water-quality samples before the site was discontinued.

The IBI fish community structure was rated fair. Fish samples at High Shoals Creek were collected after the site was discontinued from the study due to mining activities in the basin. The fish community structure is not representative of natural stream conditions.

In order to obtain sufficient sample size in Limestone Creek, the benthic macroinvertebrates and fish were sampled at a location downstream from a swine farm. The bioclassification rating of the site was poor, and the fish community structure rating was good. Again, none of these results are indicative of natural conditions at this site due to the effect of upstream development.

Chinkapin Creek tributary and W.P. Brice Creek represent typical Coastal Plain Province streams that impose stress on their biota under natural conditions. Chinkapin Creek tributary had a mean pH of 4.9 and a mean dissolved-oxygen concentration of 6.8 mg/L, and it often went dry below the sampling site. As a result of these stresses, this stream received a bioclassification of poor and a fish community structure rating of fair. Because of these stream conditions, however, the evaluation of the fish community structure is questionable because recruitment is limited to upstream swamps much of the time.

The mean concentration of dissolved oxygen and mean pH in W.P. Brice Creek are less than in Chinkapin Creek tributary, but a permanent aquatic habitat is maintained during low-flow periods. Additional stress may also result from elevated chloride concentrations during low-flow periods (table 9) due to encroachment of saline water from the Neuse-Pamlico estuary. W.P. Brice Creek received a bioclassification rating of good to fair and a fish community structure rating of poor to fair.

## SUMMARY

This report presents the findings of a study conducted from July 1985 through September 1988 to characterize selected physical, chemical, and biological components of streams draining undeveloped, forested basins. This study is the final phase of an earlier investigation (1973-78) to provide a basis for defining background water-quality conditions in streams throughout North Carolina. Data on sediment quality, synthetic organic compounds, fish tissue analyses, precipitation chemistry, and biological communities, which were not addressed in the 1973-78 study, were included in this study.

Stream-water quality and biological communities are largely influenced by the quality of precipitation, soils and rocks, runoff intensity, channel characteristics, and low-flow conditions. Factors common to forested basins that affect stream-water quality are the forest canopy and forest litter.

Nine sampling sites were established on streams that drain undeveloped, forested basins. Particular care was taken to select basins that contained no roads, residences, farms, or other man-influenced activities. The selected sites drain forested basins ranging in size from 0.67 to 11.2 $mi^2$ and represent five geochemical zones across North Carolina.

During the study period, annual precipitation throughout North Carolina was below normal in 1986 and 1988. Most of the State experienced a severe drought in the summer of 1986. The lack of precipitation was reflected in streamflow, which was also below normal during these periods. These conditions reduced the opportunity to collect the number of samples during periods of stormflow needed to define water quality throughout a full range of discharge.

Measured specific conductance values ranged from 8 to 120 µS/cm at 25 °C, and mean values tended to be slightly greater at study sites in the eastern half of the State. Specific conductance during low-flow conditions was slightly greater than during stormflow, reflecting the influence of a more mineralized ground-water contribution to streamflow.

The relation between dissolved-oxygen concentration and water temperature varied from west to east across the State, especially during the summer months. For natural streamflow conditions, the daytime mean water temperature and mean dissolved-oxygen concentration at Beetree Creek in the Blue Ridge Province were 18 °C and 8.3 mg/L, respectively. At W.P. Brice Creek in the Coastal Plain Province, these values were 22 °C and 4.6 mg/L. Dissolved-oxygen concentrations less than 5 mg/L at the Coastal Plain study sites are attributed to sluggish, non-turbulent summertime streamflow, and to an abundance of decaying organic matter that rapidly depletes dissolved oxygen in the streams.

Sediment discharge in streams draining forested basins is highly variable and is greatest in the streams in the Blue Ridge and Piedmont Provinces. The sediment yield ranged from 170 tons/mi$^2$ at North Harper Creek in 1987 to 0.7 ton/mi$^2$ at Chinkapin Creek tributary in 1988. Estimated sediment yields were 1 to 11 times greater during the year when precipitation was normal to above normal than during the drier years.

Observed values of stream water pH ranged from 3.5 units in Limestone and W.P. Brice Creeks to 7.7 in Dutchmans Creek. In general, the mean pH of stream water was lowest at the three easternmost study sites, presumably due to the presence of acidic soil conditions and abundant decaying organic matter.

Analyses of major dissolved constituents included the ions of calcium, magnesium, potassium, sodium, silica, chloride, fluoride, and sulfate, and the dissolved solids (sum of major ions) constituent. Precipitation data showed that concentrations of calcium, magnesium, potassium, and sodium constitute no more than 9 percent of stormflow concentrations of these constituents. Chloride concentrations in precipitation tended to be greater in the eastern part of the State; concentrations of sulfate in precipitation ranged between 20 and 30 percent of stormflow concentrations, but no geographic trends in concentration were observed.

Because concentrations of major dissolved solids in stream water are influenced by the geology of a basin, mean concentrations of these constituents were grouped by geochemical zone and by flow condition and compared with ranges of values reported by earlier investigators. About 73 percent of the mean values for this study are within the ranges of values given in the earlier study.

Nutrients in stream water were analyzed as several combinations of nitrogen compounds and total phosphorus. Concentrations of total nitrogen under natural conditions varied across the State and ranged from a mean concentration of 0.16 mg/L during low-flow conditions to 1.2 mg/L during stormflow; both measurement extremes were from North Harper Creek in the Blue Ridge Province. Organic nitrogen accounted for 60 to 85 percent of the total nitrogen concentration at all study sites. Mean concentrations of ammonia nitrogen ranged from 0.01 to 0.07 mg/L during all flow conditions. During low-flow conditions at all sites, mean concentrations of ammonia nitrogen equalled or exceeded the suggested limit of 0.02 mg/L for waters suitable for fish reproduction. Except for ammonia nitrogen, mean concentrations of the other nitrogen constituents tended to be about twice as great during stormflow as during low flows.

Mean concentrations of total phosphorus were nearly uniform across the State and ranged from 0.01 to 0.03 mg/L for low-flow conditions to 0.01 to 0.04 mg/L for stormflow conditions. The ratios of mean concentrations of total nitrogen to total phosphorus ranged from 11:1 to 110:1, an indication that phosphorus was the limiting nutrient factor.

A limited number of streambed samples were analyzed for nutrients. Nearly all of the total nitrogen in these samples was organic nitrogen compared to about 70 percent in stream water. Although the reason is not understood, the streambed sediments of Limestone Creek, New Hope River tributary, and Beetree Creek had significantly greater mean total nitrogen concentrations than at other sites. Phosphorus concentrations in streambed material were reported as orthosphosphate. There were insufficient data to explain large differences in mean concentrations of orthophosphate, such as 157 mg/kg at Beetree Creek and 6.7 mg/kg at Limestone Creek.

Water and streambed material were collected and analyzed for selected minor constituents that included aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, and zinc. Concentrations of total iron, total aluminum, and total manganese vary directly with streamflow conditions and are related to suspended-sediment concentrations. All mean concentrations of total iron and many mean concentrations of total manganese in stream water exceeded recommended limits for these constituents.

Zinc is a widespread constituent, but its concentration in stream water from forested basins is usually less than 10 µg/L. However, at least one sample from each of five sites equalled or exceeded the State of North Carolina standard of 50 µg/L.

Arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, and selenium occurred in very low concentrations and were below detection limits in most analyses. One low-flow sample at North Harper Creek contained a total lead concentration of 64 µg/L, which was the only value to exceed the recommended Federal maximum contaminant level.

Mean and maximum concentrations of total copper, total lead, and total zinc in streambed material were non-elevated with respect to a classification that uses adjective ratings to evaluate the presence of some minor constituents in streambeds. Two streambed samples at New Hope River tributary contained highly or extremely elevated concentrations of total chromium, and one sample at High Shoals Creek was classified as extremely elevated in total mercury concentration.

Stream waters in the forested basins were free of organochlorine insecticides at the time of sampling. However, insecticides were detected in 18 of 60 samples of streambed material and ranged from 0.1 to 3.3 µg/kg in concentration. The insecticides detected were DDD, DDE, DDT, Lindane, and Mirex.

The mean biochemical oxygen demand concentration in streams draining forested basins ranged from 0.35 mg/L to 1.0 mg/L. There was a general increase in the mean BOD concentration from west to east across the State.

The biological characteristics of streams that drain undeveloped, forested basins that were monitored were fish tissue analyses, fish community structure, and analyses of benthic macroinvertebrates. Fish tissue was analyzed for 6 minor constituents and 18 synthetic organic chemicals, and the results compared to a statewide ambient fish tissue monitoring network data base.

About 35 percent of the analyses showed detectable concentrations of copper, lead, mercury, and nickel in fish tissue. Two fish samples from Dutchmans Creek contained relatively high concentrations of mercury (0.34

and 0.30 mg/kg) compared with the ambient fish tissue data base, and one fish sample from W.P. Brice Creek contained a relatively high concentration of lead at 1.2 mg/kg. Synthetic organic chemicals were not detected in fish tissue.

The fish community structure data were scored and rated using the Karr's Index of Biotic Integrity as modified for North Carolina. The streams rated from poor to good. Limestone Creek was the only stream rated good, and North Harper Creek and Suck Creek tributary were rated poor.

Stress on the fish communities was notable in all streams but was not necessarily attributed to poor water quality. The results of the IBI tend to be skewed toward the low end of the index due to long periods of no flow at nearly half of the study sites, in addition to low nutrient levels, as would be expected in headwater streams. Thus, the IBI may not be a good indicator of water quality, but rather an indicator of stress due to hydrologic and(or) low nutrient conditions.

Results of the benthic macroinvertebrate surveys indicate that five of the nine streams selected for this investigation were rated excellent using taxa richness and biotic indexes developed for bioclassification of forested streams in North Carolina. These five streams were Beetree Creek, North Harper Creek, Dutchmans Creek, New Hope River tributary, and Suck Creek tributary. Swamp-like conditions in Chinkapin Creek tributary and W.P. Brice Creek may have contributed to ratings of poor and good to fair, respectively. However, these results represent natural conditions at these sites.

The bioclassification rating of High Shoals Creek was good, but was based on sampling conducted before it was discovered that mining operations were occurring in the basin, and the results are not representative of natural conditions. Likewise, the rating of Limestone Creek was poor because the benthic macroinvertebrate sampling site was downstream of a swine farm.

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# APPENDIX

**Benthic macroinvertebrate taxa list by forested basin**

## Appendix--*Benthic macroinvertebrate taxa list by forested basin*

[spp., more than one species; group or complex, assemblages of related taxa; sp., single species; sp. 14, distinct species within a genus. R, rare; C, common; A, abundant; ---, absent]

| CLASS<br>ORDER<br>Family<br>*Genus species*<br>*Subgenus* | Bee-tree Creek | High Shoals Creek | North Harper Creek | Dutch-mans Creek | New Hope River tribu-tary | Suck Creek tribu-tary | Lime-stone Creek | Chinka-pin Creek tribu-tary | W.P. Brice Creek |
|---|---|---|---|---|---|---|---|---|---|
| TURBELLARIA | | | | | | | | | |
| TRICLADIDA | | | | | | | | | |
| Planariidae | | | | | | | | | |
| *Dugesia tigrinia* | R | --- | --- | --- | --- | --- | --- | --- | --- |
| OLIGOCHAETA | | | | | | | | | |
| HAPLOTAXIDA | | | | | | | | | |
| Enchytraeidae | --- | --- | --- | --- | --- | --- | R | R | R |
| *Chaetogaster* spp. | --- | --- | --- | --- | --- | --- | --- | C | --- |
| *Nais* spp. | R | --- | --- | --- | R | --- | --- | A | --- |
| Tubificidae | | | | | | | | | |
| *Ilyodrilus templetoni* | --- | --- | --- | R | --- | R | C | --- | R |
| *Isochaetides curvisetosus* | --- | --- | --- | --- | --- | --- | C | --- | --- |
| *Isochaetides freyi* | --- | --- | --- | --- | --- | --- | C | --- | --- |
| *Limnodrilus* spp. | --- | R | --- | --- | R | --- | --- | --- | C |
| *Rhyacodrilus cocinneus* | --- | --- | --- | --- | --- | --- | --- | A | --- |
| *Spirosperma nikolskyi* | --- | --- | --- | --- | --- | --- | A | --- | R |
| *Spirosperma* spp. | --- | --- | --- | --- | --- | --- | A | --- | --- |
| Opistosystidae | | | | | | | | | |
| *Opisthopora* spp. | --- | --- | --- | --- | --- | R | --- | --- | --- |
| LUMBRICULIDA | | | | | | | | | |
| Lumbriculidae | C | R | C | A | A | R | A | C | C |
| HIRUDINEA | | | | | | | | | |
| RHYNCHOBDELLIDA | | | | | | | | | |
| Glossiphoniidae | | | | | | | | | |
| *Placobdella papillifera* | --- | --- | R | --- | --- | --- | --- | --- | --- |
| BRANCHIOBDELLIDA | | | | | | | | | |
| Branchiobdellidae | | | | | | | | | |
| *Cambarincola* spp. | R | R | A | --- | R | --- | --- | --- | --- |
| CRUSTACEA | | | | | | | | | |
| ISOPODA | | | | | | | | | |
| Asellidae | | | | | | | | | |
| *Asellus* spp. | --- | --- | --- | --- | --- | --- | A | A | C |
| AMPHIPODA | | | | | | | | | |
| Gammaridae | | | | | | | | | |
| *Crangonyx* spp. | --- | --- | --- | --- | A | C | A | A | A |
| DECAPODA | | | | | | | | | |
| Astacidae | C | --- | R | --- | --- | --- | --- | --- | --- |
| *Cambarus* spp. | --- | A | --- | C | A | A | --- | --- | --- |
| *Procambarus* spp. | --- | --- | --- | --- | --- | --- | A | R | C |
| ARACHNOIDEA | | | | | | | | | |
| HYDRACARINA | --- | R | R | --- | R | --- | --- | R | C |
| INSECTA | | | | | | | | | |
| EPHEMEROPTERA | | | | | | | | | |
| Baetidae | | | | | | | | | |
| *Acentrella amplus* | R | --- | --- | --- | A | --- | --- | --- | --- |
| *Baetis ephippiatus* | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Baetis flavistriga* | A | C | --- | C | --- | --- | --- | --- | --- |
| *Baetis hageni* | --- | --- | --- | R | --- | --- | --- | --- | --- |
| *Baetis intercalaris* | --- | R | --- | --- | --- | --- | --- | --- | --- |
| *Baetis pluto* | --- | --- | R | C | --- | --- | --- | --- | --- |
| *Cloeon* spp. | --- | --- | --- | R | C | --- | --- | --- | --- |
| *Pseudocloeon* spp. | --- | R | R | --- | A | --- | --- | --- | --- |
| Caenidae | | | | | | | | | |
| *Caenis* spp. | --- | R | --- | R | A | --- | --- | --- | --- |
| Ephemerellidae | | | | | | | | | |
| *Drunella conestee* | --- | --- | A | --- | --- | --- | --- | --- | --- |
| *Ephemerella catawba* (group) | C | --- | C | --- | C | --- | --- | --- | --- |
| *Ephemerella invaria* (group) | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Ephemerella rossi* (group) | C | R | --- | --- | --- | --- | --- | --- | --- |
| *Eurylophella bicolor* | --- | --- | --- | --- | A | R | --- | --- | --- |
| *Eurylophella temporalis* | C | C | C | --- | C | --- | --- | --- | A |
| *Serratella deficiens* | | | | C | | | | | |
| Ephemeridae | | | | | | | | | |
| *Ephemera* spp. | R | C | --- | --- | --- | --- | --- | --- | --- |
| *Hexagenia* spp. | --- | C | A | --- | --- | --- | --- | --- | --- |

Appendix--*Benthic macroinvertebrate taxa list by forested basin*--Continued

[spp., more than one species; group or complex, assemblages of related taxa; sp., single species; sp. 14, distinct species within a genus. R, rare; C, common; A, abundant; ---, absent]

| CLASS<br>ORDER<br>Family<br>*Genus species*<br>*Subgenus* | Beetree Creek | High Shoals Creek | North Harper Creek | Dutchmans Creek | New Hope River tributary | Suck Creek tributary | Limestone Creek | Chinkapin Creek tributary | W.P. Brice Creek |
|---|---|---|---|---|---|---|---|---|---|
| INSECTA (Continued) | | | | | | | | | |
| EPHEMEROPTERA (Continued) | | | | | | | | | |
| Heptageniidae | | | | | | | | | |
| *Cinygmula subaequalis* | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Epeorus dispar* | R | --- | C | --- | --- | --- | --- | --- | --- |
| *Epeorus pleuralis* | A | --- | --- | --- | --- | --- | --- | --- | --- |
| *Epeorus* spp. | --- | A | --- | A | --- | --- | --- | --- | --- |
| *Heptagenia marginalis* | --- | --- | A | --- | --- | --- | --- | --- | --- |
| *Heptagenia* spp. | --- | --- | C | --- | --- | --- | --- | --- | --- |
| *Leucrocuta aphrodite* | A | --- | --- | A | A | --- | --- | --- | --- |
| *Stenacron interpunctatum* | --- | --- | --- | C | C | --- | --- | --- | --- |
| *Stenacron pallidum* | R | A | C | A | --- | --- | --- | --- | --- |
| *Stenonema femoratum* | --- | --- | --- | --- | A | --- | --- | --- | --- |
| *Stenonema ithaca* | C | --- | --- | --- | --- | --- | --- | --- | --- |
| *Stenonema modestum* | A | A | --- | R | --- | A | --- | --- | A |
| *Stenonema terminatum* | --- | --- | C | --- | --- | --- | --- | --- | --- |
| Leptophlebiidae | | | | | | | | | |
| *Habrophlebia* spp. | R | --- | --- | --- | R | --- | --- | --- | --- |
| *Habrophlebia vibrans* | --- | --- | --- | --- | --- | A | --- | --- | --- |
| *Leptophlebia* spp. | C | --- | --- | --- | --- | C | A | --- | C |
| *Paraleptophlebia* spp. | A | R | C | R | A | --- | --- | --- | --- |
| Oligoneuriidae | | | | | | | | | |
| *Isonychia* spp. | --- | C | A | --- | --- | --- | --- | --- | --- |
| Siphlonuridae | | | | | | | | | |
| *Ameletus lineatus* | R | --- | R | --- | A | --- | --- | --- | --- |
| ODONATA | | | | | | | | | |
| Aeshnidae | | | | | | | | | |
| *Boyeria vinosa* | --- | C | R | R | --- | --- | R | --- | R |
| *Enallagma* spp. | --- | --- | --- | --- | --- | --- | --- | --- | C |
| Calopterygidae | | | | | | | | | |
| *Calopteryx* spp. | --- | R | --- | R | R | A | R | --- | A |
| Coenagrionidae | | | | | | | | | |
| *Argia* spp. | --- | --- | --- | --- | --- | --- | --- | --- | A |
| Cordulegastridae | | | | | | | | | |
| *Cordulegaster* spp. | --- | R | R | --- | --- | --- | --- | --- | --- |
| Corduliidae | | | | | | | | | |
| *Helocordulia selysi* | --- | --- | --- | --- | C | --- | --- | --- | --- |
| *Somatochlora* spp. | --- | --- | --- | --- | --- | --- | A | --- | R |
| Gomphidae | | | | | | | | | |
| *Gomphus* spp. | --- | A | --- | --- | --- | --- | --- | --- | --- |
| *Lanthus* spp. | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Lanthus vernalis* | --- | A | A | --- | --- | A | --- | --- | --- |
| *Stylogomphus albistylus* | --- | --- | --- | R | R | R | --- | --- | --- |
| Libellulidae | | | | | | | | | |
| *Libellula* spp. | --- | --- | --- | --- | --- | --- | --- | C | --- |
| PLECOPTERA | | | | | | | | | |
| Capniidae | | | | | | | | | |
| *Allocapnia* spp. | A | A | A | R | --- | R | --- | --- | --- |
| Chloroperlidae | | | | | | | | | |
| *Haploperla brevis* | --- | --- | --- | --- | C | --- | --- | --- | --- |
| *Sweltsa* spp. | --- | --- | C | --- | --- | C | --- | --- | --- |
| Nemouridae | | | | | | | | | |
| *Amphinemura* spp. | R | --- | R | --- | A | --- | --- | --- | --- |
| *Prostoia* sp. | --- | --- | --- | --- | --- | --- | --- | R | --- |
| Peltoperlidae | | | | | | | | | |
| *Tallaperla* spp. | C | C | A | --- | --- | --- | --- | --- | --- |
| Perlidae | | | | | | | | | |
| *Acroneuria abnormis* | A | A | --- | A | --- | --- | --- | --- | --- |
| *Eccoptura xanthenes* | --- | --- | C | --- | R | A | --- | --- | --- |
| *Perlesta placida* | --- | R | C | --- | C | R | --- | --- | A |

Appendix--*Benthic macroinvertebrate taxa list by forested basin*--Continued

[spp., more than one species; group or complex, assemblages of related taxa; sp., single species; sp. 14, distinct species within a genus. R, rare; C, common; A, abundant; ---, absent]

| CLASS<br>ORDER<br>Family<br>*Genus species*<br>*Subgenus* | Beetree Creek | High Shoals Creek | North Harper Creek | Dutchmans Creek | New Hope River tributary | Suck Creek tributary | Limestone Creek | Chinkapin Creek tributary | W.P. Brice Creek |
|---|---|---|---|---|---|---|---|---|---|
| INSECTA (Continued) | | | | | | | | | |
| PLECOPTERA (Continued) | | | | | | | | | |
| Perlodidae | | | | | | | | | |
| *Clioperla clio* | --- | --- | --- | --- | A | --- | --- | --- | --- |
| *Diploperla duplicata* | A | --- | --- | --- | --- | --- | --- | --- | --- |
| *Diploperla* sp. | --- | --- | A | --- | --- | --- | --- | --- | --- |
| *Isoperla bilineata* | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Isoperla holochlora* | R | --- | C | --- | --- | --- | --- | --- | --- |
| *Isoperla* spp. | --- | --- | --- | --- | --- | C | --- | --- | --- |
| Pteronarcyidae | | | | | | | | | |
| *Pteronarcys dorsata* | C | C | R | --- | --- | --- | --- | --- | --- |
| Taeniopterygidae | | | | | | | | | |
| *Strophopteryx* spp. | C | --- | --- | --- | --- | A | --- | --- | --- |
| TRICHOPTERA | | | | | | | | | |
| Brachycentridae | | | | | | | | | |
| *Brachycentrus nigrosoma* | --- | R | --- | --- | --- | --- | --- | --- | --- |
| Calamoceratidae | | | | | | | | | |
| *Anisocentropus pyraloides* | --- | C | --- | R | --- | A | --- | --- | --- |
| *Heteroplectron americanum* | --- | R | --- | --- | --- | C | --- | --- | A |
| Glossosomatidae | | | | | | | | | |
| *Glossosoma* spp. | --- | C | --- | C | --- | --- | --- | --- | --- |
| Hydropsychidae | | | | | | | | | |
| *Arctopsyche irrorata* | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Cheumatopsyche* spp. | C | C | --- | A | C | --- | --- | --- | C |
| *Diplectrona modesta* | A | R | A | --- | --- | A | --- | --- | --- |
| *Hydropsyche betteni* | --- | --- | --- | R | --- | C | --- | --- | --- |
| *Hydropsyche decalda* | --- | --- | --- | --- | --- | --- | --- | --- | A |
| *Hydropsyche macleodi* | --- | --- | A | --- | --- | --- | --- | --- | --- |
| *Hydropsyche rossi* | R | R | R | --- | --- | --- | --- | --- | --- |
| *Symphitopsyche morosa* | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Symphitopsyche slossonae* | C | --- | --- | --- | --- | --- | --- | --- | --- |
| *Symphitopsyche sparna* | --- | R | --- | A | --- | --- | --- | --- | --- |
| Hydroptilidae | | | | | | | | | |
| *Hydroptila* spp. | --- | --- | C | --- | C | --- | --- | --- | --- |
| Lepidostomatidae | | | | | | | | | |
| *Lepidostoma* spp. | C | C | C | --- | --- | --- | --- | --- | --- |
| Leptoceridae | | | | | | | | | |
| *Oecetis* spp. | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Triaenodes abus* | --- | --- | --- | --- | C | --- | --- | --- | R |
| *Triaenodes* spp. | --- | --- | --- | --- | --- | R | --- | --- | --- |
| *Triaenodes tardus* | --- | --- | --- | --- | --- | --- | --- | --- | R |
| Limnephilidae | | | | | | | | | |
| *Apatania* | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Goera* spp. | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Ironoquia punctatissima* | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Neophylax mitchelli* | --- | --- | C | --- | --- | --- | --- | --- | --- |
| *Neophylax* spp. | C | C | --- | --- | --- | --- | --- | --- | --- |
| *Pycnopsyche guttifer* | A | --- | --- | --- | --- | R | --- | --- | --- |
| *Pycnopsyche scabripennis* | C | --- | --- | --- | --- | --- | --- | --- | --- |
| *Pycnopsyche* spp. | --- | C | A | --- | --- | --- | --- | --- | C |
| Molannidae | | | | | | | | | |
| *Molanna blenda* | --- | --- | --- | --- | --- | --- | --- | --- | R |
| Odontoceridae | | | | | | | | | |
| *Psilotreta* spp. | --- | --- | R | R | --- | C | --- | --- | --- |
| Philopotamidae | | | | | | | | | |
| *Chimarra* spp. | --- | --- | --- | C | --- | --- | --- | --- | --- |
| *Dolophilodes* spp. | --- | R | R | A | C | --- | --- | --- | --- |
| *Wormaldia* spp. | --- | --- | --- | --- | C | R | --- | --- | --- |
| Phryganeidae | | | | | | | | | |
| *Ptilostomis* spp. | --- | --- | R | --- | --- | --- | --- | --- | --- |
| Polycentropodidae | | | | | | | | | |
| *Nyctiophylax moestus* | --- | --- | --- | --- | A | --- | --- | --- | C |
| *Nyctiophylax* spp. | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Phylocentropus* spp. | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Polycentropus* spp. | C | --- | C | R | C | C | --- | --- | --- |

## Appendix--*Benthic macroinvertebrate taxa list by forested basin*--Continued

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|---|---|---|---|---|---|---|---|---|---|
| INSECTA (Continued) | | | | | | | | | |
| TRICHOPTERA (Continued) | | | | | | | | | |
| Psychomyiidae | | | | | | | | | |
| *Lype diversa* | C | C | --- | --- | --- | --- | --- | --- | --- |
| Rhyacophilidae | | | | | | | | | |
| *Rhyacophila carolina* | R | --- | R | --- | C | R | --- | --- | --- |
| *Rhyacophila fuscula* | C | C | R | R | --- | --- | --- | --- | --- |
| *Rhyacophila glaberrima* | --- | --- | --- | --- | A | --- | --- | --- | --- |
| *Rhyacophila ledra* | --- | --- | --- | --- | C | --- | --- | --- | --- |
| *Rhyacophila nigrita* | --- | --- | A | --- | --- | --- | --- | --- | --- |
| *Rhyacophila torva* | --- | --- | --- | --- | --- | R | --- | --- | --- |
| MEGALOPTERA | | | | | | | | | |
| Corydalidae | | | | | | | | | |
| *Corydalus cornutus* | --- | --- | --- | R | --- | --- | --- | --- | --- |
| *Nigronia fasciatus* | --- | --- | --- | --- | --- | R | --- | --- | --- |
| *Nigronia serricornis* | --- | R | --- | C | C | C | --- | --- | C |
| Sialidae | | | | | | | | | |
| *Sialis* spp. | --- | R | A | C | R | R | --- | --- | R |
| HEMIPTERA | | | | | | | | | |
| Corixidae | | | | | | | | | |
| *Sigara* spp. | --- | --- | R | --- | --- | --- | C | R | --- |
| Nepidae | | | | | | | | | |
| *Ranatra* spp. | --- | --- | --- | --- | --- | --- | --- | --- | R |
| Notonectidae | | | | | | | | | |
| *Notonecta* spp. | --- | --- | --- | --- | --- | --- | R | --- | R |
| Dryopidae | | | | | | | | | |
| *Helichus* sp. | --- | R | R | C | C | R | --- | --- | --- |
| Dytiscidae | | | | | | | | | |
| *Copelatus* spp. | --- | --- | --- | --- | --- | --- | R | --- | --- |
| *Deronectes griseostriatus* | --- | --- | --- | --- | --- | --- | --- | R | --- |
| *Deronectes* sp. | --- | --- | --- | C | --- | C | --- | --- | --- |
| *Hydaticus bimarginatus* | --- | --- | --- | --- | --- | --- | C | --- | --- |
| *Hydroporus* spp. | --- | --- | C | R | --- | --- | A | A | A |
| Elmidae | | | | | | | | | |
| *Ancyronyx variegatus* | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Dubiraphia quadrinotata* | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Macronychus glabratus* | --- | R | --- | R | --- | --- | --- | --- | --- |
| *Microcylloepus pusillus* | --- | --- | --- | R | --- | --- | --- | --- | --- |
| *Optioservus* spp. | --- | R | A | R | --- | --- | --- | --- | --- |
| *Oulimnius* spp. | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Promoresia tardella* | --- | --- | C | R | --- | --- | --- | --- | --- |
| *Stenelmis* spp. | --- | --- | --- | C | C | --- | R | --- | --- |
| Eubriidae | | | | | | | | | |
| *Ectopria nervosa* | --- | C | C | C | --- | --- | --- | --- | --- |
| Gyrinidae | | | | | | | | | |
| *Dineutes* spp. | --- | --- | --- | --- | --- | --- | C | --- | R |
| *Dubiraphia* spp. | --- | A | --- | R | --- | --- | --- | --- | --- |
| *Gyrinus* spp. | --- | R | --- | --- | --- | --- | --- | --- | --- |
| Helodidae | | | | | | | | | |
| *Scirtes* sp. | R | --- | --- | --- | --- | --- | --- | --- | --- |
| Hydrophilidae | | | | | | | | | |
| *Enochrus* spp. | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Laccobius* | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Sperchopsis tessellatus* | --- | --- | --- | --- | --- | --- | R | --- | --- |
| Noteridae | | | | | | | | | |
| *Hydrocanthus* spp. | --- | --- | --- | --- | --- | --- | --- | R | --- |
| Psephenidae | | | | | | | | | |
| *Psephenus herricki* | --- | A | --- | A | A | --- | --- | --- | --- |
| Ptilodactylidae | | | | | | | | | |
| *Anchytarsus bicolor* | --- | R | --- | R | R | A | --- | --- | --- |
| DIPTERA | | | | | | | | | |
| Blephariceridae | | | | | | | | | |
| *Blepharicera* spp. | R | --- | --- | --- | --- | --- | --- | --- | --- |

Appendix--*Benthic macroinvertebrate taxa list by forested basin*--Continued

[spp., more than one species; group or complex, assemblages of related taxa; sp., single species; sp. 14, distinct species within a genus. R, rare; C, common; A, abundant; ---, absent]

| CLASS<br>ORDER<br>Family<br>*Genus species*<br>*Subgenus* | Bee-tree Creek | High Shoals Creek | North Harper Creek | Dutch-mans Creek | New Hope River tribu-tary | Suck Creek tribu-tary | Lime-stone Creek | Chinka-pin Creek tribu-tary | W.P. Brice Creek |
|---|---|---|---|---|---|---|---|---|---|
| INSECTA (Continued) | | | | | | | | | |
| DIPTERA (Continued) | | | | | | | | | |
| Ceratopogonidae | | | | | | | | | |
| *Atrichopogon* spp. | --- | --- | --- | R | --- | --- | --- | --- | --- |
| *Pakointua* (complex) | C | R | C | --- | R | C | --- | C | C |
| Chironomidae | | | | | | | | | |
| *Ablabesmyia mallochi* | --- | --- | --- | --- | --- | A | --- | --- | C |
| *Ablabesmyia parajanta/janta* | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Brundiniella eumorpha* | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Chironomus* spp. | --- | --- | --- | --- | --- | --- | R | A | R |
| *Cladotanytarsus* sp. 1 | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Cladotanytarsus* sp. 2 | --- | C | --- | --- | --- | --- | --- | --- | |
| *Cladotanytarsus* spp. | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Conchapelopia* (group) | C | A | C | --- | C | A | R | C | A |
| *Constempellina* spp. | --- | --- | --- | --- | C | --- | --- | --- | --- |
| *Corynoneura* spp. | R | --- | --- | --- | R | C | R | R | --- |
| *Cricotopus/Orthocladius* sp. 1 | --- | R | --- | --- | R | --- | --- | --- | --- |
| *Cricotopus/Orthocladius* sp. 6 | --- | --- | --- | --- | R | A | --- | --- | --- |
| *Cricotopus/Orthocladius* sp. 10 | --- | --- | --- | --- | --- | --- | --- | A | --- |
| *Cricotopus/Orthocladius* sp. 12 | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Cricotopus/Orthocladius* sp. 52 | --- | --- | --- | --- | --- | --- | A | C | --- |
| *Cricotopus/Orthocladius* sp. 54 | --- | R | --- | --- | --- | --- | --- | C | --- |
| *Cryptochironomus fulvus* | --- | C | R | R | --- | --- | C | --- | R |
| *Demicryptochironomus* sp. 3 | --- | --- | --- | --- | --- | --- | R | --- | --- |
| *Diamesa* spp. | --- | --- | A | --- | --- | --- | --- | --- | --- |
| *Eukiefferiella* sp. 1 | --- | --- | --- | --- | --- | --- | --- | R | --- |
| *Eukiefferiella* sp. 3 | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Eukiefferiella* sp. 6 | --- | --- | --- | --- | --- | C | --- | --- | --- |
| *Eukiefferiella* sp. 11 | R | --- | --- | --- | R | --- | --- | --- | --- |
| *Eukiefferiella* sp. 14 | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Heleniella* spp. | R | --- | R | --- | --- | --- | --- | --- | --- |
| *Heterotrissocladius* sp. 2 | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Heterotrissocladius* spp. | C | --- | --- | --- | --- | --- | --- | --- | --- |
| *Hydrobaenus* spp. | --- | --- | --- | --- | --- | --- | --- | C | --- |
| *Krenosmittia* spp. | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Labrundinia pilosella* | --- | --- | --- | R | --- | --- | --- | --- | --- |
| *Labrundinia virescens* | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Larsia* spp. | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Limnophyes* spp. | --- | --- | --- | --- | --- | --- | --- | R | --- |
| *Micropsectra* sp. 5A | A | --- | --- | --- | --- | --- | --- | --- | --- |
| *Micropsectra* spp. | --- | --- | --- | --- | R | A | --- | --- | --- |
| *Microtendipes* sp. 1 | --- | --- | --- | --- | R | C | --- | --- | --- |
| *Microtendipes* spp. | --- | A | R | --- | --- | --- | --- | --- | --- |
| *Nanocladius downesi* | --- | --- | --- | R | --- | | --- | --- | --- |
| *Nanocladius* spp. | --- | --- | --- | --- | R | --- | --- | --- | --- |
| *Natarsia* spp. | --- | R | --- | R | --- | --- | --- | --- | --- |
| *Odontomesa fulva* | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Oliveridia* sp. 2 | --- | --- | --- | --- | --- | A | --- | --- | --- |
| *Pagastia* spp. | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Paracladopelma undine* | --- | --- | --- | --- | --- | R | --- | --- | --- |
| *Parametricnemus lundbecki* | --- | --- | --- | --- | --- | A | --- | --- | --- |
| *Paraphaenocladius* sp. 2 | A | A | C | --- | A | --- | --- | --- | --- |
| *Paratendipes* spp. | --- | --- | --- | R | --- | --- | --- | --- | --- |
| *Phaenopsectra flavipes* | --- | C | --- | --- | --- | A | --- | --- | --- |
| *Phaenopsectra* sp. 2 | --- | --- | --- | --- | --- | --- | R | --- | --- |
| *Phaenopsectra* spp. | --- | --- | C | --- | --- | --- | --- | --- | --- |
| *Polypedilum aviceps* | --- | --- | --- | --- | A | --- | --- | --- | --- |
| *Polypedilum convictum* | R | --- | R | --- | --- | A | --- | --- | --- |
| *Polypedilum fallax* | --- | A | R | R | --- | C | --- | --- | --- |
| *Polypedilum halterale* | --- | --- | --- | --- | R | --- | R | --- | --- |
| *Polypedilum illinoense* | --- | --- | R | R | --- | --- | A | C | R |
| *Polypedilum scalaenum* | --- | --- | R | --- | --- | --- | --- | --- | --- |
| *Procladius* spp. | --- | --- | C | --- | --- | --- | --- | --- | --- |
| *Prodiamesa olivacea* | R | --- | --- | --- | --- | --- | --- | --- | --- |
| *Psectrotanypus* spp. | --- | --- | --- | --- | --- | --- | A | --- | --- |

## Appendix--*Benthic macroinvertebrate taxa list by forested basin*--Continued

[spp., more than one species; group or complex, assemblages of related taxa; sp., single species; sp. 14, distinct species within a genus. R, rare; C, common; A, abundant; ---, absent]

| CLASS<br>ORDER<br>Family<br>*Genus species*<br>*Subgenus* | Beetree Creek | High Shoals Creek | North Harper Creek | Dutchmans Creek | New Hope River tributary | Suck Creek tributary | Limestone Creek | Chinkapin Creek tributary | W.P. Brice Creek |
|---|---|---|---|---|---|---|---|---|---|
| INSECTA (Continued) | | | | | | | | | |
| DIPTERA (Continued) | | | | | | | | | |
| Chironomidae (Continued) | | | | | | | | | |
| *Rheocricotopus* sp. 1 | C | C | R | R | R | --- | --- | --- | --- |
| *Rheocricotopus* sp. 2A | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Rheotanytarsus* spp. | --- | --- | C | --- | --- | C | --- | --- | A |
| *Robackia demeijerei* | --- | R | --- | --- | --- | --- | --- | --- | --- |
| *Saetheria tylus* | --- | C | --- | --- | --- | --- | --- | --- | --- |
| *Stempellina* spp. | --- | --- | --- | --- | --- | R | --- | --- | --- |
| *Stempellinella* spp. | --- | --- | --- | --- | --- | R | --- | --- | --- |
| *Stenochironomus* spp. | --- | R | --- | --- | --- | R | R | --- | A |
| *Stictochironomus* spp. | --- | --- | --- | --- | --- | C | --- | --- | --- |
| *Symposiocladius lignicola* | --- | R | R | --- | --- | --- | --- | --- | --- |
| *Sympotthastia* spp. | --- | R | --- | --- | --- | --- | --- | --- | --- |
| *Tanytarsus* sp. 2 | --- | --- | C | --- | --- | --- | --- | --- | --- |
| *Tanytarsus* sp. 2C | --- | --- | --- | --- | --- | --- | A | --- | A |
| *Tanytarsus* sp. 3 | --- | --- | C | --- | --- | --- | --- | --- | --- |
| *Tanytarsus* sp. 14 | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Tanytarsus* spp. | --- | --- | --- | --- | --- | C | --- | C | --- |
| *Thienemaniella* spp. | C | --- | R | C | C | A | --- | --- | --- |
| *Tribelos* spp. | --- | C | R | --- | --- | A | --- | --- | A |
| *Unniella multivirga* | --- | --- | --- | --- | --- | A | --- | --- | C |
| *Xylotopus par* | --- | --- | R | --- | --- | R | --- | --- | --- |
| *Zavrelia* spp. | --- | --- | --- | --- | C | --- | --- | --- | --- |
| *Zavrelimyia* spp. | R | --- | C | --- | --- | --- | --- | --- | --- |
| Genus near *Nanocladius* | --- | --- | --- | --- | --- | --- | --- | R | --- |
| Culicidae | | | | | | | | | |
| *Aedes* sp. | --- | --- | --- | --- | --- | --- | --- | C | --- |
| *Anopheles* spp. | --- | --- | --- | C | --- | --- | --- | --- | --- |
| Dixidae | | | | | | | | | |
| *Dixa* spp. | R | --- | R | R | R | R | --- | --- | --- |
| Muscidae | --- | --- | --- | --- | --- | --- | --- | R | --- |
| Simuliidae | | | | | | | | | |
| *Cnephia mutata* | --- | --- | --- | --- | C | --- | --- | --- | --- |
| *Prosimulium mixtum* | C | --- | --- | --- | A | R | --- | --- | --- |
| *Simulium congareenarum* | --- | --- | --- | --- | --- | --- | C | C | A |
| *Simulium tuberosum* | --- | --- | --- | --- | --- | --- | --- | --- | R |
| *Simulium venustum* | --- | --- | --- | --- | C | --- | --- | R | --- |
| *Simulium vittatum* | --- | --- | --- | C | A | A | --- | --- | --- |
| *Simulium* spp. | --- | C | R | --- | --- | --- | --- | --- | --- |
| Tabanidae | | | | | | | | | |
| *Chrysops* spp. | --- | R | --- | --- | --- | --- | R | --- | --- |
| Tipulidae | | | | | | | | | |
| *Antocha* spp. | --- | C | R | R | R | --- | --- | --- | --- |
| *Dicranota* spp. | C | C | A | --- | --- | --- | --- | --- | --- |
| *Hexatoma* spp. | A | R | C | --- | A | C | --- | --- | --- |
| *Pedicia* sp. | --- | --- | --- | --- | --- | --- | --- | R | --- |
| *Polymera/Ormosia* spp. | A | --- | C | --- | --- | --- | --- | --- | --- |
| *Pseudolimnophila* spp. | --- | --- | --- | --- | A | C | --- | C | --- |
| *Tipula* spp. | C | --- | --- | --- | A | R | --- | R | --- |
| GASTROPODA | | | | | | | | | |
| MESOGASTROPODA | | | | | | | | | |
| Pleuroceridae | | | | | | | | | |
| *Elimia* sp. | A | A | --- | A | --- | --- | --- | --- | --- |
| BASOMMATOPHORA | | | | | | | | | |
| Ancylidae | | | | | | | | | |
| *Ferrissia* spp. | --- | --- | --- | --- | --- | --- | --- | --- | R |
| PELECYPODA | | | | | | | | | |
| PROTOBRANCHIATA | | | | | | | | | |
| Sphaeriidae | | | | | | | | | |
| *Pisidium* spp. | --- | --- | R | --- | --- | --- | --- | --- | --- |

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