# WATER QUALITY IN REEDY FORK AND BUFFALO CREEK BASINS IN THE GREENSBORO AREA, NORTH CAROLINA, 1986-87

By Marjorie S. Davenport

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**U.S. GEOLOGICAL SURVEY**

Water-Resources Investigations Report 88-4210

Prepared in cooperation with

**THE CITY OF GREENSBORO**

Raleigh, North Carolina

1989

**DEPARTMENT OF THE INTERIOR**

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# WATER QUALITY IN REEDY FORK AND BUFFALO CREEK BASINS IN THE GREENSBORO AREA, NORTH CAROLINA, 1986-87

By Marjorie S. Davenport

## ABSTRACT

Water and bottom-sediment samples were collected from April 1986 through September 1987 at 19 sites in Guilford County and the City of Greensboro, North Carolina. Sampling locations included 13 stream sites, two lakes that supply the City of Greensboro with drinking water, two City of Greensboro finished drinking-water filtration plants, and effluent from the two municipal wastewater plants prior to outfall into receiving streams. Water sampling consisted of six surveys during various stages of steady ground-water flow at all sites and high-flow-event sampling during two storms at six sites. Bottom-sediment samples were collected at three sites during two routine sampling surveys.

A summary of nearly 22,000 separate chemical or physical analyses of water samples or bottom sediment is presented and discussed as individual values, ranges of values, or median values with respect to the locations of sampling sites, streamflow conditions, or other information bearing on water-quality conditions under discussion. The results include discussions of general water-quality indicators; major ion, nutrient, and trace-element concentrations; acid and base/neutral extractable organic compounds; volatile organic compounds; and organochlorine and organophosphorus pesticides detected at each sampling site. Loadings of selected constituents are also estimated on a yearly and daily basis.

The quality of the raw and finished water, municipal effluents, and streams in the Greensboro area are characterized by using State and Federal water-quality standards. Inorganic constituents most commonly found in excess of standards were iron, copper, zinc, arsenic, phosphorus, manganese, cyanide, and mercury. Relatively few organic compounds were detected; however, those consistently reported were phthalate, trihalomethane, organophosphorus pesticide, benzol, and phenolic compounds.

Selected inorganic, physical, and total organic carbon data are used in a Wilcoxon test for two independent variables to statistically compare water-quality characteristics in selected rural, semideveloped and urban basins. During low-flow sampling, the constituents that differed significantly among all sites were calcium, magnesium, and chloride. During low flows, concentrations of orthophosphate, fluoride, sulfate, and TOC differed at the urban site from the rural and semideveloped and urban sites. There were no significant differences among sites in concentrations of sodium, suspended sediment, nickel, zinc, copper, and mercury during low flows. The Wilcoxon test performed on high-flow data indicated that concentrations of TOC, chloride, sulfate, suspended sediment, and nickel were not significantly different among the sites.

## INTRODUCTION

Greensboro, North Carolina, is among the largest cities in the State with a 1980 census population of 155,642 people (North Carolina Office of Management and Budget, 1983). The city is located in the north-central Piedmont in Guilford County near the headwaters of the Haw River (fig. 1). The Haw River is the major tributary to B. Everett Jordan Lake, which lies approximately 50 miles downstream from the Greensboro area. Jordan Lake, a newly developed (1981) multipurpose reservoir, is used for recreation, flood control, and water supply. Downstream from Jordan Lake, the Haw River joins other rivers to form the largest river basin in the State, the Cape Fear River basin (fig. 1).

Greensboro is an industrial and manufacturing city that is undergoing rapid development in its rural areas. One area of growth is occurring in and near the city's surface-water supply watershed in the upper Reedy Fork Creek basin. Watersheds in developed areas may have several potential sources of contamination, including municipal wastewater-treatment plants, industrial areas, and runoff from streets, residential lawns, and large construction sites, all of which could affect water-supply sources.

The environs of Greensboro are a potential source of contamination of the Haw and Cape Fear River basins due to development in the water-supply watershed area, the locations of two major wastewater-treatment plants, the

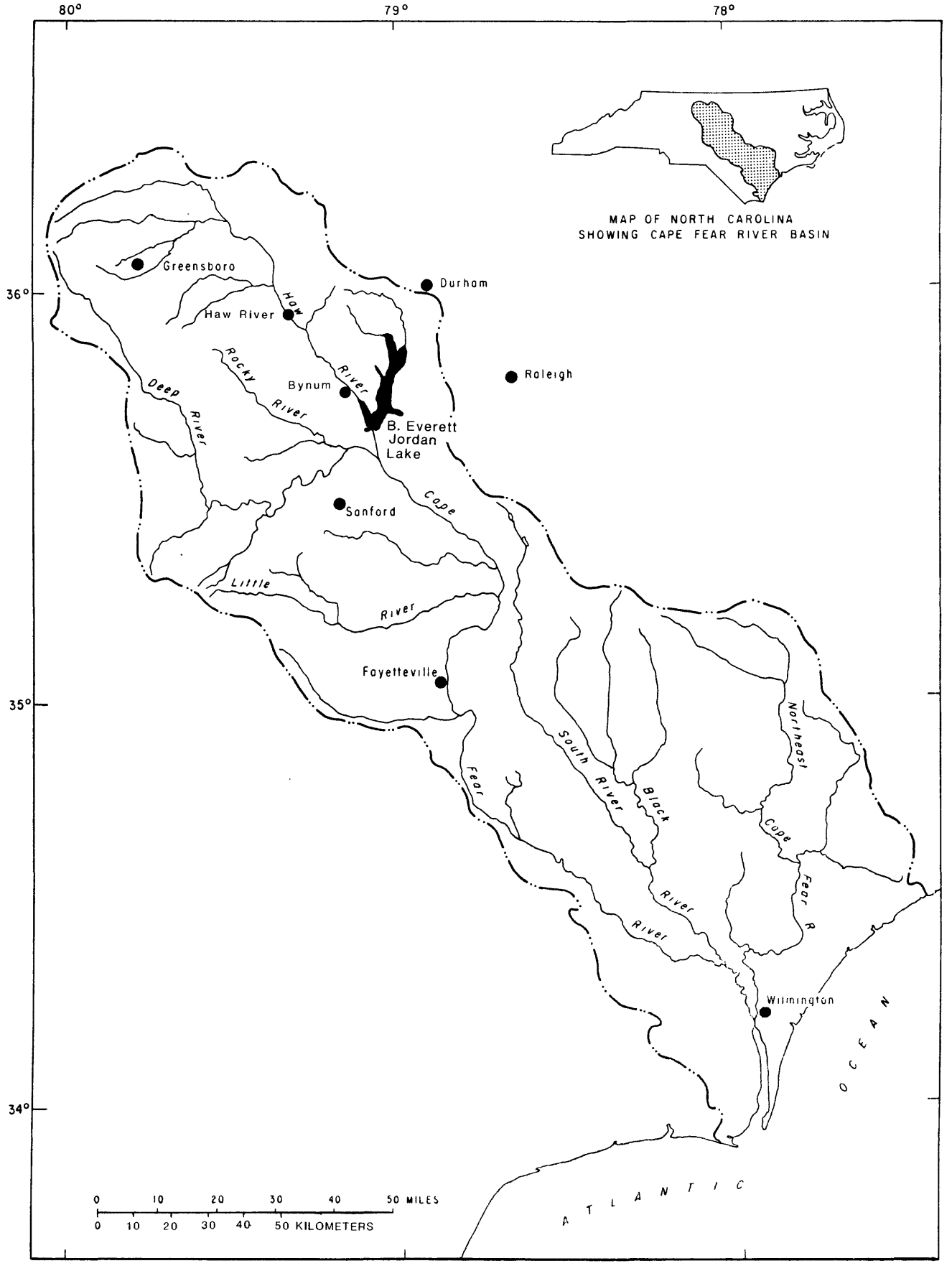


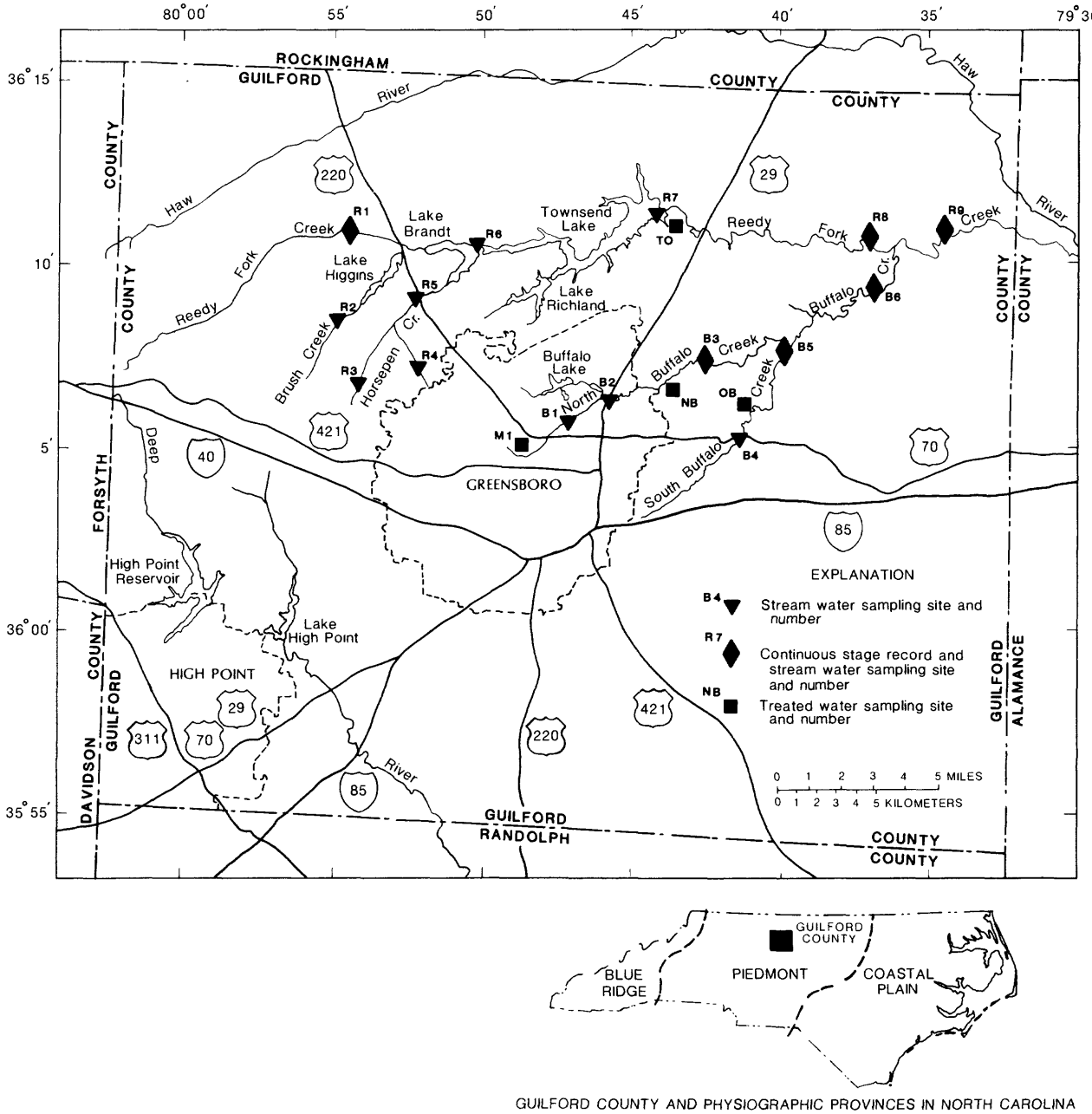

Figure 1.--The Cape Fear River basin, North Carolina.

city's large urban and residential land areas, and a heavy concentration of industry. As a result, the U.S. Geological Survey in cooperation with the City of Greensboro conducted a study designed to define the water-quality characteristics of surface waters in the Greensboro area on a reconnaissance and comparative basis. Such a characterization was appropriate for several reasons: (1) to determine the quality of the city's drinking-water supply; (2) to characterize the effect of Greensboro's wastewater-treatment plant effluents on receiving streams; and (3) to examine whether synthetic organic compounds introduced into the Greensboro area from various sources pose a threat to the quality of water downstream in the Haw and Cape Fear River basins.

The specific objectives of the study were (1) to define the quality of water at the intake of Greensboro's raw water supply; (2) to define the quality of effluents from Greensboro's municipal wastewater-treatment plants; and (3) to define the quality of water of streams in the Greensboro area by comparing water quality in rural, semideveloped, and urban watersheds by identifying relative amounts of constituents coming from various point and nonpoint sources and by estimating loadings of selected inorganic and physical constituents.

## Purpose and Scope

The purpose of this report is to present a reconnaissance evaluation of water quality in the Reedy Fork and Buffalo Creek basins in the Greensboro area of northern Guilford County (fig. 2), which includes water-supply streams, raw and treated drinking water, treated effluent discharge, receiving streams, and bottom sediment, as well as an appraisal of the effects of basin development. Specific objectives were to define the quality of Greensboro's raw water supply, municipal effluents, and streams in the area by comparing water quality in rural, semideveloped, and urban watersheds and to estimate loads for selected constituents. Samples were collected over an 18-month period that began April 15, 1986, and included raw water from water-supply reservoirs at two City of Greensboro drinking-water supply intakes, treated drinking water from two city water-treatment plants, effluents from the two city wastewater-treatment plants, and samples from 13 stream sites. Samples were collected during high flows at six stream sites, and stage-discharge ratings were developed through measure-




GUILFORD COUNTY AND PHYSIOGRAPHIC PROVINCES IN NORTH CAROLINA

Figure 2.--Locations of sampling sites in and around the City of Greensboro, North Carolina, 1986-87.

ments of discharge. Hydrologic and analytical data from the sampling phase of the project are available in a companion report (Davenport, 1988).


## Acknowledgments

Various individuals with the City of Greensboro deserve special appreciation. Ray Shaw, Assistant Director of Public Works, played a key role in the planning of this study. Ken Brown, chemist at the T.Z. Osborne Wastewater Treatment Plant, and Joyce Patton, chemist at the Townsend Lake Filtration Plant, worked conscientiously collecting and analyzing water samples. Their coworkers in their respective laboratories also deserve recognition.


## PHYSICAL SETTING

The topography of the Greensboro area consists of rounded hills and long, flat-topped ridges that tend to lie in a north-eastern direction. A few isolated hills lie apart from the more prominent lines of hills. Local topographic relief is as much as 100 feet between interstream divides and stream bottoms. Altitudes vary between 600 and 900 feet above mean sea level and fall from west to east in the county.

Greensboro is located within the watersheds of Reedy Fork and Buffalo Creeks (fig. 2), which cover approximately 37 percent of the county. Reedy Fork Creek lies approximately 7 miles north of the central city. Three manmade impoundments along its course (Lake Higgins, Lake Brandt, and Townsend Lake) are Greensboro's water-supply reservoirs. Lake Brandt and Townsend Lake have drainage areas of 68 and 105 square miles ($mi^2$), respectively, and were constructed for water supply and recreational purposes. Lake Brandt is fed by Reedy Fork Creek, Horsepen Creek, and Brush Creek via Lake Higgins. Lake Higgins has a drainage area of 11.6 $mi^2$ at its outlet. Lake Richland, fourth impoundment in the basin, is a privately-owned lake with a drainage area of 7.6 $mi^2$. Its outlet flows into Townsend Lake.

North and South Buffalo Creeks have headwaters west of the central city and flow eastward, skirting the southern portion of downtown Greensboro.

They converge approximately 10 miles northeast of the central city to form Buffalo Creek, which flows to the northeast another 6 miles before entering Reedy Fork Creek. Reedy Fork Creek enters the Haw River 5 miles further downstream in Alamance County (fig. 2).

## Land Use

The municipality of Greensboro covers approximately 70 $mi^2$, or about 12 percent of Guilford County. The majority of land use within Greensboro's city limits is residential with commercial and industrial complexes densely situated along major streets.

A study done in 1984 by the Advance Planning Section of the Guilford County Planning Division reports that over 83 percent of the land in the county, excluding areas within the principal cities of Greensboro and High Point, is used either for agriculture or is fallow. About 11 percent of the land in the county is residential property, and 2 percent is commercial or industrial property. Hospitals, parks, schools, churches, the military, and Federal, State, and local governments occupy approximately 4 percent of the land (Jim Morrison, Guilford County Planning Division, written commun., 1984).

## Wastewater Discharge

The City of Greensboro and two private corporations are permitted by the State to discharge treated wastewater into streams in the area. Greensboro operates two wastewater-treatment plants on the eastern edge of the city that are permitted to discharge approximately 36 million gallons per day (Mgal/d) into North and South Buffalo Creeks (City of Greensboro, 1984). The North Buffalo Creek Wastewater Treatment Plant provides tertiary or "traveling bridge filter" treatment of municipal sewage and industrial waste from the northern half of the city at a capacity of 16 Mgal/d. The treatment plant outfall is upstream from site B3 (fig. 2).

In 1984, the T.Z. Osborne Wastewater Treatment Plant was established to provide an advanced level of treatment of municipal sewage and industrial wastes from the southern half of Greensboro. It has the capability to remove over 95 percent of the inorganic and organic constituents from an

average flow of 20 Mgal/d and, at peak rates, up to 50 Mgal/d during wet weather. The outfall is above site B5 on South Buffalo Creek (fig. 2). Other dischargers permitted by the State include a textile mill, which can pass as much as 1.1 Mgal/d to North Buffalo Creek, and a tobacco mill, which transfers 0.16 Mgal/d from a cooling operation into North Buffalo Creek.

## DATA COLLECTION

The data-collection network consisted of 19 sites in the Reedy Fork Creek and Buffalo Creek basins (fig. 2). Data collected included streamflow, bottom sediment quality, and water quality, although not all these types of data were gathered at each data site. There were 13 data sites in streams, 2 lake sites, 2 treated drinking-water sites at treatment plants, and 2 treated-effluent sites at wastewater treatment plants.

The data sites, their station names and numbers, drainage areas, and types of discharge records are shown in table 1, which also shows whether the sites are affected by impoundments or effluent outfalls. More detailed descriptions of each site, along with the data values, are given in a separate report (Davenport, 1988).

The data sites were categorized on the basis of their locations in the drainage basins relative to water supplies and effluent discharge points. One group, designated as water-supply sites (WS in table 1), includes 5 stream sites (R1, R2, R3, R4, and R5 in fig. 2) and 2 lake sites (R6 and R7) in the Reedy Fork Creek basin. The drinking-water group (DW) of samples consists of finished drinking-water samples from the Mitchell Treatment Plant (MI) and the Townsend Lake Filtration Plant (TO). Because of their location upstream from industrial and municipal wastewater outfalls, sites on North Buffalo Creek (B1), South Buffalo Creek (B4), and Reedy Fork Creek (R8) comprise a third group of sampling sites denoted as the sites above outfalls (AO). Sites B2, B3, B5, B6 and R9 are grouped together as the sites below the wastewater outfalls (BO). The final group is the municipal wastewater effluent sites (EFF). Undiluted treated effluent samples from the North Buffalo Wastewater Treatment Plant (site NB) and the T.Z. Osborne Wastewater Treatment Plant (site OS) comprise this group.

Table 1.--*Water-quality sampling sites in the Greensboro area, North Carolina, 1986-87*

[Station number, U.S. Geological Survey downstream order identification number; Site, location during the study (fig. 2); Regulated, unnatural flows due to impoundments or effluent outfalls; Location/use classification: WS, water supply; DW, finished drinking water; AO, above outfalls; BO, below outfalls; EFF, effluent]

| Station number | Site | Station name | Drainage area (square miles) | Discharge records | | Regulated | Location/use classification |
|---|---|---|---|---|---|---|---|
| | | | | Type | Date began | | |
| 02093800 | R1 | Reedy Fork Creek near Oak Ridge | 20.6 | Continuous | Oct. 1955 | No | WS |
| 0209387800 | R2 | Brush Creek near Oak Ridge | 7.46 | Intermittent | Apr. 10, 1986 | No | WS |
| 0209391880 | R3 | Horsepen Creek near Guilford College | 7.52 | Intermittent | Apr. 9, 1986 | No | WS |
| 0209395900 | R4 | Horsepen Creek tributary near Guilford College | 3.04 | Intermittent | Feb. 6, 1986 | No | WS |
| 0209399200 | R5 | Horsepen Creek near Greensboro | 15.9 | Intermittent | May 20, 1986 | No | WS |
| 0209411700 | R6 | Reedy Fork Creek at Lake Brandt Dam | 68.4 | -- | -- | -- | WS |
| 0209411705 | MI | Mitchell Water Treatment Plant | -- | -- | -- | -- | DW |
| 0209430500 | R7 | Reedy Fork Creek at Townsend Lake Dam | 105 | -- | -- | -- | WS |
| 0209430505 | TO | Lake Townsend Water Treatment Plant | -- | -- | -- | -- | DW |
| 02094500 | R8 | Reedy Fork Creek near Gibsonville | 131 | Continuous | Sept. 1928 | Yes | AO |
| 0209560800 | R9 | Reedy Fork Creek at N.C. 61 | 243 | Continuous | Apr. 3, 1986 | Yes | BO |
| 0209521700 | B1 | North Buffalo Creek at Church Street | 14.2 | Intermittent | Apr. 8, 1986 | No | AO |
| 0209531600 | B2 | North Buffalo Creek at Summit Avenue | 21.7 | Intermittent | Feb. 4, 1986 | Yes | BO |
| 0209533500 | NB | North Buffalo Wastewater Treatment Plant | -- | -- | -- | -- | EFF |
| 02095500 | B3 | North Buffalo Creek near Greensboro | 37.1 | Continuous | Aug. 1928 | Yes | BO |
| 0209504600 | B4 | South Buffalo Creek at U.S. 70 | 39.0 | Intermittent | Feb. 3, 1986 | No | AO |
| 0209505100 | OS | T.Z. Osborne Wastewater Treatment Plant | -- | -- | -- | -- | EFF |
| 0209509100 | B5 | South Buffalo Creek at Harvest Road | 43.5 | Continuous | Feb. 21, 1986 | Yes | BO |
| 0209555450 | B6 | Buffalo Creek at High Rock Road | 97.4 | Continuous | Apr. 25, 1986 | Yes | BO |

## Streamflow

Discharge was determined at the time of each sampling at the 13 stream sites. Intermittent discharge records were gathered from sites R2, R3, R4, R5, B1, B2, and B4 (table 1). Discharge was continuously monitored at sites R1, R8, and R9 on Reedy Fork Creek; sites B3 and B5 on North and South Buffalo Creeks, respectively, and at site B6 on Buffalo Creek.

Site R1 on Reedy Fork Creek is located in a rural area (fig. 2) and can be used as representative of natural flow. Although there is some diurnal fluctuation at medium and low flows, the hydrograph at this site represents the most natural response to ground-water flow and climatological events in the study area. A comparison of daily discharge at site R1 for the 1986-87 water years with median daily discharge for 20 years of discharge records beginning in 1967 shows streamflow to be less than median discharge during most of the 1986 water year and about the same during the 1987 water year (fig. 3).

## Water Quality

Water-quality samples were collected at all data sites and were analyzed for a variety of physical and chemical inorganic and organic constituents. Physical analyses included suspended, total, and dissolved solids; turbidity; and suspended sediment. Chemical analyses for inorganic constituents included water quality indicators such as pH and specific conductance; major ions; dissolved and total nutrients; and dissolved and total trace metals and cyanide. Organic analyses performed included gas chromatograph/mass spectrometric (GC/MS) quantification of detectable concentrations of acid and base/neutral extractable (ABN) and volatile compounds. Computerized library searches were performed on all GC/MS spectrograms for all ABN and volatile samples based on spectral libraries maintained by the National Bureau of Standards and the Environmental Protection Agency--National Institute of Health. Tests were also performed for detection of organochlorine and organophosphorus pesticide compounds.

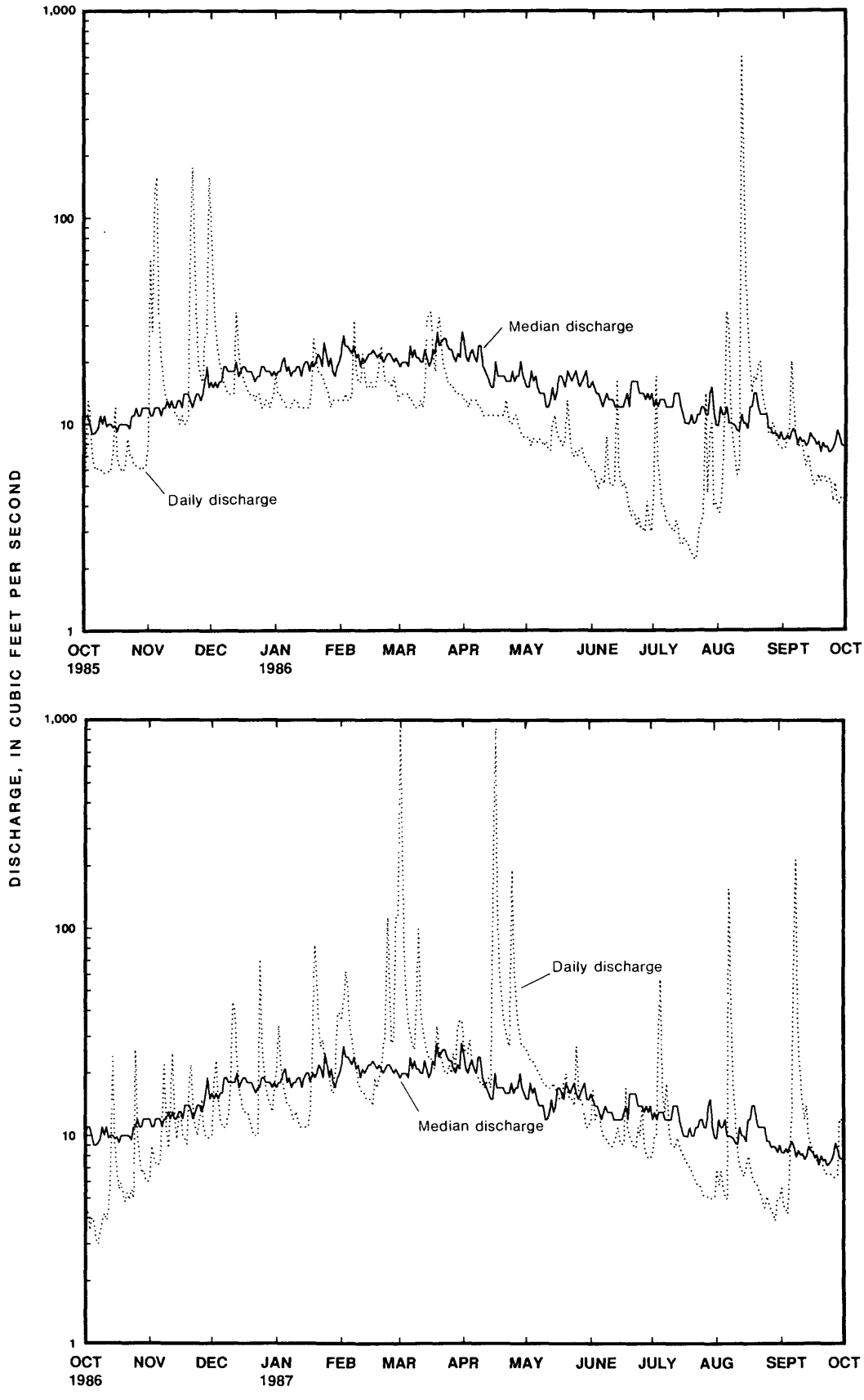



Figure 3.-- Daily discharge for 1986-87 water years and median daily discharge for 1967-87 water years at site R1, Reedy Fork Creek near Oak Ridge, Guilford County, North Carolina.

## Sampling Schedule

The 18-month water-quality sampling period included sampling during periods of low flow and high flow. Samples were collected at approximately 2-month intervals during periods of low flow at all 19 sites and consisted of five sets of inorganic and four sets of organic samples. A sixth set of samples was collected during the late recession stage of high flow in March 1987.

High-flow samples were collected at six stream sites during rising, peak, and falling stages. These samples were collected during four storms between August 1986 and April 1987 and analyzed for both inorganic and organic constituents. Sampling dates, type of flow, sites sampled, and the analyses performed are shown in table 2.

## Field Procedures

The major goal of water-quality sampling is to obtain a sample that represents the *in-situ* quality of the water. To assure this, field measurements, such as water temperature, specific conductance, pH, and dissolved oxygen (DO), were made on site whenever possible as the samples were taken. On-site measurements of these constituents minimized changes that can occur during sample processing. Procedures for these on-site measurements and for collecting, treating, and shipping samples were followed as outlined by Guy and Norman (1970); Stevens and others (1975); R.J. Pickering, U.S. Geological Survey, written communication (1976); Wershaw and others (1983); and Fishman and Friedman (1985). A detailed description of field procedures and data-collection techniques for this study are given in Davenport (1988).

## Quality Control

Three quality-control methods were employed during the course of the study to assure the integrity of the analytical results. These included: (1) participation of laboratories performing inorganic analyses in the U.S. Geological Survey (Survey) standard-reference water-sample program, (2) analyses of blank and duplicate samples, and (3) determination of the cation-anion balance in the water samples.

Table 2.--*Water and bottom-sediment sampling dates, type of flow at sites sampled, and analyses performed on samples collected in the Greensboro area, North Carolina, 1986-87*

| Dates | Type of flow | Sites sampled | Type of sample collected | Analyses performed |
|---|---|---|---|---|
| April 15-16, 1986 | Low flow | All 19 | Water | Inorganic |
| June 17-19, 1986 | Low flow | All 19 | Water, bottom sediment | Inorganic (water only), organic |
| August 12-13, 1986 | High flow | R1, R5, R9 | Water | Inorganic, organic |
| October 1-3, 1986 | Low flow | All 19 | Water | Inorganic, organic |
| November 18-20, 1986 | Low flow | All 19 | Water | Inorganic |
| November 20, 1986 | High flow | B1, B3 | Water | Inorganic, organic |
| January 13-15, 1987 | Low flow | All 19 | Water | Inorganic |
| January 18-20, 1987 | High flow | R1, R5, B1, B3, B5 | Water | Inorganic, organic |
| March 10-12, 1987 | Latter stages of high flow | All 19 | Water | Inorganic, organic |
| April 15-17, 1987 | High flow | R9, B5 | Water | Inorganic, organic |
| June 9-10, 1987 | Low flow | All 19 | Water, bottom sediment | Organic |
| September 1-2, 1987 | Low flow | All 19 | Water, bottom sediment | Organic |

All laboratories performing chemical analyses involving inorganic compounds have been participating in the QA program. The QA program allows performance evaluation of the participating laboratories, identification of analytical problem areas, and evaluation of the accuracy and precision of analytical methods (Victor Janzer, U.S. Geological Survey, written commun., 1986). Occasionally, reported analytical results are suspicious due to possible field or laboratory contamination. These results were not used in any statistical analyses in this report but are listed, flagged with an asterisk, and footnoted (Davenport, 1988, appendixes B through E).

Laboratories were sent duplicate and blind samples appropriate to the analyses they were conducting during the study. The City of Greensboro's Townsend Lake Filtration Plant and the T.Z. Osborne Wastewater Treatment Plant analyzed water samples for inorganic constituents. Total organic carbon (TOC) analyses were contracted by the City of Greensboro, and suspended-sediment concentrations were determined in the Survey sediment laboratory in Raleigh, North Carolina. Analyses for organic constituents in water and bottom-sediment samples were done at the Survey National Water Quality Laboratory in Arvada, Colorado, or by the Tennessee Valley Authority (TVA) in Chattanooga, Tennessee.

Both City of Greensboro laboratories processed blind field samples following the same procedures used on regular water samples. Field blanks were made from the Lake Townsend Filtration Plant Laboratory distillation still. The still was equipped with two high-capacity cartridges for removing ions from the water and a 0.2 micrometer filter. However, it was not equipped with a carbon cartridge for removing organic compounds.

Laboratories conducting organic analyses were sent at least one blind field blank during each low-flow sampling; occasionally, blanks were also sent with samples collected during high flows. Additionally, unopened empty sample bottles were sent to the TVA laboratory where they were filled with deionized water from the TVA distillation and deionization unit, and treated as real samples in the analysis process. This was done as a check on the sample bottles and the deionized water. These results are on file in the North Carolina District office of the U.S. Geological Survey.

The final quality-control procedure was to check the electrochemical balance based on reported cation and anion concentrations. For most samples the percent difference between cations and anions was within the accepted range of 10 percent. Ionic imbalances observed in some samples from effluents and stream sites below outfall may be the result of matrix-effect interferences during chemical analyses.

### Bottom Sediment Quality

Because certain organic compounds, which are sparingly soluble in water, can readily sorb to clay and other fine particles, they are transported attached to sediments and may eventually become deposited in the streambed. Thus, the assessment of water quality in the Reedy Fork and Buffalo Creek basins also includes streambed sediments.

Bottom-sediment samples were collected in June 1986 and June and September 1987 during low flow from the three most downstream sites: site R8 on Reedy Fork Creek, site B6 on Buffalo Creek, and site R9 on Reedy Fork Creek (fig. 2). The samples were analyzed for acid and base/neutral extractable (ABN) compounds and organochlorine pesticides. Some samples were also analyzed for organophosphorus pesticides. Duplicate sample analyses were performed in the laboratory for quality assurance.

## WATER-QUALITY IN REEDY FORK AND BUFFALO CREEK BASINS

The results of nearly 22,000 separate chemical and physical analyses of samples collected in Reedy Fork and Buffalo Creek basins are assessed in terms of constituent concentrations at individual sampling sites, exceedance of water-quality standards or criteria, and estimates of loading or bottom-sediment quality as it relates to water quality. Because of the structure of the sampling program, at least two of the above topics are used to present water-quality characteristics in each group of parameters, such as general water-quality indicators, major ions, nutrients, trace elements, and cyanide; and volatile organic, ABN extractable, and organochlorine and organophosphorous pesticide compounds. Within each grouping, the analytical results from each sampling site are discussed.

The results are compared to State or Federal water-quality standards or criteria. Standards are legally enforcible limits on constituent concentrations in water, whereas criteria are non-binding suggested limits, both of which are formulated by the U.S. Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 1978, 1979, 1986, and 1987) for protection of drinking water, water supplies, and freshwaters. Using EPA recommendations, the North Carolina Department of Natural Resources and Community Development (NRCD), Division of Environmental Management, has established water-quality standards for freshwaters and tidal saltwaters with more stringent standards for freshwaters to be used as water supply (North Carolina Department of Natural Resources and Community Development, 1986), and the North Carolina Department of Human Resources has established water-quality standards for treated drinking water (North Carolina Department of Human Resources, 1988).

In addition to the water-quality standards, the North Carolina Administrative Code (NCAC) lists chemical substances that require special attention. The list includes chemicals that either are on the EPA's priority pollutant list or "...are known to be present in industrial and domestic compounds that could find their way into the State's waters. They are suspected of being toxic, carcinogenic, teratogenic, mutagenic, or neurotoxic, but sufficient data are not presently available to adopt statewide numerical concentrations limits for each one..." (North Carolina Department of Natural Resources and Community Development, 1986). With few exceptions, the majority of analyses for organic compounds made during this study were for compounds on the NCAC toxic substances list.

Analytical results compared with appropriate standards or criteria are summarized in tables 3, 4, and 5. The results of sampling at the drinking-water sites MI and TO are reported in table 3; results for water-supply sites (R1, R2, R3, R4, R5, R6, and R7) are given in table 4; and the results at sites above wastewater outfalls (B1, B4, and R8) and below the outfalls (B2, B3, B5, B6, and R9) are presented in table 5.

Many of the State and Federal recommended criteria for maximum concentrations of synthetic organic compounds in water supplies and freshwaters should be zero, according to the EPA (1986). Because of the limitations of current analytical methodologies, the feasibility of the zero

Table 3.--*Federal and State water-quality standards for drinking-water samples and the number of exceedances per number of treated drinking-water samples collected at sites MI and TO*

[µg/L, microgram per liter; mg/L, milligrams per liter; NSC, no standard or criteria; NTU, nephelometric turbidity]

| Constituents | Detection limit | Units | State standard or criteria[1] [2] | Federal standard or criteria[2] [3] [4] | Number of exceedances per number of samples | |
|---|---|---|---|---|---|---|
| | | | | | State | Federal |
| Inorganic | | | | | | |
| Arsenic | 55.0 | µg/L | 50.0 | 50.0 | 0/12 | 0/12 |
| Barium | 2 | µg/L | 1,000 | 1,000 | 0/12 | 0/12 |
| Cadmium | 10 | µg/L | 10 | 10 | 0/12 | 0/12 |
| Chloride | .1 | mg/L | 250 | 250 | 0/12 | 0/12 |
| Chromium | 10 | µg/L | 50 | 50 | 0/12 | 0/12 |
| Color | 1 | color | 15 | 15 | 0/12 | 0/12 |
| Copper | 10 | µg/L | 1,000 | 1,000 | 0/12 | 0/12 |
| Corrosivity | .001 | Langelier | <0 | <0 | 0/12 | 0/12 |
| Cyanide | 1 | mg/L | NSC | 200 | NSC | 0/2 |
| Fluoride | .001 | mg/L | 4 | 2 | 0/12 | 0/12 |
| Iron | 55 | µg/L | 300 | 300 | 0/12 | 0/12 |
| Lead | 55 | µg/L | 50 | 50 | 0/12 | 0/12 |
| Manganese | 10 | µg/L | 50 | 50 | 0/12 | 0/12 |
| Mercury | .05 | µg/L | 2 | 2 | 0/12 | 0/12 |
| Nitrate | .001 | mg/L | 10 | 10 | 0/12 | 0/12 |
| pH | .1 | pH | >6.5, <8.5 | >6.5, <8.5 | 0/12 | 0/12 |
| Selenium | .1 | µg/L | 10 | 10 | 0/12 | 0/12 |
| Silver | 10 | µg/L | 50 | 50 | 0/12 | 0/12 |
| Sulfate | .1 | mg/L | 250 | 250 | 0/12 | 0/12 |
| Total dissolved solids | 1 | mg/L | 500 | 500 | 0/12 | 0/12 |
| Turbidity | .01 | NTU | [5]1 | 1 | 0/12 | 0/12 |
| Zinc | 10 | µg/L | 5,000 | 5,000 | 0/12 | 0/12 |
| Organic | | | | | | |
| Benzene | .2 | µg/L | 5 | 5 | 1/8 | 1/8 |
| Carbon tetrachloride | .2 | µg/L | 5 | 5 | 0/8 | 0/8 |
| 1,4-dichlorobenzen | .2 | µg/L | 75 | 75 | 0/10 | 0/10 |
| 1,2-dichloroethane | .2 | µg/L | 5 | 5 | 0/8 | 0/8 |
| 1,1-dichloroethylene | .2 | µg/L | 7 | 7 | 0/8 | 0/8 |
| Endrin | .01 | µg/L | .2 | .2 | 0/10 | 0/10 |
| Lindane | .01 | µg/L | 4 | 4 | 0/10 | 0/10 |
| Methoxychlor | .01 | µg/L | 100 | 100 | 0/4 | 0/4 |
| Toxaphene | .05 | µg/L | 5 | 5 | 0/10 | 0/10 |
| 1,1,1-trichloroethane | .2 | µg/L | 200 | 200 | 0/8 | 0/8 |
| Trichloroethylene | .2 | µg/L | 5 | 5 | 1/8 | 1/8 |
| Total trihalomethanes | .2 | µg/L | 100 | NSC | 5/8 | NSC |
| Vinyl chloride | .2 | µg/L | 2 | 2 | 0/8 | 0/8 |

[1] North Carolina Department of Natural Resources and Community Development, 1988.
[2] U.S. Environmental Protection Agency, 1979.
[3] U.S. Environmental Protection Agency, 1986.
[4] U.S. Environmental Protection Agency, 1978.
[5] Monthly average.

Table 4.--*Federal and State water-quality standards and criteria for water supplies and the number of exceedances per number of samples collected at water-supply sites R1, R2, R3, R4, R5, R6, and R7*

[mg/L, milligrams per liter; NSC, no standard or criteria; µg/L, micrograms per liter; NTU, nephelometric turbidity; LVN, limits vary numerically; VRL, various risk levels (For maximum protection of human health, the recommended criteria should be zero. Current methodology does not allow for a zero limit; therefore, various limits are given for various risk levels.)]

| Constituents | Detection limit | Units | State standard or criteria[1] | Federal standard or criteria[2 3] | Number of exceedances per number of samples | |
|---|---|---|---|---|---|---|
| | | | | | State | Federal |
| Inorganic | | | | | | |
| Ammonia | 0.001 | mg/L | NSC | 0.5 | NSC | 0/56 |
| Arsenic | 55 | µg/L | 50 | 50 | 1/56 | 1/56 |
| Barium | 2 | µg/L | 1,000 | 1,000 | 0/56 | 0/56 |
| Cadmium | 10 | µg/L | 2 | 10 | 0/56 | 0/56 |
| Chloride | .1 | mg/L | 250 | 250 | 0/56 | 0/56 |
| Chromium | 10 | µg/L | 50 | 50 | 0/56 | 0/56 |
| Color | 1 | color | NSC | 75 | NSC | 3/56 |
| Copper | 10 | µg/L | 15 | 1,000 | 10/56 | 0/56 |
| Cyanide | 1 | mg/L | 5 | 200 | 7/7 | 0/7 |
| Dissolved oxygen | .1 | mg/L | >5 | NSC | [4]0/39 | NSC |
| Fluoride | .001 | mg/L | 1.8 | [5]1.4-2.4 | 0/56 | 0/56 |
| Hardness | .1 | mg/L | 100 | NSC | 0/56 | NSC |
| Iron | 55 | µg/L | 1,000 | 300 | 37/56 | 51/56 |
| Lead | 55 | µg/L | 25 | 50 | NSC | 1/56 |
| Manganese | 10 | µg/L | 50 | 50 | 56/56 | 56/56 |
| Mercury | .05 | µg/L | .2 | 2 | 12/56 | 0/56 |
| Nickel | 10 | µg/L | 25 | NSC | 0/56 | NSC |
| Nitrate | .001 | mg/L | 10 | 10 | 0/56 | 0/56 |
| pH | .1 | pH | NSC | >5,<9 | NSC | 0/56 |
| Selenium | .1 | µg/L | 10 | 10 | 0/56 | 0/56 |
| Silver | 10 | µg/L | 10 | 50 | 0/56 | 0/56 |
| Sulfate | .1 | mg/L | 250 | 250 | 0/56 | 0/56 |
| Total dissolved solids | 1 | mg/L | 500 | NSC | 1/56 | NSC |
| Turbidity | .01 | NTU | 50 | NSC | 5/42 | NSC |
| Zinc | 10 | µg/L | 50 | 5,000 | 6/56 | 0/56 |
| Organic | | | | | | |
| Acenaphthene | 5 | µg/L | LVN | [6]20 | 0/35 | 0/35 |
| Aldrin | .01 | µg/L | .002 | .001 | 0/35 | 0/35 |
| Benzene | .2 | µg/L | LVN | VRL | 6/28 | 6/28 |
| Benzidine | 50 | µg/L | LVN | VRL | 0/35 | 0/35 |
| bis(2-chloroethyl)ether | 5 | µg/L | LVN | VRL | 0/35 | 0/35 |
| bis(2-chloroisopropyl)ether | 5 | µg/L | LVN | 34.7 | 0/35 | 0/35 |
| bis(2-chloromethyl)ether | 5 | µg/L | LVN | VRL | 0/35 | 0/35 |
| bis(2-ethylhexyl)phthalate | .005 | mg/L | LVN | 15 | 0/35 | 0/35 |

Footnotes at end of table.

Table 4.--*Federal and State water-quality standards and criteria for water supplies and the number of exceedances per number of samples collected at water-supply sites R1, R2, R3, R4, R5, R6, and R7*--Continued

[mg/L, milligrams per liter; NSC, no standard or criteria; µg/L, microgram per liter; NTU, nephelometric turbidity; LVN, limits vary numerically; VRL, various risk levels (For maximum protection of human health, the recommended criteria should be zero. Current methodology does not allow for a zero limit; therefore, various limits are given for various risk levels.)]

| Constituents | Detection limit | Units | State standard or criteria[1] | Federal standard or criteria[2] [3] | Number of exceedances per number of samples | |
|---|---|---|---|---|---|---|
| | | | | | State | Federal |
| Organic--Continued | | | | | | |
| Bromodichloromethane | .2 | µg/L | LVN | VRL | 0/28 | 2/28 |
| Bromoform | .2 | µg/L | LVN | VRL | 0/28 | 0/28 |
| Bromomethane (methyl bromide) | .2 | µg/L | LVN | VRL | 1/28 | 1/28 |
| Carbon tetrachloride | .2 | µg/L | LVN | VRL | 0/28 | 0/28 |
| Chlordane | .01 | µg/L | .004 | .003 | 0/35 | 0/35 |
| Chlorobenzene | .2 | µg/L | LVN | VRL | 0/35 | 0/35 |
| Chloroform | .2 | µg/L | LVN | VRL | 9/28 | 9/28 |
| Chloromethane (methyl chloride) | .2 | µg/L | LVN | VRL | 6/28 | 6/28 |
| 2-chlorophenol | 5 | µg/L | LVN | [6].1 | 0/35 | 0/35 |
| p, p' DDD | .01 | µg/L | LVN | [4].001 | 0/35 | 0/35 |
| p, p' DDE | .01 | µg/L | LVN | .001 | 0/35 | 0/35 |
| p, p' DDT | .01 | µg/L | .001 | [4].05 | 0/35 | 0/35 |
| Diazinon | .01 | µg/L | LVN | .009 | 1/21 | 1/21 |
| Dibutyl phthalate | .005 | mg/L | LVN | 34 | 0/35 | 0/35 |
| Dichlorobenzenes | .2 | µg/L | LVN | 400 | 0/35 | 0/35 |
| 3,3'-dichlorobenzidine | 25 | µg/L | LVN | VRL | 0/35 | 0/35 |
| Dichlorodifluoromethane | .2 | µg/L | LVN | VRL | 0/28 | 0/28 |
| 1,1-dichloroethylene | .2 | µg/L | LVN | [6].3 | 0/28 | 0/28 |
| 2,4-dichlorophenol | 5 | µg/L | LVN | VRL | 0/35 | 0/35 |
| Dieldrin | .01 | µg/L | .002 | .001 | 0/35 | 0/35 |
| Dichloromethane (methylene chloride) | .2 | µg/L | LVN | VRL | 1/28 | 1/28 |
| Diethyl phthalate | .005 | mg/L | LVN | 350 | 0/35 | 0/35 |
| 2,4-dimethylphenol | 5 | µg/L | LVN | [6]400 | 0/35 | 0/35 |
| Dimethylphthalate | .005 | mg/L | LVN | 313 | 0/35 | 0/35 |
| 2,4-dinitro-o-cresol | 30 | µg/L | LVN | 13.4 | 0/35 | 0/35 |
| Dinitrophenol | 30 | µg/L | LVN | 70 | 0/35 | 0/35 |
| 2,4-dinitrotoluene | 5 | µg/L | LVN | [2]NSC | 0/35 | 0/35 |
| Dioctyl phthalate | .005 | mg/L | LVN | 15 | 0/35 | 0/35 |
| Endosulfan | .01 | µg/L | .05 | NSC | 0/35 | NSC |
| Endrin | .01 | µg/L | .002 | .2 | 0/35 | 0/35 |
| Ethion | .01 | µg/L | LVN | .02 | 0/21 | 0/21 |

Footnotes at end of table.

Table 4.--*Federal and State water-quality standards and criteria for water supplies and the number of exceedances per number of samples collected at water-supply sites R1, R2, R3, R4, R5, R6, and R7*--Continued

[mg/L, milligrams per liter; NSC, no standard or criteria; µg/L, microgram per liter; NTU, nephelometric turbidity; LVN, limits vary numerically; VRL, various risk levels (For maximum protection of human health, the recommended criteria should be zero. Current methodology does not allow for a zero limit; therefore, various limits are given for various risk levels.)]

| Constituents | Detection limit | Units | State standard or criteria[1] | Federal standard or criteria[2] [3] | Number of exceedances per number of samples | |
|---|---|---|---|---|---|---|
| | | | | | State | Federal |
| Organic--Continued | | | | | | |
| Ethylbenzene | .2 | µg/L | LVN | 1,400 | 0/35 | 0/35 |
| Fluoranthene | 5 | µg/L | LVN | 42 | 0/35 | 0/35 |
| Halomethanes (sum of methyl choride, methyl bromide, methylene chloride, bromodichloromethane, bromoform, dichloro-difluoromethane, tri-chlorofluoromethane) | .2 | µg/L | LVN | VRL | 13/28 | 13/28 |
| Heptachlor | .01 | µg/L | .004 | .1 | 0/35 | 0/35 |
| Hexachlorobutadiene | 5 | µg/L | LVN | VRL | 0/35 | 0/35 |
| Hexachlorocyclohexane (BHC) | .01 | µg/L | LVN | VRL | 1/35 | 1/35 |
| Hexachlorocyclopentadiene | 5 | µg/L | LVN | [6]1 | 0/35 | 0/35 |
| Isophorone | 5 | µg/L | LVN | 5,200 | 0/35 | 0/35 |
| Lindane (gamma-BHC) | .01 | µg/L | .01 | 4 | 0/35 | 0/35 |
| Malathion | .01 | µg/L | LVN | .1 | 0/21 | 0/21 |
| Methoxychlor | .01 | µg/L | .03 | 100 | 0/14 | 0/14 |
| 3-Methyl-4-chlorophenol | 30 | µg/L | LVN | [6]3,000 | 0/35 | 0/35 |
| Nitrobenzene | 5 | µg/L | LVN | 30 | 0/35 | 0/35 |
| Parathion | .01 | µg/L | .04 | .04 | 0/21 | 0/21 |
| PCB | .01 | µg/L | .001 | [6]NSC | 0/35 | 0/35 |
| Pentachlorophenol | 30 | µg/L | LVN | [6]30 | 0/35 | 0/35 |
| Phenolic compounds | 5 | µg/L | 1 | 1 | 3/35 | 3/35 |
| Tetrachloroethylene | .2 | µg/L | LVN | VRL | 3/28 | 3/28 |
| Toluene | .2 | mg/L | LVN | 14.3 | 0/28 | 0/28 |
| Toxaphene | .5 | µg/L | .013 | 5 | 0/35 | 0/35 |
| 1,1,1-trichloroethane | .2 | µg/L | LVN | 1.03 | 0/28 | 0/28 |
| Trichloroethylene | .2 | µg/L | LVN | VRL | 1/28 | 1/28 |
| Trichlorofluoromethane | .2 | µg/L | LVN | VRL | 0/28 | 0/28 |
| 2,4,6-trichlorophenol | 20 | µg/L | LVN | [6]2 | 0/35 | 0/35 |
| Vinyl chloride | .2 | µg/L | LVN | VRL | 0/28 | 0/28 |

[1] North Carolina Department of Natural Resources and Community Development, 1986.
[2] U.S. Environmental Protection Agency, 1973.
[3] U.S. Environmental Protection Agency, 1986.
[4] 24-hour average.
[5] Temperature dependent.
[6] Criteria for control of undesirable taste and odor.

Table 5.--*Federal and State water-quality standards and criteria for freshwaters and the number of exceedances per number of samples collected at sites above wastewater outfalls (sites B1, B4, and R8) and below wastewater outfalls (sites B2, B3, B5, B6, and R9)*

[µg/L, microgram per liter; VRL, various risk levels (For maximum protection of human health, the recommended criteria should be zero. Current methodology does not allow for a zero limit; therefore, various limits are given for various risk levels.); mg/L, milligrams per liter; NSC, no standard or criteria; NTU, nephelometric turbidity; LVN, limits vary numerically]

| Constituents | Detection limit | Units | State standard or criteria[1] | Federal standard or criteria[2 3] | Number of exceedances per number of samples above outfalls | | below outfalls | |
|---|---|---|---|---|---|---|---|---|
| | | | | | State | Federal | State | Federal |
| Inorganic | | | | | | | | |
| Arsenic | 55.0 | µg/L | 50.0 | VRL | 0/24 | 0/24 | 4/53 | 4/53 |
| Cadmium | 10 | µg/L | 2 | 10 | 1/24 | 0/24 | 0/53 | 0/53 |
| Chromium | 10 | µg/L | 50 | 50 | 0/24 | 0/24 | 0/53 | 0/53 |
| Copper | 10 | µg/L | 15 | [4]1,000 | 1/24 | 0/24 | 4/53 | 0/53 |
| Cyanide | 1 | µg/L | 5 | 200 | 3/3 | 0/3 | 13/43 | 0/43 |
| Fluoride | .001 | mg/L | 1.8 | NSC | 0/24 | NSC | 0/53 | NSC |
| Iron | 55 | µg/L | 1,000 | 1,000 | 17/24 | 17/24 | 34/53 | 34/53 |
| Lead | 55 | µg/L | 25 | 50 | 1/24 | 1/24 | 0/53 | 0/53 |
| Mercury | .05 | µg/L | .2 | .144 | 1/24 | 5/24 | 10/53 | 14/53 |
| Nickel | 10 | µg/L | 50 | 632 | 3/24 | 0/24 | 1/53 | 0/53 |
| pH | .01 | standard | >6,<9 | >6.5,<9 | 0/18 | 1/18 | 0/36 | 0/36 |
| Phosphorus | .001 | mg/L | NSC | .100 | NSC | 13/24 | NSC | 53/53 |
| Selenium | .1 | µg/L | 10 | 10 | 0/24 | 0/24 | 0/53 | 0/53 |
| Silver | 10 | µg/L | 10 | 50 | 0/24 | 0/24 | 0/53 | 0/53 |
| Turbidity | .01 | NTU | 50 | NSC | 4/20 | NSC | 3/36 | NSC |
| Zinc | 10 | µg/L | 50 | [4]5,000 | 6/24 | 0/24 | 28/53 | 0/53 |
| Organic | | | | | | | | |
| Acenaphthene | 5 | µg/L | LVN | [4]20 | 1/15 | 0/15 | 1/30 | 0/30 |
| Aldrin | .01 | µg/L | .002 | [4]NSC | 0/15 | 0/15 | 5/47 | 0/47 |
| Benzene | .2 | µg/L | LVN | VRL | 2/12 | 2/12 | 5/41 | 5/41 |
| Benzidine | 50 | µg/L | LVN | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| bis(2-chloroethyl)ether | 5 | µg/L | LVN | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| bis(2-chloroisopropyl)ether | 5 | µg/L | LVN | 34.7 | 0/15 | 0/15 | 0/47 | 0/47 |
| bis(2-chloromethyl)ether | 5 | µg/L | LVN | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| bis(2-ethylhexyl)phthalate | .005 | mg/L | LVN | 15 | 6/15 | 0/15 | 13/41 | 0/41 |
| Bromodichloromethane | .2 | µg/L | LVN | VRL | 2/12 | 2/12 | 15/41 | 15/41 |
| Bromoform | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 1/41 | 1/41 |
| Bromomethane (methyl bromide) | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 4/41 | 4/41 |
| Carbon tetrachloride | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 0/41 | 0/41 |

Footnotes at end of table.

Table 5.--*Federal and State water-quality standards and criteria for freshwaters and the number of exceedances per number of samples collected at sites above wastewater outfalls (sites B1, B4, and R8) and below wastewater outfalls (sites B2, B3, B5, B6, and R9)*--Continued

[µg/L, microgram per liter; VRL, various risk levels (For maximum protection of human health, the recommended criteria should be zero. Current methodology does not allow for a zero limit; therefore, various limits are given for various risk levels.); mg/L, milligrams per liter; NSC, no standard or criteria; NTU, nephelometric turbidity; LVN, limits vary numerically]

| Constituents | Detection limit | Units | State standard or criteria[1] | Federal standard or criteria[2] [3] | Number of exceedances per number of samples above outfalls | | below outfalls | |
|---|---|---|---|---|---|---|---|---|
| | | | | | State | Federal | State | Federal |
| Organic--Continued | | | | | | | | |
| Chlordane | .01 | µg/L | .004 | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| Chlorobenzene | .2 | µg/L | LVN | [4]20 | 0/12 | 0/12 | 2/41 | 0/41 |
| Chloroform | .2 | µg/L | LVN | VRL | 3/12 | 3/12 | 36/41 | 36/41 |
| Chloromethane (methyl chloride) | .2 | µg/L | LVN | VRL | 2/12 | 2/12 | 4/41 | 4/41 |
| 2-chlorophenol | 5 | µg/L | LVN | [4].1 | 0/15 | 0/15 | 0/47 | 0/47 |
| p, p' DDD | .01 | µg/L | LVN | [5].001 | 0/15 | 0/15 | 0/47 | 0/47 |
| p, p' DDE | .01 | µg/L | LVN | [5].001 | 1/15 | 1/15 | 0/47 | 0/47 |
| p, p' DDT | .01 | µg/L | .001 | [5].001 | 0/15 | 0/15 | 0/47 | 0/47 |
| Diazinon | .01 | µg/L | LVN | .009 | 3/9 | 2/9 | 8/30 | 8/30 |
| Dibutyl phthalate | .005 | mg/L | LVN | 34 | 0/15 | 0/15 | 0/47 | 0/47 |
| Dichlorobenzenes | .2 | µg/L | LVN | 400 | 0/15 | 0/15 | 0/47 | 0/47 |
| 3,3'-dichlorobenzidine | 25 | µg/L | LVN | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| Dichlorodifluoromethane | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 1/41 | 1/41 |
| 1,1-dichloroethylene | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 3/41 | 3/41 |
| 2,4-dichlorophenol | 5 | µg/L | LVN | [4].3 | 0/15 | 0/15 | 0/47 | 0/47 |
| Dieldrin | .01 | µg/L | .002 | 1 | 1/15 | 1/15 | 1/47 | 1/47 |
| Dichloromethane (methylene chloride) | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 2/41 | 2/41 |
| Diethyl phthalate | .005 | mg/L | LVN | 350 | 0/15 | 0/15 | 0/47 | 0/47 |
| 2,4-dimethylphenol | 5 | µg/L | LVN | [4]400 | 0/15 | 0/15 | 0/47 | 0/47 |
| Dimethylphthalate | .005 | mg/L | LVN | 313 | 0/15 | 0/15 | 0/47 | 0/47 |
| 2,4-dinitro-o-cresol | 30 | µg/L | LVN | 13.4 | 0/15 | 0/15 | 0/47 | 0/47 |
| Dinitrophenol | 30 | µg/L | LVN | 70 | 0/15 | 0/15 | 0/47 | 0/47 |
| 2,4-dinitrotoluene | 5 | µg/L | LVN | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| Dioctylphthalate | .005 | mg/L | LVN | 15 | 0/15 | 0/15 | 0/47 | 0/47 |
| Endosulfan | .01 | µg/L | .05 | [5].06 | 0/15 | 0/15 | 0/47 | 0/47 |
| Endrin | .01 | µg/L | .002 | .002 | 0/15 | 0/15 | 0/47 | 0/47 |
| Ethion | .01 | µg/L | LVN | .02 | 0/9 | 0/9 | 3/30 | 3/30 |
| Ethylbenzene | .2 | µg/L | LVN | 1,400 | 0/15 | 0/15 | 0/47 | 0/47 |

Footnotes at end of table.

Table 5.--*Federal and State water-quality standards and criteria for freshwaters and the number of exceedances per number of samples collected at sites above wastewater outfalls (sites B1, B4, and R8) and below wastewater outfalls (sites B2, B3, B5, B6, and R9)*--Continued

[µg/L, microgram per liter; VRL, various risk levels (For maximum protection of human health, the recommended criteria should be zero. Current methodology does not allow for a zero limit; therefore, various limits are given for various risk levels.); mg/L, milligrams per liter; NSC, no standard or criteria; NTU, nephelometric turbidity; LVN, limits vary numerically]

| Constituents | Detection limit | Units | State standard or criteria[1] | Federal standard or criteria[2] [3] | Number of exceedances per number of samples above outfalls: State | above outfalls: Federal | below outfalls: State | below outfalls: Federal |
|---|---|---|---|---|---|---|---|---|
| Organic--Continued | | | | | | | | |
| Fluoranthene | 5 | µg/L | LVN | 42 | 0/15 | 0/15 | 1/47 | 0/47 |
| Halomethanes (sum of methyl choride, methyl bromide, methylene chloride, bromodichloromethane, bromoform, dichloro-difluoromethane, tri-chlorofluoromethane) | .2 | µg/L | LVN | VRL | 4/12 | 4/12 | 40/41 | 40/41 |
| Heptachlor | .01 | µg/L | .004 | [5].004 | 0/15 | 0/15 | 3/47 | 3/47 |
| Hexachlorobutadiene | 5 | µg/L | LVN | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| Hexachlorocyclohexane (BHC) | .01 | µg/L | LVN | VRL | 0/15 | 0/15 | 3/47 | 3/47 |
| Hexachlorocyclopentadiene | 5 | µg/L | LVN | [4]1 | 0/15 | 0/15 | 0/47 | 0/47 |
| Isophorone | 5 | µg/L | LVN | 5,200 | 0/15 | 0/15 | 0/47 | 0/47 |
| Lindane (gamma-BHC) | .01 | µg/L | .01 | VRL | 0/15 | 0/15 | 18/47 | 18/47 |
| Malathion | .01 | µg/L | LVN | .1 | 0/9 | 0/9 | 8/30 | 0/30 |
| Methoxychlor | .01 | µg/L | .03 | .03 | 0/6 | 0/6 | 0/12 | 0/12 |
| 3-Methyl-4-chlorophenol | 30 | µg/L | LVN | [4]3,000 | 0/15 | 0/15 | 0/47 | 0/47 |
| Nitrobenzene | 5 | µg/L | LVN | 30 | 0/15 | 0/15 | 0/47 | 0/47 |
| Parathion | .01 | µg/L | .04 | .04 | 0/9 | 0/9 | 5/30 | 5/30 |
| PCB | .01 | µg/L | .001 | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| Pentachlorophenol | 30 | µg/L | LVN | [4]30 | 0/15 | 0/15 | 0/47 | 0/47 |
| Phenolic compounds | 5 | µg/L | NSC | [4]300 | NSC | 0/15 | NSC | 0/30 |
| Tetrachloroethylene | .2 | µg/L | LVN | VRL | 1/12 | 1/12 | 16/41 | 16/41 |
| Toluene | .2 | mg/L | LVN | 14.3 | 0/12 | 0/12 | 5/41 | 0/41 |
| Toxaphene | .5 | µg/L | .013 | VRL | 0/15 | 0/15 | 0/47 | 0/47 |
| 1,1,1-trichloroethane | .2 | µg/L | LVN | 1.03 | 0/12 | 0/12 | 15/41 | 4/41 |
| Trichloroethylene | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 6/41 | 6/41 |
| Trichlorofluormethane | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 3/41 | 3/41 |
| 2,4,6-trichlorophenol | 20 | µg/L | LVN | [4]2 | 0/15 | 0/15 | 0/47 | 0/47 |
| Vinyl chloride | .2 | µg/L | LVN | VRL | 0/12 | 0/12 | 0/41 | 0/41 |

[1] North Carolina Department of Natural Resources and Community Development, 1986.
[2] U.S. Environmental Protection Agency, 1973.
[3] U.S. Environmental Protection Agency, 1986.
[4] Criteria for control of undesirable taste and odor.
[5] 24-hour average.

limit is unattainable. Therefore, in the discussions of standards and criteria, data will be compared only with non-zero standards or criteria listed in tables 3, 4 and 5. Exceedances of the recommended zero criteria are listed in the tables but are not discussed in the text.

Loading estimates for some constituents in Reedy Fork Creek where it flows out of Guilford County (fig. 2, site R9) were calculated using daily mean flows. Because of the small number of samples (19), the loading rates given are considered estimates that require additional sampling for verification. Loads were calculated for selected inorganic constituents and water-quality indicators. Because the detection of organic compounds above detection levels was infrequent, loadings of these constituents were not calculated.

Loading estimates were calculated using the method of Simmons (1976). Constituent concentrations in milligrams per liter (mg/L) were multiplied by instantaneous discharge in cubic feet per second (cfs) and converted to instantaneous constituent discharges in tons per day (tons/d). These instantaneous constituent discharges and daily mean discharges were regressed to develop an equation that was used to estimate daily loads using daily mean discharge as the independent variable. Daily loads were estimated by substituting daily mean discharge at site R9 from May 1, 1986, to April 30, 1987, into the regression equations. The annual loads (in tons per year) were calculated by summing the daily load estimates. The average daily loading was then calculated by dividing the estimated yearly load by 365.

Discussion of results of bottom sediment analyses at the three most downstream sites (fig. 2, sites R8, R9, and B6) is also included in this section. The collection of these data were limited to nine samples in which SOC's were detected in six of them. However, no water-quality standards or criteria apply to bottom sediments.

## General Water-Quality Indicators

Water-quality indicators are characteristics directly related to the chemical and (or) physical properties of water but are not necessarily related to concentrations of any one particular compound. These indicators

are used to estimate relative quality of water. Some are direct measurements that are made at the time of sampling while others involve analysis of water in a laboratory. The indicators evaluated include suspended sediment, turbidity, dissolved solids, specific conductivity, TOC, hardness, carbon dioxide, color, pH, temperature, dissolved oxygen, alkalinity, and corrosivity.

### Indicator Constituent Values

Median suspended-sediment concentrations and turbidity values from samples collected at all sites during low-flow periods are shown in figure 4. The suspended-sediment concentrations closely parallel the turbidity values, with the highest medians for each parameter occurring at site R2 in the water-supply area. These values are probably due to bridge maintenance work directly upstream from site R2 during the study; there also is the possibility of development upstream. Brush Creek at site R2 is a small dredged channel with low water velocities. Any or all of these factors are possible contributors to the turbid conditions at the site.

Results of treatment of the raw lake water for removal of solids are seen when comparing values from samples from these sites with the treated drinking water from sites MI and TO (fig. 4). Turbidity values are near zero at sites MI and TO, whereas median values at lake sites R6 and R7 are 7.2 and 3.0 nephelometric turbidity units (NTU), respectively (fig. 4).

The effluent samples also contained low median turbidity values of less than 5 NTU. Turbidity in site NB effluents was about half that observed in OS effluents due to the presence of traveling bridge filters at the North Buffalo Treatment Plant. No suspended-sediment concentrations were obtained for either treated drinking-water or effluent sites.

At the sites in the AO and BO groups, median suspended-sediment concentrations were less than 10 mg/L with the exception of site B2, which had a median concentration of 12 mg/L. Median turbidity values at these sites were less than 10 NTU with the exception of a median value of 12 NTU at site R8; this site is downhill from an eroded pasture, and it is possible that the erosion contributed to the turbidity of the stream.

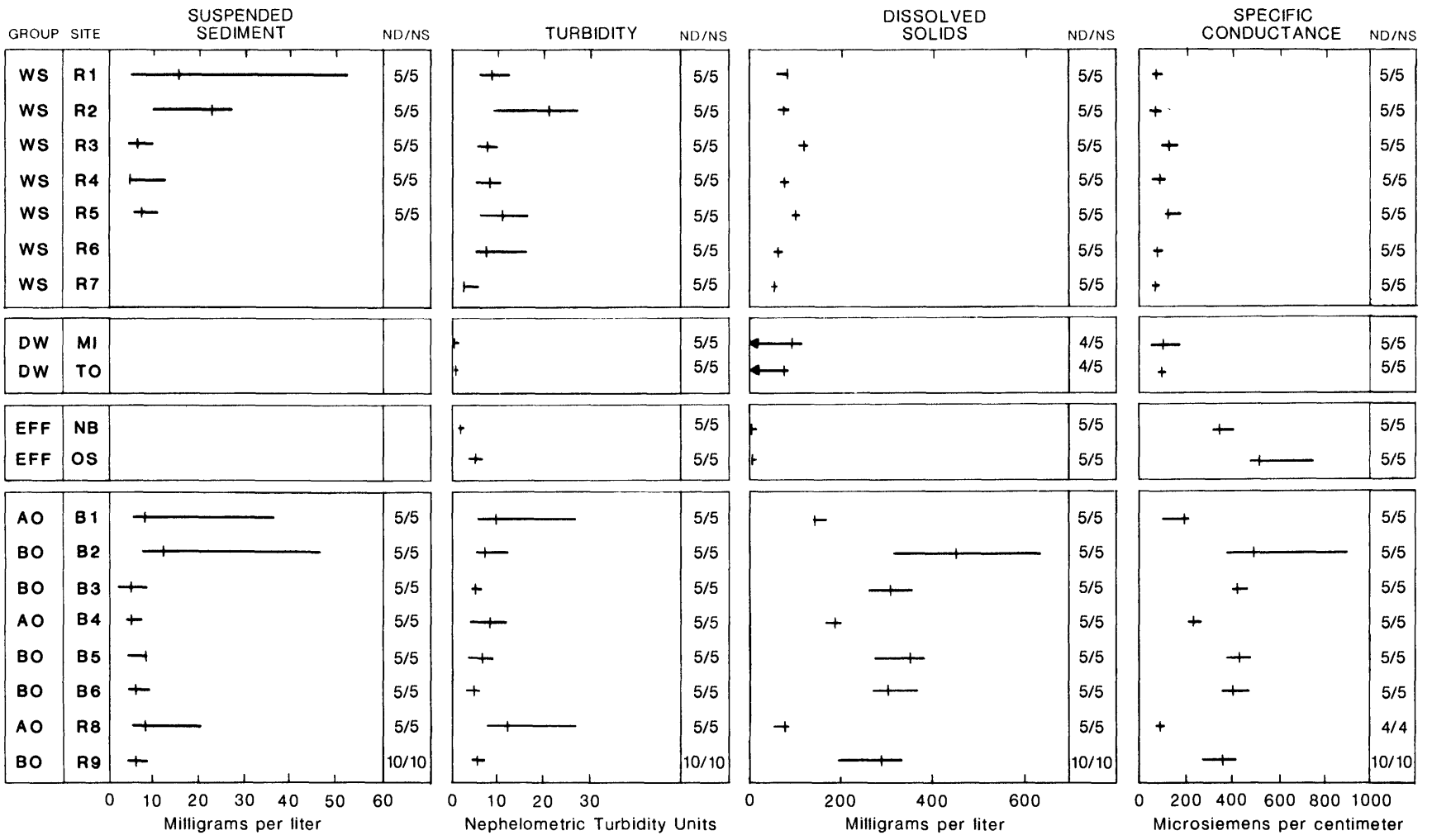



Figure 4.--Suspended-sediment and dissolved-solids concentrations and turbidity and specific conductance values at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

Concentrations of suspended sediment increased during high flows. Median suspended-sediment concentrations are listed for samples collected at six stream sites during low and high flows in table 6. In some instances, median concentrations increased by two orders of magnitude during periods of high flow as a result of runoff from neighboring lands and the scouring of stream channels by the high-velocity waters. The greatest concentrations of suspended sediment occurred at site R9 (fig. 2).

Table 6.--*Median suspended-sediment, suspended-solids, and dissolved-solids concentrations and specific conductance values during low and high flows at selected stream sites in the Greensboro area, North Carolina, 1986-87*

[mg/L, milligram per liter; µS/cm, microsiemens per centimeter; Site, location during the study (fig. 2); n, number of samples (varies during high flow)]

| Site | Suspended sediment (mg/L) | | Suspended solids (mg/L) | | Dissolved solids (mg/L) | | Specific conductance (µS/cm) | |
|---|---|---|---|---|---|---|---|---|
| | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 |
| R1 | 15 | 195 | 6 | 207 | 76 | 106.5 | 81 | 62 |
| R5 | 5 | 305 | 7 | 266 | 97 | 103 | 127 | 80 |
| R9 | 6 | 513 | 6 | 537 | 267 | 131 | 351 | -- |
| B1 | 8 | 402 | 9 | 389 | 142 | 71 | 192 | 68 |
| B3 | 5 | 326 | 5 | 272 | 307 | 99 | 419 | 97.5 |
| B5 | 8 | 302 | 7 | 207 | 348 | 143 | 421 | 146 |

Specific conductance values and dissolved solids concentrations for samples collected at the 19 sites are given in figure 4. Median specific conductance values during low flows at the water-supply sites, at site R8 downstream from the water-supply area, and in the drinking-water samples were less than 140 microsiemens per centimeter (µS/cm), whereas all but one of the median values in the other sites were greater than 150 µS/cm. However, the influence of the high conductance values in the municipal sewage effluents on downstream values are seen when comparing specific conductance values above and below the two outfalls. Median specific conductance values were 341 and 520 µS/cm at sites NB and OS, respectively, whereas average median specific conductance values were 210 and 414 µS/cm above and below the outfalls, respectively. The value at site B2 (484 µS/cm) was among the highest due to the entrance of treated industrial effluent into North Buffalo Creek between sites B1 and B2 (fig. 4).

An inverse relation between suspended- and dissolved-solids concentrations during low and high flows is shown in table 6. During

periods of low flow when velocities are slower, dissolved solids constitute a greater portion of the total solids concentrations than the suspended solids due to the contribution of natural ions in ground water and a lessened capacity to dilute any anthropogenic influences. However, during periods of increased flow due to storm runoff, this relation is reversed (table 6) as a result of increased suspended solids. Dissolved-solids concentrations and specific-conductance values also tend to decrease during high flow compared to values obtained during low flow.

Median concentrations of TOC at the water-supply and drinking-water sites during low flow were less than 7.5 mg/L, whereas concentrations at the other sites ranged between 5 and 23 mg/L (fig. 5). Median concentrations were less than 9 mg/L at sites R8, B1, and B4 that were either downstream from the water-supply area or were above municipal outfalls.

The effect of municipal effluents on TOC concentrations is seen when comparing medians from sites B1 with B3 (8 and 13 mg/L, respectively) and sites B4 with B5 (9 and 19 mg/L, respectively). The increases in TOC in the downstream sites are primarily due to the introduction of NB and OS effluents (12 and 23 mg/L, respectively) into the streams.

There is little difference between median hardness concentrations among samples from the water-supply and drinking-water sites, and low-flow samples at site R8 downstream of the water-supply area (fig. 5). Concentrations at these sites range between 24 and 67 mg/L as calcium carbonate ($CaCO_3$). There are only slight differences in the concentrations between sites in the Buffalo Creek basin.

Median carbon dioxide concentrations at the water-supply and drinking-water sites were generally less than 4 mg/L compared to median concentrations in effluents that were 14.3 and 7.8 mg/L at sites NB and OS, respectively, (fig. 5). However, carbon dioxide concentrations in the effluents did not seem to have an affect on concentrations at sites below the outfalls.

The elevated color values at site R2 compared to those in the remaining watershed area are probably related to the turbid conditions at the site (figs. 4 and 5). The highest values were at site B5 directly downstream

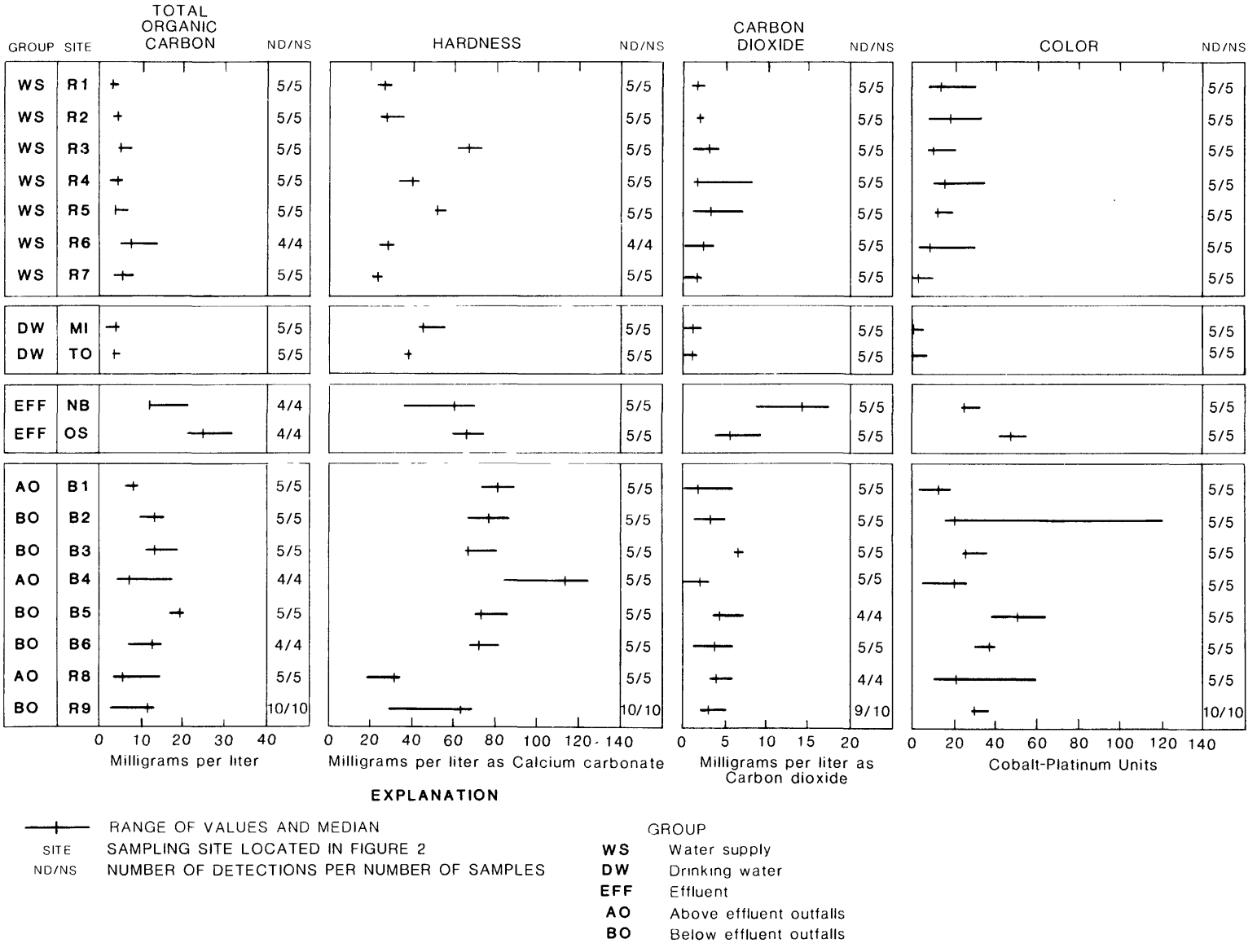



Figure 5.--Total organic carbon, hardness, and carbon dioxide concentrations and color values at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

from the OS effluent outfall, and at site B2 directly downstream from the outfall of treated industrial waste.

The ranges of pH and water-temperature values were fairly consistent between the sampling sites. Values of pH in all low-flow samples ranged from 6.6 to 7.6 with the least variation at sites R3, R4, and B3. Water temperatures varied seasonally and ranged between 3.5 and 27.5 $^{o}$C as measured during low-flow periods. Sites below municipal outfalls were generally slightly warmer than upstream sites because of the introduction of heated effluents.

Median dissolved oxygen concentrations ranged between 6.8 and 9.7 mg/L at all sites during low flows with the exception of those sites downstream from effluent outfalls (fig. 6). Median concentrations at sites B2, B3, and B6 were generally less than 7 mg/L, and site B5 had the lowest at 4.4 mg/L. Results in Davenport (1988, Appendix B) show dissolved oxygen concentrations fell as drought conditions contributed to the decline of dissolved oxygen at minimum streamflow.

There was little difference in alkalinity concentrations between sampling sites (fig. 6). The highest median concentration was over 100 mg/L as $CaCO_3$ at site B2 below a treated textile wastewater outfall. Textile waste tends to be alkaline in nature and could explain these concentrations at site B2.

The Langelier saturation index was used to quantify corrosivity with negative indexes indicating tendencies to dissolve calcium carbonate; positive indexes indicate tendencies to deposit calcium carbonate. All corrosivity values were negative except for the sample taken in June 1986 at station B4 where the corrosivity was +1.10. Negative values ranged from -0.75 to -3.36.

### Standards and Criteria

Limits on maximum or minimum concentrations or values of seven general water-quality indicators are regulated or recommended by State or Federal standards or criteria. These water-quality indicators include turbidity, color, pH, corrosivity, total dissolved solids, hardness, and dissolved oxygen (tables 3, 4, and 5).

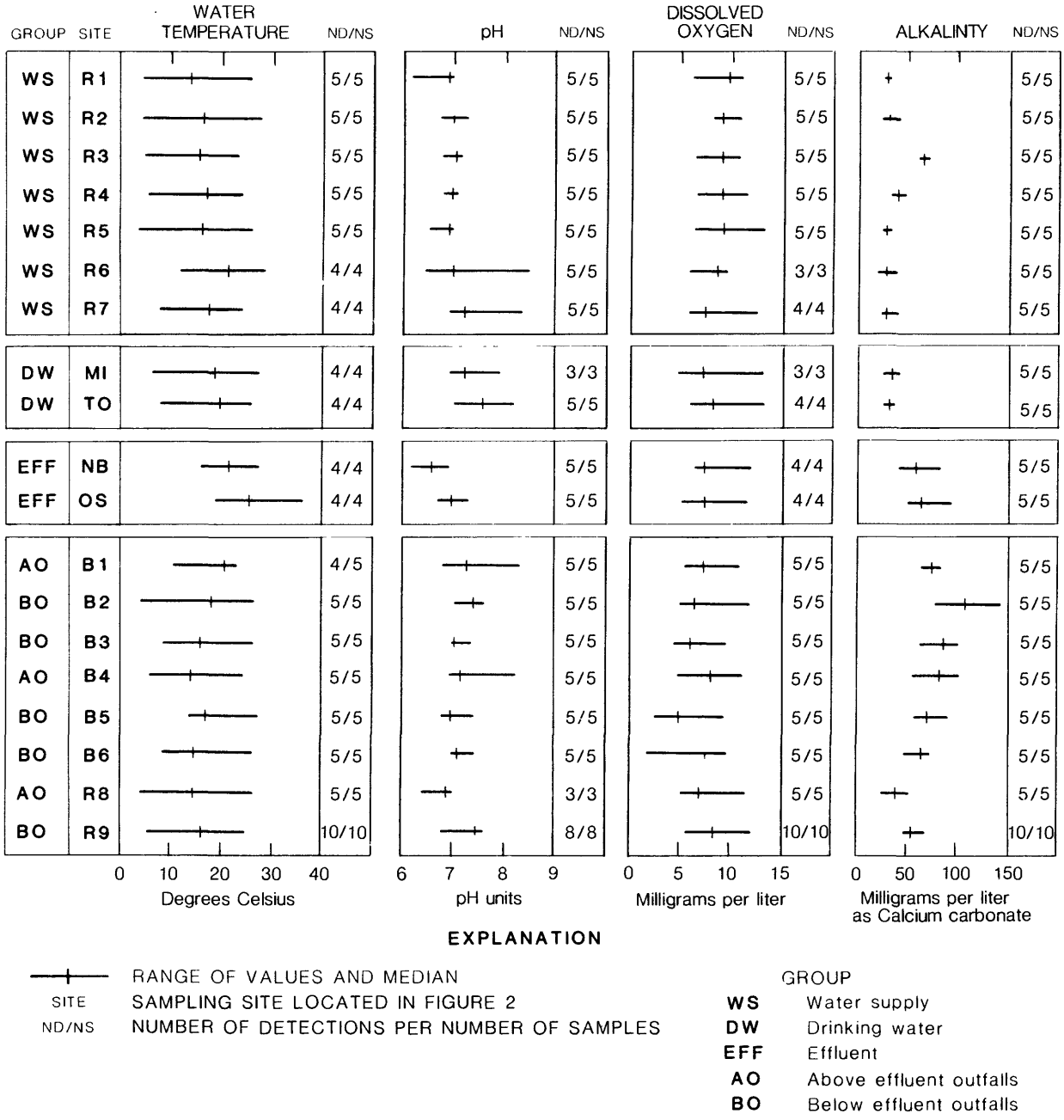



Figure 6.--Water temperature, pH, and concentrations of dissolved oxygen and alkalinity at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

All of the 12 drinking-water samples met the standard for turbidity of less than 1 NTU. However, 5 of 42 turbidity values for samples from low and high flows at water-supply sites (fig. 2) exceeded the standard for water supplies of 50 NTU. At sites above effluent outfalls, 4 of 20 samples from low and high flows showed turbidity values higher than the 50 NTU North Carolina standard for freshwaters; those below outfalls exceeded the standard in 3 of 36 samples. All of the exceedances of turbidity occurred during the receding streamflows in March 1987. During low-flow periods, turbidity was within the standard at all sites.

The drinking-water standard for color is 15 color units; none of 12 drinking-water samples exceeded this standard. Of 56 samples from the water-supply sites, 3 exceeded the Federal criteria of 75 color units. These exceedances occurred during the March 1987 sampling when stream stages were receding from high flows, and the turbid conditions during this time contributed to the excess color in these samples. All remaining samples were within the respective limits for drinking water and water supplies. There are no color criteria or standards for freshwaters.

State and Federal standards or criteria limit pH units in drinking water to between 6.5 and 8.5 pH units; between 5 and 9 pH units in water supplies; and between 6.0 or 6.5 and 9 pH units in freshwaters. All drinking-water and water-supply samples were within their respective limits (tables 3 and 4).

Drinking water and all but one water-supply sample met the various standards or criteria for corrosivity, total dissolved solids, hardness, and dissolved oxygen. Total dissolved solids concentration in excess of 500 mg/L was reported for one water-supply sample.

### Loading

Estimated daily and annual loadings at site R9 on Reedy Fork Creek (fig. 2) were calculated for suspended sediment by use of linear regression analyses based on 19 sample concentrations. The regression equations and associated statistics for these parameters are given in table 7.

Table 7.--*Regression equations and related statistics for loadings of selected parameters at site R9, Reedy Fork Creek*

[$R^2$, coefficient of determination; n, number of samples; estimated loadings are based on daily mean discharge for May 1, 1986, through April 30, 1987, at site R9; abbreviations in parentheses represent chemical compounds and constituents; Q, daily mean discharge]

| Parameter | $R^2$ | Significance level (Percent) | Standard error of regression | n | Regression equation (tons per day) | Estimated loadings | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Tons per year | Tons per day | Tons per square mile per year |
| Suspended sediment (SS) | 0.87 | 0.01 | 0.6043 | 19 | Log (SS) = 2.06 Log Q - 3.70 | 87,000 | 240.0 | 360.0 |
| Total organic carbon (TOC) | .90 | .01 | .2731 | 19 | Log (TOC) = 1.02 Log Q - 1.60 | 2,800 | 11 | 12 |
| Calcium (Ca) | .98 | .01 | .0926 | 19 | Log (Ca) = .78 Log Q - .94 | 2,700 | 7 | 11 |
| Magnesium (Mg) | .98 | .01 | .0785 | 19 | Log (Mg) = .78 Log Q - 1.47 | 810 | 2 | 3 |
| Potassium (K) | .95 | .01 | .1168 | 19 | Log (K) = .65 Log Q - .94 | 1,200 | 3 | 5 |
| Sodium (Na) | .70 | .01 | .2132 | 19 | Log (Na) = .41 Log Q + .1494 | 2,000 | 6 | 8 |
| Sulfate ($SO_4$) | .94 | .01 | .1668 | 19 | Log ($SO_4$) = .82 Log Q - .64 | 6,800 | 19 | 28 |
| Chloride (Cl) | .92 | .01 | .0990 | 19 | Log (Cl) = .42 Log Q - .03 | 2,700 | 7 | 11 |
| Fluoride (F) | .96 | .01 | .0968 | 19 | Log (F) = .61 Log Q - 2.07 | 70 | .2 | .3 |
| Phosphorus (P) | .76 | .01 | .3428 | 19 | Log (P) = .76 Log Q - 1.82 | 320 | .9 | 1. |
| Orthophosphorus (OP) | .73 | .01 | .3369 | 19 | Log (OP) = .70 Log Q - 1.68 | 300 | .8 | 1. |
| Nitrate ($NO_3$) | .86 | .01 | .1531 | 19 | Log ($NO_3$) = .47 Log Q - .81 | 630 | 2 | 3 |
| Ammonia ($NH_3$) | .71 | .01 | .4498 | 19 | Log ($NH_3$) = .89 Log Q - 2.96 | 52 | .1 | .2 |
| Iron (Fe) | .88 | .01 | .5844 | 19 | Log (Fe) = 1.97 Log Q - 4.53 | 5,800 | 16 | 24 |
| Barium (Ba) | .93 | .01 | .3193 | 19 | Log (Ba) = 1.43 Log Q - 5.14 | 16 | .04 | .07 |
| Manganese (Mn) | .85 | .01 | .4802 | 19 | Log (Mn) = 1.45 Log Q - 4.57 | 72 | .2 | .3 |
| Zinc (Zn) | .87 | .01 | .3850 | 19 | Log (Zn) = 1.27 Log Q - 4.43 | 24 | .06 | .10 |

During the study period, an estimated 87,000 tons per year (tons/yr) of suspended sediment left Guilford County by way of Reedy Fork Creek. By using a drainage area of 243 $mi^2$, the estimated average annual suspended-sediment yield, was 360 tons per square mile ($tons/mi^2$). However, it is emphasized that the values in table 7 were estimated by using regression relations based on 19 samples and that additional sampling data are needed to improve accuracy of regression relations.

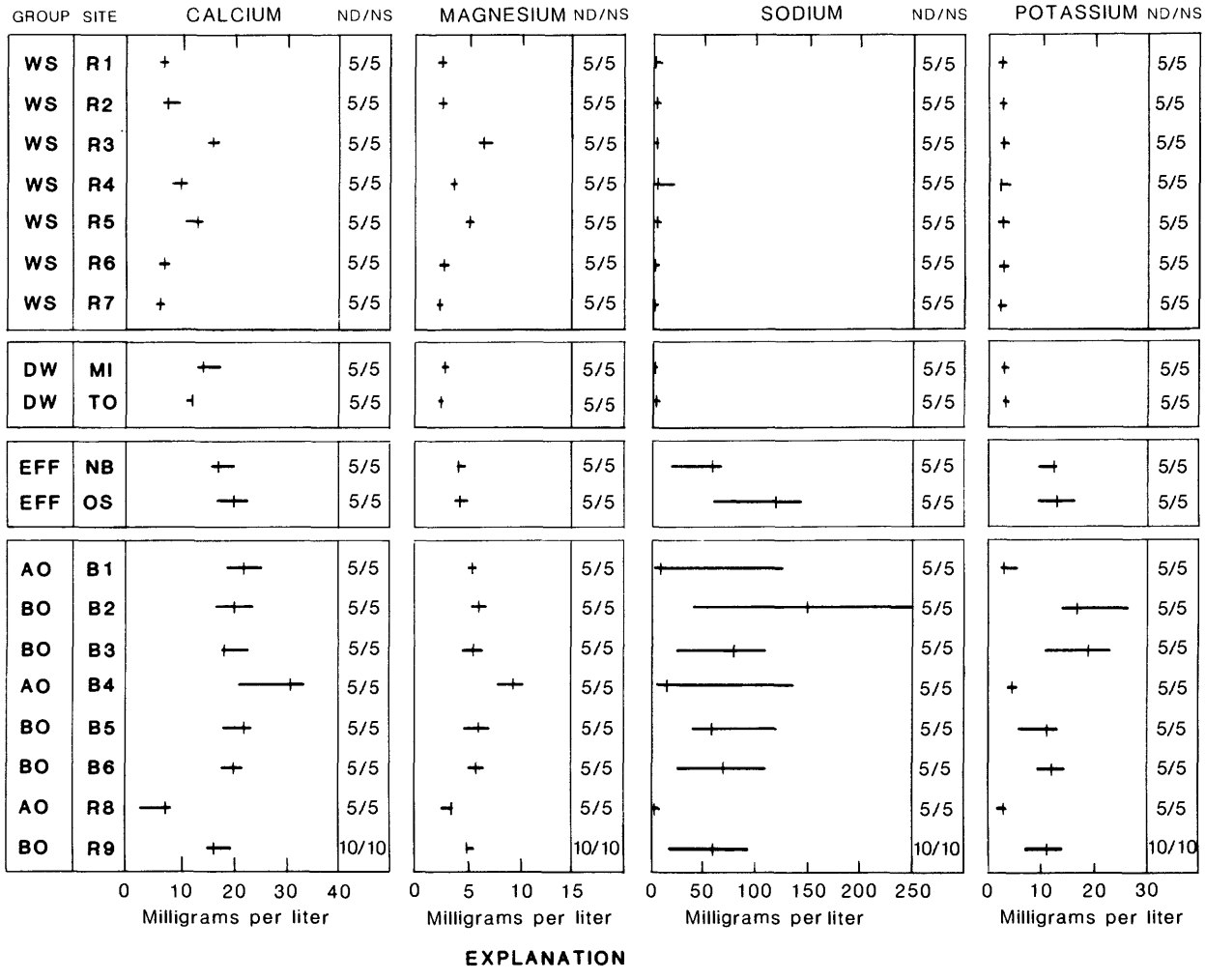
The sediment yield estimated at site R9 may be compared with an average annual sediment yield at a station on the Haw River at the town of Haw River (fig. 1). Simmons (1976) reports an average annual sediment yield of 214 $tons/mi^2$ and an average annual suspended-sediment discharge of 128,400 tons at the Haw River site for the period of 1969-73. The estimated Reedy Fork Creek sediment yield is approximately 70 percent higher than the Haw River yield may be due to the differences in drainage basin areas and differences in land use in the basins. In addition, the Reedy Fork Creek site is located farther west than the Haw River site, in the more hilly terrane of the Piedmont province where slopes are steeper and more likely to erode.

## Major Ions

Major ions are those ions commonly present in natural waters in concentrations exceeding 1.0 mg/L (Hem, 1985). The ions, which constitute a major part of the dissolved-solids content in water, are the cations: calcium, magnesium, sodium, and potassium; and the anions: chloride, sulfate, fluoride, and nitrate. (Nitrate will be discussed in the nutrients section.) Results of analyses for major ions are reported by Davenport (1988, Appendix B).

### Constituent Concentrations

The cations calcium, magnesium, sodium, and potassium are products of weathering processes, and their occurrence in streams draining undeveloped basins is attributed largely to ground-water contributions to streamflow. In developed basins contributions from agricultural chemicals, urban runoff, and point discharges may increase the concentration of these cations. Median concentrations of the cations calcium, magnesium, sodium, and potassium at all 19 sampling sites are presented in figure 7. During high flow, their concentrations are diluted by rainfall and overland runoff.




**EXPLANATION**

RANGE OF VALUES AND MEDIAN

SITE SAMPLING SITE LOCATED IN FIGURE 2

ND/NS NUMBER OF DETECTIONS PER NUMBER OF SAMPLES

GROUP

**WS** Water supply

**DW** Drinking water

**EFF** Effluent

**AO** Above effluent outfalls

**BO** Below effluent outfalls

Figure 7.--Calcium, magnesium, sodium, and potassium concentrations at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

Median concentrations of calcium, magnesium, sodium, and potassium in samples collected during low and high flows are compared in table 8. The data show this dilution effect. During high flows, concentrations of calcium, magnesium, and sodium were less at every site and concentrations of potassium were less at four of six sites.

Table 8.--*Median calcium, magnesium, sodium, and potassium concentrations during low and high flows at selected stream sites in the Greensboro area, North Carolina, 1986-87*

[mg/L, milligram per liter; Site, location during the study (fig. 2); n, number of samples (varies during high flow)]

| Site | Calcium (mg/L) | | Magnesium (mg/L) | | Sodium (mg/L) | | Potassium (mg/L) | |
|---|---|---|---|---|---|---|---|---|
| | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 |
| R1 | 6.7 | 4.7 | 2.4 | 1.7 | 4.6 | 1.35 | 2.6 | 2.8 |
| R5 | 13 | 7 | 5.1 | 2.45 | 6.2 | 1.75 | 2.1 | 2.5 |
| R9 | 16 | 7.10 | 4.9 | 2 | 59 | 7.1 | 11 | 2.8 |
| B1 | 22 | 7.1 | 6.3 | 1.75 | 10 | .7 | 3 | 2.6 |
| B3 | 18 | 8.05 | 5.4 | 2.50 | 79 | 3.05 | 14 | 4 |
| B5 | 22 | 12.5 | 5.9 | 3.35 | 58 | 5.35 | 11 | 3.6 |

Calcium concentrations are usually greater than magnesium concentrations in natural water at low flows, and this pattern is seen at most sites. Calcium added during the drinking-water treatment processes may account for the increase in this constituent in samples from sites MI and TO compared to those from lake sites R6 and R7. Samples from sites below outfalls seem to have calcium and magnesium concentrations that decrease with downstream progression of sampling sites, possibly due to a dilution effect.

Sodium and potassium concentrations were similar at all water-supply and drinking-water sites; median concentrations were less than 10 and 4 mg/L, respectively, for sodium and potassium at these sites (fig. 8). Some of the highest concentrations were found at the effluent sites, with median sodium concentrations of 61 and 99 mg/L and median potassium concentrations of 12 and 13 mg/L at sites NB and OS, respectively. Median concentrations of these cations from sites B1, B4, and R8 above outfalls are comparable with concentrations found in the water-supply streams. Median concentrations of 150 and 22 mg/L for sodium and potassium, respectively,

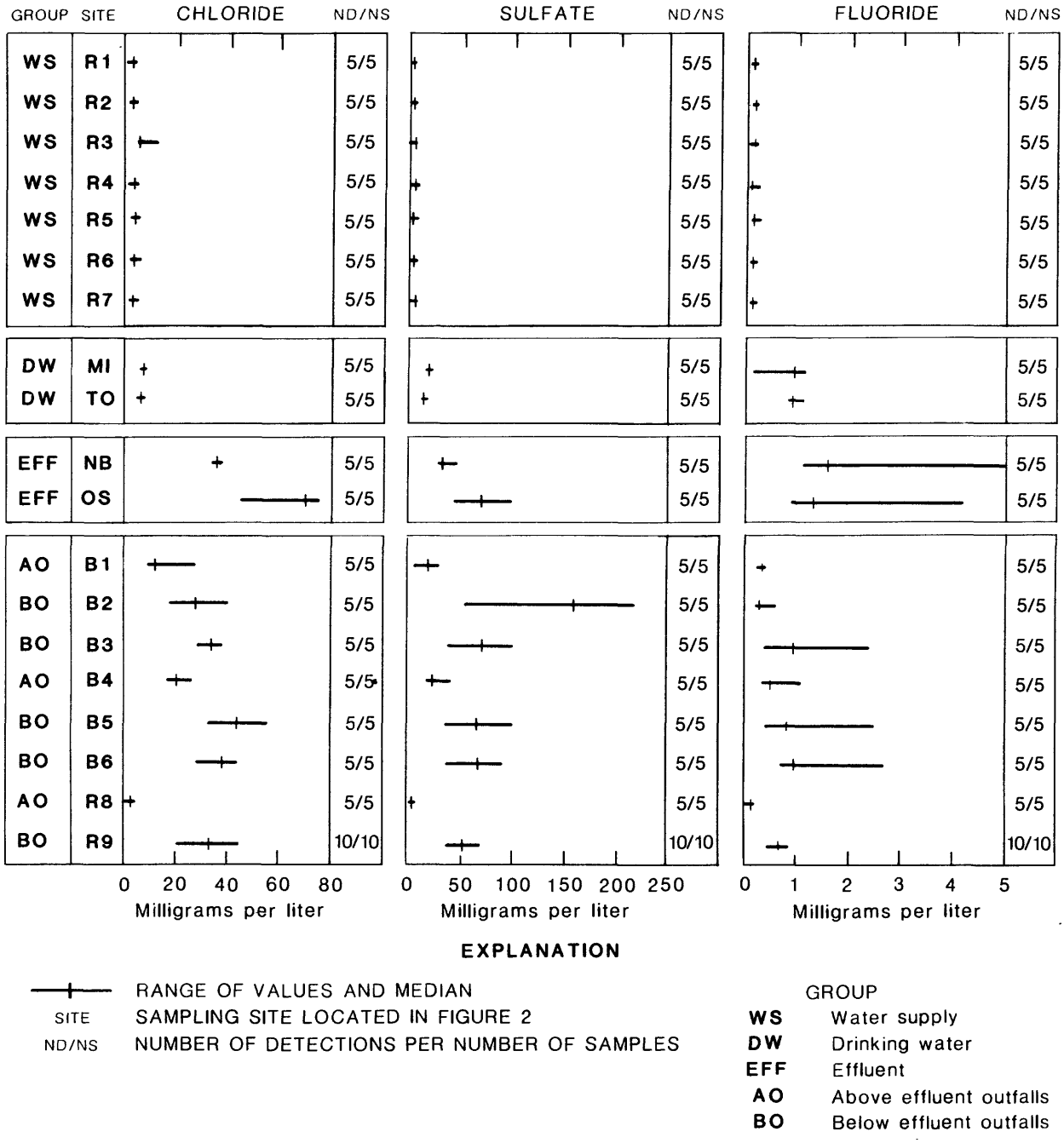



Figure 8.--Chloride, sulfate, and fluoride concentrations at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

are reported at site B2 below the industrial wastewater outfall. Sodium chloride is used as a softener in the industrial process and is not removed in the water-treatment process.

Concentrations of chloride, sulfate, and fluoride did not vary significantly among the water-supply sites (fig. 8); however, median concentrations of these anions are elevated slightly in the drinking-water samples because of the treatment processes. Particularly evident are increases in median fluoride concentrations due to fluoridation. Effects of chlorination and other treatment processes can also be seen in the effluent data. Median chloride concentrations in the NB and OS effluents were 30 and 53 mg/L, respectively. Median sulfate concentrations were 32 and 69 mg/L, and median fluoride values were less than 1.6 mg/L at both sites.

Chloride concentrations show a pattern of increasing concentration with respect to downstream position in North and South Buffalo Creeks (fig. 8). Median concentrations were lowest at sites above outfalls (site B1, 13 mg/L; and site B4, 21 mg/L) and showed large increases in concentrations at sites below outfalls (site B3, 33 mg/L; and site B5, 44 mg/L). An increase in chloride concentrations between sites B1 and B2 is attributed to sodium chloride used as a softener at the industrial plant above site B2.

The greatest median sulfate concentration in the Buffalo Creek basin was at site B2 (160 mg/L), which was more than twice as large as the next highest median concentration at site B3 (71 mg/L). Sulfate concentrations at site B2 apparently were also affected by the industrial outfall upstream, although fluoride concentrations were not.

For all the major ions, the concentrations at site R8 on Reedy Fork Creek were lower than those found at all other sites in the AO and BO groups. To a certain extent, these low values moderated the higher concentrations in Buffalo Creek as it flowed into Reedy Fork Creek upstream from site R9, but the discharge in Buffalo Creek at site B6 was at least twice that at site R8 (Davenport, 1988, Appendix A), so that concentrations at the most downstream site R9 were decreased only slightly.

A comparison of chloride and sulfate concentrations at selected stream sites sampled during high and low flows shows that chloride and sulfate

concentrations in stream waters tend to decrease during high flows (table 9). The exceptions are at the rural water-supply sites R1 and R5, where sulfate concentrations more than doubled over periods of ground-water flow. The reason for this increase during high flows is not known.

Table 9.--*Median chloride and sulfate concentrations during low and high flows at selected stream sites in the Greensboro area, North Carolina, 1986-87*

[mg/L, milligram per liter; Site, location during the study (fig. 2); n, number of samples (varies during high flow)]

| Site | Chloride (mg/L) | | Sulfate (mg/L) | |
|---|---|---|---|---|
| | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 |
| R1 | 3.5 | 3.0 | 4.1 | 10.25 |
| R5 | 4.5 | 3 | 4.4 | 11.5 |
| R9 | 33 | 4.5 | 52 | 18 |
| B1 | 13 | 2.25 | 18 | 7.75 |
| B3 | 33 | 5 | 71 | 23 |
| B5 | 44 | 8.5 | 66 | 35 |

## Standards and Criteria

Of the major ions discussed, only chloride, sulfate, and fluoride are regulated by State or Federal standards. Choride and sulfate concentrations are each mandated to not exceed 250 mg/L in drinking water and water supplies (tables 3 and 4). Fluoride concentration is limited in drinking water, water supplies, and all freshwaters (tables 3, 4, and 5). No samples contained concentrations of any one of these major ion constituents above its respective limit.

## Loading

Estimates of calcium, magnesium, potassium, sodium, sulfate, chloride, and fluoride loads at site R9 on Reedy Fork Creek are listed in table 7.

The estimated loads that left Guilford County range from 70 tons/yr of fluoride to 6,800 tons/yr of sulfate. Other estimated loads are less than the 2,700 tons/yr estimates for both calcium and chloride. The regression equations in table 7 are based on 19 samples.

## Nutrients

Nutrients in water are those constituents that provide nutrition for various microbes, bacteria, and plants, such as algae. Among the most common nutrients are nitrate, ammonia, phosphorus, and orthophosphate compounds. For the purpose of this discussion, the nutrient group includes analyses for concentrations of dissolved nitrate as N, dissolved ammonia as N, total phosphorus as P, and total orthophosphate as P. Results of nutrient analyses in water samples are given in Davenport (1988, Appendix B).

### Constituent Concentrations

Median concentrations of nitrate and ammonia are less than 0.48 and 0.065 mg/L, respectively, at the water-supply and drinking-water sites (fig. 9). Effects of human waste in the municipal effluents are seen with the median nitrate concentrations of 10.5 and 11.1 mg/L at sites NB and OS, respectively, and ammonia concentrations were 2.24 and 0.48 mg/L at those sites. The effects of the effluent in North and South Buffalo Creeks below the municipal outfalls elevated nitrate concentrations at sites B3 and B5 to 5.1 and 10.1 mg/L, respectively. Ammonia concentration at site B3 was 3.15 mg/L. These concentrations are an order of magnitude greater than those at sampling sites above the outfalls.

Median concentrations of nutrients during low and high flows at selected stream sites are shown in table 10. Both nitrate and ammonia concentrations remained approximately the same during low and high flows at sites R1, R5, and B1; these sites are all located above industrial or municipal effluent outfalls. However, concentrations of nitrate and ammonia decreased significantly at sites B3, B5, and R9 during high flows due to the diluting effect of rainfall and runoff on effluent concentrations.

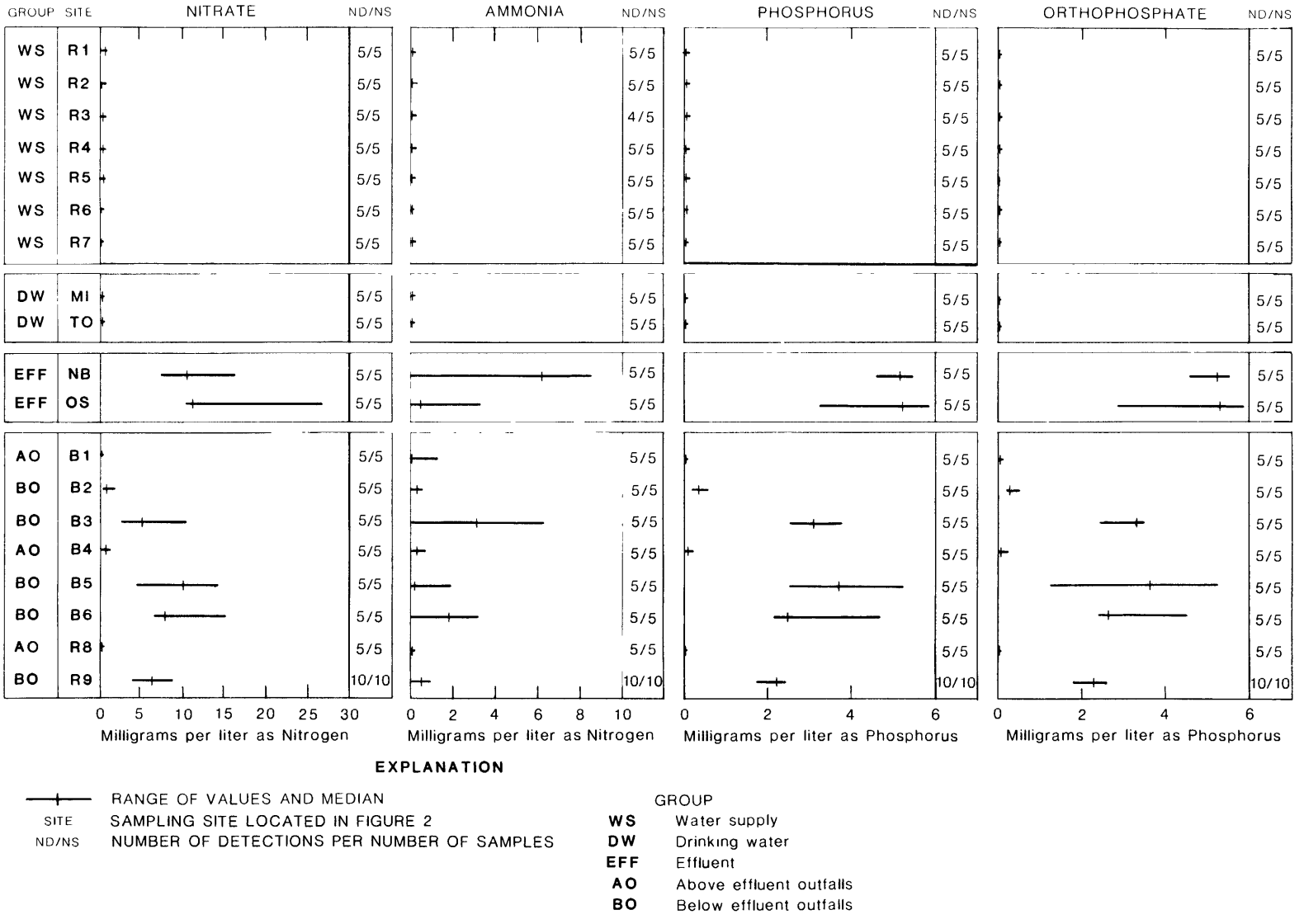



Figure 9.--Nitrate, ammonia, phosphorus, and orthophosphate concentrations at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

Table 10.--*Median nitrate, ammonia, phosphorus, and orthophosphate concentrations during low and high flows at selected stream sites in the Greensboro area, North Carolina, 1986-87*

[mg/L, milligram per liter; Site, location during the study (fig. 2); n, number of samples (varies during high flow)]

| Site | Nitrate (mg/L) | | Ammonia (mg/L) | | Phosphorus (mg/L) | | Orthophosphate (mg/L) | |
|---|---|---|---|---|---|---|---|---|
| | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 |
| R1 | 0.45 | 0.56 | 0.06 | 0.05 | 0.04 | 0.43 | 0.02 | 0.35 |
| R5 | .41 | .84 | .05 | .09 | .04 | .42 | .02 | .33 |
| R9 | 6.56 | 1.08 | .47 | .18 | 2.23 | 1.29 | 2.32 | 1.13 |
| B1 | .4 | .60 | .03 | .16 | .08 | .66 | .05 | .58 |
| B3 | 5.14 | 1.03 | 3.15 | .30 | 3.10 | .99 | 3.34 | .93 |
| B5 | 10.10 | 1.79 | .10 | .19 | 3.74 | .89 | 3.63 | .82 |

Concentrations of phosphorus were near zero at water-supply, drinking-water, and sites above outfalls (fig. 9). Just as with the nitrogen-based nutrients, phosphorus concentrations were greatest in the effluents, with median concentrations ranging from 4.2 to 5 mg/L. Effluent discharge influenced the phosphorus and orthophosphate concentrations downstream from the outfalls at sites B3, B5, B6, and R9, where median concentrations ranged between 2 and 4 mg/L.

Median phosphorus and orthophosphate concentrations in samples collected during high flows at sites R1, R5, and B1 increased by an order of magnitude from median concentrations during low flow (table 10). These differences may be attributed to agricultural and residential runoff of phosphorus fertilizers. Concentrations of these constituents at sites below municipal outfalls were less during high flow due to dilution of the effluents by rainfall and runoff. Median concentrations of phosphorus and orthophosphate were an order of magnitude less at sites B3 and B5 during high flows than at low flows.

## Standards and Criteria

Nutrient concentrations are either mandated or recommended by State or Federal agencies for nitrate, ammonia, and phosphorus. The standard for nitrate concentrations in drinking water is 10 mg/L; no drinking-water samples exceeded this standard (table 3). Nitrate and ammonia concentrations did not exceed their respective standards or criteria of 10 and 0.5 mg/L at the water-supply sites (table 4).

Recommended criteria for phosphorus concentration in streams flowing indirectly into lakes is 0.100 mg/L (table 5). All samples in the BO group exceeded the criteria, as did 13 of 24 samples in the AO group. Runoff from residential lawns and effluent from the wastewater outfalls are the likely sources.

### Loading

Estimates of phosphorus, orthophosphate, nitrate, and ammonia loads from site R9 on Reedy Fork Creek (fig. 2), are listed in table 7. The estimated loads are 52, 300, and 320 tons/yr for ammonia, orthophosphate, and phosphorus, respectively, and the estimated nitrate load is 630 tons/yr. Linear regression equations and related statistics used to estimate these loads are given in table 7 and are based on 19 samples.

The estimated load for phosphorus of 320 tons/yr at site R9 is compared with the load calculated for the Haw River at Bynum, North Carolina (fig. 1). Based on 350 samples collected during 1985-86, the annual phosphorus load in the Haw River at Bynum was 414 tons/yr (Piedmont Triad Council of Governments, 1987). Greensboro is the largest municipality upstream from Bynum, and its two wastewater treatment plants approximate 56 percent of the treatment plant load in the drainage basin. Because phosphorus loading is primarily from treatment plant effluents, the estimated load at site R9 and the calculated load at Bynum are comparable.

## Trace Elements and Cyanide

Trace elements are naturally occurring constituents that generally are present in water at concentrations less than 1.0 mg/L. Of the basic groups of elements, trace elements for the purpose of this study are either alkaline earth metals, transition metals, or nonmetallic elements. Trace elements discussed in this section are total iron, manganese, aluminum, nickel, barium, copper, zinc, mercury, arsenic, selenium, lead, cadmium, chromium, and silver. Cyanide, an inorganic carbon compound, is also discussed in this section. Complete results of trace element analyses are given in Davenport (1988, Appendix B).

## Constituent Concentrations

Median iron concentrations range broadly from about 2,800 micrograms per liter (μg/L) to near the detection limit (fig. 10). Water-supply sites and sites above effluent outfalls reported the greatest median concentrations of iron in samples, as well as the widest ranges of values, presumably due to the samples containing suspended sediment.

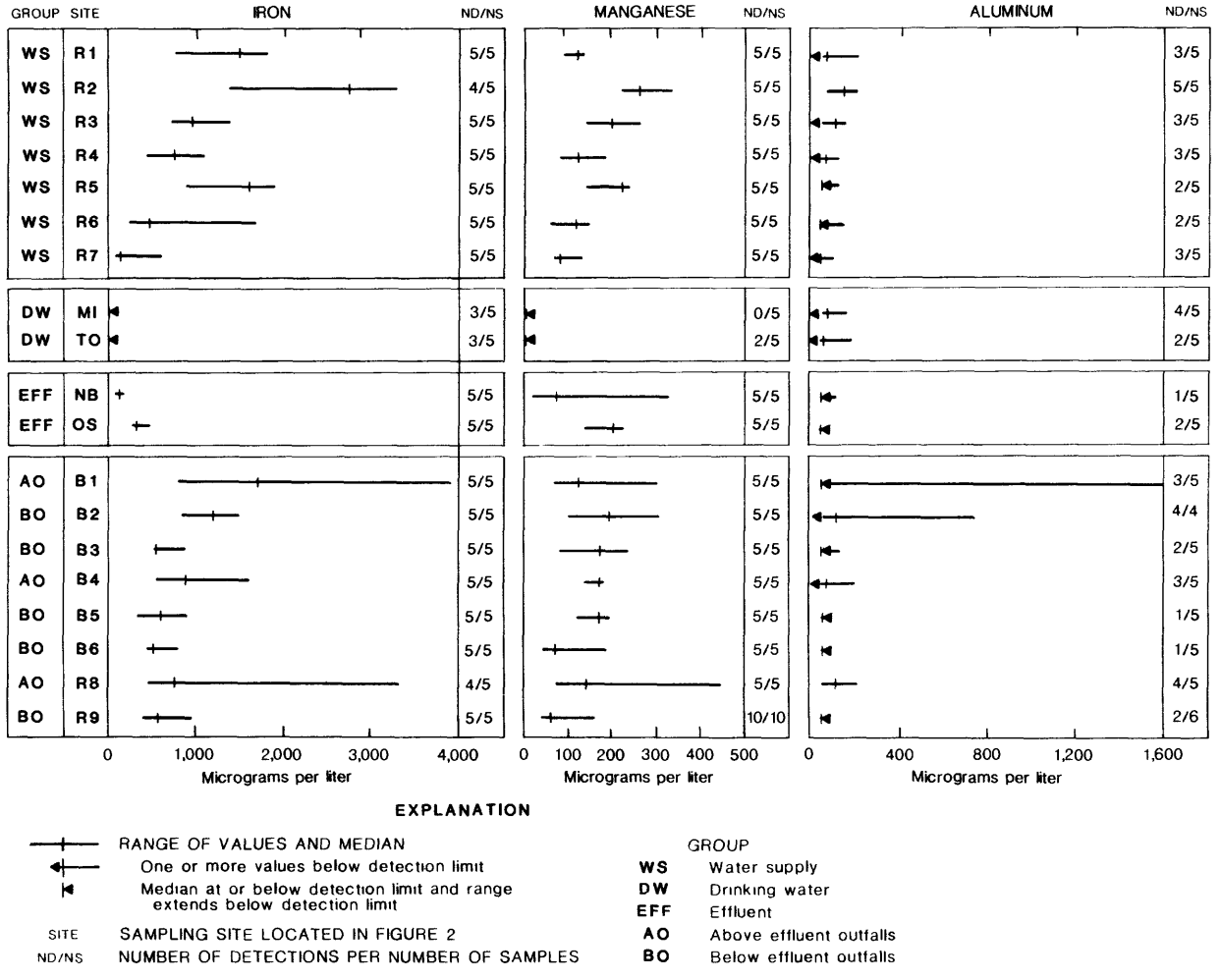



Figure 10.--Iron, manganese, and aluminum concentrations at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

Samples collected at drinking-water sites and at effluent discharge sites showed the lowest concentrations of total iron. Streamflow at sites below effluent outfalls was diluted by the introduction of effluent that contained low iron concentrations, and, consequently, samples at these sites contained slightly lower median concentrations than at water-supply sites or at sites above outfalls.

Concentrations of total iron in Piedmont streams follow a typical pattern of low concentration during low flow and elevated concentrations during high flows. During high flow, there is a relation between high concentrations of total iron and suspended sediment. Iron oxides are tightly bound to the sediment particles and, upon settling in slower velocity water, both iron and sediment concentrations in water decrease (Eddins and Crawford, 1984). A comparison of median iron concentrations at selected stream sites during low and high flows shows that, in some cases, concentrations during high flows increased by two orders of magnitude over concentrations during low flows (table 11).

Median manganese concentrations at the water-supply sites ranged from 80 to 260 µg/L, with the highest concentration at site R2 (fig. 10). Two samples from drinking-water site TO had manganese at the detection level, but at the effluent sites NB and OS, median concentrations of manganese ranged from 70 to 200 µg/L, respectively. However, manganese in the effluent did not seem to affect manganese concentrations in South Buffalo Creek below the outfall, as median manganese concentrations varied little above or below the outfall. Within the AO and BO group of sites, median concentrations ranged from 60 to 190 µg/L during low flows; the lowest median concentrations were at site R9. No consistent pattern was seen for manganese with respect to low or high flows at stream sites.

Median aluminum concentrations at the water-supply sites ranged from 70 to 150 µg/L (fig. 10). Because, aluminum sulfate is a coagulent used in water treatment for removing turbidity (Hammer, 1986), the median concentrations observed in drinking-water sites MI (80 µg/L) and TO (60 µg/L) may be a carryover from the treatment process. In effluent water at sites NB and OS, aluminum concentrations also ranged from 60 to 80 µg/L. Aluminum was detected more frequently in samples above outfalls than in those below outfalls, and median concentrations were slightly higher also,

Table 11.--*Median iron, nickel, barium, copper, and zinc concentrations during low and high flows at selected stream sites in the Greensboro area, North Carolina, 1986-87*

[µg/L, micrograms per liter; Site, location during the study (fig. 2); n, number of samples (varies during high flow)]

| Site | Iron (µg/L) | | Nickel (µg/L) | | Barium (µg/L) | | Copper (µg/L) | | Zinc (µg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 | Low flow n = 5 | High flow n = 6-8 |
| R1 | 1,500 | 17,000 | ≤10 | 20 | 35 | 70 | <10 | 10 | <10 | 60 |
| R5 | 1,600 | 25,000 | 25 | 20 | 40 | 60 | <10 | 25 | <10 | 45 |
| R9 | 575 | 41,000 | ≤10 | 30 | 20 | 80 | <10 | 70 | 45 | 190 |
| B1 | 1,700 | 28,500 | 20 | 60 | 30 | 65 | <10 | 60 | 20 | 175 |
| B3 | 560 | 25,500 | 10 | 25 | 20 | 60 | ≤10 | 50 | 100 | 230 |
| B5 | 600 | 17,000 | 20 | 35 | 10 | 65 | 10 | 30 | 50 | 80 |

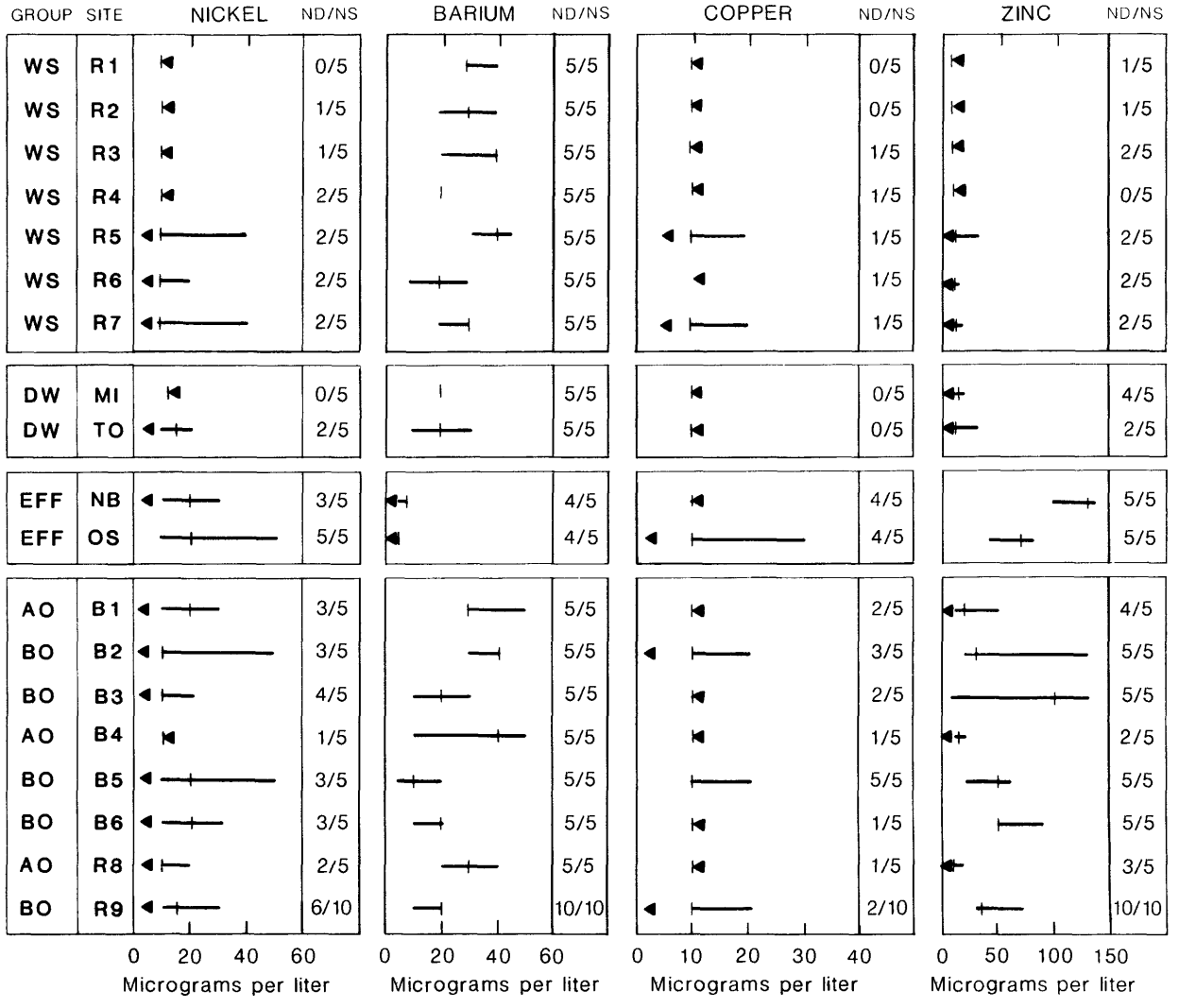
but the overall ranges of aluminum concentrations in these samples were similar to concentrations at water-supply sites. As with manganese, aluminum concentrations did not have any significant correlation with high or low streamflows.

Nickel, copper, and zinc were found in 45, 30, and 65 percent, respectively, of the samples collected during low flow (fig. 11). The largest percentage of detections, excluding the effluents, are in the sites below wastewater outfalls. The least number of detections were in the water-supply area. Nickel, copper, and zinc concentrations in high-flow samples were greater than in low-flow samples (table 11). These increases are most likely caused by run-off from non-point sources.

Barium was detected in all but two samples during low-flow conditions (fig. 11). There were no distinct patterns of barium concentrations among groups of sites; however, concentrations in the effluents seemed to be some of the lowest found. Greater barium concentrations were found in high-flow samples than in low-flow samples (table 11).

Median mercury concentrations at low flows varied from $\leq$ 0.05 to 0.41 $\mu$g/L. Median mercury concentrations at water-supply sites ranged from 0.07 $\mu$g/L at site R7 to 0.21 $\mu$g/L at site R5 (fig. 12). Ranges in concentrations in finished water tended to be similar to the values in the raw water, but median values were slightly higher. Median mercury concentrations in water from the effluent and above and below municipal outfall sites ranged between 0.10 and 0.13 $\mu$g/L. Although one sample from site NB approached 0.8 $\mu$g/L, the treatment process apparently is responsible for the lowered mercury concentrations. However, the consistently lower mercury values in stream water of the lower parts of the Buffalo Creek basin remain unexplained.

Selenium was detected in 27 of 100 samples and was notably absent in most of the water samples from the water-supply and drinking-water groups. Concentrations of selenium ranged from 0.11 to 0.13 $\mu$g/L in single samples from the lake sites (R6 and R7), and one sample at site R5 contained an unexplained level of 1.22 $\mu$g/L (fig. 12). Most of the effluent samples contained detectable concentrations ranging from 0.14 to 0.48 $\mu$g/L. Selenium concentrations among the sites upstream and downstream of outfalls ranged between 0.10 and 0.65 $\mu$g/L.




**EXPLANATION**

RANGE OF VALUES AND MEDIAN

One or more values below detection limit

Median at or below detection limit and range extends below detection limit

SITE SAMPLING SITE LOCATED IN FIGURE 2

ND/NS NUMBER OF DETECTIONS PER NUMBER OF SAMPLES

GROUP

**WS** Water supply

**DW** Drinking water

**EFF** Effluent

**AO** Above effluent outfalls

**BO** Below effluent outfalls

Figure 11.--Nickel, barium, copper, and zinc concentrations at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

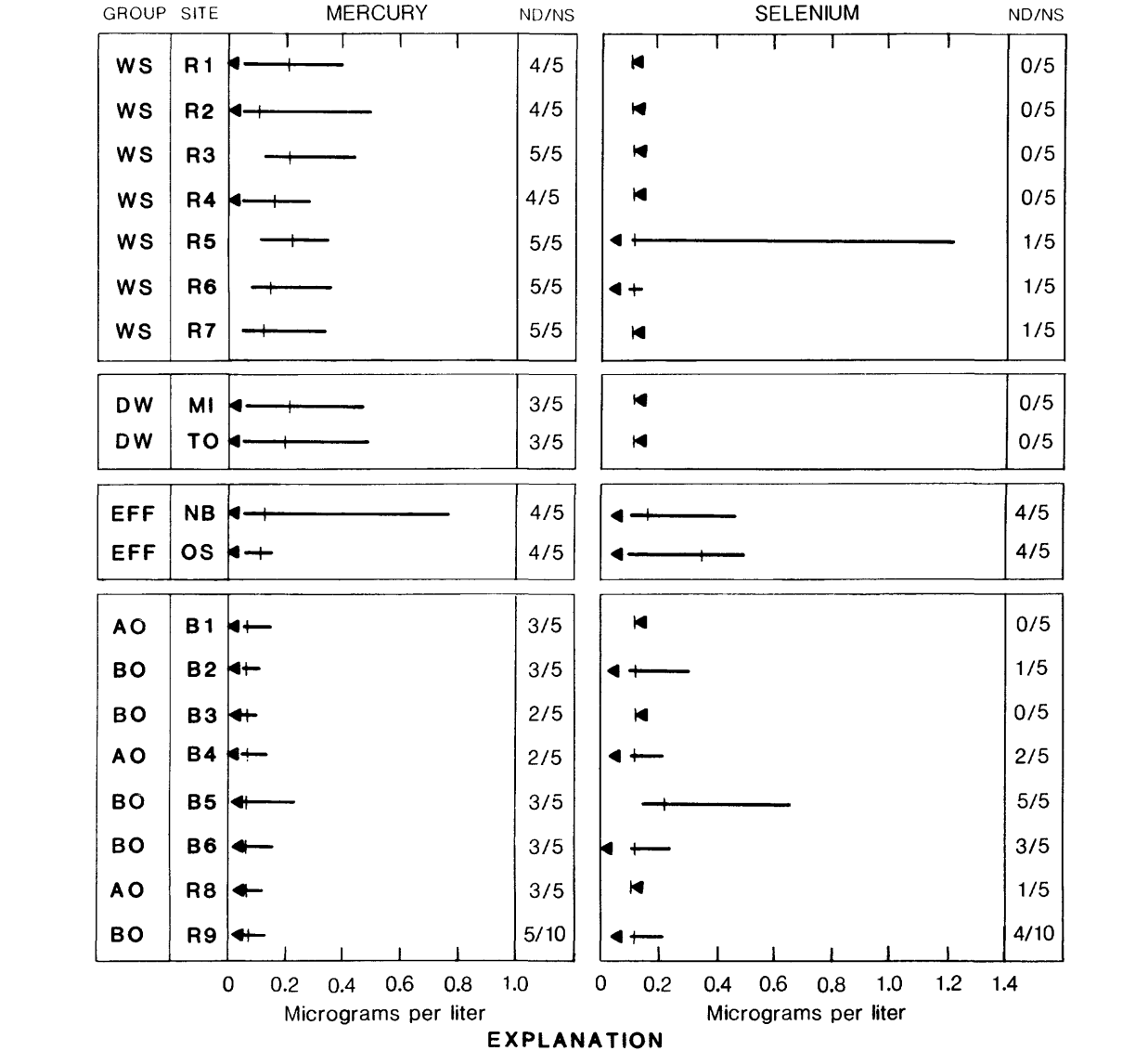



Figure 12.--Mercury and selenium concentrations at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

Arsenic, lead, cadmium, and chromium were detected in only a few samples at or near detection limits; silver was not found in any samples. Arsenic was detected in only 7 water samples during the study. These included one sample from site R5, two effluent samples from site OS; 3 of 10 samples at sites B2 and B3, and a single sample from site B6. Lead was detected in one sample at site R3 and in two high-flow samples from sites R1 and B1. Cadmium was found in one high-flow sample from site B1, and chromium was detected in two high-flow samples at sites R1 and R5.

Due to complications with laboratory equipment, cyanide analyses prior to March 1987 were not used in any statistical or comparative analyses. Only cyanide data from the March sampling and the subsequent April high-flow sampling were used. Cyanide concentrations were lowest at the drinking-water sites and greatest in the effluents.

### Standards and Criteria

The most strict water-quality standards are those that apply to contaminant concentrations in drinking water; many of the same constituents are also regulated in water supplies and/or freshwaters (tables 3, 4, and 5). Drinking-water standards have been established for iron, manganese, barium, copper, zinc, mercury, arsenic, selenium, lead, cadmium, chromium, silver, and cyanide. None of 12 drinking-water samples showed concentrations of these constituents exceeded their respective water-quality standards or criteria.

Of the 13 trace elements regulated in drinking water, all are also regulated in water supplies, with the addition of nickel. The majority of the concentrations exceeding water-quality standards in water supplies were due to iron and manganese. The Federal criteria for iron is 300 $\mu$g/L; the State standard is 1,000 $\mu$g/L. Over 90 percent of stream-water samples exceeded the Federal criteria, and about 66 percent exceeded the State standard. All streamflow samples exceeded the State standard for manganese.

Copper, zinc, mercury, lead, and cyanide concentrations in some of the water-supply samples exceeded State standards for water supplies but not Federal criteria, because the State standards are lower (table 4). Only 1 of 56 samples exceeded the State and Federal standards for arsenic and none

exceeded the State standard for nickel concentrations in water supplies. No samples exceeded the Federal criteria for copper concentrations in water supplies; however, 10 of 56 samples contained copper greater than the State standard. Zinc concentrations exceeded State standards in 6 of 56 samples, but none of these 56 samples surpassed Federal criteria. Mercury concentrations exceeded the State water-supply standard in 10 of 56 samples. Lead concentrations surpassed Federal criteria in only 1 of 56 samples, but the detection limit was greater than the State standard of 25 μg/L, so no exceedance data could be determined. All cyanide detections exceeded State standard; however, none surpassed Federal criteria.

Water-quality standards exist for barium, selenium, cadmium, chromium, and silver. Of the samples taken from the water-supply area, none contained concentrations of these trace elements that exceeded their respective standards or criteria.

### Loading

Estimates of iron, barium, manganese, and zinc loads at site R9 on Reedy Fork Creek (fig. 2) are listed in table 7. Because iron and manganese are common components of Piedmont clay soils, the estimated stream loads of 5,800 and 72 tons/yr, respectively, for these parameters are readily explained. The barium loading estimate was 16 tons/yr. Barium is also naturally occurring but not to as great a degree as iron and manganese.

Linear regression equations and related statistics used to estimate the loads are listed in table 7. Values of $R^2$ ranged between 0.85 and 0.93. However, the estimated loads as regression correlations are based on data from 19 samples. Comparison with other loads in table 7 indicates that high iron loads are related to clay and silt fractions of the sediment load as it is a component of clay and silts.

### Volatile Organic Compounds

Volatile organic compounds (VOC's) evaporate easily from water when exposed to air. Samples were analyzed by purge and trap gas chromatograph/mass spectrometer methods for 33 VOC's; only 20 of these were detected at concentrations greater than or equal to 0.2 μg/L. Types of

VOC's detected during this study were halomethanes, short-chained chlorinated hydrocarbons, and monocyclic aromatic compounds. Complete results of VOC's analyses in water samples are given in Davenport (1988, Appendix D).

### Constituent Concentrations

Halomethane compounds are by-products of chlorination processes and are commonly present in treated wastewater and chlorinated drinking water. Those discussed in this section include methyl chloride, methyl bromide, methylene chloride, bromodichloromethane, chlorodibromomethane, bromoform, and chloroform. Due to the substitution of three bromine, chlorine, and fluorine atoms for three hydrogen atoms on the methane molecule, some of these compounds are trihalomethane compounds. Dichlorodifluoromethane and trichlorofluoromethane compounds are also halomethane compounds that were detected in some samples.

Methyl chloride, Methyl bromide, and methylene chloride were found in concentrations below or near detection level in the majority of 18, 7, and 3 of 60 samples, respectively, collected during periods of low flow (table 12). Only 2 of 23 high-flow samples contained concentrations above detection limits. Methyl chloride and methyl bromide were present most frequently in samples of finished drinking water as products of water treatment.

Chloroform, also a product of water treatment, was detected in 41 of 60 samples collected during low flow in concentrations ranging from the detection limit to as great as 140 µg/L (table 12). However, only 10 of 60 chloroform concentrations exceeded 10 µg/L. The largest of these concentrations occurred in the finished drinking-water samples (fig. 13).

Bromodichloromethane, chlorodibromomethane, and bromoform are common byproducts of wastewater treatment processes due to the use of brominated disinfectants. However, these compounds are also found in drinking water. Bromodichloromethane and chlorodibromomethane were found in all drinking-water and effluent samples and in as many as 9 of 18 samples collected during low flows below the outfalls (table 12). Bromoform was not detected as often as it was found in only 3 of 60 low-flow samples.

Table 12.--*Volatile organic compounds detected in water samples in the Greensboro area, North Carolina, 1986-87*

[WS, water supply; DW, drinking water; AO, above municipal effluent outfalls; EFF, municipal effluents; BO, below municipal effluent outfalls]

| Compound | Use or sources | Number of detections per number of samples at Low-flow sites | | | | | High-flow sites |
|---|---|---|---|---|---|---|---|
| | | WS | DW | AO | EFF | BO | BO |
| | Halomethanes[1] | | | | | | |
| Methyl chloride | Used in synthesis of other organic compounds; propellent; herbicide[2] | 6/21 | 4/6 | 2/9 | 2/6 | 4/18 | 0/23 |
| Methyl bromide | Used in synthesis of organic compounds; space and soil fumigant in agriculture and industry; selective solvent in aniline dyes; laboratory procedures[3] | 1/21 | 2/6 | 0/9 | 0/6 | 4/18 | 0/23 |
| Methylene chloride | Used in manufacture of paint and varnish removers, insecticides and fumigants, solvents, cleaners, and pressurized spray products[2]; used in analytical work as an extractant and solvent | 1/21 | 0/6 | 0/9 | 2/6 | 0/18 | 2/23 |
| Bromodichloromethane | Used in fire extinguishers and as a solvent for fats, waxes, and resins[4] | 2/21 | 6/6 | 1/9 | 6/6 | 9/18 | 5/23 |
| Chlorodibromomethane | | 1/21 | 6/6 | 0/9 | 6/6 | 5/18 | 1/23 |
| Bromoform | Used in pharmaceutical manufacture; solvent for waxes, greases, and oils[2] | 0/21 | 1/6 | 0/9 | 1/6 | 1/18 | 0/23 |
| Chloroform | Used in synthesis of organic compounds, drugs, cosmetics, toothpaste, vitamins, grain fumigants, and pesticides; used as an industrial solvent[5] | 9/21 | 6/6 | 2/9 | 6/6 | 18/18 | 18/23 |
| Dichlorodifluoro-methane | Used as a refrigerant[6] | 0/21 | 0/6 | 0/9 | 0/6 | 0/18 | 1/23 |
| Trichlorofluoro-methane | Used in manufacture of aerosal sprays, refrigerants, and cleaning compounds; in fire extinguishers[2] | 0/21 | 0/6 | 0/9 | 0/6 | 0/18 | 3/23 |

Footnotes at end of table.

Table 12.--*Volatile organic compounds detected in water samples in the Greensboro area, North Carolina, 1986-87*--Continued

[WS, water supply; DW, drinking water; AO, above municipal effluent outfalls; EFF, municipal effluents; BO, below municipal effluent outfalls]

| Compound | Use or sources | Number of detections per number of samples at Low-flow sites WS | DW | AO | EFF | BO | High-flow sites BO |
|---|---|---|---|---|---|---|---|
| | Chained carbon compounds | | | | | | |
| 1,1-dichloroethane | Used as chemical intermediate, in manufacture of vinyl chloride and rubber and silicon greases, as a dewaxer of mineral oils and as a fumigant | 0/21 | 0/6 | 0/9 | 1/6 | 4/18 | 0/23 |
| 1,1,1-trichloroethane | Used as a cleaning solvent for greases, resins, and adhesives; solvent for drain cleaners, shoe polishes, spot removers insecticides, and printing inks[5] | 0/21 | 0/6 | 0/9 | 0/6 | 4/18 | 10/23 |
| 1,1,2,2-tetrachloroethane | Used in organic syntheses; as a solvent for fats, oils, waxes, resins, cellulose, acetate, rubber; in manufacture of paint, varnish, and rustremovers; in soil sterilization, weed killing, and insecticide formulations[5] | 0/21 | 0/6 | 0/9 | 0/6 | 1/18 | 0/23 |
| 1,1-dichloroethylene | Used in adhesives and as a component of synthetic fibers[4] | 0/21 | 0/6 | 0/9 | 0/6 | 1/18 | 4/23 |
| Trichloroethylene | Used in synthesis of organic compounds; used in dry cleaning and degreasing of fats, waxes; solvent for dyes; fumigant[4] | 1/21 | 1/6 | 0/9 | 1/6 | 1/18 | 5/23 |
| Tetrachloroethylene | Used in dry cleaning processes and degreasing of metals; heat exchange fluid; drug for hookworm and nematode control[5] | 3/21 | 2/6 | 1/9 | 2/6 | 3/18 | 13/23 |
| 1,2-dichloropropane | Soil fumigant; solvent for grease, paint, varnish; in antiknock fluids[3] | 0/21 | 0/6 | 0/9 | 1/6 | 1/18 | 0/23 |
| 1,3-dichloropropene | Soil fumigant; nematacide[4] | 0/21 | 0/6 | 0/9 | 1/6 | 0/18 | 0/23 |

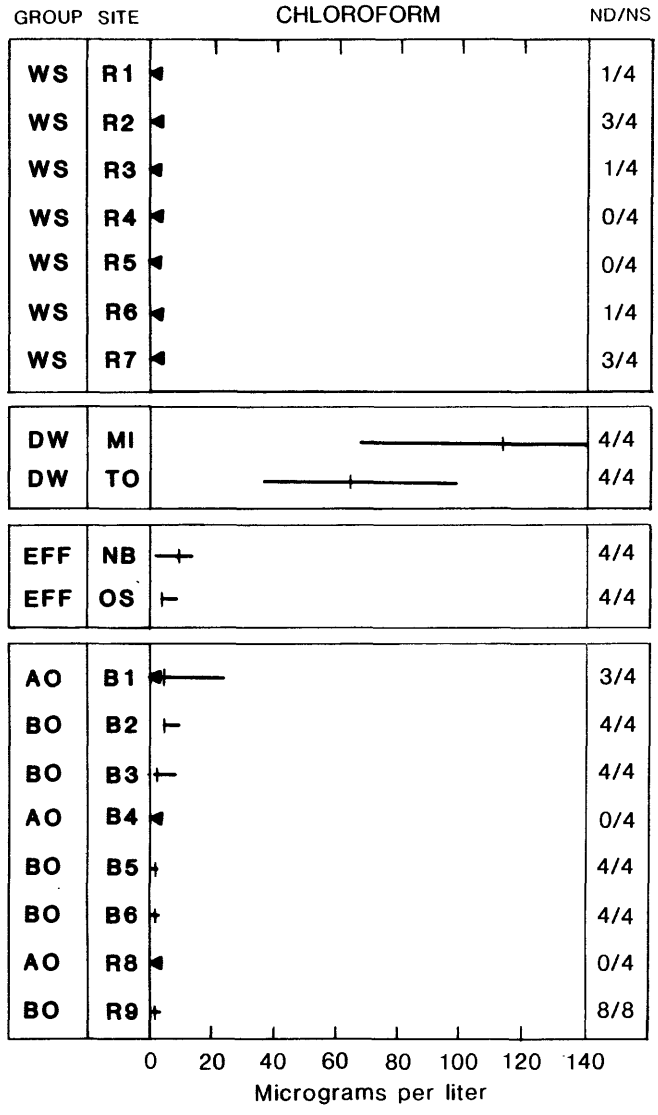
Footnotes at end of table.

Table 12.--*Volatile organic compounds detected in water samples in the Greensboro area, North Carolina, 1986-87*--Continued

[WS, water supply; DW, drinking water; AO, above municipal effluent outfalls; EFF, municipal effluents; BO, below municipal effluent outfalls]

| Compound | Use or sources | Number of detections per number of samples at Low-flow sites WS | DW | AO | EFF | BO | High-flow sites BO |
|---|---|---|---|---|---|---|---|
| | Ringed carbon compounds | | | | | | |
| Benzene | Manufacture of medicinal chemicals, dyes, artificial leather, linoleum, oilcloth, airplane dopes, varnishes, lacquers; solvent for waxes, resins, oils[7]; used in synthesis of organic chemicals[4] | 6/21 | 1/6 | 0/9 | 1/6 | 3/18 | 2/23 |
| Toluene | Same as benzene; used in manufacture of saccharin, perfumes, TNT, and as a gasoline additive[2] | 1/21 | 0/6 | 0/9 | 4/6 | 0/18 | 5/23 |
| Chlorobenzene | Used in manufacture of aniline, insecticides, and as intermediate in manufacture of dyestuffs; may be formed during chlorination of water[2]; fiber swelling agent and dye carrier[3] | 0/21 | 0/6 | 0/9 | 0/6 | 1/18 | 1/23 |

[1] Most compounds commonly formed during chlorination of water.
[2] National Research Council, 1977.
[3] Mackison and others, 1981.
[4] Verschueren, 1983.
[5] Huisingh and others, 1982.
[6] National Research Council, 1980b.
[7] Windholz, 1983.




**EXPLANATION**

RANGE OF VALUES AND MEDIAN

One or more values below detection limit

Median at or below detection limit and range extends below detection limit

SITE SAMPLING SITE LOCATED IN FIGURE 2

ND/NS NUMBER OF DETECTIONS PER NUMBER OF SAMPLES

GROUP

**WS** Water supply

**DW** Drinking water

**EFF** Effluent

**AO** Above effluent outfalls

**BO** Below effluent outfalls

Figure 13.--Chloroform concentrations at water-quality sampling sites in the Greensboro area, North Carolina, 1986-87.

Dichlorodifluoromethane and trichlorofluoromethane were present in high-flow samples from site B5 in concentrations ranging from 0.3 to 0.4 µg/L (table 12). The latter compound was also detected in a sample at site R9 at the detection limit of 0.2 µg/L.

Volatile chlorinated aliphatic compounds detected in water samples include 1,1-dichloroethane; 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1-dichloroethylene; trichloroethylene; and tetrachloroethylene, each with two carbons; and 1,2-dichloropropane and 1,3-dichloropropene, each with three carbon chains. Five of 60 samples collected during low flow had detectable concentrations of 1,1-dichloroethane, and 4 of 60 samples had concentrations of 1,1,1-trichloroethane above detection limits (table 12). Although no high-flow samples had detectable concentrations of 1,1-dichloroethane, 10 of 23 of the samples had 1,1,1-trichloroethane above detection limits. 1,1,2,2-tetrachloroethane and 1,1-dichloroethylene were detected in only 1 of 60 samples collected during low flow. No samples during high flows contained the former compound; 4 of 23 of the same samples contained 1,1-dichloroethylene. Trichloroethylene and tetrachloroethylene were detected in 4 of 60 and 11 of 60 samples, respectively, during low flows (table 12). The latter compound was found in 13 of 23 high-flow samples, and the former was detected in 5 of the 23 samples. The three carbon-chained compounds 1,2-dichloropropane and 1,3-dichloropropene were found in 2 of 60 and 1 of 60 low-flow samples and in no high-flow samples.

Volatile monocyclic aromatic compounds contain six carbons bonded in a ring with either other hydrocarbons or halogens substituted for hydrogen atoms. Aromatic VOC's detected in the water samples during this study were benzene, toluene, and chlorobenzene. Benzene was detected in 10 of 60 samples collected during low flows in concentrations from the detection limit to 0.3 µg/L. However, a concentration of 2.5 µg/L was detected in one lake sample. Because this sample was taken directly from Lake Brandt, a likely source is oil or gasoline from motor boats that are permitted on the lake. Toluene was detected in 5 of 60 samples collected during low flow; chlorobenzene was found in only 1 of 60 samples. Detections of benzene, toluene, and chlorobenzene in high-flow samples were less than 6 of 23 samples and near the detection limit.

### Standards and Criteria

Concentrations of 18 VOC's in water supplies and freshwaters are regulated or recommended by State and Federal agencies; however, only 8 of the 18 are regulated in drinking water. State and Federal standards exist for maximum concentrations of benzene, trichloroethylene, total of trihalomethanes, carbon tetrachloride, 1,2-dichloroethane, 1,1-dichloroethylene, 1,1,1-trichloroethane, and vinyl chloride in drinking water (table 3). Recommended maximum toluene and 1,1,1-trichloroethane concentrations in water supplies and freshwaters have been developed by the U.S. Environmental Protection Agency (1986), but no single numerical criteria for maximum concentrations of benzene, bromodichloromethane, bromoform, methyl bromide, carbon tetrachloride, chlorobenzene, chloroform, methyl chloride, 1,1-dichloroethylene, dichlorodifluoromethane, methylene chloride, tetrachloroethylene, trichloroethylene, trichlorofluoromethane, and vinyl choride in water supplies and freshwaters have been developed (tables 4 and 5).

Benzene, trichloroethylene and total trihalomethane concentrations exceeded drinking-water standards in some samples. Benzene and trichloroethylene concentrations exceeded the standards of 5 µg/L each in 1 of 8 samples (table 3). Total trihalomethane concentrations exceeded a State standard of 100 µg/L in 5 of 8 samples. Because trihalomethane compounds are by-products of chlorination, their presence in drinking water is common. The remaining five VOC's were not detected in drinking-water samples at concentrations exceeding standards.

Four water-supply and freshwater samples out of a total of 81 exceeded Federal criteria of 1.03 µg/L for 1,1,1-trichloroethane (tables 4 and 5). None of the water-supply and freshwater samples exceeded Federal criteria for toluene.

### Acid and Base/Neutral Extractable Compounds

Acid and base/neutral extractable compounds are those which are extracted from water and water-suspended sediment mixtures with a solvent and analyzed using gas chromatography and a mass spectrometric detector (Wershaw and others, 1983). Of the 57 ABN extractable compounds looked for

in the water samples, the only ones detected were nine members of the phenol, phthalate, and polycyclic aromatic hydrocarbon (PAH) families of compounds. Complete results of ABN analyses are given in Davenport (1988, Appendix C).

### Constituent Concentrations

The ABN extractable phenol compounds detected during the study were phenol and 4-bromophenylphenyl ether. Phenol was found in 6 of 80 samples collected during low flow in concentrations ranging from detection limit to 10 µg/L (table 13). Only 1 of 80 samples collected during low flow had a detectable concentration of 4-bromophenylphenyl ether. No high-flow samples contained detectable concentrations of these phenol family compounds.

Acenaphthene, pyrene, and fluoranthene are PAH compounds that were detected in no more than 1 of 80 samples collected during low flow. Concentrations were at or near detection level. Only 1 of 41 high-flow samples contained detectable concentrations of pyrene and fluoranthene (table 13).

Phthalates are synthetic esters of dicarboxylic acid found in virtually all plastics. Compounds detected in water samples were bis(2-ethylhexyl) phthalate, diethyl phthalate, di-n-octyl phthalate, and di-n-butyl phthalate. Bis(2-ethylhexyl) phthalate was found in 25 of 80 samples collected during low flow and 6 of 41 samples collected during high flow (table 13). Concentrations ranged from the detection limit to 500 µg/L.

Diethyl phthalate, dioctyl phthalate, and di-n-butyl phthalate were detected less frequently in samples collected during low flow than bis(2-ethylhexyl) phthalate and were not found in any high-flow samples. These three phthalates were not found in more than 4 of 80 samples; concentrations were near the detection limit.

### Standards and Criteria

The U.S. Environmental Protection Agency has recommended criteria or standards for maximum concentrations of 28 ABN compounds in water supplies and freshwaters and for one ABN in drinking water (U.S. Environmental

Table 13.--*Acid and base/neutral extractable compounds detected in water samples in the Greensboro area, North Carolina, 1986-87*

[WS, water supply; DW, drinking water; AO, above municipal effluent outfalls; EFF, municipal effluents; BO, below municipal effluent outfalls]

| Compound | Use or sources | Number of detections per number of samples at Low-flow sites WS | DW | AO | EFF | BO | High-flow sites BO |
|---|---|---|---|---|---|---|---|
| **Phenol compounds** | | | | | | | |
| Phenol | General disinfectant for toilets, stables cesspools, floors, drains, in manufacture of many medical and industrial organic compounds and dyes; reagent in chemical analysis[1]; excreted by man in urine, feces, and sweat; found in domestic sewage effluent[2] | 3/28 | 0/8 | 0/12 | 1/8 | 2/24 | 0/41 |
| 4-bromophenyl-phenylether | Can be by-product of chlorination | 0/28 | 0/8 | 0/12 | 0/8 | 1/24 | 0/41 |
| **Polycyclic aromatic hydrocarbons** | | | | | | | |
| Acenaphthene | Used in dye, plastic, insecticide, fungicide manufacturing; constituent in asphalt and produced in combustion of tobacco and aromatic fuels doped with pyridine[2] | 0/28 | 0/8 | 1/12 | 0/8 | 1/24 | 0/41 |
| Pyrene | Found in gasoline, wood preservative sludge, and domestic sewage effluent[2] | 0/28 | 0/8 | 1/12 | 0/8 | 0/24 | 1/41 |
| Fluoranthene | Found in crude oil, gasoline, lubricating motor oils, and in domestic sewage effluent[2] | 0/28 | 0/8 | 0/12 | 0/8 | 0/24 | 1/41 |
| **Phthalates** | | | | | | | |
| Bis(2-ethylhexyl) phthalate | Liquids with plasticizing properties that are added to synthetic polymers to give them improved flexibility and workability[3] | 12/28 | 0/8 | 4/12 | 2/8 | 7/24 | 6/41 |
| Diethyl phthalate | | 1/28 | 3/8 | 0/12 | 0/8 | 0/24 | 0/41 |
| Dioctyl phthalate | | 0/28 | 0/8 | 0/12 | 0/8 | 2/24 | 0/41 |
| Di-n-butyl phthalate | | 1/28 | 0/8 | 0/12 | 0/8 | 0/24 | 0/41 |

[1] Windholz, 1983.
[2] Verschueren, 1983.
[3] Connell and Miller, 1984.

Protection Agency, 1973, 1978, 1986). Benzidine, bis(2-chloroethyl) ether, bis(2-chloromethyl) ether, 3,3-dichlorobenzidine, 2,4-dinitrotoluene, and hexachlorobutadiene have recommended criteria of zero but were not found above detection limits in water-supply and freshwater samples.

Acenaphthene, bis(2-chloroisopropyl) ether, bis(2-ethylhexyl) phthalate, 2-chlorophenol, dibutyl phthalate, dichlorobenzene, 2,4-dichlorophenol, diethyl phthalate, 2,4-dimethylphenol, dimethyl phthalate, 2,4-dinitro-o-cresol, dinitrophenol, dioctyl phthalate, ethylbenzene, fluoranthene, hexachlorocyclopentadiene, isophorone, 3-methyl-4-chlorophenol, nitrobenzene, pentachlorophenol, and 2,4,6-trichlorophenol concentrations were all below detection levels and Federally recommended criteria for these compounds in all water-supply and freshwater samples analyzed (tables 4 and 5). Only 3 of 35 samples from water-supply sites exceeded standards for phenol compounds. 1,4-dichlorobenzene has mandated State and Federal standards for maximum concentration in drinking water, but none of the drinking-water samples contained concentrations that exceeded these standards (table 3).

### Bottom Sediment Quality

Bottom-sediment samples from sites B6, R8, and R9 were analyzed for 54 ABN extractable organic compounds. Results presented in the Greensboro data report (Davenport, 1988, Appendix C) show that seven ABN extractable organics were detected in these samples. N-butylbenzylphthalate occurred in concentrations ranging from 2,100 to 11,000 micrograms per kilogram ($\mu$g/kg) in sediment at sites R8 and R9, and bis(2-ethylhexyl) phthalate were detected in concentrations of 50 and 57 $\mu$g/kg at sites B6 and R9. The phthalate compounds are plasticizers, which have become common in the environment.

The compound 4-bromophenylphenyl ether occurred in all sediment samples collected in June 1986 in concentrations ranging from 7,300 to 120,000 $\mu$g/kg. Chyrsene and benzo(a)anthracene were detected at site R9 in concentrations between 88 and 1,200 $\mu$g/kg. Fluoranthene (44 and 86 $\mu$g/kg) and pyrene (41 and 78 $\mu$g/kg) were detected at sites R9 and B6 in September 1987; pyrene (2,400 $\mu$g/kg) was observed in bottom sediments at site R9 in June 1986. Chrysene, fluoranthene, pyrene, and benzo-a-anthracene may be

derived from petroleum products and are common in industrial and municipal sewage; 4-bromophenylphenylether may be a by-product of chlorination treatment processes. The petroleum product constituents occurred in bottom sediment samples at site B6 below the municipal treatment plants in the Buffalo Creek basin and further downstream at site R9. Because concentrations of petroleum products were not detected at site R8, the source of these compounds appears to be restricted to the Buffalo Creek basin.

## Organochlorine and Organophosphorus Pesticide Compounds

Water samples were analyzed for the presence of detectable concentrations of 34 organochlorine and seven organophosphorus pesticide compounds. Ten organochlorine pesticides and seven organophosphorus pesticides were detected in the water samples collected in the study area. No other pesticide compounds were found. Complete results of these analyses are given in Appendix E of the basic data report (Davenport, 1988).

### Constituent Concentrations

Compounds within the group of organochlorine pesticides are typically multi-carbon compounds with many chlorine atoms. The compounds detected in this study were lindane (gamma-BHC), beta-benzene hexachloride (beta-BHC), delta-benzene hexachloride (delta-BHC), alpha-benzene hexachloride (alpha-BHC), aldrin, dieldrin, 2,2-bis-(p-chlorophenyl)-1,1-dichloroethylene (DDE), heptachlor, heptachlor epoxide, and polychlorinated naphthalenes (PCN's).

Of the four members of the BHC family detected in the water samples, lindane was found most frequently. Sixteen of 76 samples collected during low flows from the effluents and below effluent outfalls contained concentrations of lindane ranging from the detection limit of 0.01 to 0.09 µg/L (table 14). Five of 23 high-flow samples contained detectable concentrations of lindane. Beta-BHC and delta-BHC were found in 3 and 1 of 76 samples, respectively, collected during low flows and in no high-flow samples. Alpha-BHC was detected in only 1 of 23 high-flow samples. Concentrations of these three BHC compounds did not exceed 0.09 µg/L. Aldrin, dieldrin, and DDE were detected in 4, 2, and 1, respectively, of 76 samples collected during low flows (table 14). Only aldrin and DDE were

found above detection limits in no more than 3 of 23 high-flow samples. Concentrations of each compound were close to the detection limit of 0.01 μg/L, with the exception of 1 sample with an aldrin concentration of 0.14 μg/L.

Table 14.--*Organochlorine and organophosphorus pesticide compounds detected in water samples in the Greensboro area, North Carolina, 1986-87*

[WS, water supply; DW, drinking water; AO, above municipal effluent outfalls; EFF, municipal effluents; BO, below municipal effluent outfalls]

| Compound | Number of detections per number of samples at Low-flow sites | | | | | High-flow sites |
|---|---|---|---|---|---|---|
| | WS | DW | AO | EFF | BO | BO sites |
| **Organochlorine pesticides** | | | | | | |
| Alpha-BHC (benzene-hexachloride) | 0/24 | 0/8 | 0/12 | 0/8 | 0/24 | 1/23 |
| Beta-BHC | 0/24 | 0/8 | 0/12 | 0/8 | 3/24 | 0/23 |
| Delta-BHC | 0/24 | 0/8 | 0/12 | 0/8 | 1/24 | 0/23 |
| Lindane (gamma-BHC) | 0/24 | 0/8 | 0/12 | 6/8 | 10/24 | 5/23 |
| Aldrin | 0/24 | 1/8 | 0/12 | 1/8 | 2/24 | 3/23 |
| Dieldrin | 0/24 | 0/8 | 1/12 | 0/8 | 1/24 | 0/23 |
| DDE | 0/24 | 0/8 | 1/12 | 0/8 | 0/24 | 1/23 |
| PCN's (polychlorinated naphthalenes) | 0/24 | 0/8 | 0/12 | 1/8 | 2/24 | 0/23 |
| Heptachlor | 0/24 | 0/8 | 0/12 | 0/8 | 0/24 | 3/23 |
| Heptachlor epoxide | 0/24 | 0/8 | 0/12 | 0/8 | 0/24 | 2/23 |
| **Organophosphorus pesticides** | | | | | | |
| Ethion | 0/14 | 0/4 | 0/6 | 2/4 | 3/12 | 0/18 |
| Parathion | 0/14 | 0/4 | 0/6 | 1/4 | 7/12 | 4/18 |
| Malathion | 0/14 | 0/4 | 0/6 | 1/4 | 3/12 | 3/18 |
| Methyl parathion | 0/14 | 0/4 | 1/6 | 1/4 | 3/12 | 0/18 |
| Methyl trithion | 0/14 | 0/4 | 0/6 | 1/4 | 4/12 | 0/18 |
| Trithion | 0/14 | 0/4 | 0/6 | 1/4 | 4/12 | 1/18 |
| Diazinon | 1/14 | 0/4 | 2/6 | 1/4 | 1/12 | 7/18 |

Heptachlor and heptachlor epoxide were detected in no more than 3 of 23 samples collected at high flows, and PCN's were found in only 3 of 76 samples collected during low flows. Concentrations of the heptachlor compounds were at the detection limit of 0.01 μg/L. However, PCN concentrations were as much as 7.3 μg/L.

Several organochlorine compounds were infrequently observed and were sporadically distributed at low concentrations (table 14). Dieldrin was detected in a sample at site B1 with a concentration of 0.03 μg/L, and downstream at site B2 a sample contained 0.01 μg/L. DDE was reported at the detection level in one sample at site B1 in March of 1987. Beta-benzene hexachloride at a level of 0.02 μg/L was observed in a sample at site R5.

It was also detected in three June 1986 samples: site B6 at 0.09 µg/L and in two samples taken from site R9 at concentrations of 0.08 µg/L each. Delta-benzene hexachloride was detected in a sample at site R9 in a concentration of 0.08 µg/L. These were the only detections of these compounds, and they were not observed in stream water samples collected at high flows.

The organophosphorus pesticides are a family of insecticides consisting of sulfur-forming thiol groups based on the phosphorus atom (McMurray, 1984). These insecticides are ethion, parathion, malathion, methyl parathion, methyl trithion, trithion, and diazinon.

Diazinon was detected at all groups of sampling sites during low and high flows except in the drinking water (table 14). Five of 40 samples collected during low flows and 7 of 18 high-flow samples contained detectable concentrations of diazinon, which ranged from the detection limit to 0.20 µg/L.

Ethion, parathion, malathion, and trithion were detected in only effluent and below effluent outfall samples collected during low flows. Parathion was detected most frequently during low flows (8 of 40 samples); ethion and malathion were found in 5 or less of 40 samples. Only parathion, malathion, and trithion were found in high-flow samples. Most concentrations of these compounds were close to the detection limit.

Methyl parathion and methyl trithion were detected in effluent samples and in samples from below outfalls; methyl parathion was also detected in one above outfall sample. However, these compounds were detected in 5 or less of 40 samples collected during low flows and in no high-flow samples. Concentrations ranged from below the detection limit to 0.17 µg/L.

### Standards and Criteria

The State of North Carolina and the U.S. Environmental Protection Agency have water-quality standards and recommended criteria for maximum concentrations of 19 organochlorine and organophosphorus pesticides. Four pesticide compounds are regulated in drinking water, and all but one of the 19 have State and/or Federal standards or criteria associated with their presence in water supplies and freshwater.

Maximum allowable endrin, lindane, methoxychlor, and toxaphene concentrations in drinking water vary between 0.2 and 100 μg/L (table 3). Out of eight samples, no concentrations of these compounds exceeded their respective State and Federal standards.

Numerical standards or criteria for water-supply areas are listed in table 4 for the 19 pesticide compounds with the exception of benezenehexachloride, which has a range of values for its criteria. Of the 19 organochlorine and organophosphorus pesticide compounds, diazinon did not meet the Federal criteria of 0.009 μg/L in one sample. All other pesticide concentrations met criteria and/or standards for water supplies.

Seven organochlorine and organophosphorus pesticides were reported in concentrations above State and Federal standards and criteria for freshwater (table 5). Dieldrin, DDE, and diazinon concentrations exceeded criteria at sites above outfalls in two or less of at least 9 samples (table 5). Diazinon, dieldrin, ethion, heptachlor, and parathion exceeded criteria in less than 8 of 30 samples from sites below outfalls, and lindane concentrations exceeded State standards in 18 of 47 samples. However, the majority of these concentrations were near the detection limits and exceeded the criteria or standards by tenths of a microgram per liter. Aldrin, chlordane, DDD, DDT, endosulfan, endrin, BHC, malathion, methoxychlor, PCB, and toxaphene did not occur in samples above or below outfalls in concentrations exceeding standards or criteria.

### Bottom Sediment Quality

Bottom sediment samples were analyzed for organochlorine and organophosphorus pesticide compounds. None of these pesticide compounds were detected in bottom sediment samples (Davenport, 1988, Appendix E).

## COMPARISON OF WATER-QUALITY CHARACTERISTICS AND DEVELOPMENT IN REEDY FORK AND BUFFALO CREEK BASINS

Comparisons of surface-water quality between basins draining rural, semideveloped, and urban areas can be made by using chemical and physical data collected during low and high streamflows at sites R1 on Reedy Fork Creek, R5 on Horsepen Creek, and B1 on North Buffalo Creek (fig. 2). The

Wilcoxon test for two independent samples, a nonparametric equivalent of the t-test, was used to test for differences in data from the three land-use sites at the 0.05 significance level (Sanders and others, 1983). Data from low-flow sample collections were tested separately from data collected during high flow. Physical characteristics used in the nonparametric statistical analyses were suspended sediment and specific conductance. Inorganic constituents used in the comparison were the ions: calcium, magnesium, sodium, chloride, sulfate, and fluoride; the nutrient, orthophosphate; and the trace elements: copper, nickel, zinc, and mercury (table 15). TOC concentrations also were used in the comparison although concentrations of specific organic compounds were not. Results of Wilcoxon testing on data collected during low flows from the three land-use areas are listed in table 16; results of statistical analyses on data collected during high flows are listed in table 17.

Types and proportion of the various land uses in the three basins are shown in figure 14. Land use upstream from site R1 on Reedy Fork Creek is a rural area with agriculture and low-density residential housing the primary land uses. Open spaces, including flood plains and recreation areas, border the total length of creek banks. Land use in the semideveloped basin upstream from site R5 on Horsepen Creek includes areas of agricultural and low-density residential, residential, industrial, and some open spaces (flood plains and recreational areas). The urban basin upstream from site B1 lies within the city limits and is mostly residential with areas of mixed use (commercial, office, light industrial, and multi-family residential) and industry. Additionally, the stream channel at site B1 is a wide, sandy channel that has been dredged in places upstream and is occasionally lined with open spaces.

Median suspended-sediment concentrations were 15, 5, and 8 mg/L at the rural, semideveloped, and urban sites, respectively, during low flow and varied only slightly in their ranges (table 15). However, during high flows, suspended-sediment concentrations increased at each site with median concentrations of 196, 305, and 408 mg/L at the respective sites. The Wilcoxon test showed no statistically significant difference in suspended sediment concentrations among the three land-use sites during either low or high flow (tables 16 and 17). Median values and ranges of suspended-sediment concentrations at each of the three sites during low and high flows

Table 15.--*Selected inorganic and physical constituents in water-quality samples collected during low and high flows from streams draining rural, semideveloped, and urban areas in the Greensboro area, North Carolina, 1986-87*

[site, location during study (fig. 2); n, number of samples (varies during high flow); µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter]

| Constituent | Low-flow Median | | | High flow Median | | |
|---|---|---|---|---|---|---|
| | Rural (site R1) n = 5 | Semideveloped (site R5) n = 5 | Urban (site B1) n = 5 | Rural (site R1) n = 5-8 | Semideveloped (site R5) n = 3-6 | Urban (site B1) n = 3-6 |
| Specific conductance (µS/cm) | 81.0 | 127.0 | 192.0 | 62.0 | 80.0 | 68.0 |
| TOC (mg/L) | 3 | 3.8 | 8 | 4.2 | 9.5 | 8 |
| Calcium (mg/L) | 6.7 | 13 | 22 | 4.7 | 7 | 7.1 |
| Magnesium (mg/L) | 2.4 | 5.1 | 6.3 | 1.8 | 2.45 | 1.7 |
| Sodium (mg/L) | 4.6 | 6.2 | 10 | 1.35 | 1.75 | .70 |
| Chloride (mg/L) | 3.5 | 4.5 | 13 | 3 | 3 | 2.25 |
| Sulfate (mg/L) | 4.1 | 4.4 | 18 | 10.2 | 11.5 | 7.7 |
| Fluoride (mg/L) | .15 | .15 | .32 | .08 | .085 | .105 |
| Orthophosphate (mg/L) | .025 | .018 | .053 | .350 | .335 | .581 |
| Mercury (µg/L) | .27 | .21 | .11 | .055 | .07 | .165 |
| Suspended sediment (mg/L) | 15 | 5 | 8 | 196 | 305 | 408 |
| Copper (µg/L) | * | [1]20 | [2]10 | 10 | 25 | 60 |
| Nickel (µg/L) | * | [2]25 | [3]30 | 20 | 20 | 60 |
| Zinc (µg/L) | [1]20 | [2]20 | [4]20 | 60 | 45 | 175 |

[1] 1 out of 5 concentrations above the detection limit.
[2] 2 out of 5 concentrations above the detection limit.
[3] 3 out of 5 concentrations above the detection limit.
[4] 4 out of 5 concentrations above the detection limit.
* Below detection limit.

Table 16.--*Number of samples, median values, and results of Wilcoxon testing at the rural (R1), semideveloped (R5), and urban (B1) sites during low flows for selected inorganic constituents, water-quality indicators, and total organic carbon in the Greensboro area, North Carolina, 1986-87*

[n, number of samples; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter]

| Constituent | Units | Rural (site R1) | | | Semideveloped (site R5) | | | Urban (site B1) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | n | Median | Wilcoxon test[1] | n | Median | Wilcoxon test[1] | n | Median | Wilcoxon test[1] |
| Suspended sediment | mg/L | 5 | 15 | A | 5 | 7 | A | 5 | 8 | A |
| Specific conductance | µS/cm | 5 | 84 | A | 5 | 127 | B | 5 | 192 | B |
| Calcium | mg/L | 5 | 6.7 | A | 5 | 13 | B | 5 | 22 | C |
| Magnesium | mg/L | 5 | 2.4 | A | 5 | 5.1 | B | 5 | 6.3 | C |
| Chloride | mg/L | 5 | 3.5 | A | 5 | 4.5 | B | 5 | 13 | C |
| Sodium | mg/L | 5 | 4.6 | A | 5 | 6.2 | A | 5 | 10 | A |
| Sulfate | mg/L | 5 | 4.1 | A | 5 | 4.4 | A | 5 | 18 | B |
| Fluoride | mg/L | 5 | .15 | A | 5 | .15 | A | 5 | .32 | B |
| Orthophosphate | mg/L | 5 | .025 | A | 5 | .018 | A | 5 | .053 | B |
| Copper | µg/L | 5 | <10 | A | 5 | <10 | A | 5 | <10 | A |
| Nickel | µg/L | 5 | <10 | A | 5 | <10 | A | 5 | 10 | A |
| Zinc | µg/L | 5 | <10 | A | 5 | <10 | A | 5 | 20 | A |
| Mercury | µg/L | 5 | .20 | A | 5 | .21 | A | 5 | .11 | A |
| Total organic carbon | mg/L | 5 | 3 | A | 5 | 3.8 | A | 5 | 8 | B |

[1]Concentrations at sites with the same letter for Wilcoxon test results are not significantly different at the 95-percent confidence level; those with different letters are significantly different. For example, there are no significant differences in the results for suspended sediment among the three sites (all with the letter A); whereas, the results for specific conductance are different at the rural site (A) from both the semideveloped and urban sites (both B) where differences are not comparatively significant.

Table 17.--*Number of samples, median values, and results of Wilcoxon testing at the rural (R1), semideveloped (R5), and urban (B1) sites during high flows for selected inorganic constituents, water-quality indicators, and total organic carbon in the Greensboro area, North Carolina, 1986-87*

[n, number of samples; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter]

| Constituent | Units | Rural (site R1) | | | Semideveloped (site R5) | | | Urban (site B1) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | n | Median | Wilcoxon test[1] | n | Median | Wilcoxon test[1] | n | Median | Wilcoxon test[1] |
| Suspended sediment | mg/L | 7 | 186.0 | A | 5 | 280.0 | A | 7 | 355.0 | A |
| Specific conductance | µS/cm | 6 | 60.5 | A | 4 | 77.5 | B | 4 | 71 | AB |
| Calcium | mg/L | 9 | 4.5 | A | 7 | 7.3 | AB | 7 | 7.4 | B |
| Magnesium | mg/L | 9 | 1.7 | A | 7 | 2.6 | B | 7 | 1.8 | AB |
| Chloride | mg/L | 9 | 3 | A | 7 | 3 | A | 7 | 2.5 | A |
| Sodium | mg/L | 9 | 1.4 | AB | 7 | 1.8 | A | 7 | .75 | B |
| Sulfate | mg/L | 9 | 9.5 | A | 7 | 12 | A | 7 | 8.8 | A |
| Fluoride | mg/L | 9 | .08 | AB | 7 | .08 | A | 7 | .11 | B |
| Orthophosphate | mg/L | 9 | .27 | A | 7 | .31 | A | 7 | .55 | B |
| Copper | µg/L | 8 | 10 | A | 6 | 25 | B | 7 | 50 | B |
| Nickel | µg/L | 8 | 20 | A | 6 | 20 | A | 6 | 55 | A |
| Zinc | µg/L | 9 | 40 | A | 7 | 40 | A | 7 | 130 | B |
| Mercury | µg/L | 9 | .05 | A | 7 | .07 | AB | 7 | .16 | B |
| Total organic carbon | mg/L | 9 | 4.4 | A | 7 | 5.8 | A | 7 | 7.5 | A |

[1]Concentrations at sites with the same letter for Wilcoxon test results are not significantly different at the 95-percent confidence level; those with different letters are significantly different. For example, there are no significant differences in the results for suspended sediment among the three sites (all with the letter A); whereas, the results for copper are different at the rural site (A) from both the semideveloped and urban sites (both B) where differences are not comparatively significant. Results for specific conductance show that significant differences occur between the rural site (A) and the semideveloped site (B), but no differences are seen when each of these two sites is compared to the urban site (AB).

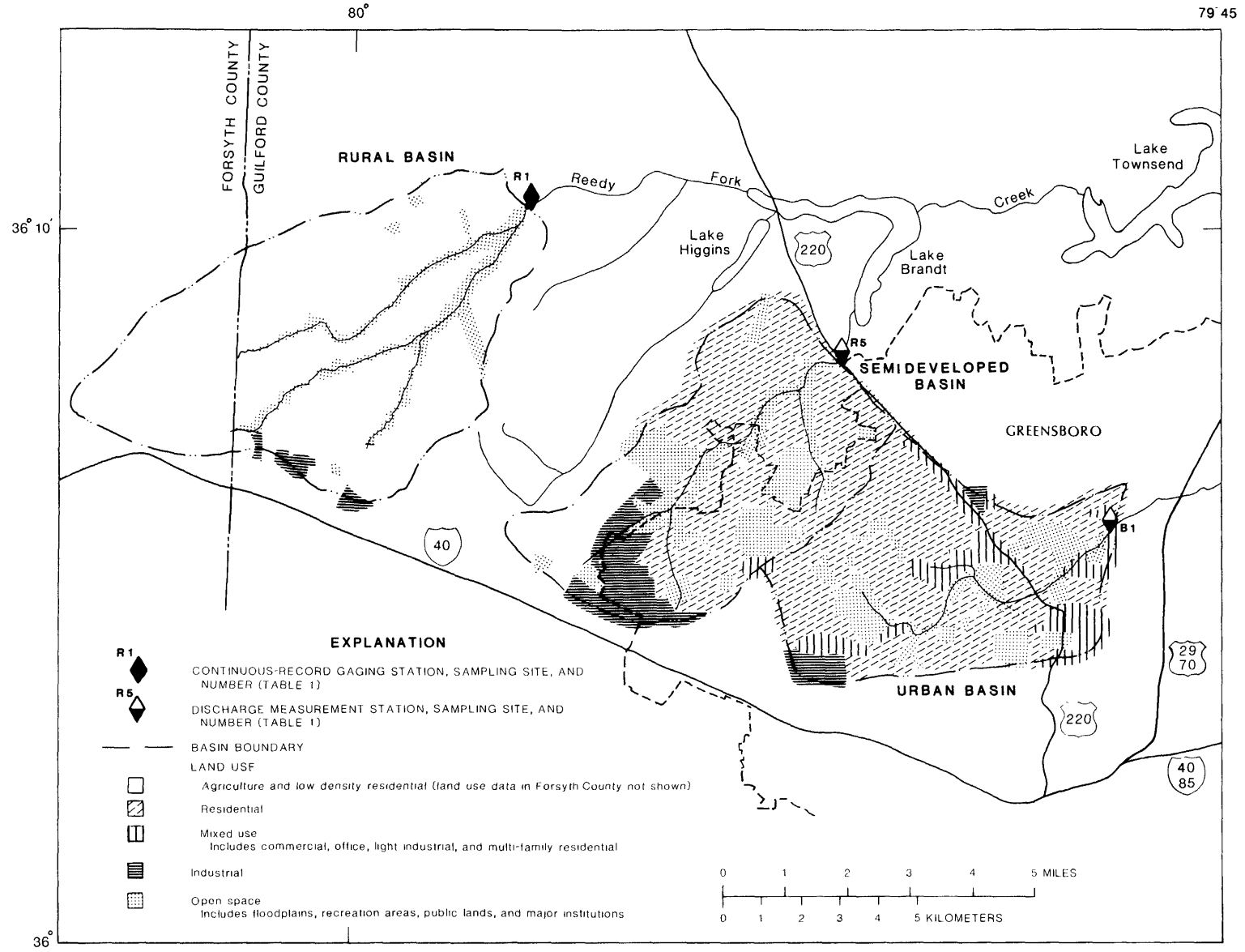



Figure 14.--Land-use and site locations in selected rural, semideveloped, and urban basins in the Greensboro area, North Carolina.
(Adapted from Guilford County Planning Division, 1984.)

are depicted in figure 15. The lack of statistical significance is probably due to the wide variability in suspended sediment concentrations at each site causing any distinction between sites to be obscured.

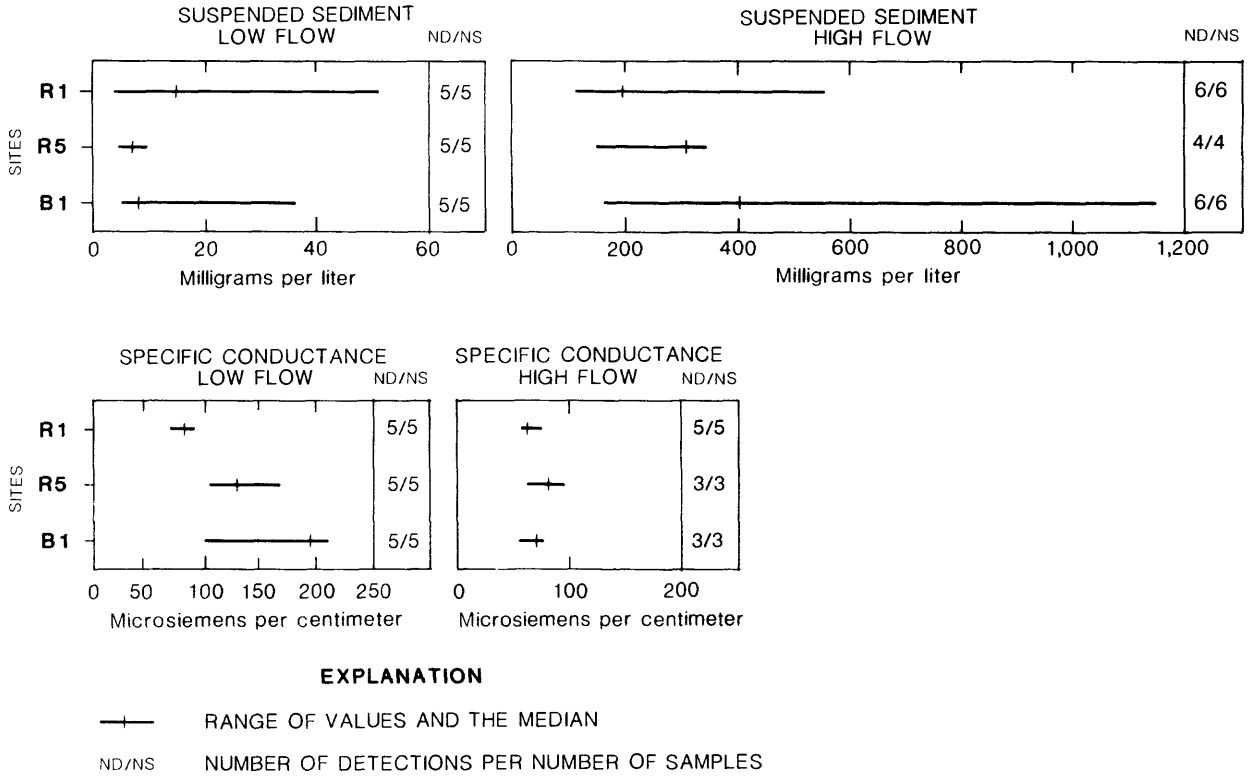



Figure 15.--Suspended sediment and specific conductance in water-quality samples collected during low and high flows at sites draining rural (R1), semideveloped (R5), and urban (B1) areas in the Greensboro area, North Carolina, 1986-87.

Median specific-conductance values were 81, 127, and 192 μS/cm during low flow and 66, 80, and 68 μS/cm during high flow at the rural, semideveloped, and urban sites (table 15). The median values during low flow reflect the influence of ground-water flow and surrounding geology on streamflow (fig. 15). Specific conductance values during high flow show dilution of the ground water by runoff.

Specific conductance values were significantly lower at the rural site than those from the semideveloped and urban sites during low flow (table 16). Specific conductance values at the rural site were also significantly lower than values from the semideveloped site during high flow (table 17).

Calcium, magnesium, and chloride concentrations in low-flow samples from each of the three basins were significantly different from one another (table 16). Median calcium concentrations increased from 6.7 to 22.0 mg/L, and magnesium concentrations from 2.4 to 6.3 mg/L, respectively, from the rural site to the urban site (fig. 16). Concentrations from the semideveloped site fell between these extremes. The same pattern was seen with chloride concentrations, increasing from 4.6 to 10 mg/L at the rural to urban sites. There was no significant difference between sodium concentrations at the three sites during low flow (table 16).

Wilcoxon tests showed that during low-flow conditions, dissolved sulfate and fluoride concentrations were significantly greater at the urban site than those from the rural and semideveloped sites (table 16). Median sulfate and fluoride concentrations varied little between rural and semideveloped sites but were at least double at the urban site. Median sulfate concentrations at the former sites were 4.1 and 4.4 mg/L, respectively, and 18 mg/L at the latter site; median fluoride concentrations at the former sites were 0.15 mg/L each and 0.32 mg/L at site B1. Thus, concentrations of sulfate and fluoride were approximately equal at sites R1 and R5 but were greater at site B1 in the urban area during low streamflow.

The nonparametric statistical analyses determined no difference between chloride and sulfate concentrations among the three sites during high flow (table 17). However, urban-area concentrations of sodium and fluoride varied significantly from semideveloped-area concentrations, and calcium data from the urban area varied significantly from data from the rural area during high flow (table 17).

On the basis of Wilcoxon testing, concentrations of the nutrient orthophosphate were significantly less in water samples collected at the rural and semideveloped sites than at the urban site during both low- and high-flow sampling (tables 16 and 17). Median concentrations during low flow were 0.02 mg/L at the former sites and 0.05 mg/L at the latter site, as compared to high-flow concentrations of 0.35 to 0.33 mg/L (rural and semideveloped) and 0.58 mg/L at the urban site (table 15). The increase in orthophosphate concentrations at site B1 is probably due to increased runoff from fertilized residential lawns and open areas in the urban setting.

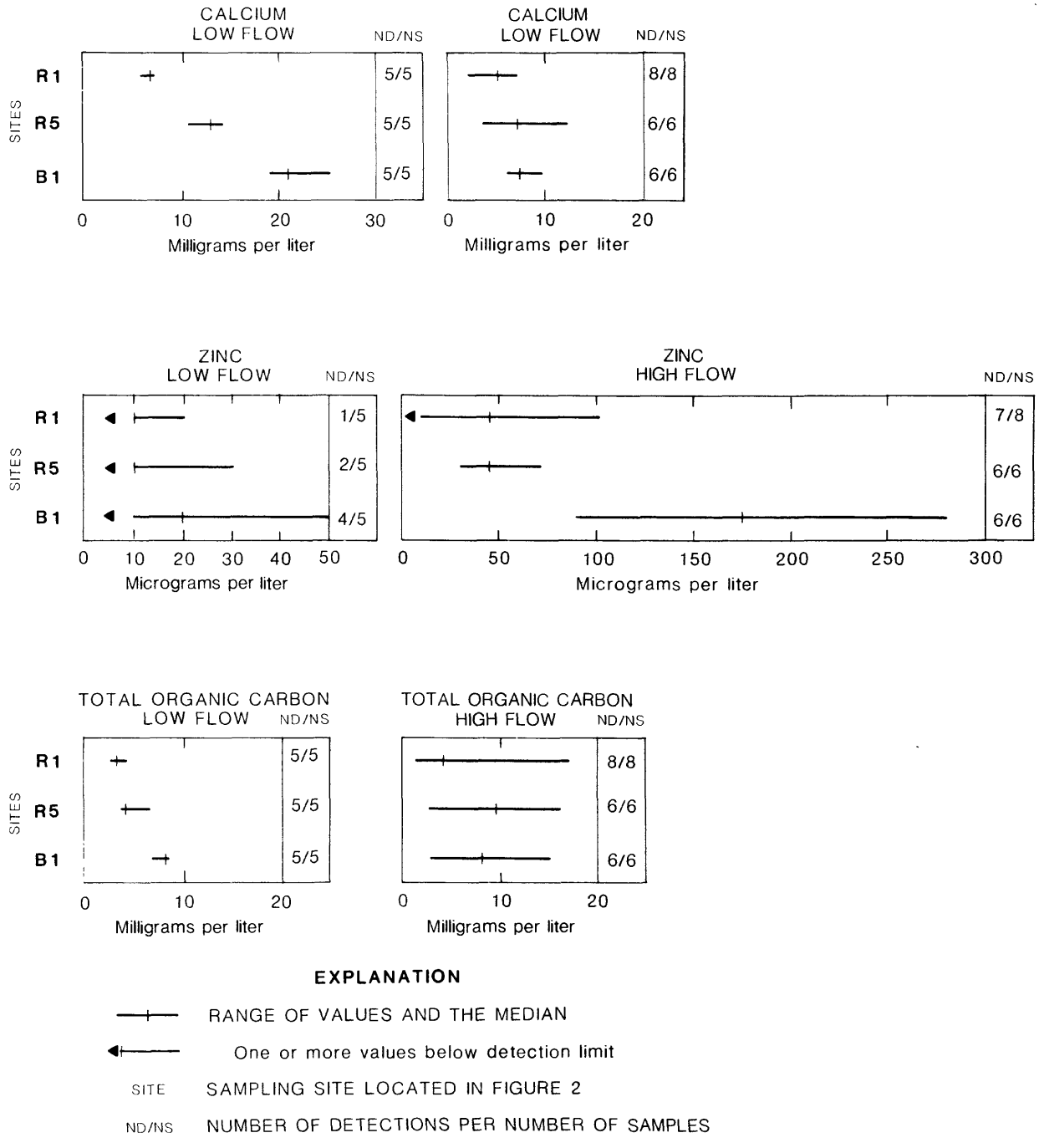



Figure 16.--Calcium, zinc, and total organic carbon in water-quality samples collected during low and high flows at sites draining rural (R1), semideveloped (R5), and urban (B1) areas in the Greensboro area, North Carolina, 1986-87.

Wilcoxon tests showed no significant difference between copper, nickel, and zinc concentrations during low flows among the three land-use sites (table 16). Copper, nickel, and zinc concentrations were near detection limits during low flows at each site but generally increased during high flows (table 15). Nickel concentrations at the semideveloped site were the only values to decline at high flows. Median copper concentrations were 10, 25, and 60 µg/L at the rural, semideveloped, and urban sites, respectively, during high flows. Nickel concentrations also were highest at the urban site (60 µg/L) with equal median concentrations at rural and semideveloped sites (20 µg/L). Zinc concentrations also were highest at the urban site (175 µg/L) and lowest at the semideveloped site (45 µg/L). Zinc concentrations are shown in figure 16 as a typical example of the fate and movement of trace-elements in streams. Increased concentrations of these trace metals are not uncommon due to the possibility of their association with suspended sediment.

Median mercury concentrations were higher in samples from the rural and semideveloped sites than at the urban site during low flows (0.27, 0.21, and 0.11 µg/L, respectively (table 15) but were not statistically different (table 16). Median concentrations were 0.05, 0.07, and 0.16 µg/L at the rural, semideveloped, and urban sites (table 15). Mercury concentrations during high flows at the urban site were significantly different from the rural site only (table 17).

On the basis of Wilcoxon testing, analyses showed no differences in TOC data from high-flow samples from the three land-use sites (table 17); however, concentrations of TOC from the urban site were significantly different from those from the rural and semideveloped sites during low flow (table 16). Median TOC concentrations were 3.0, 3.8, and 8.0 mg/L at the rural, semideveloped, and urban sites, respectively (table 15, fig. 16). During high flow, TOC concentrations were greatest at the semideveloped and urban sites (9.5 and 8.0 mg/L) and least at the rural site (4.2 mg/L) (table 15, fig. 16).

The Wilcoxon test for two independent samples was used on low- and high-flow sampling results for selected constituents (tables 16 and 17). During low-flow sampling, the constituents that differed significantly among all sites were calcium, magnesium, and chloride. During low flows, concen-

trations of orthophosphate, fluoride, sulfate, and TOC differed at the urban site from the rural and semideveloped site, and specific conductance varied at the rural site from the semideveloped and urban sites. There were no significant differences among sites in concentrations of sodium, suspended sediment, nickel, zinc, copper, and mercury during low flows. The Wilcoxon test performed on high-flow data indicated that concentrations of TOC, chloride, sulfate, suspended sediment, and nickel were not significantly different among the sites.

## SUMMARY

Water and bottom sediment samples were collected from April 1986 to September 1987 at 19 sites in the Reedy Fork and Buffalo Creek basins of the Greensboro area, North Carolina. Sampling locations included 13 stream sites, two lakes that serve as Greensboro' drinking-water supply, two finished drinking-water filtration plants, and effluent from two municipal wastewater plants prior to outfall into receiving streams.

Bottom sediment samples were collected at three sites in the lower portion of the Reedy Fork Creek basin and analyzed for organic compounds. Routine water-quality samples were collected at all sites, and six stream sites were selected for sampling during high flows at pre-peak, peak, and post-peak stages.

The sampling sites used during the project were categorized on the basis of their locations in the drainage basins. Because Lake Brandt and Townsend Lake are Greensboro's water-supply reservoirs, the five stream sites located in those drainage basin areas and the two lake sites were defined as water-supply sites. Analytical results of finished drinking-water samples from the Mitchell Treatment Plant and the Townsend Lake Filtration Plant are referred to as the drinking-water group of samples. Because of their location upstream from industrial and municipal wastewater outfalls, three stream sites composed a third group of sampling sites denoted as the sites above outfalls. The remaining stream sites were grouped together as the stream sites below the wastewater outfalls. The final group comprises the two municipal wastewater effluent sites at the North Buffalo Wastewater Treatment Plant and the T.Z. Osborne Wastewater Treatment Plant.

Nearly 22,000 separate analyses were made to define water-quality characteristics in the study basins. Analyses for physical, inorganic, and organic constituents in water samples included general water-quality indicators, major ions, nutrients, trace elements, cyanide, volatile organic compounds, acid and base/neutral extractable compounds, and organochlorine and organophosphorus pesticide compounds. Bottom sediment analyses were analyzed for ABN extractable and organochlorine-organophosphorus pesticides.

Various groups of water-quality indicators had similar patterns of detections. Dissolved solids, carbon dioxide, and total organic carbon concentrations and specific conductance values were largest in the effluents and downstream from wastewater outfalls. Values of pH and temperature and dissolved oxygen concentrations indicated little variation between any of the sampling sites. Alkalinity and hardness concentrations were in the greatest concentrations in the basins downstream from the city and receiving wastewater effluents. Color values were greatest at site B2 downstream from the industrial wastewater outfall.

Among the major ions, calcium- and magnesium-concentration patterns varied from those of sodium, potassium, chloride, sulfate, and fluoride. There were only slight differences between calcium and magnesium concentrations among the sites. Concentrations of the remaining cations and anions generally were no different from the calcium and magnesium concentrations in the water-supply and drinking-water groups of sites; however, concentrations of these five ions increased and varied widely in the effluent, above outfall and below outfall groups of sites.

Nutrient concentrations at the water-supply, drinking-water, and above-outfall groups of sites were near detection limit, although concentrations below the outfalls were affected by nutrient content of the municipal effluents. Concentrations of nitrate, ammonia, phosphorus, and orthophosphate were largest in the effluent samples and next largest directly below the municipal outfalls on North and South Buffalo Creek.

The trace elements that occurred most frequently and in the greatest concentrations were iron and manganese. Aluminum concentrations were greatest above the municipal outfall on North Buffalo Creek, but the median concentrations were approximately the same at all sites. Nickel, barium,

copper, zinc, mercury, and selenium were found in a limited number of samples and most frequently at the sites in the North and South Buffalo Creek basins.

Volatile organic compounds were detected in water samples; however, only 9 of the 20 compounds that were detected were found in more than 10 percent of both low- and high-flow samples. Methyl chloride, bromodichloromethane, chlorodibromomethane, 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, benzene, toluene, and chloroform occurred at or above the detection limit of 0.2 µg/L. Three of these compounds can be traced to trihalomethane compound formation during water and wastewater treatment.

In tests for 57 ABN extractable compounds on water samples collected during low and high flows, the only compounds detected were nine members of the phenol, polycyclic aromatic hydrocarbon (PAH), and phthalate families. Phenol family members phenol and 4-bromo-phenylphenyl ether were found in 6 or less of 121 samples, and the PAH compounds acenaphthene, pyrene, and fluoranthene were detected in 2 or less of 121 samples. The phthalate family members diethyl phthalate, dioctyl phthalate, and di-n-butyl phthalate were not detected in more than 4 of 121 samples; however, bis(2-ethylhexyl) phthalate was found in 31 of 121 samples.

Organochlorine pesticides were detected in some water samples. The organochlorine compounds alpha-benzene hexachloride (BHC), beta-BHC, delta-BHC, dieldrin, DDE, PCN's heptachlor, and heptachlor epoxide were found in 3 or less of 99 samples collected during low and high flows. Lindane and aldrin were detected in 21 and 7 of 99 samples, respectively. Most concentrations were near detection limits.

Organophosphorus pesticides were found sporadically at concentrations near detection limits in samples collected during low and high flows. Parathion and diazinon were detected in 12 of 58 samples; ethion, malathion, methyl parathion, methyl trithion, and trithion were found in 7 or less of 58 samples.

State drinking-water standards were exceeded in 1 of 8 samples by two VOC's, benzene and trichloroethylene, but 5 of 8 total trihalomethane concentrations exceeded the standards. No other standards for trace metal,

nutrient, organic compound, and major ion concentrations or water-quality indicators in drinking water were exceeded.

Standards for water supplies are either a set numerical limit or a varying limit dependent upon toxicological testing. Copper, cyanide, iron, manganese, mercury, and zinc concentrations and turbidity values exceeded State standards in greater than 10 percent of the samples. Synthetic organic compounds (SOC's) with varying units that were frequently detected were benzene, chloroform, methyl chloride, and total trihalomethanes.

Concentrations of cyanide, iron, nickel, mercury, zinc, and aldrin and turbidity values each exceeded State and/or U.S. Environmental Protection Agency freshwater standards in at least 10 percent of the samples. Benzene, bis(2-ethylhexyl) phthalate, bromodichloromethane, chloroform, methyl chloride, diazinon, ethion, halomethanes, lindane, malathion, parathion, tetrachloroethylene, toluene, 1,1,1-trichloroethane, and trichloroethylene were each found in at least 10 percent of the samples; however, the State has not determined set numerical limits for these SOC's. The remaining constituents were either undetected or found in less than 10 percent of the samples and did not exceed any water-quality standards or criteria.

Estimates of constituent loading in Reedy Fork Creek where it flows out of Guilford County at site R9 were calculated by using daily mean flows. Linear regression analyses were used to estimate loadings for suspended sediment, TOC, calcium, magnesium, potassium, sodium, sulfate, chloride, fluoride, phosphorus, orthophosphate, nitrate, ammonia, iron, barium, manganese, and zinc. Suspended sediment (87,000 tons/yr), sulfate (6,800 tons/yr), and iron (5,800 tons/yr) were the largest estimated loadings. Because the loading estimates were based on relations developed from 19 samples, additional sampling is needed to validate these relations.

Bottom-sediment samples were analyzed for 54 ABN extractable organic compounds; however, only seven compounds were detected at concentrations ranging from 2.1 to 86 µg/kg. These compounds were butylbenzylphthalate, bis(2-ethylhexyl) phthalate, 4-bromophenyl, phenylether, chyrsene, benzo(a)anthracene, fluoranthene, and pyrene. No criteria or standards currently exist for these compounds in bottom sediments.

Comparisons of surface-water quality in basins in rural, semideveloped, and urban settings were made using the study data from sites R1 on Reedy Fork Creek, R5 on Horsepen Creek, and B1 on North Buffalo Creek, respectively. Physical quantities compared were suspended sediment and specific conductance. Inorganic constituents used in the nonparametric statistical analyses were the ions: calcium, magnesium, sodium, choride, sulfate, and fluoride; the nutrient, orthophosphate; and the trace elements: copper, nickel, zinc, and mercury. Total organic carbon concentrations also were used in the comparison although concentrations of specific organic compounds were not.

The Wilcoxon test for two independent samples was used on low- and high-flow sampling results for selected constituents. During low-flow sampling, the constituents that differed significantly among all sites were calcium, magnesium, and chloride. During low flows, concentrations of orthophosphate, fluoride, sulfate, and TOC differed at the urban site from the rural and semideveloped sites; specific conductance varied at the rural site from the semideveloped and urban sites. There were no significant differences among sites in concentrations of sodium, suspended sediment, nickel, zinc, copper, and mercury during low flows. The Wilcoxon test performed on high-flow data showed that because of wide variability at individual sites, concentrations of TOC, chloride, sulfate, suspended sediment, and nickel were not significantly different among the sites.

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