Water Quality of North Carolina Streams

Chapter E

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North Carolina Streams

By DOUGLAS HARNED and DANN MEYER

GEOLOGICAL SURVEY WATER–SUPPLY PAPER 2185–E
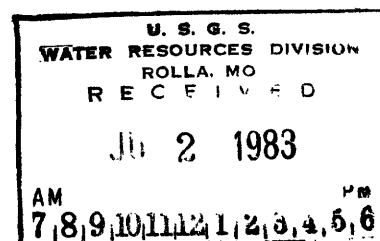
UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY
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PREFACE

In 1972, the U.S. Geological Survey and the North Carolina Department of Natural Resources and Community Development jointly designed and implemented a statewide monitoring program to help identify current and emerging water-quality problems. As part of this program the U.S. Geological Survey devised a study to make a detailed accounting of water quality in the large rivers of North Carolina at key locations. The three major goals of the Large Rivers Study are:

1. Definition of variation in water quality,
2. Determination of pollution loads in streams, and
3. Determination of trends in water quality.

Data collected since the 1940's have been used in this study to define water-quality variation and trends. Data recently collected from unpolluted streams were compared to data collected from large rivers to estimate pollution loads of the large rivers.

This water-supply paper series includes all of the reports produced in the Large Rivers Study in the sequence that they were written. Methodologies presented in the reports have changed with time, and the emphasis of individual reports differ somewhat because of the data used and the individuality of the authors. However, each of the reports devoted to a large river follows a similar format to allow comparison between streams.

Chapter A describes in detail the initial design and philosophy of the U.S. Geological Survey water-quality program in North Carolina. Specific methodologies for the estimation of baseline water quality, pollution, and the evaluation of trends in water quality discussed in Chapter A are applied and refined in subsequent chapters that present water-quality assessments of individual large rivers. Chapter B elaborates on the methodology used in estimating baseline water quality, and presents the results of a statewide baseline survey. Chapters C and D present water-quality assessments of the French Board and Neuse Rivers, respectively. Chapter E is a water-quality assessment of the Yadkin-Pee Dee River system. Assessments of the water quality of other large rivers in North Carolina will be published in this series as the information becomes available.

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Water Quality of the Yadkin-Pee Dee River System, North Carolina—Variability, Pollution Loads, and Long-Term Trends

By Douglas Harned *and* Dann Meyer

Abstract

Interpretation of water-quality data collected by the U.S. Geological Survey and the North Carolina Department of Natural Resources and Community Development, for the Yadkin-Pee Dee River system, has identified water-quality variations, characterized the current condition of the river in reference to water-quality standards, estimated the degree of pollution caused by man, and evaluated long-term trends in concentrations of major dissolved constituents.

Three stations, Yadkin River at Yadkin College (02116500), Rocky River near Norwood (02126000), and Pee Dee River near Rockingham (02129000) have been sampled over different periods of time beginning in 1906. The Yadkin College station is located downstream from Winston-Salem, N.C., a city of over 130,000 people, and upstream from a chain of multipurpose lakes on the river. The Norwood station gages Rocky River, one of the largest tributaries to the Yadkin-Pee Dee River system. The Rockingham station is on the Pee Dee River downstream from the lakes, and is near the North Carolina-South Carolina State line.

Overall, the ambient water quality of the Yadkin-Pee Dee River system is satisfactory for most water uses. Iron and manganese concentrations are often above desirable levels, but they are not unusually high in comparison to other North Carolina streams. Lead concentrations also periodically rise above the recommended criterion for domestic water use. Mercury concentrations frequently exceed, and pH levels fall below, the recommended criteria for protection of aquatic life. Dissolved-oxygen levels, while general-ly good, are lowest at the Pee Dee near Rockingham, due to the station's location not far downstream from a lake.

Suspended sediment is the most significant water-quality problem of the Yadkin-Pee Dee River. A dramatically decreasing trend in suspended-sediment concentration since 1951, observed for the Yadkin River at Yadkin College, is probably due to changes of agricultural practices and land use in the basin.

A double-peaked response of suspended-sediment concentration to stormflows is characteristic for the Yadkin River at Yadkin College. The first peak is caused by flushing of sediments from Muddy Creek, a tributary that drains southern Winston-Salem, and the second peak is the response of the Yadkin River itself. The concentration peak from the Muddy River occurs before the peak in the hydrograph, demonstrating a first-flush effect commonly observed in storm-water-quality studies of urban areas.

The major cation in the river is sodium and the major anions are bicarbonate and carbonate. Concentrations of major dissolved constituents, and specific conductance values are generally highest at the Rocky River near Norwood. Concentrations of most dissolved constituents can be satisfactorily estimated from regressions of constituent concentration on specific conductance.

Nutrient concentrations are high enough to allow rich algal growth. Eutrophication is currently a problem in the Yadkin-Pee Dee, particularly in High Rock Lake. An estimated nutrient and sediment balance of the system indicates that lakes along the Yadkin-Pee Dee River serve as a sink for sediment, ammonia, and phosphorus. The lower ammonia concentrations downstream from the lakes are due primarily to ox-idation, but lower phosphorus concentrations are due probably to consumption by algae and precipitation with sediment in the lake system. Phosphorus is the dominant limiting nutrient.

Pollution makes up approximately 59 percent of the total dissolved-solids load of the Yadkin River at Yadkin College, 43 percent for the Rocky River near Norwood, and 29 percent for the Pee Dee River near Rockingham. The estimate of base flow used in this calculation was 54 percent of the total flow for the Yadkin River at Yadkin College and 26 percent for the Rocky River near Norwood. Base flow for the Pee Dee River near Rockingham was assumed to be 50 percent of the total flow.

Statistically significant trends show a pattern of increasing concentration of most dissolved constituents over time, with a leveling off and decline in the middle to late 1970's. The pattern shows the most extreme rise and fall for Rocky River constituent concentrations, while the decrease is less pronounced for the Pee Dee River near Rockingham, and least apparent with Yadkin College concentrations. These results may be evidence that upgraded waste-water treatment or changes in industrial processes have improved or at least slowed deterioration of water quality in the river system.

Relatively steady increases in sulfate and in nitrate and a steady decrease in pH with time probably are largely due to the increasing acidity of atmospheric precipitation.

INTRODUCTION

Growth of population, urbanization, and industrialization in North Carolina has brought a corresponding increase in water pollution. In 1972, to help identify current and emerging water-quality problems, the U.S. Geological Survey joined with the North Carolina Department of Natural Resources and Community Development in designing and implementing a statewide water-quality monitoring program (Wilder and Simmons, 1978). As an outgrowth of this program, the U.S. Geological Survey began a study of the water-quality of the large rivers of the State. The program incorporates strategically located streamflow-gaging and water-quality-sampling stations in nine river basins. Each station serves to continuously update evaluations of ambient river-water quality.

The Geological Survey's study has three major goals:
1. Definition of variation in water quality,
2. Determination of pollution loads in streams, and
3. Determination of trends in water quality.
Identification of the presence of dissolved and suspended materials in stream water, and knowledge of how the amounts of these materials change with stream conditions, are critical to any evaluation of stream pollution. It is also important to separate pollution, defined here as any substance that is present in the stream as a result of man's activities, from the natural water-quality of the stream. Finally, the evaluation of long-term trends in water quality provides a historical perspective on the changing character of the stream.

Purpose and Scope

The purpose of this report is to present the results of analyses of water-quality data for three long-term stations in the Yadkin-Pee Dee River basin. Data collected in the period 1906–78 from the Yadkin River station at Yadkin College, the Rocky River station near Norwood, and the Pee Dee station near Rockingham will be examined.

The results of this study are organized in a manner designed to allow comparison with the results produced from studies already completed (Daniel and others, 1979; Harned, 1980) and other studies. First, a basin description gives characteristics which have important relationships to water quality. These characteristics include population distributions, physical features of the basin such as topography and geology, industrial and municipal waste-disposal points, and ongoing programs of stream-channel modification for flood control or navigation. Second, a summary of water-quality

analyses gives an overview of the condition of the river. Next, an accounting of pollution and baseline water quality reveals the effect man has had on the stream. Finally, water-quality changes throughout the total period of data collection allow an examination of past and projected trends in pollution of the Yadkin-Pee Dee River system.

Recent Water-Quality Studies

The Yadkin-Pee Dee River basin is currently (1980) the focus of a comprehensive effort, primarily by North Carolina, South Carolina, and Federal water-resources agencies, to define the problems of and propose options for effective management of water-resources allocation, development, and use. This type of comprehensive planning study, termed a "Level B study" represents the second phase of the three-part planning process outlined by the Water Resources Council (1973) as part of the requirements of the Water Resources Planning Act of 1965 (Public Law 89–90, 89th Congress, July 22, 1965, and Public Law 94–112, 94th Congress, H.R. 5952, October 16, 1975).

The first phase of this comprehensive planning study, Level A, resulted in the North Carolina Water Resources Framework Study conducted by the North Carolina Department of Natural and Economic Resources (1977) which outlines major water resources problems throughout the State. Problems listed in the report and the Pee Dee Basin Framework Study (South Carolina Water Resources Commission, 1977) for the Yadkin-Pee Dee River basin in North Carolina include erosion and sedimentation, protection of water supplies, optimal operation of hydropower and flood-control lakes, interbasin transfer of water, and pollution control.

The second phase of the comprehensive study, Level B, defines alternative plans to address the problems compiled in the earlier phase. Several reports of the Comprehensive Water Resources Study for the Yadkin-Pee Dee River system have been produced (North Carolina Department of Natural Resources and Community Development and others, 1979a, 1979b, 1980a, 1980b, 1980c, 1980d). These studies are designed to lead eventually to direct implementation of an optimal water-resources plan for the Yadkin-Pee Dee River basin (the Level C phase).

Other recent studies have been produced that are related to the comprehensive water-resources study or that discuss more specific basin problems. A report on erosion and sediment within the basin is one of eight environmental inventories published by the U.S. Depart-

ment of Agriculture (1979) for the Level B study. This report emphasizes that sediment is the most significant nonpoint source pollutant in the basin. A report by TRW (1975) prepared for the National Commission on Water Quality gives a detailed overview of the water quality and quantity of the Yadkin-Pee Dee basin using the basin as a representative example to help the Commission in their assessment of the condition of the Nation's waters. The environmental impact statement for the Perkins Nuclear Station (Duke Power Company, 1975) to be built not far from the Yadkin College gaging station is a catalog of specific environmental and demographic information for a large section of the upper Yadkin-Pee Dee basin. Olmsted and Leiper (1978) also report on environmental data in the vicinity of the proposed plant. One of the major impacts of the proposed Perkins Power Plant will be the consumptive use of water by the plant's cooling operations. This issue has been addressed in a study by the North Carolina Department of Natural and Economic Resources (1976b) and with results of a flow-prediction model (Tang, 1976). Another report, compiled by faculty and students of Davidson College, focuses on the problems of the Rocky River basin, the primary tributary of the Yadkin-Pee Dee River system (Gable and Lammers, 1976).

Wiess and others (1981) recently completed a comprehensive study assessing the water quality of the Upper Yadkin River and the High Rock Lake. This detailed study is based on data collected during the period of October 1977 to September 1978.

ACKNOWLEDGMENTS

BASIN DESCRIPTION

The Yadkin-Pee Dee River basin lies in central North Carolina, extending from Virginia into South Carolina (fig. 1). Originating on the eastern slopes of the Blue Ridge Mountains of North Carolina, the Yadkin River flows east for about 100 miles before turning sharply south near Winston-Salem. In south-central North Carolina, the Yadkin River joins the Uwharrie River from the east. Downstream from this confluence, the river is known as the Pee Dee River. In eastern South Carolina, the Pee Dee River joins the Lumber River, which drains southeastern North Carolina. The 10,556 mi^2 combined drainage area of the Yadkin-Pee Dee-Lumber Rivers is the largest river basin in North Carolina.

This report concerns only the upper 6,870 mi^2 of the basin upstream from the U.S. Geological Survey's water-quality monitoring station at mile 192 of the Pee Dee River near Rockingham (fig. 1). This area includes all or part of 22 North Carolina counties, as well as small areas in Virginia and South Carolina. Major tributary streams in this part of the Yadkin-Pee Dee basin include the Ararat River, Deep Creek, Muddy Creek, Abbotts Creek, South Yadkin River, Uwharrie River, Little River, and Rocky River (fig. 1), and many smaller streams. Hereafter, any reference to the Yadkin-Pee Dee basin will refer to the basin area upstream from Rockingham.

Many large dams impound the waters of the trunk stream throughout its course. The lakes, which were originally built for hydropower, now serve as multipurpose impoundments providing flood control, hydro-

EXPLANATION

02126000

▼   Water-quality sampling station and number

▲   Stream-gaging station

——··—— Basin boundary

Figure 1. Locations of water-quality sampling stations used in the Yadkin-Pee Dee River basin study.

electric power, cooling water, recreation, and water supply for the basin.

Climate

The climate in the Yadkin-Pee Dee basin is characterized by hot, humid summers and mild winters. The mountain areas in the northwestern section of the basin receive the largest mean annual precipitation, of up to 53 in (Idlewild weather station: National Oceanic and Atmospheric Administration or NOAA, 1973). In the southern part of the basin, the mean annual precipitation at the Mount Gilead weather station is 43 in (NOAA, 1973). The northwestern part of the basin is the coolest, with a mean annual temperature of about 57°F. (13.9°C.). The southern part of the basin has a mean annual temperature of about 62°F. (16.7°C. NOAA, 1973).

Streamflow

The average daily discharge of the Yadkin River at the Yadkin College station is 2,970 ft³/s (range: 177–80,200 ft³/s) for the 50-year period of record beginning in 1928. With a drainage area of 2,280 mi², the average discharge is 1.30 (ft³/s)/mi².

The average daily discharge of Rocky River at Norwood is 1,330 ft³/s (range: 17–10,500 ft³/s) or 0.97 (ft³/s)/mi² (drainage area 1,370 mi²) for the 49-year period of record (1929–78). The discharge of the Pee Dee River near Rockingham is affected by regulation of the hydroelectric dams on the river. The average daily discharge of Rockingham is 7,997 ft³/s or 1.16 (ft³/s)/mi² for the drainage area of 6,870 mi² (range: 50–276,000 ft³/s).

Discharge at the three stations tends to be lowest in the early autumn, increasing to maximum during the winter.

Geology and Physiography

Most of the Yadkin-Pee Dee River basin lies in the Piedmont physiographic province of North Carolina. The Piedmont is divided into three major geologic units. The Inner Piedmont consists of a northeast-southwest-trending band composed of a large variety of gneisses and schists. The Charlotte Belt is roughly parallel to, but east of, the Inner Piedmont and consists of granitic and dioritic rocks. The Carolina Slate Belt lies still further east and consists of slatelike rocks of volcanic origin, as well as mafic and felsic volcanic rocks.

Smaller subdivisions in the Piedmont include the Kings Mountain Belt which consists of metasedimentary rocks. The Kings Mountain Belt lies between the Inner Piedmont and Charlotte Belts. Two Triassic basins lie in the Yadkin-Pee Dee drainage area, one in Yadkin and Davie Counties and the other, the Wadesboro Basin, in Anson and Montgomery counties. Rocks in these basins consist of red to purple sandstone and conglomerate.

As much as 200 ft of saprolite, the residium of in-place weathering and leaching of bedrock, form most of the surficial unit in the Piedmont. The depth of leaching is determined by structural features of the bedrock, particularly faults, joints, and fractures. However, because erosion tends to remove products of weathering from the uplands, the thickest saprolite usually occurs on lower valley walls and beneath alluvial-valley fill.

The Yadkin River originates in the northwestern extreme of the basin among the gneisses and schists of the Grandfather Mountain Window (an area where erosion has penetrated a thrust fault to expose metasedimentary rocks lying beneath) and other metamorphic rocks of the Blue Ridge Front. Tributaries of the Pee Dee River in Richmond County at the southern margin of the drainage basin drain small areas underlain by the Upper Cretaceous Cape Fear and Middendorf Formation consisting of sands and clays.

The stream gradient of the Yadkin River as it descends the Blue Ridge to the W. Kerr Scott Reservoir in Wilkes County is 3.8 ft/mi. The free-flowing Yadkin River downstream from the W. Kerr Scott Reservoir has an average gradient of 2.9 ft/mi to High Rock Lake, near the center of the basin. The large stream gradient (7.5 ft/mi) as the river enters and traverses the Carolina Slate Belt, is harnessed by a series of hydroelectric dams. Downstream from the last dam at Lake Tillery to the South Carolina border the gradient is 2.5 ft/mi.

Population

The 1970 population of the Yadkin-Pee Dee basin in North Carolina was approximately 875,000 persons (North Carolina Department of Water and Air Resources, 1972). The percentages of total basin population in subbasins of the Yadkin-Pee Dee basin are given in figure 2. The 1970 population represents an increase of about 11 percent over the 1960 population. As the population increases, it is becoming more urbanized. Most cities and towns have shown population growth during 1960–70. By 1970, 34 percent of the basin population was residing in large towns and cities of over 10,000 persons, and 45 percent of the population lived in municipalities of 1,000 persons or more.

Table 1. Major municipal and industrial waste-water discharges in the Yadkin-Pee Dee River basin (data from North Carolina Department of Natural and Economic Resources, 1975, and Environmental Management Division files)

Facility	Location	Location of waste discharge	Design flow (ft³/s)
1___Wilkesboro	Wilkes County	Cub Creek	5.1
2___Chatham Manufacturing Company, Elkin	Surry County	Yadkin River	6.2
3___Elkin	___do___	___do___	4.7
4___Mt. Airy	___do___	Ararat River	24.8
5___Salisbury	Rowan County	Grants Creek	7.8
6___NC Finishing Company	___do___	High Rock Lake	6.6
7___Duke Power Company	___do___	___do___	7.0
8___Winston-Salem	Forsyth County	Salem Creek	55.8
9___Statesville	Iredell County	Third Creek	6.2
10___High Point	Davidson County	Rich Fork Creek	6.2
11___Thomasville	___do___	Hamby Creek	6.2
12___Mooresville Industrial	Iredell County	Dye Branch	6.2
13___Cannon Mills Company	Kannapolis	___do___	26.4
14___Concord Regional	Cabarrus County	Rocky River	37.2
15___Monroe	Monroe County	Richardson Creek	7.0
16___Rockingham	Richmond County	Hitchcock Creek	9.3
Total			222.6
Total basin			325.3

Water Uses and Waste Disposal

The North Carolina Department of Natural and Economic Resources (1976c) catalogued all major point sources of effluent discharge into the Yadkin-Pee Dee River system. Sixty-eight percent (222.6 ft³/s) of the total waste water discharged into the river system (325.3 ft³/s) is from 16 large sources which are given in table 1. The location of these 16 major discharges, together with the proportion of total waste-water discharge accountable to point sources per subbasin are given in figure 3. A general correspondence of discharge of waste water and population per subbasin is evident from a comparison of figures 2 and 3. The Archie Elledge Waste-Water Treatment Plant at Winston-Salem is the single largest effluent source. For comparison, the average 7-day, 10-year minimum low-flow value at Yadkin College is 640 ft³/s, 40 ft³/s at the Norwood station, and 1,110 ft³/s at the Rockingham station. These low-flow values are based on the log-Pearson analysis of 1929–78 discharge data. Recent variation due to regulation at the W. Kerr Scott Dam for the Winston-Salem water supply has increased the Yadkin College minimum flow value.

Hydrologic Modifications

The discharge through the lakes on the Yadkin River, including Tuckertown Lake, Badin Lake (Nar-rows Lake), Blewett Falls Lake, and Lake Tillery, is determined by the level of High Rock Lake and regulated by the Federal Power Commission. Recreational needs place additional constraints on the management of High Rock Lake. A discharge of 8,000 ft³/s through High Rock Dam may be maintained, if the lake level is higher than 654 ft National Geodetic Vertical Datum (NGVD) of 1929 during summer, although the same discharge can be maintained during the rest of the year at lake levels as low as 644 ft NGVD of 1929. Federal Power Commission regulations require lower rates of discharge from the dam if High Rock Lake's level falls below 644 ft NGVD of 1929. Neither Lake Tillery nor Blewett Falls Lake are strictly regulated and are rarely drawn down very much. Flow is regulated at the W. Kerr Scott Dam site so that a minimum flow of 700 ft³/s is maintained at Yadkin College and the maximum flow at Wilkesboro (02112000) is 5,400 ft³/s.

Additionally, there are about 30 impoundments on tributary streams used for municipal water supplies and for many smaller impoundments and farm ponds.

The Soil Conservation Service (1979) has planned or completed channel improvements on five tributary streams in the northern section of the basin above High Rock Lake and along tributaries of Rocky River. The Army Corps of Engineers has not undertaken any channel improvement projects in the basin during this century (U.S. Army Corps of Engineers, 1979).

Figure 2. The percentage of the total basin population residing in each Yadkin-Pee Dee subbasin.

EXPLANATION

▼ Water-quality sampling station

4 % Percentage of total basin population

----- Subbasin boundary
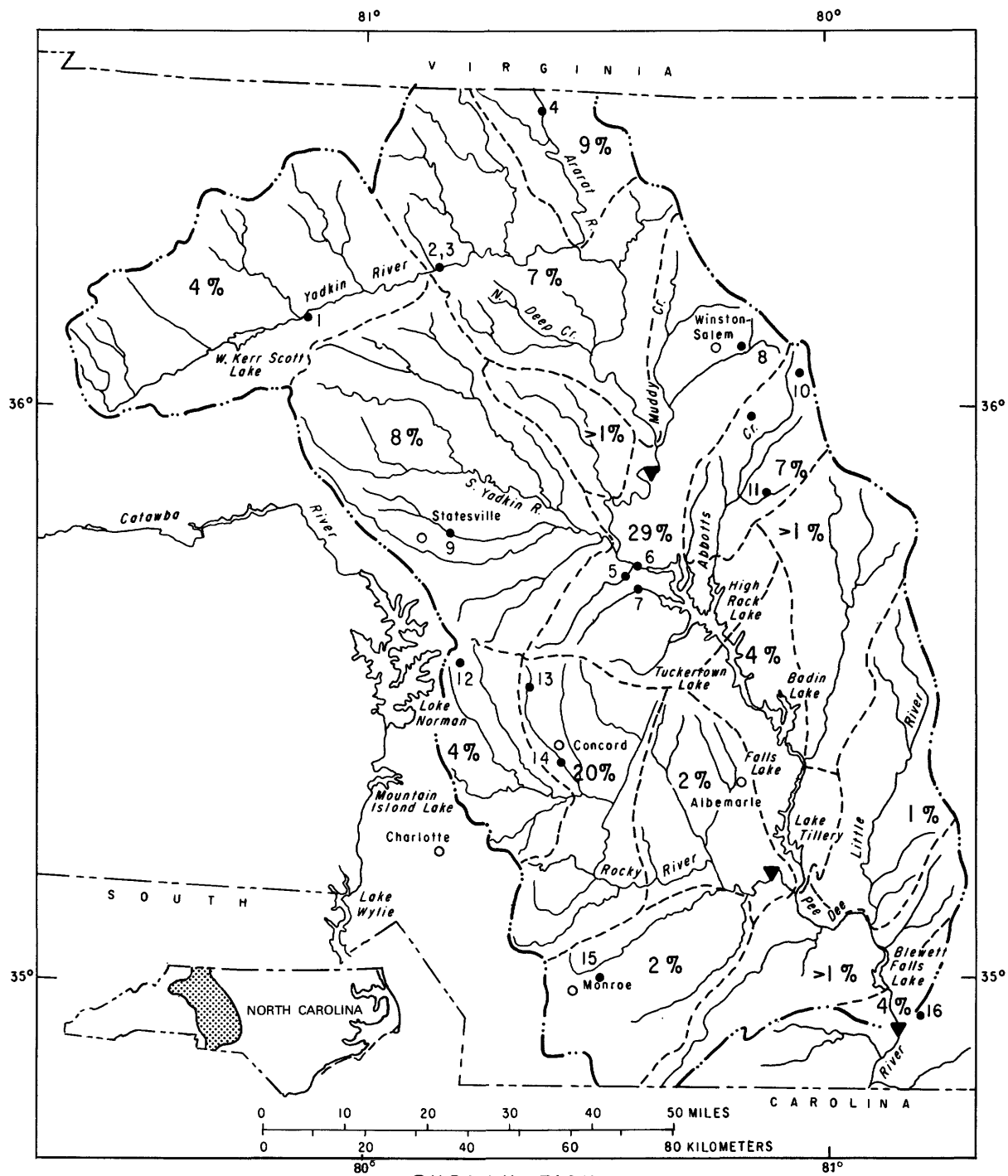
——··—— Basin boundary

EXPLANATION

▼   Water-quality sampling station

4 %   Percentage of total municipal and industral waste-water discharges

I●   Effluent point sources (number of source listed in table I.)

----   Subbasin boundary

—··—   Basin boundary

Figure 3. The percentage of total industrial and municipal point-source waste-water discharge originating in each Yadkin-Pee Dee subbasin.

DATA COLLECTION

The U.S. Geological Survey has regularly monitored streamflow at 29 stations in the basin. Monitoring has been continuous for 30 years or more at nine of these stations. Water-quality data have been collected regularly at three stations: (1) Yadkin River at Yadkin College (02116500), (2) Pee Dee River near Rockingham (02129000), and (3) Rocky River near Norwood (02126000). The Yadkin College station gages 2,280 square miles of the basin; the Norwood station gages 1,370 mi^2; and the Rockingham station gages 6,870 mi^2 of the basin. The locations of the stations are given in figure 1, and the period of record is illustrated in figure 4.

The station at Yadkin College provides information about the segment of the Yadkin River upstream from the extensive lake system. This station is located downstream from Winston-Salem, a city of over 130,000 (U.S. Bureau of the Census, 1971). The Yadkin College station is part of the National Stream Quality Accounting Network (NASQAN) of the U.S. Geological Survey (Ficke and Hawkinson, 1975).

Chemical data for the Yadkin River have been collected at Yadkin College during the 1944, 1951, and 1956-80 water years (a water year begins on October 1 and ends September 30). Samples at the three Yadkin-Pee Dee stations prior to 1973 were analyzed for major ions, dissolved solids, hardness, specific conductance, and pH. Daily sediment samples have been collected at Yadkin College since 1950. A continuous-recording water-quality monitor was used to measure dissolved oxygen, specific conductance, temperature, and pH from 1971 to 1976 at Yadkin College.

The station on the Rocky River near Norwood provides water-quality data for the Rocky River, a major tributary to the Yadkin-Pee Dee, at a location just before it enters the Pee Dee River. Chemical data for the Rocky River have been collected near Norwood for the 1948, 1956-58, 1968-73, and 1977-80 water years. Chemical data for the water years 1959-67 were collected at Gaddy, near Norwood. The Gaddy station was approximately 2 mi upstream from the Norwood gaging station. For the purposes of this report, the Gaddy and Norwood station data will be merged and treated as one station, hereafter referred to as Rocky River near Norwood.

Chemical data for the Pee Dee River have been collected near Rockingham during the 1908, 1947-48, and the 1958-80 water years. This station is also part of the NASQAN.

An expanded program of water-quality data collection at the three Yadkin-Pee Dee stations began in

EXPLANATION

Daily discharge record   Chemical data collected
Daily specific conductance data   Sediment data collected
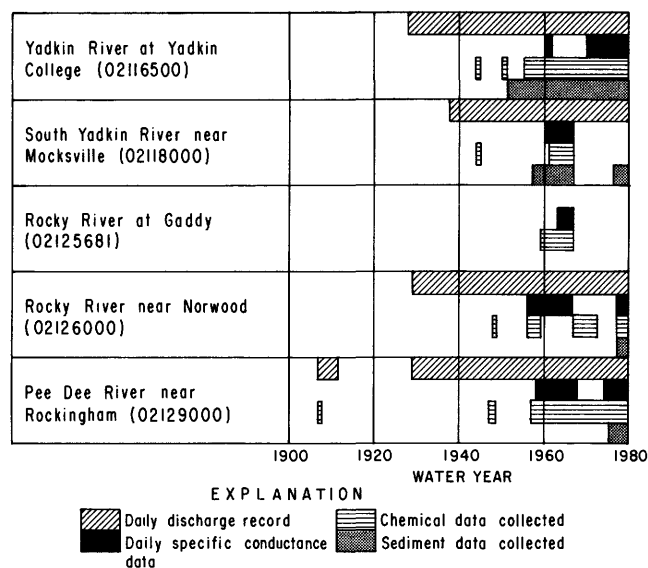
Figure 4. Period of record for water-quality sample collection and discharge measurement at five stations in the Yadkin-Pee Dee River basin.

1973. Periodic measurements of organic substances, nutrients, toxic materials, metals, and biota are now also part of the ongoing study.

WATER-QUALITY VARIATION

Water quality of rivers varies with changing environmental conditions. Seasonal variation is caused by changing temperature, discharge, photo-period, and many other associated environmental variables. Diel variation in water quality is produced by the many small environmental changes that occur during the day-night cycle. In addition, dramatic changes can result from rapidly occurring events, like a flood, or a malfunction at a waste-water treatment plant.

In light of the range of variation in ambient water quality observed in streams, the evaluation of water quality presented in this report is referenced, when appropriate, to the frequency of occurrence of the sample concentrations or values. In addition, water-quality criteria set by the U.S. Environmental Protection Agency (1976) are used to indicate the relevance of the water quality to various uses of the water. Only relatively recent (1970-78) water-quality data are used in this evaluation to better reflect the current status of the water quality of the Yadkin-Pee Dee River system.

Physical Characteristics

Dissolved Oxygen and Water Temperature

River-water temperature mimics air temperature in a general manner, although the heat storage capacity of water prevents rapid temperature variation, and causes a lag in the response to air temperature. The comparison given in figure 5 between daily average air temperature and daily average river-water temperature at Yadkin College demonstrates the response of the water to variations in air temperature for 1977. A summary of water temperature statistics appears with statistics for other physical characteristics in table 2.

Another example of the interplay between air and water temperatures is given in figure 6. A storm near the Yadkin College station in January 1975 was associated with a dramatic drop in air temperature. However, the water temperature variation is much less extreme, illustrating the damping effect of the heat-storage capacity of water.

The solubility of oxygen in water varies inversely with water temperature, so that the saturation concentration of oxygen in water is greater in cold water than it is in warm water. Thus, the lowest dissolved-oxygen concentrations will occur during summer months when the water is warmest. U.S. Environmental Protection Agency (1976) criteria purport 5.0 milligrams of oxygen per liter of water to be a minimum for the maintenance of a varied fish population. Although lesser dissolved-oxygen concentrations do not necessarily cause fishkills, particularly if the phenomenon is short-lived, oxygen-depleted waters encourage more tolerant fish species and lessen species diversity among the fish population in the stream.

Plots of water temperature versus dissolved-oxygen concentration for Yadkin College, Norwood, and Rockingham stations are given in figure 7. These data represent daytime dissolved-oxygen concentrations because all sampling was done during the day (for the difference between day and night dissolved-oxygen concentrations see the section, "Diel Variations"). Daytime dissolved-oxygen concentrations are often higher than at night because during the day, photosynthesis of plants in the stream produces more oxygen than is consumed by respiration and decomposition of these plants. At night, respiration and decomposition continue to consume oxygen, lowering daytime dissolved oxygen levels. Neither Yadkin College nor Norwood show serious oxygen depletion, although the observed concentrations are often below saturation levels. The mean dissolved-oxygen concentration near Rockingham is the lowest of the three stations (table 2), and the plot

of dissolved oxygen versus temperature (fig. 7) shows that a substantial number of sample concentrations fell well below oxygen-saturation levels. Several sample concentrations fell below the U.S. Environmental Protection Agency (1976) minimum criterion for dissolved oxygen. The Rockingham station lies only 8 mi downstream of Blewett Falls Dam, the terminus of the series of lakes and dams on the Yadkin-Pee Dee River system. These large lakes strongly affect the physical conditions of the Pee Dee River near Rockingham. The low dissolved-oxygen concentrations often found at the Rockingham station are largely the effect of discharge of water with lower levels of dissolved oxygen from the bottom of Blewett Falls Lake.

Large impoundments tend to limit the interchange of gases between the atmosphere and water by decreasing the surface-to-volume ratio and by lowering turbulence. Furthermore, eutrophic lakes, such as High Rock Lake (Weiss and Kuenzler, 1976), can accelerate the depletion of dissolved oxygen as algae die and become oxygen-demanding decaying matter.

pH

The slight variation present among the pH measurements at the three stations is evident from table 2. Samples collected at Norwood are less acidic than either Rockingham or Yadkin College samples. Yadkin College samples are usually the most acidic. The river water at all stations is suitable for domestic water supply, falling within the pH range recommended by the U.S. Evironmental Protection Agency (1976). The more stringent range of pH values recommended for the protection of fish (pH 6.5–9.0) is not met at Norwood in 20 percent of the samples, at Rockingham in about 30 percent of the samples, and in 50 percent of the samples from Yadkin College. Although slightly acidic waters may not be in themselves toxic to fish, the toxicity of other substances can be increased under acidic conditions.

Suspended Sediment

Suspended sediment includes all material, organic and inorganic, held in suspension by the streamflow. The muddiness of North Carolina rivers due to this suspended load was not characteristic of these rivers in their pristine state as described by early explorers of the State (North Carolina Department of Natural Resources and Community Development, 1979). Causes of increased suspended sediment in the Yadkin-Pee Dee basin include agricultural practices, urban storm run-
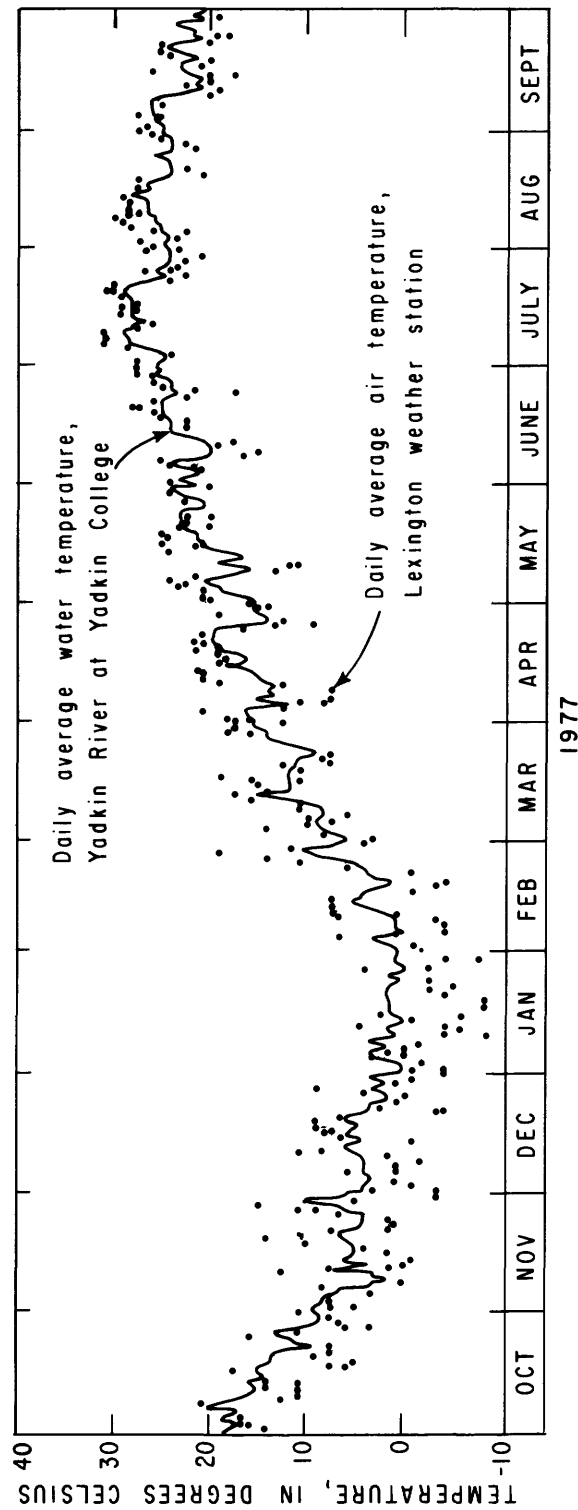
Figure 5. Air and water temperatures versus time for water year 1977 for the Yadkin River at Yadkin College.
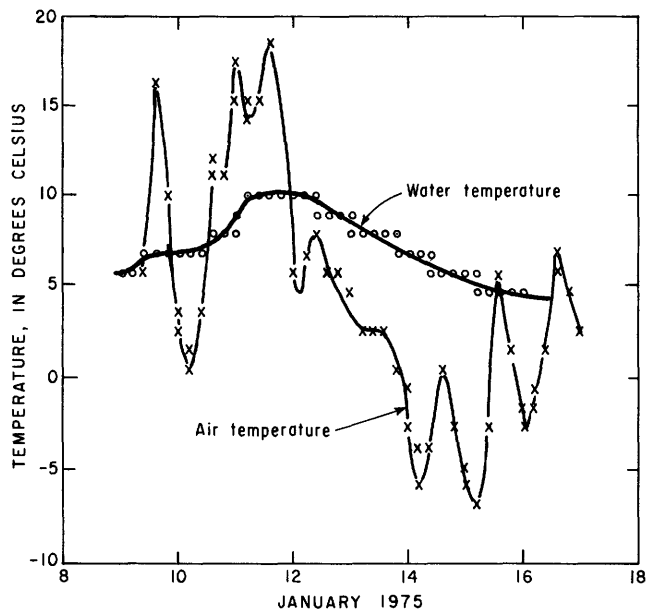
Figure 6. Air and water temperatures during the flood of January 9-18, 1975, on the Yadkin River at Yadkin College.

off, atmospheric fallout, construction practices, and waste-water discharge.

Stream sediment is associated with a number of environmental problems. Sedimentation affects the storage capacity and, thereby, the long-term usefulness of lakes. Contaminants, especially nutrients, pesticides, and some metals, tend to be concentrated in sediment. Sediment can choke or bury aquatic fauna and decrease the penetration of sunlight which in turn decreases photosynthetic activity. The net biological affect of excessive sediment is a reduction in the abundance and variety of life in the stream or lake. Finally, an unquantifiable amount of aesthetic damage is done to streams and lakes choked by sediment.

Suspended sediment is the most significant water-quality problem in the Yadkin-Pee Dee River system. At Yadkin College, high suspended-sediment concentrations are typically associated with the initial peak discharge of floods. The double-peaked hydrograph and suspended-sediment concentration curve of a storm which occurred on January 9-17, 1975, are given in figure 8. In this event, sediment concentration peaks shortly before the discharge peaks. An initial flushing effect, whereby easily erodable material is removed by the stream, causes all subsequent peaks on the sediment-concentration curve to be lower, even though the subsequent discharge peak is higher than the first. A double-peaked sediment-concentration curve associated

with each discharge peak often occurs at Yadkin College. This multiple peak is probably due to a superimposition of the peak of sediment concentration flushed from the Muddy Creek tributary over the sediment-concentration peak of the Yadkin River itself. The first peak corresponds to the rapid response of Muddy Creek, and the second peak corresponds to the slower-responding Yadkin River.

Suspended-sediment concentrations versus discharge for samples collected at Yadkin College are plotted in figure 9, for Norwood in figure 10, and for Rockingham in figure 11. The relation between suspended-sediment concentrations and discharge for Yadkin College has been broken down into two lines. At high discharges, the plot for Yadkin College flattens out, indicating possibly that above approximately 7,500 ft^3/s the sediment supply potential of the catchment area upstream from Yadkin College has been almost reached. The correlation between suspended-sediment concentration and discharge is greatest at Norwood (correlation coefficient; $r = 0.89$), intermediate at Yadkin College ($r = 0.78$), and least at Rockingham ($r = 0.56$). These results indicate that suspended-sediment concentrations in the Pee Dee River near Rockingham are less dependent on discharge than are the suspended-sediment concentrations at Yadkin College and Norwood. Flow regulation of the lakes upstream from Rockingham and the settling of sediments in the lakes may be the cause of the difference in these relations. In addition, the data for the Pee Dee River near Rockingham show two distinct clusters, one at low discharge (300-1,000 ft^3/s) and one at high discharge (7,000-30,000 ft^3/s). For each cluster, the value of r would be very small. This clustering is probably due to flow regulation.

Sediment Transport

Annual sediment transport, the total annual load of suspended sediment in a stream flowing past some location along the stream, was calculated for the Yadkin River at Yadkin College, the South Yadkin River near Mocksville, Rocky River near Norwood, and the Pee Dee River near Rockingham. Methods described by Miller (1951) and Colby (1956) were used in this analysis. Sediment transport results for water years 1974-78 are given in table 3. With the exception of Rockingham, total sediment transport is roughly proportional to drainage area. Sediment yield is greatest at Yadkin College and least at Rockingham.

The sediment-transport calculations allow an estimation of the amount of sediment deposited each year throughout the series of lakes. In this estimation, a specific weight of 64 lb/ft^3 (Reeder, 1973) was used to

Table 2. Summary statistics of physical characteristics of the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham (water years 1970–78, unless indicated otherwise)

Physical parameter	Yadkin River at Yadkin College			Rocky River near Norwood			Pee Dee River near Rockingham			U.S. E.P.A. Criteria (1976)
	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	
Discharge[2] at time of sampling (ft³/s)	4,800 (3,800–5,800)	950–41,100	135	5,800 (3,100–8,600)	69–29,100	40	10,300 (8,600–12,000)	309–57,600	97	
Discharge daily values (ft³/s)	2,970	177–80,200	350 yr[3]	1,330	17–10,500	349 yr[3]	7,997	58–276,000	356 yr[3]	
Temperature (°C)	16.4 (15.3–17.5)	2.0–28.0	141	14.6 (12.0–17.2)	0.5–33.0	45	18.5 (17.4–19.7)	2.0–30.0	151	
Dissolved oxygen (mg/L)	8.9 (8.6–9.2)	2.1–13.7	128	10.0 (9.2–10.7)	6.0–15.1	42	8.3 (7.9–8.7)	3.8–16.2	134	Freshwater aquatic life: 5.0 mg/L minimum.
pH[4]	6.4 (6.4–6.5)	5.7–7.5	94	6.7 (6.4–7.3)	5.5–8.0	39	6.5 (6.3–6.6)	5.3–8.0	156	Domestic water supply 5.9 pH units. Freshwater aquatic life: 6.5–9 pH units.
Suspended sediment (mg/L)	158 (147–169)	7.0–1,670	1,461	149 (91–207)	3–538	29	33 (26–40)	7–147	53	
Turbidity (JTU)[5]	31.5 (–)	9.0–57.0	4	62.2 (–)	5.0–93.0	2	27.2 (19.6–34.8)	1.0–120.0	49	

[1] The 95-percent confidence interval means that with 95-percent confidence, we estimate the mean to fall within the given range (in parentheses), assuming that the number of samples is large enough, and that the samples are randomly collected.
[2] Discharge measurements made during water-quality sampling, used in all water-quality calculations.
[3] Years given are period of record.
[4] Means are calculated from mean hydrogen-ion concentration.
[5] JTU is Jackson Turbidity Unit.
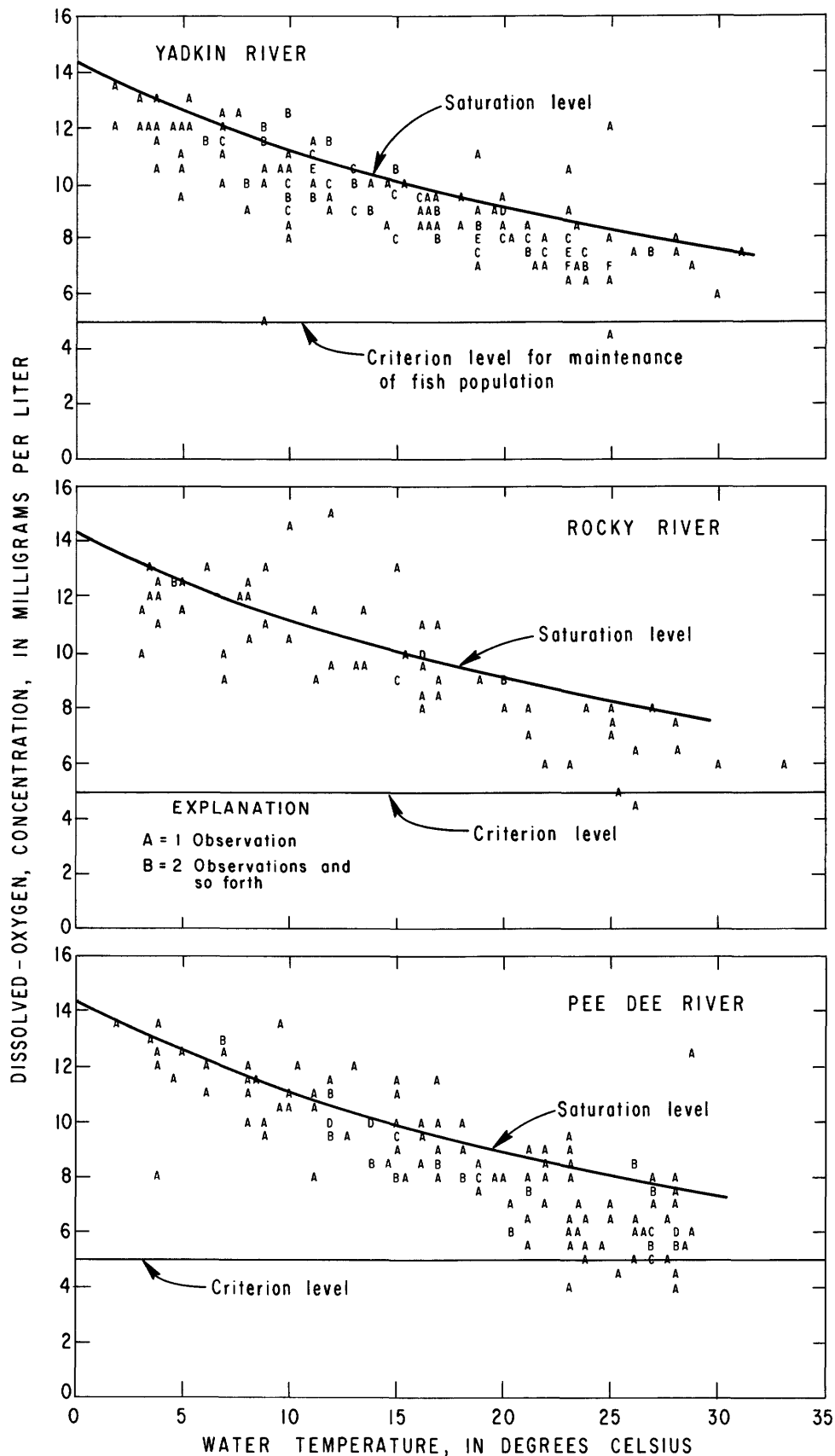
Figure 7. Dissolved-oxygen concentration versus water temperature for water years 1970–78 at the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham.
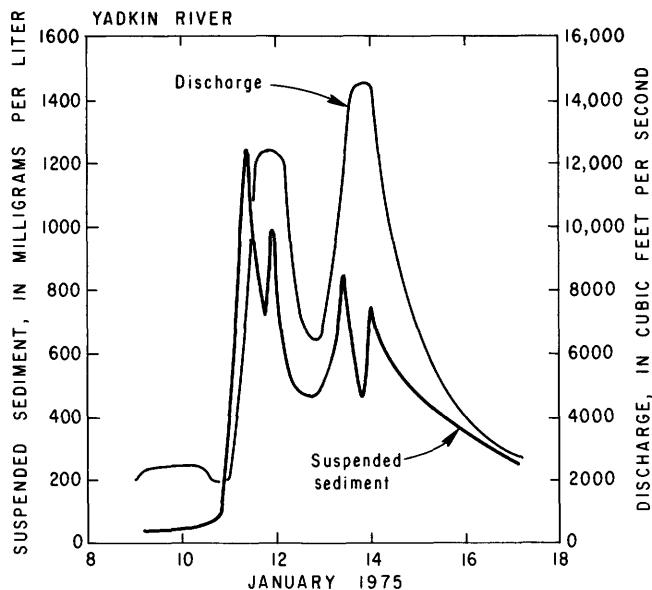
Figure 8. Suspended-sediment concentration and discharge for the Yadkin River at Yadkin College through a storm event occurring January 9-17, 1975.

Figure 9. Suspended-sediment concentration versus discharge for the 1974-78 water years at the Yadkin River at Yadkin College (r= correlation coefficient).

calculate sediment volumes. The estimation for each water year is given in table 3, but each must be interpreted as a minimum value because the sediment transported into the lakes from several small tributaries has not been taken into account, and no estimate of bedload sediment or sediment carried in sheet runoff directly into the reservoirs has been made. The suspended-sediment input, estimated from Yadkin College, Mocksville, and Norwood data, is not matched by the output at Rockingham. The difference between the input and output of sediment to and from the lake system represents the sediment deposited in the lakes. An average of approximately 1 million tons of sediment is deposited annually in the lakes by the three streams. This represents around 800 acre-ft/yr or approximately 0.10 percent the total volume of the lakes. However, of the total calculated input of lake sediment given in table 3, between 68 percent and 92 percent is derived from the upper Yadkin River and the South Yadkin River, both of which drain directly into High Rock Lake. This lake, therefore, is the most heavily loaded by sediment. About 27 percent of the sediment that enters the lake system is carried past the Rockingham station. That is, the Yadkin-Pee Dee lakes capture at least 73 percent of the sediment that enters them.

The estimated sediment volumes presented in table 3 are somewhat lower than the values reported in the Yadkin-Pee Dee River basin erosion and sediment inventory (U.S. Department of Agriculture, 1979). This is not surprising because the sediment inventory used a

procedure employing soils, erosion, and land-use information that gives a more general sediment-transport estimation than the simple mass balance described here.

Turbidity

There are very little turbidity data for the Yadkin College and Norwood stations, but the data are more complete for Rockingham, as given in table 2. All stations show a wide range of turbidity values, with relatively high values at Norwood and Rockingham. For the period of 1970-78, over 50 percent of the Rockingham samples are greater than 25 Jackson Turbidity Units. High turbidity values reduce sunlight penetration, which may limit algal growth capacity.

Diel Variations

The physical conditions of a body of water vary during the day-to-night cycle. Heat and sunlight alter water chemistry and properties either directly or through waterborne agents, such as algae. Water temperature, dissolved-oxygen concentration, pH, and specific conductance are common parameters known to show diel effects (Livingstone, 1963; Hem, 1970). The diel behavior of these four physical parameters for an idealized system are briefly summarized below:
1. Water temperature increases during daylight hours. Because the buffered response of water temperature to
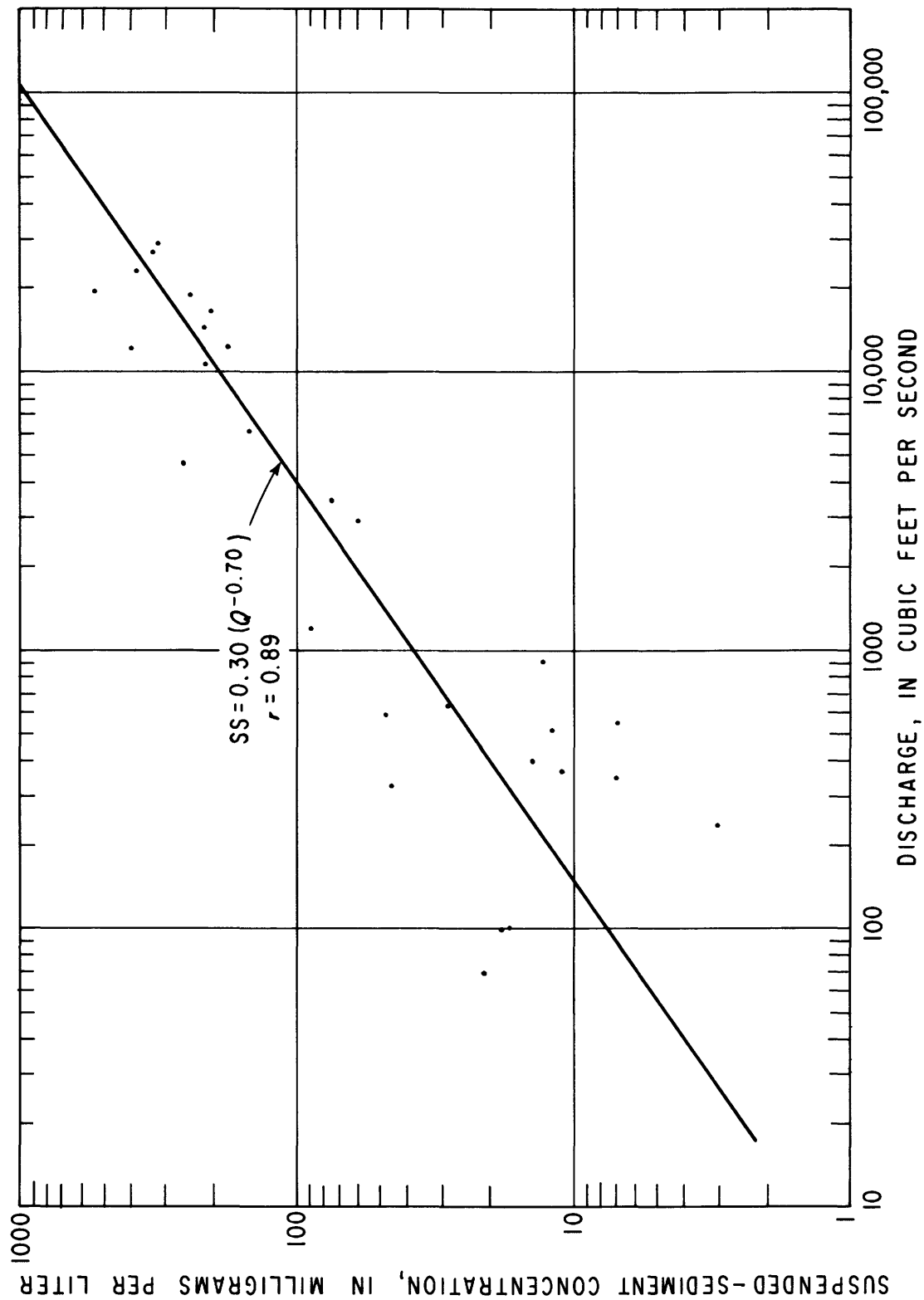
Figure 10. Suspended-sediment concentration (SS) versus discharge (Q) for the 1974–78 water years at the Rocky River near Norwood (r = correlation coefficient).

$$SS = 0.30\,(Q^{-0.70})$$
$$r = 0.89$$
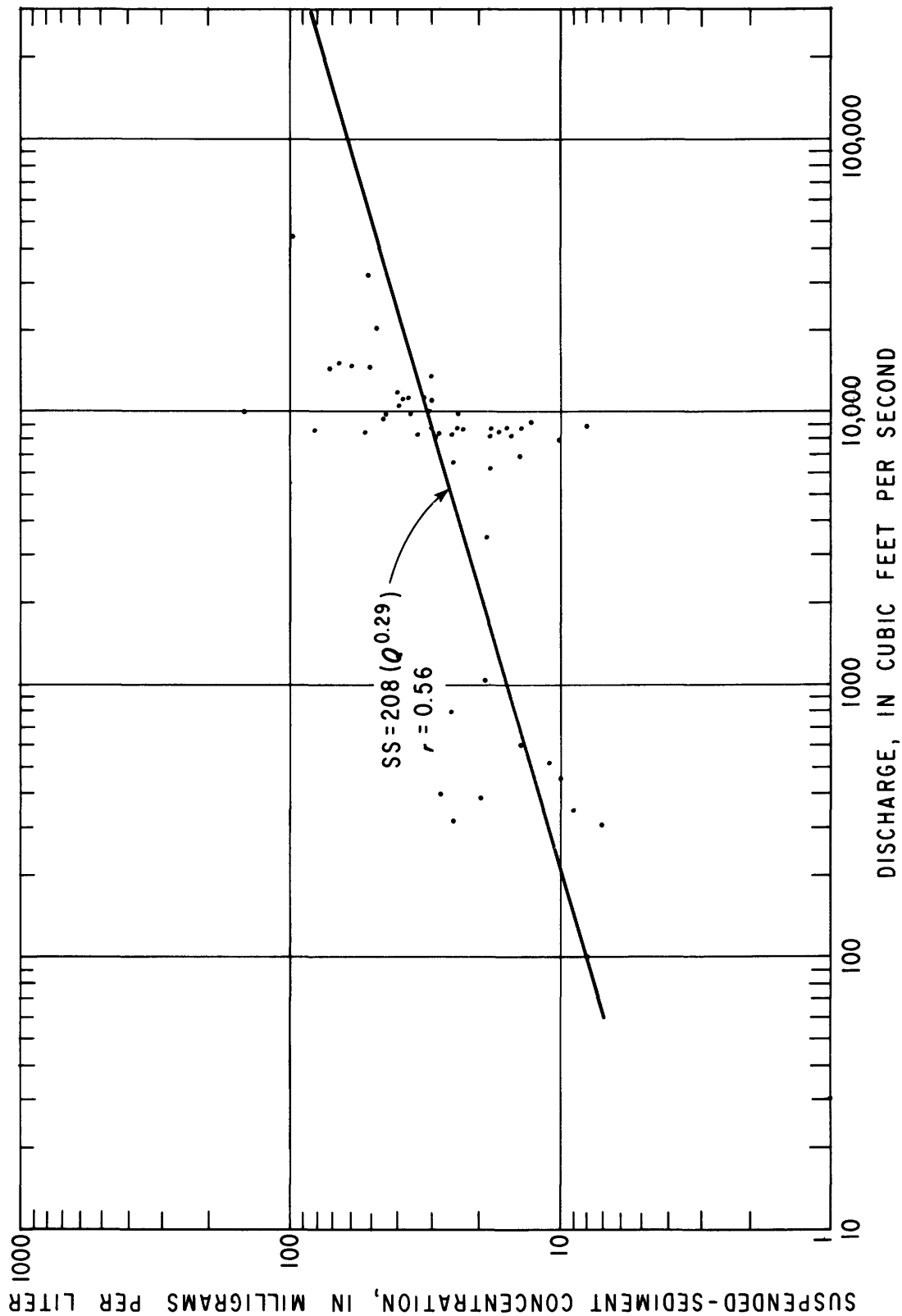
Figure 11. Suspended-sediment concentration (SS) versus discharge (Q) for the 1974–78 water years at the Pee Dee River near Rockingham (r= correlation coefficient).

$$SS = 208 \, (Q^{0.29})$$
$$r = 0.56$$

Table 3. Annual suspended-sediment transport and estimates of minimum sediment deposition in the Yadkin-Pee Dee lakes

Water year	Station	Mean annual discharge (ft³/s)	Annual sediment transport (tons)	Sediment remaining in lakes: Yadkin College + Mocksville + Norwood − Rockingham =			
				Tons	Acre-feet	Percentage of lake volume	Percentage
1974	Yadkin College	4,000	1,462,000				
	Mocksville	404	44,000	1,273,000	974	0.12	22
	Norwood	1,218	130,000				
	Rockingham	9,516	363,000				
1975	Yadkin College	3,919	1,522,000				
	Mocksville	487	180,000	1,558,000	1,192	.15	28
	Norwood	2,492	453,000				
	Rockingham	13,000	597,000				
1976	Yadkin College	2,711	714,000				
	Mocksville	273	15,000	590,000	451	.06	26
	Norwood	868	73,000				
	Rockingham	6,683	212,000				
1977	Yadkin College	2,743	608,000				
	Mocksville	312	53,000	622,000	476	.06	35
	Norwood	1,661	302,000				
	Rockingham	8,428	341,000				
1978	Yadkin College	3,840	1,423,000				
	Mocksville	457	122,000	1,408,000	1,078	.13	25
	Norwood	1,791	324,000				
	Rockingham	10,630	461,000				
Mean				1,090,200	834	.10	27

changes in air temperature, the maximum daily water temperature is generally lagged behind maximum daily air temperature.

2. Specific conductance, a measure of the ability of water to conduct electric current, responds to an increase or decrease in the number of ions dissolved in the water. Diel increases or decreases in ionic content of the water would, therefore, cause a diel change in specific conductance. Specific conductance will be discussed in detail in the section on major dissolved substances because specific conductance is usually used as an indirect measure of the relative amounts of chemical ions in solution.

3. Diel dissolved-oxygen concentrations are affected by temperature, reaeration, photosynthesis, plant and animal respiration, and decomposition. Photosynthesis produces oxygen and adds it to the water. Respiration by plants and animals consumes oxygen. Oxygen-demanding wastes and dead organisms consume oxygen as they decay. Thus, the diel pattern of oxygen in a stream would show increasing oxygen concentrations during daylight hours as photosynthetic organisms are actively adding oxygen to the water. Respiration and

decay are also occurring, but photosynthesis produces more oxygen than is consumed by these processes. At night, photosynthesis ceases, but respiration and decay continue so dissolved-oxygen concentrations fall. Superimposed on this pattern is the effect of increasing daytime water temperatures, causing the saturation point to be lowered. All the while, turbulence adds oxygen when concentrations are below saturation and removes oxygen when ambient concentrations are greater than saturation. In sum, the usual pattern is one of increasing dissolved-oxygen concentrations in the daytime until a peak is reached in midafternoon, and declining concentrations through the night.

4. The pH of an uncontaminated water body is chiefly affected by the concentration of dissolved CO_2. Increased CO_2 concentration should, all else being equal, increase the carbonic acid production in water which in turn decreases the pH. Conversely, reducing the CO_2 concentration should increase pH. The CO_2 concentration is itself a function of photosynthesis and water temperature. Green plants and algae consume CO_2 during photosynthesis and incorporate it into their cells. Thus, during daylight hours dissolved CO_2, and thereby

acidity, should decrease causing an increase in pH. Respiration during hours of darkness produces the opposite effect, and pH decreases. If photosynthesis is not of major importance in a water body, pH may show no apparent diel effect; or, if CO_2 concentration is near saturation, temperature may be the major control on CO_2 concentration and pH. Higher water temperatures result in lower CO_2 solubility. Cool waters saturated with respect to CO_2 can become supersaturated with daytime heating. The acid-producing reaction will proceed and lower the pH. A fall in pH with rising afternoon temperatures should be expected under these conditions.

Observed Diel Patterns

A continuous monitor record for July 18–19, 1976, of water level, pH, water temperature, dissolved oxygen, and specific conductance for the Yadkin River at Yadkin College is shown in figure 12. The patterns exemplify the expected behavior of the river's physical properties for summer months. Dissolved oxygen concentrations typically climb during daylight hours, peaking at about 6:00 p.m. Water temperature increases a few degrees each afternoon. The consumption of CO_2 by photosynthesis causes decreased acidity, and pH shows a slight daily rise. Specific conductance increases dielly in response possibly to ionic changes occurring in, the stream as a result of temperature changes. Similar patterns can be recognized in spring and fall.

In late fall, a small alteration of the summer pattern is evident. Daily temperature increases are accompanied by slight decreases in pH. The difference rests in the lesser importance of photosynthesis in late fall than midsummer.

Diel behavior of physical properties may be obscured by rapid changes in streamflows. The specific effects of any storm event may vary, but a recurrent pattern, unlike the normal diel effects, is given in figure 13. On May 16, 1976, temperature appears to behave normally although discharge, represented by gage height, increases during the day, then peaks in the evening. Most notable is the briefly depressed dissolved-oxygen concentration and increased specific-conductance readings accompanying the initial rise of stage at the gage. The slug of oxygen-depleted water represents the flushing of oxygen-demanding litter from streambeds and tributaries as well as material accumulated on the land washed into the streams by runoff. Similiar observations of dissolved-oxygen sags associated with flood events have been reported for the Neuse River, N.C. (Triangle J Council of Governments, 1976). During the peak stage, dissolved-oxygen concentrations are

relatively high. This is probably due to the input of aerated rainwater and increased instream turbulence and aeration. The increased specific conductance indicates this slug of water contained a greater concentration of dissolved material than the normal low-flow concentration. The increase is followed by a depression of specific conductance resulting from dilution of dissolved constituents by floodflow. The pH appears to decrease through the rise of river stage, possibly in response to dissolved constituents, input of humic and organic acids, or acid in storm-water runoff.

The flushing of streams and the washing of their bed and bank material can cause dramatic changes in stream conditions. An extreme case occurred on August 8, 1976, when a mild storm followed a month of dry weather in the upper Yadkin River basin. The result was a fishkill downstream from Muddy Creek near Winston-Salem to High Rock Lake. A plot of the event (fig. 14) shows a slug of oxygen-depleted water reaching Yadkin College, accompanied by other physical changes often related to stormflows. The environmental damage was caused by floodflow scouring of oxygen-demanding sediments from the streambed of Muddy Creek. The sediments had accumulated during dry weather primarily from solids discharged to the stream from the Archie Elledge Waste-Water Treatment Plant (North Carolina Department of Natural and Economic Resources, 1976a).

Summary plots of diel effects for several periods, each characterized by the relatively steady stage of the Yadkin River at Yadkin College, are given in figures 15, 16, and 17. Over the time intervals given in the plots, the readings from the continuous monitor were averaged for each hour and then were plotted by hour. A plot of similarly derived hourly temperature is superimposed on each plot. The diel effects cause very small variations, but the daily patterns are distinctive.

A dissolved-oxygen plot for a spring interval (April 12–30, 1975) is given in figure 15. Here, a midday peak of dissolved-oxygen concentration is probably due to free oxygen produced by photosynthesis. The evening decline in dissolved oxygen is probably due to oxygen consumption by animal and plant respiration. During February 1–19 and 27–29, 1976 (fig. 17), and June 20–24, 1975 (fig. 16), storms apparently cleared the river of much of its riverborne algae, and diel plots show dissolved-oxygen concentrations to be greatly affected by temperature, showing greater concentrations in cool early morning water and lesser concentrations in warmer afternoon water.
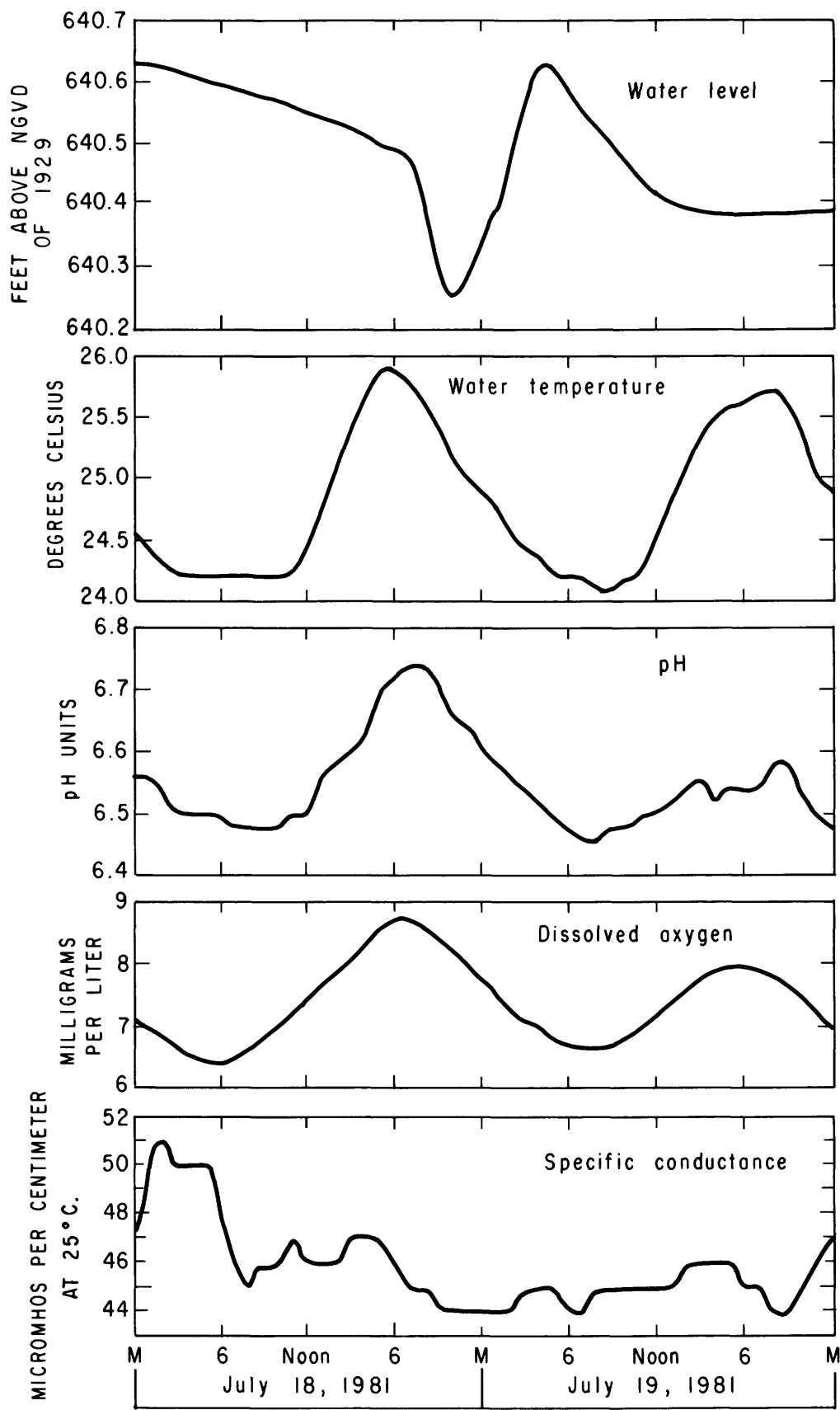
Figure 12. Continuous monitor plots of water level, dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College, July 18–19, 1976.
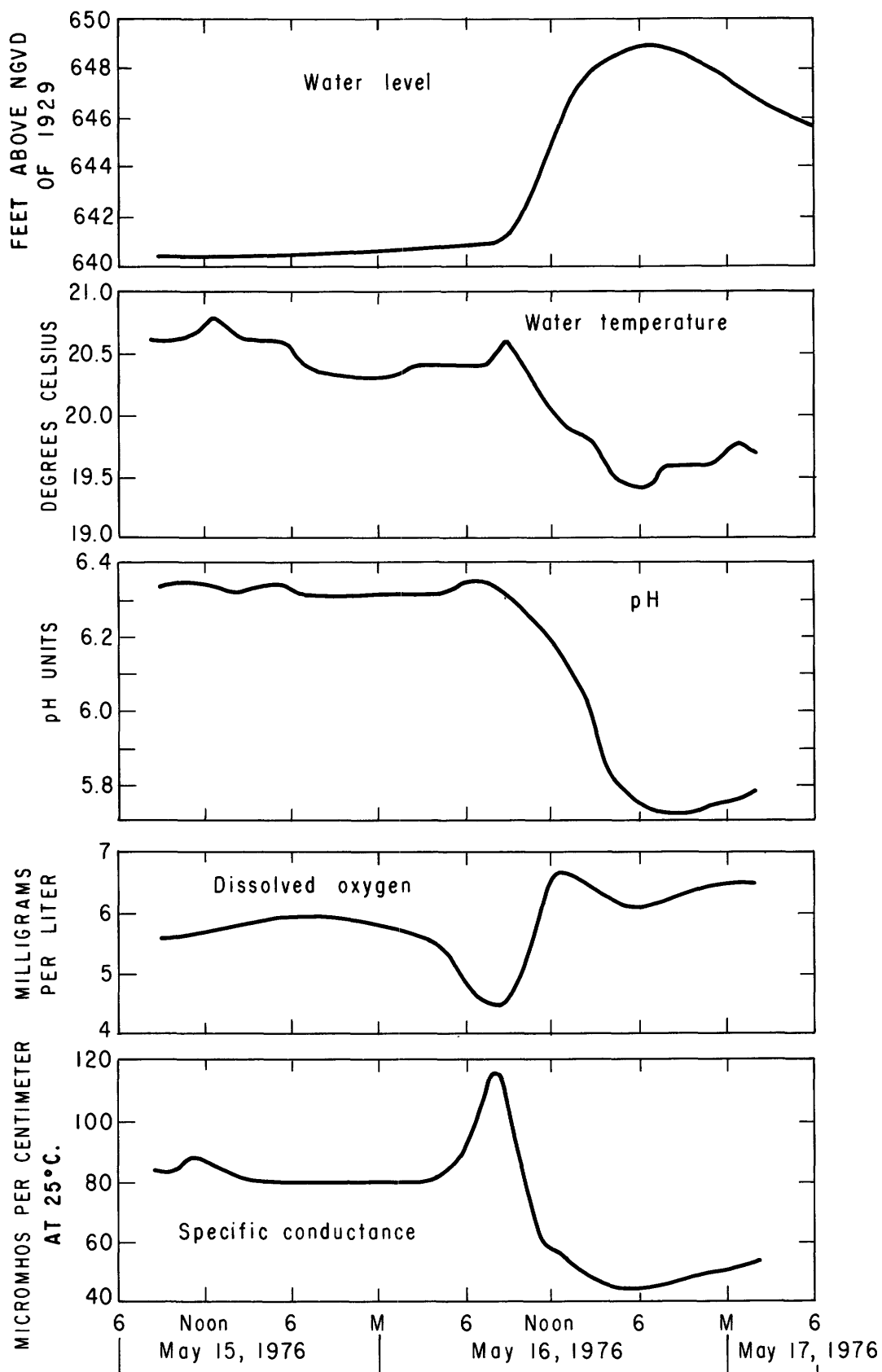
Figure 13. Continuous monitor plots of water level, dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College, May 15-16, 1976.
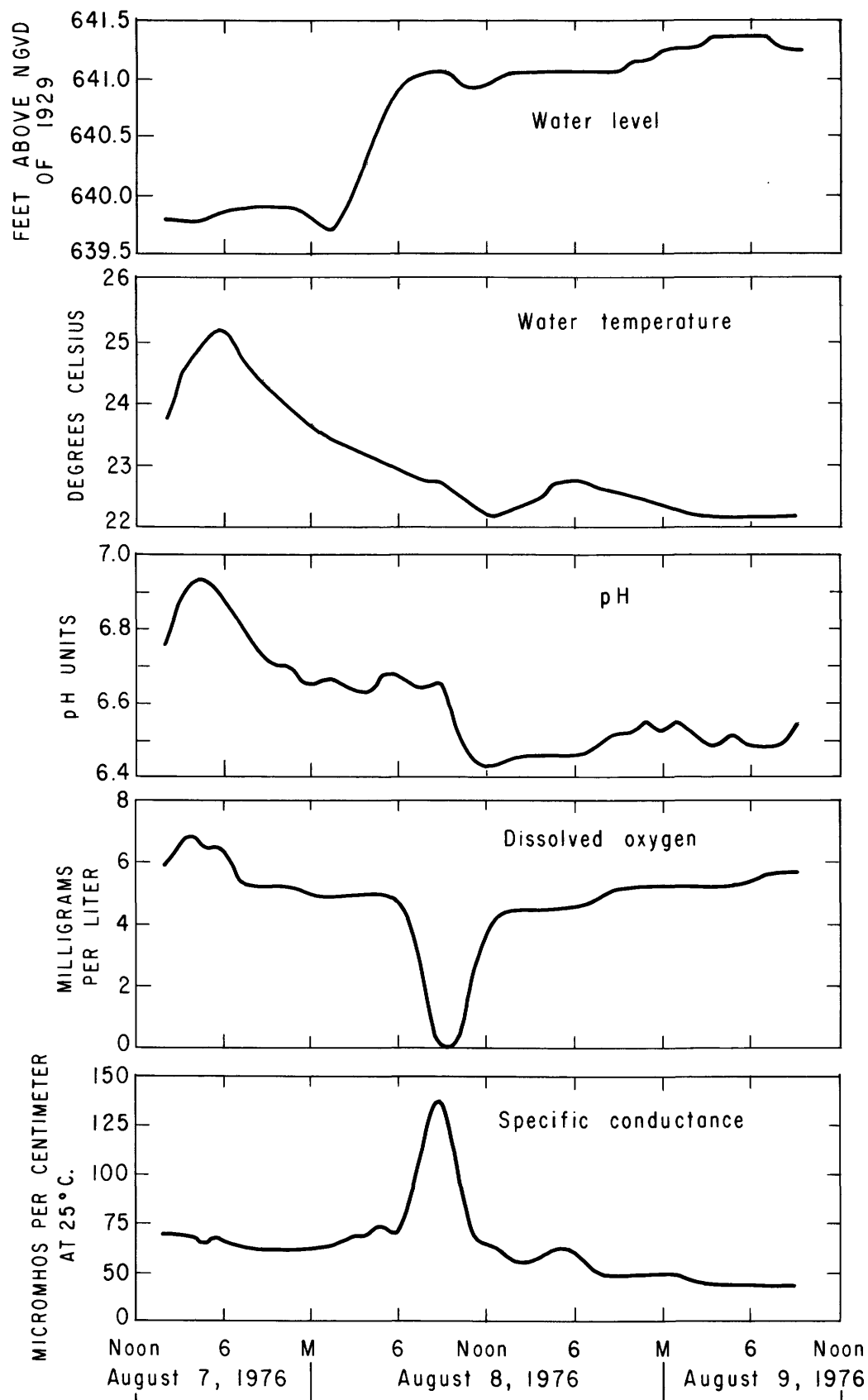
Figure 14. Continuous monitor plots of water level, dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College, August 8, 1976.
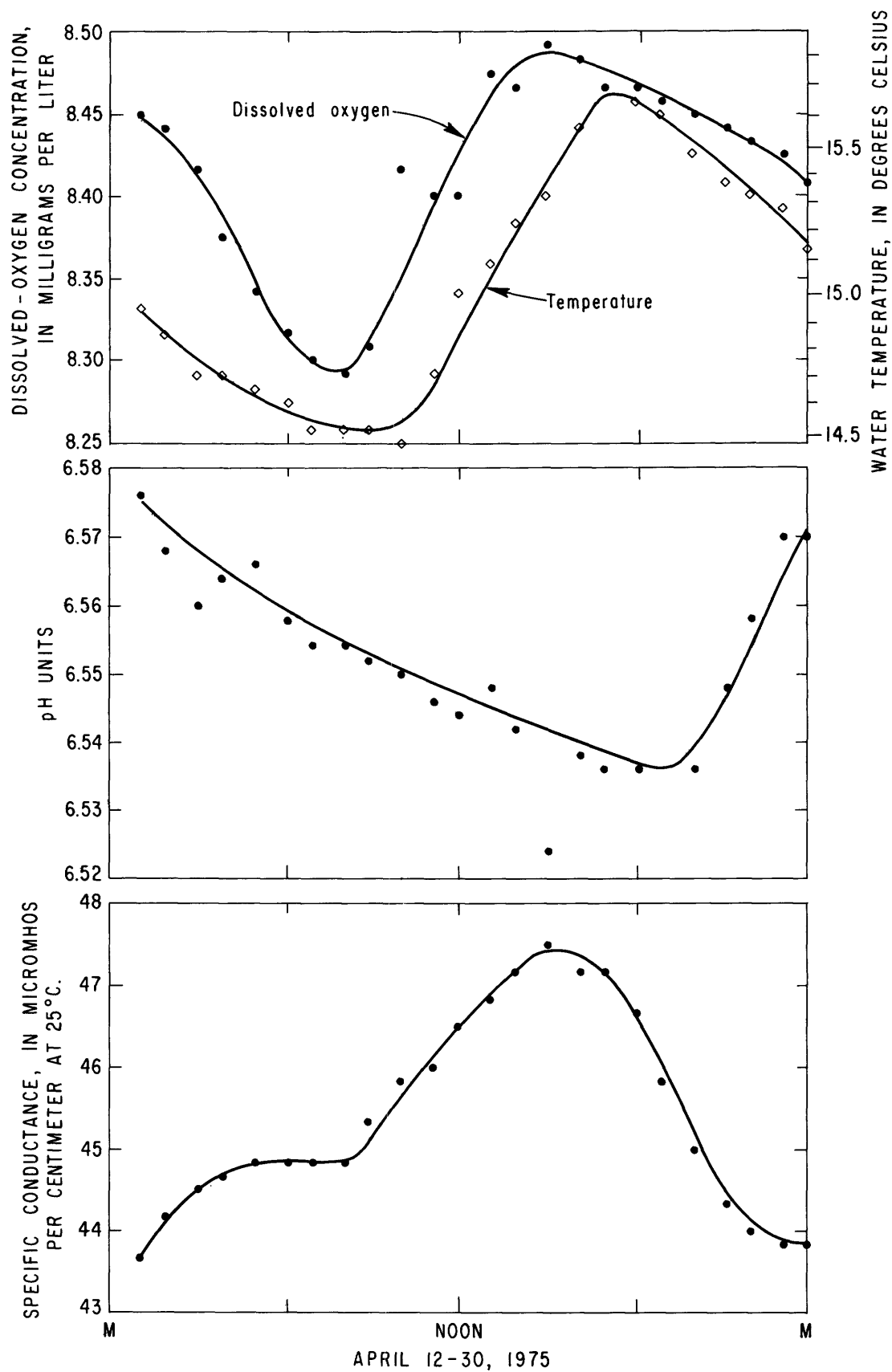
Figure 15. Mean hourly dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College during April 12–30, 1975.
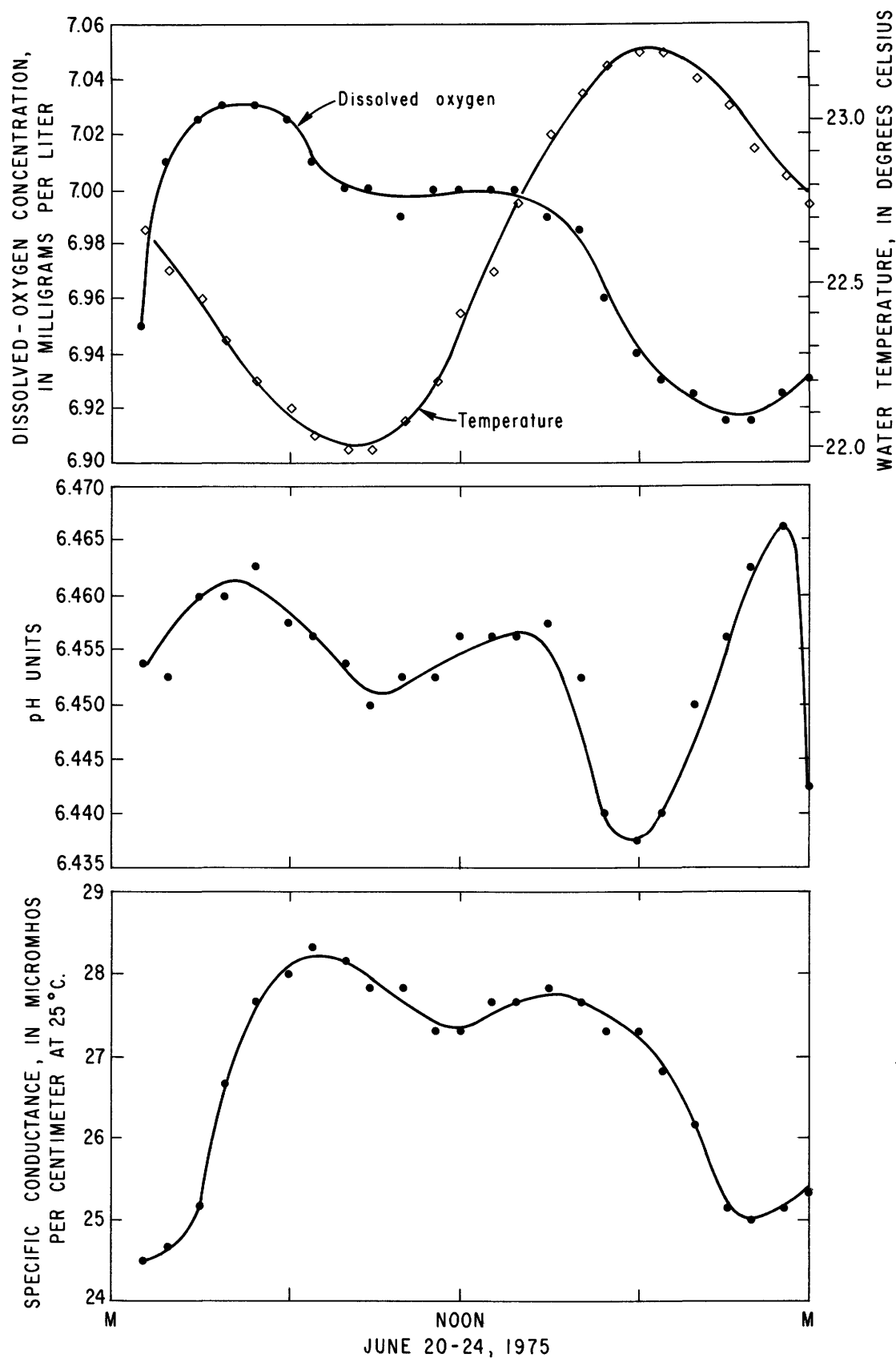
Figure 16. Mean hourly dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College during June 20-24, 1975.
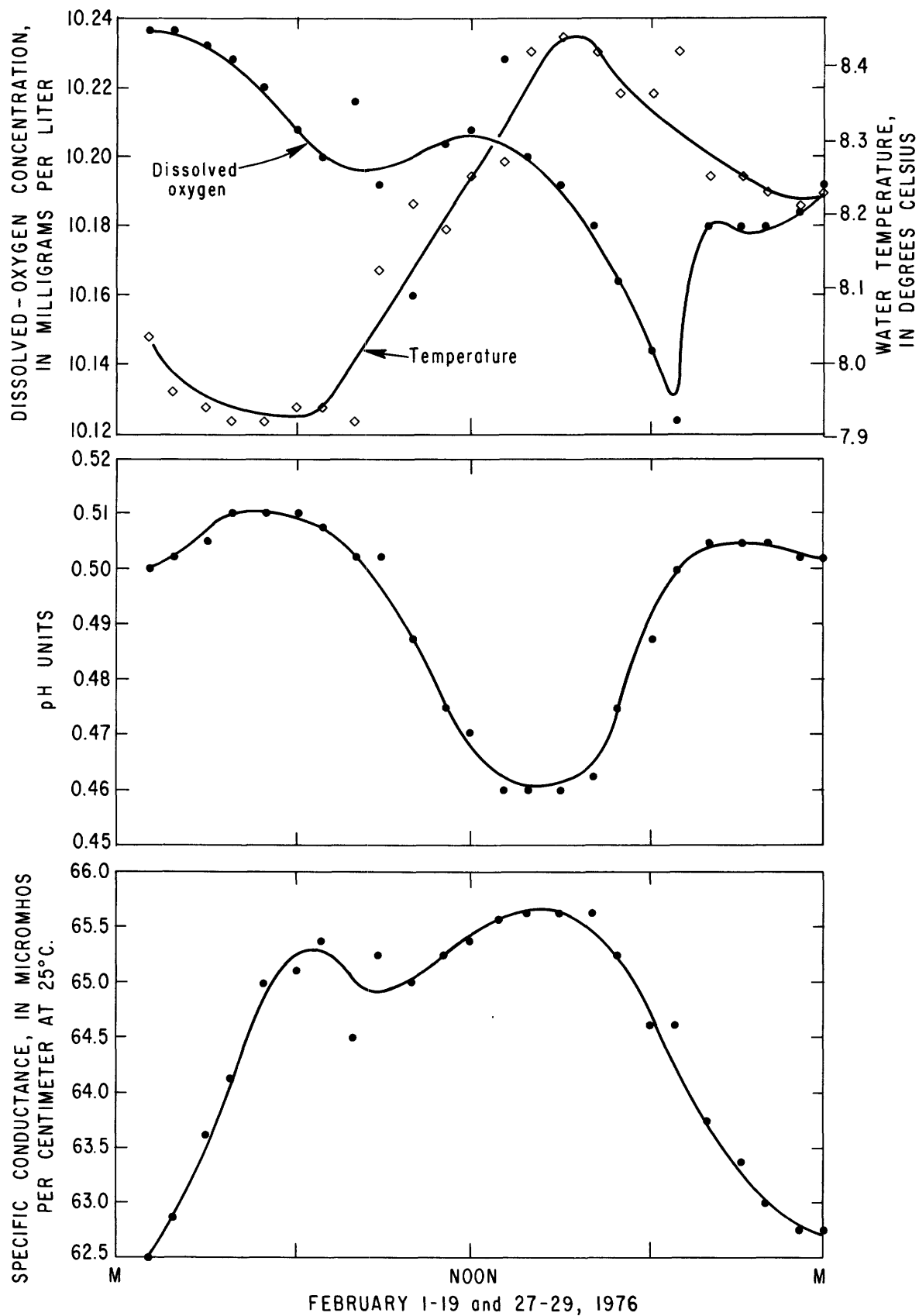
Figure 17. Mean hourly dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College during February 1–19 and 27–29, 1976.

Plots of pH for the same periods show a relation to temperature. The pattern of decreased pH with increased temperature is expected when photosynthesis is not operative (February 1–19 and 27–29, 1976, and June 20–24, 1975). The result of the April 12–30, 1975, plot is unexpected if, as suggested above, photosynthesis is actively occurring and is the major control of the pH of the water. Apparently, the effect of photosynthesis on pH may be transcended by other influences such as waste-water effluent or presence of dissolved constituents.

The plots of mean hourly specific conductance represent values which have been corrected for temperature. The diel pattern for specific conductance is double-peaked, with the earlier peak (6:00 a.m.) being of variable magnitude. The double-peaked pattern may possibly result from Winston-Salem's Archie Elledge Waste-Water Treatment Plant, each peak appearing at Yadkin College representing a peak discharge from the plant approximately 19–24 hours earlier (Lindskov, 1974). Winston-Salem water use and waste disposal may also explain the diel pattern evident in the stage data for each of the three periods (fig. 18). The peak stage appears near midnight and declines to the lowest point in late afternoon. The peaks may correspond to a morning surge in output of the treatment plant.

Diel variation of physical parameters in the Yadkin River at Yadkin College is not always consistent with principles governing uncontaminated natural water bodies. Differences in the expected diel behavior of the physical properties of the river water may be due to changes in the flow rate or due to human activities, particularly as these relate to the quantity and type of dissolved and suspended load of the river. It is apparent from this study that natural physical processes of the river are often overwhelmed by man's activities and byproducts.

Major Dissolved Substances

Statistics for nine constituents in water samples from Yadkin College, Norwood, and Rockingham collected during the 1970–78 water years are given in table 4. In the instances where U.S. Environmental Protection Agency criteria have been established, the concentrations of substances in the water are within acceptable levels. All mean concentrations are within the ranges of most surface water (Hem, 1970) and within levels for potable water (Todd, 1970). Maximum concentrations rarely meet or exceed the prescribed limits shown.
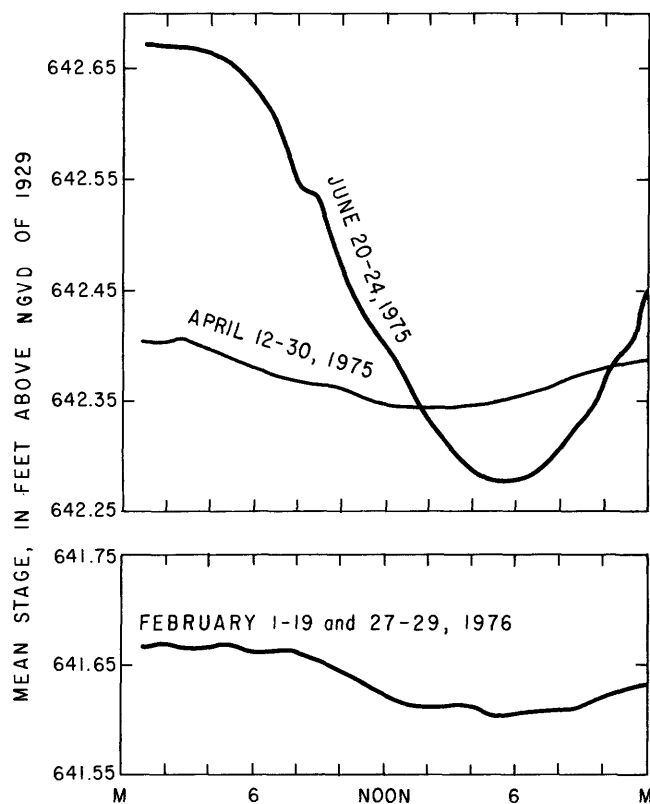
Figure 18. Mean diel stage for the periods of April 12–30, 1975, June 20–24, 1975, and February 1–19 and 27–29, 1976, for the Yadkin River at Yadkin College.

Most notable on table 4 are the consistently higher mean concentrations for all substances at Norwood, as compared to the other stations. Similarly, the highest individual values were nearly always measured in Rocky River samples. The degree of development in the Rocky River basin is no greater than the basin upstream from Yadkin College; indeed, the waste-water inputs from the Winston-Salem area are much greater than those of the Rocky River (see table 1, fig. 3). However, the mean discharge near Norwood is much less than at Yadkin College; therefore, much less water for dilution of waste water is generally available in the Rocky River than at the other stations.

Cation-anion diagrams (Stiff, 1951) for the three stations, showing the averages of 1974–78 analyses, are presented in figure 19. Comparison of the three diagrams shows the Yadkin River at Yadkin College to be the most dilute and the Rocky River to be the most concentrated in major dissolved constituents. At all three stations, the major cation is sodium and the major anions are bicarbonate and carbonate. Magnesium and sulfate are the least concentrated ions at all stations. Samples collected at the three stations show similar pro-
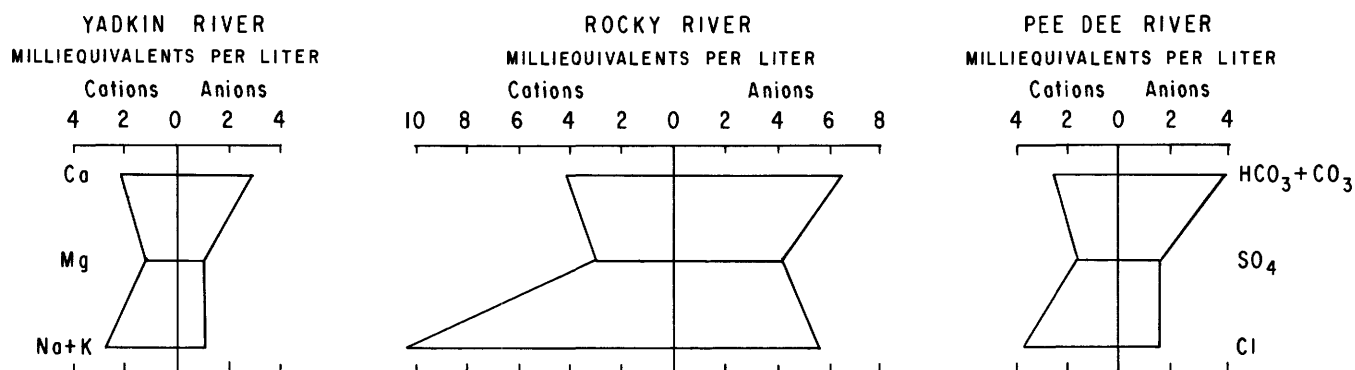
Figure 19. Cation-anion distributions for water years 1974-78 for the Yadkin River at Yadkin College, Rocky River near Norwood, and the Pee Dee River near Rockingham.

portions of major dissolved constituents, but differ greatly in absolute concentrations of these cations and anions.

Dissolved solids (residue at 180°C.), hardness, and specific conductance repeat the general pattern: the highest mean values and highest measured values were found at Norwood. Again, this is probably due to the relatively smaller quantity of water in the Rocky River available for dilution of waste water than is generally available at the other locations. Rockingham values are much lower than Norwood values, but slightly greater than those at Yadkin College. Frequency distributions of dissolved solids (residue at 180°C.) for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham are given in figure 20. The distribution for the Rocky River near Norwood is given in figure 21. Frequency distributions for specific conductance for the Yadkin and Pee Dee stations are given in figure 22. The Rocky River specific-conductance distribution is given in figure 23. The distributions of both dissolved solids and specific conductance show similar patterns. The distributions of values at Yadkin College overlap with the lower ends of the Rockingham distributions. However, the Rocky River distributions cover ranges of values much higher than the other stations. These distributions show that the frequency of similar values for the Yadkin College and Rockingham samples is great, and there is an overall frequency of higher values at Norwood than the other stations. In fact, the higher values measured at Norwood probably account for most of the overall downstream increases in dissolved-constitutent concentrations that occur in the river segment between Yadkin College and Rockingham.

Conductance may be satisfactorily related to the concentration of most major dissolved substances. These relations can, in turn, be used to estimate dissolved-constituent concentrations for periods where only specific conductances are known. Regression equations and statistics for relations between major dissolved constituents and specific conductance for the three stations are given in table 5.

The relation between dissolved solids (residue at 180°C.) and discharge is shown in figure 24 for the Rocky River near Norwood. The regression curve is in the form $C = bQ^m$, or, in logarithmic form:

$$\ln C = \ln (bQ^m) = \ln b + m \ln Q \qquad (1)$$

where C is constituent concentration, Q is discharge, ln b is the y-intercept, and m is the slope. The relation in figure 24 shows dissolved solids to be strongly affected by discharge at Norwood. The relation between dissolved-solids concentration and discharge is evident at Yadkin College and not at all evident at Rockingham. The lack of relation for the Pee Dee near Rockingham is due to upstream impoundments that moderate normal flow patterns and chemical changes.

Trace Elements

Statistics for trace elements in samples from the three Yadkin-Pee Dee stations are given in table 6. Only iron and manganese concentrations are consistently higher than criteria levels suggested for domestic water supply (U.S. Environmental Protection Agency, 1976). Concentrations of iron exceed the criterion at Yadkin College in 97 percent of the samples and near Norwood and Rockingham in all of the samples. Concentrations of manganese exceed the criterion in 66 percent of the samples collected at Yadkin College, 100 percent of the samples collected near Norwood, and 96 percent of the samples collected near Rockingham. However, the iron and manganese levels observed at these Yadkin-Pee Dee stations are not unusually high for North Carolina streams. Furthermore, the criteria are set for total values in untreated water. Treatment processes will

Table 4. Summary of statistics of major dissolved constituents for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham (1970–78 water years)
(Results in milligrams per liter except as indicated)

Constituent	Yadkin River at Yadkin College			Rocky River near Norwood			Pee Dee River near Rockingham			U.S. E.P.A. Criteria (1976)
	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	
Silica (SiO2)	10.9 (10.1–11.8)	4.4–15.0	45	11.6 (10.0–13.1)	5.1–19.0	30	10.4 (10.1–10.7)	6.5–13.0	70	
Calcium (Ca)	3.8 (3.5–4.2)	1.2–8.6	45	7.9 (7.0–8.8)	3.6–13.0	30	4.5 (4.4–4.7)	2.7–6.2	69	
Magnesium (Mg)	1.3 (1.2–1.4)	.4–2.2	45	3.8 (3.4–4.2)	2.1–5.9	30	2.1 (1.9–2.3)	1.3–9.0	69	
Sodium (Na)	4.6 (4.1–5.2)	.5–10.0	45	29.8 (18.5–41.1)	3.8–120.0	30	7.3 (6.8–7.8)	3.3–13.0	69	
Potassium (K)	2.3 (2.2–2.5)	1.2–3.5	45	3.6 (2.8–4.5)	1.9–10.0	30	2.3 (2.2–2.4)	1.4–4.1	69	
Bicarbonate (HCO3⁻)	18.7 (17.1–20.3)	7.0–31.0	46	51.8 (36.8–66.9)	10.0–162.0	32	24.1 (23.0–25.2)	15.0–33.0	72	
Sulfate (SO4⁻)	4.7 (4.4–5.0)	2.7–6.5	45	21.3 (17.1–25.6)	8.8–56.0	30	6.9 (6.7–7.2)	2.0–11.0	71	Upper limit. Domestic water supply: 250 mg/L.
Chloride (Cl⁺)	3.9 (3.5–4.3)	1.4–8.2	45	24.7 (16.6–32.8)	5.2–96.0	30	6.4 (6.0–6.7)	3.2–11.0	70	Upper limit. Domestic water supply: 250 mg/L.
Fluoride (F)	.15 (.13–.17)	.0–.3	45	.19 (.15–.25)	.10–.60	30	.16 (.14–.18)	.0–.5	70	
Dissolved solids (residue at 180°C)	45.2 (42.2–48.2)	20.0–69.0	44	146.7 (112.7–180.6)	60.0–418.0	30	61.6 (59.6–63.6)	42.0–79.0	70	
Hardness (as CaCO3)	14.8 (13.7–15.9)	8.0–28.0	45	35.5 (31.6–39.4)	18.0–55.0	30	19.5 (18.9–20.1)	14.0–29.0	69	
Specific conductance (μmhos/cm at 25°C)	55.7 (53.0–58.4)	34.0–95.0	94	215 (162–267)	60.0–698	38	80.4 (76.9–83.9)	15.0–190	152	Category: Soft water

[1] The 95-percent confidence interval means that with 95-percent confidence, we estimate the mean to fall within the given range (in parentheses), assuming that the number of samples is large enough and that the samples are randomly collected.
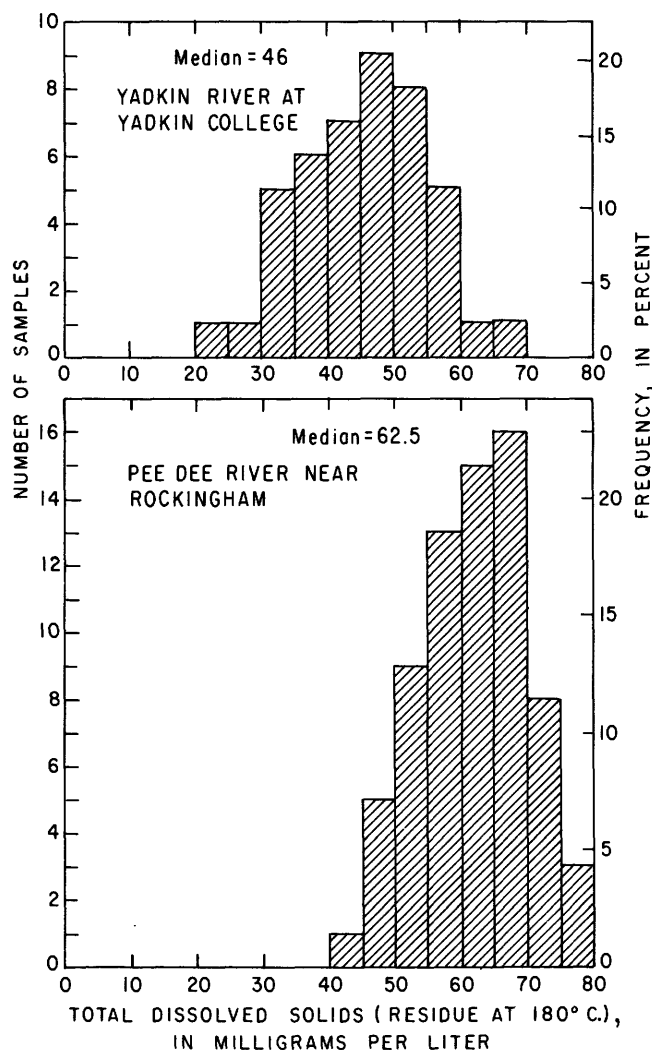
Figure 20. Frequency distributions of dissolved solids for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham (1974–78 water years).

Figure 21. Frequency distribution of dissolved solids for the Rocky River near Norwood (1974–78 water years).

remove much of the suspended material in the water which account for a substantial proportion of the total trace-element concentration in the river. Because of treatment, problems caused by high iron and manganese concentrations, including undesirable water tastes, scaling, and staining, may normally be avoided.

Certain trace elements such as mercury, lead, arsenic, selenium, and cadmium can be highly toxic to both humans and wildlife. Even minute concentrations of these toxic substances are of concern because higher concentrations are frequently accumulated in aquatic organisms feeding in contaminated waters. Concentrations of lead exceed the U.S. Environmental Protection Agency (1976) criterion for domestic water use at

Yadkin College in 6 percent of the samples, near Norwood in 14 percent of the samples, and near Rockingham in 8 percent of the samples. At Yadkin College, the criterion for protection of aquatic life for mercury was exceeded in 53 percent of the samples collected. All of the mercury samples taken near Norwood and 56 percent of the samples taken near Rockingham exceeded the criterion for protection of aquatic life. Norwood samples have the highest mean concentrations of most trace metals. Samples from Yadkin College exceed Norwood only in iron, manganese, selenium, and zinc concentration.

Available data allow the waterborne trace elements to be subdivided into dissolved and suspended constituents (table 7) with the total (shown earlier in table 6) being a sum of these. The ratio of mean suspended iron to mean dissolved iron is high, suggesting that the high total iron concentrations measured in the Yadkin River are indeed primarily due to suspended sediment.

A profile of variation in concentration of several trace elements and dissolved solids during a January 9–17, 1975, flood for the Yadkin River at Yadkin College demonstrates several important water-quality relations (fig. 25). The stormflow of January 9–17, 1975, shown in figure 8 to cause a double-peaked response in suspended-sediment concentration, also caused a dilution of dissolved-solid concentration and a peaking of several total trace-element concentrations. The small number of analyses does not allow a fine definition of the trace metal response; however, it is quite likely that the total trace-element concentrations respond very much like suspended sediment during stormflows because of adsorption of trace elements to sediment. Trace-element data taken during this and other storm events show that only a few of the dissolved forms tend to be diluted by stormflows in a similar manner to the

Figure 23. Frequency distribution of daily specific conductance for the Rocky River near Norwood (1977 and 1979 water years).

Nutrients

Carbon, nitrogen, and phosphorus are primary chemical elements required by plants for growth. An overabundance of nutrients may result in nuisance algae growth, which can be particularly troublesome in lakes and other slow-moving water bodies. Eutrophication, defined as nutrient and organic enrichment that results in increased biological productivity, a reduction in variety of biota, and reduced ecological stability, is currently a problem in the Yadkin-Pee Dee lake system, especially High Rock Lake (Weiss and Kuenzler, 1976; Weiss and others, 1981).

A summary of statistics for nutrients for all three stations is given in table 8. The mean and maximum values for the Pee Dee River near Rockingham are lower than those for the other two stations, probably due to use of nutrients by algae and aquatic plants in the lakes upstream from Rockingham.

Carbon

The total organic carbon concentration in unpolluted rivers in the eastern Piedmont of North Carolina has been asserted to be 5–15 mg/L (Weiss and others, 1973). In the Yadkin-Pee Dee River basin on the Western Piedmont, only the Rockingham station is consistently within this unpolluted range. The measured values for total organic carbon exceed 15 mg/L at Yadkin College in about 20 percent of the instances, but

Figure 22. Frequency distributions of daily specific conductance for the Yadkin River at Yadkin College (1974–77 water years) and the Pee Dee River near Rockingham (1975–77 and 1979 water years).

dissolved-solids response given in figure 25. Data other than that shown in figure 25 show that only dissolved arsenic and selenium appear to be diluted by floodflows for the Yadkin River at Yadkin College.

Table 5. Regression equations of constituent concentration versus specific conductance relations for the Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham

(Water years 1970–78; SC = Specific conductance)

| Constituent | Yadkin River at Yadkin College | | | Rocky River near Norwood | | | Pee Dee River near Rockingham | | |
| | Squared correlation | | | Squared correlation | | | Squared correlation | | |
	Regression equation	Coefficient	Probability[1]	Regression equation	Coefficient	Probability[1]	Regression equation	Coefficient	Probability[1]
Silica	$Si = 3.437 + 0.126$ (SC)	0.31	0.0001	$Si = 9.584 + 0.00846$ (SC)	0.13	0.0455	$Si = 8.839 + 0.0193$ (SC)	0.03	0.123
Calcium	$Ca = 1.735 + 0.0351$ (SC)	.14	.0117	$Ca = 5.495 + 0.0109$ (SC)	.57	.0001	$Ca = 4.0420 + 0.00596$ (SC)	.01	.428
Magnesium	$Mg = 0.821 + 0.00751$ (SC)	.10	.0342	$Mg = 2.488 + 0.00581$ (SC)	.74	.0001	$Mg = 1.426 + 0.00798$ (SC)	.01	.448
Sodium	$Na = -2.873 + 0.126$ (SC)	.81	.0001	$Na = -11.802 + 0.188$ (SC)	.98	.0001	$Na = -6.0647 + 0.166$ (SC)	.78	.0001
Potassium	$K = 1.966 + 0.00636$ (SC)	.02	.306	$K = 1.0991 + 0.0115$ (SC)	.75	.0001	$K = 0.790 + 0.0190$ (SC)	.16	.0005
Bicarbonate	$HCO_3 = -2.529 + 0.358$ (SC)	.69	.0001	$HCO_3 = 0.0473 + 0.242$ (SC)	.91	.0001	$HCO_3 = 3.121 + 0.262$ (SC)	.38	.0001
Sulfate	$SO_4 = 5.0549 - 0.00601$ (SC)	.01	.589	$SO_4 = 5.347 + 0.734$ (SC)	.97	.0001	$SO_4 = 3.557 + 0.0415$ (SC)	.12	.003
Chloride	$Cl = 0.716 + 0.0780$ (SC)	.59	.0001	$Cl = -5.191 + 0.136$ (SC)	.98	.0001	$Cl = -2.959 + 0.116$ (SC)	.69	.0001
Fluoride	$Fl = 0.253 + 0.00172$ (SC)	.09	.0454	$Fl = 0.083 + 0.000503$ (SC)	.45	.0001	$Fl = 0.138 + 0.000353$ (SC)	.75	.002
Dissolved solids	$DS = 26.641 + 0.314$ (SC)	.16	.007	$DS = 22.852 + 0.561$ (SC)	.98	.0001	$DS = 43.42 + 0.226$ (SC)	.09	.013
Hardness	$H = 7.688 + 0.12$ (SC)	.17	.004	$H = 24.0270 + 0.0518$ (SC)	.67	.0001	$H = 17.305 + 0.0269$ (SC)	.01	.339

[1] Probability of obtaining a sample slope this large, if the population slope is really zero.
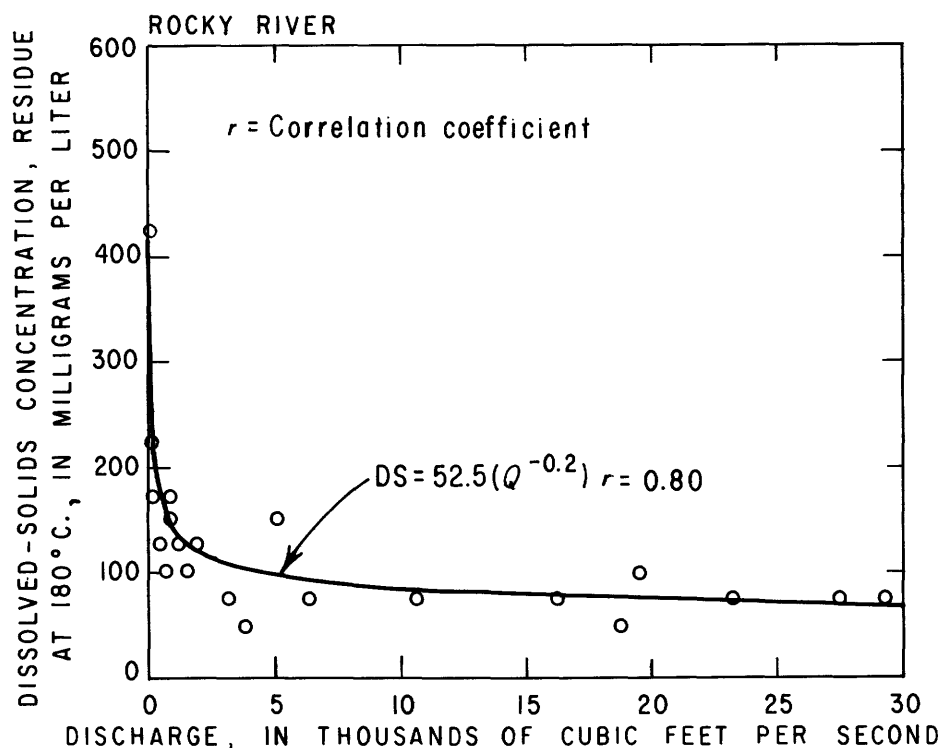
Figure 24. Total dissolved solids (DS) versus instantaneous streamflow (Q) for water years 1974–78 for the Rocky River near Norwood.

in only one instance at Norwood. Mean and maximum values for carbon species at Rockingham are lower than at the other stations. The relatively high organic carbon levels at Yadkin College indicate organic pollution, probably originating primarily from upstream wastewater treatment plants.

Nitrogen

The oxidation of reduced forms of nitrogen (NH_3 and organic forms) in surface waters is readily accomplished by aerobic aquatic biota, which produce nitrite and nitrate as oxidized species. Although natural processes oxidize reduced nitrogen, concentrations of reduced forms often transiently occur in surface water. Weiss and others (1973) considered concentrations of total ammonia nitrogen greater than 0.5 mg/L (as N) indicative of animal or human contamination. At no time was the measured total ammonia concentration as high as 0.5 mg/L at any of the three stations. The highest measured value is 0.45 mg/L at Norwood, although the highest mean value is at Yadkin College. The lowest range of measured values is found at Rockingham, as is the lowest mean value.

The lowest mean and maximum values for combined ammonia and organic nitrogen occur at Rockingham. Organic forms of nitrogen constitute the greater proportion of reduced nitrogen in the river water at all three stations.

Total nitrite + nitrate nitrogen is within the U.S. Environmental Protection Agency (1976) maximum criterion of 10 mg/L for domestic water supply at all three stations. The frequency distributions of nitrite + nitrate nitrogen for the three stations are given in figure 26. These distributions show similar nitrite + nitrate concentrations at Yadkin College and Rockingham, with the highest concentrations occurring in the Rocky River near Norwood. Dissolved nitrate concentrations are also greatest at Norwood, but greater for the Yadkin River at Yadkin College than the Pee Dee River near Rockingham.

Phosphorus

Phosphorus, in the form of phosphate, is also essential to algal growth. Values in table 8 show the lowest concentrations of dissolved orthophosphorus and total phosphorus at Rockingham, suggesting consumption of these species in the lake system. The criterion level of 0.05 mg/L (National Technical Advisory Committee, 1968) applicable to Yadkin College and Norwood, which are upstream from impoundments, is exceeded in every case at Yadkin College, and in 96 percent of the Norwood samples (all but one). Fre-

Table 6. Summary of statistics for trace-element concentrations for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Dee River near Rockingham (1970–78 water years) (Results in micrograms per liter)

Total trace element	Yadkin River at Yadkin College			Rocky River near Norwood			Pee Dee River near Rockingham			U.S. E.P.A. Criteria (1976)
	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number samples	
Arsenic (AS) ------	3.5 (1.8–5.1)	0–9.0	15	4.4 (0–8.9)	1.0–10.0	5	3.9 (0.3–7.5)	0–40.0	25	Domestic water supply: 50 µg/L maximum.
Cadmium (Cd) --	1.9 (0–3.8)	0–10.0	15	10.0 (0–37.8)	0–50.0	5	.8 (0–1.8)	0–10.0	23	Domestic water supply: 10 µg/L maximum. Aquatic life: 4 µg/L maximum.
Cobalt (Co) ------	8.2 (4.0–12.4)	0–25.0	15	21.2 (0–75.9)	0–100	5	9.2 (0–20.6)	0–100	25	
Copper (Cu) ------	11.9 (8.6–15.1)	0–33.0	34	20.9 (12.3–29.4)	6.0–74.0	23	7.8 (3.2–12.4)	0–50.0	26	Domestic water supply: 1,000 µg/L maximum.
Iron (Fe) ----------	18,700 (1,900–35,500)	0–300,000	36	10,757 (5,350–16,160)	550–41,000	22	1,720 (1,200–2,240)	320–6,100	26	Domestic water supply: 300 µg/L maximum. Aquatic life: 1000 mg/L maximum.
Lead (Pb) ---------	19.7 (12.7–26.7)	0–100	34	25.8 (14.1–37.5)	0–100	23	16.2 (5.5–26.9)	0–100	26	Domestic water supply: 50 µg/L maximum.
Manganese (Mn) --	274.5 (143.6–405.3)	20.0–730	15	156.0 (32.3–279.7)	50.0–300	5	119.2 (89.4–149)	40.0–370	24	Do.
Mercury (Hg) ----	.3 (.1– .4)	0–1.4	21	1.1 (0–2.8)	.1–8.8	11	0.2 (0.1– .3)	0–1.2	25	Domestic water supply: 2µg/L maximum. Aquatic life: 0.05 µg/L maximum.
Selenium (Se) ----	1.9 (.4–3.4)	0–7.0	15	.5 (0–1.4)	0–1.0	4	0.4 (0– .9)	0–5.0	23	Domestic water supply: 10 µg/L maximum.
Zinc (Zn) ----------	38.8 (27.4–50.1)	0–110	34	37.8 (28.7–47.0)	0–110	23	32.9 (5.8–60.0)	0–350	26	Domestic water supply: 5,000 µg/L maximum.

[1] The 95-percent confidence interval means that with 95-percent confidence, we estimate the mean to fall within the given range (in parentheses), assuming that the number of samples is large enough and that the samples are randomly collected.

Table 7. Summary of statistics for dissolved and suspended trace-element concentrations for the Yadkin River at Yadkin College (1974–78 water years)
(Results in micrograms per liter)

Trace element	Dissolved			Suspended			Ratio of mean suspended to mean dissolved
	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	
Arsenic _____	1.43 (.13–2.72)	0–7	14	2.36 (0.73–3.98)	0–8	14	1.65
Cadmium _____	.36 (0– .72)	0–2	14	1.14 (0–2.74)	0–10	14	3.17
Cobalt _____	.93 (.27–1.59)	0–3	14	7.86 (3.53–12.19)	0–25	14	8.45
Copper _____	3.82 (2.82–4.82)	0–11	33	8.27 (5.42–11.13)	0–29	33	2.16
Iron _____	146.4 (111.5–181.2)	40–550	33	33,870 (3,140–64,600)	40–360,000	33	231
Lead _____	3.21 (1.48–4.95)	0–22	33	15.67 (8.75–22.58)	0–96	33	4.88
Manganese _____	20.19 (9.84–33.16)	0–63	14	267.9 (137.3–398.5)	0–700	14	13.27
Mercury _____	.11 (.02– .20)	0–.5	14	.11 (0– .27)	0–.9	14	1
Selenium _____	2.57 (0–5.67)	0–20	14	.43 (0– .97)	0–3	14	0.17
Zinc _____	5.91 (2.56–9.26)	0–40	33	33.0 (22.0–44.1)	0–100	33	5.58

[1] The 95-percent confidence interval means that with 95-percent confidence we estimate the mean to fall within the given range (in parentheses), assuming that the number of samples is large enough and that the samples are randomly collected.

quency histograms of total phosphorus for three stations are given in figure 27. The reduction of phosphorus concentration in the Pee Dee River near Rockingham is quite evident from a comparison of the histograms.

Nutrient Balance

An estimate of the nutrient balance can be calculated using the mean concentration given in table 8 and the mean discharge from table 2. The results of this excercise (table 9) show an apparent loss of ammonia, organic nitrogen, and phosphorus within the lake system. The loss of ammonia and organic nitrogen is due, at least in part, to oxidation by either organic or inorganic means. However, the imbalance of phosphorus and nitrogen compounds is also due to consumption in the lake system by algae and precipitation of nutrient species with sediment. The actual difference between input and output of nutrients is undoubtedly greater than that indicated in table 9 because smaller tributaries to the lakes and other inputs were not considered. In fact,

the sum of the mean discharges of the Yadkin River and the Rocky River is only 53 percent of the mean Rockingham discharge. Hence, the estimate of nutrient input into the lakes is extremely conservative. If all of the upstream nutrient inputs could be accounted for, a more dramatic picture of nutrient consumption in the lake system could be drawn.

Nutrient Relations

The ratio of total nitrogen to total phosphorus in natural uncontaminated lakes is about 10:1 (National Technical Advisory Committee, 1968; Weiss and Kuenzler, 1976). The mean nutrient ratios for stations at Yadkin College and near Norwood fall below 10:1, and the ratio at the Rockingham station is 10.10:1 (table 8). The higher nutrient ratio at Rockingham suggests that phosphorus is consumed relative to nitrogen in the lake system between the two upstream stations and Rockingham. In addition, the frequency histogram for total phosphorus (fig. 27) and the nutrient balance (table 9) show that a dramatic reduction of phosphorus occurs
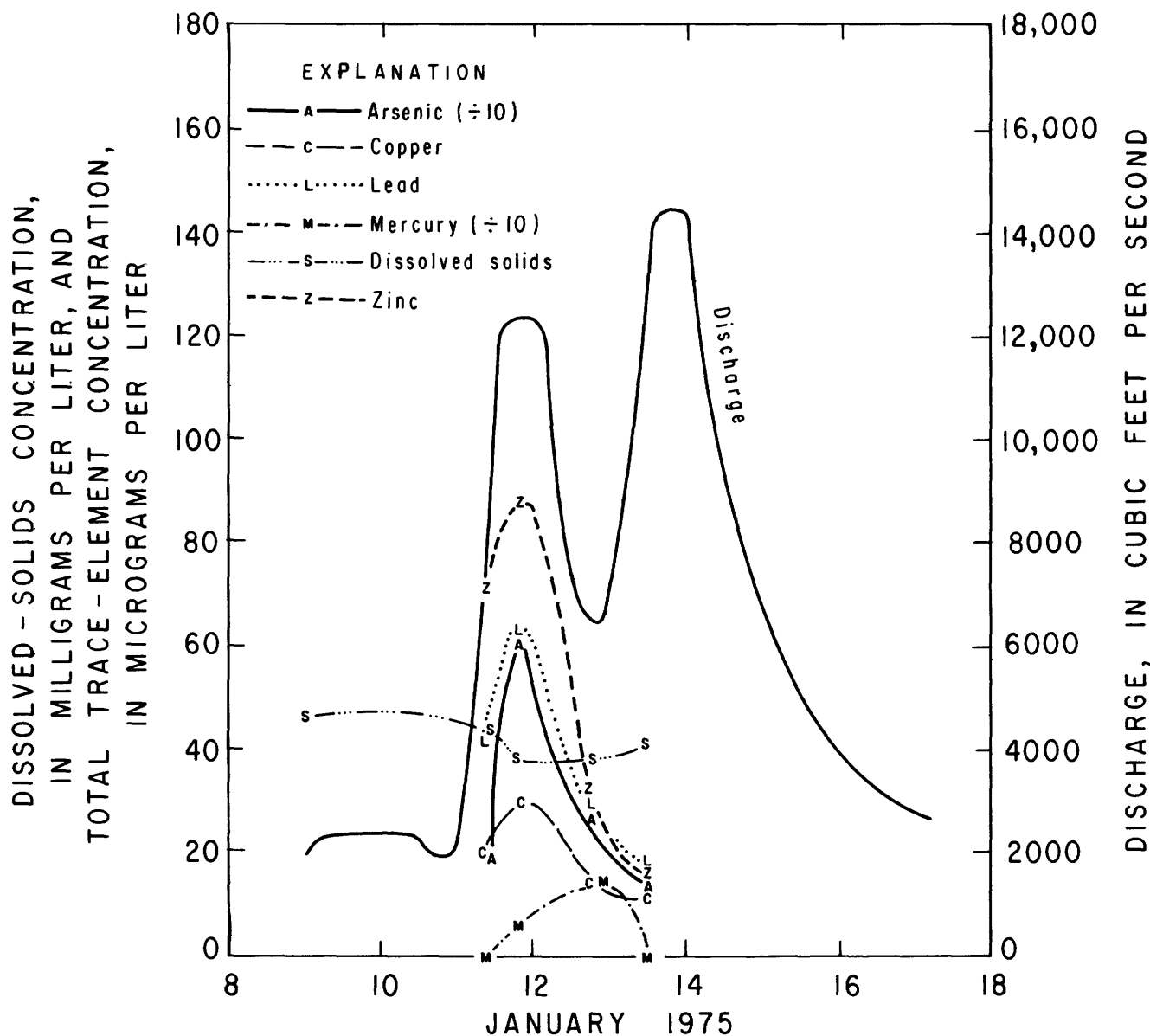
Figure 25. Trace-element (total concentration) and dissolved-solids concentration and discharge for the Yadkin River at Yadkin College through a storm event occurring January 9-17, 1975.

somewhere between the Yadkin College station and the Rockingham station. These observations strongly indicate that phosphorus acts as the limiting nutrient. In fact, studies by the U.S. Environmental Protection Agency (1975a, 1975b, 1975c, 1975d) cite phosphorus as the limiting nutrient in all but Blewett Falls Lake, which showed both nitrogen and phosphorus limitation, depending on station location. The bulk of the evidence shows phosphorus to be limiting.

The concentration of nutrients in the Yadkin-Pee Dee River system clearly indicates a potential for excess plant and algal growth, particularly in the large lakes. Furthermore, the downstream change in nutrient occur-

rence and concentration indicates the presence of substantial algal growth within the basin. In fact, High Rock and Tuckertown Lakes are eutrophic, and Badin, Tillery, and Blewett Falls Lakes are mesotrophic (Weiss and Kuenzler, 1976; U.S. Environmental Protection Agency 1975a, 1975b, 1975c, and 1975d; North Carolina Department of Natural and Economic Resources, 1975; Weiss and others, 1981).

Biological Characteristics

The types of biota and number of organisms living in a body of water can be used to evaluate water quality.

Table 9. Summary of statistics for nutrients for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham (1970–73 water years)

(Results in milligrams per liter)

Nutrient or parameter	Yadkin River at Yadkin College			Rocky River near Norwood			Pee Dee River near Rockingham			U.S. E.P.A. Criteria (1976)
	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number samples	
Total organic carbon	10.5 (7.3–13.7)	1.5–37.0	24	9.9 (7.6–12.2)	4.9–18.0	12	7.1 (6.0–8.2)	4.1–15.0	26	
Dissolved organic carbon	6.9 (5.0–8.7)	1.0–26.0	30	10.3 (7.9–12.7)	5.8–27.0	18	5.8 (3.6–8.0)	3.0–10.0	8	
Total ammonia nitrogen (as N)	.17 (.13–.21)	0–.38	29	0.15 (.09–.21)	.01–.45	20	.08 (.06–.10)	.01–.17	21	
Dissolved ammonia nitrogen (as N)	.14 (.06–.21)	0–1.0	29	0.11 (.06–.16)	.01–.42	20	.06 (.02–.10)	0–.14	8	
Total organic nitrogen (as N)	0.9 (.43–1.37)	0–6.9	30	1.0 (.7–1.2)	.3–2.6	20	.4 (.3–.5)	.2–.7	16	
Dissolved organic nitrogen (as N)	0.3 (.2–.5)	0–2.2	30	0.6 (.4–.7)	.2–1.4	19	.3 (.2–.4)	.2–.4	8	
Total ammonia and organic nitrogen (as N)	0.81 (.61–1.01)	.08–2.4	31	1.07 (.82–1.32)	.4–2.8	21	.49 (.39–.59)	.10–2.60	48	
Total nitrite + nitrate nitrogen (as N)	0.5 (0.4–.5)	.2–1.0	31	1.2 (.8–1.5)	.6–3.5	20	.5 (.4–.5)	.01–1.0	54	Domestic water supply: 10 mg/L
Dissolved nitrate nitrogen (as N)	0.47 (.02–.92)	.06–.70	4	0.77 (.48–1.06)	.5–1.1	5	.39 (.17–.61)	.02–.60		
Dissolved ortho-phosphorus (as PO4)[2]	0.6 (.0–1.4)	0–13.0	35	.72 (1.13–.31)	.1–4.3	29	.04 (.02–.06)	0–.15	17	
Total phosphorus (as P)	0.3 (.2–.3)	.1–.8	35	.4 (.3–.5)	.3–1.4	25	.08 (.07–.09)	0–.3	63	Streams feeding impoundments: 0.05 mg/L
Nutrient ratio[3]: 1	4.31 (3.57–5.05)	.35–8.50	29	5.17 (3.89–6.45)	2.07–8.20	18	10.10 (6.41–13.79)	4.41–16.33	8	

[1] The 95-percent confidence interval means that with 95-percent confidence we estimate the mean to fall within the given range (in parentheses), assuming that the number of samples is large enough and that the samples are randomly collected.

[2] Dissolved orthophosphorus is listed here as PO4 because this is the most common way it is reported. To convert to dissolved orthophosphorus as P, use the equation: $P = 0.326 (PO_4)$.

[3] The nutrient ratio as used here is the ratio of total nitrogen to total phosphorus. Total nitrogen is calculated as the sum of ammonia nitrogen, organic nitrogen, NO_2, and NO_3.
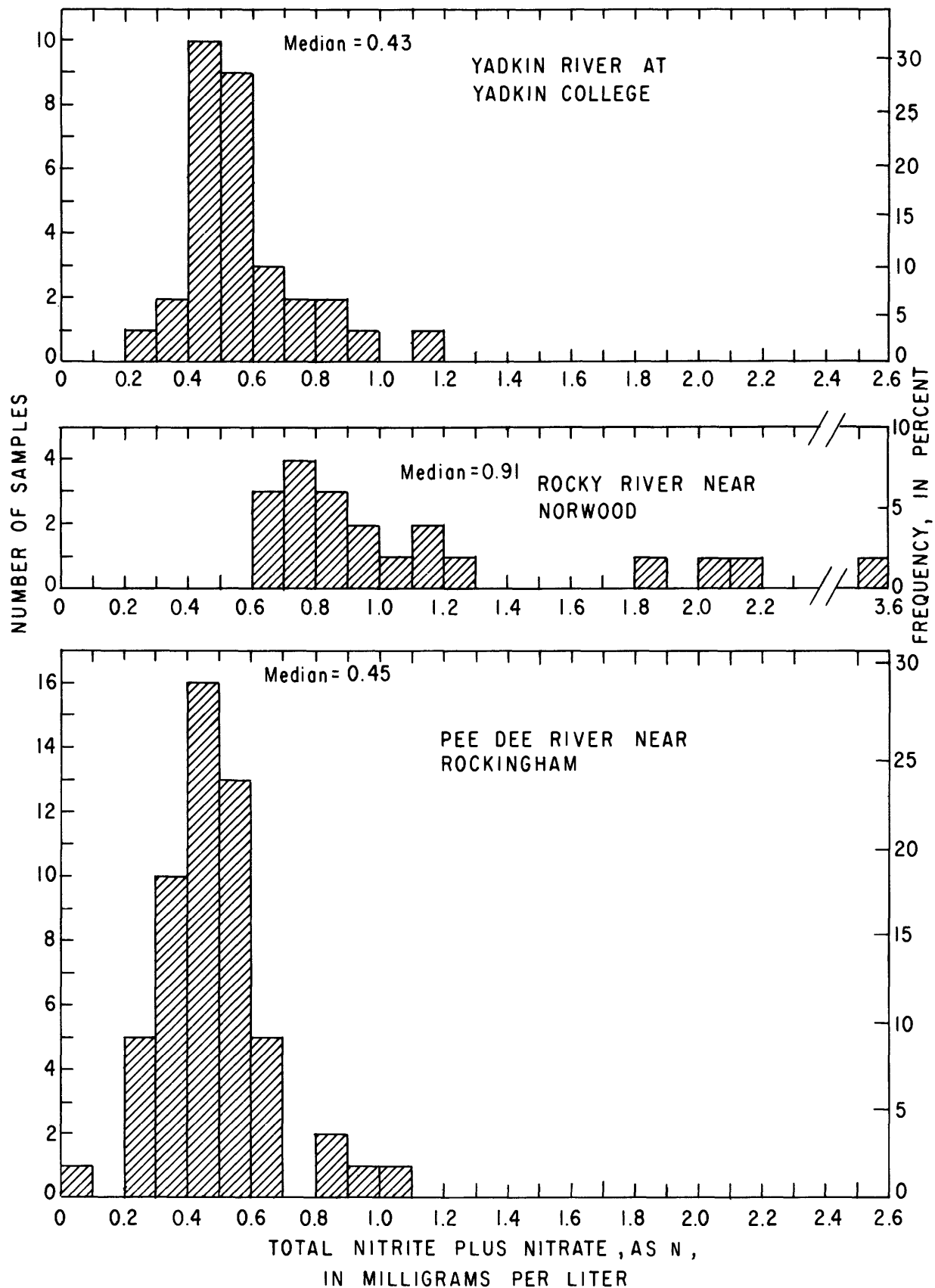
Figure 26. Frequency distributions of nitrite + nitrate nitrogen concentrations for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham (1974–78 water years).
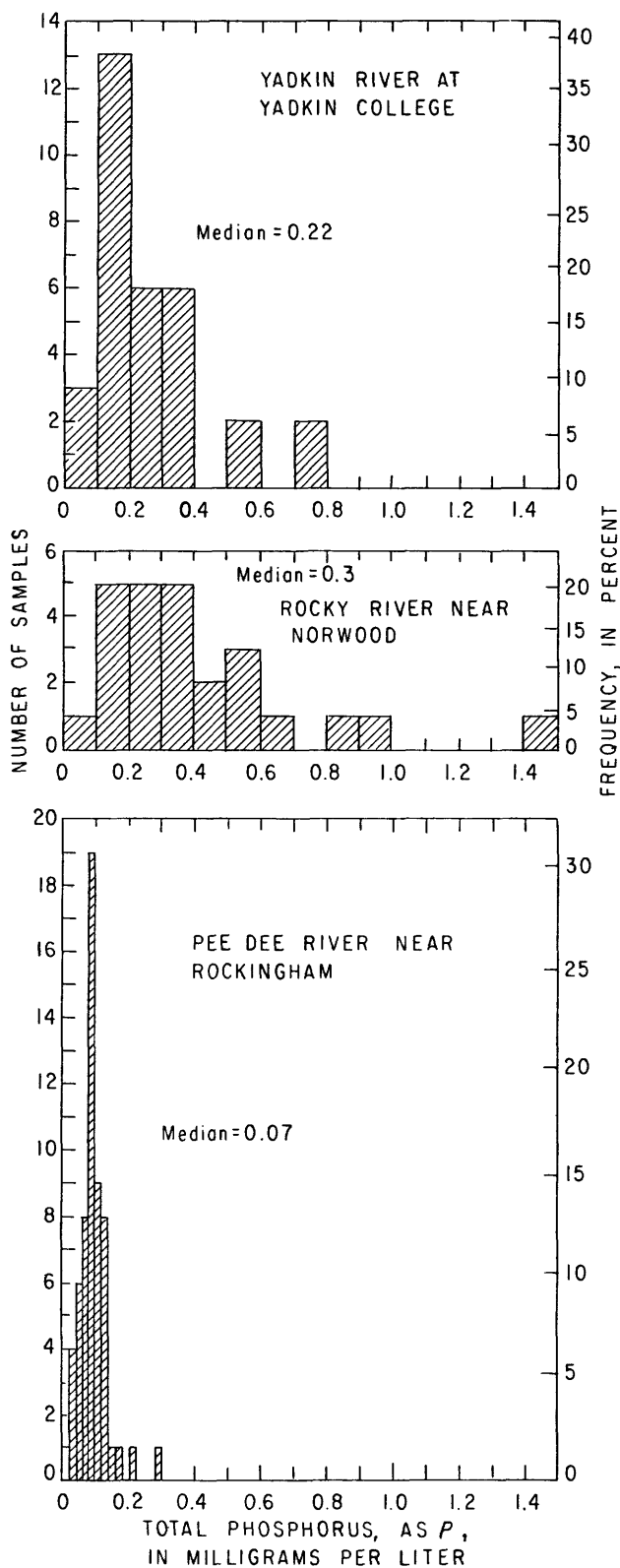
Figure 27. Frequency histograms for total phosphorus (as P) for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham (1970-78 water years).

Normally, physical and chemical measures of water quality are referenced to their biological impacts in order to be useful. The evaluation of biological characteristics in a river is therefore both a direct way to assess water quality and also a means of supplementing the assessments made for the more easily quantifiable measures of chemical and physical characteristics.

Several traditional methods of assessment of biological water-quality conditions include the use of indicator organisms, numerical diversity indices, and nonspecific biological tests. Indicator organisms include organisms that have been correlated to water contamination (coliform bacteria tests), and organisms associated with eutrophic conditions (certain genera and species of algae). Numerical indices quantify numbers of different kinds of aquatic organisms and their relative abundance in order to give a general measure of water quality. The 5-day biochemical oxygen demand test (BOD_5) is an example of a general-purpose method of evaluating the amount of organic pollution that can be assimilated by natural stream processes or in biological waste-water treatment.

The systematic collection of biological data at the Yadkin-Pee Dee River system stations began in late 1973. No algal data were taken prior to 1974. Only scattered data for fecal coliform bacteria, fecal streptococcus bacteria, and BOD_5 are available prior to water year 1973. Fecal streptoccocus bacteria colony counts are available only for samples from the Pee Dee River near Rockingham.

Bacteria

Fecal coliform bacteria are commonly found living in the gut or feces of warmblooded animals. Although all species of this group are not human pathogens, their occurrence indicates probable fecal contamination and possible presence of pathogenic species. The U.S. Environmental Protection Agency (1976) raw-water criteria for body contact is a geometric mean of 200 fecal coliforms per 100 mL of water.

Fecal coliforms statistics for all three stations are given in table 10. Only Yadkin College, with a geometric mean of 630 fecal coliforms/100 mL, exceeds the criterion. However, fecal coliform levels occasionally peak to levels substantially above the criterion at both Norwood and Rockingham.

Fecal streptococcus bacteria also indicate fecal contamination from warmblooded animals. The fecal streptococci levels measured at Rockingham have a geometric mean of 60 fecal streptococci/100 mL providing further evidence that fecal contamination is not a major problem at this point in the river. The ratio of fecal coliforms to fecal streptococci is sometimes used

Table 9. Calculation of the nutrient balance for the lakes of the Yadkin-Pee Dee River system, using data from the Yadkin River at Yadkin College and the Rocky River near Norwood as input, and data from the Pee Dee River near Rockingham as output (Results in tons per year except as indicated)

Nutrient or Parameter	A Yadkin River at Yadkin College	B Rocky River near Norwood	C (A + B = C) Sum of Inputs	D Pee Dee River near Rockingham	E (D− C= E) Difference (Negative values indicate a loss in lake system)
Period-of-record mean discharge (ft³/s)	2,970	1,300	4,270	7,997	3,727
Total organic carbon	30,700	12,700	43,400	55,900	12,500
Dissolved organic carbon	20,200	13,200	33,400	45,700	12,300
Total ammonia nitrogen (as N)	500	190	690	630	− 60
Dissolved ammonia nitrogen (as N)	410	140	550	470	− 80
Total organic nitrogen (as N)	2,600	1,300	3,900	3,100	− 800
Dissolved organic nitrogen (as N)	880	770	1,650	2,400	750
Total ammonia and organic nitrogen (as N)	2,400	1,400	3,800	4,000	200
Total nitrite + nitrate nitrogen (as N)	1,500	1,500	3,000	3,900	900
Dissolved nitrate nitrogen (as N)	1,400	1,000	2,400	3,100	700
Dissolved orthophosphorus (as PO₄)	1,800	900	2,700	300	− 2,400
Total phosphorus (as P)	880	520	1,400	630	− 770

to identify the origin of bacterial contamination (Geldriech, 1966). Ratios greater than 4.0:1 indicate contamination primarily of human origin, while ratios less than 0.6:1 indicate animal origin. Of the 22 times when both fecal coliforms and streptococci were measured at Rockingham, the ratio was greater than 4.0 once. On ten occasions, the ratio was less than 0.6. These ratios indicate that fecal contamination at Rockingham is predominately of animal origin.

Biochemical Oxygen Demand

The uptake of oxygen during the metabolism of organics in water can be measured by the BOD₅ test. The test is important because it helps to evaluate the amount of organic material in the stream being used by organisms. At the stations monitored in the Yadkin-Pee Dee River basin, average BOD₅ values are low, ranging from 0.8 to 3.8 mg/L, indicating low to moderate organic material levels in the river. The highest levels of BOD₅ were recorded at the Yadkin College station (table 10). These high BOD₅ concentrations may be attributable to waste water from various sources in and around Winston-Salem.

Algae

Algal cell counts for samples from the Yadkin-Pee Dee stations are typical of waters of medium fertility. Algal populations fluctuate rather dramatically over time and with discharge in the river. Sampling has been most frequent in the Pee Dee River near Rockingham. The magnitude and periodicity of the fluctuations of the total numbers of algal cells at Rockingham are given in figure 28. In each of the 4 years of record, 1975–78, algal cell numbers increased greatly during the summer months. Winter blooms of algae are apparent in 1976 and 1977. Winter algal blooms are not unusual for lakes in this region. Given the rich nutrient conditions of the Yadkin-Pee Dee River system and favorable climatic conditions, algal blooms will appear during any season.

In the Yadkin River at Yadkin College, diatoms and blue-green algae dominate the phytoplankton assemblage. Among the most common genera are the diatoms *Navicula, Synedra, Nitzschia,* and *Melosira.* Common blue-green algae include *Anabaena, Apanizomenon, Lyngbya,* and *Oscillatoria.* An assemblage of these genera is indicative of eutrophic water (Wetzel, 1975). Wiess and others (1981) give a detailed description of algal species found in High Rock Lake during the 1978 water year. In the Pee Dee River near Rockingham, diatoms dominate the phytoplankton assemblage. Blue-green algae are present, and at times, comprise a significant part of the assemblage, but their numbers and importance are reduced, compared to the data from Yadkin College. *Oscillarotia* is the blue-green genus present in greatest abundance in the Pee Dee River near Rockingham. *Nitzschia* and *Melosira* are diatoms frequently found in abundance. The green algae *Scenedesmus* is also common. This assemblage,

Table 10. Summary of statistics for biological characteristics of the Yadkin River at Yadkin River College, the Rocky River near Norwood, and the Pee Dee River near Rockingham (1974–78 water years)

Physical parameter	Yadkin River at Yadkin College			Rocky River near Norwood			Pee Dee River near Rockingham		
	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples	Mean and 95-percent confidence interval[1]	Range	Number of samples
Five day biological oxygen demand (BOD$_5$) (mg/L)	2.0 (1.8–2.2)	0.8–3.8	41	1.6 (1.2–1.9)	1.2–2.0	5	1.6 (.6–3.8)	1.1–2.1	2
Fecal coliforms (colonies/100mL)	[2]630 (–)	20–26,000	52	[2]29 (–)	10–100	7	29 (–)	1–520	31
Fecal streptococci (colonies/100mL)	– (–)	–	–	– (–)	–	–	[2]60 (–)	4–1,400	23
Phytoplankton count (cells/mL)	[2]2,100 (–)	350–5,800	9	[2]4,400 (–)	2,600–7,600	2	[2]510 (–)	7–9,000	39
Palmer index (Palmer, 1969)	15 (12–19)	9–21	9	– (–)	–	–	13 (11–15)	4–31	39
Phytoplankton diversity: Division (bits/cell)	.81 (.47–1.2)	0–1.4	9	– (–)	–	–	0.86 (.73–.99)	0–1.7	39
Class (bits/cell)	.85 (.53–1.2)	0–1.4	9	– (–)	–	–	0.87 (.73–1.0)	0–1.3	39
Order (bits/cell)	1.2 (.71–1.7)	0–2.2	9	– (–)	–	–	1.4 (1.2–1.5)	0–2.4	39
Family (bits/cell)	2.4 (2.0–2.7)	1.8–2.9	9	– (–)	–	–	1.9 (1.7–2.1)	.60–3.0	39
Genus (bits/cell)	2.7 (2.2–3.2)	1.8–3.5	9	– (–)	–	–	2.1 (1.9–2.3)	.70–3.4	39

[1] The 95-percent confidence interval means that with 95-percent confidence we estimate the mean to fall within the given range (in parentheses), assuming that the number of samples is large enough and that the samples are randomly collected.
[2] Geometric mean.
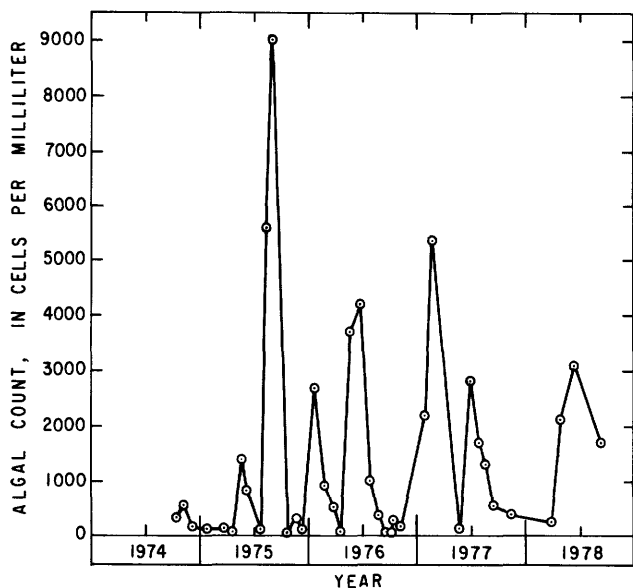
Figure 28. Algal cell counts for the Pee Dee River near Rockingham.

Figure 29. Palmer index values for phytoplankton samples from the Yadkin River at Yadkin College and the Pee Dee River near Rockingham (yr = year and r = correlation coefficient).

because of the reduced occurrence of blue-green algae, indicates that water at Rockingham is less eutrophic than at Yadkin College and could best be characterized as mesotrophic. For the two samples of Rocky River water analyzed, diatoms were dominant in the sample taken in May and blue-green algae were dominant in July.

Two additional quantative measures of water quality can be gleaned from the algae data. The first, the Palmer index (Palmer, 1969) (fig. 32), quantifies an assemblage of algae based on the number of genera present that are associated with polluted waters. For this index, higher numbers indicate poorer water quality. A second index measures the diversity of organisms (Wilhm and Dorris, 1968). The diversity index increases with a higher diversity of organisms and better water quality.

Palmer index values are plotted in figure 29 and given in table 10. Most values for the Palmer index fall within the range of 10–20 for data from both Rockingham and Yadkin College. Palmer (1969) cites an index value of 20 or more to indicate "high organic pollution while a score of 15 to 19 is taken as probable evidence of high organic pollution." Therefore, based on the Palmer index, waters at Rockingham and Yadkin College are being affected by organic enrichment.

Further examination of figure 29 reveals a statistically significant (two-tailed t-test at a probability of 0.05) increasing trend over time in the Palmer index near Rockingham. This is evidence of increasing organic

pollution at both stations. The quality of the river at both stations has degraded slightly since 1974, although little trend is evident after 1977. This flattening of trend may be due to improved waste-water treatment in recent years.

A diversity index is a somewhat better key to community health of the plants and animals in the river than the Palmer index. It has the advantage of considering relative numbers of organisms in each taxon. The diversity index is calculated from the formula:

$$\delta = - \sum_{i=1}^{s} p_i \log_2 p_i = - \sum (n_i/n)\log_2(n_i/n) \qquad (2)$$

where: δ = species diversity or information content of the sample (bits/individual). The term δ often is denoted by H;

s = number of species in the sample;

$p_i = n_i/n$ = proportion of the total sample belonging to the ith species.

There is some controversey over the use of diversity indices to evaluate water quality. Diversity indices have been shown to incorrectly rank water quality of certain streams (Hilsenhoff, 1977). Therefore, evidence of eutrophication given by diversity indices must be considered along with other evidence.

Diversity index values based on classification of phytoplankton to genus fall within the range of 1.0–3.0, with a small percentage of samples above 3.0 for the Yadkin-Pee Dee stations. Wilhm and Dorris (1968) indicated that values of greater than 3.0 are expected in areas of low productivity, when the index is applied to benthic macroinvertebrates. Values of 1.0–3.0 indicate

moderate eutrophication, and a value less than 1.0 for diversity of benthic macroinvertebrates indicates severe eutrophication. The ranges observed for diversity indexes for phytoplankton in oligotrophic and eutrophic lakes are similar (Margalef, 1968). These diversity index ranges suggest that the Yadkin-Pee Dee River system is moderately eutrophic (table 10).

Summary of Water-Quality Variation

Data collected by the U.S. Geological Survey shows instances of failure to meet U.S. Environmental Protection Agency (1976) minimum criteria for water-quality at all stations.

Measurements of specific conductance show no outstanding extreme values at the Yadkin College and Rockingham stations. However, specific conductance measurements for the Rocky River near Norwood are high, relative to other North Carolina streams, reflecting the major impact man has had on the water quality of this river.

Dissolved-oxygen concentrations are lowest at the Pee Dee station near Rockingham, due largely to its location downstream from Blewett Falls Lake. Diel patterns of dissolved-oxygen concentrations typically show a dependence on variation of water temperature. During the summer months, photosynthesis, respiration, and decomposition have a detectable effect on diel patterns. In particular, a midday rise in dissolved oxygen occurs, due probably to algal photosynthesis. This rise follows an earlier peak that is related to a decrease in temperature. Other diel patterns in dissolved oxygen are caused by man's activities.

Values for pH show the Yadkin-Pee Dee River system to be slightly acidic in reference to the U.S. Environmental Protection Agency (1976) criteria recommended for the protection of fish populations.

The predominant cation in the Yadkin-Pee Dee River system is sodium, and the major anions are bicarbonate and carbonate. The major ionic constituents occur at concentrations that are satisfactory for most uses of the water. Specific conductance can be satisfactorily related to many dissolved-constituent concentrations and used to predict these concentrations, when only specific conductance data are available.

Trace elements generally occur in low concentrations at all three stations. Only iron and manganese concentrations are consistently above levels suggested for domestic water supply. Concentrations of lead periodically rise above the suggested criterion for domestic uses (U.S. Environmental Protection Agency, 1976) at all stations and mercury concentrations are usually higher at all stations than levels recommended for protection of aquatic life.

Suspended sediment is the most significant water-quality problem in the Yadkin-Pee Dee River system. The many impacts of high suspended-sediment concentrations and loads are difficult to quantify. Suspended-sediment concentrations during stormflows at Yadkin College typically show two peaks; the first corresponding to the hydrologic response of Muddy Creek and the second to the response of the Yadkin River. The Muddy Creek peak occurs prior to the hydrograph peak. Suspended and total lead concentrations behave similarly to suspended-sediment concentrations during storm events. Only dissolved arsenic and dissolved selenium show dilution during storm events at Yadkin College.

Nutrient levels are usually high, allowing an abundant supply for plant growth in the Yadkin-Pee Dee lakes. Eutrophication is currently a problem in the lakes, and particularly in High Rock Lake (Weiss and Kuenzler, 1976).

An approximate balance of major sediment and nutrient inputs and outputs of the lake system shows an apparent loss of sediment, ammonia, and phosphorus to the lakes. The ammonia is due primarily to oxidation, and the phosphorus reduction is due to consumption by algae and precipitation with sediment. This approximate balance indicates that phosphorus is the limiting nutrient in the lake system, a conclusion common to other studies. Total nutrient concentrations tend to increase during stormflows, while dissolved-nutrient concentrations tend to decrease.

Biological data available for the Yadkin-Pee Dee stations characterize the river system as eutrophic and organically enriched with some degree of fecal contamination. Ambient BOD_5 levels are moderate to low at the Yadkin-Pee Dee stations. Fecal coliform and fecal streptococci bacteria occasionally peak above criterion levels recommended for body contact at all three stations. Fecal coliform:fecal streptococci ratios indicate that fecal contamination at Rockingham is primarily of animal origin.

Algae data give a good indication that organic pollution at Rockingham has been increasing since 1970. Algal diversity indices show the river system to be moderately eutrophic.

POLLUTION

A primary goal of this study is to identify how much of the total amount of dissolved and suspended material transported by the Yadkin-Pee Dee is man-made pollution; that is, to find how man has changed

the natural state of the stream. The accuracy of this evaluation hinges on the data available on the quality of water in the Yadkin-Pee Dee, prior to the influences of man. Very little, if any, natural water-quality data are available for the Yadkin-Pee Dee; therefore, it is necessary to make estimates of the natural state of the river, on the basis of data collected from other comparatively unpolluted streams.

Baseline Water Quality

Any effort to determine the type and quantity of stream pollution must necessarily account for the contribution of naturally occurring water quality to measured water quality. The methods described in Wilder and Simmons (1978) and Simmons and Heath (1979) have been applied to study baseline water quality in 39 small near-pristine basins through North Carolina. Although no surface water can be assumed to be totally free from the effects of man's activity, these baseline basins meet criteria for being free from significant human disruption in the form of agriculture, logging, construction, roads, or livestock. The sampling sites in the baseline water-quality network which lie within the Yadkin-Pee Dee basin are given in figure 30. Baseline stations were sampled at high and low-flow statewide, allowing zones of similar baseline water quality to be delineated. There are five of these zones in the State, and the Yadkin-Pee Dee basin lies almost entirely in zones I and II. A small, and hereafter neglected, area in the southeastern section of the basin includes zone III (fig. 30).

The estimated baseline water quality for each station (tables 11-13) is calculated from analyses of water samples collected at baseline sites lying in the basin. A mean base-flow composition and mean high-flow composition were calculated for each of the two geochemical zones included in the basin. The proportion of each basin upstream from Yadkin College, Norwood, and Rockingham lying in each geochemical zone was determined from figure 30. The basin upstream from Yadkin College is entirely (2,280 mi²) in zone I. The Rocky River (Norwood) subbasin is 34 percent (490 mi²) in zone I and 66 percent (942 mi²) in zone II. The basin upstream from Rockingham is 65 percent (4,400 mi²) in zone I and 35 percent (2,500 mi²) in zone II. Finally, the annual baseline load of each constituent was calculated for each of the three stations by multiplying the annual volume of water at base flow (Q_B) by the base-flow concentration of an ion or species (C_B). This process was repeated for high flow (Q_H, C_H), and the result was

summed to the base-flow value. Thus, baseline load (L_B) equals:

$$L_B = Q_B C_B + Q_H C_H. \qquad (3)$$

Cation-anion diagrams (Stiff, 1951) provide a graphic means for comparison of the ionic composition of water at the baseline water-quality sites to the ionic composition of water from the Yadkin-Pee Dee River (figure 31). The baseline water-quality diagram, in this example representing the mean of all baseline samples in the Yadkin-Pee Dee basin, is superimposed over the observed water-quality diagrams for the Yadkin and Pee Dee River stations. Concentrations of pollutants, as represented in the diagrams by the difference between the measured and baseline water quality, are greatest at Rocky River near Norwood and least at the Yadkin River at Yadkin College.

Tables 11 and 12 show baseline water quality for the Yadkin College and Norwood stations. Each table also shows, for comparison, means of measured concentrations of several constituents at these two stations. At the Yadkin College station, the mean base-flow contribution to the total annual flow was 54 percent, with a corresponding high-flow contribution of 46 percent. For the Rocky River near Norwood, the mean base-flow component of total annual discharge was 26 percent, with a corresponding mean high-flow component of 74 percent.

Evaluation of the differences between the measured concentrations and the baseline concentrations gives an estimate of the proportion of pollution in observed water quality. At all stations, 50 percent or more of the observed concentration of many substances is pollution. The few cases in which baseline concentrations exceeded mean measured values (especially in silica, iron, and mercury) point up the difficulties in this analysis, and in selecting sites that are truly baseline indicating that further sampling is required for several substances.

Although baseline water quality can be estimated for the Rockingham station in the same manner as above, the usefulness of the concept of base-flow and high-flow water quality is inapplicable in a stream in which the flow is regulated by lakes. The estimated baseline water quality for the Pee Dee River near Rockingham, derived without regard for flow, is given in table 13. For each geochemical (baseline) zone, a mean concentration was calculated from measurements at baseline stations lying within the Yadkin-Pee Dee basin, but the stage of the baseline streams was disregarded. These means were weighted by the proportion of the basin lying in each geochemical zone and were summed

81° 80°

V I R G I N I A

Ararat R.

Yadkin River

N. Deep Cr.

Winston-Salem

Muddy

Cr.

W. Kerr Scott Lake

36° 36°

Catawba

S. Yadkin R.

Statesville

River

Abbotts

High Rock Lake

I

II

Tuckertown Lake

Badin Lake

River

Lake Norman

Concord

Falls Lake

Albemarle

Little

Mountain Island Lake

Charlotte

Lake Tillery

Racky River

S O U T H

Lake Wylie

III

Blewett Falls Lake

35° 35°

Monroe

Pee Dee

River

NORTH CAROLINA

River

C A R O L I N A

0	10	20	30	40	50 MILES
0	20	40	60	80 KILOMETERS	

81° 80°

EXPLANATION

▼ Water-quality sampling station

● Baseline water-quality station

II Geochemical zone designation

—— Geochemical zone boundary

—··—··—Basin boundary

Figure 30. Baseline water-quality stations and geochemical zones in the Yadkin-Pee Dee River basin.

Table 11. Comparison of water quality of analyses for the Yadkin River at Yadkin College with analyses from baseline water-quality sites in the basin upstream from Yadkin College

| Constituent | A Baseline water quality | | | B Existing water quality | | | Percent attributable to pollution {[(B − A)/B]× 100} | |
| | Mean concentration (mg/L) | | Range of all samples (mg/L) | Mean concentration (mg/L) | | Range of all samples (mg/L) | | |
	Base flow	High flow		Base flow (<2000 ft³/s)	High flow (>2000 ft³/s)		Base flow	High flow
Dissolved:								
Calcium	1.4	0.6	0.6-1.6	4.5	3.6	1.2-8.6	69	83
Magnesium	.8	.9	.8- .9	1.3	1.1	.4-2.2	38	18
Sodium	1.9	1.3	1.3-2.1	5.8	3.8	.5-10.0	67	66
Potassium	1.1	.4	.4-1.25	2.0	1.7	1.2-3.5	45	76
Bicarbonate	9.3	8.0	8-9.5	24.4	17.9	7.0-31.0	62	55
Sulfate	1.7	.8	.8-1.75	3.5	3.4	2.7-6.5	51	76
Chloride	1.1	.6	.1-1.6	4.6	3.1	1.4-8.2	76	81
Fluoride	.1	.0	0- .01	.1	.1	0- .3	0	100
Silica	8.5	8.3	7.5-9.0	12.9	12.0	4.4-15.0	34	31
Solids	25.7	8	8-30	50.0	43.4	20-69	49	82
Total:								
Nitrogen	.3	.22	.12- .36	—	—	—	—	—
Organic nitrogen	.18	.09	.08- .24	1.52	.74	0-6.9	88	88
Nitrite + nitrate nitrogen	.125	.128	.01- .28	.49	.46	.2-1.0	74	72
Ammonia nitrogen	.003	.008	0- .01	.22	.16	0- .38	99	95
Phosphorus	.02	.02	.01- .025	.29	.27	.1- .8	93	93
Arsenic	0	0	0- .001	.003	.004	0- .009	100	100
Chromium	.01	.01	.01- .02	—	—	—	—	—
Copper	.007	.003	.003- .009	.006	.013	0- .033	17	77
Iron	.3	1.6	.1-3.0	.36	7.1	0-300	80	77
Lead	.0045	.013	.003- .013	.023	.019	0- .1	80	32
Mercury	.0005	.0005	.005	.0003	.0003	0- .0014	—	—
Selenium	0	0	0	.005	.002	0- .007	100	100
Zinc	.005	.01	.005- .01	.016	.045	0- .11	69	78

Table 12. Comparison of water quality of analyses for the Rocky River near Norwood with analyses from baseline water-quality sites in the basin upstream from Norwood

Constituent	A. Baseline water quality			B. Existing water quality			Percent attributable to pollution $\{[(B-A)/B]\times 100\}$	
	Mean concentration (mg/L)		Range of all samples (mg/L)	Mean concentration (mg/L)		Range of all samples (mg/L)		
	Base flow	High flow		Base flow (<250 ft³/s)	High flow (>250 ft³/s)		Base flow	High flow
Dissolved:								
Calcium	5.0	1.6	0.6–10	10.7	6.9	3.6–13	53	77
Magnesium	2.0	.8	.7–4.1	4.6	3.2	2.1–5.9	57	75
Sodium	5.0	2.1	1.3–7.3	74.5	17.2	3.8–120	93	88
Potassium	1.5	1.3	.4–1.8	6.3	2.5	1.9–10	76	48
Bicarbonate	26.9	4.7	3–44	110.4	36.2	10–162	76	87
Sulfate	4.1	5.6	.8–8.2	38.8	161.	8.8–56.0	89	65
Chloride	4.7	2.1	.1–10	59.1	15.2	5.2–96.0	92	86
Fluoride	.06	0	0–.1	.3	.1	.1–.6	80	100
Silica	16.4	8.2	7.5–28	12.9	11.1	5.1–19.0	—	26
Solids	60.9	42.3	8–98	277.4	108.2	46–723	78	61
Total:								
Nitrogen	.2	.5	0.1–.7	—	—	—	—	—
Organic nitrogen	.2	.5	.02–.7	.96	.94	.3–2.6	79	47
Nitrite+nitrate nitrogen	.5	.04	0–.3	.76	1.22	.6–3.5	34	97
Ammonia nitrogen	.004	.009	0–.01	.02	.17	.01–.45	80	95
Phosphorus	.02	.03	.01–.04	.68	.31	.03–1.4	97	90
Arsenic	.0003	.007	0–.001	.006	.004	.001–.01	95	83
Chromium	.013	.01	.01–.02	—	—	—	—	—
Copper	.006	.004	.003–.01	.008	.023	.006–.074	25	83
Iron	1.1	1.6	.1–3	.28	10.8	.55–41.0	—	85
Lead	.004	.009	.003–.013	.005	.029	0–.1	20	69
Mercury	.0005	.0005	.005	.0003	.0003	.1–8.8	83	—
Selenium	0	0	0	.001	.0003	0–1.0	100	100
Zinc	.008	.01	0–.01	.026	.04	0–.11	69	75

to produce the baseline water quality for the Pee Dee River given in table 13.

This treatment of the baseline data for the Pee Dee River near Rockingham presumes that the volume of water derived from the base flow is equivalent to the high-flow volume. The approximate equivalence between the volume of base flow and the volume of high-flow runoff in the Yadkin River at Yadkin College suggests that this presumption is correct.

The difference between the observed and baseline concentration of each species gives an estimate of the contribution of pollution to the observed values near Rockingham (table 13). These estimates for Rockingham are comparable to, and in a few cases lower than, the estimates for the other two stations. The lower values may be caused by loss of material due to sedimentation in the upstream reservoirs.

The annual loads for dissolved solids are given in table 14 for Yadkin College, table 15 for Norwood, and table 16 for Rockingham. The annual load resulting from base flow at Yadkin College (table 14) is much greater than the high-flow component, ranging from 74 percent to 84 percent of the total dissolved load. At Norwood (table 15), the reverse is true, with the high-flow component forming 50 percent to 78 percent of the annual load of dissolved solids. Although dissolved-solids concentrations are generally lower at high flow at both stations, the volume of water generated at high flow is proportionally much greater at Norwood than at Yadkin College, thus causing the disparity between the river chemistry at these two stations.

It is also interesting that the baseline annual load of dissolved solids is much greater for most water years in the Rocky River than in the Yadkin River, although the volume of annual discharge of the former is about half of the latter. This results from the generally higher baseline concentrations for the Rocky River basin compared to the upper Yadkin basin.

The greatest annual dissolved-solids loads appear in the Pee Dee River near Rockingham (table 16). The large annual flow volumes near Rockingham account for these large loads.

Pollution Loads

Two additional steps are required to estimate the annual pollution load once the annual baseline load has been evaluated. First, the total annual load must be calculated. The calculation of the annual load has been discussed by Harned (1980). Since actual dissolved-constituent concentrations are usually measured only once a month, daily dissolved-constituent concentra-

tions are estimated using linear regressions between dissolved-constituent concentrations and specific conductance. Daily loads of each constituent are evaulated by multiplying the estimated concentrations by the daily-discharge volume. Annual loads are calculated by summing the daily loads for each year. The results of these calculations for total dissolved solids are given in tables 14-16 for Yadkin College, Norwood, and Rockingham, respectively. The annual pollution load (also given in tables 14-16) is the difference between the total annual dissolved-solids load and the annual baseline load. The dissolved-solids loads plotted in figures 32-35 vividly demonstrate the importance of pollution in the makeup of the overall water quality of the Yadkin-Pee Dee River system. The area between the total dissolved-solids line and the baseline total dissolved-solids line in figures 32-35 represents pollution. However, these load estimates are probably high because they include the effects of airborne pollutants.

The percentages of annual dissolved-solids load attributable to pollution are given in tables 14-16. The highest mean value (59 percent) occurs at Yadkin College. The lowest mean is near Rockingham (29 percent), with Norwood (43 percent) between the extremes. The high proportion of pollution at Yadkin College is due to the low baseline concentrations of zone I (fig. 30) used in estimating baseline loads for the Yadkin River. On the other hand, baseline constituent concentrations are higher for zone II, which covers most of the rest of the basin area gaged by the Norwood and Rockingham stations. The baseline projections for the Rocky River near Norwood show especially high baseline concentrations, causing the percentage of the total load that is attributed to pollution to fall below that of Yadkin College. The variance in baseline concentrations among the different stations may be, in part, due to variation in atmospheric deposition of pollutants on the baseline basins.

A plot of the proportion of dissolved-solids load attributed to pollution against time for the three stations is given in figure 35. The correlations and slopes of regressions between time and proportion of dissolved-solids load attributed to pollution for each station are given in table 17. The pollution-derived proportion of the annual load at Yadkin College shows a slight decline from 1957 to 1978, although the load proportion due to pollution grew slowly from the late 1950's to the late 1960's. Norwood shows an increase in the proportion of the pollution-derived dissolved solids load over the 11-year period, 1957-67, with the period of 1962-67 showing a particularly rapid increase. The 1977 and 1978 years show a substantial decrease in the proportion of pollution-derived dissolved-solids load at Norwood.

Table 13. Comparison of water quality of analyses for the Pee Dee River near Rockingham with analyses from baseline water-quality sites in the basin upstream from Rockingham

Constituent	A Baseline water quality		B Existing water quality		Percent attributable to pollution $\{[(B-A)/B] \times 100\}$
	Mean concentra-tion (mg/L)	Range of all samples (mg/L)	Mean concentra-tion (mg/L)	Range of all samples (mg/L)	
Dissolved:					
Calcium	2.7	0.6–10	4.5	2.7–6.2	40
Magnesium	1.3	.7–4.1	2.1	1.3–9.0	38
Sodium	3.0	1.3–7.3	7.3	3.3–13.0	59
Potassium	1.2	.4–1.8	2.3	1.4–4.1	48
Bicarbonate	14.9	3–44	24.1	15.0–33.0	38
Sulfate	3.2	.8–8.2	6.9	2.0–11.0	54
Chloride	2.6	.1–10	6.4	3.2–11.0	59
Fluoride	.04	0– .1	.16	0– .5	75
Silica	11.4	7.5–28	10.4	6.5–13.0	—
Solids	40.3	17–78	61.6	42.0–79.0	35
Total:					
Nitrogen	.29	.1– .7	—	—	—
Organic nitrogen	.20	.02– .7	.4	.2– .7	50
Nitrite + nitrate nitrogen	.08	0– .3	.5	.1–1.0	84
Ammonia nitrogen	.006	0– .01	.08	.01– .17	93
Phosphorus	.02	.01– .04	.08	.0– .3	75
Arsenic	.0003	0– .001	.0004	0– .4	25
Chromium	.011	.01– .02	—	—	—
Copper	.005	.003– .01	.008	0– .05	38
Iron	1.05	.1–3	1.72	.32–6.10	39
Lead	.006	.003– .013	.016	0– .1	63
Mercury	.0005	.0005	.0002	0– .001	—
Selenium	0	0	.0004	0– .005	100
Zinc	.008	0– .1	.033	0– .35	76

YADKIN RIVER
MILLIEQUIVALENTS PER LITER

ROCKY RIVER
MILLIEQUIVALENTS PER LITER

PEE DEE RIVER
MILLIEQUIVALENTS PER LITER

EXPLANATION

Baseline
Pollution
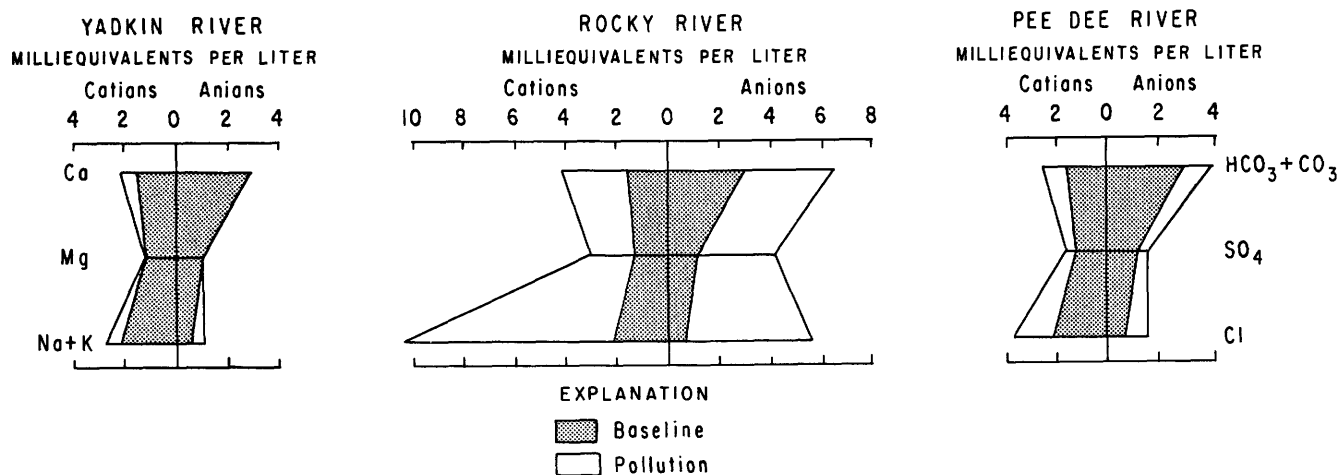
Figure 31. Comparisons of baseline water quality and observed water quality using cation-anion diagrams. The observed-data diagrams represent the mean concentrations of all samples taken in the 1974–78 water years. The baseline water-quality diagrams represent the mean concentration of all samples taken from baseline stations within the Yadkin-Pee Dee River basin.

Table 14. Dissolved-solids loads and concentrations for the Yadkin River at Yadkin College

Water year	Measured at Yadkin River at Yadkin College		Estimated from baseline-quality network		Annual loads			Annual concentrations		
	A Discharge (ft³/yr× 10³)	B Dissolved-solids load[1] (tons/yr)	C Dissolved-solids load[1] base flow (tons/yr)	D Dissolved-solids load[1] high flow (tons/yr)	E Baseline dissolved-solids load[1] (tons/yr) C + D	F Pollution dissolved-solids load[1] (tons/yr) B − E	G Percentage of total load from pollution FB × 100	H Total annual concentration (mg/L) B/A× 1.13× 10⁻³	I Baseline annual concentration (mg/L) E/A× 1.13× 10⁻³	J Annual pollution concentration (mg/L) H − I
1956 ———	1.8	62,630	24,164	4,794	28,958	33,671	54	39	18	21
1957 ———	3.3	188,301	37,342	10,931	48,274	140,027	74	65	17	48
1958 ———	4.8	158,411	54,931	15,726	70,657	87,753	55	37	17	21
1959 ———	2.8	103,397	30,767	9,561	40,328	63,068	61	42	16	26
1960 ———	5.4	174,877	63,972	17,095	81,068	93,808	54	37	17	20
1961 ———	3.4	128,192	35,150	12,301	47,452	80,740	63	43	16	27
1962 ———	4.0	142,438	43,945	13,671	57,616	84,822	60	40	16	24
1963 ———	3.3	123,562	35,150	11,616	46,767	76,795	62	42	16	26
1964 ———	2.8	111,041	32,958	8,876	41,835	69,205	62	45	17	28
1965 ———	4.2	162,110	48,328	13,671	62,000	100,110	62	44	17	27
1966 ———	2.8	102,466	28,547	10,246	38,794	63,671	62	41	16	26
1967 ———	2.2	90,521	26,356	6,849	33,205	57,315	63	67	17	29
1974 ———	4.6	168,055	63,698	11,616	75,315	92,740	55	41	19	23
1975 ———	4.5	135,699	59,315	12,301	71,616	64,082	47	34	17	16
1976 ———	3.2	118,438	39,534	9,561	49,095	69,342	59	42	17	25
1977 ———	3.2	105,288	41,726	8,219	49,945	55,342	53	37	18	19
1978 ———	4.4	170,055	59,315	11,616	70,932	99,123	58	44	18	26
Mean _	3.6	132,087	42,659	11,098	53,757	78,330	59	42	17	25

[1] Residue at 180°C.

Table 15. Dissolved-solids loads and concentrations for the Rocky River near Norwood

Water year	Measured at Rocky River near Norwood		Estimated from baseline-quality network		Annual loads			Annual concentrations		
	A Discharge (ft³/yr× 10³)	B Dissolved-solids load¹ (tons/yr)	C Dissolved-solids load¹ base flow (tons/yr)	D Dissolved-solids load¹ high flow (tons/yr)	E Baseline dissolved-solids load¹ (tons/yr) C+D	F Pollution dissolved-solids load¹ (tons/yr) B−E	G Percentage of total load from pollution FB×100 B/A×1.13×10⁻³	H Total annual concentration (mg/L) E/A× 1.13×10⁻³	I Baseline annual concentration (mg/L) H−I	J Annual pollution concentration (mg/L)
1956	1.13	–	14,575	30,739	45,315	–	–	–	45	–
1957	.95	69,288	18,547	22,411	40,959	28,329	41	82	49	34
1958	1.85	109,425	30,712	45,561	76,274	33,151	30	67	47	20
1959	1.69	107,890	14,575	50,986	65,562	42,329	39	72	44	28
1960	2.71	147,014	28,630	78,109	106,740	40,274	27	61	45	17
1961	1.43	97,699	19,780	37,972	57,753	39,945	41	77	46	32
1962	1.80	110,384	21,342	50,246	71,589	38,795	35	69	45	24
1963	1.39	104,000	19,780	36,520	56,301	47,699	46	85	46	39
1964	1.84	136,658	15,616	55,671	71,288	65,370	48	84	44	40
1965	2.26	164,466	28,109	62,191	90,301	74,164	45	82	45	37
1966	1.04	100,438	13,013	28,575	41,589	58,849	59	109	45	64
1967	.87	137,260	14,054	21,698	35,753	101,507	74	178	46	132
1974	1.40	–	19,780	36,876	56,658	–	–	–	46	–
1975	2.87	–	32,274	81,342	113,616	–	–	–	45	–
1976	1.10	–	21,342	21,698	43,041	–	–	–	44	–
1977	1.91	108,055	23,425	52,795	76,219	31,836	30	64	45	19
1978	2.06	153,562	26,027	56,411	82,438	71,123	46	84	45	39
Mean	1.66	118,933	21,269	45,283	66,552	51,797	43	86	45	40

¹ Residue at 180°C.

Table 16. Dissolved-solids loads and concentrations for the Pee Dee River near Rockingham

Water year	Measured at Pee Dee River near Rockingham		Annual loads			Annual concentrations		
	A Discharge (ft³/yr× 10¹³)	B Dissolved-solids load¹ (tons/yr)	C Baseline dissolved-solids load¹ (tons/yr)	D Pollution dissolved-solids load¹ (tons/yr) B−C	E Percentage from pollution D/B× 100	F Total annual concentration (mg/L) B/A× 1.13× 10⁻³	G Baseline annual concentration (mg/L) C/A× 1.13× 10⁻³	H Annual pollution concentration (mg/L) F−G
1956	5.4	—	186,027	—	—	—	39	—
1957	7.3	—	251,507	—	—	—	39	—
1958	12.1	482,466	416,712	65,753	14	45	39	6.1
1959	10.1	393,699	347,945	45,753	12	44	39	5.1
1960	14.8	605,753	509,863	95,890	16	46	39	7.3
1961	8.5	413,151	292,877	120,274	29	55	39	16.0
1962	9.8	457,260	337,534	119,726	26	53	39	13.8
1963	8.4	429,589	289,315	140,274	33	58	39	18.9
1964	8.7	442,192	299,726	142,466	32	57	39	18.5
1965	11.8	590,685	406,575	184,110	31	57	39	17.6
1966	6.6	357,808	227,397	130,411	36	61	39	22.3
1967	5.0	266,849	172,329	94,521	35	60	39	21.4
1974	11.0	—	378,904	—	—	—	39	—
1975	15.0	723,288	516,712	206,575	29	55	39	16.0
1976	7.7	417,808	265,205	152,603	37	61	39	22.4
1977	9.7	541,096	334,247	206,849	38	63	39	24.1
1978	12.2	684,658	420,274	264,384	39	63	39	24.5
Mean	9.7	486,164	332,538	140,685	29	56	39	16.7

¹ Residue at 180°C.
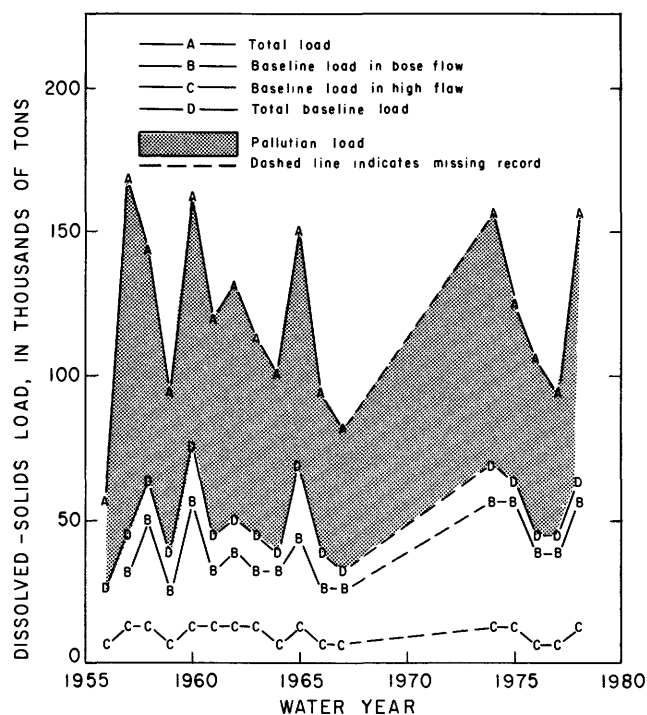
Figure 32. Dissolved-solids loads for the Yadkin River at Yadkin College.

Figure 33. Dissolved-solids loads for the Rocky River near Norwood.

The Pee Dee River near Rockingham shows a moderate overall increase in the proportion of the total dissolved-solids load derived as pollution over the period of 1958–67, with only a slight further increase during 1975–78.

Apparently, water-quality as measured by dissolved solids has improved at these three locations or, at least, has degenerated much more slowly in recent years than 10–20 years ago.

Comparisons between dissolved-solids loads at the three stations on the basis of load per square mile of drainage area are given in table 18 for total loads, baseline loads, and pollution loads. The Rocky River near Norwood has the greatest mean loads per square mile for all except the baseline load, where it matches the Pee Dee River near Rockingham.

TRENDS

Trend Analysis Techniques

The final goal of this study is to quantify how water quality in the Yadkin-Pee Dee River system has changed in the last 20 years. Determination of trends is

Figure 34. Dissolved-solids loads for the Pee Dee River near Rockingham.

not a simple problem. Different trend evaluation techniques may yield different or even conflicting results. In order to reduce the chance of making false conclusions
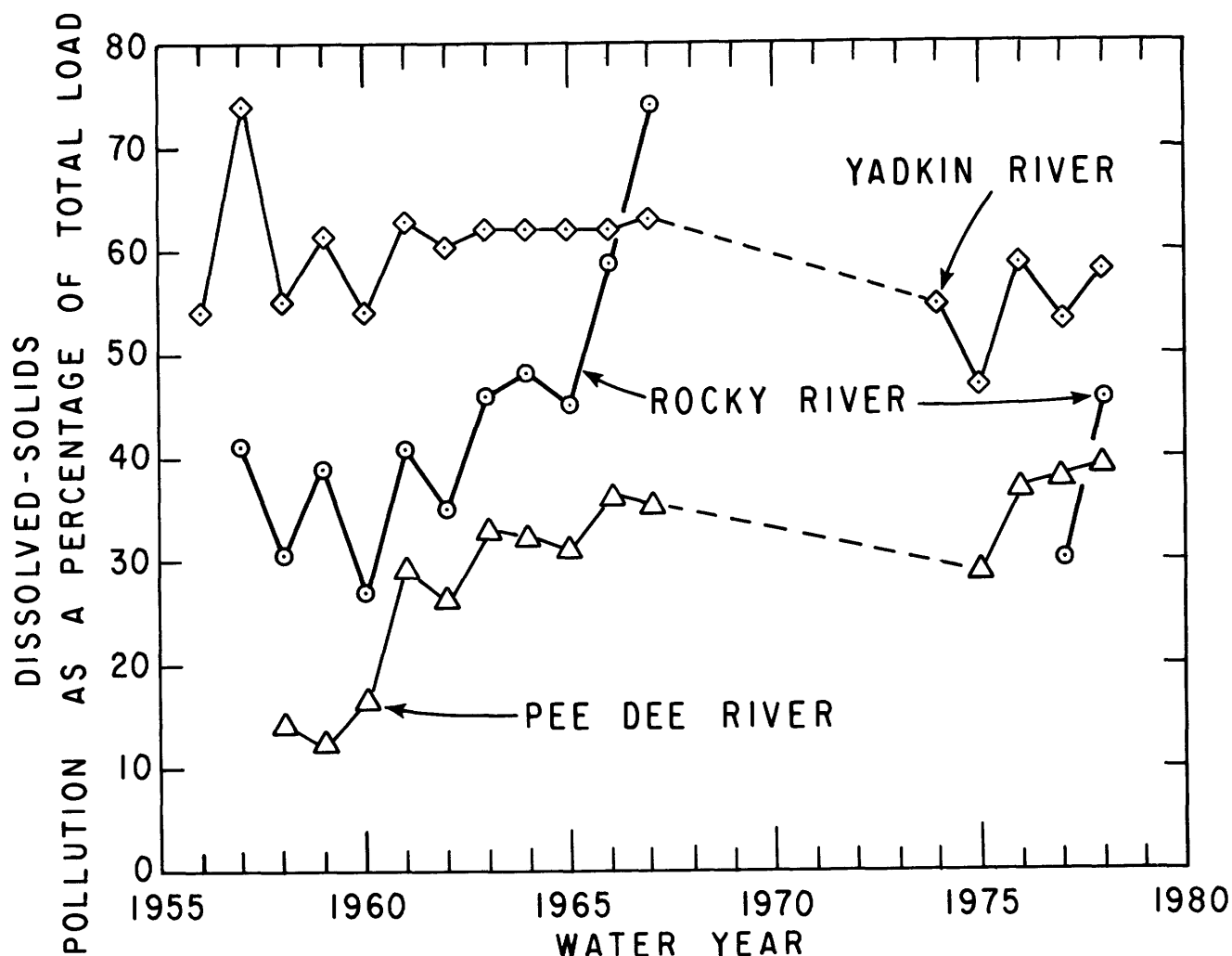
Figure 35. Dissolved-solids pollution as a percentage of total load for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham. (The dashed line indicates missing records.)

Table 17. Regression equations of percentage pollution versus time relations for the Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham (water years 1956-78, WY = water year - 1900)

Location	Regression equation for water years 1956-78	Squared correlation coefficient (r^2)	Probability[1]	Regression equation for water years 1956-67	Squared correlation coefficient (r^2)	Probability[1]
Yadkin River at Yadkin College	$YPP = 69.88 - 0.00247(WY^2)$	0.18	0.0922	$YPP = 53.774 + 0.00191(WY^2)$	0.03	0.625
Rocky River near Norwood	$NPP = -84.92 + 26.01(WY) - 0.189(WY^2)$	.41	.0730	$NPP = 2494.443 - 82.412(WY) + 0.690(WY^2)$	.85	.0005
Pee Dee River near Rockingham	$RPP = -645.42 + 19.01(WY) - 0.132(WY^2)$	.80	.0032	$RPP = -143.297 + 2.715(WY)$	.82	.0003

[1] Probability of obtaining a sample slope this large if the population slope is really zero.

about water-quality trends due to the peculiarities of a particular data-evaluation method, the results of four different approaches to trend analysis will be presented here:

1. Pollution load estimation,

2. Discharge normalization,
3. Discharge-frequency weighting, and
4. Multiple-regression analysis.

Pollution loads determined from the procedure described earlier (see "Pollution") can be plotted against

Table 18. Comparison of the annual yield of total dissolved solids, baseline dissolved solids, and pollution dissolved solids (Results in tons per year per square mile)

Water year	Total dissolved-solids load			Baseline dissolved-solids loads			Pollution dissolved-solids loads		
	Yadkin College	Norwood	Rockingham	Yadkin College	Norwood	Rockingham	Yadkin College	Norwood	Rockingham
1956 _____	1.00	—	—	0.46	1.21	0.99	0.54	—	—
1957 _____	3.01	1.85	—	.77	1.09	1.34	2.24	0.75	—
1958 _____	2.54	2.92	2.56	1.13	2.03	2.21	1.40	.88	0.35
1959 _____	1.66	2.87	2.09	.65	1.75	1.85	1.01	1.13	.24
1960 _____	2.80	3.92	3.22	1.30	2.84	2.71	1.50	1.07	.51
1961 _____	2.05	2.60	2.20	.76	1.54	1.56	1.29	1.06	.64
1962 _____	2.28	2.94	2.43	.92	1.91	1.79	1.36	1.03	.64
1963 _____	1.98	2.77	2.28	.75	1.50	1.54	1.23	1.27	.75
1964 _____	1.78	3.64	2.35	.67	1.90	1.59	1.11	1.74	.76
1965 _____	2.60	4.38	3.14	.99	2.41	2.16	1.60	1.98	.98
1966 _____	1.64	2.68	1.90	.62	1.11	1.21	1.02	1.57	.69
1967 _____	1.45	3.66	1.42	.53	.95	.92	.92	2.70	.50
1974 _____	2.69	—	—	1.21	1.51	2.01	1.48	—	—
1975 _____	2.17	—	3.84	1.15	3.03	2.75	1.03	—	1.10
1976 _____	1.90	—	2.22	.79	1.15	1.41	1.11	—	.81
1977 _____	1.69	2.88	2.87	.80	2.03	1.78	.89	.85	1.10
1978 _____	2.72	4.09	3.64	1.14	2.20	2.23	1.59	1.89	1.40
Mean ___	2.12	3.17	2.58	.86	1.77	1.77	1.29	1.38	.75

time to give a rough measure of trends in water quality. However, the magnitude of the annual load is highly dependent on annual discharge. Extraction of the effect of discharge from the actual trend is desirable.

Multiple regression is the curve-fitting method traditionally used when it is desirable to control for a specific variable, such as discharge. In this case, regression is used to define the water-quality constituent variable (C) as a function (f) of both time (t) and discharge (Q):

$$C = f(t, Q). \qquad (4)$$

When plotted, this function takes the form of a surface in three-dimensional space.

Three-dimensional plots are not very easy to interpret; however, plots of C versus t at constant values of Q can be used to illustrate trends with time. With the selection of an applicable regression model, multiple regression can define a long-term trend for the period of record being analyzed. It is not, however, capable of detecting shorter-term changes within the period, although residuals analysis may be used to show individual annual values (Harned and others, 1981).

Discharge normalization and discharge-frequency weighting are two methods of compensating for the effects of discharge in trend analysis that were developed for this study. Both methods produce discrete annual values that have been adjusted for discharge. Discharge

normalization adjusts daily discharges so that the central value of each annual discharge-frequency distribution coincides with the central value of the period-of-record discharge-frequency distribution. The method then recalculates daily specific conductance from the adjusted discharges and from regressions of specific conductance on discharge. Normalized concentrations for many constituents can then be calculated from linear relationships between specific conductance and constituent concentrations. Discharge normalization is essentially a modeling technique, and it has substantial data requirements. The annual normalized values produced by the method can be plotted and regressed against time to illustrate trends. The discharge-normalization technique is discussed in detail by Harned (1980) and by Harned and others (1981).

Discharge-frequency weighting assigns a statistical weight to each observed concentration. The weights consist of a fraction of the total area underneath the period-of-record discharge-frequency distribution. The weighted concentrations are summed for each year, plotted, and regressed against time to illustrate trends. This technique which is described in detail in Harned (1980) and Harned and others (1981), has the advantage of being simple, inexpensive, and easy to use. A comparsion of the results of discharge normalization, discharge-frequency weighting, and multiple regression is given in Harned and others (1980).

Results

Long-Term Trends

Pollution-load estimation, discharge normalization, and discharge-frequency weighting all produce annual values for water-quality parameters. These values are plotted against time, and regression lines evaluated for the plots represent trends over the period of record. Possible explanations for peaks or dips in values for individual years are of interest; however, such evalution will not be made here.

Equations for regression curves fit through the annual values of major constituent concentrations produced by each of the three methods are given in table 19 for the Yadkin River at Yadkin College, in table 20 for the Rocky River near Norwood, and in table 21 for the Pee Dee River near Rockingham. Multiple-regression results are also given in tables 19–21. Equations with time-slope terms that are statistically different from a zero slope (two-tailed t-test, probability level = 0.05) are indicated. The equations listed in tables 19–21 were determined using stepwise multiple regression with a careful examination of many regression models. The equations shown for pollution load, weighted concentrations, and normalized concentrations are the best equations found by varying only the form of the time term, since discharge was presumably accounted for by other means. The equations shown for multiple regression concentrations were the best found after a comparison of 19 different regression models where the forms of both the time and discharge terms were varied. The final equations shown in tables 19–21, for the multiple regression concentrations, were chosen from this exercise.

If all the slopes of the time terms in each equation were significantly different from a slope of zero, then the time slope was considered significant. Significance of the regression coefficients in a polynomial equation alone says little about how the time trend is behaving. In addition, the presentation of four different trend tests for each constituent in tables 19–21 is not meant as a comparison between methods. Different methods produce different regression models and different statistics. The results in tables 19–21 are shown simply to indicate which constituents show significant time trends. When several or all of the trend analysis approaches show significance, more confidence can be put in the examination of how the concentration or load of a particular constituent has varied over time.

Regression fits of sodium and chloride results have time slopes significantly different from a zero slope for all of the methods at all of the stations. Plots of weighted sodium results for the three stations are given in figure 36. Weighted chloride results for the station are given in figure 37.

The plots in figures 36 and 37 are typical of the overall pattern of water-quality change evident from this analysis of dissolved constituent water-quality data. A pattern of increasing concentration with time, up until about 1970 when concentrations begin to decrease slightly, is characteristic of the trends seen for most of the constituents examined for the Yadkin-Pee Dee River system stations. The trend pattern evident at Rocky River shows a dramatic decrease in concentration after 1970, while the decrease is generally not as pronounced at the Yadkin College station. The time when concentrations first decrease is particularly hard to define for the Rocky River, because data are available for only a few recent years. The trend patterns evident in figures 36 and 37 are similar for trends in sulfate, potassium, calcium, magnesium, dissolved solids, and specific conductance; however, the time slopes for calcium and magnesium results for Yadkin College are not statistically significant using any of the methods. A plot of weighted dissolved-soilds concentration against time for the three stations is given in figure 38. Dissolved-solids concentrations have remained relatively stable at Yadkin College and show a slight increase over time at Rockingham. Dissolved-solids concentrations for the Rocky River near Norwood, which show a rapid increase in concentration over time until the late 1960's, have decreased substantially in the late 1970's.

The recent decrease in major constituent concentrations, most evident at the Rocky River and Pee Dee River stations, corresponds to general improvement of municipal and industrial waste-water treatment facilities in recent years and changes in industrial production processes aimed at reducing pollution. However, ordinary municipal waste-water treatment processes do not generally remove dissolved constituents from the waste water. Therefore, the probable cause of the reduction in concentrations of dissolved constituents is a change in industrial processing. One industrial change that may have had a major impact on water quality in this region was the conversion in the textile mills from the manufacturing of cotton products to the use primarily of synthetic fabrics. The switch to snythetic fabrics has been known to cause dramatic decreases in dissolved-solids concentrations in the effluent from individual textile mills (Page Benton, North Carolina Department of Natural Resources and Community Development, verbal commun., February 1981). The observed decreases in major constituent concentrations may be only temporary as population growth outstrips the gains made by better waste-water treatment and industrial processing technology, or consumer tastes may

Table 19. Regression equations for water-quality trends for the Yadkin River at Yadkin College. The test of significance of the regression time slope was a two-tailed t-test at a probability level of 0.05

[Y = water year − 1950; $\bar{Q}$ = mean water year discharge; Q = sample discharge; T = year + (julian date/no. of days in year) − 1950; loads are in tons/yr; concentrations are mg/L]

Constituent	Regression equation	Squared correlation coefficient (r^2)	Is the time slope statistically different from zero?
Silica pollution load	$29894 - 0.666(Y \pm) + 2.390(\bar{Q})$	0.17	No
Normalized silica concentration	$14.271 - 0.00387(Y^2)$	.41	Yes
Weighted silica concentration	$13.098 - 0.0000914(Y^3)$	.27	Yes
Multiple regression silica concentration	$206.345 - 0.099(T) + 2039.047(\frac{1}{Q})$	.22	Yes
Calcium pollution load	$8639 - 0.0311(Y^3) + 0.533(\bar{Q})$	.13	No
Normalized calcium concentration	$3.467 + 0.00624(Y^2) - 0.000219(Y^3)$	.10	No
Weighted calcium concentration	$4.0885 - 0.00000985(Y^3)$	.27	No
Multiple regression calcium concentration	$-22.767 + 0.013(T) + 2307.069(\frac{1}{Q})$	.29	No
Magnesium pollution load	$2880 - 79.955(Y) + 0.455(\bar{Q})$	.34	No
Normalized magnesium concentration	$1.471 - 0.00305(Y^2) + 0.000107(Y^3)$	.10	No
Weighted magnesium concentration	$1.0340 + 0.00861(Y)$	.11	No
Multiple regression magnesium concentration	$-8.432 + 0.0005(T) + 222.592(\frac{1}{Q})$	.03	No
Sodium pollution load	$7.540 + 251.269(Y)$	.54	Yes
Normalized sodium concentration	$3.185 + 0.0630(Y)$	.59	Yes
Weighted sodium concentration	$3.718 + 0.0653(Y)$	.52	Yes
Multiple regression sodium concentration	$-122.033 + 0.063(T) + 4936.844(\frac{1}{Q})$	.71	Yes
Potassium pollution load	$796 + 137.893(Y) + 0.498(\bar{Q})$	.81	Yes
Normalized potassium concentration	$1.188 + 0.00206(Y^2)$	.63	Yes
Weighted potassium concentration	$1.0648 + 0.0478(Y)$	.81	Yes
Multiple regression potassium concentration	$-106.107 + 0.055(T) + 714.946(\frac{1}{Q})$	.40	Yes
Bicarbonate pollution load	$47683 - 2.0342(Y^2) + 1.549(\bar{Q})$	.07	No
Normalized bicarbonate concentration	$20.163 - 0.0397(Y)$	.03	No
Weighted bicarbonate concentration	$21.104 + 0.0000572(Y)$	.32	No
Multiple regression bicarbonate concentration	$2.917 + 0.00823(T) + 15922(\frac{1}{Q})$	.51	No
Sulfate pollution load	$1932 + 320.650(Y) + 0.902(\bar{Q})$	.71	Yes
Normalized sulfate concentration	$0.944 + 0.173(Y)$	.70	Yes
Weighted sulfate concentration	$1.454 + 0.0178(Y^2) - 0.000518(Y^3)$	.69	Yes
Multiple regression sulfate concentration	$-274.963 + 0.142(T) + 683.690(\frac{1}{Q})$	.43	Yes
Chloride pollution load	$5780 + 242.697(Y)$	.60	Yes
Normalized chloride concentration	$2.245 + 0.0121(Y) - 0.000361(Y^2)$	.67	Yes
Weighted chloride concentration	$2.804 + 0.0558(Y)$	.42	Yes
Multiple regression chloride concentration	$-127.081 + 0.066(T) + 3406.487(\frac{1}{Q})$	.49	Yes
Nitrate pollution load	$3146.5 + 4.445(Y^2) + 0.33698(\bar{Q})$	.61	Yes
Normalized nitrate concentration	$1.270 + 0.0545(Y)$	.32	Yes
Weighted nitrate concentration	$1.1656 + 0.0553(Y)$	.67	Yes
Multiple regression nitrate concentration	$-110.508 + 0.057(T) + 449.08(\frac{1}{Q})$	.24	Yes
Dissolved-solids pollution load	$123115 - 579.754(Y) + 4.322(Q)$		No
Normalized dissolved-solids concentration	$4.960 + 8.584(Y) - 0.538(Y^2) + 0.0103(Y^3)$	.37	Yes
Weighted dissolved-solids concentration	$35.650 + 1.265(Y) - 0.0312(Y^2)$	.27	No
Multiple regression dissolved-solids concentration	$-345.461 + 0.195(T) + 17814.109(\frac{1}{Q})$	.39	Yes

Table 20.—Regression equations for water-quality trends for the Rocky River near Norwood. The test of significance of the regression time slope was a two-tailed t-test at a probability level of 0.05

[Y = water year − 1950; $\overline{Q}$ = mean water year discharge; Q = sample discharge; T = year + (julian date/no. of days in year) − 1950; loads are in tons/yr; concentrations are mg/L]

Constituent	Regression equation	Squared correlation coefficient (r^2)	Is the time slope statistically different from zero?
Silica pollution load	$12774 - 1.231(Y^3) + 4.174(\overline{Q})$	0.58	Yes
Normalized silica concentration	$21.0431 - 0.0000796(Y^2)$	.03	No
Weighted silica concentration	$12.284 + 0.151(Y)$	.38	Yes
Multiple regression silica concentration	$127.784 - 0.059(T) + 0.000003(Q)$	.03	Yes
Calcium pollution load	$6162 - 0.486(Y^3) + 2.122(\overline{Q})$	.69	Yes
Normalized calcium concentration	$9.000420 + 0.126(Y)$	.72	No
Weighted calcium concentration	$8.0873 + 0.0164(Y^2) - 0.000513(Y^3)$	.64	Yes
Multiple regression calcium concentration	$-27.508 + 0.011(T) - 0.00003(Q)$	.08	No
Magnesium pollution load	$2361 - 0.234(Y^3) + 0.977(\overline{Q})$	.66	Yes
Normalized magnesium concentration	$4.152 + 0.0000371(Y^3)$	.12	No
Weighted magnesium concentration	$3.592 + 0.0000341(Y^3)$	.42	Yes
Multiple regression magnesium concentration	$-35.441 + 0.019(T) - 0.000002(Q)$	.05	Yes
Sodium pollution load	$2980 + 180.222(Y^2) - 5.906(Y^3)$	.63	Yes
Normalized sodium concentration	$-3.584 + 0.294(Y^2) - 0.00979(Y^3)$	.49	Yes
Weighted sodium concentration	$34.0578 + 0.191(Y^2) - 0.00710(Y^3)$	.53	Yes
Multiple regression sodium concentration	$-141.124 + 0.076(T) - 0.00018(\overline{Q})$	.31	Yes
Potassium pollution load	$627 + 14.505(Y^2) - 0.567(Y^3) + 0.537(Q)$	.66	No
Normalized potassium concentration	$1.671 + 0.0154(Y^2) - 0.000452(Y^3)$	.64	Yes
Weighted potassium concentration	$3.0774 + 0.0122(Y^2) - 0.000433(Y^3)$	.66	Yes
Multiple regression potassium concentration	$-81.849 + 0.43(T) - 0.000017(Q)$	.36	Yes
Bicarbonate pollution load	$27184 + 238.845(Y^2) - 9.925(Y^3) + 5.681(\overline{Q})$	.55	Yes
Normalized bicarbonate concentration	$200.0206 - 36.491(Y) + 2.747(Y^2) - 0.0592(Y^3)$	.81	Yes
Weighted bicarbonate concentration	$97.993 - 0.00176(Y^3)$	.55	Yes
Multiple regression bicarbonate concentration	$-568.403 + 0.334(T) - 0.00435(Q)$	.16	No
Sulfate pollution load	$8894 - 0.120(Y^3) + 2.282(\overline{Q})$	.66	No
Normalized sulfate concentration	$8.306 + 0.550(Y)$	.64	Yes
Weighted sulfate concentration	$15.590 + 0.0133(Y^2)$	.76	Yes
Multiple regression sulfate concentration	$324.432 + 0.168(T) + 0.000003(Q)$	.41	Yes
Chloride pollution load	$3259 + 127.707(Y^2) - 4.051(\overline{Q})$	.47	Yes
Normalized chloride concentration	$-1.672 + 0.214(Y^2) - 0.00701(Y^3)$	.45	Yes
Weighted chloride concentration	$18.569 + 0.198(Y^2) - 0.00681(Y^3)$	.52	Yes
Multiple regression chloride concentration	$160.799 + 0.085(T) - 0.0001(Q)$	.20	Yes
Nitrate pollution load	$2610.4 - 86.6071(Y) + 0.3494(\overline{Q})$	.16	No
Normalized nitrate concentration	$4.156 - 0.06878(Y^2) + 0.003959(Y^3)$	.74	Yes
Weighted nitrate concentration	$1.5796 + 0.00589(Y)$	.87	Yes
Multiple regression nitrate concentration	$-310.073 + 0.1593(T) + 0.000044(\tfrac{1}{Q})$	.25	Yes
Dissolved-solids pollution load	$40277 + 598.187(Y^2) - 23.738(Y^3) + 17.415(\overline{Q})$	.64	Yes
Normalized dissolved-solids concentration	$63.873 + 0.807(Y^2) - 0.0262(Y^3)$	.55	Yes
Weighted dissolved-solids concentration	$102.91 + 1.0306(Y^2) - 0.0347(Y^3)$	.62	Yes
Multiple regression dissolved-solids concentration	$859.480 + 0.468(T) - 0.0002(Q)$	.18	Yes

Table 21. Regression equations for water-quality trends for the Pee Dee River near Rockingham. The test of significance of the regression time slope was a two-tailed t-test at a probability level of 0.05

[Y = water year − 1950; $\bar{Q}$ = mean water year discharge; Q = sample discharge; T = year + (julian date/no. of days in year) − 1950; loads are in tons/yr; concentrations are mg/L]

Constituent	Regression equation	Squared correlation coefficient (r^2)	Is the time slope statistically different from zero?
Silica pollution load	$15352 - 1060.119(Y) + 10.509(\bar{Q})$	0.82	No
Normalized silica concentration	$16.564 - 0.0382(Y^2) + 0.00118(Y^3)$	.52	Yes
Weighted silica concentration	$11.677 - 0.0553(Y)$	.21	Yes
Multiple regression silica concentration	$127.785 - 0.059(T) + 0.000003(Q)$	.08	Yes
Calcium pollution load	$11210 + 359.554(Y) + 2.817(\bar{Q})$	.37	No
Normalized calcium concentration	$5.0738 + 0.00671(Y^2) - 0.000226(Y^3)$	.19	No
Weighted calcium concentration	$1.187 + 0.768(Y) - 0.0468(Y^2) + 0.000866(Y^3)$	.27	Yes
Multiple regression calcium concentration	$27.508 + 0.011(T) - 0.00003(Q)$	.08	No
Magnesium pollution load	$-12.745 + 0.0435(Y^3) + 1.549(\bar{Q})$	.67	No
Normalized magnesium concentration	$1.899 + 0.00000875(Y^3)$	.07	No
Weighted magnesium concentration	$1.445 + 0.0226(Y)$	.24	Yes
Multiple regression magnesium concentration	$-35.441 + 0.019(T) - 0.000002(Q)$	.05	Yes
Sodium pollution load	$6270 + 232.0711(Y^2) - 7.711(Y^3) + 3.152(\bar{Q})$	.82	Yes
Normalized sodium concentration	$-1.694 + 1.215(Y) - 0.0335(Y^2)$	.71	Yes
Weighted sodium concentration	$-1.364 + 1.194(Y) - 0.0328(Y^2)$	.55	Yes
Multiple regression sodium concentration	$-141.124 + 0.076(T) - 0.00018(Q)$	.31	Yes
Potassium pollution load	$-908.997 + 625.202(Y) + 0.959(\bar{Q})$	.26	No
Normalized potassium concentration	$1.382 + 0.0506(Y)$	.48	Yes
Weighted potassium concentration	$0.167 + 0.184(Y) - 0.000143(Y^3)$	.66	Yes
Multiple regression potassium concentration	$-81.849 + 0.043(T) - 0.000017(Q)$	.36	Yes
Bicarbonate pollution load	$85005 + 1413.494(Y) + 13.346(\bar{Q})$	.15	No
Normalized bicarbonate concentration	$25.383 + 0.0653(Y^2) - 0.00239(Y^3)$	.35	No
Weighted bicarbonate concentration	$-8.685 + 6.778(Y) - 0.356(Y^2) + 0.00554(Y^3)$	.63	Yes
Multiple regression bicarbonate concentration	$259.264 - 0.1166(T) - 0.00039(Q)$	.29	Yes
Sulfate pollution load	$-9398 + 923.486(Y) + 4.553(\bar{Q})$	.73	Yes
Normalized sulfate concentration	$-15.713 + 4.00323(Y) - 0.228(Y^2) + 0.00415(Y^3)$	.72	Yes
Weighted sulfate concentration	$2.936 + 0.0249(Y^2) - 0.000716(Y^3)$	.65	Yes
Multiple regression sulfate concentration	$-324.432 + 0.168(T) + 0.000003(Q)$	.41	Yes
Chloride pollution load	$-37334 + 6322.759(Y) - 153.0855(Y^2) + 2.915(\bar{Q})$	.77	Yes
Normalized chloride concentration	$-3.0370 + 1.112(Y) - 0.0287(Y^2)$	.60	Yes
Weighted chloride concentration	$-1.406 + 0.946(Y) - 0.0244(Y^2)$	.58	Yes
Multiple regression chloride concentration	$-160.799 + 0.085(T) - 0.0002(Q)$	.20	Yes
Nitrate pollution load	$-6805.6 + 413.168(Y) + 1.7629(\bar{Q})$	.73	No
Normalized nitrate concentration	$0.8566 + 0.005299(Y^2)$	.64	Yes
Weighted nitrate concentration	$1.2337 + 0.02217(Y)$	.54	Yes
Multiple regression nitrate concentration	$-50.9 + 0.026(T) + 0.000011(Q)$	.07	Yes
Dissolved-solids pollution load	$23338 + 5103.474(Y) + 42.805(\bar{Q})$	.92	Yes
Normalized dissolved-solids concentration	$58.567 + 0.562(Y)$	.57	Yes
Weighted dissolved-solids concentration	$31.0789 + 3.482(Y) - 0.0883(Y^2)$	.52	Yes
Multiple regression dissolved-solids concentration	$-859.489 + 0.468(T) - 0.002(Q)$	.18	Yes

Figure 36. Weighted sodium concentrations for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham. (The dashed line indicates missing records.)

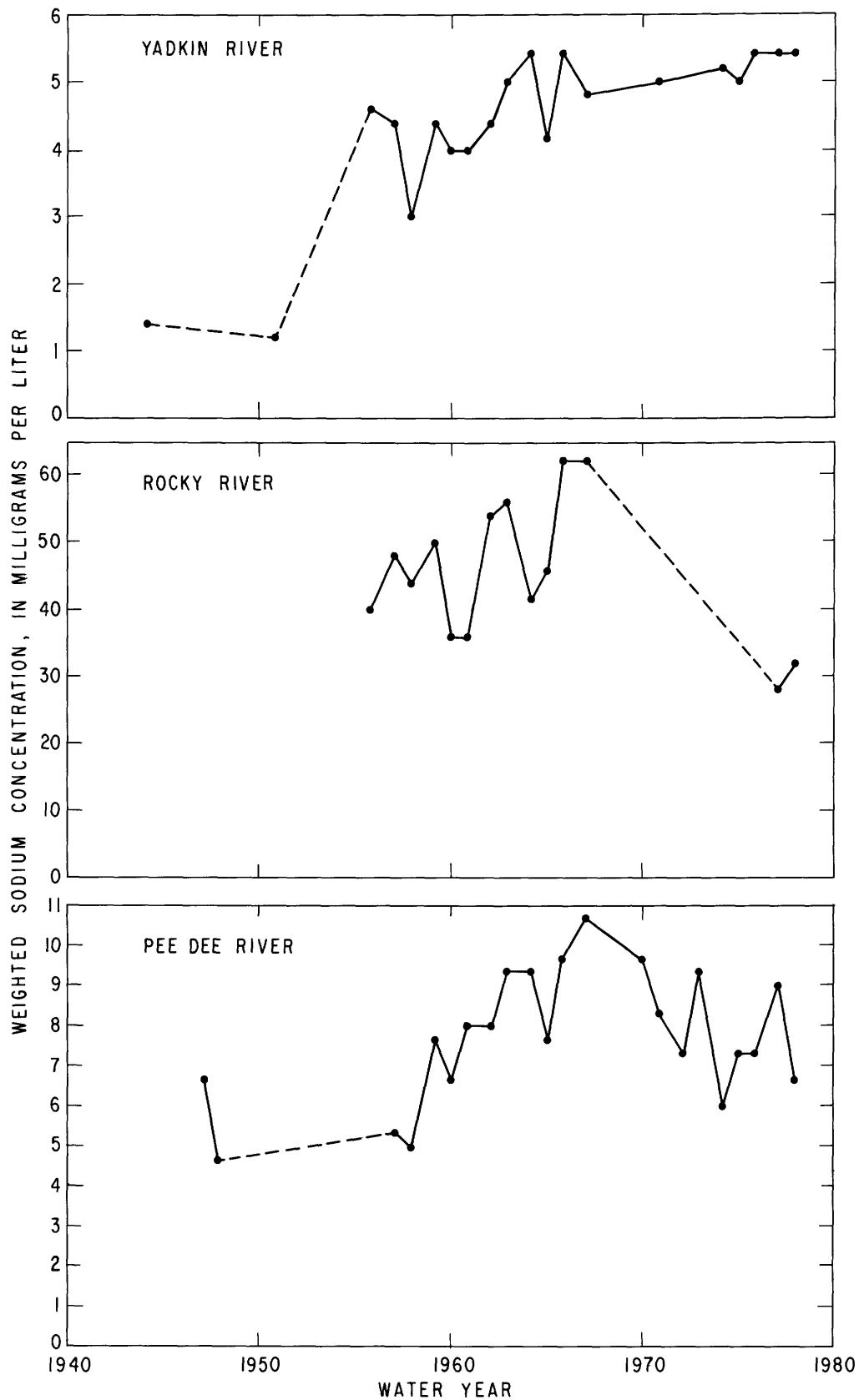**Figure 37.** Weighted chloride concentrations for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham. (The dashed line indicates missing records.)

Figure 38. Weighted dissolved-solids concentrations for the Yadkin River at the Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham. (The dashed line indicates missing records.)
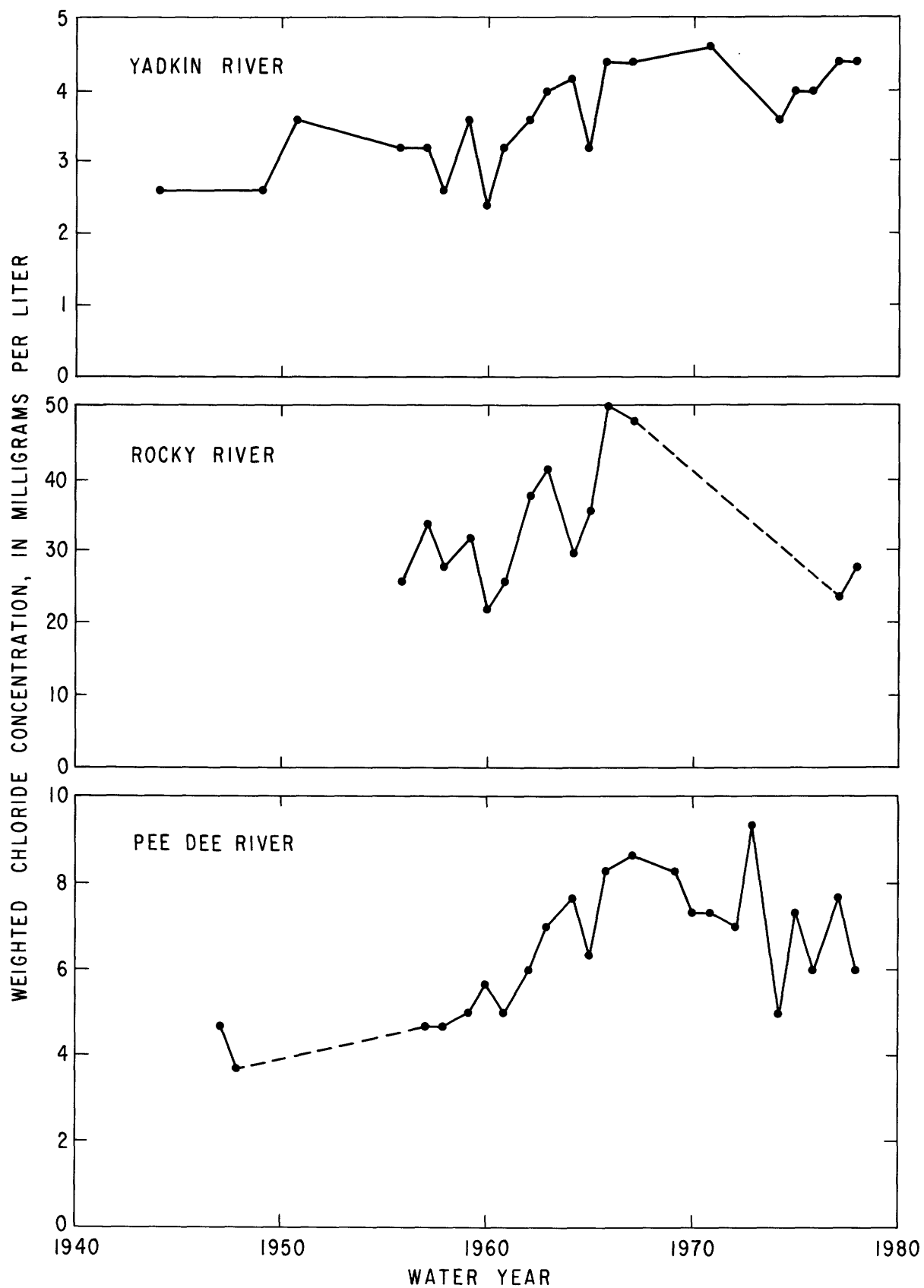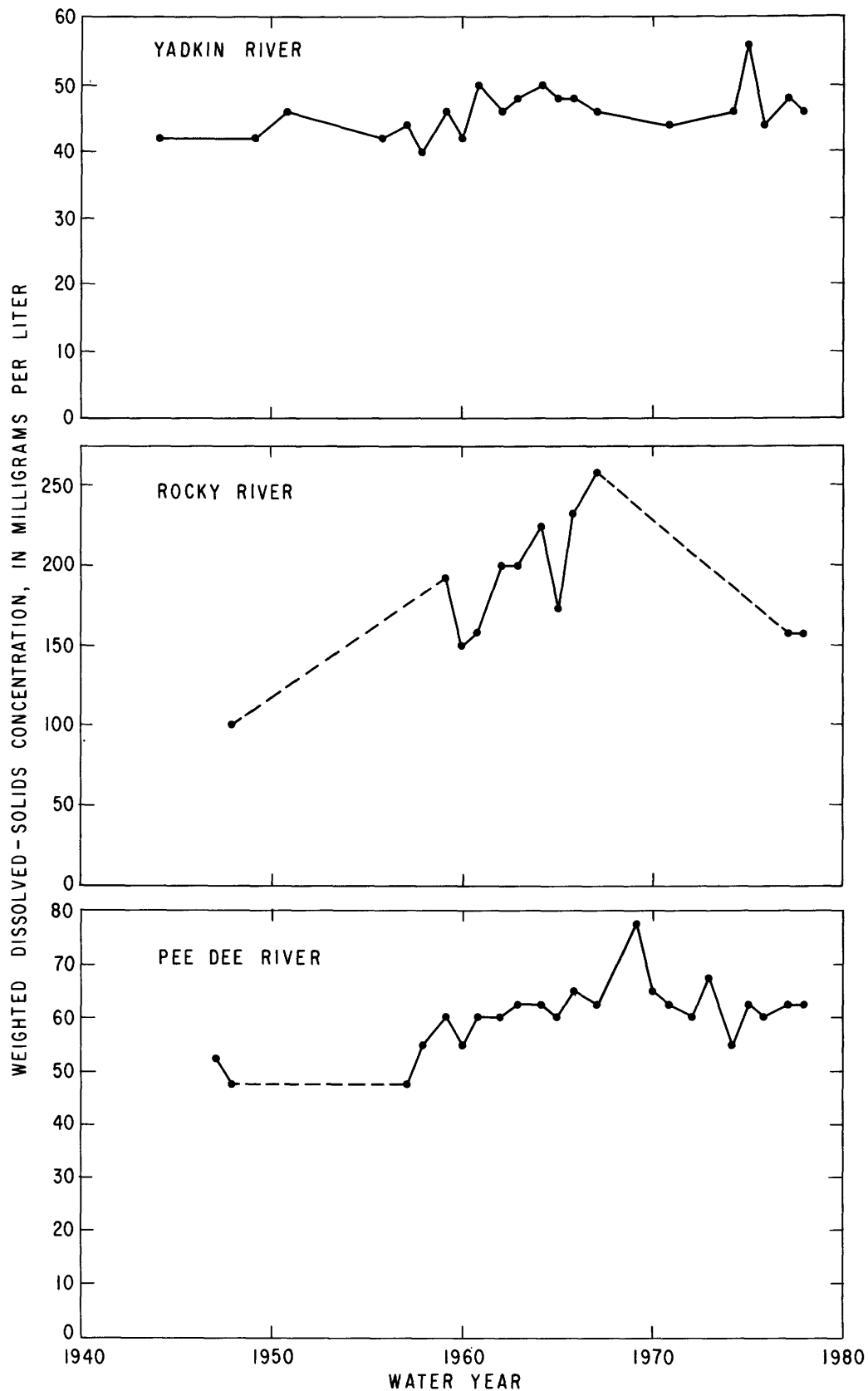
change, causing factories to use materials that have a greater water-quality impact.

Results for dissolved sulfate, given in figure 39, are somewhat anomalous. Sulfate concentrations have steadily increased, even at Rocky River. One probable cause for the observed increase in sulfate concentration is air pollution. Sulfate is but one of the many forms that sulfur may take when released into the air from the combustion of coal and oil. Oxidation in the atmosphere of inorganic gases including hydrogen sulfide (H_2S), sulfur dioxide (SO_2), and sulfur trioxide (SO_3) can produce acids such as sulfuric acid (H_2SO_4), which are prime components of acid precipitation (Likens and others, 1979). In fact, pH at both Yadkin College and Rockingham has decreased significantly over the last 20 years (J. K. Crawford, U.S. Geological Survey, written commun., March 13, 1980). Plots of pH against time for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham are given in figure 40.

The increases seen in most constituents are an indication of the subtle long-term change in the chemistry of the Yadkin-Pee Dee River system. Although these major dissolved constituents are not as relevant to water-quality impact evaluation as constituents such as nutrients or toxic materials, the observed long-term increases are indications of the increasing impact of man on the Yadkin-Pee Dee River System.

Plots of dissolved nitrate against time (fig. 41) give some idea of how nutrient levels in the river system have increased with time.

Sediment concentrations for the Yadkin River at Yadkin College show a dramatic decrease since 1951. Weighted sediment concentrations at this station, given in figure 42, indicate that much of this decrease occurred during 1951–65. From 1965 on, weighted sediment concentration has changed very little. Possible causes of this trend are the large-scale conversion of cropland to pasture that occurred during this period (Ospina and Danielson, 1973) and agricultural practices aimed at reducing soil erosion. In spite of this improvement, sediment concentrations remain the single most important problem in the Yadkin-Pee Dee basin (see "Water-Quality Variations" section). This conclusion, which is based on the many detrimental impacts of high sediment concentrations and loads, is substantiated by results of the Yadkin Pee Dee basin Level B study (U.S. Department of Agriculture, 1979; North Carolina Department of Natural Resources and Community Development and others, 1980d).

Overall, trend analysis of the water quality of major chemical constituents shows that concentrations of most constituents have increased substantially over time. However, a recent decrease in concentrations, probably due largely to improved waste-water treatment or changes in industrial processes in the basin, is also evident.

Water Quality—Population Relations

Pollution and population are closely related. Increases in population are inevitably matched with increases in amounts of man-produced wastes. The level of pollution of rivers is largely a function of the amount of waste produced and of how the wastes are disposed. Although simple relations between population and pollution exclude the effect of reduction of pollution by waste treatment, they provide an approximate means of estimating future water-quality conditions from population projections.

County population projections available in the Level B Comprehensive Water Resources Study (North Carolina Department of Natural Resources and Community Development and others, 1979b) and from the North Carolina Office of State Budget and Management (1980) were regressed with weighted and normalized dissolved-constituent concentrations to produce equations that can be used to predict future water-quality conditions in the Yadkin-Pee Dee River system. The equations that have slopes statistically different from zero (two-tailed t-test at a probability level of 0.05) are listed in table 22. Several of the lines produced by these equations are given in figure 43.

The projected trend of normalized sulfate for the Pee Dee River near Rockingham shows a dramatic and unlikely projected increase. Although trend projections of this sort may be statistically sound, they may not necessarily reflect reality. Considerable care must be used when making estimates of conditions for outside the range of the observed data. More complex multiple-regression analysis involving other important independent variables, such as land-use or employment indexes, may prove to be fruitful.

SUMMARY

Assessment of water quality of the Yadkin-Pee Dee River system included an identification of water-quality variation in reference to water-quality criteria, an estimation of the amount of pollution caused by man, and an evaluation of long-term trends in concentrations of major dissolved constituents.

Three stations, Yadkin River at Yadkin College (02116500), Rocky River near Norwood (02126000), and Pee Dee River near Rockingham (02129000), have been sampled with some frequency over the last 25
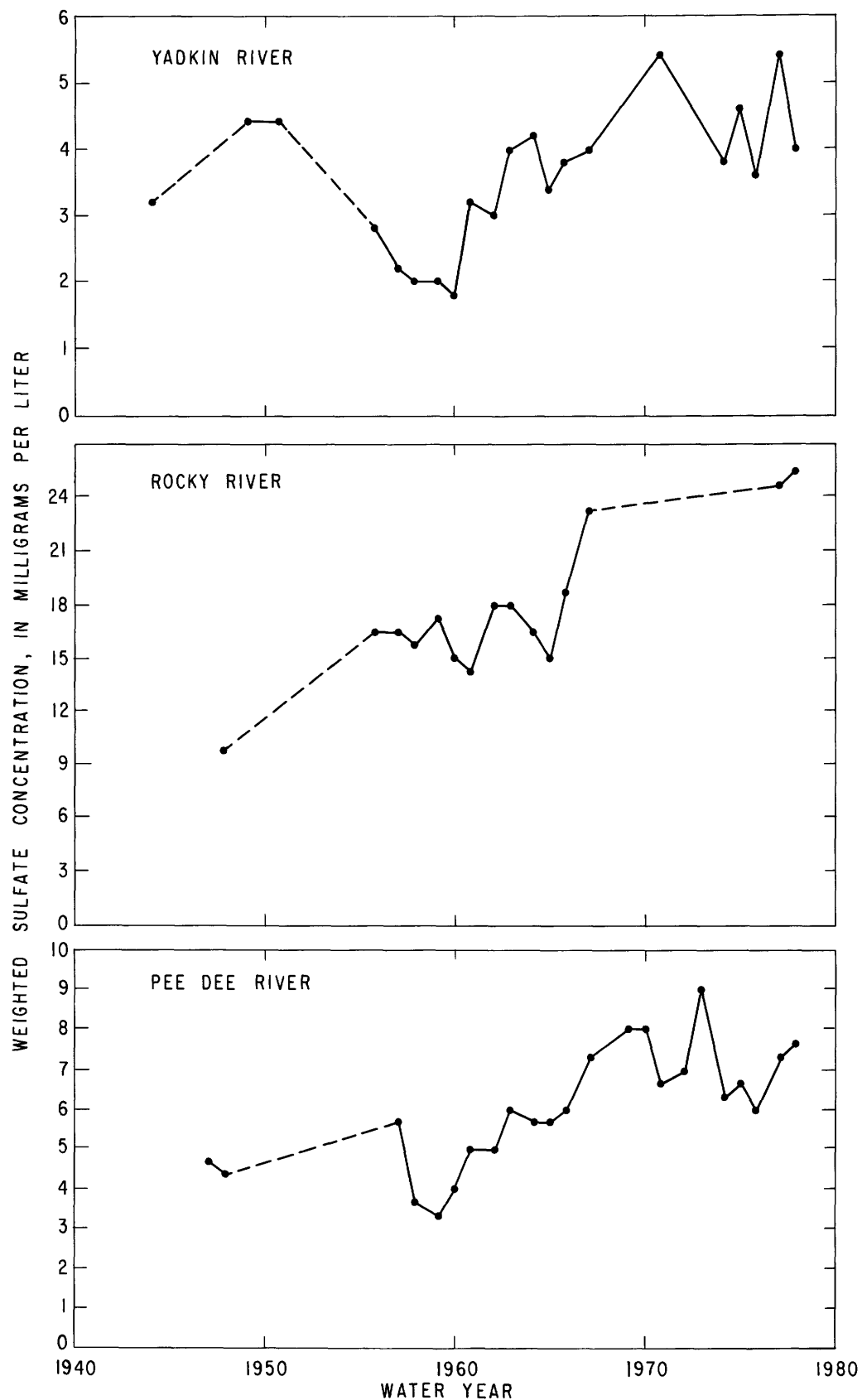
Figure 39. Weighted dissolved-sulfate concentrations for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham. (The dashed line indicates missing records.)

YADKIN RIVER AT YADKIN COLLEGE

```
9 |                                                         |
                                      EXPLANATION
                                   A = 1 Observation
                                   B = 2 Observations, and
                                        so forth
8 |           A                                           A
                 A              B
         BA   A A ACA  A                      A
         BACAABB ABB A BAAA B                 ACB           A
7 |AA AA AB A       A B A                     AA A      A  A
  AA A CA BBA  ACB A ACBABA                   AA BC    A    DC
  |A A    BAB    BA ABAA    A A    B    BCGAAAAC A A A A A
  |       A  A              A  A   A  A AABA  AA     A
         AA              AA / A AA    ACBAB      AA  ABA
6 |AA        A              A A   BABB B A       A     A A|
                               A                   A   A
      pH=57.966-0.0260(T)          A
         r = -0.40                      A

5 |                                                       |

4 |_____|_____|_____|_____|_____|
1960     1965     1970     1975     1980
```

PEE DEE RIVER NEAR ROCKINGHAM

```
9 |                                                       |

8 |                     A
      A        A A
      ABA     A  A A              B A
   B   A ABAAABB      A        AAA  BA A              BA
7 |AAABABCB BBAAA BBBB B        AA AA B  A A       A  BAC
  |A A   CA   BAA A AA          A    A   A
  | A A AAAA A A  BBAB   C BCABAABBAA  BAAABBAABBBAA  A
  AA  A  A   AA ABA A B /A    BB  AB B  A AA ABA       BB
  A        A            /     AA     A   BAA B  A BB AB
  A         A           /    AA A B  BA   AB  B  AB  A
6 |                          A  A  A C A       A   A   C
      pH = 72.652 - 0.0334 (T)              A
         r = -0.47                    A
                                      A           A
                                      A           A        A
5 |                                                       |

4 |_____|_____|_____|_____|_____|
1960     1965     1970     1975     1980
                    YEAR
```
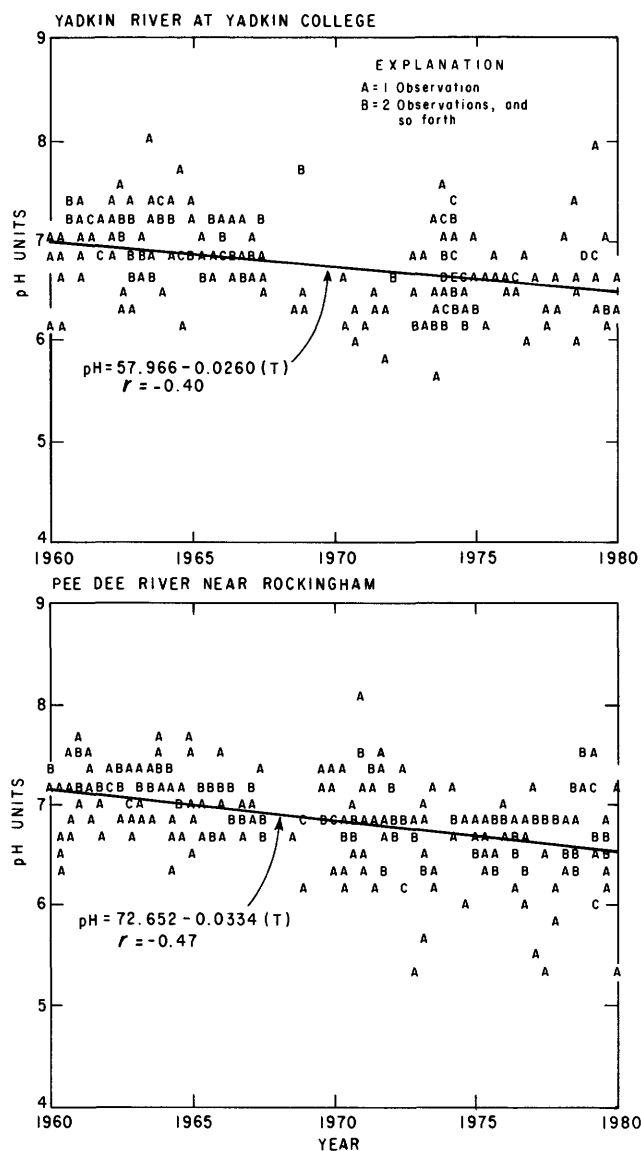
Figure 40. Trends in pH for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham. [T = year + (julian date/number of days in the year) − 1950; r = correlation coefficient.]

water quality. The constituent concentrations measured in these streams were extrapolated to the Yadkin-Pee Dee River system in order to estimate baseline loads of the major chemical constituents.

The Yadkin-Pee Dee River system is an important water-supply and valuable recreational and ecological resource. The basin is currently (1980) the subject of a large-scale Level B planning study designed to define the problems of and propose options for effective management of water-resources allocation, development, and use. Reports that have been written in various stages of this comprehensive planning effort list: sediment and nonpoint-source pollution, protection of water supplies, optimal operation of hydropower and flood-control lakes, and pollution control as just a few of the Yadkin-Pee Dee basin problems that must be addressed in future management of the river system.

The Yadkin-Pee Dee River system plays an important role in waste disposal. Much industrial effluent is treated by municipal treatment plants. The total average waste-water input to the Yadkin-Pee Dee River system upstream from Rockingham, 325.3 ft^3/s, is approximately 29 percent of the 7-day, 10-year minimum flow at that station (1,110 ft^3/s).

Specific conductance shows no extreme values at the Yadkin College and Rockingham stations. However, the large range and relatively high values measured for the Rocky River near Norwood is an indication of pollution.

Dissolved-oxygen values measured at the three stations are lowest for the Pee Dee near Rockingham, probably due mainly to the low dissolved-oxygen levels of water discharged from the bottom of Blewett Falls Lake, which is not far upstream from the station. Diel patterns of dissolved oxygen typically show a dependence on variation of water temperature. In addition, during summer months, a midday rise in the dissolved-oxygen concentration is probably due to algal photosynthesis. Short-term declines in dissolved-oxygen concentrations in the Yadkin River at Yadkin College are often associated with the first flush of storm events.

Values for pH show the Yadkin-Pee Dee River system to be slightly acidic in reference to the U.S. Environmental Protection Agency (1976) criteria recommended for the protection of fish populations. Fifty percent of the pH measurements of the Yadkin River at Yadkin College, 20 percent of the measurements for the Rocky River near Norwood, and 30 percent of the Pee Dee River near Rockingham measurements are below 6.5 pH units.

The major cation in the Yadkin-Pee Dee River system is sodium and the predominant anions are bicarbonate and carbonate. As with specific conductance,

years. The station at Yadkin College is located downstream from Winston-Salem, a city with a (1970) population of 133,000 (U.S. Bureau of the Census, 1971) and upstream from the extensive system of lakes on the Yadkin River. The station on the Rocky River, a major tributary to the Yadkin-Pee Dee, is located near the confluence of the Rocky River with the Pee Dee River. The station on the Pee Dee River near Rockingham is close to the North Carolina-South Carolina State line.

A network of temporary stations located on small rural streams was used to define essentially unpolluted
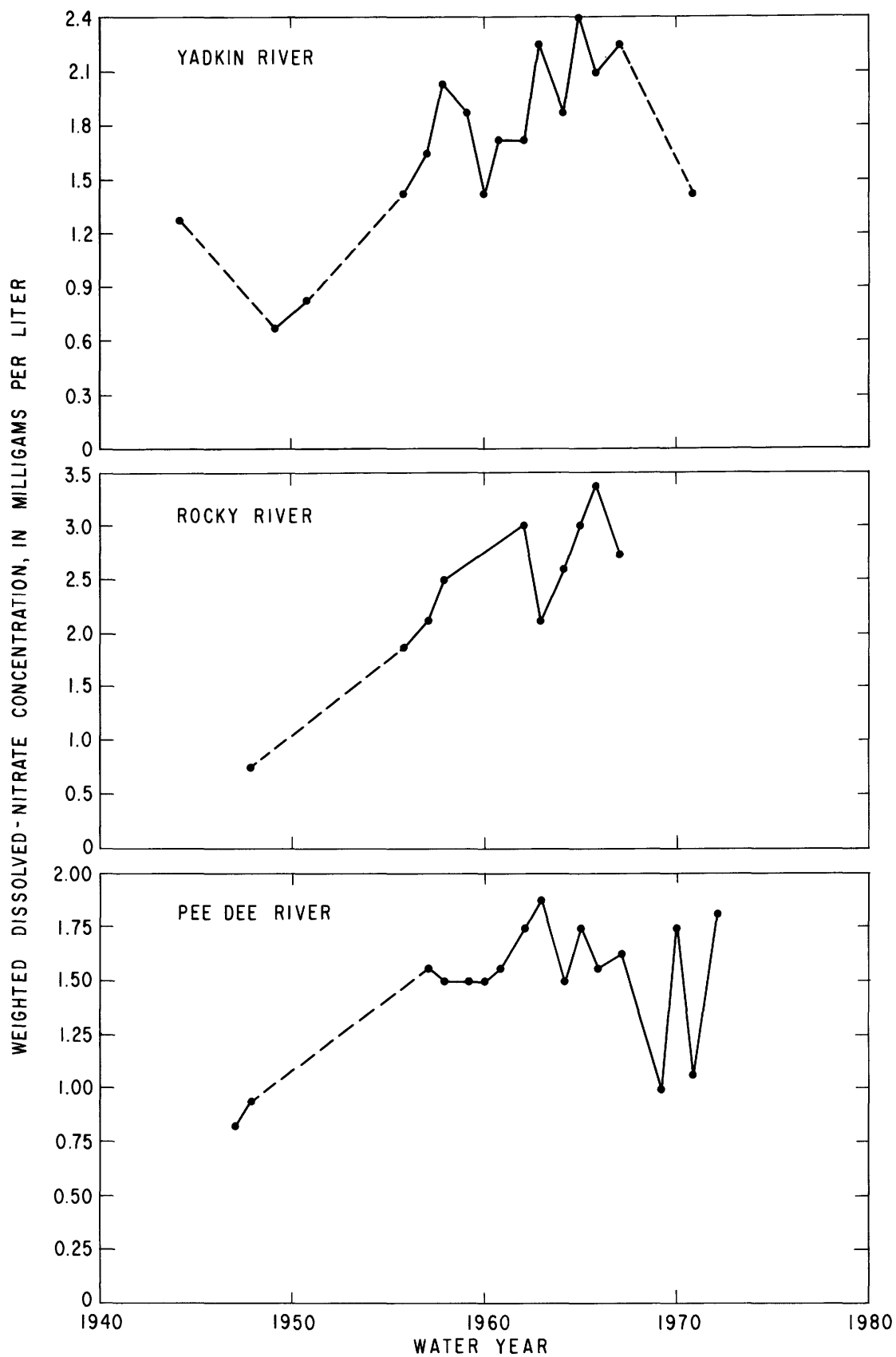
Figure 41. Weighted dissolved-nitrate concentrations for the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham. (The dashed line indicates missing records.)

Table 22. Multiple regression equations for relations between chemical or physical measures of water quality, time, and populations. All equations have slopes significantly different from a zero slope (two-tailed t-test, probability$= 0.05$) $T=$ year; county population breakdown: $UP=$ (Davidson$+$ Davie$+$ Forsyth$+$ Guilford$+$ Iredell$+$ Randolph$+$ Rowan$+$ Surry$+$ Wilkes$+$ Yadkin)/1000; $LOW=$ (Anson$+$ Cabarrus$+$ Montgomery$+$ Richmond$+$ Stanly$+$ Union)/1000

Constituent (mg/L)	Multiple regression equation	Squared correlation coefficient (r^2)
Yadkin River at Yadkin College		
Weighted silica concentration	$-39.756 - 2.109$ $(T) + 0.00169$ (Union)	0.80
Weighted calcium concentration	$5.691 - 0.000180$ (Cabarrus)$+ .0121$ (UP)	.74
Weighted sodium concentration	$3.228 + 0.0820$ (T)	.92
Weighted potassium concentration	$-5.75 + 0.000177$ (Cabarrus)$- 0.00577$ (UP)	.96
Weighted sulfate concentration	$-83.0848 + 0.00201$ (Cabarrus)$- 0.000912$ (Union)$- 0.0135$ (UP)	.95
Weighted chloride concentration	$-7.107 + 0.601$ $(T) + 0.000550$ (Cabarrus)$- 0.000763$ (Union)	.99
Normalized potassium concentration	$-5.521 + 0.000121$ (Cabarrus)	.66
Pee Dee River near Rockingham		
Weighted silica concentration	$26.895 - 0.000614$ (Davidson)$+ 0.000551$ (Randolph)	.77
Weighted magnesium concentration	$-93.289 - 0.714$ $(T) + 0.000847$ (Forsyth)$- 0.000945$ (Randolph)	.91
Weighted sodium concentration	$12.134 + 0.000814$ (Davidson)$- 0.00112$ (Iredel)	.52
Weighted potassium concentration	$-5.71 + 0.000342$ (Davidson)$- 0.000322$ (Randolph)	.67
Weighted sulfate concentration	$-5.922 + 0.000131$ (Davidson)	.44
Weighted dissolved-solids concentration	$-383.976 + 5.306(T) + 0.0124$ (Davidson)$- 0.00634$ (Forsyth)$+ 0.00785$ (Iredell)$- 0.0107$ (Randolph)	.91
Weighted specific conductance	$1,417.574 + 13.653(T) - 6.241$ (LOW)	.69
Normalized sulfate concentration	$-110.911 + 1.824$ $(LOW) - 0.00166$ (Forsyth)	.86

concentrations of major dissolved constituents are generally highest at Norwood. However, these concentrations are still satisfactory for most uses of the water. Specific conductance can be satisfactorily related to most dissolved-constituent concentrations.

Iron and manganese are the only trace elements that appear in concentrations consistently above levels suggested for domestic water supply. Lead concentrations exceed U.S. Environmental Protection Agency (1976) criteria for domestic water supply in 6 percent of the samples from Yadkin College and 8 percent of the Rockingham samples. All of the samples taken at the Norwood station, 56 percent of the Rockingham samples, and 53 percent of the Yadkin College samples exceeded mercury concentrations recommended for the protection of aquatic life.

Suspended sediment is the most significant water-quality problem of the Yadkin-Pee Dee River system. The levels of suspended sediment are high in comparison to levels observed in pristine streams; however, impacts of sediment are so numerous that the effects of these high levels are difficult to quantify. The response of suspended-sediment concentration to storm discharge of the Yadkin River at Yadkin College is double peaked. The first peak in suspended-sediment concen-

tration represents the hydrologic response of Muddy Creek, a tributary draining the south of Winston-Salem. The second peak in suspended-sediment concentration is the response of the Yadkin River. The Muddy Creek peak occurs prior to the peak in discharge demonstrating what is termed the "first flush" effect. Suspended-sediment response during floodflow has not been recorded in detail at either of the other two stations. The response at Rocky River is rapid and probably similar to Yadkin College. The changes in discharge at Rockingham are nearly paralleled by changes in sediment concentration, due to the large basin area and the lakes upstream.

Suspended and total lead concentrations behave similarly to suspended-sediment concentrations during storms. Only dissolved arsenic and dissolved selenium show dilution during storms. Total nutrient concentrations tend to increase during stormflows, while dissolved nutrient concentrations tend to decrease.

High nutrient concentrations in the river system provide a rich medium for algal growth. Eutrophication is currently a problem in the Yadkin-Pee Dee lakes, particularly High Rock Lake. Approximate nutrient and sediment balances of the lake system indicate that the lakes serve as a sink for sediment, ammonia nitrogen,
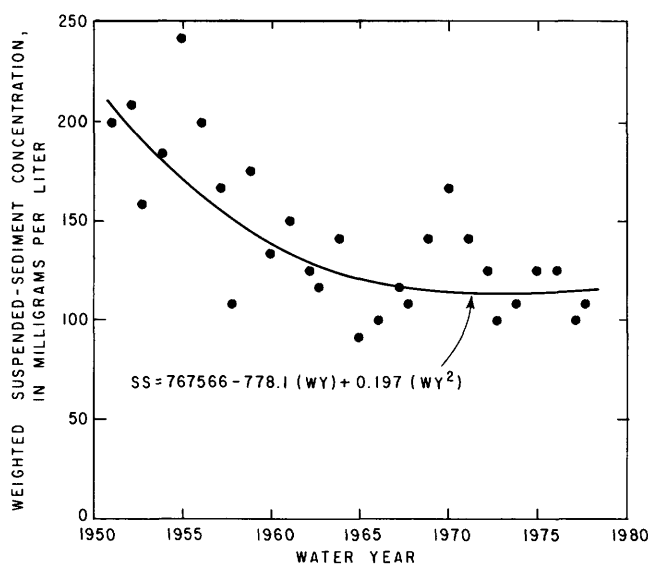
Figure 42. Weighted suspended-sediment concentrations (SS) for the Yadkin River at Yadkin College (WY = water year).

and phosphorus. The ammonia reduction between input to and output from the lake system is due primarily to oxidation to other nitrogen species. The phosphorus reduction is probably due to consumption by algae and precipitation with sediment. The predominance of evidence indicates that phosphorus is limiting.

Algal data indicate that organic pollution has been increasing since 1975. Algal diversity indices and genus identification show the river system to be moderately eutrophic. In the Yadkin River at Yadkin College, diatoms and blue-green algae dominate the phytoplankton assemblage. Diatoms dominate the assemblage observed for the Pee Dee River near Rockingham. The reduced occurrence of blue-green algae indicates that the water is less eutrophic at Rockingham than at Yadkin College.

Fecal coliforms and fecal streptococci bacteria occasionally peak above the U.S. Environmental Protection Agency (1976) criterion levels recommended for body contact. The ratio of the fecal coliform count to the fecal streptococci count for the Pee Dee River near Rockingham indicates that fecal contamination at this point in the river is primarily of nonhuman origin.

An approximation of pollution in the Yadkin-Pee Dee River system was determined by subtracting estimated baseline constituent loads from measured total loads. In order to evaluate baseline loads from the baseline water-quality network, an estimate of the proportions of base flow and high flow that make up the total flow is needed. For the Yadkin River at Yadkin College, base flow was estimated to be 54 percent with high flow 46 percent of the total volume of flow. At the
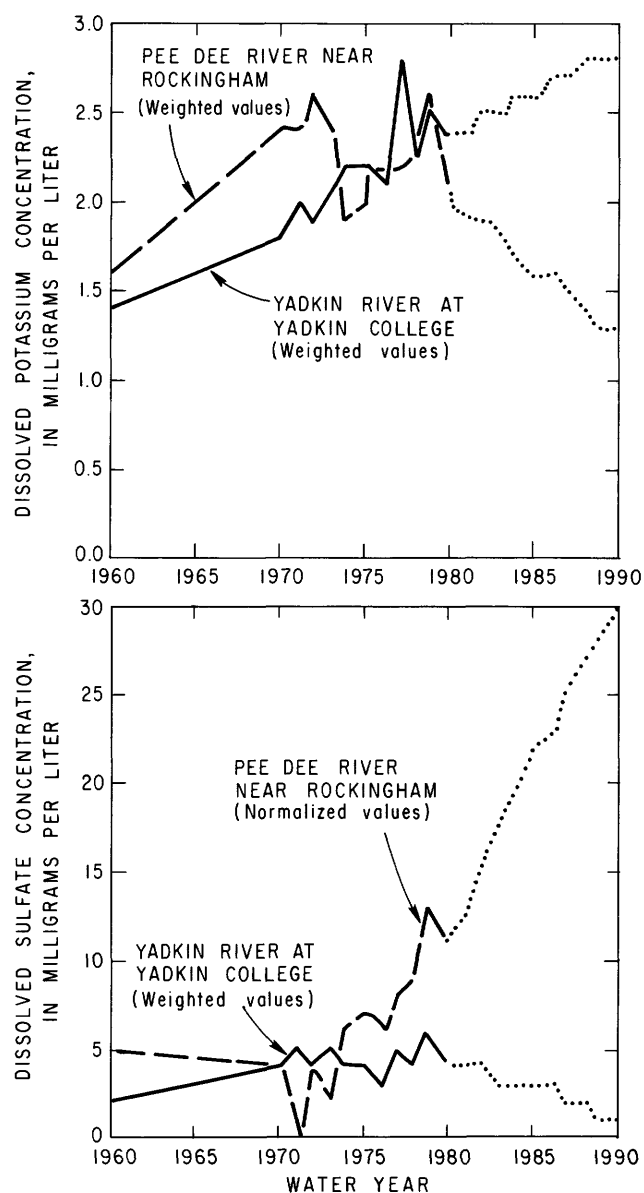

Figure 43. Projected trends of dissolved-sulfate and dissolved-potassium concentrations for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham, from equations listed in table 21. (The dotted line indicates projected trends.)

Rocky River near Norwood, the base-flow component of the total annual discharge was 26 percent with a corresponding high-flow component of 74 percent. Meaningful estimates were not possible for the Pee Dee River near Rockingham because of the upstream lakes, so the proportions of high and base flow were each assumed to be 50 percent of the total flow.

Pollution makes up approximately 59 percent of the total dissolved-solids load of the Yadkin River at Yadkin College, 43 percent for the Rocky River near

Norwood, and 29 percent for the Pee Dee River near Rockingham. However, on the basis of loads per square mile of drainage area, Rocky River near Norwood has the greatest mean total load and mean pollution load.

Dramatic, statistically significant trends are evident in major dissolved ionic-constituent concentrations at all three stations. The trends over time, seen in dissolved sodium and chloride, are typical of the overall pattern of water-quality change. The pattern shows increasing concentration with time, with a leveling off and decline in the middle to late 1970's. The pattern shows the most extreme rise and fall for Rocky River results, while the decrease is less pronounced for the Pee Dee River near Rockingham and least apparent with Yadkin River at Yadkin College results.

These trend patterns suggest that something happened in the middle 1970's to bring about an improvement in the long-term deterioration of water quality of the Yadkin-Pee Dee River and the Rocky River. This time period corresponds to general improvement of waste-water treatment and changes in industrial processing aimed at reducing pollution in the basin. Processes used in municipal waste-water treatment do not normally reduce dissolved-constituent concentrations. Therefore, the reductions in concentrations seen in the Rocky and Yadkin Rivers are probably due to changes in industrial processing. One change that may account for the reduction is the recent conversion at textile mills from processing of primarily cotton fabrics to synthetic fabrics.

The trend of dissolved sulfate shows a relatively steady increase in concentration over time. Increases in sulfate and nitrate concentration are probably largely a result of the increasing acidity of precipitation with time. The acids carried by rain and other precipitation are made up predominately of sulfur and nitrogen compounds. Decreasing trends in pH with time in the Yadkin-Pee Dee River system illustrate the large-scale effect of the increasing acidity of precipitation.

A dramatic decrease in weighted sediment concentration over time has occurred in the Yadkin River at Yadkin College. This decrease is probably due to agricultural land-use changes that have occurred in the basin and to improved erosion-control.

Relations between water-quality and population provide a rough means of predicting future water quality. However, projections made with these simplistic relations must be used with care.

The ongoing collection of water-quality data by the U.S. Geological Survey and other agencies reflects the growing awareness of the need to accurately assess the water quality of the Yadkin-Pee Dee River system on a continuing basis. Growing environmental aware-

ness and improved laboratory techniques have promoted accurate identification and routine monitoring of many important trace materials in water, including manmade substances only recently created. These data, along with the framework provided by improved data-analysis techniques, will be invaluable in future assessments of the water quality of the Yadkin-Pee Dee River system.

REFERENCES CITED

Colby, B. R., 1956, Relationship of sediment discharge to streamflow: U.S. Geological Survey Open-File Report, 170 p.

Daniel, C. C., III, Wilder, H. B., and Weiner, M. S., 1979, Water quality of the French Broad River, North Carolina—An analysis of data collected at Marshall, 1958–77: U.S. Geological Survey Water-Resources Investigations 79–87, 53 p.

Duke Power Company, 1975, Final environmental statement related to the construction of Perkins Nuclear Station, units 1, 2, and 3: October.

Ficke, J. F., and Hawkinson, R. O., 1975, The national stream quality accounting network (NASQAN)—Some questions and answers: U.S. Geological Survey Circular 719, 23 p.

Gable, R. W., and Lammers, W. T., ed., 1976, A report of the Rocky River study center for honors studies: Davidson College, Davidson, N.C.

Geldriech, E. E., 1966, Sanitary significance of fecal coliforms in the environment: Federal Water Pollution Control Administration WP-20-3, 122 p.

Harned, Douglas A., 1980, Water quality of the Neuse River, North Carolina—Variability, pollution loads, and long-term trends: U.S. Geological Survey Water-Resources Investigations 80–36, 88 p.

Harned, D. A., Daniel, C. C., III, and Crawford, J. K., 1981, Methods of discharge compensation as an aid to the evaluation of water quality trends: Water Resources Research, October, v. 17, no. 5, p. 1389–1400.

Hem, John D., 1970, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Hilsenhoff, William L., 1977, Use of Arthropods to evaluate water quality of streams: Wisconsin Department of Natural Resources, Bulletin No. 100.

Likens, G. E., Wright, R. F., Galloway, J. N., and Butler, T. J., 1979, Acid rain: Scientific American, October, v. 241, no. 4, p. 43–51.

Lindskov, K. L., 1974, Movement and dispersion of soluble materials in Salem Creek, Muddy Creek, and Yadkin River between Winston-Salem and Salisbury, North Carolina: U.S. Geological Survey Water-Resources Investigations 6–74, 26 p.

Livingstone, D. A., 1963, Chemical composition of rivers and lakes *in*, Data of Geochemistry (6th ed.): U.S. Geological Survey Professional Paper 440-G, 64 p.

Margalef, Ramon, 1968, Perspectives in ecological theory: The University of Chicago Press, Chicago, Ill., 111 p.

Miller, C. R., 1951, Analysis of flow-duration, sediment rating curve, method of computing sediment yield: Denver, U.S. Bureau of Reclamation, 15 p.

National Oceanic and Atmospheric Administration, 1973, Monthly normals of temperature, precipitation, and heating and cooling days 1941-70, North Carolina: Climatography of the U.S. no. 81, National Climatic Center, Asheville, N.C.

National Technical Advisory Committee, 1968, Water-quality criteria, a report of the National Technical Advisory Committee to the Secretary of the Interior: U.S. Government Printing Office, Washington, D.C.

North Carolina Department of Water and Air Resources, 1972, Basin population: Water Resource Planning Section.

North Carolina Department of Natural and Economic Resources, 1975, Report of water-quality study—special report—status of pollution controls and water quality, High Rock Lake: Division of Environmental Management, Water-Quality Section, September.

————1976a, Report of investigation—Muddy Creek and Yadkin River fishkill, Yadkin-Pee Dee River basin: Division of Environment Management, Water-Quality Section.

————1976b, Report on an investigation of water use in the Yadkin River basin.

————1976c, Water quality management plan—Yadkin River basin, Parts 1-3: Division of Environmental Management, Environmental Management Commission.

————1977, North Carolina water resources framework study: Division of Environmental Management, North Carolina Water Plan.

North Carolina Department of Natural Resources and Community Development, 1979, Water quality management plan, executive summary: Division of Environmental Management, 25 p.

North Carolina Department of Natural Resources and Community Development, South Carolina Water Resources Commission, and U.S. Water Resources Council, 1979a, Comprehensive water-resources study, Yadkin-Pee Dee River basin, Plan of Study (Draft): April.

————1979b, Comprehensive water-resources study, Yadkin-Pee Dee River basin, Existing Plan: October.

————1980a, Comprehensive water-resources study, Yadkin-Pee Dee River basin, Analysis of floodplains and wetlands: August.

————1980b, Comprehensive water-resources study, Yadkin-Pee Dee River basin, Alternative plans (Draft): August.

————1980c, Comprehensive water-resources study, Yadkin-Pee Dee River basin, Alternative plans, Technical appendix, Detailed analysis: August.

————1980d, Comprehensive water-resources study, Yadkin-Pee Dee River basin, Preliminary Draft Recommended Plan: December.

North Carolina Office of State Budget and Management, 1980, North Carolina population projections—update: Department of Demographic Research, June.

Olmsted, L. D., and Leiper, A. S., ed., 1978, Baseline environmental summary on the Yadkin River in the vicinity of the Perkins Nuclear Station: Duke Power Co., 78-05.

Ospina, Enrique, and Danielson, Leon, 1973, Land-use planning in North Carolina: N.C. Agricultural Extension Service.

Palmer, C. Mervin, 1969, A composite rating of algae tolerating organic pollution: Journal of Phycology, v. 5, p. 78-82.

Reeder, Howard E., 1973, Sediment resulting from construction of an interstate highway in the Piedmont area of North Carolina: U.S. Geological Survey Open-File Report, 17 p.

Simmons, C. E., and Heath, R. C., 1979, Water-quality characteristics of forested and rural basins in North Carolina: U.S. Geological Survey Water Resources Investigations 79-108, 49 p.

Soil Conservation Service, 1979, Watershed progress: North Carolina: U.S. Department of Agriculture, Raleigh, N.C., 20 p.

South Carolina Water Resources Commission, 1977, Pee Dee framework study: January.

Stiff, H. A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, v. 3, no. 10, p. 15-17.

Tang, Hai C., 1976, A recursive simulation model for water resources planning and management: N.C. Dept. of Natural and Economic Resources.

Todd, D. K., 1970, The water encyclopedia: Water Information Center, 559 p.

TRW, 1975, A survey of water characteristics for the Yadkin-Pee Dee River basin, Interim Report No. 1: Prepared for the National Commission on Water Quality, Washington, D.C., 20036, January.

Triangle J Council of Governments, 1976, 208 Pollution source analysis: TJCOG, P.O. Box 12276, Research Triangle Park, N.C., p. V.E. 20-27.

U.S. Army Corps of Engineers, 1979, Water-resources development by the U.S. Army Corps of Engineers in North Carolina: U.S. Army Engineer Division, South Atlantic, Atlanta, Ga. 123 p.

U.S. Bureau of the Census, 1971, Number of Inhabitants—North Carolina: U.S. Department of Commerce, PC(1)-A35.

U.S. Environmental Protection Agency, 1975a, Report on Badin Lake, Montgomery and Stanly Counties, North Carolina: EPA Region IV Working Paper No. 377.

————1975b, Report on Blewett Falls Lake, Anson and Richmond Counties, North Carolina: EPA Region IV Working Paper No. 378.

―――1975c, Report on High Rock Lake, Davidson and Rowan Counties, North Carolina: EPA Region IV Working Paper No. 381.

―――1975d, Report on Lake Tillery, Montgomery and Stanly Counties, North Carolina: EPA Region IV Working Paper No. 390.

―――1976, Quality criteria for water: U.S. Government Printing Office, Washington, D.C., 256 p.

U.S. Department of Agriculture, 1979, Special report―Erosion and sediment inventory, Yadkin-Pee Dee basin cooperative study: December, 25 p.

Water Resources Council, 1973, Principles and standards for planning water and related land resources: Federal Register, v. 38, no. 174, September 10.

Weiss, C. M., Francisco, D. E., and Lenat, D. R., 1973, Preimpoundment studies―Falls project―water-quality characteristics, in U.S. Army Corps of Engineers draft environmental statement, Falls Lake, Neuse River basin, North Carolina, Appendix I: U.S. Army Engineers District, Wilmington, N.C.

Weiss, C. M., and Kuenzler, E. J., 1976, The trophic state of North Carolina lakes: North Carolina Water Resources Research Institute Report No. 119, 224 p.

Weiss, C. M., Anderson, T. P., and Campbell, P. H., 1981, The Water quality of the rivers and tributaries of the upper Yadkin drainage basin and its impact on High Rock Lake: Department of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, Chapel Hill, E.S.E. Pub. No. 553, 518 p.

Wetzel, Robert G., 1975, Limnology: W. B. Saunders Company, Philadelphia, Pa., 743 p.

Wilder, H. B., and Simmons, C. E., 1978, Program for evaluation of stream quality in North Carolina: U.S. Geological Survey Circular 764, 16 p.

Wilhm, J. L., and Dorris, T. C., 1968, Biological parameters for water-quality criteria: Bioscience, v. 18, no. 6, p. 477–481.

Metric Conversion Factors

The following factors may be used to convert inch-pound units published herein to the International System (SI).

Multiply inch-pound unit	By	To obtain SI unit
Length		
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4047	square meter (m²)
	.4047	hectare (ha)
	.004047	square kilometer (km²)
square mile (mi²)	2.590	square kilometer (km²)
Volume		
gallon (gal)	3.785	liter (L)
	.003785	cubic meter (m³)
million gallons (Mgal)	3785	cubic meter (m³)
cubic foot (ft³)	.02832	cubic meter (m³)
acre-foot (acre-ft)	1233.5	cubic meter (m³)
Flow		
cubic foot per second (ft³/s)	28.32	liter per second (L/s)
	.02832	cubic meter per second (m³/s)
million gallons per day (Mgal/d)	.04381	cubic meter per second (m³/s)
gallon per day (gal/d)	.0038	cubic meter per day (m³/d)
Flow per area		
cubic foot per second per square mile [(ft³/s)/mi²]	.01093	cubic meter per second per square kilometer [(m³/s)/km²]
Temperature		
degree Fahrenheit (°F.)	5/9(°F–32)	degree Celsius (°C.)
Mass		
ton (short, 2,000 pounds)	.9072	megagram (Mg), or metric ton (t)
pounds (lb)	453.59	grams (g)
Specific conductance		
micromho (μmho)	1.00	microsiemens (μS)

Note:
National Geodetic Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada, formerly called "mean sea level."