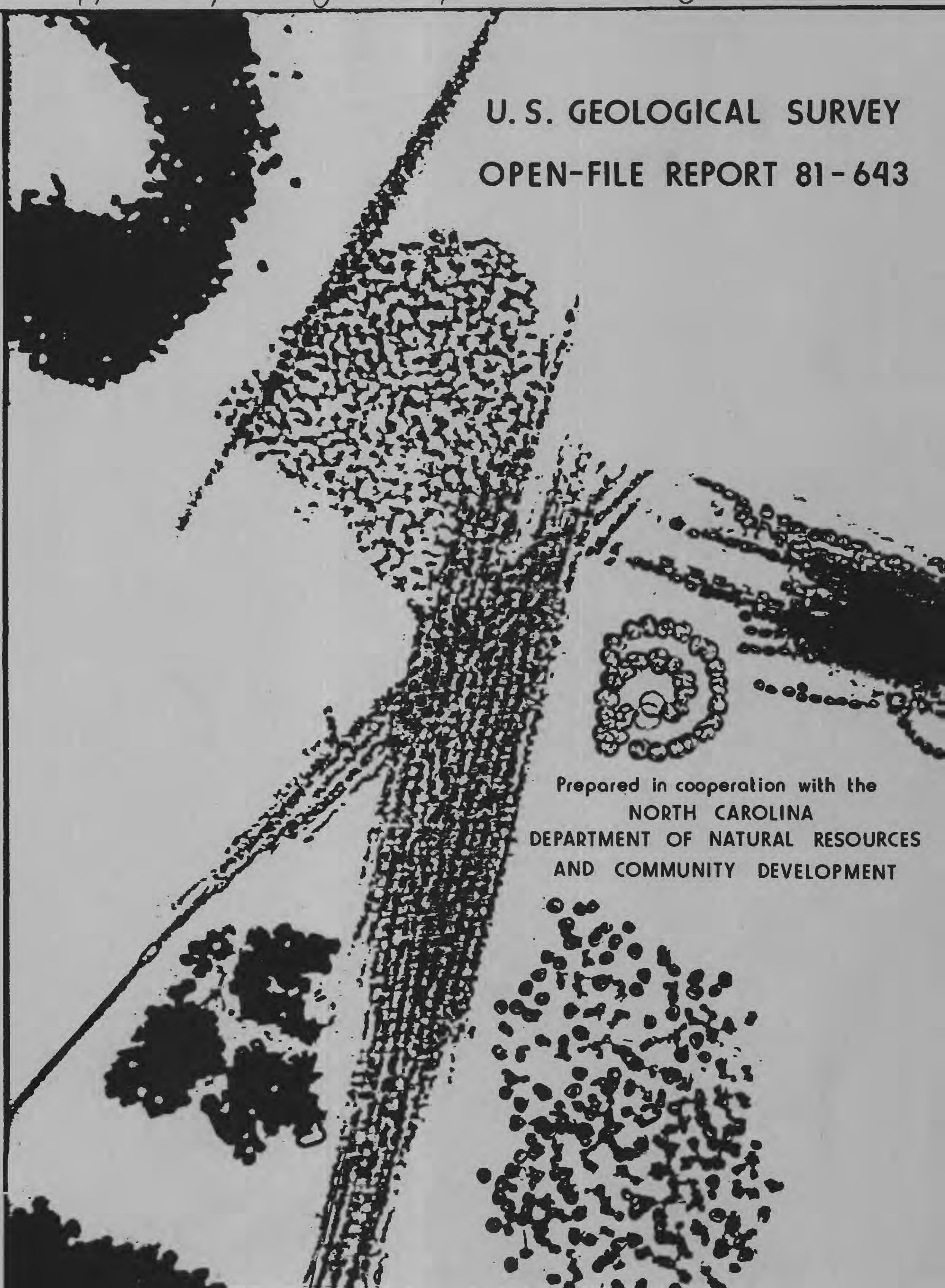
WATER QUALITY OF THE YADKIN-PEE DEE RIVER SYSTEM, NORTH CAROLINA

Variability, pollution loads, and long-term trends

Harned, Douglas & Dann Meyer



U. S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 81-643

Prepared in cooperation with the
NORTH CAROLINA
DEPARTMENT OF NATURAL RESOURCES
AND COMMUNITY DEVELOPMENT

WATER QUALITY OF THE YADKIN-PEE DEE RIVER SYSTEM, NORTH CAROLINA-VARIABILITY, POLLUTION LOADS, AND LONG-TERM TRENDS

By

Douglas Harned and Dann Meyer

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Raleigh, North Carolina
1981

UNITED STATES DEPARTMENT OF THE INTERIOR

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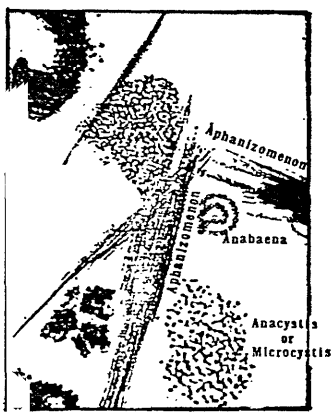

COVER PHOTO: "Annie, Fannie, and Mike," - Algae characteristic of eutrophic waters and of the same type found in the Yadkin-Pee Dee River system. From the collection of E. F. Stoermer, Great Lakes Research Division, University of Michigan, Ann Arbor.

INTERNATIONAL SYSTEM UNITS

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)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4047	square meter (m^2)
	0.4047	hectare (ha)
	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
million gallons (Mgal)	3785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre foot (acre-ft)	1233.5	cubic meter (m^3)
Flow		
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.0038	cubic meter per day (m^3/d)
Flow per Area		
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer $(m^3/s)/km^2$
Temperature		
degree Fahrenheit (°F)	5/9(°F-32)	degree Celsius (°C)
Mass		
ton (short, 2,000 pounds)	0.9072	megagram (Mg), or metric ton (t)
pounds (lbs)	453.59	grams(g)
Specific Conductance		
micromho (µmho)	1.	microsiemens (µS)

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, formally called "Mean Sea Level."

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 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 generally good, are lowest at 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 stormwater-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 oxidation, 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 mid 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, 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 1906-1978 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, 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. Department of Agriculture (1979) for the Level-B study. This report emphasizes that sediment is the most significant non-point 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 catalogue 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 High Rock Lake. This detailed study is based on data collected during the period of October 1977 to September 1978.

ACKNOWLEDGMENTS

J. Kent Crawford wrote the section on Biological Characteristics, and did much of the multiple-regression analysis and pH trend analysis in the Trends section.

Ervin Shoaf of Lexington, N.C., has collected daily suspended-sediment samples at the Yadkin College station for at least 25 years and has measured daily specific conductance and temperatures since 1973. Wayne Norman of Lexington, N.C., and George Norman of Advance, N.C., took sediment samples during flood events prior to 1975, and are credited with the discovery that the sediment response to floodflows at Yadkin College is double peaked.

Pines Crump of Norwood, N.C., measured daily specific conductance and water temperature of the Rocky River for 1976-80. Calvin McCormick of Lilesville, N.C., measured daily specific conductance and water temperatures for the Pee Dee River near Rockingham from 1974-80.

Some of the data on dissolved oxygen, chemical oxygen demand, biochemical oxygen demand, and fecal coliform bacteria used in this report were collected by scientists and technicians working for the North Carolina Department of Natural Resources and Community Development.

This report was reviewed for the North Carolina Department of Natural Resources and Community Development by: John D. Sutherland, Fin Johnson, Forrest Westall, Alan Klimeck, and Tom Nelson. Comments received from these reviewers prompted numerous improvements in the manuscript.

Janet L. McBride and Catherine E. Harrington typed and helped to edit the manuscript. John Teel drafted the illustrations.

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 square miles of the basin upstream from the U.S. Geological Survey water-quality monitoring station at mile 192 of the Pee Dee River near Rockingham (figure 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, hydroelectric 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 inches (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 inches (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).

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

Streamflow

The average daily discharge of the Yadkin River at the Yadkin College station is 2,970 ft^3/s (range: 177 to 80,200 ft^3/s) for the 50-year period of record beginning in 1928. With a drainage area of 2,280 mi^2, the average discharge is 1.30 $(ft^3/s)/mi^2$.

The average daily discharge of Rocky River at Norwood is 1,330 ft^3/s (range: 17 - 10,500 ft^3/s) or 0.97 $(ft^3/s)/mi^2$ (drainage area 1,370 mi^2) 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 ft^3/s or 1.16 $(ft^3/s)/mi^2$ for the drainage area of 6,870 mi^2 (range: 50 to 276,000 ft^3/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, consisting 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.

Up to 200 feet 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.

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 ft^3/s) of the total waste water discharged into the river system (325.3 ft^3/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 acccountable 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 ft^3/s, 40 ft^3/s at

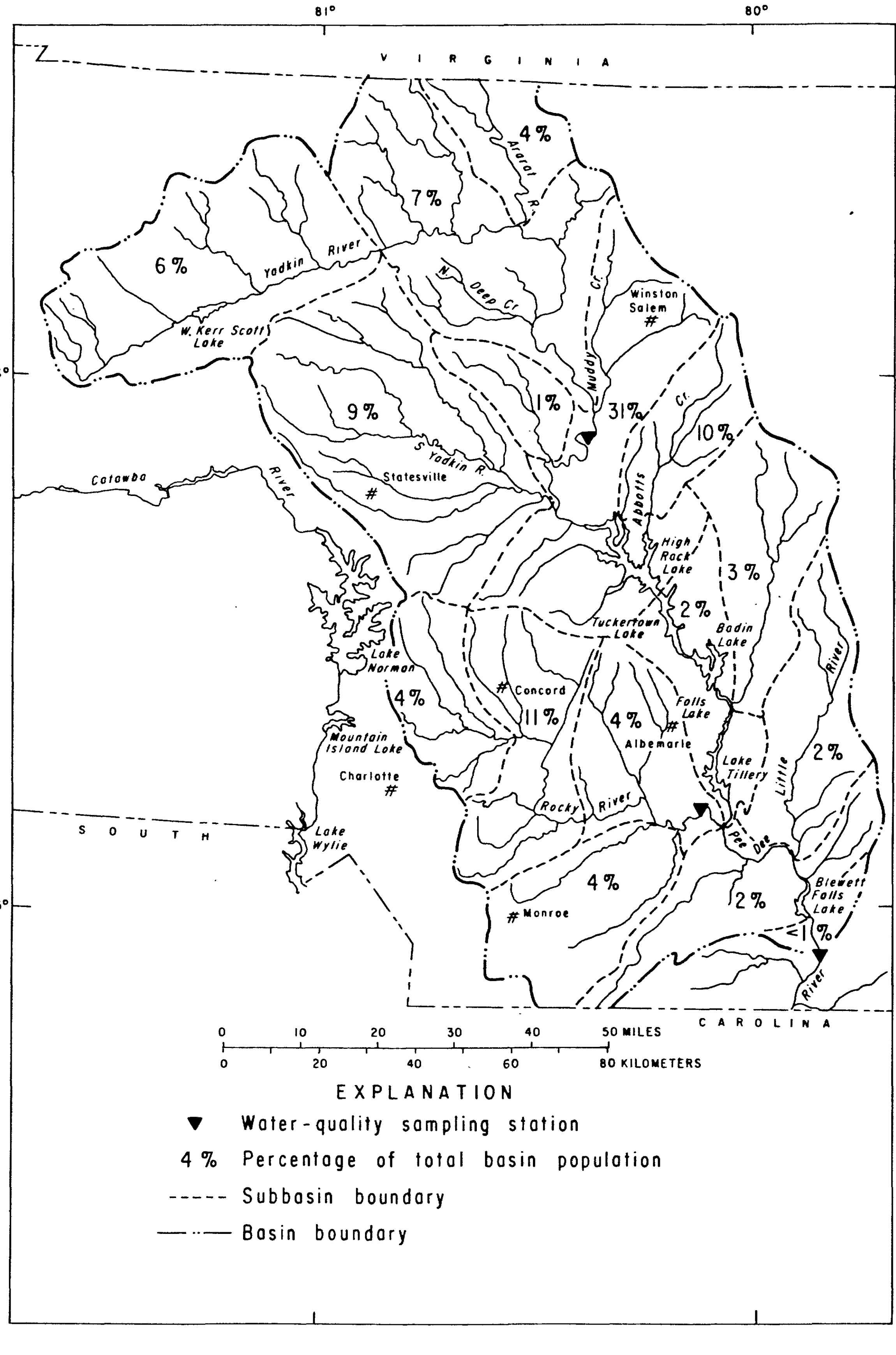

Figure 2.--The percentage of the total basin population residing in each Yadkin-Pee Dee subbasin.

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

	Facility	Location	Location of waste discharge	Design flow ft^3/s
1	Wilkesboro Municipal	Wilkes County	Cub Creek	5.1
2	Chatham Manufacturing Company, Elkin	Surry County	Yadkin River	6.2
3	Elkin Municipal	Surry County	Yadkin River	4.7
4	Mt. Airy Municipal	Surry County	Ararat River	24.8
5	Salisbury Municipal	Rowan County	Grants Creek	7.8
6	NC Finishing Company	Rowan County	High Rock Lake	6.6
7	Duke Power Company	Rowan County	High Rock Lake	7.0
8	Winston-Salem Municipal	Forsyth County	Salem Creek	55.8
9	Statesville Municipal	Iredell County	Third Creek	6.2
10	High Point Municipal	Davidson County	Rich Fork Creek	6.2
11	Thomasville Municipal	Davidson County	Hamby Creek	6.2
12	Mooresville Industrial	Iredell County	Dye Branch	6.2
13	Cannon Mills Company	Kannapolis	Dye Branch	26.4
14	Concord Regional	Cabarrus County	Rocky River	37.2
15	Monroe Municipal	Monroe County	Richardson Creek	7.0
16	Rockingham Municipal	Richmond County	Hitchcock Creek	9.3
			Total	222.6
			Total basin	325.3

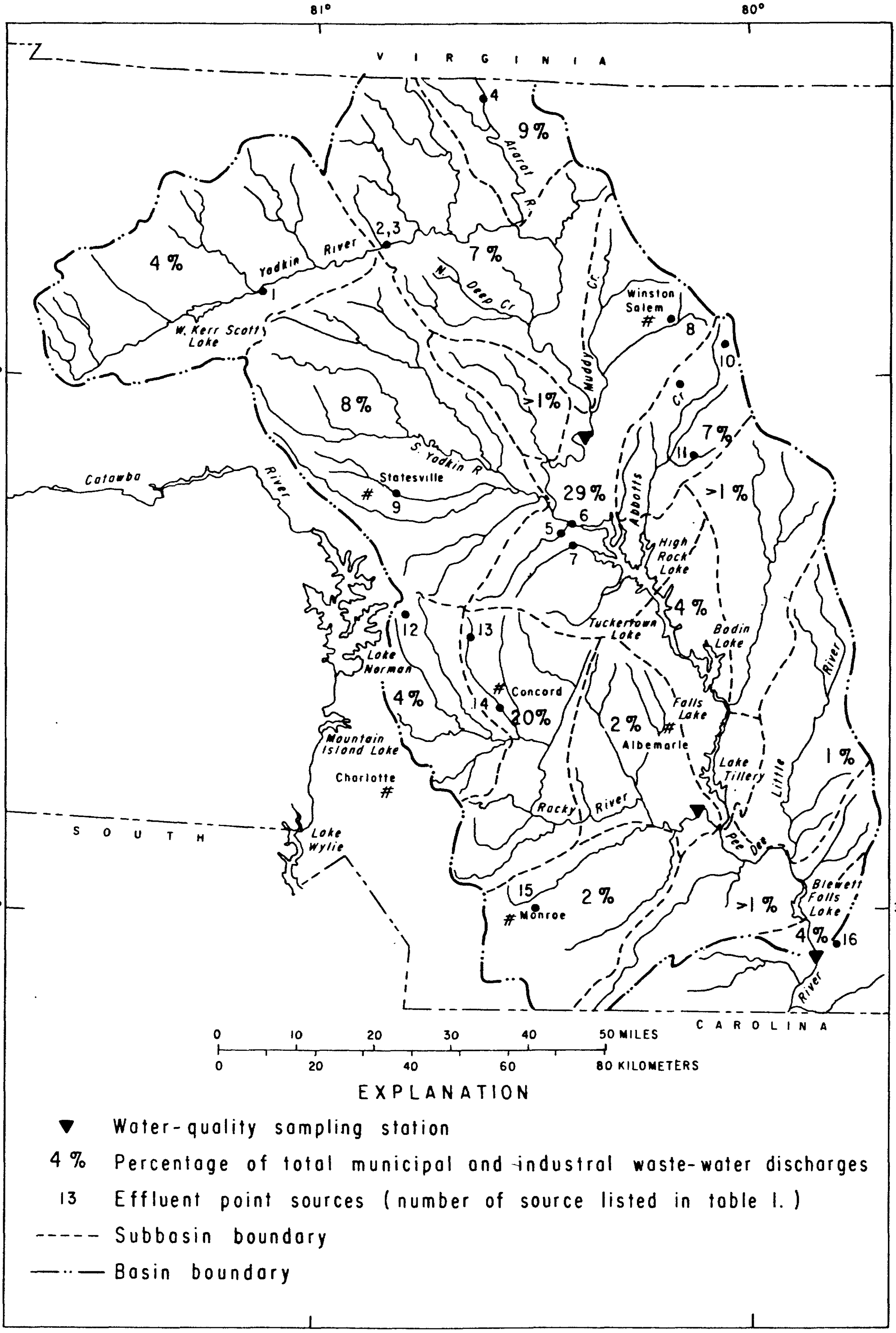

Figure 3.--Percent of total industrial and municipal point-source waste-water discharge originating in each Yadkin-Pee Dee subbasin.

the Norwood station, and 1,110 ft^3/s at the Rockingham station. These low-flow values are based on 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 (Narrows Lake), 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 ft^3/s through High Rock Dam may be maintained if the lake level is higher than 654 feet NGVD (National Geodetic Vertical Datum) of 1929 during summer, although the same discharge can be maintained during the rest of the year at lake levels as low as 644 feet NGVD of 1929. Federal Power Commission regulations require lower rates of discharge from the dam if High Rock Lake's level falls below 644 feet 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 ft^3/s is maintained at Yadkin College and the maximum flow at Wilkesboro (02112000) is 5,400 ft^3/s.

Additionally, there are about 30 impoundments on tributary streams used for municipal water supplies, and 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, as well as 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).

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 square miles; and the Rockingham station gages 6,870 square miles of the basin. The locations of the stations are given in figure 1 and the period of record is illustrated in figure 4.

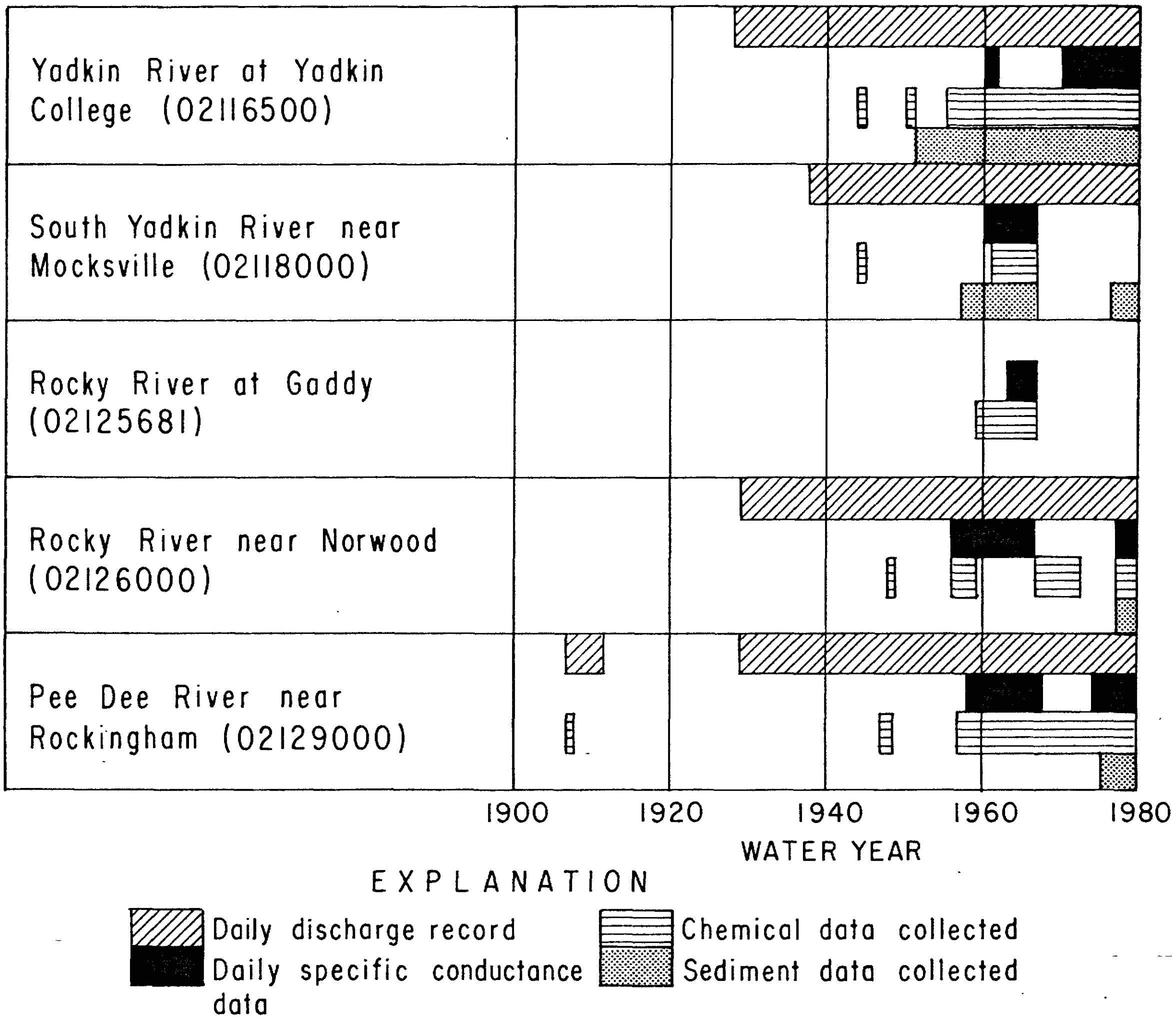

Figure 4.--Period of record for water-quality sample collection and discharge measurement at five stations in the Yadkin-Pee Dee River basin.

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 1971-76 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 two miles 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 National Stream Quality Accounting Network.

An expanded program of water-quality data collection at the three Yadkin-Pee Dee stations began in 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 average daily air temperature and average daily river-water temperature at Yadkin College demonstrates the response of the water to variations in air temperatures 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 fish kills, 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 on 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 at 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 miles downstream of Blewett Falls Dam, the terminus of the series of lakes and dams on the Yadkin-Pee

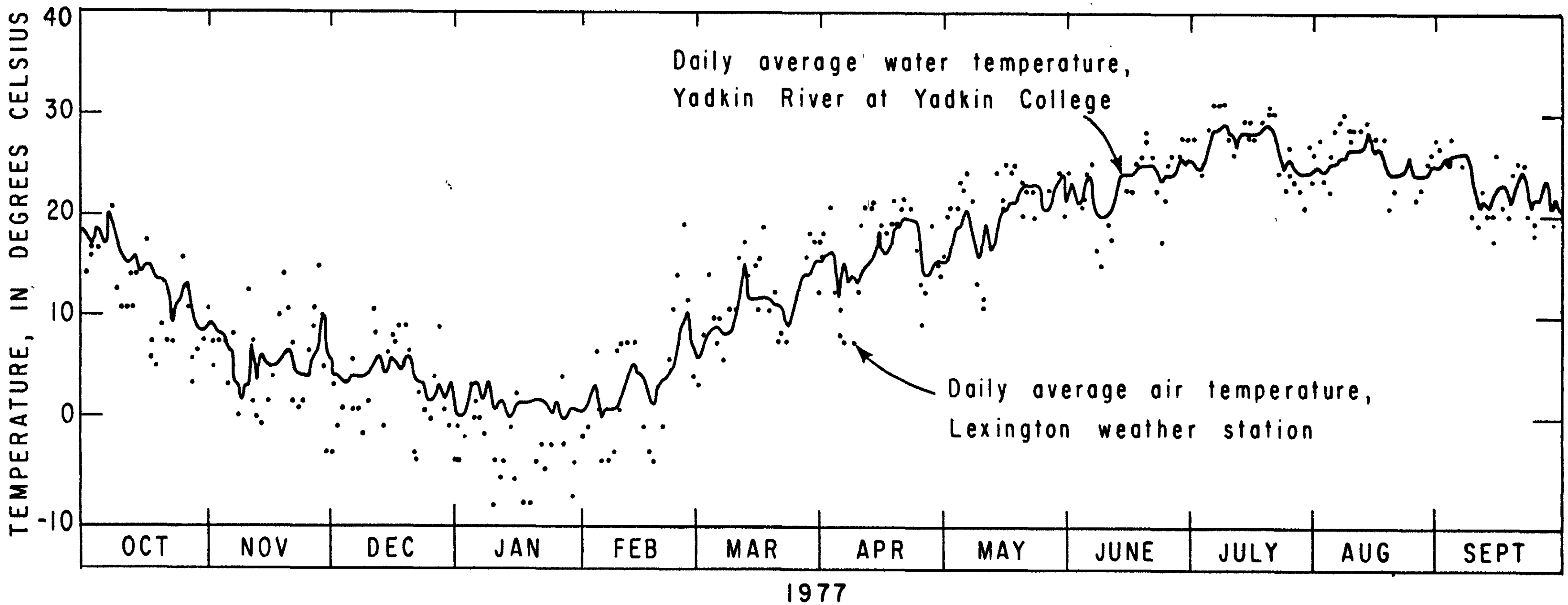

Figure 5.--Air and water temperatures versus time, for water year 1977, for the Yadkin River at Yadkin College.

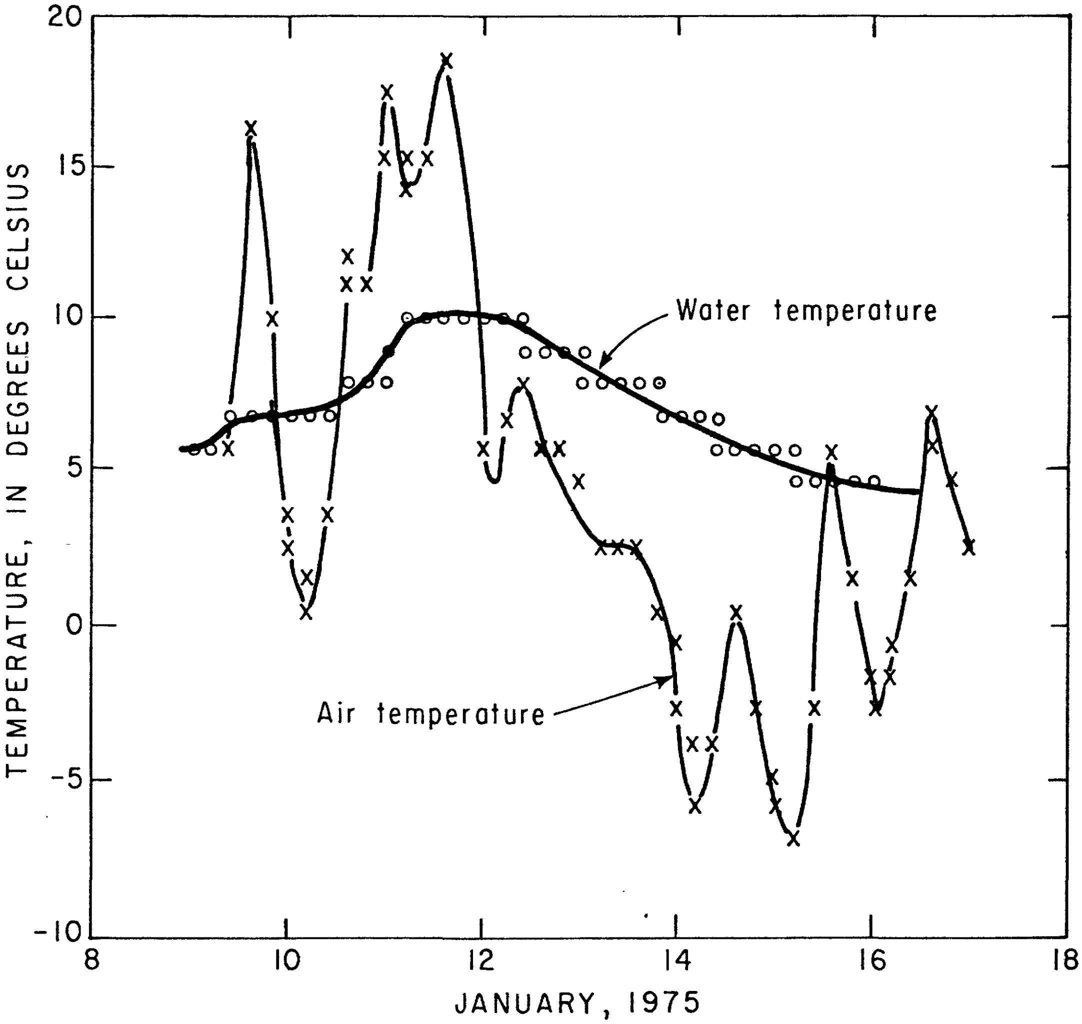

Figure 6.--Air and water temperatures during the flood of January 9-18, 1975, on the Yadkin River at Yadkin College.

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

	YADKIN RIVER AT YADKIN COLLEGE			ROCKY RIVER NEAR NORWOOD			PEE DEE RIVER NEAR ROCKINGHAM			
Physical parameter	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	U.S. E.P.A. Criteria (1976)
Discharge[2/] at time of sampling (ft^3/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 (ft^3/s)	2,970	177- 80,200	50 yrs[3/]	1,300	17- 105,200	49 yrs[3/]	7,997	58- 276,000	56 yrs[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 9	6.5 6.3-6.6	5.3- 8.0	156	Domestic water supply 5.9 pH units. Fresh-water 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)	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, assuming 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.

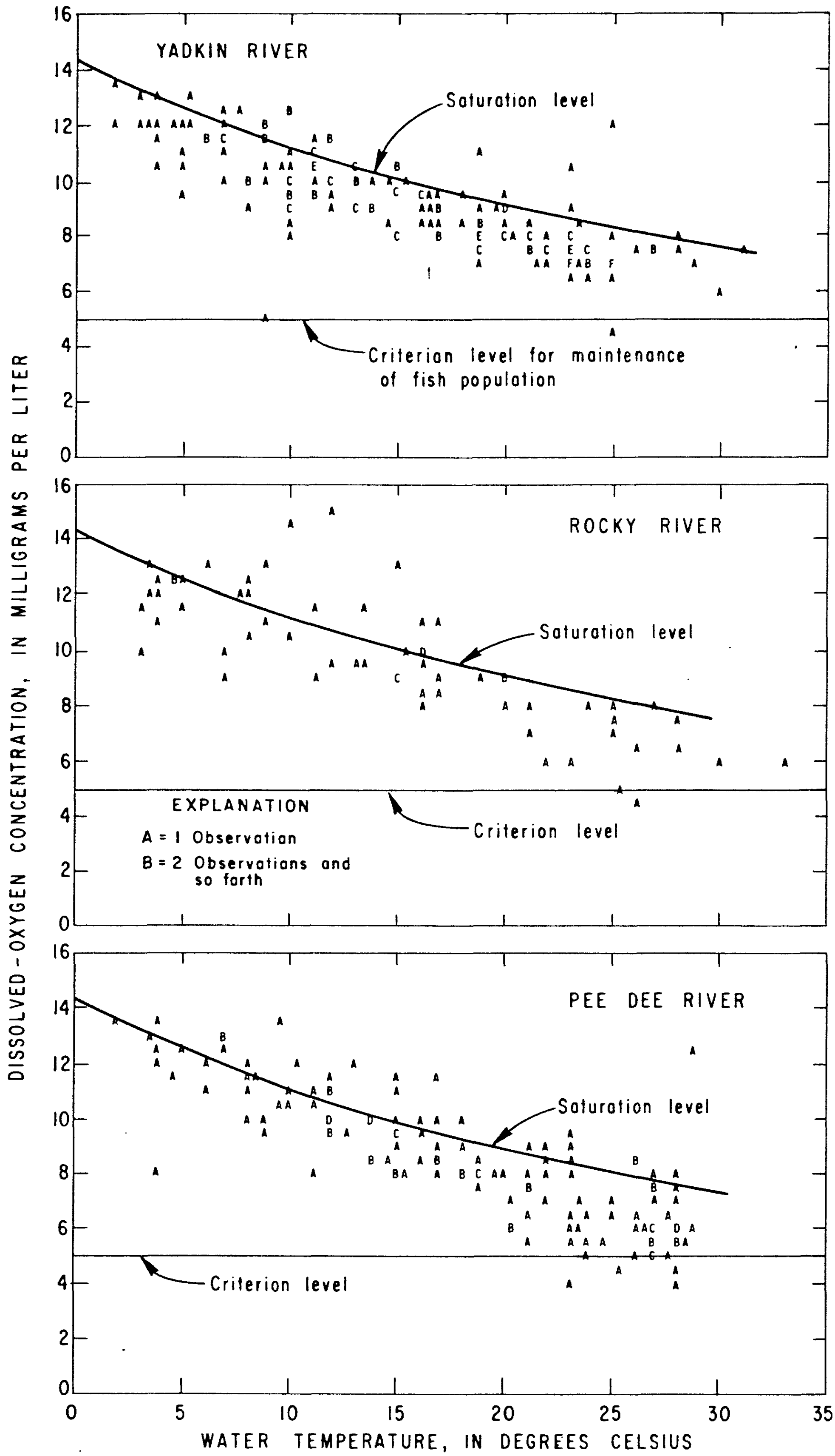

Figure 7.--Dissolved-oxygen concentration versus water temperature for water years 1970-78 at the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham.

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 is largely the effect of discharge of water with low 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. Environmental 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 runoff, 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 10-16, 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 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.

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 calculate sediment volumes. The estimation for each water year is given in table 3, but each must be interpreted as a minimum value since 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

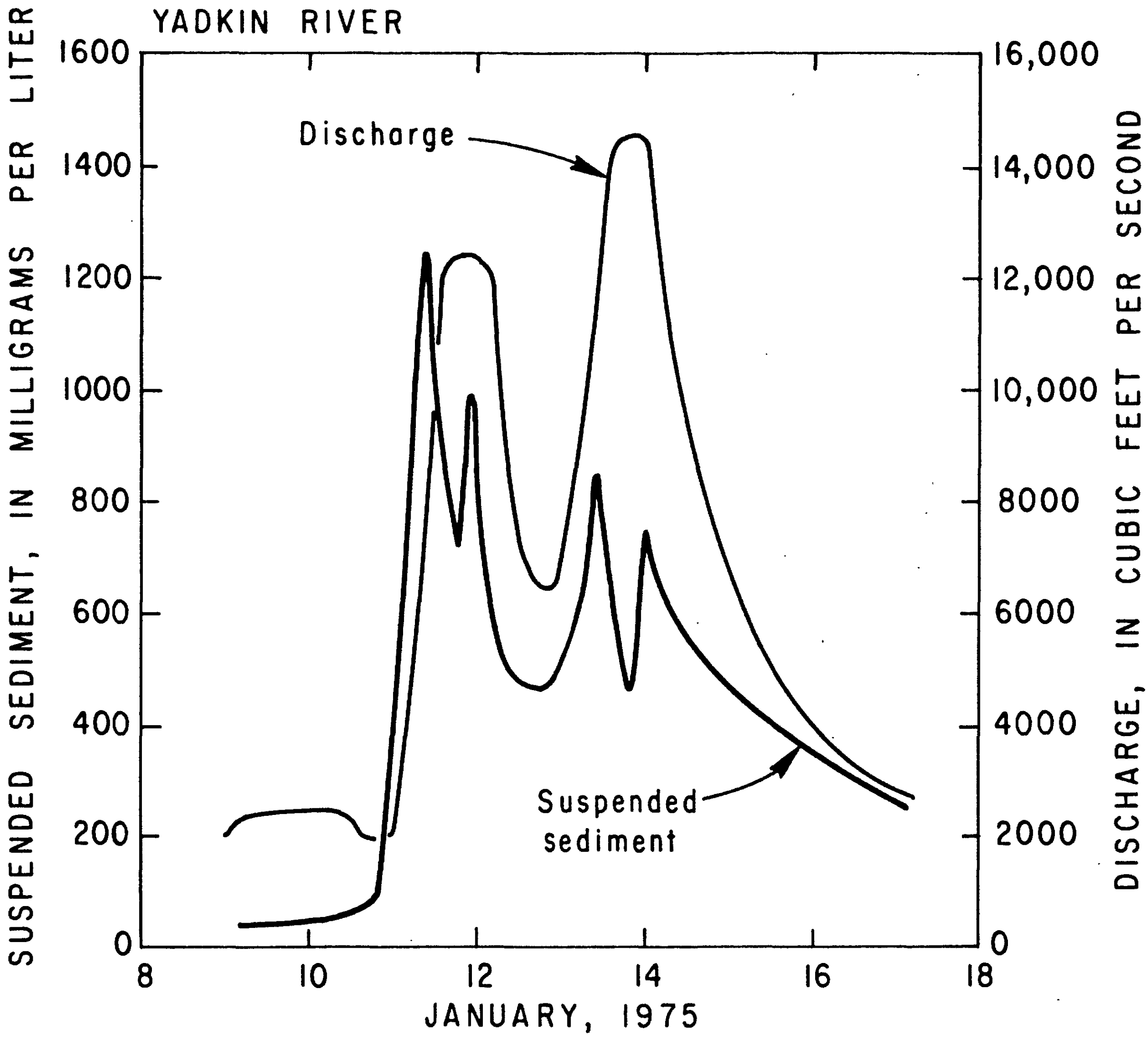

Figure 8.--Suspended-sediment concentration and discharge for the Yadkin River at Yadkin College through a storm event occurring January 9-17, 1975.

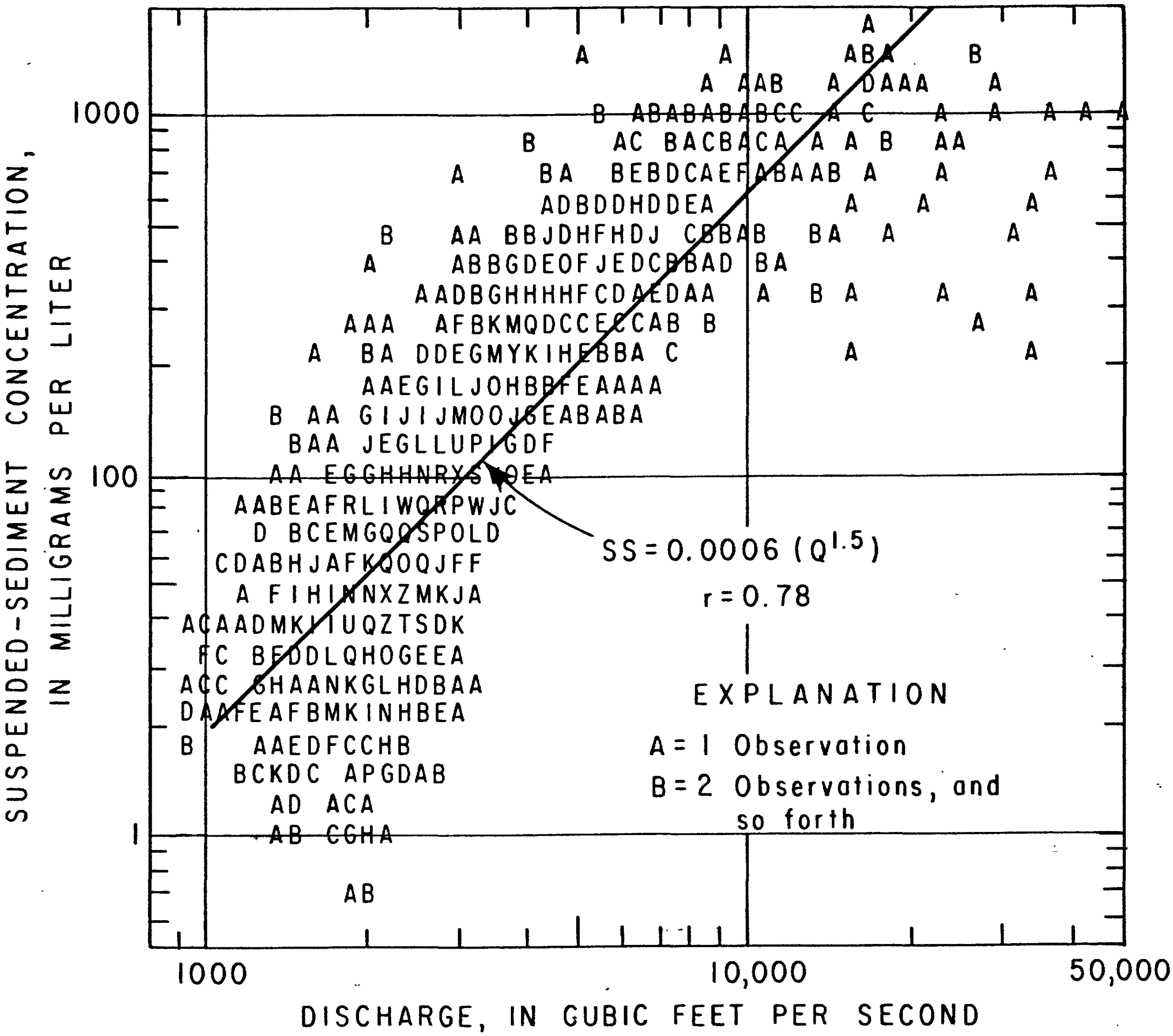

Figure 9.--Suspended-sediment concentration versus discharge for the 1974-78 water years at the Yadkin River at Yadkin College.

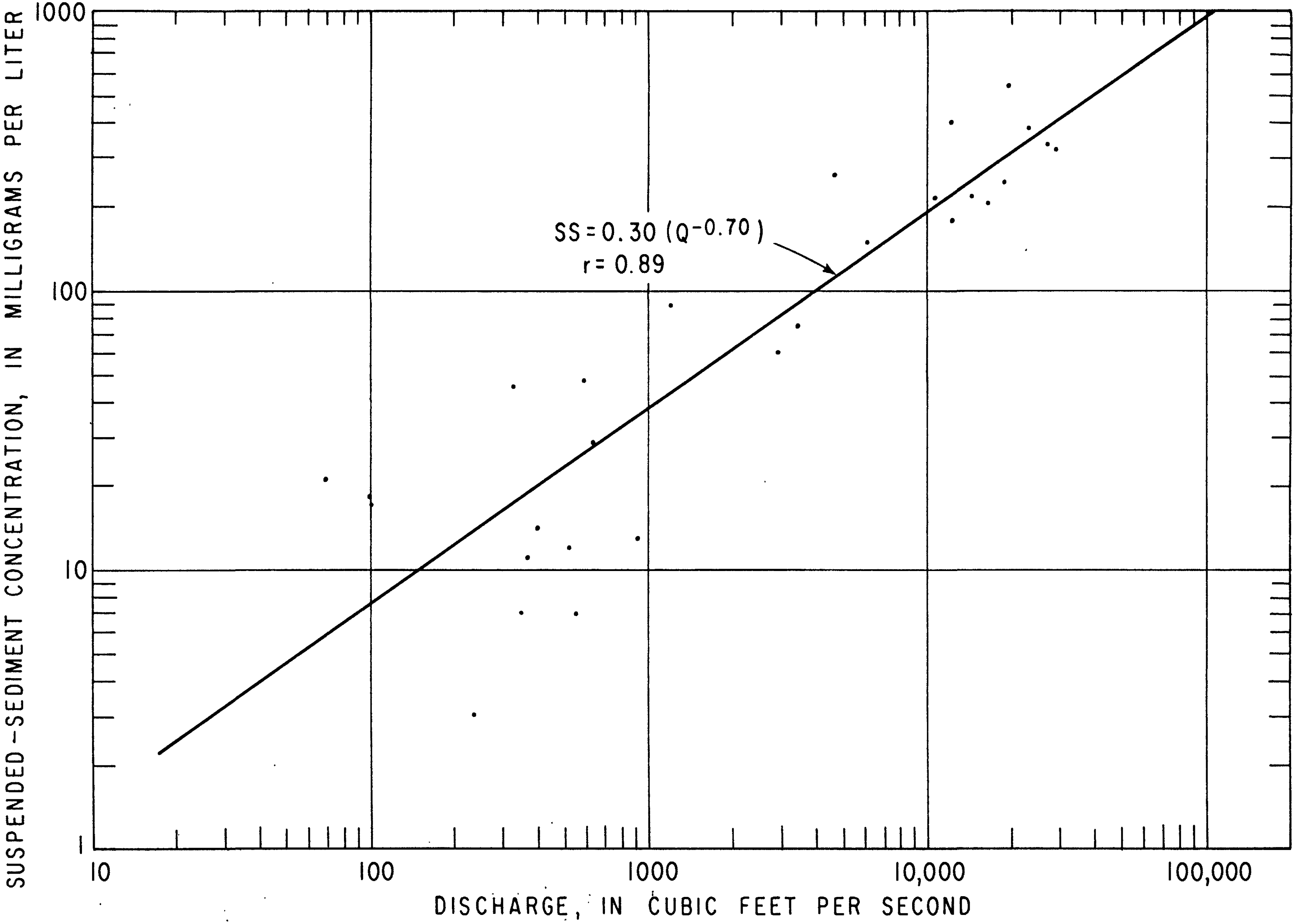

Figure 10.--Suspended-sediment concentration versus discharge for the 1974-78 water years at the Rocky River near Norwood.

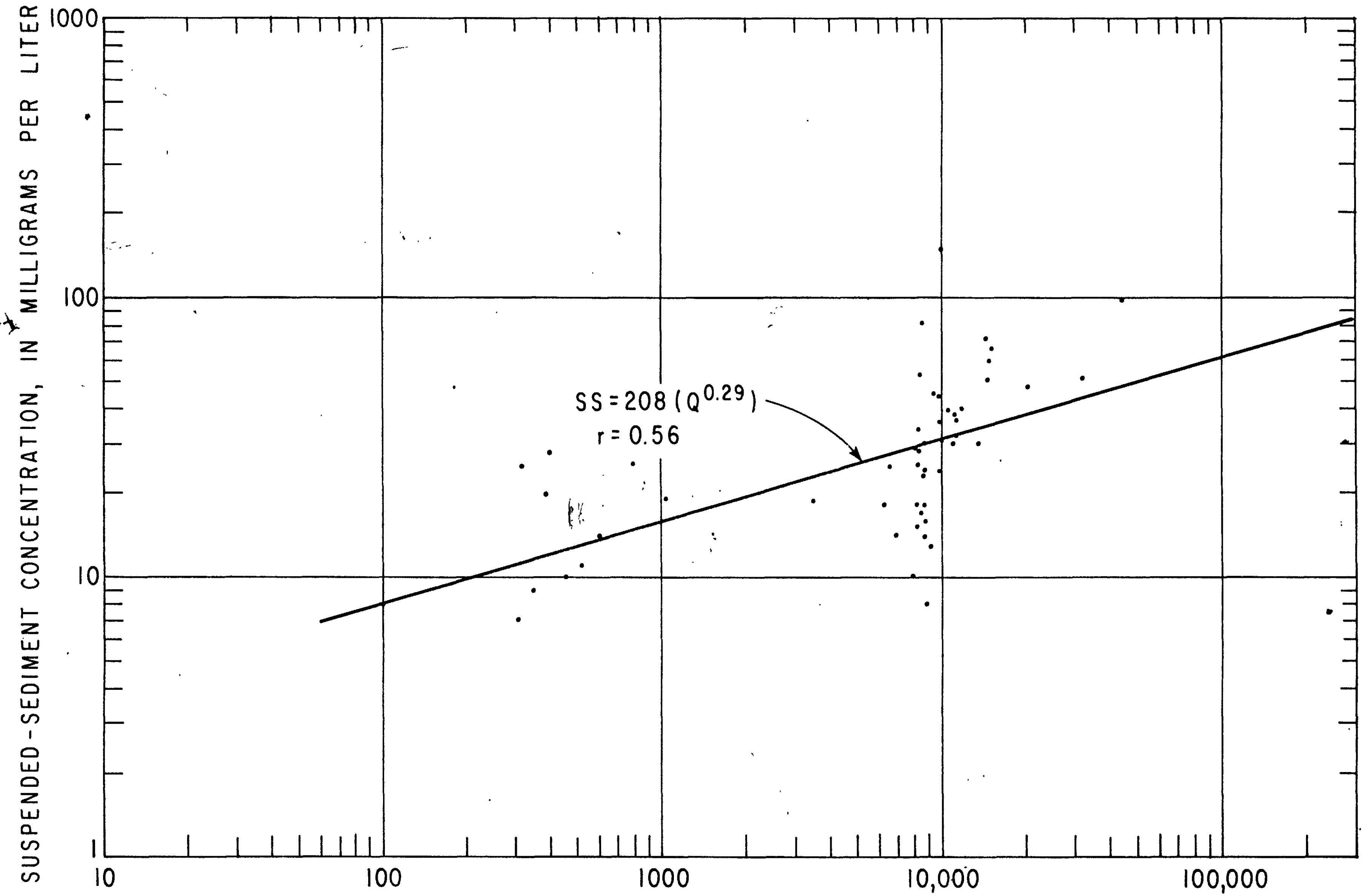

Figure 11.--Suspended-sediment concentration (SS) versus discharge (Q) for the 1974-78 water years at the Pee Dee River near Rockingham.

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

Water year	Station	Mean annual discharge (ft^3/s)	Annual sediment transport (tons)	Sediment remaining in lakes input minus output = tons	acre-ft	percent of lake volume	output/input in percent
1974	Yadkin College	4,000	1,462,000	1,273,000	974	0.12	22
	Mocksville	404	44,000				
	Norwood	1,218	130,000				
	Rockingham	9,516	363,000				
1975	Yadkin College	3,919	1,522,000	1,558,000	1,192	.15	28
	Mocksville	487	180,000				
	Norwood	2,492	453,000				
	Rockingham	13,000	597,000				
1976	Yadkin College	2,711	714,000	590,000	451	.06	27
	Mocksville	273	15,000				
	Norwood	868	73,000				
	Rockingham	6,683	212,000				
1977	Yadkin College	2,743	608,000	622,000	476	.06	35
	Mocksville	312	53,000				
	Norwood	1,661	302,000				
	Rockingham	8,428	341,000				
1978	Yadkin College	3,840	1,423,000	1,408,000	1,078	.13	25
	Mocksville	457	122,000				
	Norwood	1,791	324,000				
	Rockingham	10,630	461,000				
Mean:				1,090,200	834	0.10	27

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 one million tons of sediment is deposited annually in the lakes by the three streams. This represents around 800 acre-feet per year 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, 1978). This is not surprising, since 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 is very little turbidity data for the Yadkin College and Norwood stations, but the data is 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 1970-1978 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 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 since 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 mid-afternoon, 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 pH, 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 mid-summer.

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 stream beds 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 in-stream 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 stormwater 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 (figure 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 (N. C. Department of Natural and Economic Resources, 1976a).

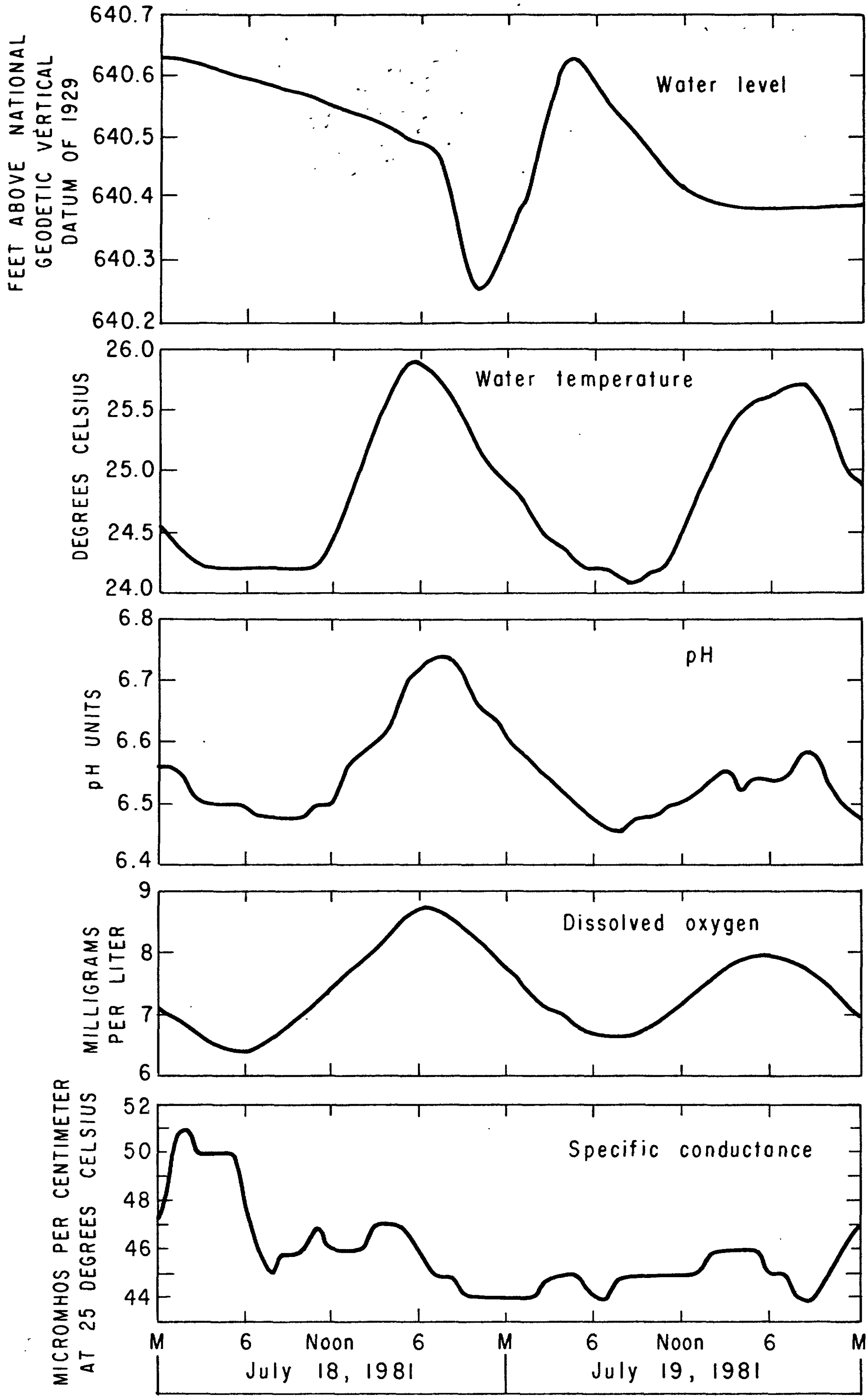

Figure 12.--Continuous monitor plots of water level, dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College, July 18-19, 1976.

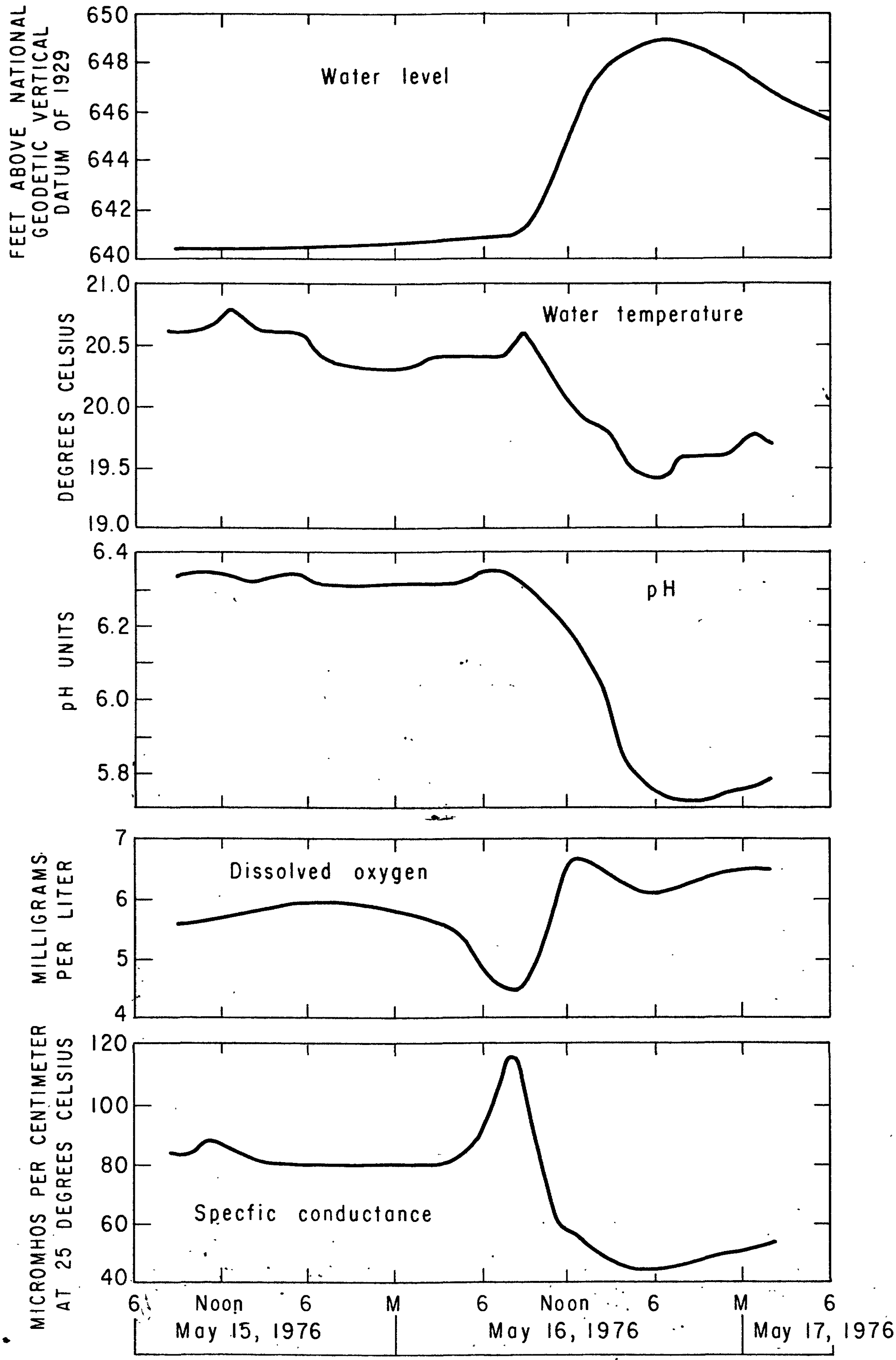

Figure 13.--Continuous monitor plots of water level, dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College, May 15-16, 1976.

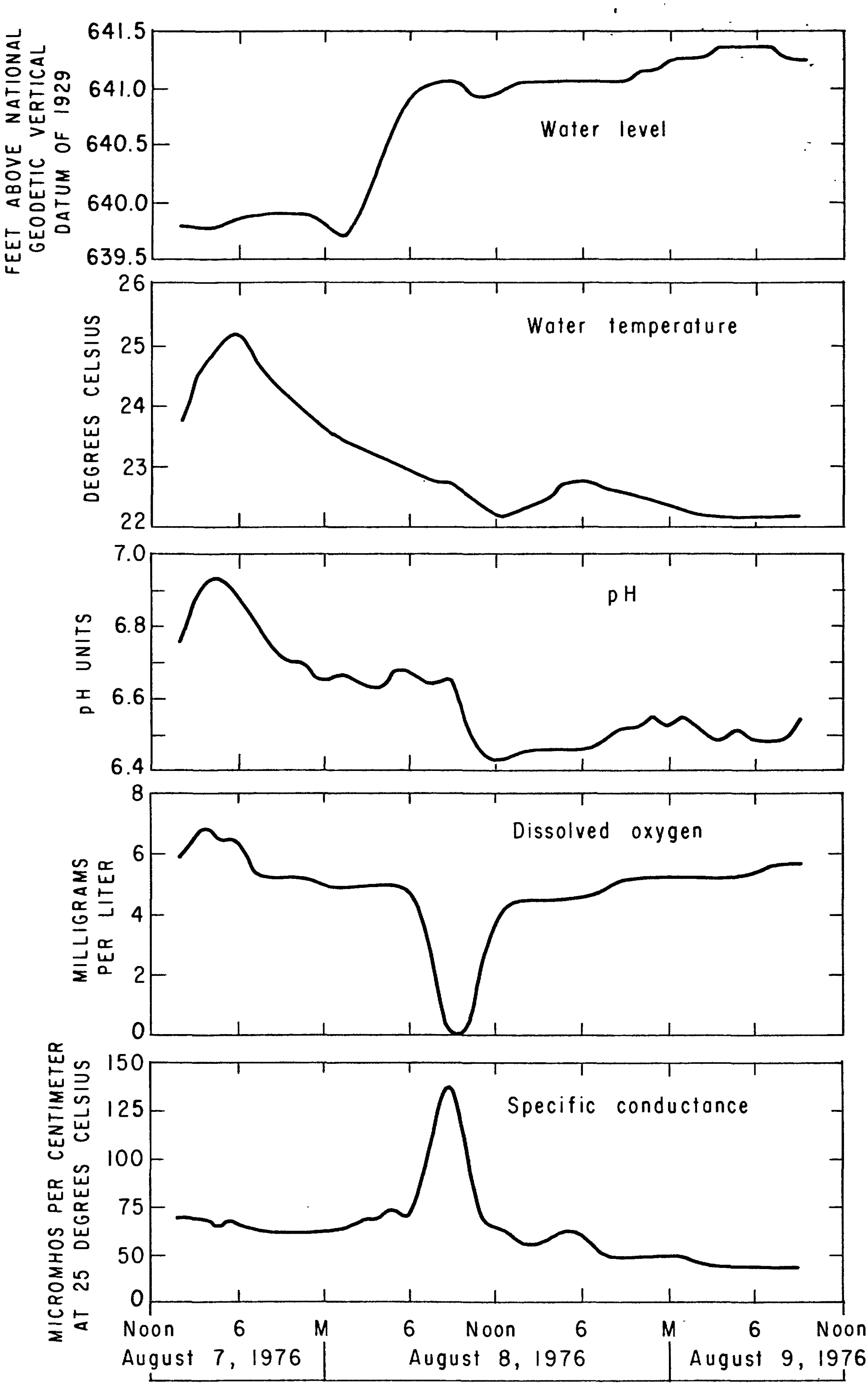

Figure 14.--Continuous monitor plots of water level, dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College, August 8, 1976.

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 each hour, and then 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. In 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.

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 and June 20-24). The result of the April 12-30 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 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 by-products.

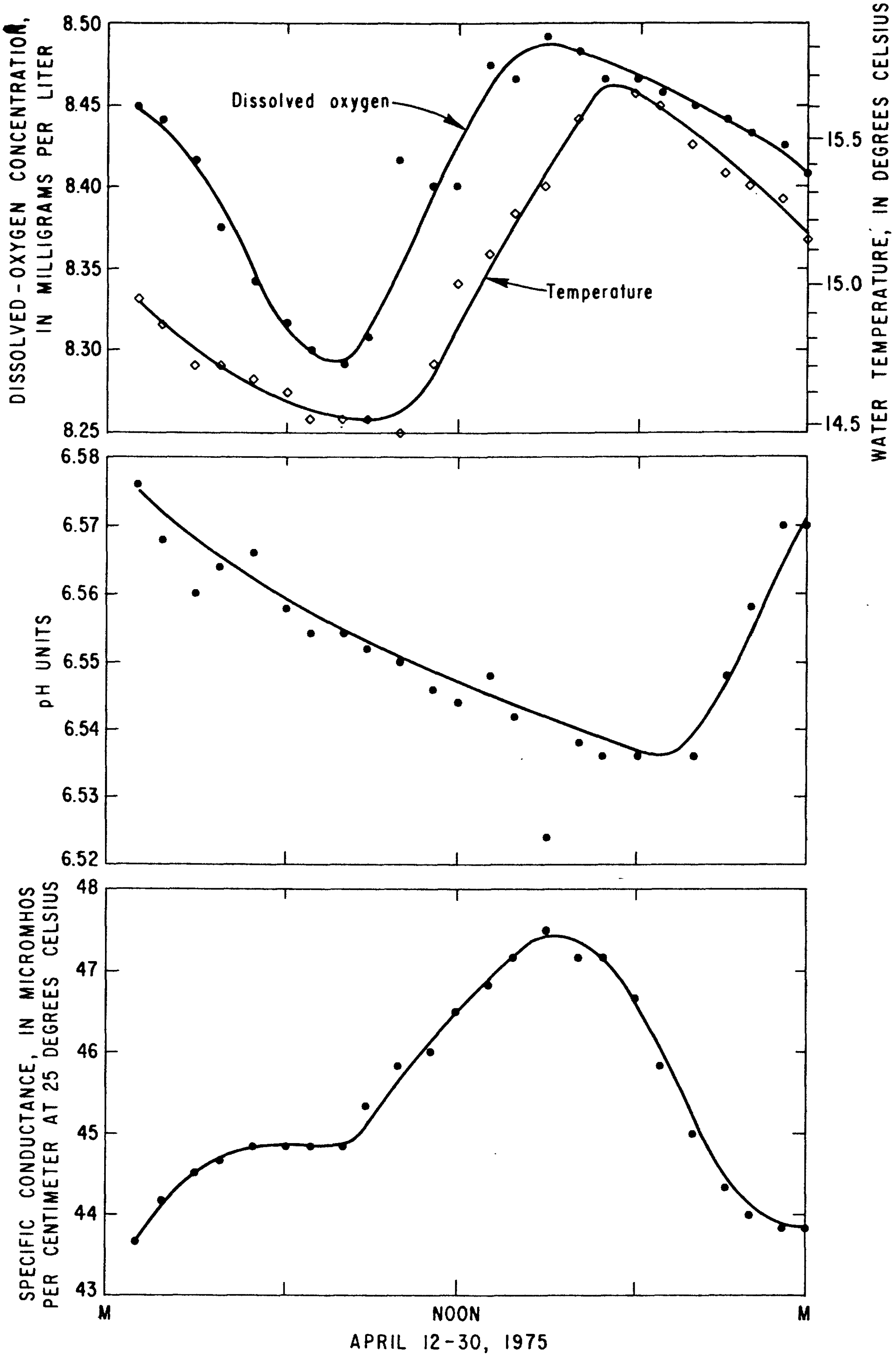

Figure 15.--Mean hourly dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College during April 12-30, 1975.

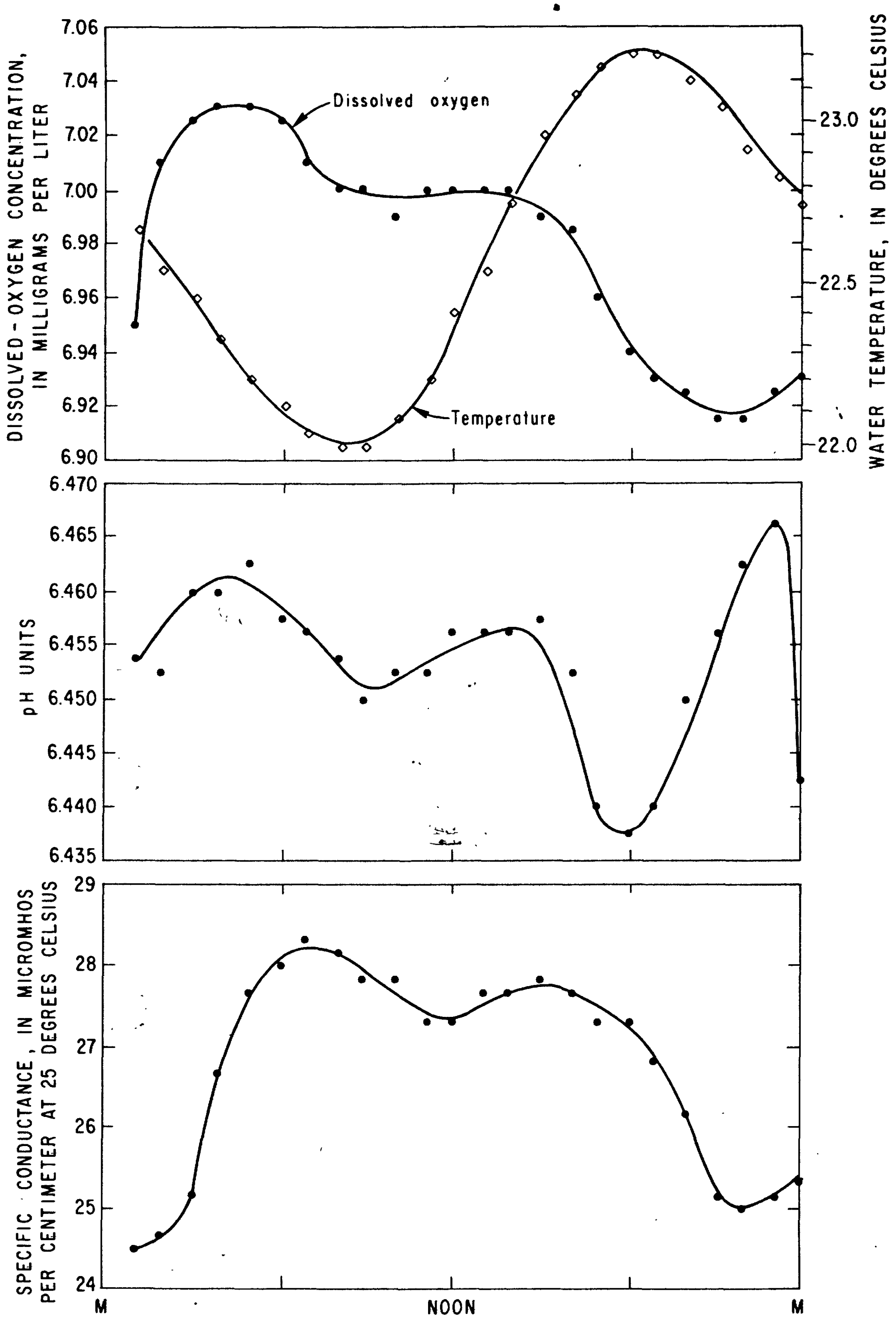

Figure 16.--Mean hourly dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College during June 20-24, 1975.

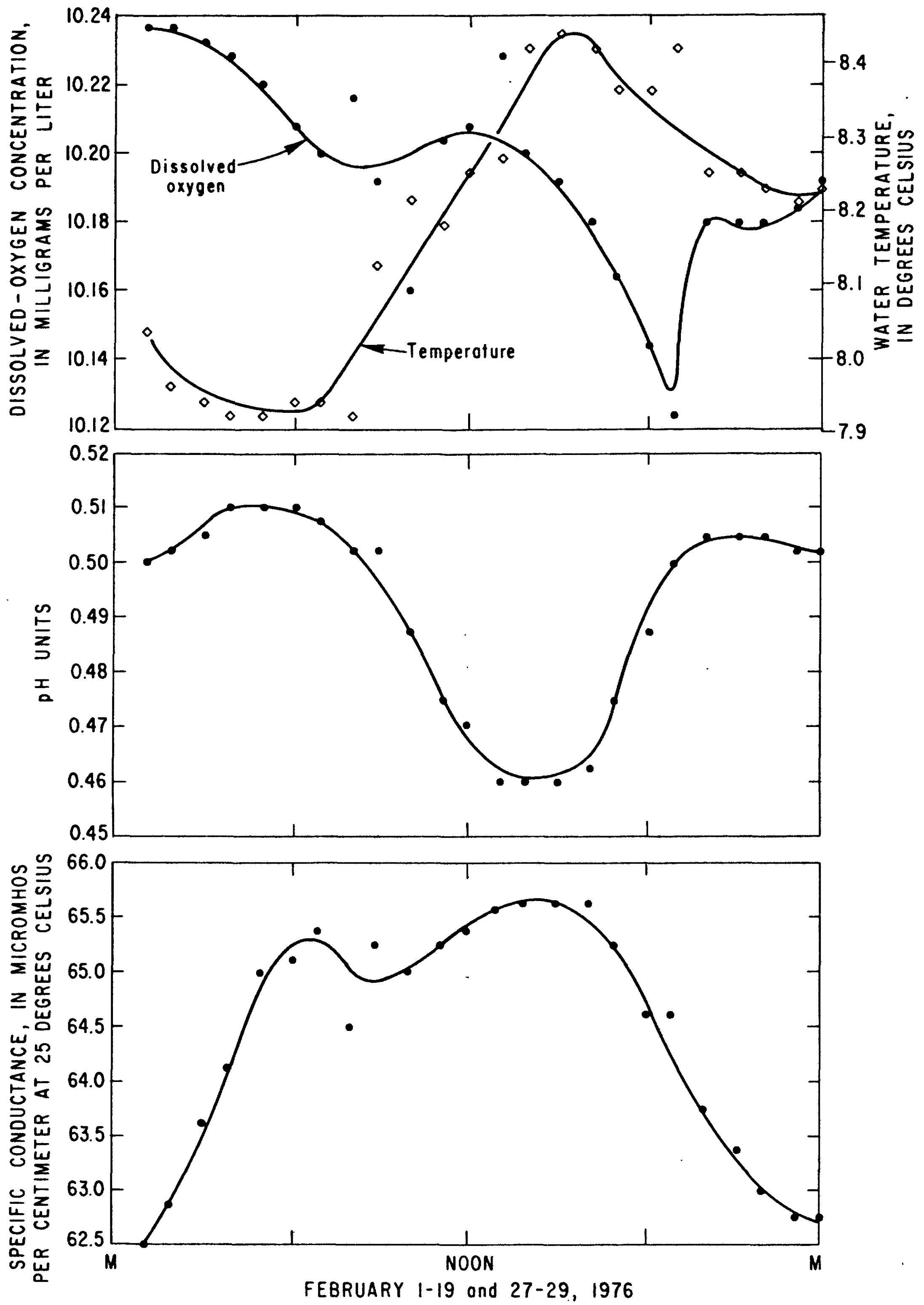

Figure 17.--Mean hourly dissolved oxygen, water temperature, pH, and specific conductance for the Yadkin River at Yadkin College during February 1-19 and 27-29, 1976.

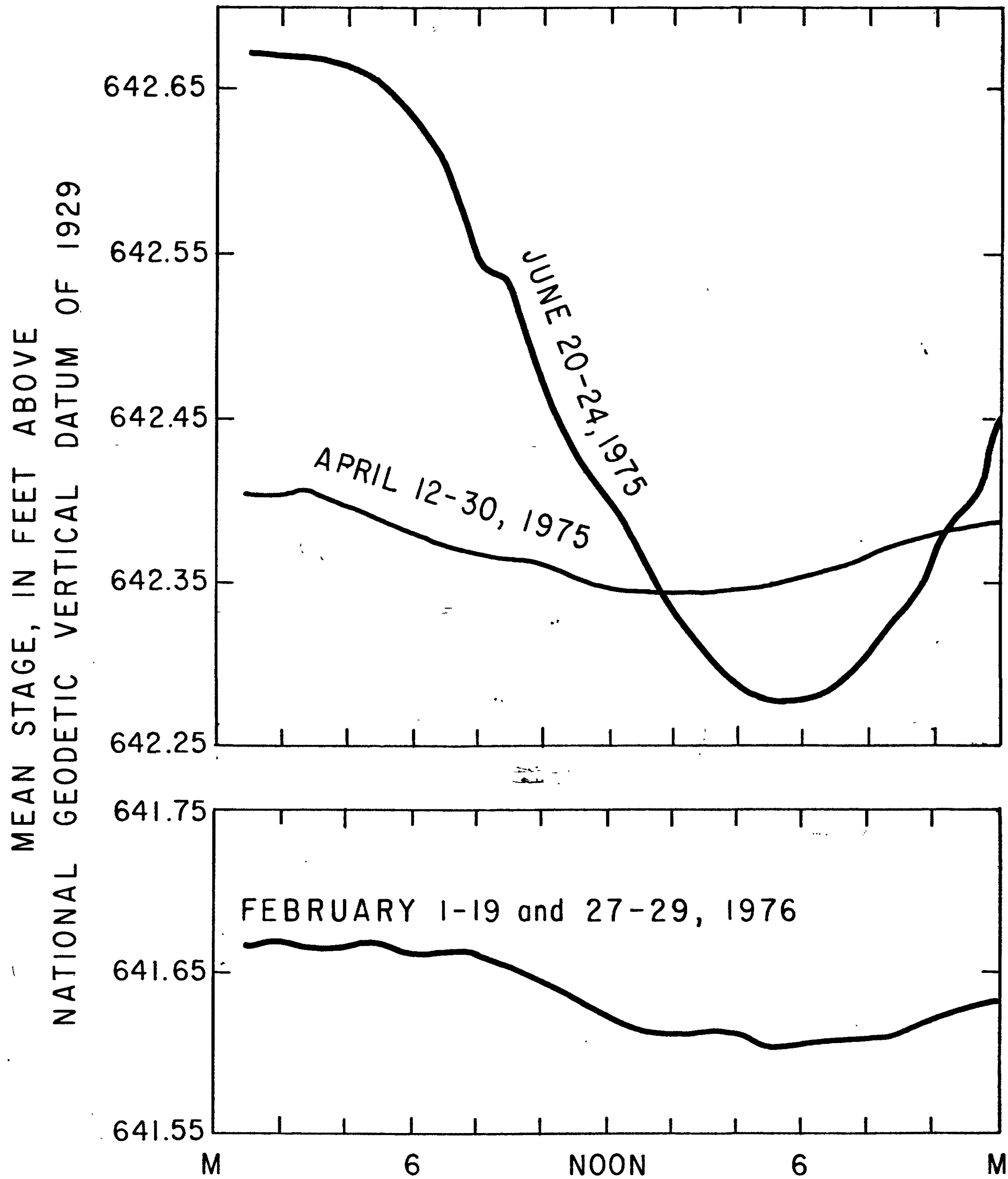

Figure 18.--Mean diel stage for the periods of April 12-30, 1975, June 20-24, 1975, and February 1-19 and 27-29, 1976, for the Yadkin River at Yadkin College.

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 proscribed limits shown.

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 and figure 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 1974-1978 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 proportions of major dissolved constituents, but differ greatly in absolute concentrations of these cations and anions.

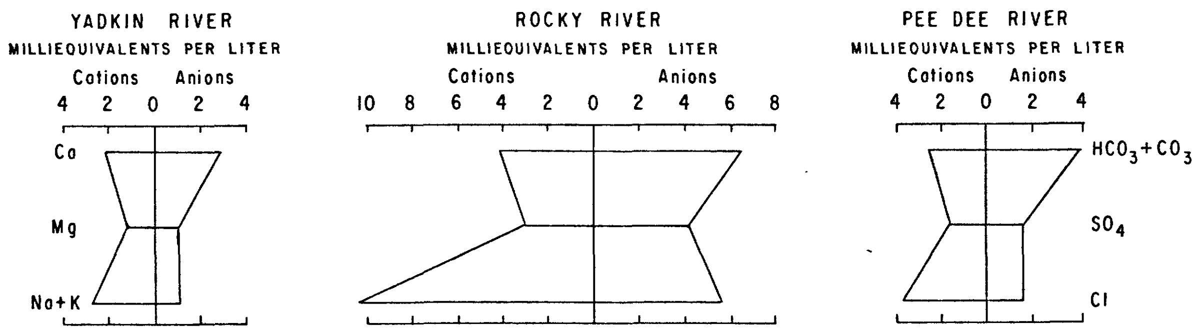

Figure 19.--Cation-anion diagrams for water years 1974-78 for the Yadkin River at Yadkin College, Rocky River near Norwood, and the Pee Dee River near Rockingham.

Table 4.--Summary of statistics of major dissolved constituents for the Yadkin River at Yadkin College, Rocky River near Norwood, and 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 (SiO_2)	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	0.4- 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	0.5- 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 (HCO_3^-)	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 ($SO_4^=$)	4.7 4.4-5.0	2.7 6.5	45	21.3 17.1-25.6	8.8 56.0	30	6.9 6.6-7.2	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)	0.15 0.13-0.17	0.0- 0.3	45	0.19 0.15-0.25	0.10- 0.60	30	0.16 0.14-0.18	0.0- 0.5	70	--
Dissolved solids (residue at $180^{\circ}C$)	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 $CaCO_3$)	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	Category: Soft water
Specific conductance (µmhos/cm at $25^{\circ}C$)	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	--

1/The 95 percent confidence interval means that with 95 percent confidence we estimate the mean to fall within the given range, assuming that the number of samples is large enough and that the samples are randomly collected.

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-constituent concentrations that occur in the river segment between Yadkin College and Rockingham.

Conductance may be satisfactorily related to the concentrations 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. Concentrations of eight major cations and anions regressed over specific conductance are shown for the Yadkin River in figure 24 for the Rocky River in figure 25, and the Pee Dee River in figure 26. Sodium, chloride, and bicarbonate plots are similar for the three different stations. Other constituents show large variations among the three stations in slope and correlation with specific conductance.

The relation between dissolved solids (residue at 180°C) and discharge is shown in figure 27 for the Rocky River near Norwood. The regresion curve is in the form $C = bQ^m$, or, in logarithmic form:

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

where C is constituent concentration, Q is discharge, ln b is the y-intercept and m is the slope. The relation in figure 27 shows dissolved solids to be strongly affected by discharge at Norwood. The relation between dissolved-solids concentration and discharge is evident at Yadkin

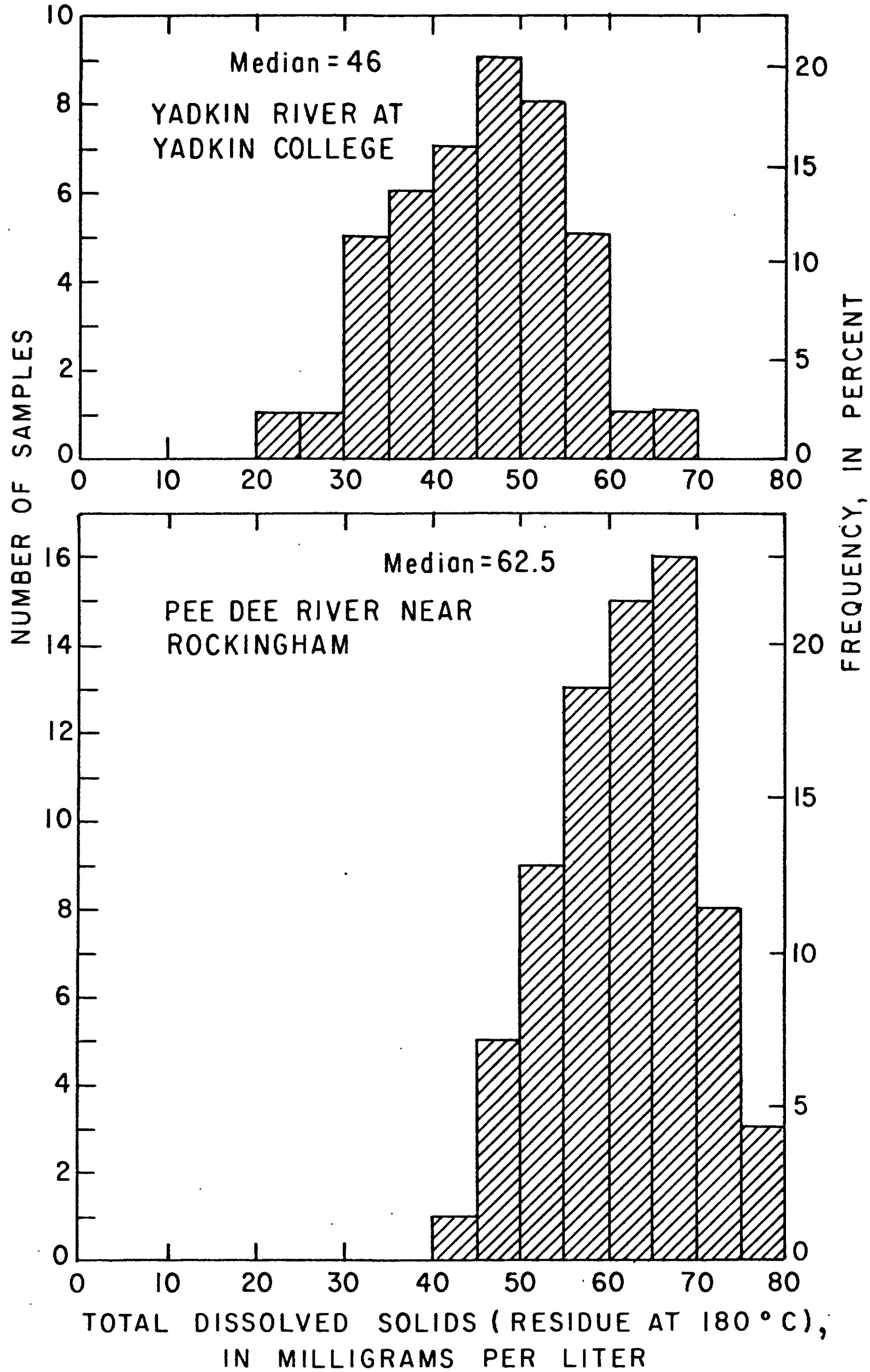

Figure 20.--Frequency distributions of dissolved solids for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham (1974-78 water years).

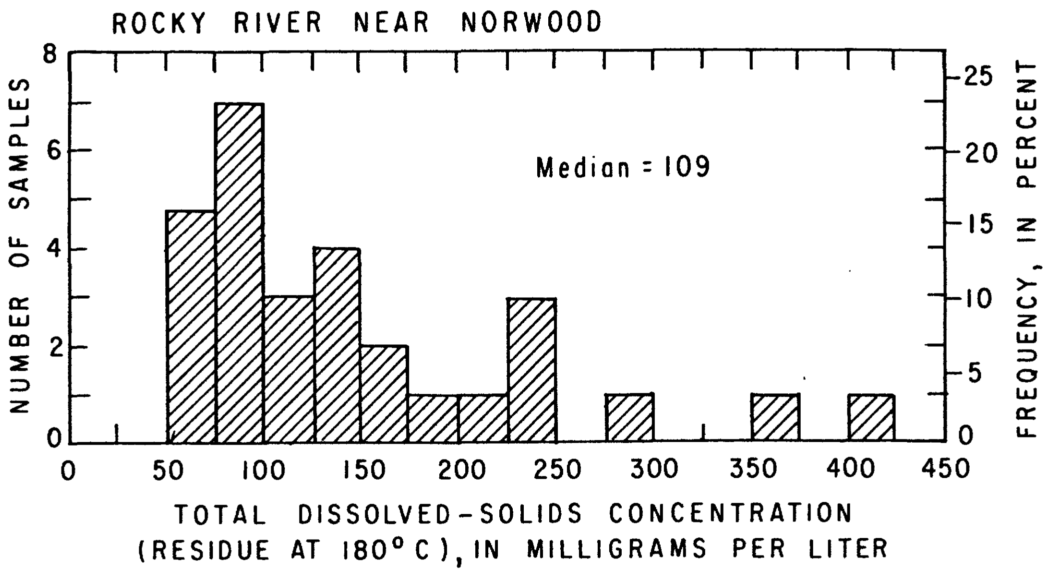

Figure 21.--Frequency distribution of dissolved solids for the Rocky River near Norwood (1974-78 water years).

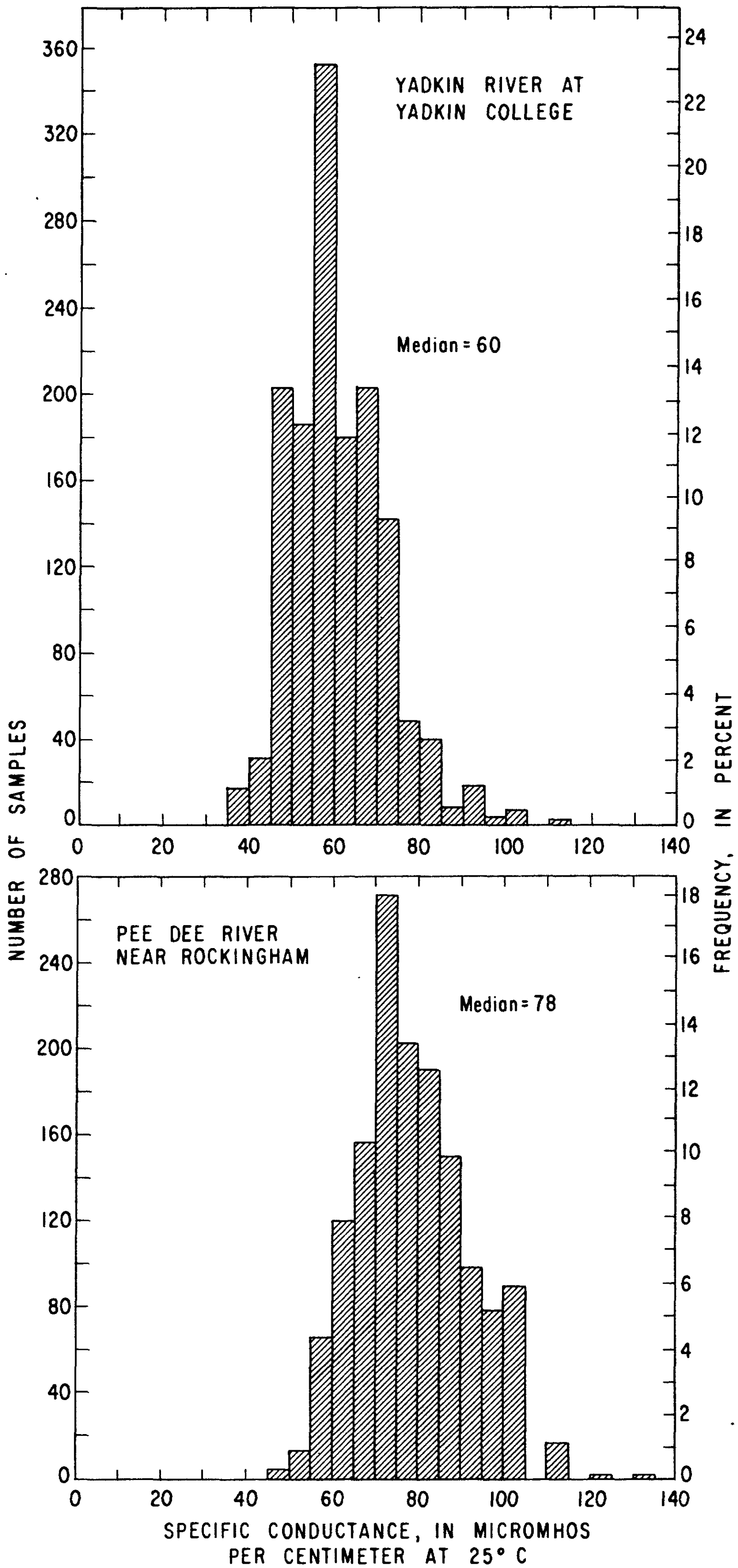

Figure 22.--Frequency distributions of daily specific conductance for the Yadkin River at Yadkin College (1974-77 water years) and the Pee Dee River near Rockingham (1975-77 and 1979 water years).

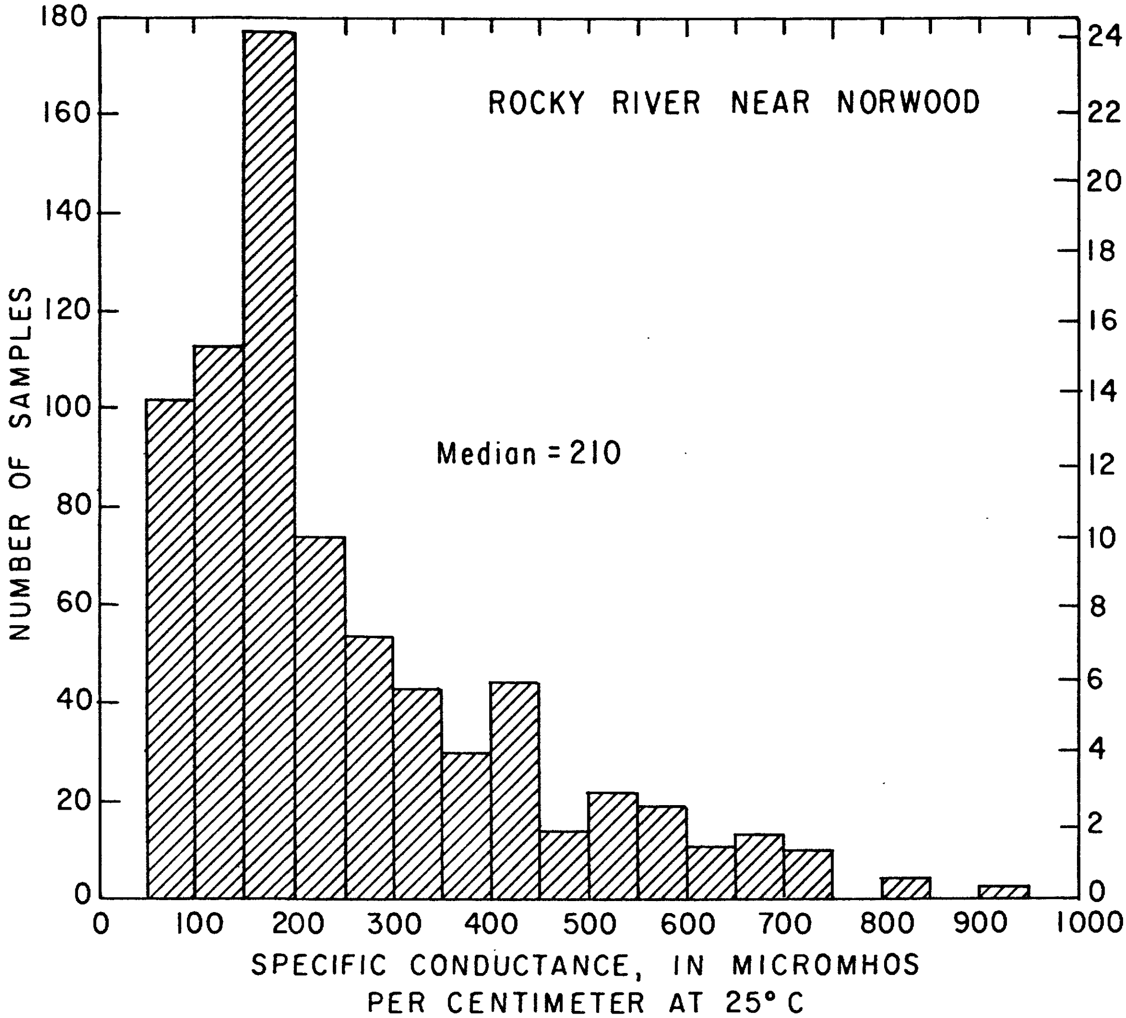

Figure 23.--Frequency distribution of daily specific conductance for the Rocky River near Norwood (1977 and 1979 water years).

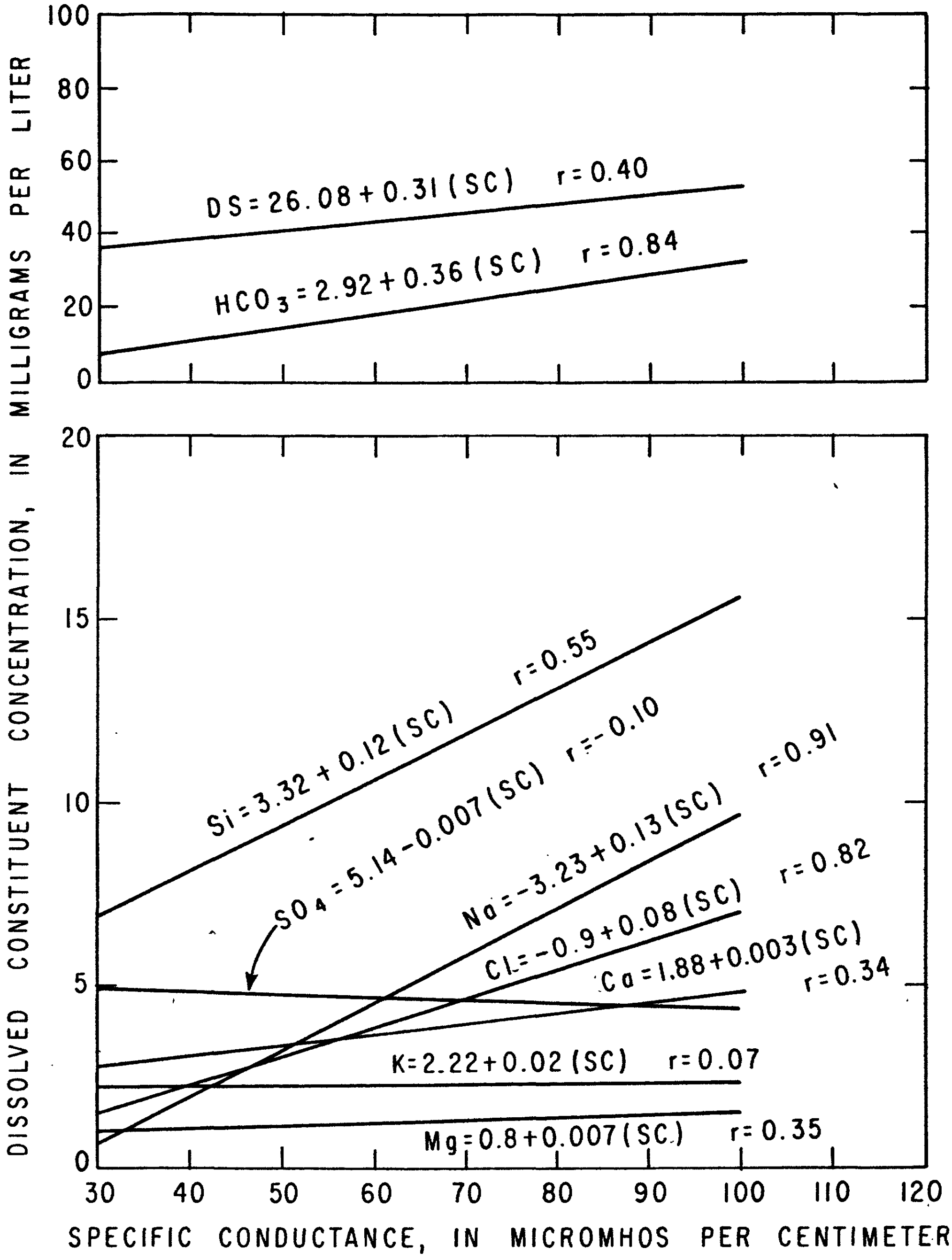

Figure 24.--Regression lines of dissolved-constituent concentration over the known range of specific conductance for the Yadkin River at Yadkin College (1974-78 water years).

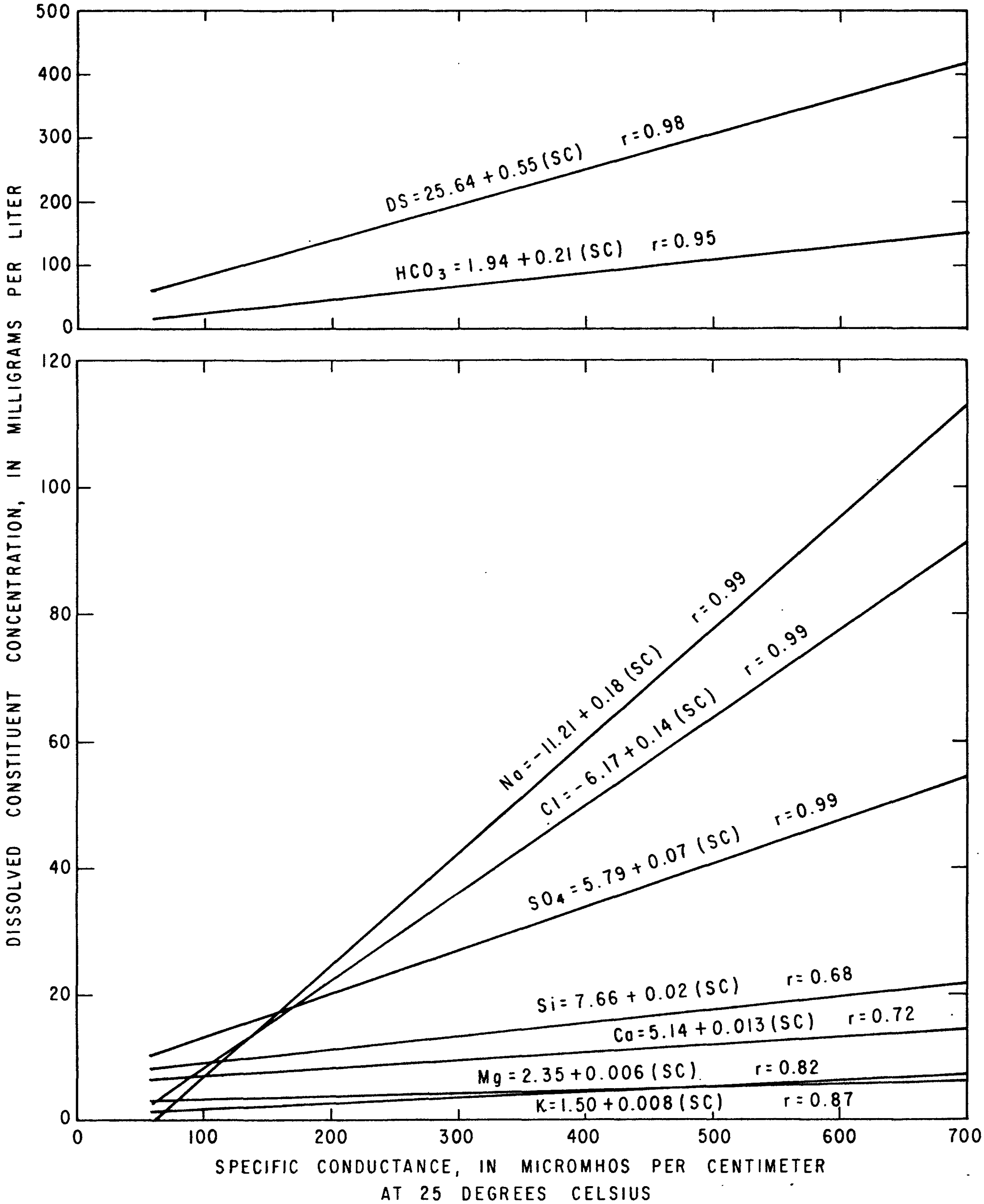

Figure 25.--Regression lines of dissolved-constituent concentration over the known range of specific conductance for the Rocky River near Norwood (1974-78 water years).

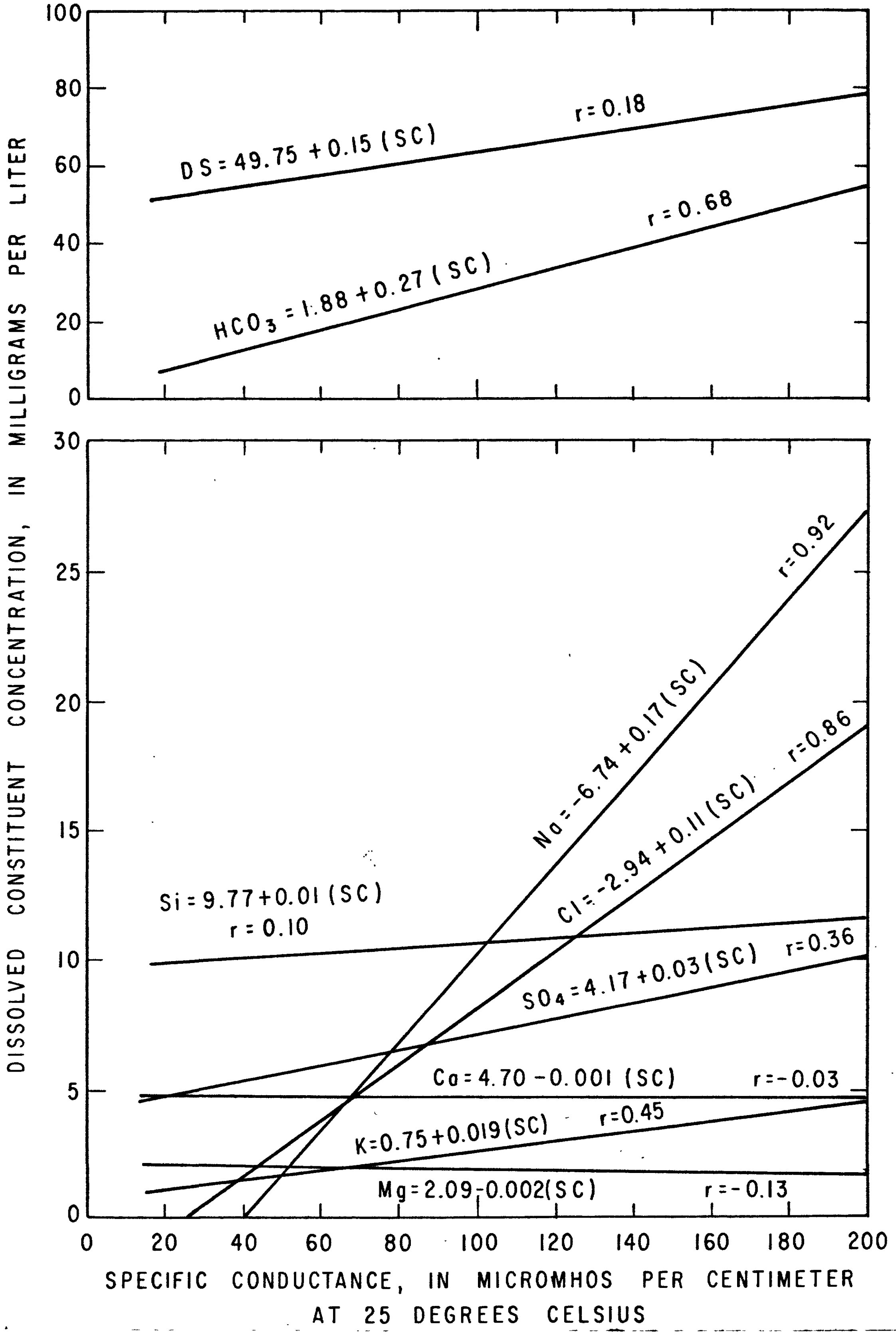

Figure 26.--Regression lines of dissolved-constituent concentration over the known range of specific conductance for the Pee Dee River near Rockingham (1974-78 water years).

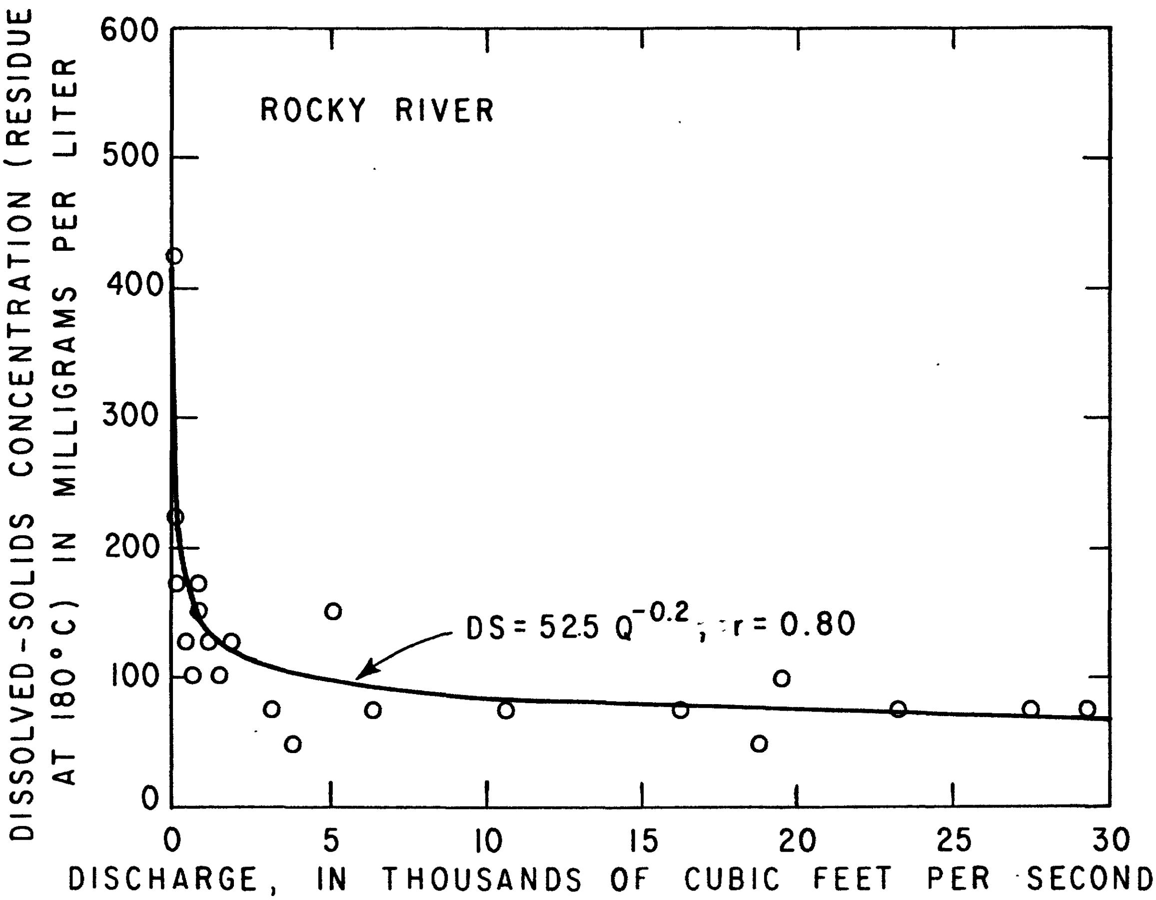

Figure 27.--Total dissolved solids (DS) versus instantaneous streamflow (Q) for water years 1974-78 for the Rocky River near Norwood.

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 5. 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 at Yadkin College, 100 percent of the samples 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 remove much of the suspended material in the water which accounts 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. However, the distributions of most trace metal values at all three stations have strong positive skewness. That is, the mean values are greater than the median values. This indicates that although high concentrations have been recorded, the majority of the samples have lower trace metal concentrations than the mean values.

Available data allow the waterborne trace elements to be subdivided into dissolved and suspended constituents (table 6) with the total (shown earlier in table 5) 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.

Table 5.--Summary of statistics for trace-element concentrations for the Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham (1970-78 water years) (Results in micrograms per liter)

	YADKIN RIVER AT YADKIN COLLEGE			ROCKY RIVER NEAR NORWOOD			PEE DEE RIVER NEAR ROCKINGHAM			
Total trace element	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	U.S. E.P.A. Criteria (1976)
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	0.8 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	Domestic water supply: 50 μg/L maximum
Mercury (Hg)	0.3 0.1-0.4	0- 1.4	21	1.1 0-2.8	0.1- 8.8	11	0.2 0.1-0.3	0- 1.2	25	Domestic water supply: 2 μg/L maximum. Aquatic life: 0.05 μg/L maximum
Selenium (Se)	1.9 0.4-3.4	0- 7.0	15	0.5 0-1.4	0- 1.0	4	0.4 0-0.9	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, assuming that the number of samples is large enough and that the samples are randomly collected.

Table 6.--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)

	DISSOLVED			SUSPENDED			
Trace element	Mean and 95 percent confidence interval[1/]	Range	Number of samples	Mean and 95 percent confidence interval[1/]	Range	Number of samples	Ratio of mean suspended to mean dissolved
Arsenic	1.43 0.13-2.72	0-7	14	2.36 0.73-3.98	0-8	14	1.65
Cadmium	0.36 0-0.72	0-2	14	1.14 0-2.74	0-10	14	3.17
Cobalt	0.93 0.27-1.59	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	0.11 0.02-0.20	0-0.5	14	0.11 0-0.27	0-0.9	14	1
Selenium	2.57 0-5.67	0-20	14	0.43 0-0.97	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, assuming that the number of samples is large enough and that the samples are randomly collected.

A profile of variation in concentration of several trace elements and dissolved solids during a January 9-17 flood for the Yadkin River at Yadkin College demonstrates several important water-quality relations (fig. 28). 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 dissolved-solids response given in figure 28. Data other than that shown in figure 28 show that only dissolved arsenic and selenium appear to be diluted by floodflows for the Yadkin River at Yadkin College.

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 7. 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 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 waste-water treatment plants.

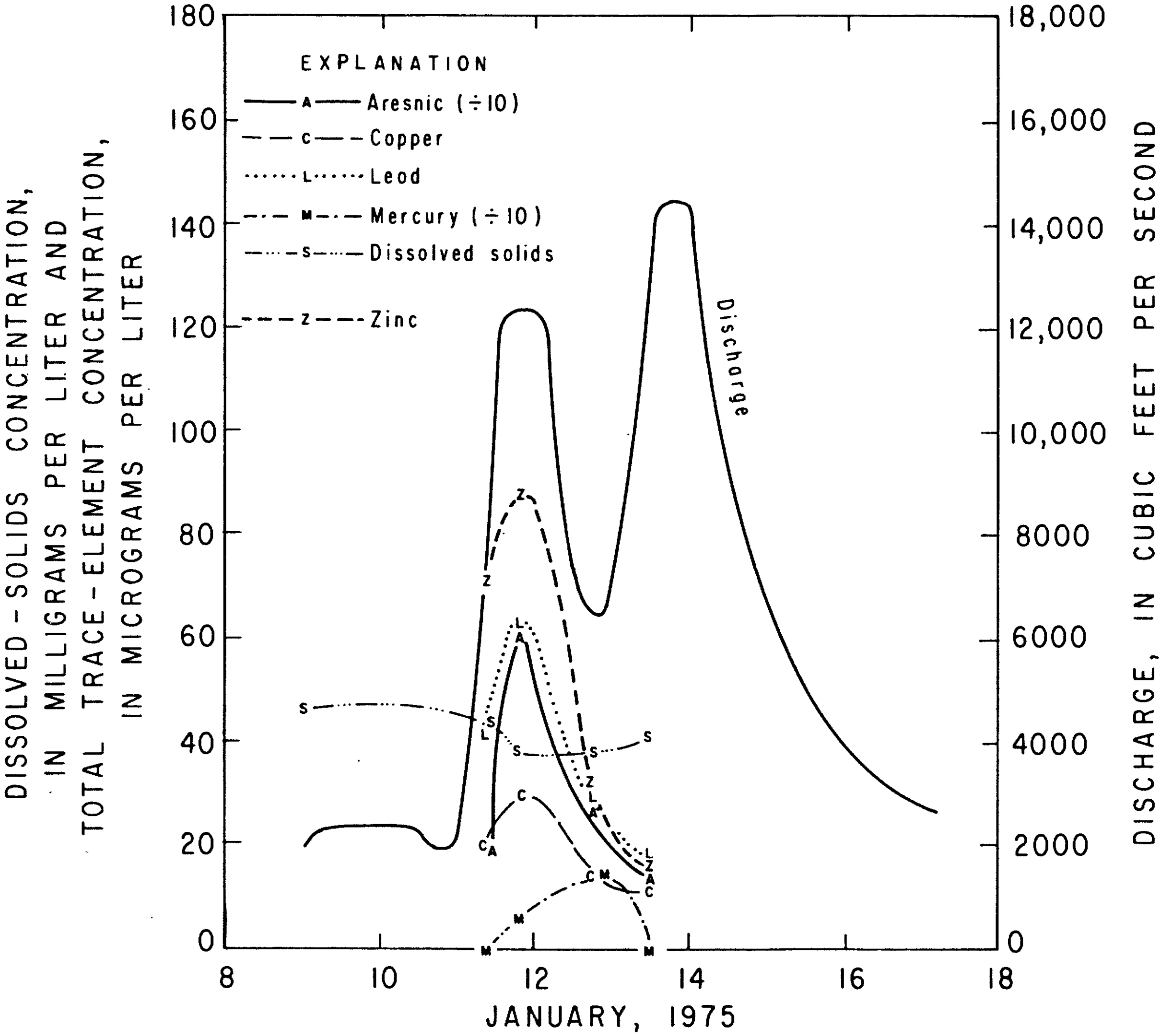

Figure 28.--Trace element (total concentration) and dissolved-solids concentration and discharge for the Yadkin River at Yadkin College through a storm event occurring January 9-17, 1975.

Table 7.--Summary of statistics for nutrients for the Yadkin River at Yadkin College, Rocky River near Norwood, and the Pee Dee River near Rockingham (1970-78 water years)
(Results in milligrams per liter)

	YADKIN RIVER AT YADKIN COLLEGE			ROCKY RIVER NEAR NORWOOD			PEE DEE RIVER NEAR ROCKINGHAM			
Nutrient or parameter	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	U.S. E.P.A. Criteria (1976)
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)	0.17 0.13-0.21	0- 0.38	29	0.15 0.09-0.21	0.01- 0.45	20	0.08 0.06-0.10	0.01- 0.17	21	
Dissolved ammonia nitrogen (as N)	0.14 0.06-0.21	0- 1.0	29	0.11 0.06-0.16	0.01- 0.42	20	0.06 0.02-0.10	0- 0.14	8	
Total organic nitrogen (as N)	0.9 .43-1.37	0- 6.9	30	1.0 0.7-1.2	0.3- 2.6	20	0.4 0.3-0.5	0.2- 0.7	16	
Dissolved organic nitrogen (as N)	0.3 0.2-0.5	0- 2.2	30	0.6 0.4-0.7	0.2- 1.4	19	0.3 0.2-0.4	0.2- 0.4	8	
Total ammonia & organic nitrogen (as N)	0.81 0.61-1.01	0.08-2.4	31	1.07 0.82-1.32	0.4-2.8	21	0.49 0.39-0.59	0.10-2.60	48	
Total nitrite + nitrate (as N)	0.5 0.4-0.5	0.2- 1.0	31	1.2 0.8-1.5	0.6- 3.5	20	0.5 0.4-0.5	0.01- 1.0	54	10 mg/L domestic water supply
Dissolved nitrate (as N)	0.47 0.02-0.92	.06-0.70	4	0.77 0.48-1.06	0.5-1.1	5	0.39 0.17-0.61	0.02- 0.60		
Dissolved ortho-phosphorus (as PO_4)[2/]	0.6 0.0-1.4	0- 13.0	35	0.72 1.13-0.31	0.1- 4.3	29	0.04 0.02-0.06	0- 0.15	17	
Total phosphorus (as P)	0.3 0.2-0.3	0.1- 0.8	35	0.4 0.3-0.5	0.3- 1.4	25	0.08 0.07-0.09	0- 0.3	63	0.05 mg/L for streams feeding impoundments
Nutrient[3/] ratio :1	4.31 3.57-5.05	0.35-8.50	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 assuming that the number of samples is large enough, and that the samples are randomly collected.

2/ Dissolved orthophosphorus is listed here as PO_4 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.

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 waters. 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 29. 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 on table 7 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). Frequency histograms of total phosphorus for three stations are given in figure 30. The reduction of phosphorus concentration in the Pee Dee River near Rockingham is quite evident from a comparison of the histograms.

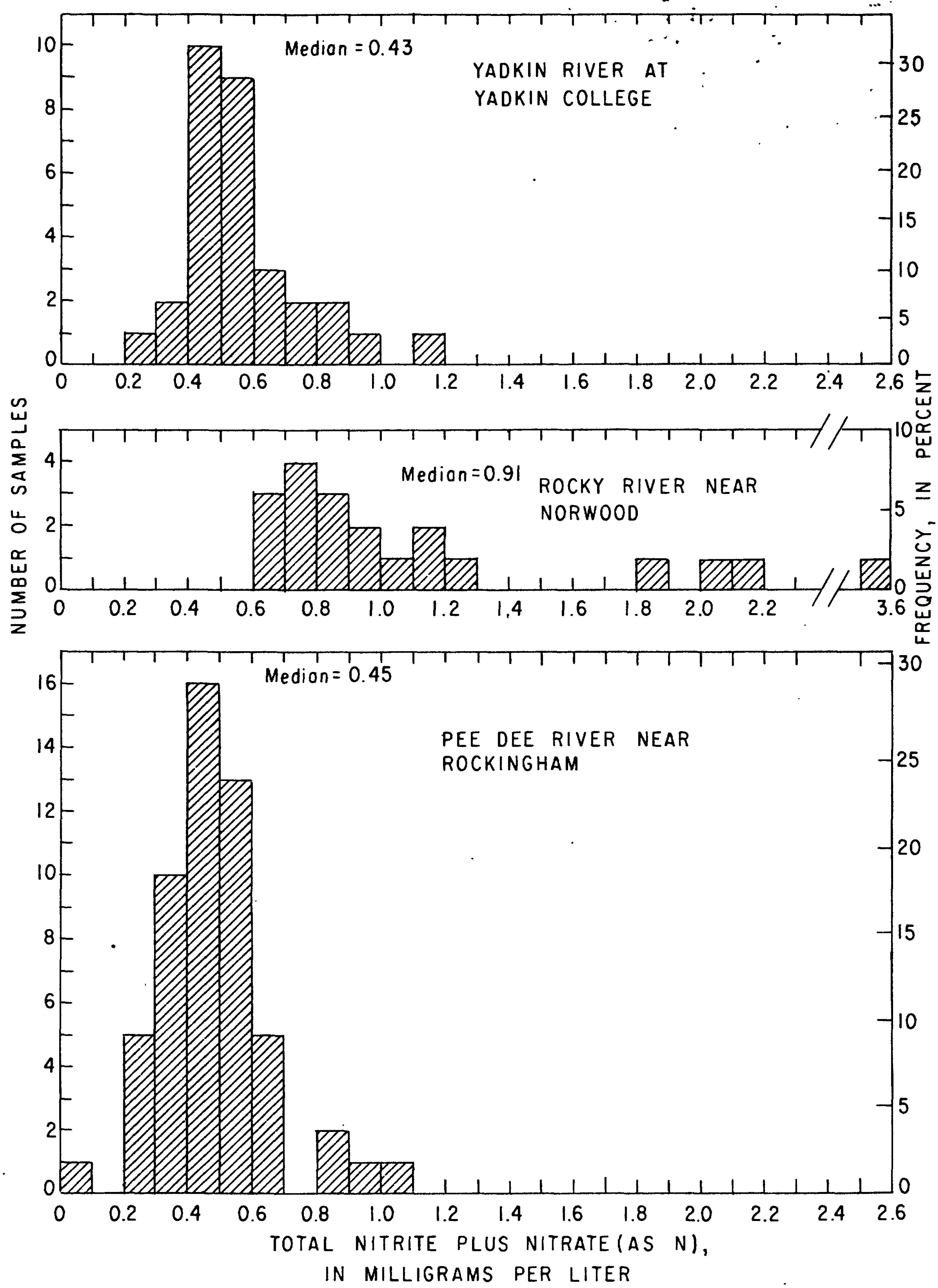

Figure 29.--Frequency distributions of nitrite + nitrate nitrogen concentrations for the Yadkin River at Yadkin College, Rocky River near Norwood, and the Pee Dee River near Rockingham (1974-78 water years).

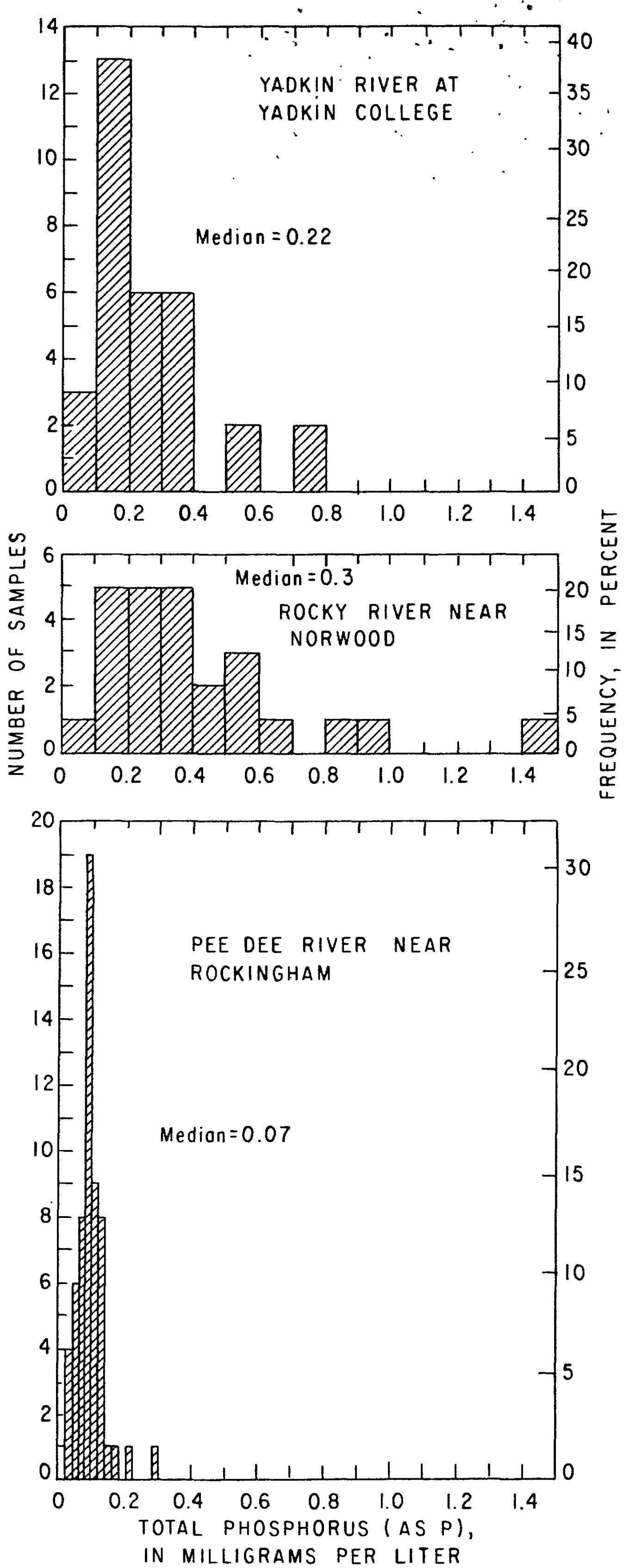

Figure 30.--Frequency histograms for total phosphorus (as P) for the Yadkin River at Yadkin College, Rocky River near Norwood, and the Pee Dee River near Rockingham (1970-78 water years).

Nutrient Balance

An estimate of the nutrient balance can be calculated using the mean concentration given in table 7 and the mean discharge from table 2. The results of this exercise (table 8) 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 on table 8 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 7). 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. 30) and the nutrient balance (table 8) show that a dramatic reduction of phosphorus occurs somewhere between the Yadkin College station and the Rockingham station. These observations strongly indicate that phosphorus acts as the limiting nutrient. In fact, U.S. Environmental Protection Agency (1975a, 1975b, 1975c, 1975d) studies 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 occurrence 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, 1975d, North Carolina Department of Natural and Economic Resources, 1975; Weiss and others, 1981).

Table 8.--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 Rocky River near Norwood data as input, and data from the Pee Dee River near Rockingham as output
(Results in tons per year except as indicated)

	A	B	C (A+B=C)	D	E (D-C=E)
Nutrient or Parameter	Yadkin River at Yadkin College	Rocky River near Norwood	SUM OF INPUTS	Pee Dee River near Rockingham	DIFFERENCE (Negative values indicate a loss in lake system)
Period-of-record mean discharge (ft^3/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 & 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 PO_4)	1,800	900	2,700	300	-2,400
Total phosphorus (as P)	880	520	1,400	630	-770

Biological Characteristics

The types of biota and number of organisms living in a body of water can be used to evaluate water quality. 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 verifying 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 non-specific 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 five-day biological 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 warm-blooded 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 coliform statistics for all three stations are given in table 9. Only Yadkin College, with a geometric mean of 633 fecal coliforms/100 mL, exceeds the criterion. However, fecal coliform levels occasionally peak to levels substantially above the criterion at both Norwood and Rockingham.

Table 9.--Summary statistics for biological characteristics of Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham (1974-78 water years).

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 0.6-3.8	1.1-2.1	2
Fecal coliform (colonies/100mL)	630[2/] --	20-26,000	52	29[2/] --	10-100	7	29 --	1-520	31
Fecal Streptococci (colonies/100mL)	-- --	--	--	-- --	--	--	60[2/] --	4-1,400	23
Phytoplankton count (cells/mL)	2,100[2/] --	350-5,800	9	4,400[2/] --	2,600-7,600	2	510[2/] --	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)	0.81 0.47-1.2	0-1.4	9	-- --	--	--	0.86 0.73-0.99	0-1.7	39
class (bits/cell)	0.85 0.53-1.2	0-1.4	9	-- --	--	--	0.87 0.73-1.0	0-1.3	39
order (bits/cell)	1.2 0.71-1.7	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	0.60-3.0	39
genus (bits/cell)	2.7 2.2-3.2	1.8-3.5	9	-- --	--	--	2.1 1.9-2.3	0.70-3.4	39

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

[2/] Geometric mean

Fecal streptococcus bacteria also indicate fecal contamination from warm-blooded 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 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 five-day biochemical oxygen demand (BOD_5) 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 BOD_5 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 BOD_5 were recorded at the Yadkin College station (table 9). These high BOD_5 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 31. 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.

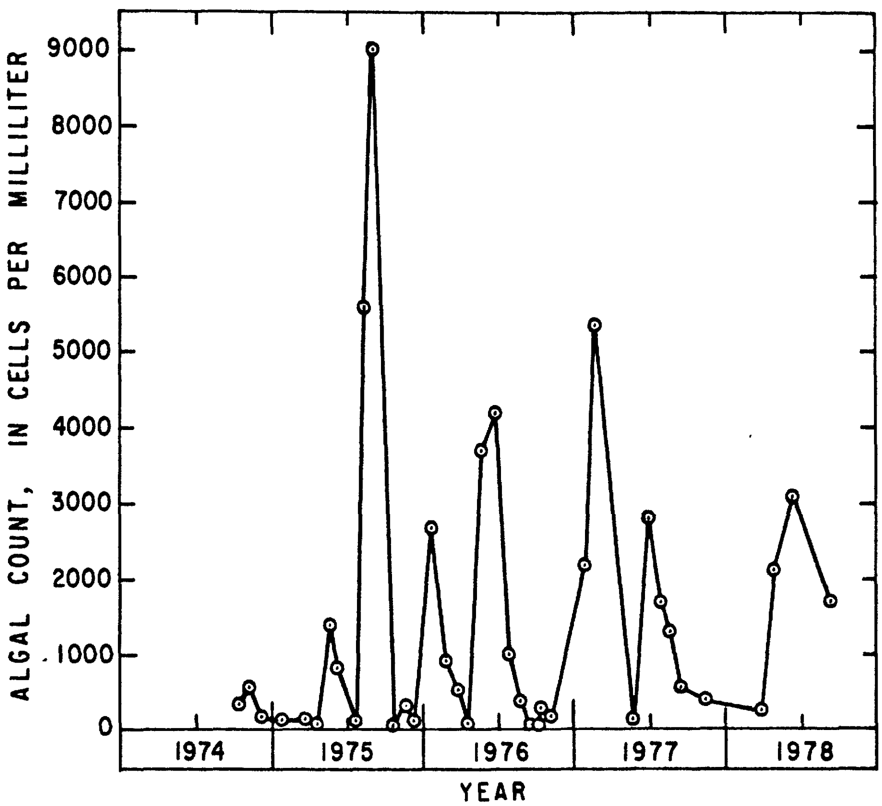

Figure 31--Algal cell counts for the Pee Dee River near Rockingham.

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). The report cover photograph shows several of the types of algae like those found in the Yadkin-Pee Dee River system. 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, 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 dominate 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), 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.

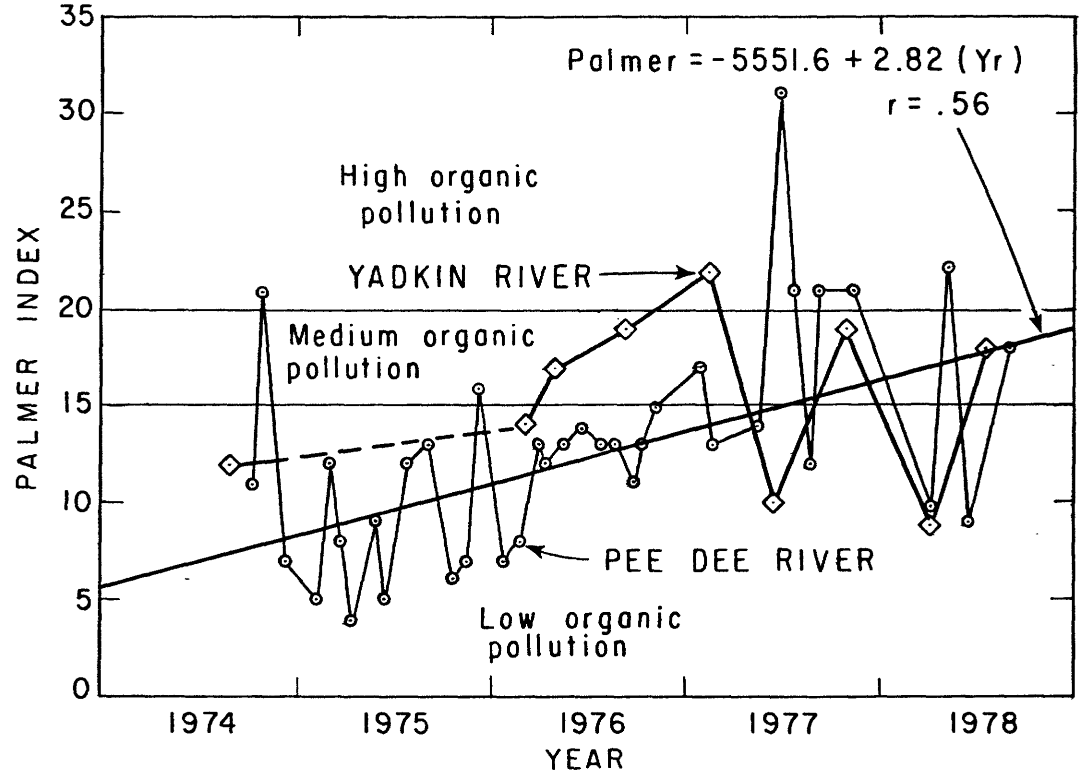

Figure 32.--Palmer index values for phytoplankton samples from the Yadkin River at Yadkin College and the Pee Dee River near Rockingham.

Palmer index values are plotted in figure 32 and given in table 9. Most values for the Palmer index fall within the range of 10 to 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 32 reveals a statistically significant (two-tailed t-test, at a probability of 0.05) increasing trend over time in Palmer index at Rockingham.

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:

$$\bar{d} = \sum_{n=1}^{i} \frac{n_i}{n} \log_2 \frac{n_i}{n} \qquad (2)$$

where $\bar{d}$ = the diversity index

n_i = the number of organisms of taxonomic group i

n = the total number of organisms

There is some controversy 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 to 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 to 3.0 indicate moderate eutrophication, and a value less than 1.0 diversity of benthic macroinvertebrates indicates severe eutropication. The ranges observed for diversity indexes for phytoplankton in oligotrophic and eutrophic lakes are similar (Margalef, 1968). Using these diversity index ranges it is apparent that the Yadkin-Pee Dee River system is moderately eutrophic (table 9).

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 reduction 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 indicies 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 manmade pollution, that is, to find how man has changed the natural state of the stream. The accuracy of this evalution hinges on the data available about 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 based on data 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 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 33. Baseline stations were sampled at high and

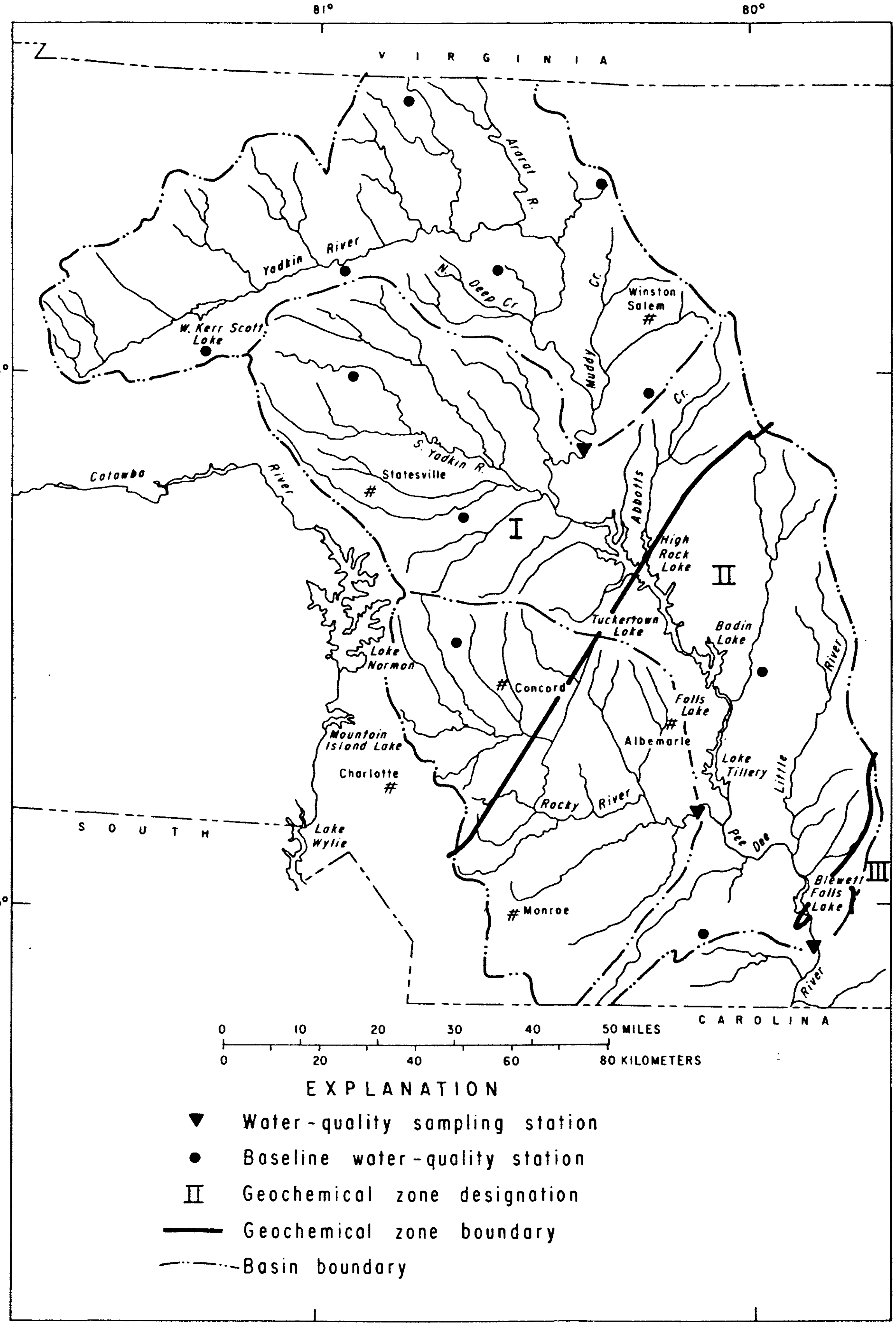

Figure 33.--Baseline water-quality stations and geochemical zones in the Yadkin-Pee Dee River basin.

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 (figure 33).

The estimated baseline water quality for each station (tables 10, 11, and 12) 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 33. The basin upstream from Yadkin College is entirely (2,280 mi^2) in zone I. The Rocky River (Norwood) subbasin is 34 percent (490 mi^2) in zone I and 66 percent (942 mi^2) in zone II. The basin upstream from Rockingham is 65 percent (4,400 mi^2) in zone I and 35 percent (2,500 mi^2) 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 34). 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 10 and 11 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.

Table 10.--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	Baseline water quality: Mean concentration (mg/L) Base flow	Baseline: Mean concentration (mg/L) High flow	Baseline: Range of all samples (mg/L)	Existing water quality: Mean concentration (mg/L) Base flow (<2000 ft^3/s)	Existing: Mean concentration (mg/L) High flow (>2000 ft^3/s)	Existing: Range of all samples (mg/L)	Percent attributable to pollution: Base flow	Percent attributable to pollution: 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	0.8-0.9	1.3	1.1	0.4-2.2	38	18
Sodium	1.9	1.3	1.3-2.1	5.8	3.8	0.5-10.0	67	66
Potassium	1.1	.4	0.4-1.25	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	0.8-1.75	3.5	3.4	2.7-6.5	51	76
Chloride	1.1	.6	0.1-1.6	4.6	3.1	1.4-8.2	76	81
Flouride	.1	.0	0-0.01	.1	.1	0-0.3	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	0.12-0.36					
Organic Nitrogen	.18	.09	0.08-0.24	1.52	.74	0-6.9	88	88
Nitrite & Nitrate Nitrogen	.125	.128	0.01-0.28	.49	.46	0.2-1.0	74	72
Ammonia Nitrogen	.003	.008	0-0.01	.22	.16	0-0.38	99	95
Phosphorus	.02	.02	0.01-0.025	.29	.27	0.1-0.8	93	93
Arsenic	0	0	0-0.001	.003	.004	0-0.009	100	100
Chromium	.01	.01	0.01-0.02	--	--			
Copper	.007	.003	0.003-0.009	.006	.013	0-0.033	--	77
Iron	.3	1.6	0.1-3.0	.36	7.1	0-300	17	77
Lead	.0045	.013	0.003-0.013	.023	.019	0-0.1	80	32
Mercury	.0005	.0005	0.005	.0003	.0003	0-0.0014	--	--
Selenium	0	0	0	.005	.002	0-0.007	100	100
Zinc	.005	.01	0.005-0.01	.016	.045	0-0.11	69	78

Table 11.--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	Baseline water quality: Mean concentration (mg/L) Base flow	Baseline water quality: Mean concentration (mg/L) High flow	Baseline water quality: Range of all samples (mg/L)	Existing water quality: Mean concentration (mg/L) Base flow (<250 ft³/s)	Existing water quality: Mean concentration (mg/L) High flow (>250 ft³/s)	Existing water quality: Range of all samples (mg/L)	Percent attributable to pollution: Base flow	Percent attributable to pollution: High flow
Dissolved								
Calcium	5.0	1.6	0.6-10	10.7	6.9	3.6-13	53	77
Magnesium	2.0	.8	0.7-4.1	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	0.4-1.8	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	0.8-8.2	38.8	16.1	8.8-56.0	89	65
Chloride	4.7	2.1	0.1-10	59.1	15.2	5.2-96.0	92	86
Flouride	.06	0	0-0.1	.3	.1	0.1-0.6	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	0.5	0.1-0.7	--	--	--	--	--
Organic Nitrogen	.2	.5	0.02-0.7	.96	.94	0.3-2.6	79	47
Nitrite + Nitrate Nitrogen	.5	.04	0-0.3	.76	1.22	0.6-3.5	34	97
Ammonia Nitrogen	.004	.009	0-0.01	.02	.17	0.01-0.45	80	95
Phosphorus	.02	.03	0.01-0.04	.68	.31	0.03-1.4	97	90
Arsenic	.0003	.007	0-0.001	.006	.004	0.001-0.01	95	83
Chromium	.013	.01	0.01-0.02	--	--	--	--	--
Copper	.006	.004	0.003-0.01	.008	.023	0.006-0.074	25	83
Iron	1.1	1.6	0.1-3	.28	10.8	0.55-41.0	--	85
Lead	.004	.009	0.003-0.013	.005	.029	0-0.1	20	69
Mercury	.0005	.0005	.005	.003	.0003	0.1-8.8	83	--
Selenium	0	0	0	.001	.0003	0-1.0	100	100
Zinc	.008	.01	0-0.01	.026	.04	0-0.11	69	75

Table 12.--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	Baseline water quality: Mean concentration (mg/L)	Baseline water quality: Range of all samples (mg/L)	Existing water quality: Mean concentration (mg/L)	Existing water quality: Range of all samples (mg/L)	Percent attributable to pollution
Dissolved					
Calcium	2.7	0.6-10	4.5	2.7-6.2	40
Magnesium	1.3	0.7-4.1	2.1	1.3-9.0	38
Sodium	3.0	1.3-7.3	7.3	3.3-13.0	59
Potassium	1.2	0.4-1.8	2.3	1.4-4.1	48
Bicarbonate	14.9	3-44	24.1	15.0-33.0	38
Sulfate	3.2	0.8-8.2	6.9	2.0-11.0	54
Chloride	2.6	0.1-10	6.4	3.2-11.0	59
Flouride	.04	0-0.1	.16	0.0-0.5	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	0.1-0.7			
Organic Nitrogen	.20	0.02-0.7	.4	0.2-0.7	50
Nitrite + Nitrate Nitrogen	.08	0-0.3	.5	0.1-1.0	84
Ammonia Nitrogen	.006	0-0.01	.08	0.01-0.17	93
Phosphorus	.02	0.01-0.04	.08	0.0-0.3	75
Arsenic	.0003	0-0.001	.0004	0-0.04	25
Chromium	.011	0.01-0.02			
Copper	.005	0.003-0.01	.008	0-0.05	38
Iron	1.05	0.1-3	1.72	0.32-6.10	39
Lead	.006	0.003-0.013	.016	0.0-0.1	63
Mercury	.0005	.0005	.0002	0-0.001	--
Selenium	0	0	.0004	0.0-0.005	100
Zinc	.008	0-0.1	.033	0.0-0.35	76

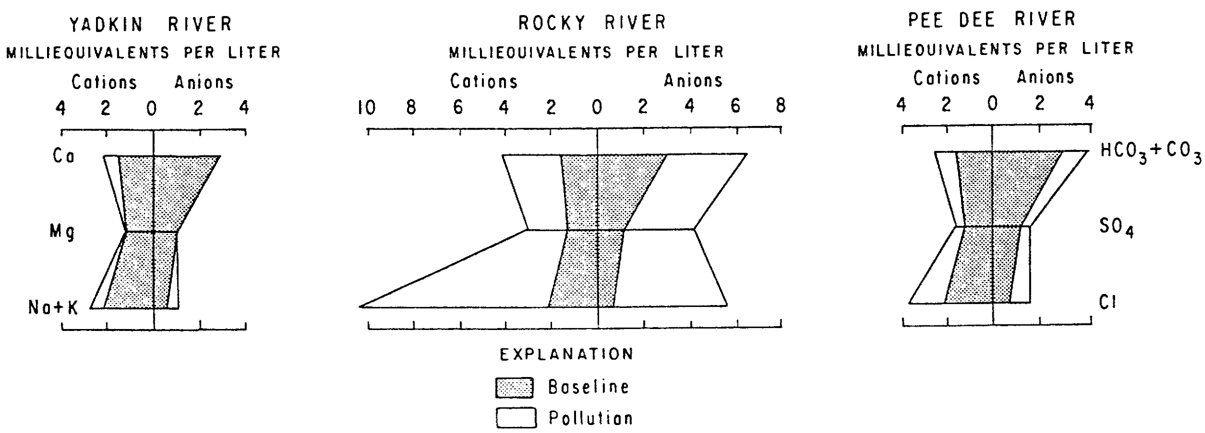

Figure 34.--Comparisons of baseline water quality and observed water quality using cation-anion diagrams. The observed-data diagrams represent the mean concentrations of all samples taken in the 1974-78 water years. The baseline water-quality diagrams represent the mean concentration of all samples taken from baseline stations within the Yadkin-Pee Dee basin.

Evaluation of the difference 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, 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 12. 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 to produce the baseline water-quality for the Pee Dee River given in table 12.

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 approximately correct.

The difference between the observed and baseline concentration of each species gives an estimate of the contribution of pollution to the observed values at Rockingham (table 12). 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 13 for Yadkin College, table 14 for Norwood, and table 15 for Rockingham. The annual load resulting from base flow at Yadkin College (table 13) is much greater than the high-flow component, ranging from 74 percent to 84 percent of the total dissolved load. At Norwood (table 14), 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.

Table 13.--Dissolved-solids loads and concentrations for the Yadkin River at Yadkin College

	Measured at Yadkin River at Yadkin College		Estimated from baseline-quality network		Annual loads			Annual concentrations		
	A	B	C	D	E	F	G	H	I	J
Water year	Discharge ($ft^3/yr \times 10^{13}$)	Dissolved solids load[1/] (tons/yr)	Dissolved-solids load[1/] base flow (tons/yr)	Dissolved-solids load[1/] high flow (tons/yr)	Baseline dissolved-solids load[1/] (tons/yr) C + D	Pollution dissolved-solids load[1/] (tons/yr) B - E	Percent of total load from pollution F/B×100	Total annual concentration (mg/L) $B/A \times 1.13 \times 10^{-3}$	Baseline annual concentration (mg/L) $E/A \times 1.13 \times 10^{-3}$	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 14.--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	B	C	D	E	F	G	H	I	J
	Discharge (ft^3/yr × 10^{13})	Dissolved solids load[1/] (tons/yr)	Dissolved-solids load[1/] base flow (tons/yr)	Dissolved-solids load[1/] high flow (tons/yr)	Baseline dissolved-solids load[1/] (tons/yr)	Pollution dissolved-solids load[1/] (tons/yr)	Percent of total load from pollution	Total annual concentration (mg/L)	Baseline annual concentration (mg/L)	Annual pollution concentration (mg/L)
					C + D	B - E	F/B×100	$B/A \times 1.13 \times 10^{-3}$	$E/A \times 1.13 \times 10^{-3}$	H - I
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 15.--Dissolved-solids loads and concentrations for the Pee Dee River near Rockingham

	Measured at Pee Dee River near Rockingham		Annual Loads			Annual Concentrations		
	A	B	C	D	E	F	G	H
Water year	Discharge ($ft^3/yr \times 10^{13}$)	Dissolved solids[1/] (tons/yr)	Baseline dissolved-solids load[1/] (tons/yr)	Pollution dissolved-solids load[1/] (tons/yr) B-C	Percent from pollution D/Bx100	Total annual concentration (mg/L) $B/A \times 1.13 \times 10^{-3}$	Baseline annual concentration (mg/L) $C/A \times 1.13 \times 10^{-3}$	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

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 15). The large annual flow volumes at 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 concentrations are estimated using linear regressions between dissolved-constituent concentrations and specific conductance (figures 25-27). Daily loads of each constituent are evaluated 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 13-15 for Yadkin College, Norwood, and Rockingham, respectively. The annual pollution load (also given in tables 13-15) is the difference between the total annual dissolved-solids load and the annual baseline load. The dissolved-solids loads plotted in figures 35-37 vividly demonstrate the importance of pollution in the make-up 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 35-37 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 13-15. The highest mean value (59 percent) occurs at Yadkin College. The lowest mean is at 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. 33) 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.

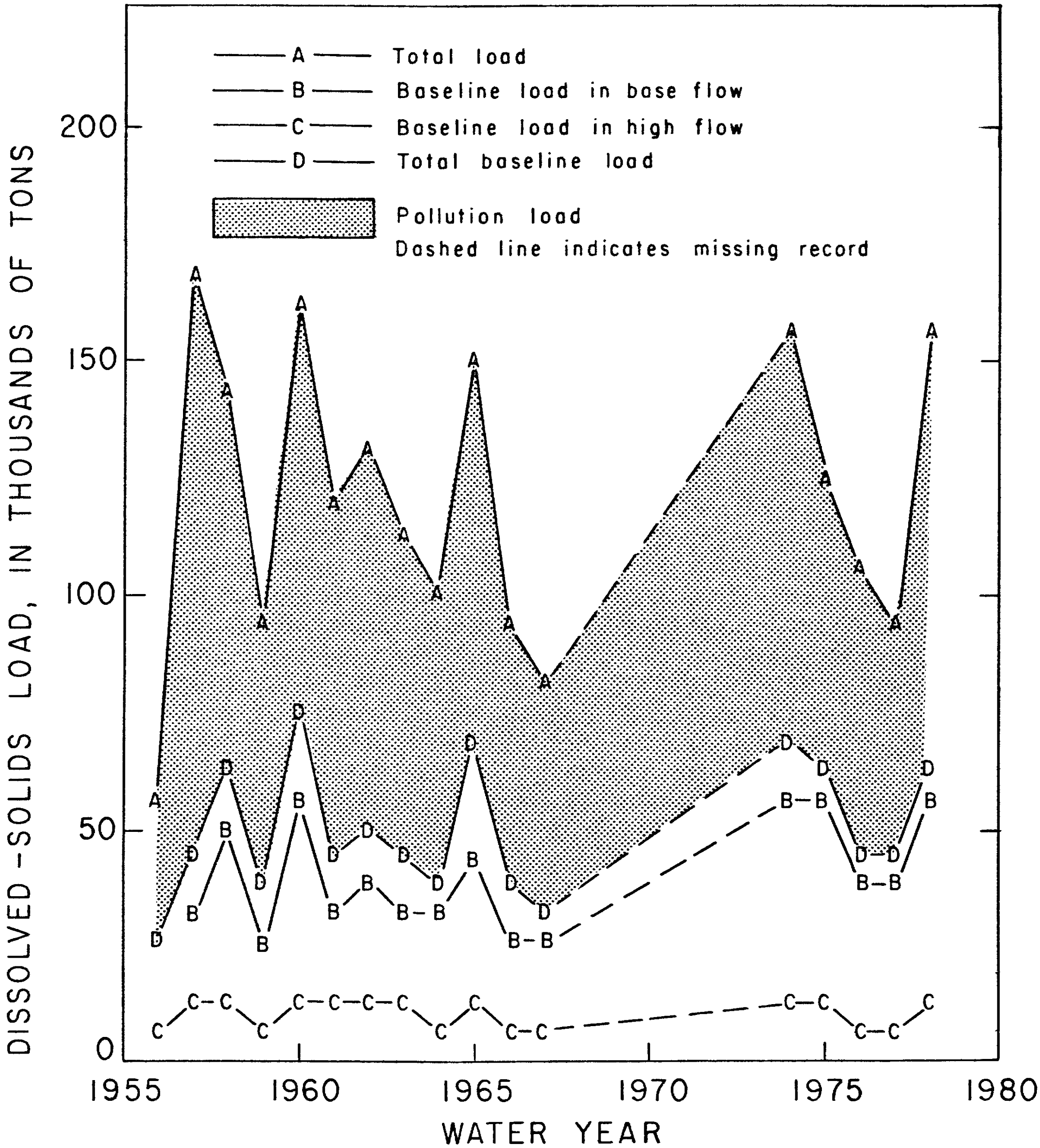

Figure 35.--Dissolved-solids loads for the Yadkin River at Yadkin College.

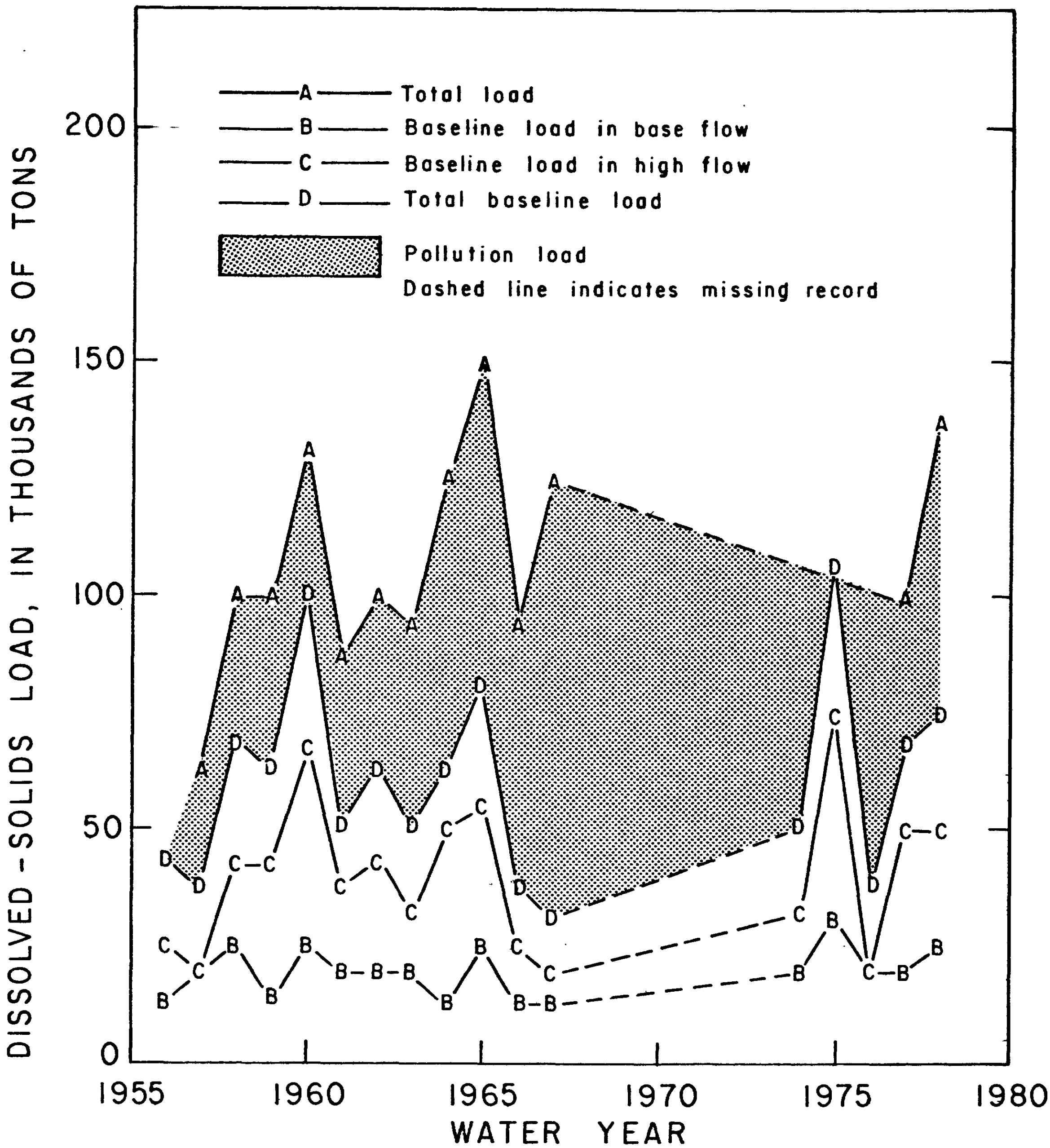

Figure 36.--Dissolved-solids loads for the Rocky River near Norwood.

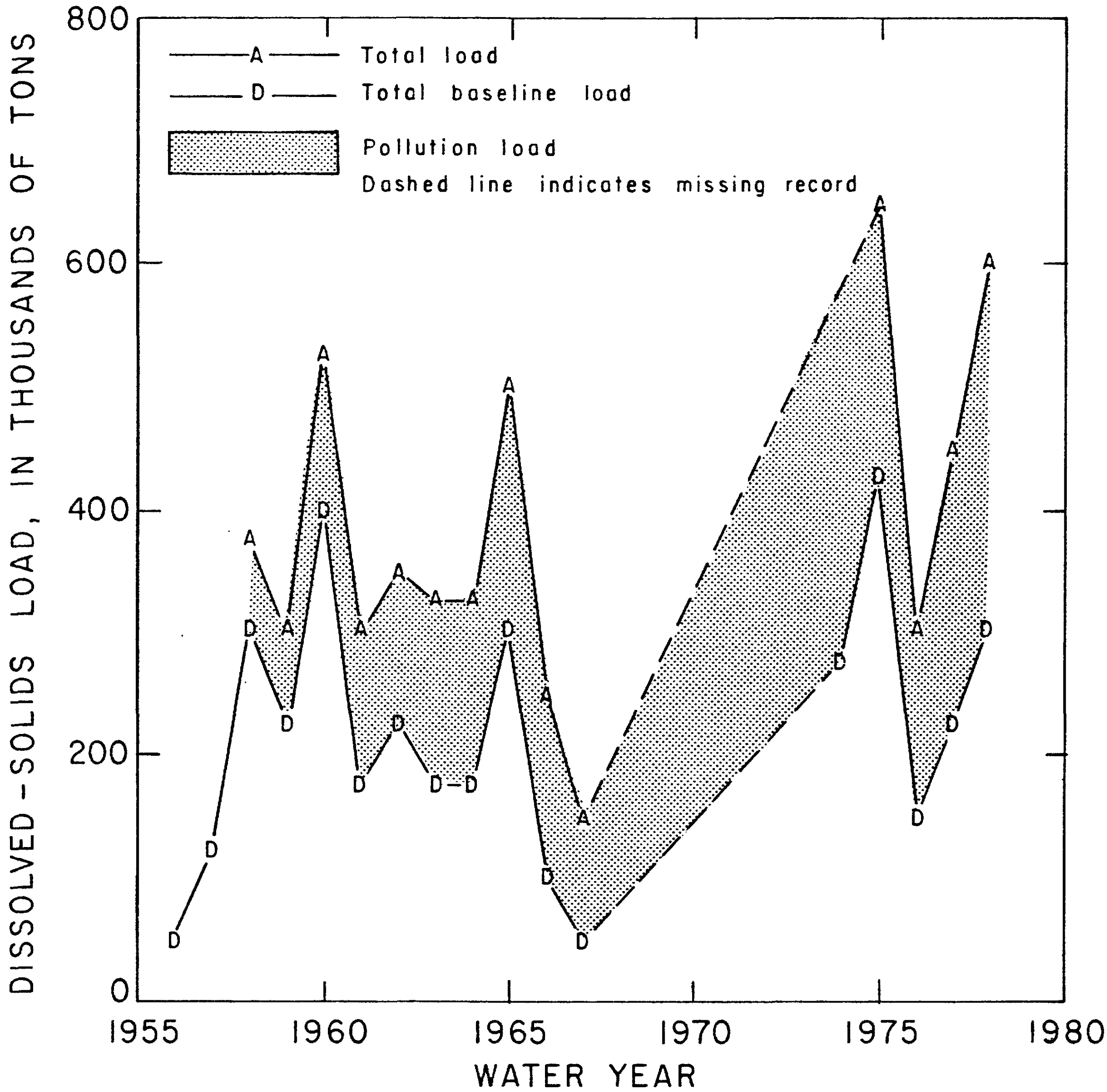

Figure 37.--Dissolved-solids loads for the Pee Dee River near Rockingham.

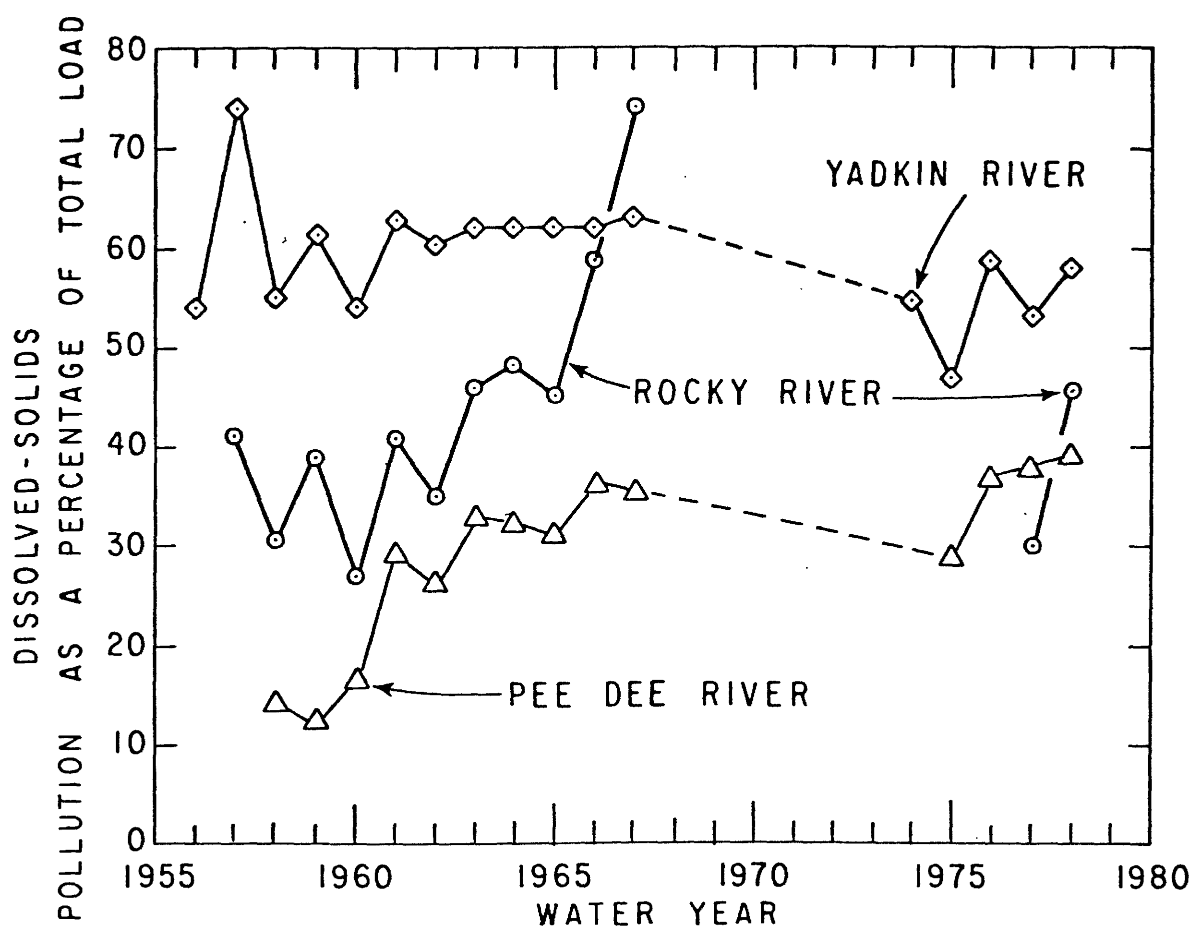

Figure 38--Dissolved-solids pollution as a percentage of total load, for the Yadkin River at Yadkin College, Rocky River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham.

A plot of the proportion of dissolved-solids load attributed to pollution against time for the three stations is given in figure 38. The slopes and correlations of regressions between time and proportion of dissolved-solids load attributed to pollution for each station are given in table 16. The pollution-derived proportion of the annual load at Yadkin College shows a slight decline from 1957-78, 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.

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 to 20 years ago.

Table 16.--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)

Location	Regression equation for water years 1956-78	Squared oorrelation ooefficient (r^2)	Probability that slope is different from zero	Regression equation for water years 1956-67	Squared correlation coefficient (r^2)	Probability that slope is different from zero
Yadkin River at Yadkin College	YPP=708.4-0.330(WY)	0.17	0.101	YPP=-407.6+239(WY)	0.02	0.627
Rocky River near Norwood	NPP=832.2+0.456(WY)	.08	.361	NPP=5274.+2.72(WY)	.60	.005
Pee Dee River near Rockingham	RPP=1821.4+0.941(WY)	.53	.0032	RPP.+2.80(WY)	.83	.0002

Comparisons between dissolved-solids loads at the three stations on the basis of load per square mile of drainage area are given in table 17 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.

Table 17.--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 Load			Pollution Dissolved-Solids Load		
	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

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 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 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 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 as a function 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 analysed. 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, 1980).

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, (1980).

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, (1980), has the advantage of being simple, inexpensive and easy to use. A comparison 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 evaluation 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 18 for the Yadkin River at Yadkin College, table 19 for the Rocky River near Norwood, and in table 20 for the Pee Dee River near Rockingham. Multiple-regression results are also given in tables 18, 19, and 20. Equations with time-slope terms that are statistically different from a zero slope (two-tailed t-test, probability level = 0.05) are indicated.

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 39. Weighted chloride results for the stations are given in figure 40.

The plots in figures 39 and 40 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

Table 18.--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	$= 29894. - 0.666(Y^2) + 2.390(\bar{Q})$	0.17	NO
Normalized silica conc.	$= 14.271 - 0.00387(Y^2)$	.41	YES
Weighted silica conc.	$= 13.0981 - 0.0000914(Y^3)$	.27	YES
Multiple regression silica conc.	$= 206.345 - 0.099(T) + 2039.047(\frac{1}{Q})$	.22	YES
Calcium pollution load	$= 8639. - 0.0311(Y^3) + 0.533(\bar{Q})$	.13	NO
Normalized calcium conc.	$= 3.467 + 0.00624(Y^2) - 0.000219(Y^3)$	.10	NO
Weighted calcium conc.	$= 4.0885 - 0.00000985(Y^3)$	.27	NO
Multiple regression calcium conc.	$= -22.767 + 0.013(T) + 2307.069(\frac{1}{Q})$	.29	NO
Magnesium pollution load	$= 2880. - 79.955(Y) + 0.455(\bar{Q})$	.34	NO
Normalized magnesium conc.	$= 1.471 - 0.00305(Y^2) + 0.000107(Y^3)$	.10	NO
Weighted magnesium conc.	$= 1.0340 + 0.00861(Y)$	.11	NO
Multiple regression magnesium conc.	$= -8.432 + 0.0005(T) + 222.592(\frac{1}{Q})$	.03	NO
Sodium pollution load	$= 7.540 + 251.269(Y)$	.54	YES
Normalized sodium conc.	$= 3.185 + 0.0630(Y)$	.59	YES
Weighted sodium conc.	$= 3.718 + 0.0653(Y)$	.52	YES
Multiple regression sodium conc.	$= -122.033 + 0.063(T) + 4936.844(\frac{1}{Q})$	.71	YES
Potassium pollution load	$= 796. + 137.893(Y) + 0.498(\bar{Q})$	.81	YES
Normalized potassium conc.	$= 1.188 + 0.00206(Y^2)$	.63	YES
Weighted potassium conc.	$= 1.0648 + 0.0478(Y)$	.81	YES
Multiple regression potassium conc.	$= -106.107 + 0.055(T) + 714.946(\frac{1}{Q})$	.40	YES
Bicarbonate pollution load	$= 47683. - 2.0342(Y^2) + 1.549(\bar{Q})$	.07	NO
Normalized bicarbonate conc.	$= 20.163 - 0.0397(Y)$	.03	NO
Weighted bicarbonate conc.	$= 21.104 + 0.0000572(Y)$	.32	NO
Multiple regression bicarbonate	$= 2.917 + 0.00823(T) + 15922(\frac{1}{Q})$	.51	NO
Sulfate pollution load	$= 1932. + 320.650(Y) + 0.902(\bar{Q})$	.71	YES
Normalized sulfate conc.	$= 0.944 + 0.173(Y)$	.70	YES
Weighted sulfate conc.	$= 1.454 + 0.0178(Y^2) - 0.000518(Y^3)$	.69	YES
Multiple regression sulfate conc.	$= -274.963 + 0.142(T) + 683.690(\frac{1}{Q})$	.43	YES
Chloride pollution load	$= 5780. + 242.697(Y)$	.60	YES
Normalized chloride conc.	$= 2.245 + 0.0121(Y) - 0.000361(Y^2)$	.67	YES
Weighted chloride conc.	$= 2.804 + 0.0558(Y)$	.42	YES
Multiple regression chloride conc.	$= -127.081 + 0.066(T) + 3406.487(\frac{1}{Q})$	.49	YES
Nitrate pollution load	$= 3146.5 + 4.445(Y^2) + 0.33698(\bar{Q})$	.61	YES
Normalized nitrate conc.	$= 1.270 + 0.0545(Y)$	.32	YES
Weighted nitrate conc.	$= 1.1656 + 0.0553(Y)$	.67	YES
Multiple regression nitrate conc.	$= -110.508 + 0.0571(T) + 449.08(\frac{1}{Q})$	.24	YES
Dissolved solids pollution load	$= 123115. - 579.754(Y) + 4.322(Q)$		NO
Normalized dissolved solids conc.	$= 4.960 + 8.584(Y) - 0.538(Y^2) + 0.0103(Y^3)$	.37	YES
Weighted dissolved solids conc.	$= 35.650 + 1.265(Y) - 0.0312(Y^2)$	.27	NO
Multiple regression dissolved solids conc.	$= -345.461 + 0.195(T) + 17814.109(\frac{1}{Q})$	.39	YES

Table 19.--Regression equations for the 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; $\bar{Q}$ = 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	$= 12774. - 1.231(Y^3) + 4.174(\bar{Q})$	0.58	YES
Normalized silica conc.	$= 21.0431 - 0.0000796(Y^3)$	.03	NO
Weighted silica conc.	$= 12.284 + 0.151(Y)$	.38	YES
Multiple regression silica conc.	$= 127.784 - 0.059(T) + 0.000003(Q)$	.03	YES
Calcium pollution load	$= 6162. - 0.486(Y^3) + 2.122(\bar{Q})$	.69	YES
Normalized calcium conc.	$= 9.000420 + 0.126(Y)$	.72	NO
Weighted calcium conc.	$= 8.0873 + 0.0164(Y^2) - 0.000513(Y^3)$	.64	YES
Multiple regression calcium conc.	$- 27.508 + 0.011(T) - 0.00003(Q)$	.08	NO
Magnesium pollution load	$= 2361. - 0.234(Y^3) + 0.977(\bar{Q})$	.66	YES
Normalized magnesium conc.	$= 4.152 + 0.0000371(Y^3)$	.12	NO
Weighted magnesium conc.	$= 3.592 + 0.0000341(Y^3)$	.42	YES
Multiple regression magnesium conc.	$= -35.441 + 0.019(T) - 0.000002(Q)$	.05	YES
Sodium pollution load	$= 2980. + 180.222(Y^2) - 5.906(Y^3)$	.63	YES
Normalized sodium conc.	$= -3.584 + 0.294(Y^2) - 0.00979(Y^3)$	.49	YES
Weighted sodium conc.	$= 34.0578 + 0.191(Y^2) - 0.00710(Y^3)$	.53	YES
Multiple regression sodium conc.	$= -141.124 + 0.076(T) - 0.00018(Q)$	.31	YES
Potassium pollution load	$= 627. + 14.505(Y^2) - 0.567(Y^3) + 0.537(Q)$	.66	NO
Normalized potassium conc.	$= 1.671 + 0.0154(Y^2) - 0.000452(Y^3)$	.64	YES
Weighted potassium conc.	$= 3.0774 + 0.0122(Y^2) - 0.000433(Y^3)$	.66	YES
Multiple regression potassium conc.	$= -81.849 + 0.43(T) - 0.000017(Q)$	.36	YES
Bicarbonate pollution load	$= 27184. + 238.845(Y^2) - 9.925(Y^3) + 5.681(\bar{Q})$	.55	YES
Normalized bicarbonate conc.	$= 200.0206 - 36.491(Y) + 2.747(Y^2) - 0.0592(Y^3)$	.81	YES
Weighted bicarbonate conc.	$= 97.993 - 0.00176(Y^3)$	.55	YES
Multiple regression bicarbonate conc.	$= -568.403 + 0.334(T) - 0.00435(Q)$	.16	NO
Sulfate pollution load	$= 8894. - 0.120(Y^3) + 2.282(\bar{Q})$	.66	NO
Normalized sulfate conc.	$= 8.306 + 0.550(Y)$	.64	YES
Weighted sulfate conc.	$= 15.590 + 0.0133\ (Y^2)$	.76	YES
Multiple regression sulfate conc.	$= 324.432 + 0.168(T) + 0.000003(Q)$	.41	YES
Chloride pollution load	$= 3259. + 127.707(Y^2) - 4.051\ (\bar{Q})$	.47	YES
Normalized chloride conc.	$= -1.672 + 0.214(Y^2) - 0.00701(Y^3)$	.45	YES
Weighted chloride conc.	$= 18.569 + 0.198(Y^3) - 0.00681(Y^3)$	.52	YES
Multiple regression chloride conc.	$= 160.799 + 0.085(T) - 0.0001(Q)$	.20	YES
Nitrate pollution load	$= 2610.4 - 86.6071(Y) + 0.3494(\bar{Q})$	.16	NO
Normalized nitrate conc.	$= 4.156 - 0.06878(Y^2) + 0.003959(Y^3)$	.74	YES
Weighted nitrate conc.	$= 1.5796 + 0.00589(Y)$	.87	YES
Multiple regression nitrate conc.	$= -310.073 + 0.1593(T) + 0.000044(\frac{1}{Q})$	.25	YES
Dissolved solids pollution load	$= 40277. + 598.187(Y^2) - 23.738(Y^3) + 17.415(\bar{Q})$	.64	YES
Normalized dissolved solids conc.	$= 63.873 + 0.807(Y^2) - 0.0262(Y^3)$	.55	YES
Weighted dissolved solids conc.	$= 102.91 + 1.0306(Y^2) - 0.0347(Y^3)$	.62	YES
Multiple regression dissolved solids conc.	$= 859.480 + 0.468(T) - 0.0002(Q)$	.18	YES

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

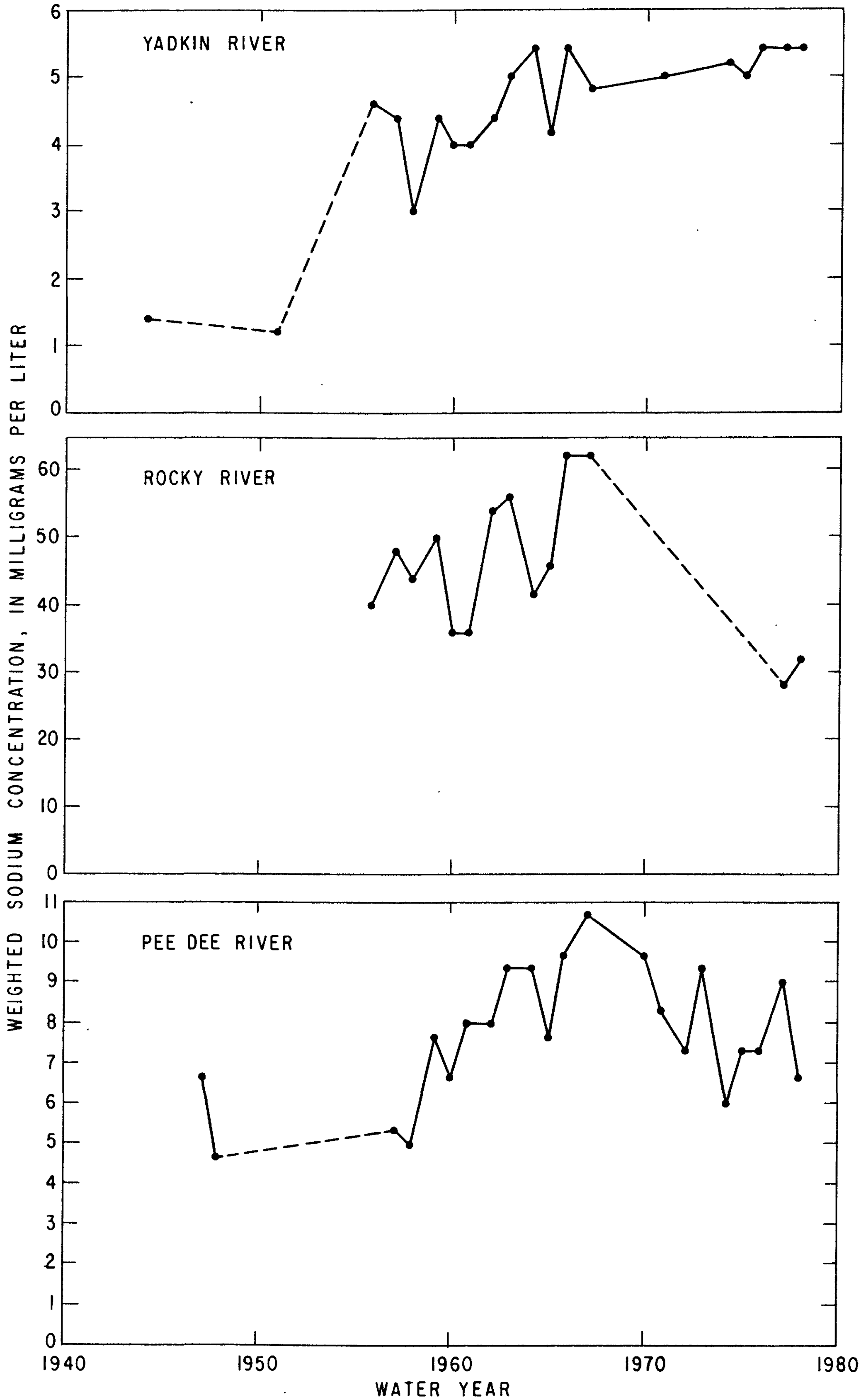

Figure 39.--Weighted sodium concentrations for the Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham.

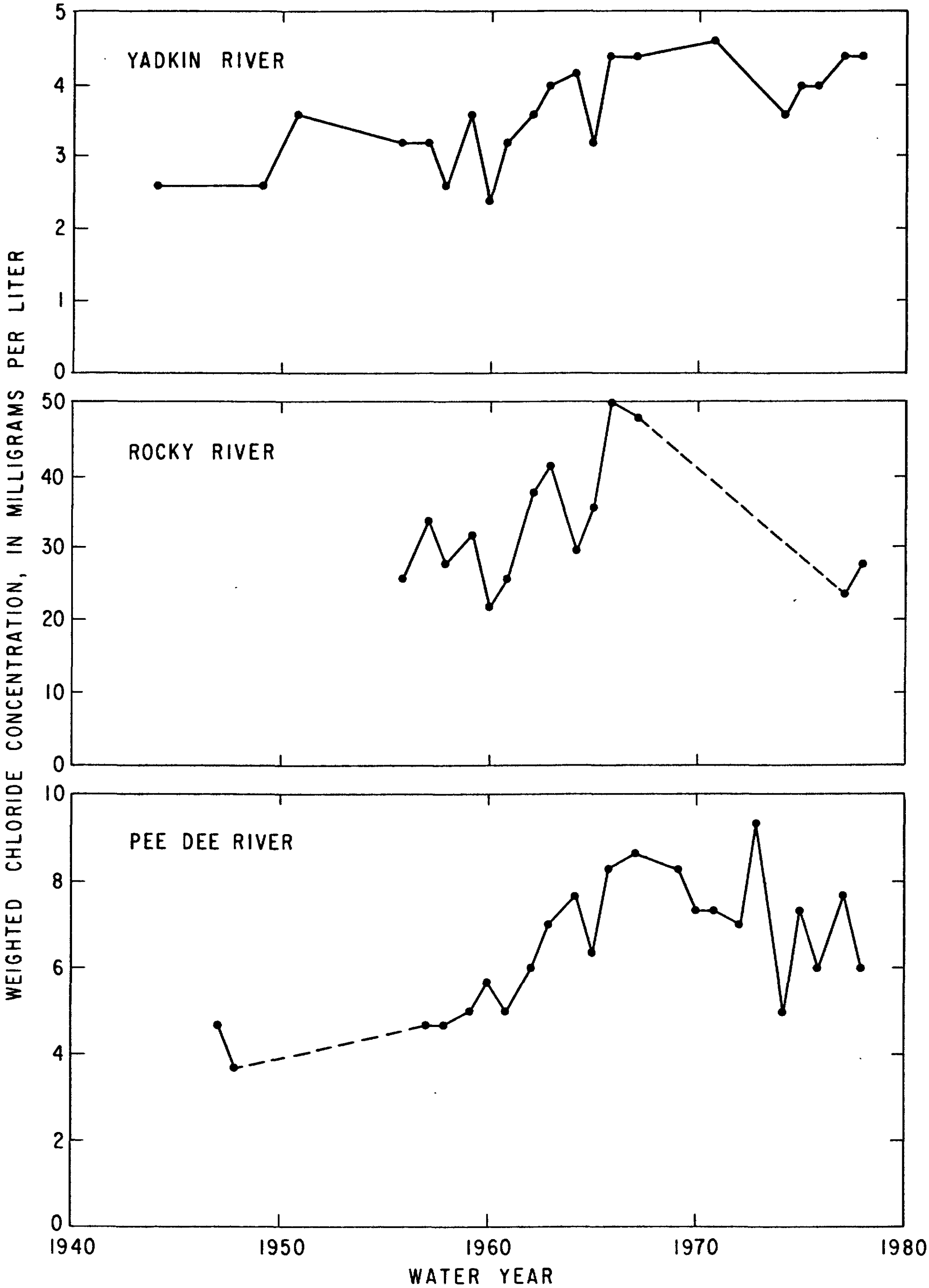

Figure 40.--Weighted chloride concentrations for the Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham.

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 39 and 40 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-solids concentration against time for the three stations is given in figure 41. 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 synthetic fabrics has been known to cause dramatic decreases in dissolved-solids concentrations in the effluent from individual textile mills (verbal commun., Page Benton, North Carolina Department of Natural Resources and Community Development, 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 change, causing factories to use materials that have a greater water-quality impact.

Results for dissolved sulfate, given in figure 42, 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

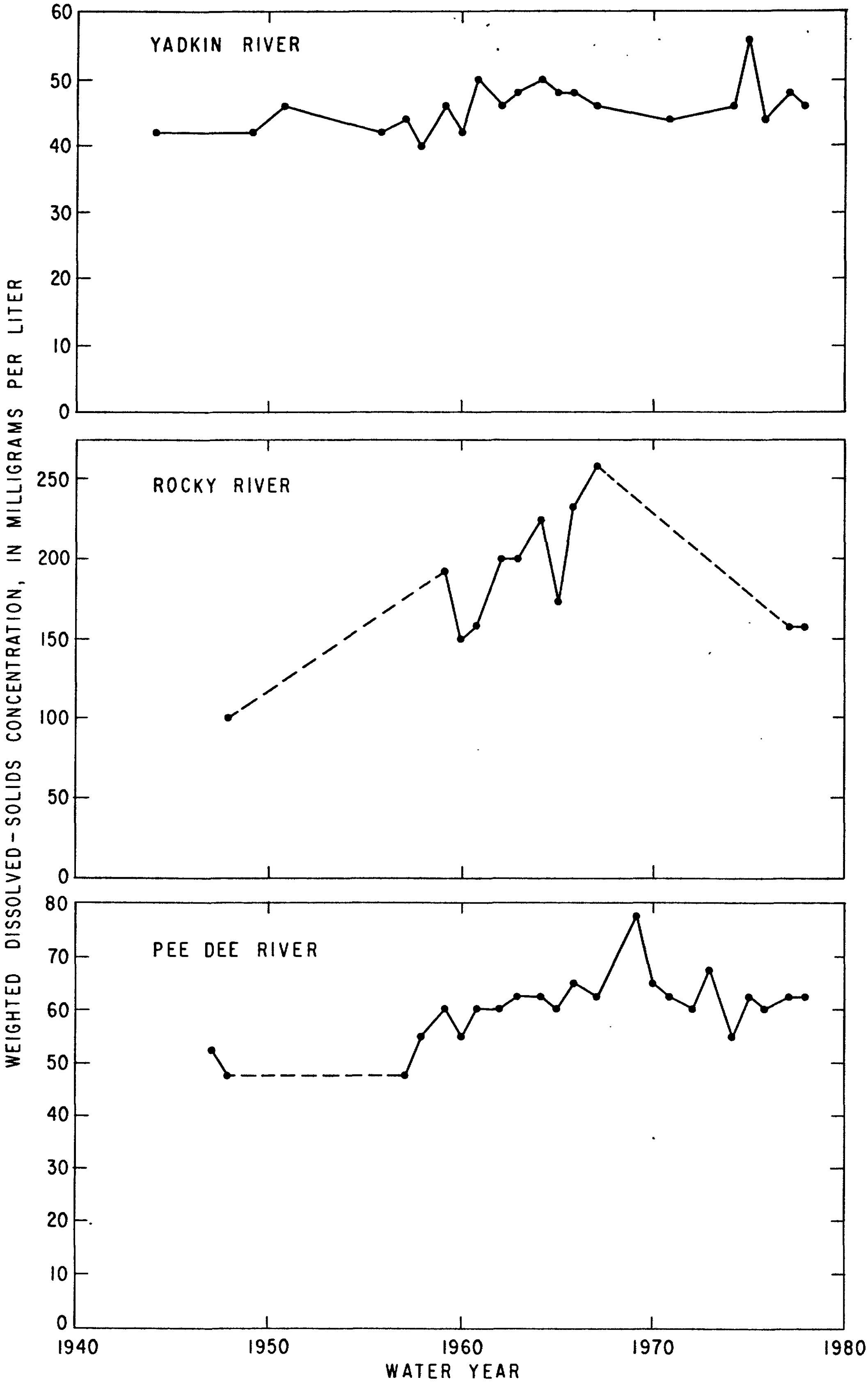

Figure 41.--Weighted dissolved-solids concentrations for the Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham.

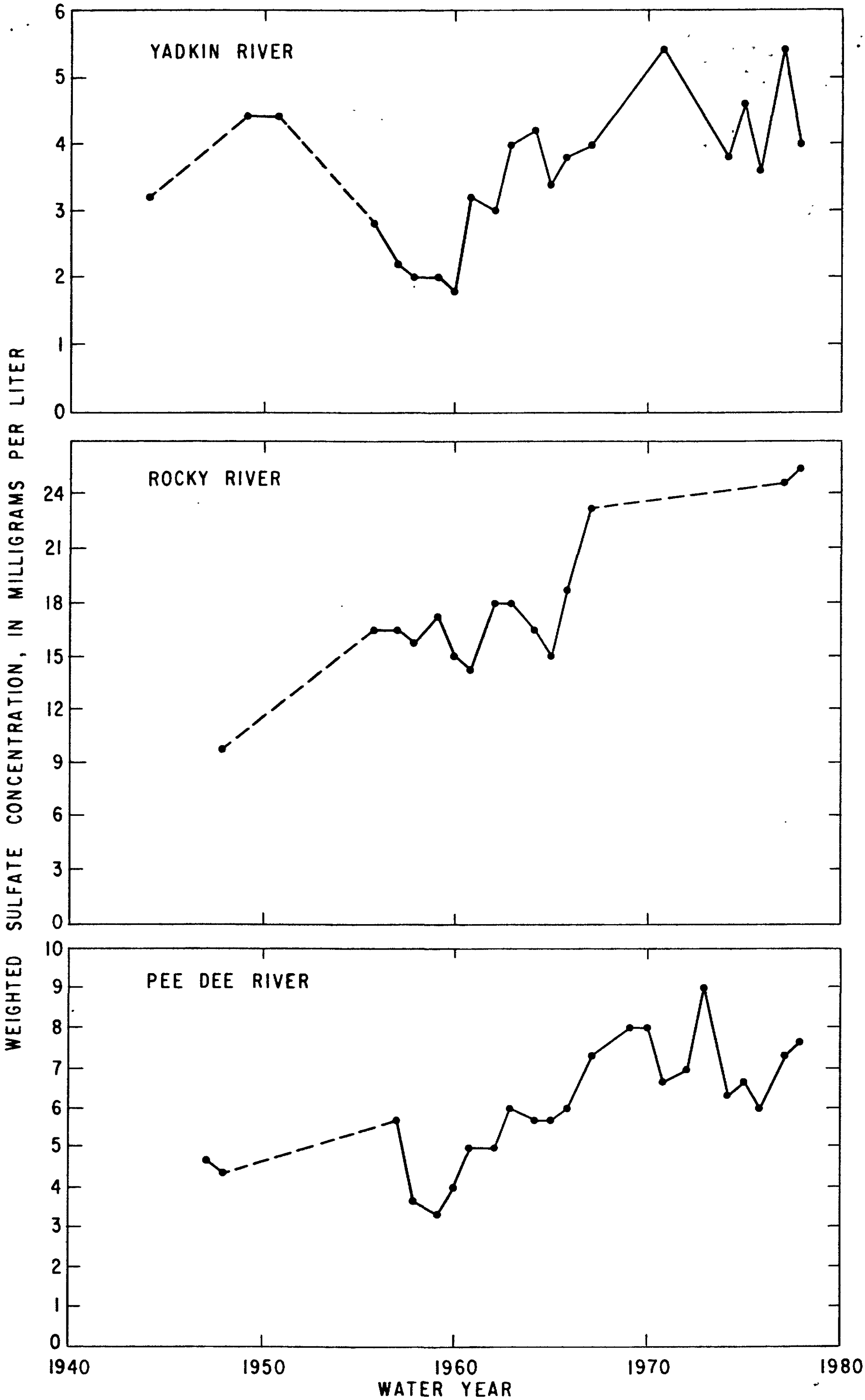

Figure 42.--Weighted dissolved-sulfate concentrations for the Yadkin River at Yadkin College, Rocky River near Norwood, and Pee Dee River near Rockingham.

(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. Kent Crawford, 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 43.

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. 44) 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 45, indicate that much of this decrease occurred during 1951 to 1965. 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.

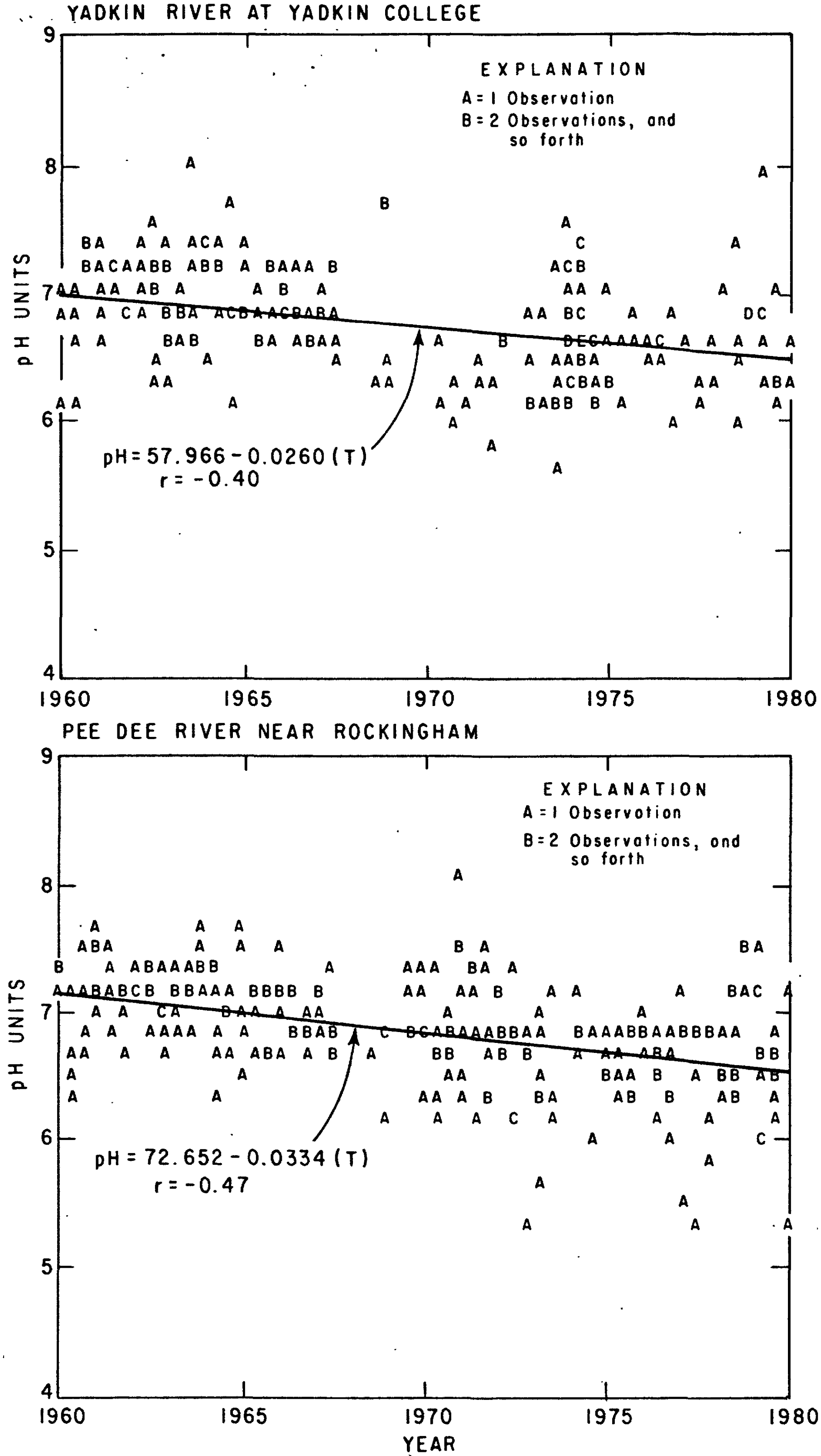

Figure 43.--Trends in pH for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham.

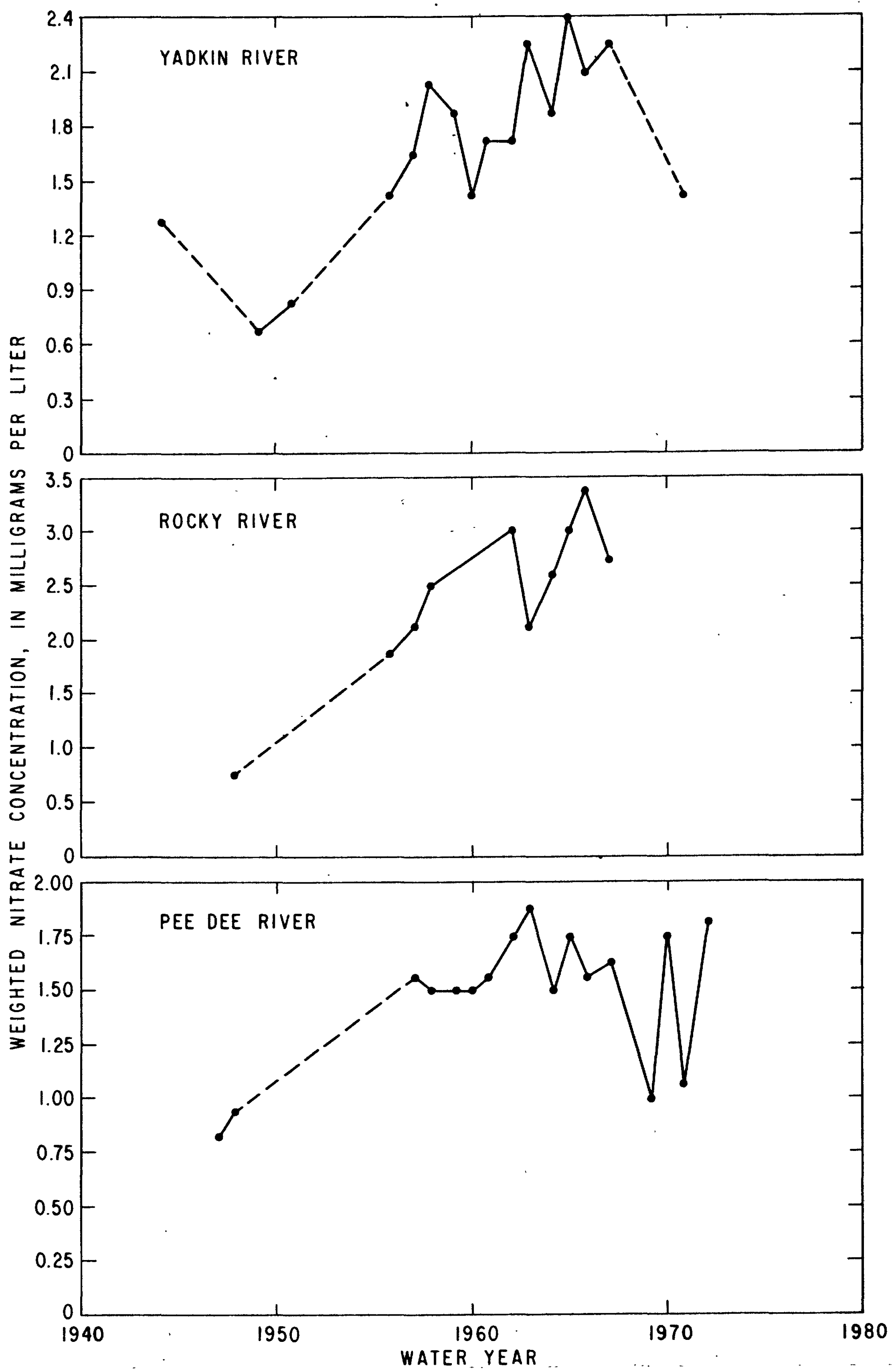

Figure 44.--Weighted dissolved nitrate-concentrations for the Yadkin River at Yadkin College, Rocky River near Norwood, and the Pee Dee River near Rockingham.

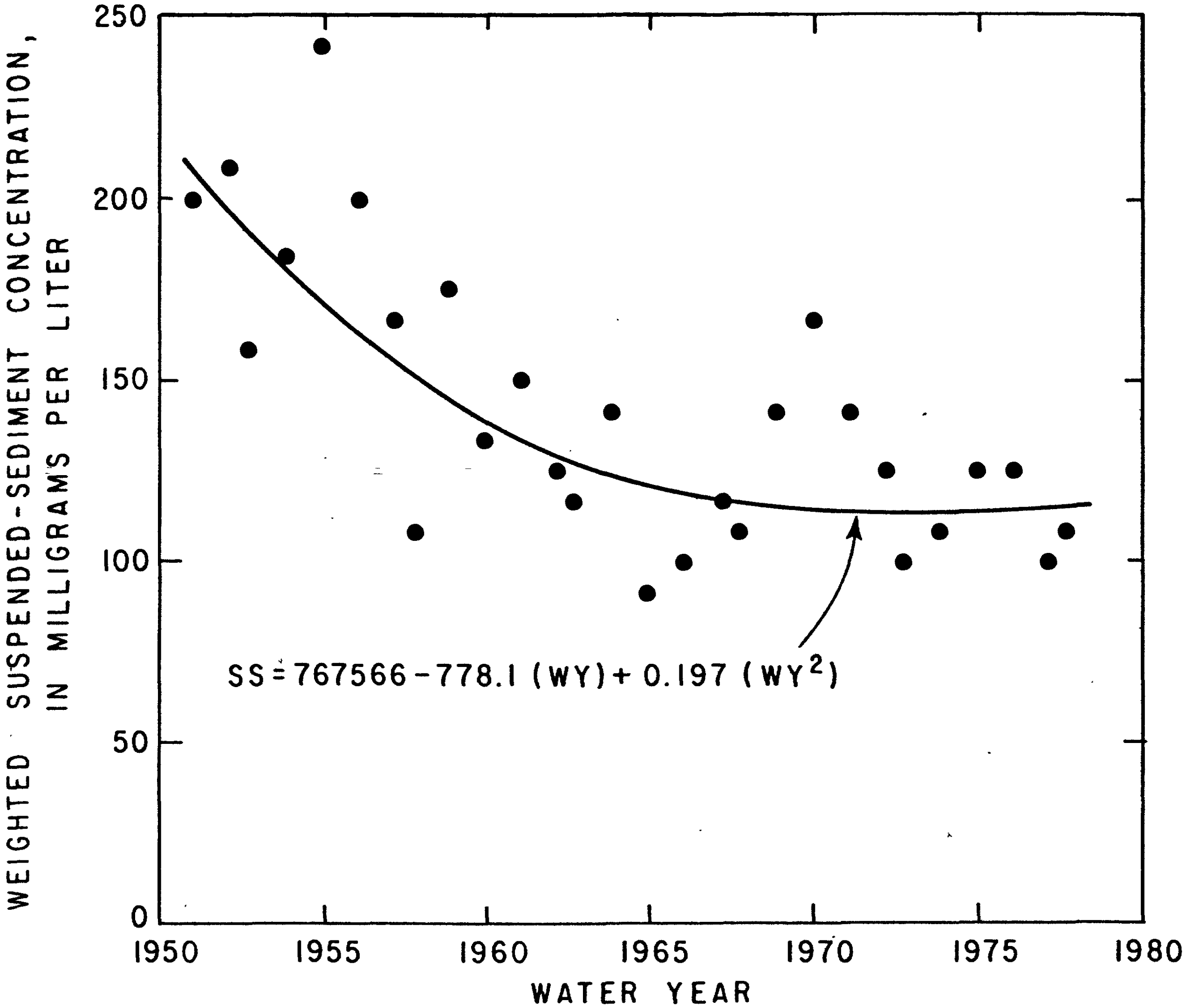

Figure 45.--Weighted suspended-sediment concentrations (SS) for the Yadkin River at Yadkin College (WY = water year).

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 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 21. Several of the lines produced by these equations are given in figure 46.

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.

Table 21.--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; UP = (Davidson + Davie + Forsyth + Guilford + Iredel + 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 conc. =	-39.756 - 2.109 (T) + 0.00169 (Union)	0.80
Weighted calcium conc. =	5.691 - 0.000180 (Cabarrus) to .0121 (UP)	.74
Weighted sodium conc. =	3.228 + 0.0820 (T)	.92
Weighted potassium conc. =	-5.75 + 0.000177 (Cabarrus) - 0.00577 (UP)	.96
Weighted sulfate conc. =	-83.0848 + 0.00201 (Cabarrus) - 0.000912 (Union) - 0.0135 (UP)	.95
Weighted chloride conc. =	-7.107 + 0.610 (T) + 0.000550 (Cabarrus) - 0.000763 (Union)	.99
Normalized potassium conc. =	-5.521 + 0.000121 (Cabarrus)	.66
	Pee Dee River near Rockingham	
Weighted silica conc. =	26.895 - 0.000614 (Davidson) + 0.000551 (Randolph)	0.77
Weighted magnesium conc. =	-93.289 - 0.714 (T) + 0.000847 (Forsyth) - 0.000945 (Randolph)	.91
Weighted sodium conc. =	12.134 + 0.000814 (Davidson) - 0.00112 (Iredel)	.52
Weighted potassium conc. =	-5.71 + 0.000342 (Davidson) - 0.000322 (Randolph)	.67
Weighted sulfate conc. =	-5.922 + 0.000131 (Davidson)	.44
Weighted dissolved-solids conc. =	383.976 + 5.306(T) + 0.0124 (Davidson)	
	- 0.00634 (Forsyth) + 0.00785 (Iredel - 0.0107 (Randolph)	.91
Weighted specific conductance =	1,417.574 + 13.653(T) - 6.241 (LOW)	.69
Normalized sulfate conc. =	-110.911 + 1.824 (LOW) - 0.00166 (Forsyth)	.86

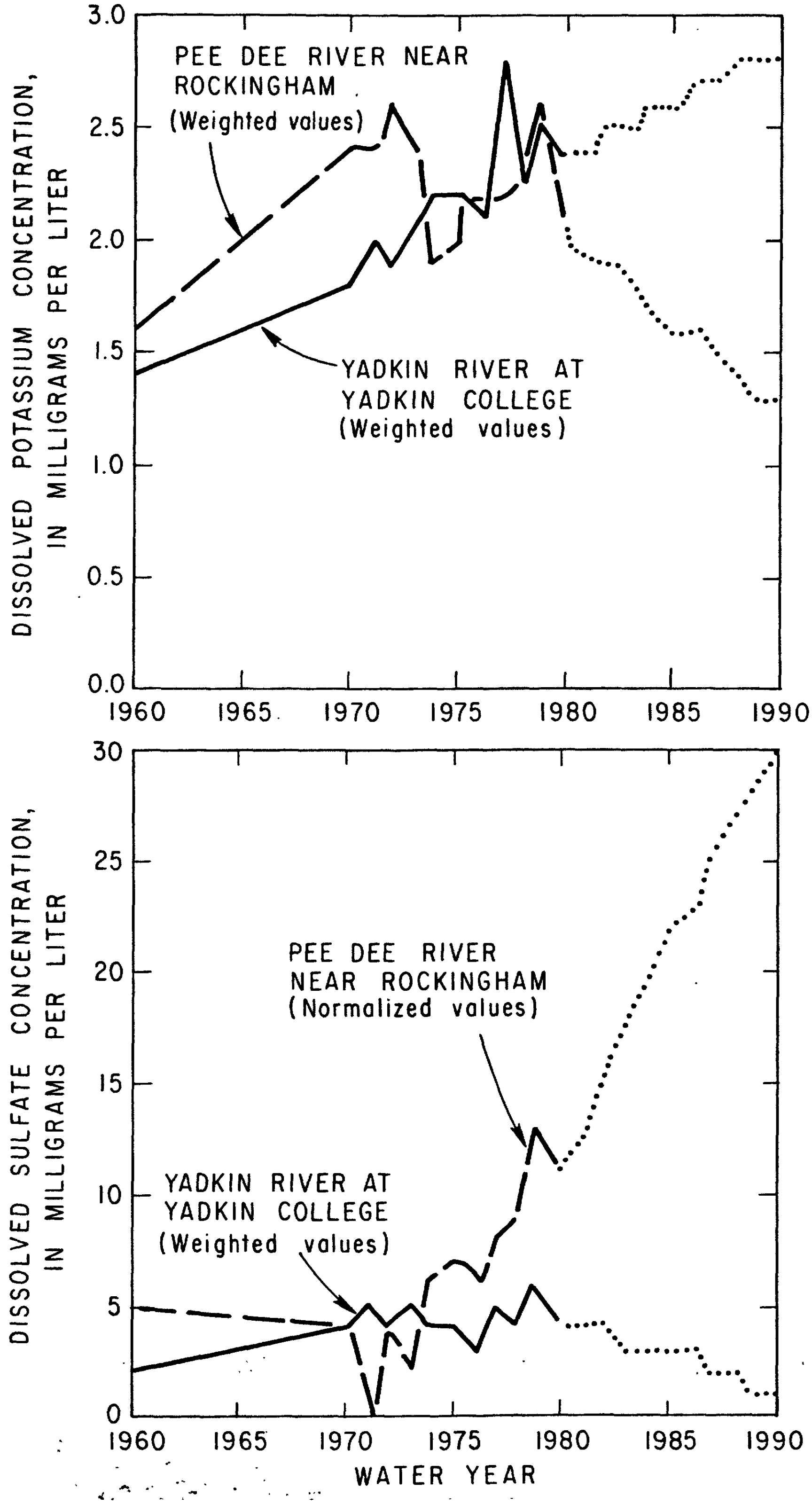

Figure 46.--Projected trends of dissolved sulfate and dissolved potassium concentrations for the Yadkin River at Yadkin College and the Pee Dee River near Rockingham, from equations listed in table 22.

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 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 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 a 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 hydro-power 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 dependance on variation of water temperature. In addition, during summer months a midday rise in the dissolved-oxygen concentration is probably due to algal photosynethesis. 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, 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 concentration 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 storm events. Only dissolved arsenic and dissolved selenium show dilution during storm events. 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, 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 coliform 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 stroptococci count for the Pee Dee River near Rockingham indicates that fecal contamination at this point in the river is primarily of non-human 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 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 mid 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 mid 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 predominatly 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 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 awareness and improved laboratory techniques have promoted accurate identification and routine monitoring of of many important trace materials in water, including man-made 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.

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